NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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

TOWNSHIP OF EAR FALLS, ONTARIO

APM-REP-06144-0020

NOVEMBER 2013

This report has been prepared under contract to the NWMO. The report has been reviewed by the NWMO, but the views and conclusions are those of the authors and do not necessarily represent those of the NWMO.

All copyright and intellectual property rights belong to the NWMO.

For more information, please contact:
Nuclear Waste Management Organization
22 St. Clair Avenue East, Sixth Floor
Toronto, Ontario M4T 2S3 Canada
Tel 416.934.9814
Toll Free 1.866.249.6966
Email contactus@nwmo.ca
www.nwmo.ca

PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT

TERRAIN AND REMOTE SENSING STUDY

TOWNSHIP OF EAR FALLS, ONTARIO

November 2013

Prepared for:

G.W. Schneider, M.Sc., P.Geo.
Golder Associates Ltd.
6925 Century Avenue, Suite 100
Mississauga, Ontario
Canada L5N 7K2

Nuclear Waste Management Organization
22 St. Clair Avenue East 6th Floor
Toronto, Ontario
Canada M4T 2S3
NWMO Report Number: APM-REP-06144-0020

Prepared by:

D.P. van Zeyl, M.Sc.
L.A. Penner, M.Sc., P.Eng., P.Geo.
J.D. Mollard and Associates (2010) Limited
810 Avord Tower, 2002 Victoria Avenue
Regina, Saskatchewan
Canada S4P 0R7

EXECUTIVE SUMMARY

In February 2012, the Township of Ear Falls, Ontario expressed interest in learning more about the Nuclear Waste Management Organization nine-step site selection process, and requested that a preliminary assessment be conducted to assess the potential suitability of the Ear Falls 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 Ear Falls and its periphery, referred to as the “Ear Falls 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 Ear Falls area (Golder, 2013). The main information sources relied on were the Canadian Digital Elevation Data (CDED), the multispectral SPOT satellite imagery and the maps from the Northern Ontario Engineering Geology Terrain Study (NOEGTS) and the available 1:50,000 scale Ontario Geological Survey surficial geology maps. 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 Ear Falls area, including estimates of overburden thickness. Areas of thin drift and abundant bedrock exposure in the Ear Falls area are mostly located on rock ridges within highland areas around the west-central, south-central and east-central margins of the Ear Falls area.

Drainage divides delineated in the provincial quaternary watershed file were confirmed using the CDED surface model. Groundwater flow within drift deposits and in shallow bedrock aquifers in the Ear Falls area is expected to mimic the pattern of surface flow, with groundwater divides coinciding with drainage divides and discharge occurring into creeks, rivers, lakes and wetlands.

Conclusive identification of features indicative of paleoseismic events and reactivation of ancient bedrock structures due to cycles of glacial loading and unloading, acting along with tectonic stresses, cannot be identified using currently available sources of information. Field investigations would be required to identify such features.

The main accessibility constraints in the Ear Falls area are large lakes, wetlands and steep slopes. The Ear Falls area includes several primary roads and a network of secondary roads that provide reasonably good access for site reconnaissance aimed at preliminary site characterization.

TABLE OF CONTENTS

LIST OF FIGURES V

1 INTRODUCTION 1
1.1 OBJECTIVES 1
1.2 LOCATION 2
1.3 DATA AND METHODS 2
1.3.1 NOEGTS 2
1.3.2 OGS AND GSC MAPS 3
1.3.3 CDED 4
1.3.4 SPOT 5
1.3.5 DRILL HOLES AND WATER WELLS 8
1.3.6 FOREST RESOURCE INVENTORY 9

2 SUMMARY OF GEOLOGY 11
2.1 BEDROCK GEOLOGY 11
2.1.1 GNEISSIC METASEDIMENTARY ROCKS OF THE ENGLISH RIVER SUBPROVINCE 11
2.1.2 PLUTONIC ROCKS 12
2.1.3 MAFIC DYKES 14
2.1.4 FAULTS AND SHEAR ZONES 14
2.1.5 METAMORPHISM 15
2.2 GEOLOGICAL AND STRUCTURAL HISTORY 17
2.3 QUATERNARY GEOLOGY 20

3 TOPOGRAPHY 23
3.1 ELEVATION 23
3.2 RELIEF 24
3.3 SLOPE 25

4 DRAINAGE 27
4.1 WATERBODIES AND WETLANDS 27
4.2 WATERSHEDS 29
4.3 SURFACE FLOW 31

5 TERRAIN CHARACTERISTICS 35
5.1 DRILL HOLE AND WATER WELL DATA 35
5.1.1 WATER WELL INFORMATION SYSTEM 35
5.1.2 ONTARIO DRILL HOLE DATABASE 36
5.2 NOEGTS TERRAIN UNITS 38
5.2.1 MORAINAL TERRAIN 38
5.2.2 GLACIOFLUVIAL TERRAIN 39
5.2.3 GLACIOLACUSTRINE TERRAIN 39
5.2.4 ORGANIC TERRAIN 40
5.2.5 BEDROCK TERRAIN 41

6 GROUNDWATER 45

7 NEOTECTONIC FEATURES 47

8 ACCESSIBILITY CONSTRAINTS 49

9 SUMMARY 53

REFERENCES 57

REPORT SIGNATURE PAGE 63

FIGURES 65

LIST OF FIGURES

Figure 1 Township of Ear Falls and surrounding area

Figure 2 Bedrock geology of the Ear Falls area

Figure 3 Surficial geology of the Ear Falls area (1:100,000)

Figure 4 Surficial geology of the Ear Falls area (1:50,000)

Figure 5 Elevation and major topographic features

Figure 6 Departure from average elevation within 20 km radius

Figure 7 Departure from average elevation within 2 km radius

Figure 8 Range in elevation within 250 m radius

Figure 9 Areas 6° or steeper in the Ear Falls area

Figure 10 Density of steep ($\geq 6^0$) slopes within 2 km radius

Figure 11 Surface drainage features of the Ear Falls area

Figure 12 Watersheds within the Ear Falls area

Figure 13 Access roads within the Ear Falls area

LIST OF TABLES

Table 1 Characteristics of SPOT 5 multispectral bands. 7

Table 2 List of SPOT 5 multispectral images acquired. 7

Table 3 Summary of the geological and structural history of the Ear Falls area. 18

Table 4 Size of lakes larger than 10 km^2 in the Ear Falls area[1]. 28

Table 5 Maximum and mean depths of lakes in or near the Ear Falls area. 30

Table 6 MOE water well data in the Ear Falls area with data on drift thickness. 37

Table 7 Selected OGS diamond drill hole data on depth to bedrock in the Ear Falls area. 38

Table 8 Qualitative summary of extent of exposed bedrock over the main bedrock formations. 43

1 INTRODUCTION

In February 2012, the Township of Ear Falls, Ontario expressed interest in learning more about the Nuclear Waste Management Organization nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess the potential suitability of the Ear Falls area for safely hosting a deep geological repository. The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations (NWMO, 2013).

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

1.1 OBJECTIVES

This report presents a synopsis of the terrain in the Ear Falls area using existing remote sensing and geoscientific information sources. The report provides information on the nature and distribution of overburden deposits in the area and discusses the topography, surface drainage and groundwater flow. The report also discusses the role of drift deposits in concealing and censoring the lengths of lineaments. The main information sources relied on in this assessment are the Canadian Digital Elevation Data (CDED) elevation model, the SPOT satellite imagery, the maps from the Northern Ontario Engineering Geology Terrain Study (NOEGTS), and the Ontario Geological Survey 1:50,000 scale surficial geology maps that cover part of the area. 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 the areas of exposed bedrock or relatively thin overburden cover;
- Identify features that may preserve evidence of neotectonics;
- Establish the main site accessibility constraints;
- Determine and/or confirm watershed and sub-catchment boundaries;

- Infer groundwater recharge and discharge zones and divides; and
- Infer regional and local groundwater and surface flow directions.

The objectives above were carried out for the Ear Falls area (Section 1.2) using the data and methodology described in Section 1.3.

1.2 LOCATION

The Ear Falls area is approximately 80 km by 46 km in size, encompassing an area of about 3,688 km^2 (Figure 1). The approximate western, northern, eastern and southern limits of the Ear Falls area are (UTM Zone 15, NAD83): 442508, 5636096, 522756, and 5590141 m. The settlement area of Ear Falls is located on the north shore of the English River near the northwest tip of Lac Seul, where Lac Seul spills into the English River.

1.3 DATA AND METHODS

This section summarizes the remote sensing and geoscientific data sources that were used to address the objectives of the terrain assessment for the Ear Falls area, including an evaluation of the quality of the data. The datasets used in this assessment are all publicly available.

1.3.1 NOEGTS

Overburden deposits within the Ear Falls area were mapped as part of a program undertaken between 1977 and 1980 entitled the Northern Ontario Engineering Geology 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 1:50,000. 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, 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 much of the Ear Falls area, maps produced from these programs currently represent the best level of detail available for surficial geology mapping and descriptions of terrain conditions.

Recently, the Ontario Geological Survey (OGS) digitized the NOEGTS maps and published the digital data (OGS, 2005a) in the form of a miscellaneous release of data (MRD). 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 15).

Four maps at a scale of 1:100,000 produced by the Northern Ontario Engineering Geology Terrain Studies (Gorman, 1989a, b; Neilson, 1989a, c) cover the Ear Falls area. Neilson (1989b) also provides a general construction capability map for the Pakwash Lake area based on these maps. Unfortunately, these NOEGTS maps were not accompanied by reports describing the terrain conditions of the Ear Falls area.

1.3.2 OGS AND GSC MAPS

Three surficial geology maps at a scale of 1:50,000 cover portions of the central and northern parts of the Ear Falls area (Ford, 1982, 1983; Prest, 1982).

Prest (1982) completed three, three-month field seasons (1978, 1979, and 1980) leading up to completion of the 1:50,000 scale surficial geology map that covers the northwest corner of the Ear Falls area. The mapping was based on a combination of ground observations, including hand augering, and air photo interpretation. Prest (1982) noted that interpretation of surficial geology from air photos is hazardous in this region, as the forest cover commonly does not provide clues to the underlying surficial materials. For example, black spruce can be found in upland areas and jackpine can be found in low-lying poorly drained areas, associations that are reversed from what is found in many other parts of the Canadian Shield. Prest suggests that these unusual relationships stem from a combination of numerous forest fires over many decades and logging operations in more recent times. Prest (1982) provides a quantitative estimate of overburden thickness for six of the seven map units. These thickness estimates represent the best available information on drift thickness for the surficial deposits mapped in the Ear Falls area, and they are used in the terrain unit descriptions provided in Section 5.2.

Ford (1982, 1983) had only one, three-month field season in 1981 with extensive use of 1:15,000 scale air photos on which to base his two maps, and hence provides few overburden thickness estimates. The surficial map of the Pakwash area (Ford, 1982) benefited from field mapping by Prest along the boundary between the Madsen (Prest, 1982) and Pakwash map areas in 1981.

The part of the Ear Falls area north of 50°45’ north is included within the 1:100,000 scale regional compilation map of Sharpe and Russell (1996). This work involved generalizing the surficial geology polygons of three 1:50,000 scale map sheets (Ford, 1982, 1983; Prest, 1982) and generating new 1:100,000 scale surficial mapping within three additional map sheets (52N/3, 52N/2, and 52K15). Mapping of the three newly mapped areas included less than four weeks of fieldwork by a two-person field crew for each map sheet. The description of each map unit includes a statement of the estimated thickness of overburden. Point symbols were used to mark the locations of small bedrock outcrops.

In summary, the 1:50,000-scale surficial geology map of Prest (1982) represents the best source of information on the thickness of overburden deposits available for the Ear Falls area. Even though the map covers only part of the Ear Falls area, the deposit thicknesses suggested are expected to be reasonable estimates for similar deposit types found elsewhere in the area.

1.3.3 CDED

This subsection describes the digital elevation model used to evaluate the terrain in this assessment. Section 4.2 describes the drainage basin analysis conducted using the CDED elevation model as the representation of the landscape.

Canadian Digital Elevation Data, 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 Ear Falls area. The digital elevation model (DEM) used for this assessment was constructed by Natural Resources Canada (NRCan) using data assembled through the Water Resources Information Program (WRIP) of the Ontario Ministry of Natural Resources (MNR). The source data were 1:20,000 scale topographic map data generated through the Ontario Base Mapping (OBM) program, which was a major photogrammetric program conducted across Ontario between about 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 good quality representation of the land surface in high relief areas. However, 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. Flat areas display minor artefacts characterized by 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. Apart from this minor issue, no additional imperfections have been found in the elevation data acquired for the Ear Falls area.

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 centered 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 slope 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.

1.3.4 SPOT

SPOT multispectral orthoimagery at a resolution of 20 m and panchromatic imagery at 10 m resolution formed a valuable information source for identifying exposed bedrock, wetlands, roads and other features within the Ear Falls area (GeoBase, 2011b). SPOT multispectral data consist of four, 8-bit 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 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). A comparison of lake shorelines in the SPOT imagery with those delineated in the MNR waterbody file suggests that the georeference is generally accurate to within 20 to 40 m or better.

Four SPOT images (or 'scenes') provided complete coverage for the Ear Falls area (Table 2). The scenes are from the SPOT 5 satellite with two images acquired on September 4th, 2006, one on May 7th, 2006, and one on August 30th, 2006. The two images captured during September cover the western part of the Ear Falls area, whereas the images captured in May and August cover the eastern part.

In order to assist with the interpretation of the location and extent of bedrock outcrops in the Ear Falls area, JDMA performed two types of multivariate analyses on the SPOT multispectral data: principal component analysis and unsupervised classification. Prior to performing these analyses, waterbodies 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 waterbodies, 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 generally 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.

After some effort in attempting to produce good results from the unsupervised classification, it was found that generally the only areas where this type of technique could be used in a straightforward way was 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, our interpretation of bedrock exposure from the SPOT imagery in this assessment has relied on the PCA composite images rather than on unsupervised classification. All references to the use of SPOT imagery in this assessment (e.g., Sections 3.3, 4.1, 5.1.1, 5.1.2, 5.2.4, 5.2.5, and 8) refer to the use of the PCA composite images. The only instance where the SPOT panchromatic imagery was used was in the delineation of unmapped resource roads (Section 8).

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.

Scene ID	Satellite	Date of image
S5_09347_5022_20060904	SPOT 5	September 4, 2006
S5_09334_5050_20060904	SPOT 5	September 4, 2006
S5_09303_5022_20060507	SPOT 5	May 7, 2006
S5_09250_5050_20060830	SPOT 5	August 30, 2006

Note that Google Earth imagery has also been cross checked against the SPOT imagery in most instances where satellite imagery have been used to identify exposed bedrock or other features such as roads or wetlands. The true-colour composite images currently displayed in Google Earth contain a higher spatial resolution than the SPOT imagery used in this assessment, which provides a useful complimentary dataset. One disadvantage of the Google Earth imagery is the higher cloud contents displayed in some scenes.

1.3.5 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 information reviewed. Additional subsurface information that could be available from the OGS Resident Geologist Program has not been reviewed as part of this preliminary assessment.

Water well records from the MOE Water Well Information System were acquired. Thirty-three wells with data on depth to bedrock are located within the Ear Falls area, and 25 are located within the Township of Ear Falls. Section 5.1.1 summarizes the well data.

The Ontario Drill Hole Database was compiled by the OGS 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 are generally located in the northern portion of the Ear Falls area, within the Birch-Uchi greenstone belt. The dip angles of the drill holes below horizontal range from 10 to 90° with an average dip of about 55°. 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 is often 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. Without knowing the terrain conditions where the drilling took place, it is generally unclear over what areas the data on depth to bedrock are representative.

1.3.6 Forest Resource Inventory

The MNR, through the Forest Resource Inventory (FRI) program, is responsible for identifying and describing the forested areas of the Province of Ontario. They provide a Forest Cover dataset, part of which identifies non-forested areas such as rock, muskeg, and developed agricultural land. This could be a useful dataset for gaining an appreciation of the extent of exposed bedrock over the entire Ear Falls area, particularly if the mapping practices are applied consistently across the area. Another FRI product is the aerial imagery and classified Digital Surface Model (DSM), which provides x, y, z coordinates and an attribute that provides land cover (vegetation, bare earth, water). This product is provided in 5 km x 5 km tiles. Unfortunately, FRI products are restricted, meaning that any private sector access must be purchased. FRI products were not acquired during the current preliminary desktop phase of the assessment.

2 SUMMARY OF GEOLOGY

A detailed discussion of the geological setting of the Ear Falls area, including bedrock geology and structural history, is provided in a separate report (Golder, 2013), and a summary is presented below.

The Township of Ear Falls is situated mainly within the English River Subprovince (Figure 2). The English River Subprovince is an east-west trending, 30 to 100 km wide by 650 km long belt of metasedimentary and metamorphosed intrusive rocks extending from Manitoba to the Moose River Basin in the James Bay Lowlands. The English River Subprovince is bordered to the north by the Uchi Subprovince and, in the Ear Falls area, by the Winnipeg River Subprovince to the south.

The Uchi Subprovince is a relatively narrow, east-west trending region dominated by belts of metasedimentary and metavolcanic rocks that interweave intrusive complexes up to 3 billion years old (Stott and Corfu, 1991).

The Winnipeg River Subprovince is a terrane more than 500 km long and composed of Mesoarchean metaplutonic rocks variably intruded by Neoarchean plutons (Beakhouse, 1992).

The northern part of the Ear Falls area is within the Uchi Subprovince, while the southern limit falls within the Winnipeg River Subprovince. Provincial-scale mapping by Percival and Easton (2007) and Stott et al. (2010) place the boundary between the English River Subprovince and the Winnipeg River Subprovince to be south of the Township of Ear Falls, although the contact between the two subprovinces is not sharply defined by any specific mappable geological feature.

2.1 BEDROCK GEOLOGY

2.1.1 GNEISSIC METASEDIMENTARY ROCKS OF THE ENGLISH RIVER SUBPROVINCE

The Ear Falls area is dominated by gneissic metasedimentary rocks of the English River Subprovince formed as a result of high-grade metamorphism of sedimentary rocks deposited between approximately 2.704 and 2.696 billion years ago (Sanborn-Barrie et al., 2004) in a foreland sedimentary setting (van de Kamp and Beakhouse, 1979; Breaks, 1992; Breaks and Bond, 1993). The generation of migmatites is attributed to low to medium pressure, high-temperature metamorphism that occurred at approximately 2.691 billion years ago (Corfu et al., 1995). The sedimentary protoliths have been interpreted as being mainly greywacke and mudstone/shale derived from reworked volcanic source rocks within the Uchi Subprovince (Breaks and Bond, 1993). In a small sector of the Township of Ear Falls, between the Bruce Lake and Pakwash Lake plutons, metasedimentary rocks also comprise chert-magnetite ironstone (Sanborn-Barrie et al., 2004). Along the western shore of Bruce Lake, the metasedimentary rocks include an 80 m thick banded iron formation (Griffith deposit). Metavolcanic rocks are not common, accounting for only about 2% of the English River Subprovince.

Nitescu et al. (2006) infer that the metasedimentary rocks throughout the English River Subprovince are on the order of less than 1 km thick where they are underlain by intrusions, and up to 4 km thick in narrow regions along the boundaries of the belt and between intrusive bodies. These depth estimates are based on the integration of surface geologic mapping with gravity and magnetic data, and Lithoprobe seismic data.

2.1.2 PLUTONIC ROCKS

Five large plutonic bodies occur within the Ear Falls area: the Wenasaga Lake batholith, the Bruce Lake pluton, the Bluffy Lake batholith, the Wapesi Lake batholith, and the Pakwash Lake pluton (Figure 2). Other smaller granitic and tonalitic intrusions are mapped in the southern portion of the Ear Falls area.

The Wenasaga Lake batholith is estimated to be of a similar age to the surrounding metasedimentary rocks, between approximately 2.700 and 2.691 billion years old (Breaks, 1992; Nitescu, 2006). It consists of a peraluminous granite mass approximately 7 km wide by 26 km long that likely formed by the partial melting of the sedimentary host rock in conjunction with local injections of fresh magma (Breaks, 1992). The Wenasaga Lake batholith is well exposed in a blast cut along the former Griffith iron mine rail line near Detector Lake (Breaks et al., 2003). At this location, biotite-muscovite pegmatitic leucogranite grades into a biotite-rich granite containing inclusions of metasedimentary gneiss incorporated from the surrounding country rock. The Wenasaga Lake batholith has been examined for potential linkage with a metasedimentary-hosted, rare-element pegmatite mineralization (the Sandy Creek beryl deposit) located adjacent to the southwestern flank of the batholith (Breaks et al., 2003). The gravity field over the Wenasaga Lake batholith exhibits a slight negative response contrasting with the surrounding country rock suggesting that the batholith extends to substantial depth.

The Bruce Lake pluton, which covers approximately 200 km^2, intrudes clastic metasedimentary rocks near the contact between the Uchi and English River subprovinces. The presence of at least one schistosity pre-dating the Bruce Lake pluton in the metasedimentary rocks around the intrusion (Shklanka, 1970), and the timing of the regional deformation described by Breaks (1992) and Stott and Corfu (1991), suggests an emplacement age of between approximately 2.690 and 2.670 billion years ago. The Bruce Lake pluton is composed of various phases including biotite-hornblende-bearing diorite, quartz diorite, monzodiorite, and gabbro. Enclaves of metasedimentary and metavolcanic rocks, including mafic metavolcanic rocks and hornblendite, commonly occur within the pluton (Breaks and Bond, 1993; Sanborn-Barrie et al., 2004). Enclaves of intermediate metavolcanic rocks, trondhjemite, or quartz-diorite also occur but are not common. The gravity field shows no discernible response to the Bruce Lake pluton and cannot be differentiated from the regional trend. Therefore, the thickness of the Bruce Lake pluton is unknown.

The approximately 2.698 billion years old Bluffy Lake batholith (Corfu et al., 1995) is located approximately 12 km east of the Township of Ear Falls and has a surface extension of approximately 705 km^2. The Bluffy Lake batholith is an intrusive complex composed of several units, with composition ranging from trondhjemite to quartz-diorite, and textures ranging from massive to foliated and locally exhibits a gneissic texture. Contacts with the metasedimentary rocks are typically sharp (Breaks, 1992). Breaks (1993) noted that heterogeneous, multicyclic intrusions and intrusive complexes are mainly found in the Winnipeg River Subprovince and that the Bluffy Lake batholith is an example of these in the English River Subprovince. The Bluffy Lake batholith shows a slight negative gravity response relative to the surrounding rocks within the Ear Falls area. Based on available gravity data, Gupta and Wadge (1986) suggest a sheet thickness of 1.5 to 3 km for the Bluffy Lake batholith.

The Wapesi Lake batholith covers an area of approximately 635 km^2, though only a portion of the batholith (approximately 50 km^2) occurs within the extreme southeast of the Ear Falls area. Breaks and Bond (1993) describe the batholith as a southwesterly-tapering mass of massive, coarse-grained to pegmatitic muscovite-biotite and biotite-muscovite quartz-monzonite diatexite, and suggest that the batholith is the result of anatectic melting of the metasedimentary country rock. The age of the Wapesi Lake batholith is given by Breaks (1992) as between approximately 2.692 and 2.668 billion years old. No information regarding the thickness of the Wapesi Lake batholith has been found in the available literature.

Several small elongated granitic bodies are mapped along the Sydney Lake fault zone and a number of elliptical 4 to 6 km long granitic bodies are mapped within the gneissic rocks south of Ear Falls and between Ear Falls and Manitou Falls (Figure 2). For example, the Pakwash Lake pluton is relatively small (10 km^2) and is located in the northwestern section of the Township of

Ear Falls (mostly beneath Pakwash Lake). The Pakwash Lake pluton is similar in mineralogy to the Bruce Lake pluton, with composition ranging from quartz-diorite to diorite. Compared to the Bruce Lake pluton, the Pakwash Lake pluton has less quartz and more mafic minerals. Shklanka (1970) suggests a common parentage and contemporaneous age for the Bruce Lake and Pakwash Lake plutons based on their mineralogical similarities. The smaller bodies are concordant to the ductile fabric of the gneissic belt and may have been generated during the migmatization of the surrounding sedimentary rocks. An unnamed granitic pluton is present in the extreme southeast portion of the Ear Falls area within rocks belonging to the Winnipeg River Subprovince. No information on the thickness of these smaller intrusive bodies was found in the literature. Other relatively large intrusive bodies occur in the northwestern and southwestern parts of the Ear Falls area, and are documented as tonalite to diorite and tonalite to granodiorite, respectively (Sanborn-Barrie et al., 2004).

2.1.3 Mafic dykes

A series of Proterozoic mafic dykes crosscuts all earlier rock types in the areas bordering the Ear Falls area. Such dykes have not been identified nor mapped within the Ear Falls area. However, mafic dykes referred to as the “Ear Falls dykes” were documented at the former Griffith mine. While there is evidence of Mesozoic-age emplacement of kimberlitic pipes and dykes elsewhere in northern Ontario, no post-Precambrian rocks are known to be present within the Ear Falls area (Stott and Josey, 2009).

2.1.4 Faults and shear zones

Two km-scale east-trending shear zones have been mapped within the Ear Falls area: the Sydney Lake fault zone and the Long Legged Lake fault zone (Figure 2). The Sydney Lake fault is 0.5 to 2 km wide (Bethune et al., 2006) and separates the metavolcanic and felsic plutonic rocks of the Uchi Subprovince to the north from the migmatized metasedimentary rocks of the English River Subprovince to the south. Displacement along the Sydney Lake fault is interpreted to have evolved from reverse (south over north) motion to dextral motion. The displacement magnitude of the dextral component is estimated to vary from 6 km (Stott and Corfu, 1991) to 30 km (Stone, 1981) along strike, whereas the displacement magnitude of the reverse component is estimated to be between 2 and 3 km (Stott and Corfu, 1991; Corfu et al., 1995). The Long Legged Lake fault runs along the northeast margin of the Bruce Lake pluton (Figure 2) and is interpreted to be related to the Sydney Lake fault. Cataclastic textures are superimposed on mylonitic textures indicating that brittle deformation followed ductile deformation (Stone, 1981).

2.1.5 METAMORPHISM

Studies on metamorphism in Precambrian rocks across the Canadian Shield have been summarized in a few publications since the 1970s, including Fraser and Heywood, (1978); Kraus and Menard (1997); Menard and Gordon (1997); Berman et al. (2000); Easton (2000a and 2000b) and Berman et al. (2005). The thermochronologic record for major parts of the Canadian Shield are given in a number of studies such as those by Berman et al. (2005), Bleeker and Hall (2007), Corrigan et al. (2007), and Pease et al. (2008).

The Superior Province largely preserves low to medium pressure – high temperature Neoarchean metamorphism from approximately 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, 2000a; 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) and locally within the Uchi Subprovince (Thurston and Paktunc, 1985). 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 $^{40}Ar/^{39}Ar$ dating to approximately 2.500 billion years ago (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).

Overall, most of the Canadian Shield, outside of unmetamorphosed late tectonic plutons, contains a complex episodic history of tectonometamorphism largely of Neoarchean age with broad tectonothermal overprints of Paleoproterozoic age around the Superior Province and culminating at the end of the Grenville Orogeny approximately 950 million years ago.

Major regional deformation and metamorphism within the English River Subprovince culminated approximately 2.691 billion years ago with two later episodes of metamorphism and pegmatite emplacement approximately 2.680 and approximately 2.669 billion years ago (Corfu et al., 1995; Sanborn-Barrie et al., 2004). Corfu et al. (1995) consider the timing (short lived and apparently cyclical) of metamorphism in the English River Subprovince to be consistent with thermal perturbations related to injection of granitic magmas generated through partial crustal melting.

Metamorphic grades are lower within the Uchi Subprovince in the north part of the Ear Falls area where lower amphibolites facies dominate along the contact with the adjacent English River strata grading to greenschist facies over most of the remainder of the Uchi Subprovince (Breaks et al., 1978).

Upper-greenschist facies metamorphic grade in the English River Subprovince is rather restricted to near its contact with the greenstone belts at the north of the subprovince. Metamorphic grade rapidly increases southward reaching upper-amphibolite facies (Breaks and Bond, 1977, 1993), although variable uplift of the English River Subprovince and the extensive fault systems frequently obscure this trend (Stone, 1981; Breaks and Bond, 1993). Two main occurrences of hornblende-granulite facies metamorphism occur near the Ear Falls area: one proximal to left side of the Miniss River fault, approximately 80 km east of the Ear Falls area, and the other about 30 km west of the settlement area of Ear Falls. Thermobarometry indicates pressure-temperature conditions of 4-6 Kbar and approximately 700-725^{o}C for the granulite facies indicating granulite metamorphism of low to medium pressure and high temperature (Chipera and Perkins, 1988; Breaks and Bond, 1993). Potential exists for the granulite isograds to extend eastward into the Ear Falls area, given the relative proximity of granulite facies metamorphism to the area. This could result in a possible lateral gradation of granulite-amphibolite facies within the Ear Falls area. Confirmation of the existence of lateral gradation in metamorphic grade across the Ear Falls area would need to be investigated in future stages of the evaluation process.

2.2 GEOLOGICAL AND STRUCTURAL HISTORY

Direct information on the geological and structural history of the Ear Falls area is limited. The geological and structural history summarized below integrates the results from studies undertaken elsewhere throughout and proximal to the region of the Ear Falls area. It is understood that there are potential problems in regional correlation of specific structural events within a D_x numbering system and in the application of such a system to the local geological history. Nonetheless, the summary below represents an initial preliminary interpretation for the Ear Falls area, which may be modified after site-specific information has been collected.

Rocks of the English River Subprovince have been subjected to multiple Archean deformation events (Westerman, 1977; Breaks et al., 1978; Breaks, 1992) as summarized Table 3. These deformation events have been traditionally interpreted as involving three folding events and one faulting event (Breaks, 1992) but this interpretation has recently been revised by Hrabi and Cruden (2006). Hrabi and Cruden (2006) interpreted the deformation events as components of a single, protracted, and complex orogeny. The work of Hrabi and Cruden (2006), which considers D_1 to D_5 events to be components of a single protracted and complex orogeny, offers a descriptive summary of the deformation events in the English Subprovince and is regarded as the most applicable interpretation of the structural geology of the Ear Falls area. Along with a protracted younger history of brittle deformation, herein termed D_6, these six deformation events form the basis of the following description of the structural history.

The first deformation event (D_1) is interpreted to have generated a weak foliation (S_1) oriented parallel to bedding in low-grade metamorphic rocks located in the north and south margins of the English River Subprovince (Hrabi and Cruden, 2006). At higher metamorphic grades, S_1 is enhanced by migmatitic leucosomes (Hrabi and Cruden, 2006). D_1 is interpreted to have overlapped with the initial migmatization stages of sedimentary rocks and is bracketed between the time of deposition of sedimentary rocks, before approximately 2.704 billion years ago, and the age of a suite of tonalite intrusions dated at approximately 2.698 billion years old and deformed by D_2 (Hrabi and Cruden, 2006). Folds related to this fabric are not commonly found and have only been documented by Breaks (1992) and Hynes (1997, 1998).

Table 3 Summary of the geological and structural history of the Ear Falls area.

Time Period (billions of years ago)	Geological Event
ca. 3.4 to 2.8	Progressive growth of the North Caribou and Winnipeg River terranes through the additions of magmatic and crustal material in continental arcs and through accretion of allochthonous crustal fragments (Tomlinson et al., 2004).
ca. 2.740 to 2.735	Emplacement of early plutons in the Uchi Subprovince.
ca. > 2.704 to 2.69	Timing of collision between the North Caribou terrane and the Winnipeg terrane (Corfu et al., 1995; Hrabi and Cruden, 2006; Sanborn-Barrie and Skulski, 2006). [D_1] • Emplacement of late granitic to granodioritic plutons within the Winnipeg River Subprovince between approximately 2.71 and 2.69 billion years ago (Breaks and Bond, 1993). • Accumulation and syn-depositional deformation of sediments in the English River Subprovince between approximately 2.704 and 2.699 billion years ago (e.g., Sanborn-Barrie et al., 2004).
ca. 2.698	Timing of intrusion of calc-alkaline plutons into sedimentary rocks of the English River Subprovince (Hrabi and Cruden, 2006). Their emplacement provides constraint on the maximum age of D_2 deformation. [2.698 > D_2 > 2.691 billion years ago]
ca. 2.691 to 2.68	Major regional deformation, amphibolite to granulite facies metamorphism, anatexis and emplacement of peraluminous granitic intrusions (Sanborn-Barrie et al., 2004). [D_3]
ca. 2.68 to > 2.67	Dextral semi-brittle movement in the Sydney Lake fault zone (Sanborn-Barrie et al., 2004; Hrabi and Cruden, 2006). [D_4] • Granulite facies metamorphic event approximately 2.680 billion years ago within the Winnipeg River Subprovince (Corfu et al., 1995). Continued metamorphism and pegmatite emplacement within the English River Subprovince (Sanborn-Barrie et al., 2004). (2006).
ca. 2.67 to 2.64	Late fault reactivation (Hrabi and Cruden, 2006). [D_5]
ca. < 2.64 to > 1.9	Post-2.6 billion years old regional faulting and brittle fracturing (Kamineni et al., 1990). [D_6]
ca. 1.9 to 1.7	Emplacement of the Ear Falls dykes (Symons et al., 1983). [D_6 con't]
Post-1.7	A complex interval of erosion, brittle fracture, repeated cycles of burial and exhumation, and glaciations, particularly from the latest Miocene to the present. [D_6 con't]

The second deformation event (D_2) was the most pronounced, and generated an east-trending moderate to intense foliation (S_2) and a stretching lineation (L_2) of varying orientation (Hrabi and Cruden, 2006). F_2 folds are isoclinal and fold the S1 foliation and migmatitic leucosomes (Hrabi and Cruden, 2006). Migmatization of sedimentary rocks continued during D_2 and the resulting migmatitic layering is interpreted to represent a composite S_0-S_1-S_2 foliation (Hrabi and Cruden, 2006). The maximum age of the D_2 deformation is constrained by the approximately 2.698 billion year old suite of tonalite intrusions which are affected overprinted by the S_2 foliation (Hrabi and Cruden, 2006).

Hrabi and Cruden (2006) attribute D_3 deformation to a period of extension. Extensional faults are indirectly evident from Lithoprobe seismic reflection profiles and are attributed to D_3. This extensional phase is consistent with the presence of approximately < 2.701 billion year old conglomeratic basins distributed along the south margin of the English River Subprovince and the three-dimensional geometry of the Uchi and English River subprovinces inferred from Lithoprobe profiles (Calvert et al., 2004) with upwarp of the Moho beneath the English River Subprovince. Based on the timing of the D_2 event, D_3 is therefore constrained to have occurred betwen approximately 2.691 and 2.68 billion years old.

The fourth deformation event (D_4) is attributed to curved east- to northeast-trending sinistral shear zones (Hrabi and Cruden, 2006). Upright moderately east- to southeast-plunging F_4 folds associated with a steeply-dipping penetrative S_4 foliation are also attributed to D_4 (Hrabi and Cruden, 2006). In terms of geometry and kinematics, D_4 shear zones are similar to the well-documented Miniss River fault located about 80 km east of the Ear Falls area (Hrabi and Cruden, 2006). The Miniss River fault is 1 to 2 km wide (Breaks, 1992), with a long history of ductile and brittle deformation (Bethune et al., 1999). The approximate age of a portion of the mylonitic ductile strain along the Miniss River fault is constrained by the age of a granitic dyke dated at approximately 2.681 billion years old, which is deformed and offset by a sinistral shear band within the fault (Bethune et al., 2006). Dextral reactivation of the southwestern portion of the Miniss River fault is interpreted to have occurred approximately 2.670 billion years ago (Bethune et al., 2006), the age of titanite porphyroblasts generated during retrograde metamorphism linked to the reactivation of the fault (Corfu et al., 1995), and may be attributed to D_5 (see below). Therefore, an age range of between approximately 2.68 and 2.669 billion years ago is considered a suitable approximation for the timing of D_4.

Geometric and kinematic relationships strongly suggest a protracted history of late fault movement that is collectively ascribed to a D_6 phase of deformation. For example, the latest displacement of the Sydney Lake fault crosscuts the Miniss River fault (Bethune et al., 2006). This interpretation is consistent with Ar-Ar geochronology indicating that motion along the Sydney Lake fault continued until approximately 2.640 billion years ago (Hanes and Archibald, 1998). However, these regional fault systems are known to have a protracted displacement history and early thrust faulting along the Sydney Lake fault zone is likely to have pre-dated the most significant component of displacement on the Miniss fault (Stone, 1981). Hrabi and Cruden (2006) hence assign faults associated with the Sydney Lake fault to a fifth deformation event (D_5). Bethune et al. (2006) propose that dextral reactivation of the Miniss River fault about 2.670 billion years ago was effectively driven by the stress regime of the younger Sydney Lake fault. Hrabi and Cruden (2006) consider D_1 to D_5 events to be components of a single protracted and complex orogeny. In addition, Hanes and Archibald (1998) suggest that approximately 2.400 billion years ago regional differential uplift was associated with movement along major fault zones throughout the Superior Province. Therefore, the D_5 episode is considered to have been a protracted event of shear zone activation and re-activation that occurred until approximately 2.400 billion years ago.

Further episodes of brittle deformation are inferred to have caused the formation of brittle fractures and faults, and to have reactivated pre-existing faults and fractures in the region. Numerous generations of fracture formation or reactivation have been identified post-dating approximately 2.5 billion years in northwestern Ontario (Brown et al., 1995; Kamineni et al., 1990).

2.3 QUATERNARY GEOLOGY

This section provides an overview of the Quaternary geology. Section 5 presents details on the extent of drift deposits and their role in concealing and censoring the lengths of lineaments.

The Quaternary deposits in the Ear Falls area accumulated during and after the last glacial maximum, known as the Late Wisconsinan Glaciation, with a significant amount of the material deposited during the progressive retreat of the Laurentide Ice Sheet. Advancement of the Laurentide Ice Sheet from the northeast across the area deposited a veneer of till throughout the areas mapped as bedrock in Figure 3 and Figure 4, with thicker accumulations of till mapped as morainal terrain. The morainal terrain located east and west of Pakwash Lake appears drumlinized, suggesting that these morainal landforms consist of relatively dense lodgement till deposited subglacially from actively flowing ice.

Episodes of stagnation during the retreat of the Laurentide Ice Sheet produced north-south trending recessional moraines in the area, which record the progressive northeasterly withdrawal of the ice sheet. The most significant end moraine in the Ear Falls area is the large north-south trending Lac Seul moraine (Figure 3). The Lac Seul moraine is generally formed of cross-stratified gravelly sand or sandy gravel of deltaic ice-contact origin, with only minor till inclusions. Sharpe and Cowan (1990) describe the Lac Seul moraine as a stratified moraine comprising predominantly glaciofluvial and glaciolacustrine sediments even though till can cover large portions of the surface.

Glacial Lake Agassiz inundated the Ear Falls area about 9,900 years ago, depositing silts and clays to thicknesses of 4 m over large areas, particularly surrounding Lac Seul, Pakwash Lake, and the English River. Wave action in Lake Agassiz produced a series of well-developed terraces on the Lac Seul moraine and sandy aprons bordering the moraine (Shklanka, 1970).

Flowing meltwater from the glacier produced relatively minor glaciofluvial deposits in the area that are exposed at surface in a few small sand bodies and eskers in the north and in portions of the western flanks of the Lac Seul moraine. The sands are typically fine to medium grained and are moderately well-sorted and quartz-rich (Ford, 1981).

Since the disappearance of the ice sheets and the gradual draining or drying up of glacial lakes about 9,000 years ago, modern streams have developed alluvial flood plains and organic deposits have accumulated in wet depressions. Organic deposits are found throughout the Ear Falls area, but the most extensive deposits are found east of Bruce Lake and northwest of Pakwash Lake (Figure 3).

3 TOPOGRAPHY

The Ear Falls area lies in the Severn Uplands physiographic region of Ontario (Thurston, 1992), a broadly rolling surface of Canadian Shield bedrock that occupies most of northwestern Ontario. First-order relief is smooth and gently rolling, whereas second-order relief is more complex, consisting of bedrock-controlled ridges and valleys. Much of this relief was produced during glaciation due to preferential erosion of structural and lithological weaknesses. Ice movement and meltwater erosion smoothed and polished resistant bedrock hills and scoured out weakness zones in the bedrock. Valleys and depressions between rock ridges and knolls typically contain lakes, bogs and relatively thick overburden deposits.

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

3.1 Elevation

The land surface elevation within the Ear Falls area (Figure 5) ranges from a low of about 316 m at the shores of Oak Lake in the southwest to a high of 452 m on a hill about 8 km south of Celt Lake, with this amount of relief being expressed over a lateral distance of about 60 km. The Griffith open pit mine, east of Bruce Lake, extends down to an elevation of 289 m. The map of elevation allows for the delineation of the major topographic features in the area.

The major topographic high in the Ear Falls area is located north of Lac Seul and south of Whitemud Lake (Figure 5 inset map). This is the largest contiguous topographic high in the area, with a large part of the Bluffy Lake batholith being located within the upland. Local summits within this feature exhibit elevations of about 430 to 450 m. A second topographic high exists west of Pakwash Lake, in the northwest corner of the Ear Falls area. Here, elevations rise toward the west. There is a minor area of high elevation around Anishinabi Lake and extending north to near Camping Lake. In this area, the topography exhibits numerous hills separated by narrow lows or depressions. It is also worthy to note the long, linear topographic ridge associated with the prominent Lac Seul moraine that runs roughly north-south through the centre of the Ear Falls area, west of Lac Seul and Wenasaga Lake. Along its length, the Lac Seul moraine typically rises

30 to 50 m above the surrounding ground surface and reaches a maximum elevation of over 440 m north of Wenasaga Lake.

The major topographic lows in the Ear Falls area are the basins and outlets associated with the main lakes and rivers that drain toward the lowest elevations in the southwest corner of the Ear Falls area around Oak Lake (Figure 5). Lac Seul, the largest lake in the area, occupies a relatively large topographic basin in the southeast corner of the area and drains westward through a break in the Lac Seul moraine via the English River and into Camping Lake. Pakwash Lake covers another topographic low that connects via the Chukuni River with Camping Lake.

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 within an area. The second was defined as the range in elevation within a circular window, providing an indication of the maximum relief within the window. Many of the areas of exposed bedrock visible in the SPOT imagery in the Ear Falls area are associated with rock ridges and hills displayed in departure maps.

A map of departures from the average elevation within a 20 km radius (Figure 6) can be used to define large contiguous blocks of high ground within the Ear Falls area. The inset map on Figure 6 shows the outlines of the major batholiths and the areas with at least 15 m of topographic prominence at this scale of calculation. The largest contiguous area of high ground is located east and southeast of Celt Lake (labelled A in Figure 6 inset). This area of high ground extends into the Bluffy Lake batholith. The other areas of high ground are relatively more fragmented.

A map of departures from the average elevation within a 2 km radius (Figure 7) can be used to highlight the location and extent of local ridges, summits and trenches in the Ear Falls area. The positive departures in elevation in the area dominantly correspond with rock ridges, but the Lac Seul moraine and some surficial deposits west of Pakwash Lake also appear prominent. At this scale of delineation, most of the rock ridges in the area are less than about 1.0 to 1.5 km in extent.

A map showing the range in elevation within a 250 m radius (Figure 8) 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 100 m. The area of granitic rocks of the Winnipeg River Subprovince (Figure 2) around Anishinabi Lake displays the largest concentration of high relief areas.

3.3 SLOPE

The distribution of slope within the Ear Falls area is highly skewed towards values less than about 10°, with values below this cutoff representing about 99% of the data. Only about 7% of the area is represented by a slope value of 6° or more (Figure 9). Part of the reason for this is the presence of large lakes represented in the digital elevation model as flat areas, but the flatness of the area is not restricted to the lakes. Even the rugged bedrock terrain is made up of areas of gentle slope interrupted only at the margins of knobs, ridges and trenches.

As indicated above, areas of steep slope form the margins of many of the rugged landforms in the Ear Falls area, such as ridges and knobs. As steep slopes on the surface of the Precambrian Shield are often associated with irregularities in the bedrock topography, with some notable exceptions (e.g., end moraines, kames, eskers), it can be assumed that the presence of steep slopes in the Ear Falls area can be an approximate indicator of minimal overburden cover. Many of the extensive areas lacking steep slopes are expected to be relatively flat due to the presence of drift filling lows in the bedrock topography. As a result, areas of low slope density could be areas where less confidence can be obtained in using SPOT and CDED to identify lineaments.

A map showing the density of steep (≥6°) slopes within a 2 km radius was prepared to determine whether this map is effective at delineating the main areas of exposed bedrock in the Ear Falls area (Figure 10). It is concluded that the slope density map, particularly the reclassified inset map, is effective at coarsely identifying the areas with the most extensive bedrock exposure in the Ear Falls area, but it fails to delineate all areas of exposed bedrock in detail and it incorrectly emphasizes some areas with poor bedrock exposure.

The slope density map correctly emphasizes several key areas of known bedrock exposure. The areas around Anishinabi Lake and Zizania Lake are correctly emphasized in the slope density map as areas with significant bedrock exposure. The map also correctly suggests that the eastern half of the Bruce Lake pluton displays greater bedrock exposure than the western half. High slope density is shown in areas of known extensive bedrock exposure within and south of the Long Legged Lake Dome along the northern part of the western boundary of the Ear Falls area. High slope density is shown over the stocks south of Aerofoil Lake (Figure 2) where the SPOT imagery displays impressive amounts of exposed bedrock on rock ridges. The inset map on

Figure 10 shows an area of high slope density 5 km north of Detector Lake, which is the area with the most bedrock exposure on the Wenasaga Lake batholith.

The slope density map fails to identify bedrock exposures on rock ridges of lesser height and steepness. For example, the slope density map underemphasizes the amount of exposed bedrock that exists within the Bluffy Lake batholith between Celt, Whitemud and Aerofoil lakes. The SPOT imagery clearly displays exposed bedrock on most of the hills scattered throughout this area. The hills are not as high and steep-sided as hills near Anishinabi Lake.

High slope density is associated with the Lac Seul moraine and other high-relief surficial deposits in the Ear Falls area. For this reason and the reason outlined in the paragraph above, a slope density map alone cannot be used to reliably interpret areas of exposed bedrock.

4 DRAINAGE

Surface water drainage and the distribution of waterbodies and wetlands are important factors to consider in the preliminary assessment. The larger lakes, many of which cover more than 10 km^2, can completely or partially conceal the surface expression of geological structures thus adding uncertainty to the results of a lineament interpretation comparing surficial and geophysical datasets (SRK, 2013). Surface water flow is also a useful indicator of groundwater flow at shallow depth. Section 4.1 provides information on the size, distribution and depth of lakes. Section 4.2 describes the existing watershed map file and the drainage analysis conducted by JDMA. Section 4.3 describes surface drainage within the Ear Falls area.

4.1 WATERBODIES AND WETLANDS

The Ear Falls area contains a large number of lakes of various sizes, with about 18% (646 km^2) of the area occupied by waterbodies (Figure 11 and Table 4). Fourteen lakes within the Ear Falls area are larger than 10 km^2, six of which are larger than 20 km^2. The largest is Lac Seul, which covers 284 km^2 of the Ear Falls area and extends beyond to a total area of more than 1,200 km^2. These large lakes and the extensive glaciolacustrine deposits surrounding them are sufficiently large to conceal the surface expression of geological structures up to about 10 km in length, and clusters of small lakes can conceal the surface expression of structures, especially when the lakes are located in areas covered by thicker overburden deposits.

In general, the largest lakes, such as Lac Seul, Pakwash Lake, Wenasaga Lake, Whitemud Lake, Camping Lake, Barnston Lake, and Wegg Lake cover the metasedimentary rocks and migmatites of the English River Subprovince that extend through the centre of the Ear Falls area, which could add further uncertainty to the identification of surface lineaments in these areas (Figure 11). Large lakes also cover portions of the main plutons. Bruce Lake (18.1 km^2) covers the western part of the Bruce Lake pluton. Bluffy Lake (25 km^2) covers the northwest part of the Bluffy Lake batholith. In the southwest corner of the Ear Falls area, Anishinabi Lake (33 km^2) and Oak Lake (42.6 km^2) cover portions of the granitic and gneissic rocks of the Winnipeg River Subprovince.

Wetlands depicted on Figure 11 are from the Wetland Unit map file produced by the MNR and obtained from Land Information Ontario (LIO). The mapping coverage provided by this file generally provides a reasonable representation of the number and extent of wetlands in the Ear Falls area, with about 6% of the Ear Falls area covered by wetlands. However, many wetlands displayed in the SPOT imagery throughout the Ear Falls area are not included in this file. A particular concentration of unmapped wetlands occurs in an area about 230 km^2 in extent located between Celt Lake and Aerofoil Lake, along the southern boundary of the Bluffy Lake batholith. The unmapped wetlands in this area form an intricate fabric of organic deposits distributed between low-relief rock and morainal ridges. The fabric of north-south trending morainal ridges oriented sub-parallel with the Lac Seul moraine south and east of Celt Lake are believed to be Rogen moraines. JDMA conducted no infill mapping of wetlands in the Ear Falls area. This was due mainly to the intricate pattern of organic deposits between Celt Lake and Aerofoil Lake and the time required to map these features. This area of the unmapped wetlands is identified in Figure 11.

The most extensive wetland complex in the Ear Falls area is located east of Bruce Lake (Figure 11). This wetland complex is about 50 km^2 in extent and covers much of the western half of the Bruce Lake pluton. In fact, along with Bruce Lake immediately to the west of the wetland complex, water features obstruct virtually the entire western half of the Bruce Lake pluton. Another large wetland complex is located northwest of Pakwash Lake in an area underlain by the Birch-Uchi greenstone belt. Apart from the extensive wetland complexes described above, which are likely associated with thicker overburden deposits, most wetlands in the Ear Falls area are relatively limited in size (< 1.0 km^2) and fill local depressions.

Table 4 Size of lakes larger than 10 km^2 in the Ear Falls area[1].

Lake	Perimeter (km)	Area (km^2)
Wilcox Lake	41.7	10.6
Camping Lake	42.0	11.2
RL-075	34.5	11.7
Whitemud Lake	50.8	12.5
Wine Lake	67.1	15.1
Wegg Lake	45.2	15.6
Bruce Lake	44.8	18.1
Wenasaga Lake	33.8	18.8
Bluffy Lake	90.4	25.0
Anishinabi Lake	75.8	33.0
Oak Lake	163.4	42.6
Wabaskang Lake	176.6	57.9
Pakwash Lake	177.3	87.2
Lac Seul	3766.8	1209.7

[1]Metrics obtained from LIO OHN Waterbody file

Maximum and mean lake depth data are available for several lakes in or near the Ear Falls area (Figure 11 and Table 5). The lake depth data were acquired from an online mapping system entitled Fish ON-Line (MNR, 2013). Unnamed lakes with depth data are labelled on Figure 11 using the object identification (OID) numbers listed in Table 5, and some of these lakes are outside of the Ear Falls area. Most of the lakes presented in Table 5 are less than 25 m deep. The greatest known lake depth in the Ear Falls area is 88 m in Anishinabi Lake. A lake depth of 88 m is not surprising given the high-relief topography associated with the granitic and gneissic rocks of the surrounding Winnipeg River Subprovince (Figure 8). Despite its extensiveness, Lac Seul is generally shallow and has a maximum depth of only 47 m (MNR, 2013).

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 basin analysis in order to confirm and, where possible, partition the most detailed available mapping of watersheds by the MNR. The delineation of drainage divides can be useful for determining surface flow directions and contributing to an initial understanding of the shallow groundwater flow system.

The best available watershed delineation for the Ear Falls 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 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, 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.

Table 5 Maximum and mean depths of lakes in or near the Ear Falls area.

OID[1]	Lake	Area[2] (km^2)	Max depth[3] (m)	Mean depth[3] (m)
725	Fatty Lake	4.6	3.0	0.8
2567	Snail Lake	0.5	3.7	2.3
2540	Ogani Lake	2.7	4.1	1.8
2376	Lower Slate Lake	2.3	5.0	2.3
584		0.3	6.0	2.8
1991	Feaver Lake	1.3	6.0	N/A
1785	East Lake	1.1	6.1	4.2
576		0.4	6.3	2.6
1657		0.7	6.4	2.4
2093	RL-099	2.9	7.0	3.8
928	Aerofoil Lake	6.7	7.5	2.9
587		0.2	8.1	3.3
1011	Detector Lake	3.5	8.2	3.7
1123	Cramp Lake	2.8	9.8	3.5
1618	Gleave Lake	1.2	10.4	6.5
1678		0.4	11.0	4.7
2110	Bug Lake	2.1	11.6	4.7
4149	Florence Lake	4.8	11.6	5.7
1389	Taber Lake	1.4	12.3	4.1
2986	Gerry Lake	0.9	13.0	3.5
1475	RL-102	2.2	13.3	3.3
224	Sunlight Lake	8.5	13.4	4.0
1855	Bluffy Lake	25.0	15.2	4.4
1954		0.9	16.1	5.6
79	Broadcast Lake	6.7	16.2	7.4
2801	Keg Lake	11.0	16.8	7.1
1710	Pakwash Lake	87.2	17.4	6.8
2108	Stone Lake	2.2	17.5	9.0
585		0.5	17.7	7.7
2935	Gullrock Lake	68.2	17.7	7.8
602		1.9	18.0	11.3
609		2.2	18.0	12.5
623	Wegg Lake	15.6	18.9	1.2
2964	Faulkenham Lake	2.3	20.0	7.0
1170	Celt Lake	8.8	21.8	N/A
1886	Whitemud Lake	12.5	22.5	7.5
4044	Bornite Lake	5.1	22.5	10.7
2619	Slate Lake	14.8	24.0	7.2
579		0.6	24.1	9.8
626	Barnston Lake	6.3	24.4	3.8
1480	Emarton Lake	1.2	24.4	13.8
818	Camping Lake	11.2	27.0	4.6
4048	Perrault Lake	33.2	27.4	9.9
4303	Wabaskang Lake	57.9	29.0	8.0
4397	Wine Lake	15.1	29.9	10.7
1980	RL-103	0.9	32.6	6.6
4135	Aerobus Lake	20.7	43.9	15.4
550	Lac Seul	1209.7	47.0	N/A
4353	Anishinabi Lake	33.0	88.4	31.4

[1]Unamed lakes have been labelled on map using this object identifier
[2]Area data obtained from LIO OHN Waterbody file
[3]Depth data obtained from MNR (2013)
N/A = Not 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 (Section 1.3.3) using the same provincial data on which the Provincial DEM was constructed. As a result, the DEM used here is comparable with that used by the Ministry of Natural Resources 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 further control surface flow directions within the basin. The drainage analysis in this assessment 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 12). The inset map of Figure 12 illustrates the tertiary watersheds in the Ear Falls area. As there is virtually no limit to the number of times that a watershed can be subdivided, JDMA had to limit the minimum size of basin in order to maintain a consistent scale of delineation across the Ear Falls area. 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. A field entitled 'Type' was created in the merged file denoting whether each portion of the catchment boundary was modelled by JDMA and MNR (0), only JDMA (1), or only MNR (2). JDMA made an effort to ensure that the newly delineated drainage divides honoured the existing watercourse map file where possible.

4.3 SURFACE FLOW

This section describes the drainage systems in the Ear Falls area and surface water flow over some of the bedrock formations identified as potentially suitable for the siting of a deep geological repository (Golder, 2011).

The Ear Falls area is located within the Nelson River Drainage Area, which drains an enormous area of about 1,000,000 km^2, including the southern parts of Alberta, Saskatchewan and Manitoba, and smaller parts of North Dakota, Minnesota and northwest Ontario. The Nelson River is the single largest contributor of freshwater to Hudson Bay and James Bay.

The secondary-scale watershed containing the Ear Falls area is the English sub-basin. Flow within the English sub-basin can be further divided into the tertiary-scale watersheds of the Central-English, Chukuni and Lower-English sub-sub-basins (see inset on Figure 12).

Surface water in the Ear Falls area generally flows from the upland areas in the north and east toward lower elevations in the southwest. The eastern area drains into Lac Seul, either directly or through Whitemud Lake into Bluffy Lake, then Wenasaga Lake before flowing into Lac Seul. The northwest outlet of Lac Seul flows westward into the English River. In the northern portion of the Ear Falls area, the Troutlake River drains westward into Bruce Lake before flowing into Pakwash Lake. The outlet at the southern end of Pakwash Lake forms the Chukuni River, which flows to the south and joins with the English River to the west of the settlement area of Ear Falls. The English River then flows toward the southwest through Camping Lake, Barnston Lake, and Wegg Lake, before joining with the Wabigoon River south of the Ear Falls area, and eventually the Winnipeg River.

Surface flow over the Bruce Lake pluton is separated by the Lac Seul moraine and dominated by flow of the Troutlake River into Bruce Lake. To the east of the Lac Seul moraine, the pluton is covered by several small lakes and channels that flow northward out of the Ear Falls area before joining with the Troutlake River, which then flows back into the Ear Falls area on the west side of the Lac Seul moraine.

The Troutlake River exhibits a distinct dendritic drainage pattern over a major wetland complex to the east of Bruce Lake. The outflow from Bruce Lake, through a northern outlet near the margin of the pluton, heads westward toward a northeast inlet on Pakwash Lake.

Topographic control of drainage over the eastern portion of the Bluffy Lake batholith results in elongated lakes and straight drainage courses that reflect the underlying bedrock structure. Surface flow over the eastern portion of the batholith drains northward to Whitemud Lake, which then flows westward through Bluffy Lake and southward from Wenasaga Lake to Lac Seul. The western portion of the Bluffy Lake batholith is covered by the relatively large expanse of Bluffy Lake. The inflow and outflow channels of Bluffy Lake appear linear and oriented northeast-southwest, suggesting structural control, but the lake itself, though similarly oriented, lacks straight shorelines, elongated islands, or linear bays.

The Wenasaga Lake batholith forms a topographic high that divides surface flow into several small watersheds. The northern portion of the batholith drains northward to Bruce Lake, whereas, the southern portion drains southward to the English River or Detector Lake. The easternmost extent of the Wenasaga Lake batholith is separated by the Lac Seul moraine, which directs surface flow eastward into Bluffy Lake or Wenesaga Lake. While there are several wetlands, there are no large lakes covering the Wenasaga Lake batholith.

5 TERRAIN CHARACTERISTICS

An understanding of the distribution and thickness of overburden within the Ear Falls area is essential for interpreting the distribution of lineaments mapped from satellite imagery and topographic surface data (SRK, 2013), particularly with respect to lineament length and density. Thick drift deposits are able to mask the surface expression of bedrock lineaments, while areas of sporadic drift deposits can conceal minor lineaments, producing low apparent lineament density. Overburden cover can also censor the lengths of major structures. In areas of thick and extensive overburden, major structures could exist that would be completely undetectable from SPOT and CDED imagery, particularly if these areas also contain large lakes.

Areas of exposed bedrock or thin drift are more readily amenable to site characterization as such locations would enable further investigation of the potentially suitable bedrock formations through outcrop mapping of bedrock structures and preliminary rock mass characterization.

The purpose of this section is to provide information to help improve the understanding of overburden deposits in the Ear Falls area generated through the NOEGTS program (Figure 3). Section 5.1 presents a preliminary review of the water well and drill hole data on overburden thickness in the Ear Falls area. 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 Ontario 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 fieldwork and air photo interpretation by Prest (1982) presented in Section 5.2.

5.1.1 WATER WELL INFORMATION SYSTEM

Water well records from the MOE Water Well Information System were acquired (Section 1.3.5). As stated in Section 1.3.5, there are 33 water well records with depth to bedrock data within the Ear Falls area and 25 within the Township of Ear Falls (Table 6). The largest cluster of wells (18 wells) is located around the settlement area of Ear Falls.

Well records suggest that depth to bedrock in the areas around the wells ranges from zero to 41 metres with an average of about 15 m. Five wells located along the Lac Seul moraine indicate depths to bedrock in excess of 30 m. The well records illustrate the great variability in drift thickness that can occur over short distances. For example, the 18 well records around the settlement area of Ear Falls clustered within a 4 km radius display depths to bedrock ranging from zero to more than 40 m.

5.1.2 ONTARIO DRILL HOLE DATABASE

There are 785 drill holes within or near the Ear Falls area containing data on depth to bedrock (Section 1.3.5), with 248 of these located inside the Ear Falls area. About 500 drill holes are located just north of the Ear Falls area, many of which are within the Birch-Uchi greenstone belt (Figure 2). Although these approximately 500 drill holes are located outside of the Ear Falls area, the information on drift thickness that they contain is likely indicative of the conditions within parts of the Ear Falls area. Drift thickness ranges from zero up to about 73 m in the 785 drill holes within or near the Ear Falls area, with an average around 10 m. About 90% of the drift thickness values are less than 25 m. Some of the maximum drift thickness values were reported from drill holes located on or near lakes. It is not known whether some of these drill holes were drilled from lake ice platforms and whether the height of the water column was included in the depth to overburden value reported.

The summary data provided in

Table 7 represent data for drill holes contained within assessment files reporting ten or more drill holes. The maximum depth to bedrock shown by these drill holes suggest an upper limit for overburden thickness of around 40 to 50 m, which is similar to the maximum depth to bedrock suggested by the water well data. In one of these assessment reports (52K13NE2007), all of the drilling was completed on bedrock, thereby resulting in zero depth to bedrock in all drill holes.

Water well and drill hole data in the Ear Falls area tends to be clustered. Therefore, a overburden thickness map cannot be produced, even though a large dataset is available.

Table 6 MOE water well data in the Ear Falls area with data on drift thickness.

Borehole ID	Well ID	Date	Elevation (m)	Depth to bedrock (m)
10182945	3102859	5/2/1990	355.7	0.0
10182943	3102857	4/24/1990	349.7	0.9
10181978	3101847	10/21/1982	357.6	1.2
10182527	3102429	1/1/1988	353.9	1.5
10181975	3101844	10/22/1982	339.4	2.4
10183228	3103151	1/1/1992	351.4	2.4
10184056	3104000	9/20/1999	374.0	4.0
11106031	3104329	5/10/2004	355.8	5.2
10184007	3103951	7/4/1999	356.9	5.5
10181371	3101080	8/16/1976	333.1	6.7
10181372	3101081	8/10/1976	350.1	7.3
10180684	3100366	10/20/1967	354.7	8.5
10181370	3101079	8/28/1976	334.0	9.1
10532308	3104232	7/17/2002	363.6	9.8
10183382	3103307	6/21/1993	347.7	10.7
10181937	3101805	5/26/1982	348.7	11.6
10182410	3102309	5/30/1987	364.0	12.2
10180639	3100321	9/30/1957	353.0	12.5
10180682	3100364	9/12/1967	344.4	13.1
10183481	3103407	7/12/1994	359.2	13.1
10180647	3100329	6/3/1966	339.7	15.8
10183349	3103274	4/16/1993	355.5	15.8
10183468	3103394	7/5/1994	349.0	17.1
10183560	3103491	4/27/1995	355.6	17.4
10181374	3101083	9/2/1976	377.8	22.6
10180640	3100322	7/7/1958	369.9	27.1
10182536	3102438	3/6/1988	342.1	29.0
10181024	3100717	7/6/1972	349.4	29.3
10180674	3100356	11/27/1966	370.5	31.1
10180675	3100357	12/7/1966	396.5	35.1
11767470	7044969	5/2/2007	362.9	35.4
10180676	3100358	12/14/1966	383.8	37.8
10532307	3104231	7/19/2002	366.4	41.5

Table 7 Selected OGS diamond drill hole data on depth to bedrock in the Ear Falls area.

		Drift thickness (m)		
AFRI FID[1]	Count[2]	Min	Max	Mean
52K13NW0006	10	0.8	16.8	6.3
52K14NW0029	10	5.9	17.8	11.5
52K15NW0039	10	1.1	12.5	4.5
52K15NE0037	12	1.7	20.0	7.6
52K13NE2007	13	0.0	0.0	0.0
52K13NW0039	13	0.9	23.6	6.0
52K14NW0026	13	0.0	25.2	12.1
52K14SE0015	13	4.0	11.2	7.9
52K14NE0030	14	11.9	45.3	26.5
52K14NE2015	14	11.9	45.3	25.7

[1]Assessment File Research Image (AFRI) file number
[2]Number of drill holes reported in assessment file

5.2 NOEGTS TERRAIN UNITS

5.2.1 MORAINAL TERRAIN

Within the Ear Falls area, NOEGTS mapping includes two morainal terrain units, ground moraine (MG) and end moraine (ME). The ground moraine units are dispersed throughout the Ear Falls area, but the most extensive coverage appears in the northwest, particularly east and west of Pakwash Lake. These areas of ground moraine include drumlins, which suggest subglacial deposition of lodgement till rather than supraglacial ablation till. In other areas, particularly between Celt Lake and Lac Seul, the ground moraine unit and areas mapped as bedrock terrain include linear features oriented perpendicular to ice retreat direction that are identified as Rogen moraines. In areas mapped as ground moraine, the terrain is typically well drained with low relief, undulating to knobby topography. Prest (1982) describes the thickness of ground moraine deposits in the Ear Falls area as one to several metres.

Within the Ear Falls area, the Lac Seul Moraine appears as a 100 to 1,000 m wide ridge that extends up to 50 m above the surrounding terrain, along which part of Highway 105 has been routed (Figure 3). This end moraine-like feature consists of cross-stratified gravelly sand or sandy gravel of deltaic ice-contact origin. Based on its topographic relief, and data from MOE water wells (Section 5.1.1), its thickness probably exceeds 40 m or more. Prest (1982) suggests that the large end moraine deposits could be tens of metres in thickness, which is consistent with what is suggested by the topographic and subsurface data.

5.2.2 GLACIOFLUVIAL TERRAIN

The most significant glaciofluvial deposits in the Ear Falls area are the ice-contact deltaic sands and gravels that comprise much of the Lac Seul moraine (Figure 3). As noted above, the Lac Seul Moraine is mapped as an end moraine, but it consists largely of cross-stratified sand and gravel deposited as an ice-contact delta into a proglacial lake to the west. The thickest overburden in the Ear Falls area is expected to be found along the axis of the Lac Seul moraine.

Esker and outwash deposits in the Ear Falls area are generally located in the north, covering portions of the Bruce Lake pluton and the Birch-Uchi greenstone belt. There are no MOE water well records for these glaciofluvial units (Figure 3), but numerous OGS diamond drill holes in the northwest part of the Ear Falls area record depths to bedrock ranging from about 1 to 30 m (Figure 3). Based on field mapping, Prest (1982) estimates thicknesses of 1 to 10 m for these glaciofluvial deposits.

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.

5.2.3 GLACIOLACUSTRINE TERRAIN

Glaciolacustrine deposits have been divided into three landform types (Gartner et al., 1981): raised beach ridge, glaciolacustrine delta, and glaciolacustrine plain. All glaciolacustrine terrain shown on Figure 3 represents lake plain, which is generally composed of silts and clays. Abandoned shorelines have been mapped as linear features on Figure 3.

Glaciolacustrine deposits in the Ear Falls area are associated with glacial Lake Agassiz and are generally located between Lac Seul and Pakwash Lake, along the English River, and toward the southwest (Figure 3). These locations represent areas of low elevation within the Ear Falls area (Figure 5). Glaciolacustrine deposits mapped by Prest (1982) are generally less than 5 m thick. MOE wells located in these areas record overburden thicknesses up to 30 m, and these thick overburden deposits likely include both glaciolacustrine deposits and underlying glacial deposits.

The geotechnical properties of silts and clays are often 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. Glaciolacustrine plains are often associated with poor drainage and organic terrain.

5.2.4 ORGANIC TERRAIN

All types of peatlands were mapped in the Northern Ontario Engineering Geology Terrain Study as organic terrain, with no attempt to distinguish between marsh, swamp, bog, or fen (Gartner et al., 1981). The organic material is peat and muck and the landform is often confined topographically with stagnant drainage or wet surface conditions.

Extensive organic deposits typically occur in areas covered by thick drift, where the peat and muck deposits are generally thin due to the gently undulating character of the terrain. Prest (1982) suggests that organic deposits in the Ear Falls area are generally less than 2 m thick. Although the organic deposits might be thin, it is important to note that the underlying drift deposits are expected to be much thicker. The most extensive organic deposits in the Ear Falls area are located east of Bruce Lake and northwest of Pakwash Lake. Organic deposits in the bedrock terrain are typically less extensive but can be thicker, as they fill depressions between bedrock ridges and knobs.

Note that the coarse scale of the NOEGTS mapping allowed only the delineation of the largest and most easily delineated organic deposits in the Ear Falls area. Smaller, unmapped organic deposits are found within all other NOEGTS terrain units, including bedrock terrain. For example, the area between Celt Lake and Aerofoil Lake, which was delineated as bedrock terrain, actually contains a significant number of unmapped organic deposits located within depressions distributed amongst areas of higher ground where exposed bedrock can be found.

The locations of deeper pockets of organic material are difficult to predict reliably without test drilling. Unfortunately, no drill holes have been advanced through the extensive organic deposits in the Ear Falls area and the low positional accuracy of the OGS drill holes and the small extent of most organic deposits renders interpreting drift thickness data tenuous. For example, if an organic deposit is 200 m in diameter and the positional accuracy of a drill hole positioned over the deposit is 1 km, then it is not possible without reviewing drill hole plans and drill logs in the associated assessment file whether the drill hole was actually advanced through the organic deposit. Even if the logs of drill holes advanced through organic deposits were reviewed, it would be impossible to know the thickness of the organic material because all of the overburden, including the drift underlying the organic material, would be grouped into a single thickness value. As a result, it is impossible to use existing drill hole data to characterize the thickness of organic deposits and it is difficult to use existing drill hole data to characterize overburden thickness within the organic terrain.

Exceptionally poor engineering characteristics can be found within areas mapped as organic terrain (Gartner et al., 1981). Peat and muck have low shear strength and high compressibility. Groundwater tables are at or near the surface in organic terrain and flooding is common.

5.2.5 BEDROCK TERRAIN

In general, the NOEGTS program delineated much of northern Ontario as bedrock terrain (Gartner et al., 1981). Note that the areas mapped as bedrock terrain do not represent exposed bedrock. These areas generally contain a thin mantle of drift, which is less than 1 m thick in most places, and the drift can be much thicker locally, especially in low areas between bedrock hills. Dense vegetation can also limit the extent of bedrock exposures.

Based on an assessment of the SPOT imagery in the Ear Falls area, the actual amount of exposed bedrock within most of the areas delineated as bedrock terrain ranges from zero to at most 20%. Only in special cases, such as east of Anishinabi Lake, were individual rock ridges mapped producing a higher percentage of exposed bedrock. In most instances, the bedrock terrain (Figure 3) represents a complex of bedrock highs and drift-covered lows. This generalized style of mapping used for the NOEGTS program contrasts with that of 1:50,000-scale surficial mapping of Prest (1982). Detailed surficial mapping projects often have two classes of bedrock terrain: one called 'bedrock' where greater than 50% of the area is exposed bedrock, and the second called 'bedrock-drift complex' or 'morainal veneer' where bedrock exposures are distributed amongst larger drift-covered areas.

Due to the generalized nature of the NOEGTS mapping, there are some differences between it and the detailed surficial mapping. Some of the areas mapped as bedrock terrain in Figure 3 are not mapped as bedrock in the detailed mapping (Figure 4). The area north of Bruce Lake is an example. It is also possible to find places where the NOEGTS mapping failed to delineate areas of exposed bedrock identified in the detailed surficial mapping. For example, Figure 3 shows almost no bedrock terrain on the Wenasaga Lake batholith, whereas Figure 4 shows a relative abundance of exposed bedrock. As a result, NOEGTS mapping overestimates bedrock exposure in some areas and underestimates it in others.

Most of the OGS drill holes advanced in bedrock terrain shown in Figure 3 are located north of the northern boundary of the Ear Falls area. However, many of these areas were not delineated as bedrock in Figure 4. The main area with drill holes, that was delineated as bedrock in both maps is located in the northwest corner of Figure 3 where a cluster of 17 drill holes about 10 km west of Gullrock Lake indicates minimum, mean and maximum drift thickness values of about 0, 5, and 25 m respectively.

A descriptive summary of the extent of exposed bedrock within the main bedrock formations is provided in Table 8. This summary integrates observations made from the NOEGTS mapping (Figure 3), 1:50,000 scale surficial mapping (Figure 4), relief maps (Figure 6 and Figure 7), and SPOT imagery.

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).

Table 8 Qualitative summary of extent of exposed bedrock over the main bedrock formations.

Bedrock unit	Qualitative description of extent of exposed bedrock
Metasedimentary rocks of the English River Subprovince (Units 7, 7c, 7d, 7e)	The largest contiguous area of bedrock terrain mapped over these rocks occurs south of the Bluffy Lake batholith, between Celt Lake, Aerofoil Lake and Lac Seul. Extensive areas of high ground with abundant bedrock exposure are also shown (Figure 6 inset) near the central west edge of the Ear Falls area within the south part of the Long Legged Lake Dome and in the migmatized metasediments to the south. The NOEGTS map (Figure 3) very coarsely identifies the two main areas of high ground where the best bedrock exposure is displayed in the SPOT imagery over this highland complex. Another metasedimentary area with exposed bedrock is the area south of Camping Lake (Figure 4).
Wenasaga Lake batholith (Unit 13)	Two east-northeast trending areas of high ground were delineated on the Wenasaga Lake batholith, each about 8 km long and 2 km wide (Figure 6 inset). These areas contain the largest concentration of bedrock exposures within the batholith. Bedrock exposures within the batholith are best delineated in the detailed surficial mapping (Figure 4).
Bruce Lake pluton (Unit 14)	Very little exposed bedrock is mapped over the Bruce Lake pluton. Bruce Lake and an extensive wetland cover the western half of the pluton. It is difficult to judge the amount of exposed bedrock on the eastern half of the pluton, where extensive forest harvesting has modified the spectral properties of the surface, but the detailed surficial mapping suggests that there is considerable exposed bedrock in that area (Figure 4).
Bluffy Lake batholith (Unit 12)	The Bluffy Lake batholith and the migmatized metasediments to the south are located within the largest contiguous area within the Ear Falls area that has been mapped as bedrock terrain. Within this area, the greatest amount of bedrock exposure is located within and to the north of a large contiguous block of high ground (8 x 20 km) extending north-northeast between Celt Lake and Aerofoil Lake (Figure 6 inset labelled ‘A’). Much of this area contains organic deposits not mapped in the NOEGTS or Wetland Unit map files (see Figure 11). The SPOT imagery displays exposed bedrock on many of the distinct hills shown on Figure 7 throughout this area of topographic prominence. In addition, hills within a burned or harvested area east of Bluffy Lake could contain exposed bedrock.
Wapesi batholith (Unit 13)	Within the part of the Wapesi batholith shown in Figure 3, the northern part of the batholith (east of the McKenzie Bay stock) contains the greatest amount of exposed bedrock. Exposed bedrock is found on the hills shown in Figure 7, with the largest bedrock hills located east of the eastern boundary of the Ear Falls area.
Intrusive rocks in SW part of Ear Falls area within Winnipeg River Subprovince (Units 12, 15)	Hills protruding from the surrounding drift-covered lows around Anishinabi Lake display the largest areas of exposed bedrock in the Ear Falls area. The largest hills (1-2 km diameter) with the best bedrock exposure are located east of Anishinabi Lake. Some of the hills in the area exceed 100 m in height above nearby lake levels.
Pakwash Lake pluton (Unit 14)	No bedrock is exposed in the only appreciable portion of the pluton that is not covered by Pakwash Lake (where Highway 105 comes to within 1 km of the northeastern shore of Pakwash Lake). The high ground in this area has been mapped as outwash.
McKenzie Bay stock (Unit 12)	No areas of exposed bedrock of any significant extent exist. Much better bedrock exposure exists in the Wapesi batholith to the east.

6 GROUNDWATER

Golder (2013) provides a detailed discussion of the hydrogeology of the Ear Falls area. Only a brief summary is provided here based on topographic information, the type and extent of surficial deposits and bedrock exposure.

In general, shallow groundwater flow is expected to mimic the pattern of surface flow suggested by Figure 12. The low topographic relief in the area would result in low hydraulic gradients for shallow groundwater movement. The pattern of shallow groundwater flow within bedrock would be influenced also by the presence of major structural or lithological discontinuities in the bedrock.

Steep slopes and the general absence of thick overburden deposits in the areas mapped as bedrock terrain should promote surface runoff. Bedrock aquifers are likely shallow with recharge occurring through discontinuities such as joints and fractures. A large proportion of the groundwater in the bedrock should be confined to fractures in the upper 45 to 60 m of bedrock, with permeability varying from impermeable to highly permeable, depending on the spacing, depth and aperture of discontinuities in the bedrock (Mollard and Mollard, 1980). Recharge would occur on the tops and sides of rock ridges where fractures and faults in the bedrock are mostly exposed due to the absence of drift deposits. The axes of these ridges would form groundwater divides.

Thicker drift deposits in topographic depressions would be recharged by groundwater from shallow bedrock aquifers on nearby uplands. Recharge would also occur through infiltration in poorly drained depressions. Discharge from these deposits occurs into creeks, rivers, lakes and wetlands.

Thick drift deposits forming topographic highs, such as the Lac Seul moraine, would represent recharge areas, especially where these deposits are composed of stratified sands and gravels. Groundwater flow from these deposits would recharge underlying surficial and bedrock aquifers.

The regional discharge zones in the Ear Falls are the large lakes and rivers occupying the major topographic lows.

No information beyond what was presented in the initial screening (Golder, 2011) on groundwater flow at typical repository depths (approximately 500 m) was found during this assessment.

7 NEOTECTONIC FEATURES

Neotectonics refers to deformations, stresses and displacements 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 principal stress orientation in central North America, based on the World Stress Map (Zoback, 1992), is NE (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 Period have induced stresses by sequentially loading and unloading the Earth's crust. The stresses associated with cycles of ice loading and unloading, acting along with tectonic stresses, may result in seismic events related to displacements along ancient discontinuities in the bedrock. 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 or modern lacustrine deposits may preserve evidence of paleo-seismic activity.

As stated in Section 5.2.3, glaciolacustrine deposits in the Ear Falls area are generally located between Lac Seul and Pakwash Lake, along the English River and toward the southwest (Figure

3). Some road and water access is available to these regions, which may allow for the investigation of the presence of neotectonic features.

8 ACCESSIBILITY CONSTRAINTS

Good access into the central and some marginal parts of the Ear Falls area is provided by four main paved roads. Provincial Highway 105 provides good access to the central part of the Ear Falls area, including direct access to the Pakwash Lake pluton and Wenasaga Lake batholith (Figure 13). Highway 804 and Highway 657 are secondary highways. Highway 804 extends west from Highway 105 approximately 4 km south of the settlement area of Ear Falls. This highway ends just past Camping Lake, and a resource road continues from the end of the highway to the northwest, beyond the western boundary of the Ear Falls area.

Roads shown in Figure 13 are based on the MNR road segment file obtained from Land Information Ontario. The MNR road segment file contains resource 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 sourced from the Ontario Road Network. Recreation trails and short-term forest operation roads or forest fire roads are not included in the file. JDMA divided the roads into main roads (Highway 105, 804, 657 and Separation Lake Road) and local roads (Figure 13). An evaluation of the road segment file against the SPOT imagery indicates that the coverage is quite good. However, the 2006 SPOT imagery displays many roads throughout the Ear Falls area, which are not included in the MNR road segment file. As a result, JDMA completed a very coarse and necessarily incomplete attempt at delineating some of the unmapped roads using the SPOT multispectral and panchromatic imagery and Google Earth imagery (Figure 13). Several roads visible in the SPOT imagery were not delineated in this mapping attempt due to the large number of unmapped roads.

Highway 105 and Separation Lake Road provide access onto the west and east margins of the Wenasaga Lake batholith, respectively. The best bedrock exposure on the Wenasaga Lake batholith (Figure 4), in the south-central part of the batholith, is located about 3 to 8 km away from the nearest roads.

Separation Lake Road provides access to the centre of the Bruce Lake pluton. The eastern half of the pluton has been the site of extensive recent forest harvesting, as indicated by the 2006 SPOT imagery. Figure 4 displays abundant exposed bedrock in the eastern margin of the pluton. Access to this part of the pluton for preliminary site reconnaissance could be provided by the many resource roads, many of which are not included in the MNR road segment file but have been mapped coarsely by JDMA (Figure 13). Bruce Lake and the associated extensive wetland render much of the western half of the pluton inaccessible by existing roads.

Access to the Bluffy Lake batholith is provided by a resource road that extends from Highway 657 to the northeast through the centre of the batholith. This resource road provides access only to the northern fringe of the most obvious area of good bedrock exposure and high ground described in Section 3.2 (labelled as 'A' on the Figure 6 inset) and Section 5.2.5 (Table 8). The main area of extensive bedrock exposure within the batholith is located between Celt, Whitemud and Aerofoil lakes south of the resource road. It is difficult to judge the extent of bedrock exposure and roads on the hills east of Bluffy Lake due to what appears to be a burn that has affected much of this area. There is a dense fabric of unmapped wetlands in the area shown on Figure 11. Wetlands would be unfavourable for road routing.

Highway 804 provides access to the west-central part of the Ear Falls area, an area of sporadic bedrock exposure underlain by migmatized metasediments of the English River Subprovince. The highway ends at the Manitou Falls Generating Station, where a resource road extends west with numerous small resource roads extending north and south.

The area with abundant rock ridges and good bedrock exposure north and south of Zizania Lake can be accessed from the north by a resource road extending west from Highway 105 just south of the Township of Ear Falls. Some of the rock ridges around Anishinabi Lake have been logged recently, and most of the resource roads onto the ridges are not included in the MNR road segment file shown in Figure 13. Alternate access to the rock ridges around Anishinabi Lake could be provided by a resource road extending north from southwest of Anishinabi Lake.

A local road that branches off from Highway 657 and extends to the southeast, near the north shore of Lac Seul (Figure 13) provides access to the southeast part of the Ear Falls area. Much of the forest shown in the SPOT imagery around this road appears to be dense regrowth that limits bedrock exposure, although there are some roads leading onto fresh clearcuts on hills along this corridor.

The portion of the Long Legged Lake dome within the Ear Falls area can be accessed using two resource roads extending south from Highway 105. One extends along the west shore of Pakwash Lake. The other extends south from near the south shore of Gullrock Lake. This road provides access to within 2 to 5 km of an upland area of good bedrock exposure about 4 km in extent, located about 5 km northwest of Dixie Lake. An old logging road extends along the southern boundary of the area of extensive bedrock exposure here. Roads extend to within a couple kilometres of another area of extensive bedrock exposure on the southern margin of the Long Legged Lake Dome about 10 southwest of Dixie Lake.

In general, the largest areas of exposed bedrock within favourable bedrock formations in the Ear Falls area are not accessible by main roads. As a result, some amount of new road construction would be required to gain access to these areas for construction purposes. Road routing and construction will need to consider in detail the wetlands, lakes, and rivers (Section 4.1) and rugged terrain (Section 3) described at the synoptic scale in this report. Extensive blasting would be required in areas of highly irregular bedrock topography, and large cuts and fills would be required to obtain good vertical and horizontal alignments in the more rugged areas. The maps generated in this report and the digital data on which they were constructed could be examined in more detail than was possible at this stage in order to further assess accessibility.

Regarding the accessibility of certain parts of the Ear Falls area for preliminary field reconnaissance, note that some of the older resource roads in the area could be heavily overgrown and choked with abundant windfall. Any of the roads mapped by JDMA shown on Figure 13 should not be relied on for access. Forest harvesting companies or the MNR could have more detailed up to date maps of accessible resource roads.

9 SUMMARY

This report presents an analysis of the terrain in the Ear Falls area using publicly available remote sensing and geoscientific information sources. The information enhances and expands upon that presented in the Ear Falls initial screening report (Golder, 2011). The main information sources relied on in this assessment are the Canadian Digital Elevation Data (CDED), the multispectral SPOT satellite imagery and the maps from the Northern Ontario Engineering Geology Terrain Study (NOEGTS) and the Ontario Geological Survey. Additional sources of information on overburden deposits included the Ontario Drill Hole Database and the Water Well Information System.

Estimates of overburden thickness within the Ear Falls area were extracted from OGS 1:50,000 scale surficial maps, as well as analysis of MOE water well records and OGS diamond drill holes. Overburden thickness varies considerably over short distances. The areas of thickest overburden in the Ear Falls area are likely associated with the Lac Seul moraine and associated underlying deposits, which likely exceed 40 m or more in thickness. The Lac Seul moraine is a prominent north-south trending ridge traversing through the centre of the area, along which parts of Highway 105 and Separation Lake Road have been routed. A significant portion of the central part of the Ear Falls area, including the areas around the major lakes and rivers, represents a low-lying area that was inundated by glacial Lake Agassiz about 9,900 years ago. This produced a mantle of fine-grained deposits ranging from massive silt to rhythmically bedded silt and clay over the existing Late Wisconsinan ground moraine deposits. It is important to recognize that the thickness estimates for specific drift deposit types presented in Section 5.2, which were based on Prest (1982), include only the specific deposit type of interest and do not include the thickness of any underlying overburden. In contrast, drill hole and water well data indicate the total thickness of overburden at point locations, but the restricted spatial distribution of the points limits the usefulness of these data in characterizing drift thickness across the Ear Falls area.

Areas of exposed bedrock or thin drift are more readily amenable to site characterization as such locations would enable further investigation of the potentially suitable bedrock formations through outcrop mapping of bedrock structures and preliminary rock mass characterization. The NOEGTS mapping provides a generalized image of the main areas where an abundance of exposed bedrock can be found including highland areas around the west-central, south-central and east-central margins of the Ear Falls area. However, cross checking against the 1:50,000 scale surficial geology mapping and against the multispectral SPOT imagery (Section 5.2.5) illustrated the limitations of the NOEGTS bedrock exposure mapping. Detailed surficial mapping projects often have two classes of bedrock terrain: one called 'bedrock' where greater than 50% of the area is exposed bedrock, and the second called 'bedrock-drift complex' or 'morainal veneer' where bedrock exposures are distributed amongst larger drift-covered areas. The NOEGTS mapping did not distinguish between these two classes. As a result, the actual amount of exposed bedrock within most of the areas delineated as bedrock terrain ranges from zero to at most 20%. Only in special cases, such as east of Anishinabi Lake, were individual rock ridges mapped producing a higher percentage of exposed bedrock. Consequently, a summary of the extent of exposed bedrock in the main bedrock formations in the Ear Falls area was prepared (Table 8) which was not based exclusively on the NOEGTS data, but which was based on an integration of the NOEGTS mapping, detailed surficial mapping and the SPOT imagery.

Several areas of thin drift and good bedrock exposure have been discussed throughout the report and most of which were summarized in Section 5.2.5 (Table 8). Rock ridges within highland areas are the best areas of exposed bedrock. As such, relief maps and a slope density map have been generated to assist with the delineation of areas of thin drift and exposed bedrock.

A drainage analysis was conducted in order to confirm and subdivide the best available watershed delineation for the Ear Falls area. 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 including drainage divides not present in the MNR quaternary watershed file. Surface water in the Ear Falls area generally flows from the upland areas in the north and east toward lower elevations in the southwest.

Groundwater flow within drift deposits and in shallow bedrock aquifers in the Ear Falls area is expected to mimic the pattern of surface flow, with groundwater divides coinciding with drainage divides and discharge occurring into topographic lows. For shallow groundwater flow, which is expected to extend to depths of 45 to 60 m into bedrock, the recharge areas will typically coincide with these drainage divides along bare rock ridges and other topographic highs, such as the Lac Seul moraine. Discharge zones will be concentrated into overburden deposits within the surrounding topographic lows and into creeks, rivers, lakes and wetlands. This assessment found no information beyond that presented in the initial screening (Golder, 2011) on groundwater flow at repository depth.

Conclusive identification of features indicative of reactivation of ancient bedrock structures due to cycles of glacial loading and unloading, acting along with tectonic stresses, cannot be identified using the information sources available in the current assessment. Field investigations would be required to identify features associated with paleoseismicity.

The main accessibility constraints in the Ear Falls area are large lakes, wetlands, and steep slopes. The Ear Falls area includes several primary roads and a network of secondary roads that provide reasonably good access for site reconnaissance aimed at preliminary site characterization. However, large parts of some potentially suitable bedrock formations are not readily accessible and would require new road development to provide access for construction purposes.

This terrain analysis has attempted, in part, to delineate areas of exposed bedrock or relatively thin overburden cover to support an assessment of whether potentially suitable bedrock formations within the Ear Falls area are also amenable to site characterization activities. Conversely, the presence of overburden deposits and water features over about 75% of the Ear Falls area (inset map in Figure 3) highlights the potential uncertainties associated with bedrock mapping products as well as identification and classification of surface structures such as faults.

REFERENCES

Baird, A. and S.D. McKinnon, 2007. Linking stress field deflection to basement structures in southern Ontario: results from numerical modeling. *Tectonophysics,* 432, 89-100.

Beakhouse, G.P. 1992. Winnipeg River Subprovince. In: P.C. Thurston, H.R. Williams, R.H. Sutcliffe and G.M. Scott (eds.), Geology of Ontario. Ontario Geological Survey, Special Volume No. 4, Part 1, pp. 279-301.

Berman, R.G., R.M. Easton and L. Nadeau, 2000. A new tectonometamorphic map of the Canadian Shield: Introduction. *The Canadian Mineralogist*, 38, 277-285.

Berman, R.G., M. Sanborn-Barrie, R.A. Stern and C.J. Carson, 2005. Tectonometamorphism at ca. 2.35 and 1.85 Ga in the Rae Domain, western Churchill Province, Nunavut, Canada: Insights from structural, metamorphic and IN SITU geochronological analysis of the southwestern Committee Bay Belt. *The Canadian Mineralogist*, 43, 409-442.

Bethune, K.M., H.H. Helmstaedt, R.B. Hrabi, 1999. Structural analysis of faults in the apical region of the Wabigoon Subprovince. In: R.M. Harrap and H.H. Helmstaedt, (eds.), Western Superior Transect 5th Annual Workshop, Ottawa, Ont. Feb. 1-3, 1999. Lithoprobe Secretariat, University of British Columbia, Vancouver, B.C., Lithoprobe Report 70, pp. 5-14.

Bethune, K., H. Helmstaedt and V. McNicoll, 2006. Structural analysis of the Miniss River and related faults, western Superior Province: post-collisional displacement initiated at terrane boundaries. *Canadian Journal of Earth Sciences*, 43, 1031-1054.

Bleeker, W. and B. Hall, 2007. The Slave Craton: Geology and metallogenic evolution. In: Goodfellow, W.D., (ed.), Mineral deposits of Canada: A synthesis of major deposit-types, district metallogeny, the evolution of geological provinces, and exploration methods. Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, pp. 849-879.

Breaks, F. W., 1992. English River Subprovince. In: P.C. Thurston, H.R. Williams, R.H. Sutcliffe and G.M. Scott (eds.), Geology of Ontario. Ontario Geological Survey, Special Volume No. 4, Part 1, pp. 239-277.

Breaks, F.W. and W.D. Bond, 1977. English River Subprovince (Marchington Lake Area), District of Kenora. In: V.G. Milne, O.L. White, R.B. Barlow and J.A. Robertson (eds.), Summary of field work 1977. Ontario Geological Survey, Misc. Paper 75, pp. 18-28.

Breaks, F.W. and W.D. Bond, 1993. The English River Subprovince-An Archean Gneiss Belt: Geology, Geochemistry and associated mineralization. Ontario Geological Survey, Open File Report 5846, v.1, pp.1-483, 884p.

Breaks, F.W., W.D. Bond and D. Stone, 1978. Preliminary geological synthesis of the English River Subprovince, northwestern Ontario and its bearing upon mineral exploration. Ontario Geological Survey, Miscellaneous Paper 72, 55p.

Breaks, F.W., J.B. Selway and A.G. Tindle, 2003. Fertile peraluminous granites and related rare-element mineralization in pegmatites, Superior Province, northwest and northeast Ontario: Operation Treasure Hunt. Ontario Geological Survey, Open File Report 6099, 179p.

Brown, A., R.A. Everitt, C.D. Martin and C.C. Davison, 1995. Past and future fracturing in AECL research areas in the Superior Province of the Canadian Precambrian Shield, with emphasis on the Lac Du Bonnet batholith. Whiteshell Laboratories, Pinawa, Manitoba; AECL Report 11214, COG-528, 133p.

Calvert, A.J., A.R. Cruden and A. Hynes, 2004. Seismic evidence for preservation of the Archean Uchi granite-greenstone belt by crustal-scale extension. *Tectonophysics*, 388, 135-143.

Campbell, J.B., 1987. Introduction to Remote Sensing. The Guilford Press.

Chipera, S. J. and D. Perkins, 1988. Evaluation of biotite-garnet geothermometers: application to the English River Subprovince, Ontario. *Contributions to Mineralogy and Petrology,* 98(1), 40-48.

Corfu, F., G.M. Stott and F.W. Breaks, 1995. U-Pb geochronology and evolution of the English River Subprovince, an Archean low P-high T metasedimentary belt in the Superior Province. *Tectonics*, 14(5), 1220-123.

Corrigan, D., A.G. Galley and S. Pehrsson, 2007. Tectonic evolution and metallogeny of the southwestern Trans-Hudson Orogen. In: Goodfellow, W.D., (ed.), Mineral deposits of Canada: A synthesis of major deposit-types, district metallogeny, the evolution of geological provinces, and exploration methods. Geological Association of Canada, Mineral Deposits Division, Special Publication No. 5, pp. 881-902.

Easton, R.M., 2000a. Metamorphism of the Canadian Shield, Ontario, Canada. I. The Superior Province. *The Canadian Mineralogist*, 38, 287-317.

Easton, R.M., 2000b. Metamorphism of the Canadian Shield, Ontario, Canada. II. Proterozoic metamorphic history. *The Canadian Mineralogist*, 38, 319-344.

Ford, M.J., 1981. Quaternary Geology of the Ear Falls and Pakwash Areas (52 K/11, 52 K/14) District of Kenora (Patricia Portion). In: J. Wood, O.L. White, R.B. Barlow and A.C. Colvine (eds.), Summary of Field Work, 1981. Ontario Geological Survey, Misc. Paper 100, pp. 104-106.

Ford, M.J., 1982. Quaternary geology of the Pakwash area, Kenora District (Patricia Portion). Ontario Geological Survey, Map P2572, scale 1:50,000.

Ford, M.J., 1983. Quaternary geology of the Ear Falls area, Kenora District (Patricia Portion). Ontario Geological Survey, Map P2585, scale 1:50,000.

Fraser, J.A. and W.W. Heywood (eds.), 1978. Metamorphism in the Canadian Shield. Geological Survey of Canada, Paper 78-10, 367p.

Gartner, J.F., J.D. Mollard and M.A. Roed, 1981. Ontario Engineering Geology Terrain Study User's Manual. Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 1.

GeoBase, 2011a. Canadian Digital Elevation Data: http://www.geobase.ca/.

GeoBase, 2011b. GeoBase Orthoimage 2005-2010: http://www.geobase.ca/.

Golder (Golder Associates Ltd.), 2011. Initial Screening for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel. The Corporation of the Township of Ear Falls, Ontario. Nuclear Waste Management Organization. April 2011.

Golder (Golder Associates Ltd.), 2013. Phase 1 Desktop Geoscientific Preliminary Assessment of Potential Suitability for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel, Township of Ear Falls, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06144-0019.

Gordon, R.G. and D.M. Jurdy, 1986. Cenozoic global plate motions. *Journal of Geophysical Research*, 91, 12,389-12,406.

Gorman, W.A., 1989a. Slate Lake, NTS 52K/NE, data base map, Northern Ontario Engineering Geology Terrain Study. Ontario Geological Survey, M5108, scale 1:100,000.

Gorman, W.A., 1989b. Vaughan Lake, NTS 52K/SE, data base map, Northern Ontario Engineering Geology Terrain Study. Ontario Geological Survey, M5110, scale 1:100,000.

Gupta, V.K. and D.R. Wadge, 1986. Gravity Study of the Birch, Uchi, and Red Lakes Area, District of Kenora (Patricia Portion). Ontario Geological Survey, Report 252, 98p. Accompanied by Maps 2492, 2493, 2494 and 2495, Scale 1:250 000.

Hanes, J.A. and D.A. Archibald, 1998. Post-orogenic tectono-thermal history of the Archean western Superior Province of the Canadian Shield as determined by conventional and laser Ar-Ar dating. In: R.M. Harrap and H.H. Helmstaedt, (eds.), Western Superior Transect 4th Annual Workshop, Toronto, Ont. March 23-24, 1998. Lithoprobe Secretariat, University of British Columbia, Vancouver, B.C., Lithoprobe Report 65, pp. 12-16.

Hrabi, R.B. and A.R. Cruden, 2006. Structure of the Archean English River subprovince: Implications for the tectonic evolution of the western Superior Province, Canada. *Canadian Journal of Earth Sciences*, 43, 947-966

Hynes, A., 1997. Constraints on the tectonic evolution of the English River Subprovince from studies in western Lac Seul. In: R.M. Harrap and H.H. Helmstaedt, (eds.), Western Superior Transect 3rd Annual Workshop, Toronto, Ont. April 11-12, 1997. Lithoprobe Secretariat, University of British Columbia, Vancouver, B.C., Lithoprobe Report 63, pp. 37-45.

Hynes, A., 1998. Evidence for fault kinematics at the English River/Winnipeg River boundary. In: R.M. Harrap and H.H. Helmstaedt, (eds.), Western Superior Transect 4th Annual Workshop, Toronto, Ont. March 23-24, 1998. Lithoprobe Secretariat, University of British Columbia, Vancouver, B.C., Lithoprobe Report 65, pp. 17-20.

Jolly, W.T., 1978. Metamorphic history of the Archean Abitibi Belt; in Metamorphism in the Canadian Shield. Geological Survey of Canada, Paper 78-10, pp. 63-78.

Kamineni, D.C., D. Stone and Z. E. Peterman, 1990. Early Proterozoic deformation in the western Superior province, Canadian Shield. *Geological Society of America Bulletin*, 102, 1623-1634.

Kraus, J. and T. Menard, 1997. A thermal gradient at constant pressure: Implications for low- to medium-pressure metamorphism in a compressional tectonic setting, Flin Flon and Kisseynew domains, Trans-Hudson Orogen, Central Canada. *The Canadian Mineralogist*, 35, 1117-1136.

MNR (Ontario Ministry of Natural Resources), 2013. Fish ON-Line. Accessed on 29 January, 2013, http://www.web2.mnr.gov.on.ca/fish_online/fishing/fishingExplorer_en.html.

Menard, T. and T.M. Gordon, 1997. Metamorphic P-T paths from the Eastern Flin Flon Belt and Kisseynew Domain, Snow Lake, Manitoba. *The Canadian Mineralogist*, 35, 1093-1115.

Mollard, D.G. and J.D. Mollard, 1980. Press Lake Area (NTS 52G/NW), District of Kenora. Ontario Geological Survey, Northern Ontario Engineering Terrain Study 23.

Neilson, J.M., 1989a. Pakwash Lake, NTS 52K/NW, data base map, Northern Ontario Engineering Geology terrain Study. Ontario Geological Survey, M5107, scale 1:100,000.

Neilson, J.M., 1989b. Pakwash Lake, NTS 52K/NW, general construction capability map, Northern Ontario Engineering Geology Terrain Study. Ontario Geological Survey, M5111, scale 1:100,000.

Neilson, J.M., 1989c. Perrault Lake, NTS 52K/SW, data base map, Northern Ontario Engineering Geology Terrain Study. Ontario Geological Survey, M5109, scale 1:100,000.

Nitescu, B., A.R. Cruden, R.C. Bailey, 2006. Integrated potential-field and seismic constraints on the structure of the Archean metasedimentary English River belt, Western Superior craton, Canada. *Precambrian Research,* 144, 261-277.

NWMO (Nuclear Waste Management Organization), 2010. Moving forward together: process for selecting a site for Canada's deep geological repository for used nuclear fuel. Nuclear Waste Management Organization, May 2010. (Available at www.nwmo.ca).

NWMO (Nuclear Waste Management Organization), 2013. Preliminary Assesment for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel - Township of Ear Falls, Ontario - Findings from Phase One Studies. NWMO Report Number APM-REP-06144-0017.

OGS (Ontario Geological Survey), 2005a. Digital Northern Ontario Engineering Geology Terrain Study (NOEGTS). Ontario Geological Survey, Miscellaneous Release of Data 160.

OGS (Ontario Geological Survey), 2005b. Ontario Drill Hole Database-December 2005 Release. Ontario Geological Survey, Data Set 13-Revision.

Pease, V., J. Percival, H. Smithies, G. Stevens and M. Van Kranendonk, 2008. When did plate tectonics begin? Evidence from the orogenic record. In: Condie, K.C. and V. Pease (eds.), When Did Plate Tectonics Begin on Earth? Geological Society of America, Special Paper 440, pp. 199-228.

Peltier, W.R. 2002. On eustatic sea level history: Last Glacial Maximum to Holocene. *Quaternary Science Reviews*, 21, 377-396.

Percival, J.A. and R.M. Easton, 2007. Geology of the Canadian Shield in Ontario: an update. Ontario Power Generation, Report No. 06819-REP-01200-10158-R00.

Percival, J.A., M. Sanborn-Barrie, T. Skulski, G.M. Stott, H. Helmstaedt and D.J. White, 2006. Tectonic evolution of the western Superior Province from NATMAP and Lithoprobe studies. *Canadian Journal of Earth Sciences*, 43, 1085-1117.

Powell, W.G., D.M. Carmichael and C.J. Hodgson, 1993. Thermobarometry in a subgreenschist to greenschist transition in metabasites of the Abitibi greenstone belt, Superior Province, Canada. *Journal of Metamorphic Geology*, 11, 165-178.

Powell, W.G., C.J. Hodgson, J.A. Hanes, D.M. Carmichael, S. McBride and E. Farrar, 1995. 40Ar/39Ar geochronological evidence for multiple postmetamorphic hydrothermal events focused along faults in the southern Abitibi greenstone belt. *Canadian Journal of Earth Sciences*, 32, 768-786.

Prest, V.K., 1982. Quaternary geology of the Madsen area, Kenora District (Patricia Portion). Ontario Geological Survey, Map P2484, scale 1:50,000.

Rona, P.A. and E.S. Richardson, 1978. Early Cenozoic Global Plate Reorganization. *Earth and Planetary Science Letters*, 40, 1-11.

Sanborn-Barrie, M., N. Rogers, T. Skulski, J. Parker, V. McNicoll and J. Devaney, 2004. Geology and Tectonostratigraphic Assemblages, East Uchi Subprovince, Red Lake and Birch-Uchi belts, Ontario. Geological Survey of Canada, Open File 4256. Ontario Geological Survey, Preliminary Map P.3460.

Sbar, M.L. and L.R. Sykes, 1973. Contemporary compressive stress and seismicity in eastern North America: An example of intra-plate tectonics. *Geological Society of America Bulletin*, 84, 1861-1882.

Shackleton, N.J., A. Berger and W.R. Peltier, 1990. An alternative astronomical calibration of the lower Pleistocene timescale based on ODP Site 677. *Transactions of the Royal Society of Edinburgh, Earth Sciences*, 81, 251-261.

Sharpe, D.R. and W.R. Cowan, 1990. Moraine formation in northwestern Ontario: product of subglacial fluvial and glaciolacustrine sedimentation. *Canadian Journal of Earth Sciences*, 27(11), 1478-1486.

Sharpe, D.R. and H.A.J. Russell, 1996. Quaternary geology of the Red Lake - Confederation Lake area. Geological Survey of Canada, Open File 2876.

Shklanka, R., 1970. Geology of the Bruce Lake Area District of Kenora. Geological Report 82, 26p.

Skulski, T., H. Sandeman, M. Sanborn-Barrie, T. MacHattie, D. Hyde, S. Johnstone, D. Panagapko and D. Byrne, 2002. Contrasting crustal domains in the Committee Bay belt, Walker Lake – Arrowsmith River area, central Nunavut. Geological Survey of Canada, Current Research 2002-C11, 11p.

SRK (SRK Consulting Inc.), 2013. Phase 1 Desktop Geoscientific Preliminary Assessment, Lineament Interpretation, Township of Ear Falls, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06144-0022.

Stone, D., 1981. The Sydney Lake fault zone in Ontario and Manitoba; Unpublished Ph.D. Thesis, University of Toronto, 146p.

Stott, G.M. and F. Corfu, 1992. Uchi Subprovince. In: P.C. Thurston, H.R. Williams, R.H. Sutcliffe and G.M. Scott (eds.), Geology of Ontario. Ontario Geological Survey, Special Volume No. 4, Part 1, pp.145-236.

Stott, G.M., M.T. Corkery, J.A. Percival, M. Simard and J. Goutier, 2010. A revised terrane subdivision of the Superior Province. In: Summary of Field Work and Other Activities 2010. Ontario Geological Survey, Open File Report 6260, pp. 20-1 to 20-10.

Stott, G.M. and S.D. Josey, 2009. Proterozoic mafic (diabase) dikes and other post-Archean intrusions of northwestern Ontario, north of latitude 49°30'. Ontario Geological Survey, Preliminary Map P.3606, scale 1:1 000 000.

Symons, D.T.A., I.A. Osmani and M. Stupavsky, 1983. Magnetization characteristics of the Algoman iron formation and host rocks at the Griffith Mine, Red Lake, Ontario. Ontario Geological Survey, Open File Rept. 5447, pp. 19-57.

Tomlinson, K.Y., G.M. Stott, J.A. Percival and D. Stone, 2004. Basement terrane correlations and crustal recycling in the western Superior Province: Nd isotopic character of granitoid and felsic volcanic rocks in the Wabigoon subprovince, N. Ontario, Canada. *Precambrian Research*, 132, 245-274.

Thurston, P.C., 1992. Geology of Ontario: Introduction. In: P.C. Thurston, H.R. Williams, R.H. Sutcliffe and G.M. Scott (eds.), Geology of Ontario. Ontario Geological Survey, Special Volume No. 4, Part 1, pp. 3-26.

Thurston, P.C. and D. Paktunc, 1985. Western Uchi Subprovince Stratigraphy (Troutlake River Area), Pakwash Lake Sheet. District of Kenora (Patricia Portion). Ontario Geological Survey, Geological Series Preliminary Map, P.2858, scale 1:50,000.

van de Kamp, P.C. and G. P. Beakhouse, 1979. Paragneisses in the Pakwash Lake area, English River gneiss belt, northwestern Ontario. *Canadian Journal of Earth Sciences*, 16, 1753-1763.

Westerman, C.J., 1977. Tectonic evolution of a part of the English River Subprovince, Northwestern Ontario; unpublished PhD thesis, McMaster University, Hamilton, Ontario, 292p.

Zoback, M.L., 1992. First- and second-order patterns of stress in the lithosphere: the world stress map project. *Journal of Geophysical Research*, 97, 11,703-11,728.

REPORT SIGNATURE PAGE

J.D. Mollard and Associates (2010) Limited

David van Zeyl, M.Sc.

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

FIGURES

Figure 1 Township of Ear Falls and surrounding area

Figure 2 Bedrock geology of the Ear Falls area

Figure 3 Surficial geology of the Ear Falls area (1:100,000)

Figure 4 Surficial geology of the Ear Falls area (1:50,000)

Figure 5 Elevation and major topographic features

Figure 6 Departure from average elevation within 20 km radius

Figure 7 Departure from average elevation within 2 km radius

Figure 8 Range in elevation within 250 m radius

Figure 9 Areas 6° or steeper in the Ear Falls area

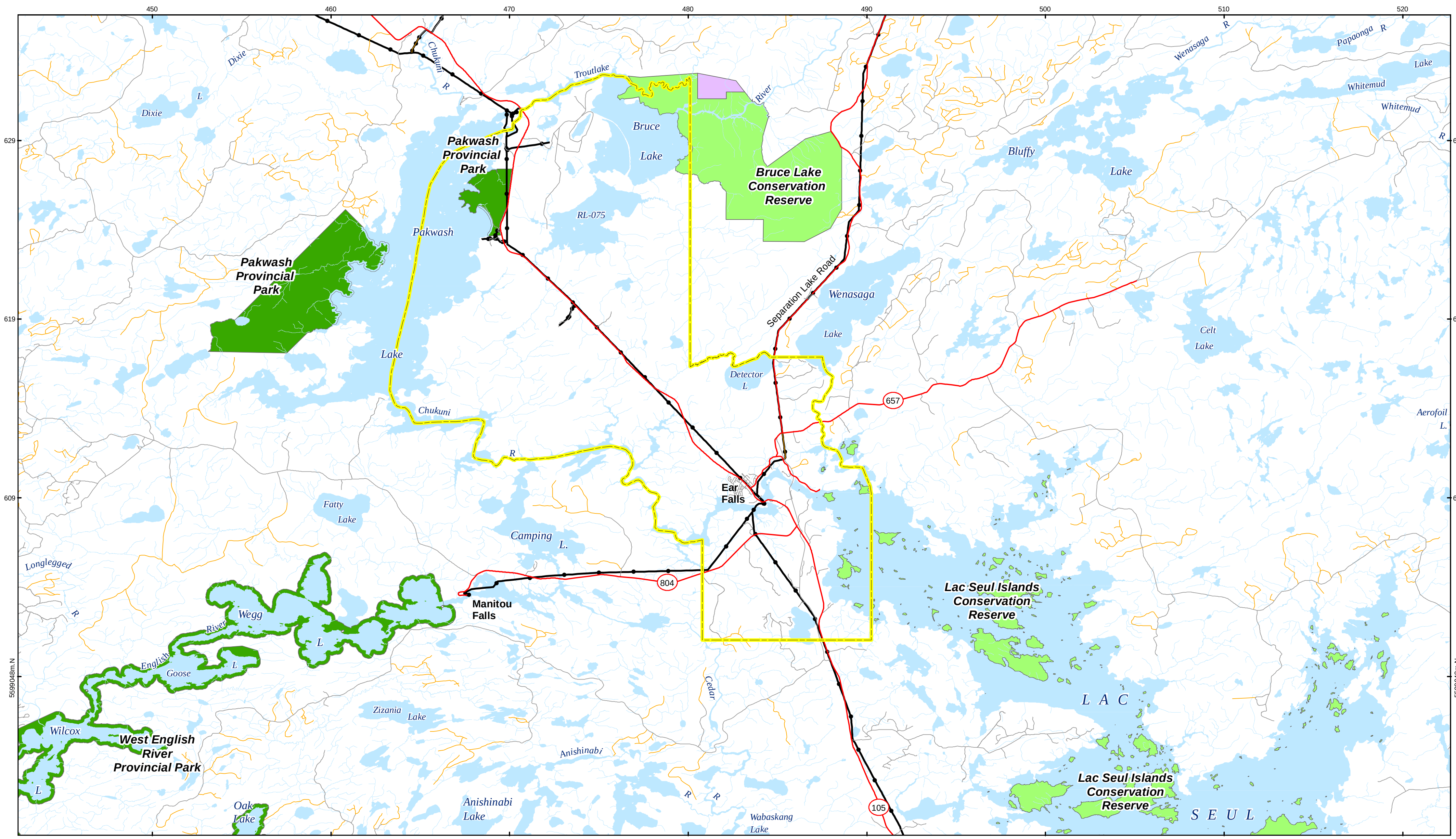
Figure 10 Density of steep (≥ 6°) slopes within 2 km radius

Figure 11 Surface drainage features of the Ear Falls area

Figure 12 Watersheds within the Ear Falls area

Figure 13 Access roads within the Ear Falls area

FIGURES

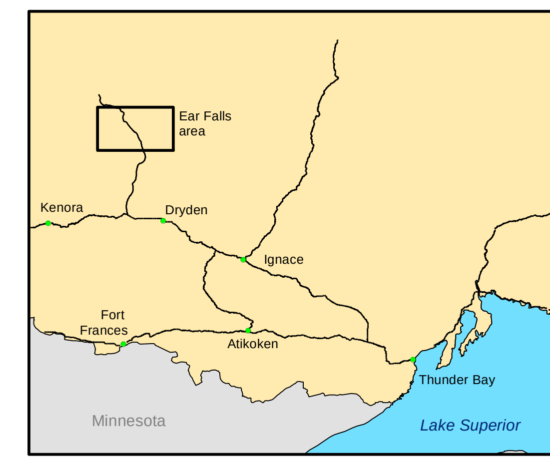


LEGEND

- Township of Ear Falls
- Main road
- Local road (MNR)
- Local road (JDMA)
- Transmission line
- Wabauskang First Nation
- Waterbody
- Watercourse

Protected areas

- Conservation Reserve
- Forest Reserve
- Provincial Park
- Recommended Provincial Park



Data sources:
Parks: LIO CLUPA designation
Main road: MNR Road Segment
Local road (MNR): MNR Road Segment
Local road (JDMA): Infill mapping by JDMA
Transmission line: LIO Utility line
Rail: LIO Railway
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse

NORTH

5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

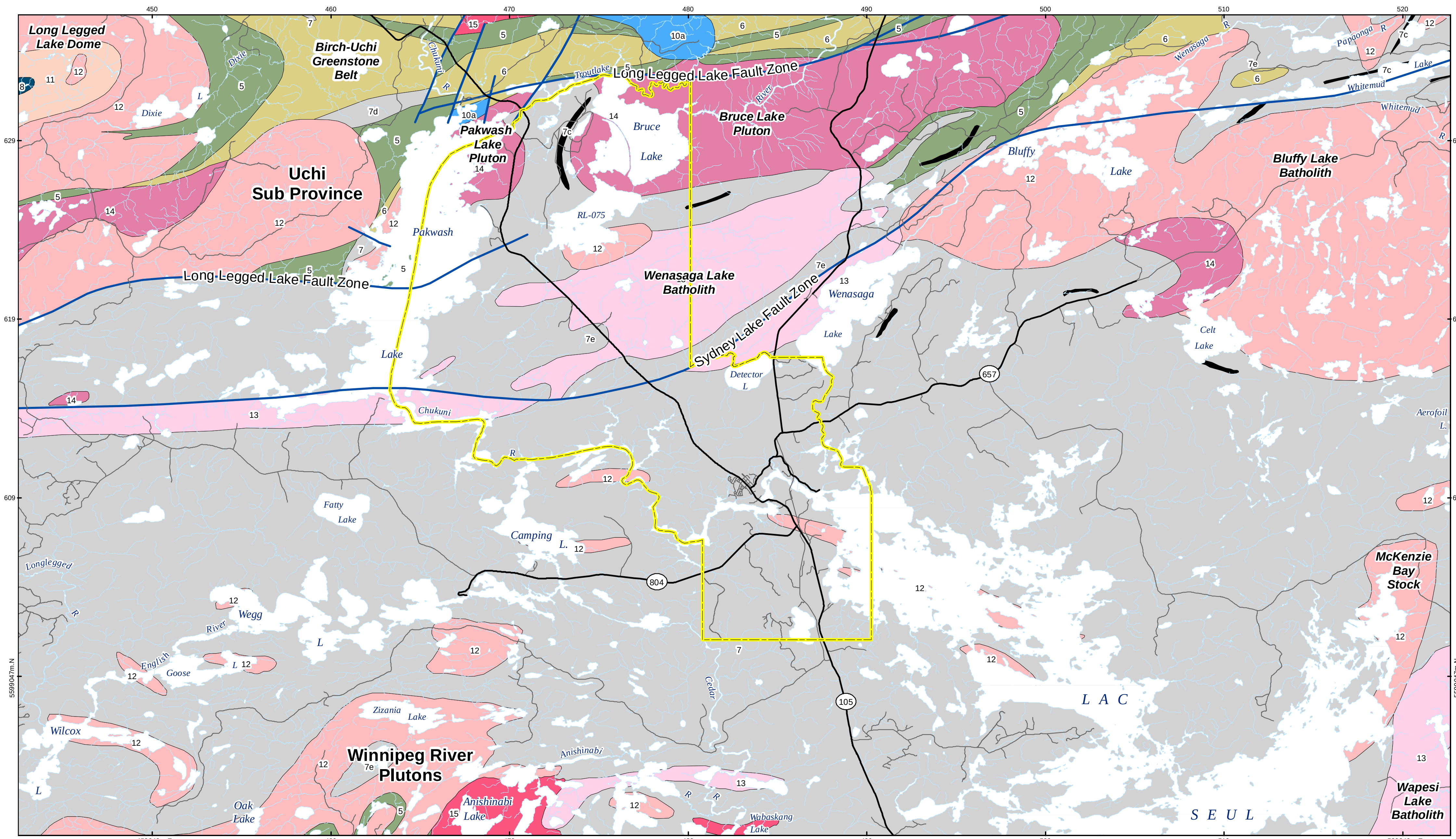
PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, EAR FALLS AREA, ONTARIO

TITLE

Township of Ear Falls and surrounding area

DESIGN	DVZ	14 SEP 2012	FIGURE 1	REVISION 4
GIS	DVZ	23 OCT 2013		UTM ZONE 15
CHECK	JIC	23 OCT 2013		NAD 1983
REVIEW	GS	23 OCT 2013		1:275,000



LEGEND

- Township of Ear Falls
- Main road
- Local road
- Mapped fault
- Waterbody
- Watercourse

Bedrock geology

- 15 Massive granodiorite to granite
- 14 Diorite-monzodiorite-granodiorite suite
- 13 Muscovite-bearing granitic rock
- 12 Foliated tonalite suite
- 11 Gneissic tonalite suite
- 10 Mafic and ultramafic rock
- 10a Gabbro
- 8 Migmatized supracrustal rocks
- 7 Metasedimentary rocks
- 7d Conglomerate and arenite
- 7e Paragneiss and migmatites
- 6 Felsic to intermediate metavolcanic rock
- 5 Mafic to intermediate metavolcanic rock
- Iron formation

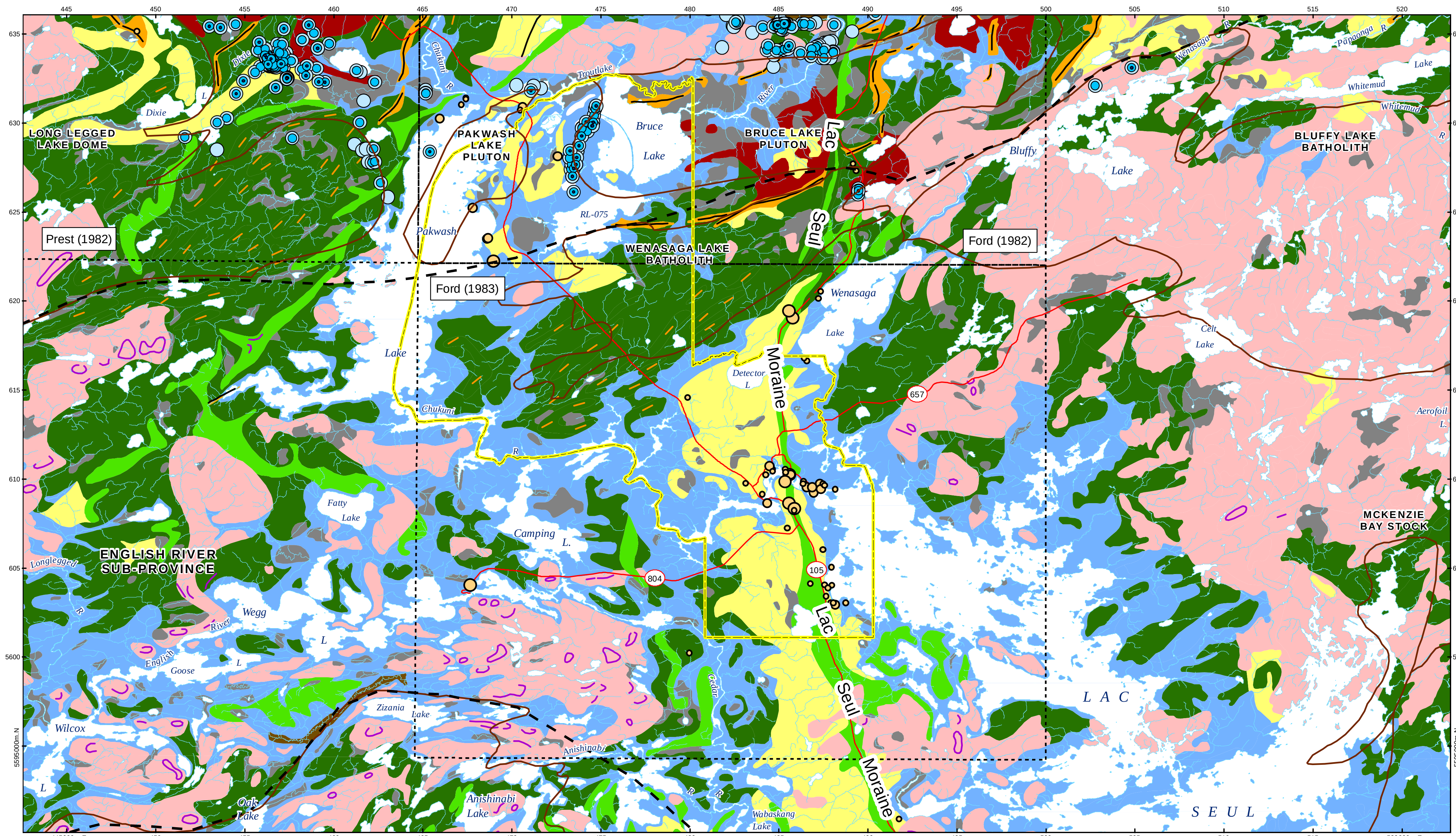
Data sources:
Bedrock: OGS MRD 126-REV1 (1:250,000)
Fault: OGS MRD 126-REV1 (1:250,000)
Road: Selected from MNR Road Segment
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse

J D MOLLARD AND ASSOCIATES (2010) LIMITED

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

TITLE
Bedrock geology of the Ear Falls area

DESIGN	DVZ	14 SEP 2012	FIGURE 2	REVISION 3
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	JIC	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:275,000



LEGEND

- Township of Ear Falls
- 1:50k surficial map
- Sub-province boundary
- Selected batholiths
- Main road
- Abandoned shoreline
- Drumlin
- Esker
- Waterbody
- Watercourse

Drill hole (OGS)

Depth to bedrock (m)

- 0 - 5
- 6 - 20
- 21 - 74

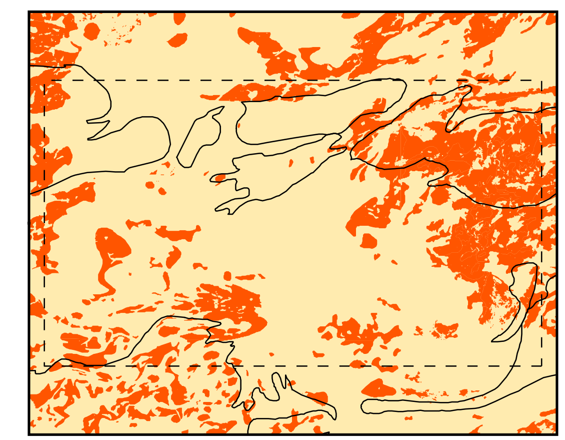
Water well MOE

Depth to bedrock (m)

- 0 - 5
- 6 - 20
- 21 - 38

Surficial geology

- Ground moraine
- End moraine
- Esker
- Outwash
- Ice-contact delta
- Glaciolacustrine
- Alluvial plain
- Organics
- Bedrock



- Selected batholiths
- Surficial/water (69%)
- Bedrock terrain (31%)

Data sources
Surficial geology: NOEGTS (1:100,000)
Road: Selected from LIO MNR Road Segment
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Drill hole: OGS Ontario Drill Hole Database
Water well: MOE Water Well Information System
Selected batholiths: OGS MRD 126-REV1

NORTH

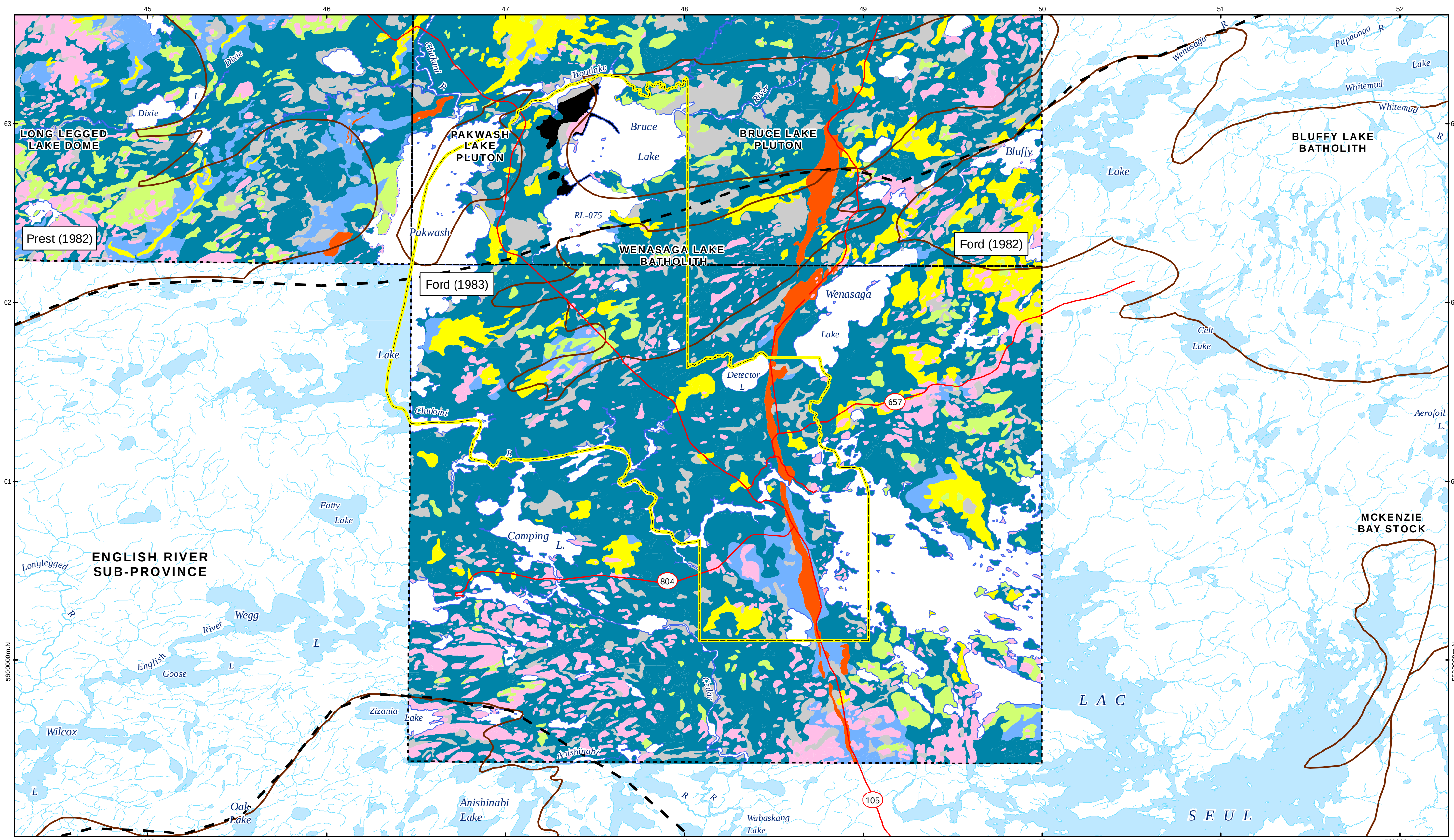
5 km

J D MOLLARD

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

TITLE
Surficial geology of the Ear Falls area (1:100,000)

DESIGN	DVZ	14 SEP 2012	FIGURE 3	REVISION 3
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	JIC	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:275,000



LEGEND

- Township of Ear Falls
- Main road
- 1:50k surficial map
- Sub-province boundary
- Selected batholiths
- 0 - Water
- 1 - Bedrock
- 2 - Glacial deposit
- 3 - Glacial and glaciofluvial deposit
- 4 - Glaciofluvial deposit
- 5 - Deep-water glaciolacustrine deposit
- 6 - Nearshore glaciolacustrine deposit
- 7 - Organic deposit
- 8 - Mine waste
- Waterbody
- Watercourse

Data sources:
Surficial geology: OGS P2484 2572 2585 (1:50,000)
Road: Selected from MNR Road Segment
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Selected batholiths: OGS MRD 126-REV1

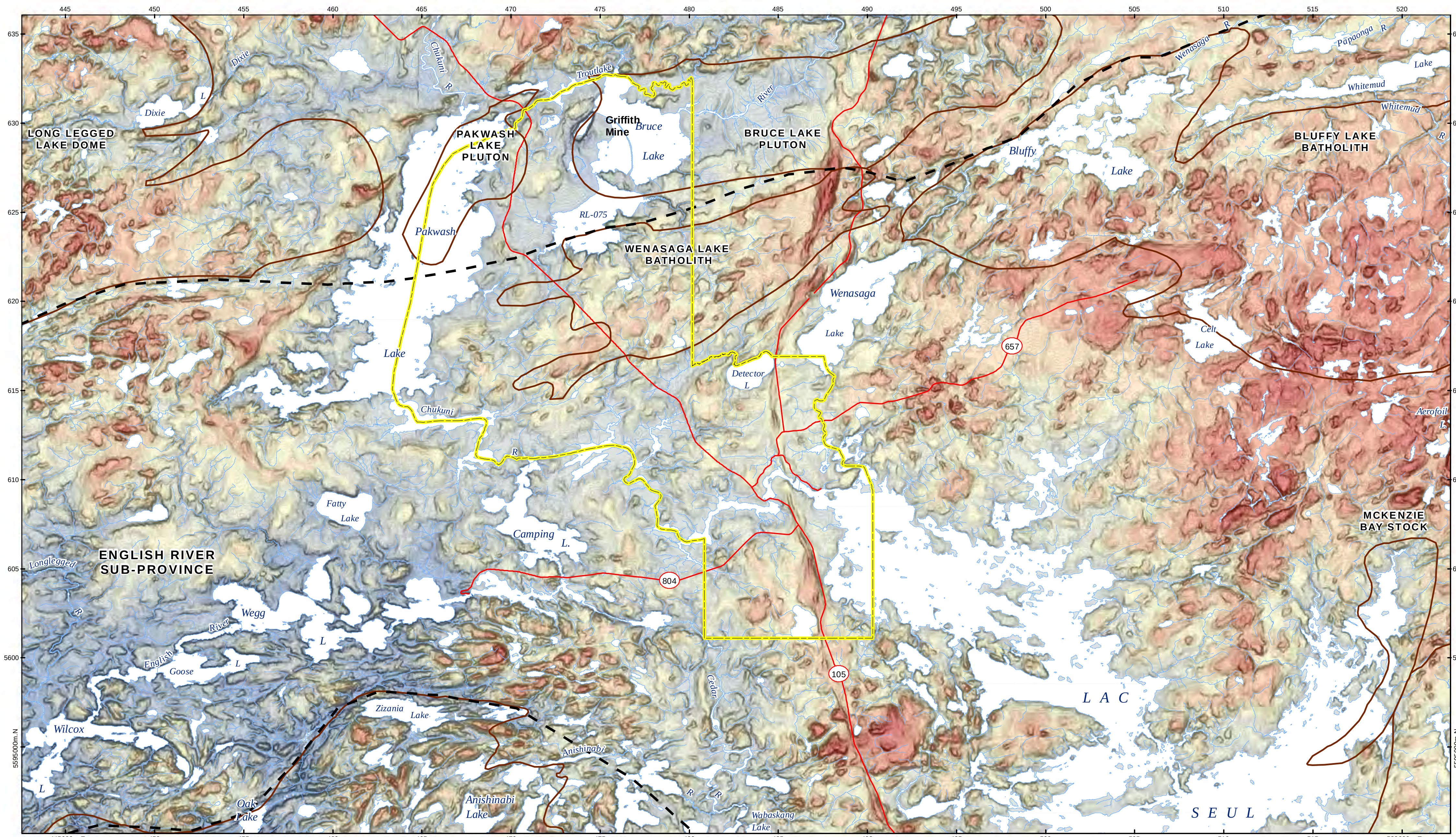
NORTH
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

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

TITLE
Surficial geology of the Ear Falls area (1:50,000)

DESIGN	DVZ	14 SEP 2012	FIGURE 4	REVISION 3
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	JIC	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:275,000



LEGEND

- Township of Ear Falls
- Sub-province boundary
- Selected batholiths
- Main road
- Waterbody
- Watercourse

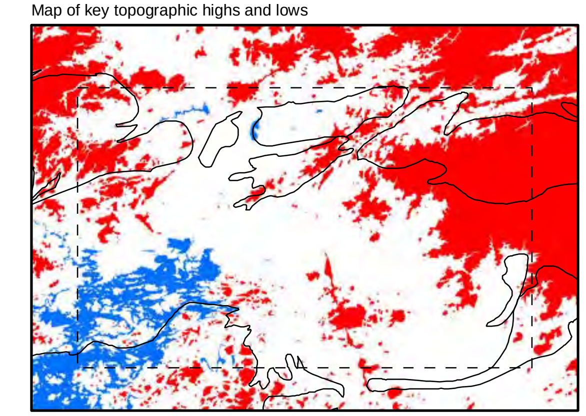
Elevation (m)

- 316 - 317.9
- 318 - 330
- 330.1 - 342.1
- 342.2 - 354.2
- 354.3 - 366.3
- 366.4 - 378.4
- 378.5 - 390.5
- 390.6 - 402.6
- 402.7 - 414.7
- 414.8 - 426.8
- 426.9 - 452

Slope (°)

- 0 - 0.3
- 0.4 - 1.4
- 1.5 - 2.6
- 2.7 - 3.8
- 3.9 - 5
- 5.1 - 6.2
- 6.3 - 7.3
- 7.4 - 29

Map of key topographic highs and lows



- Selected batholiths

Elevation (m)

- 289 - 340
- 340.1 - 385
- 385.1 - 472

Data sources:
DEM: CDED (1:50,000)
Main road: MNR Road Segment
Local road (MNR): MNR Road Segment
Local road (JDMA): Infill mapping by JDMA
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Selected batholiths: OGS MRD 126-REV1

NORTH

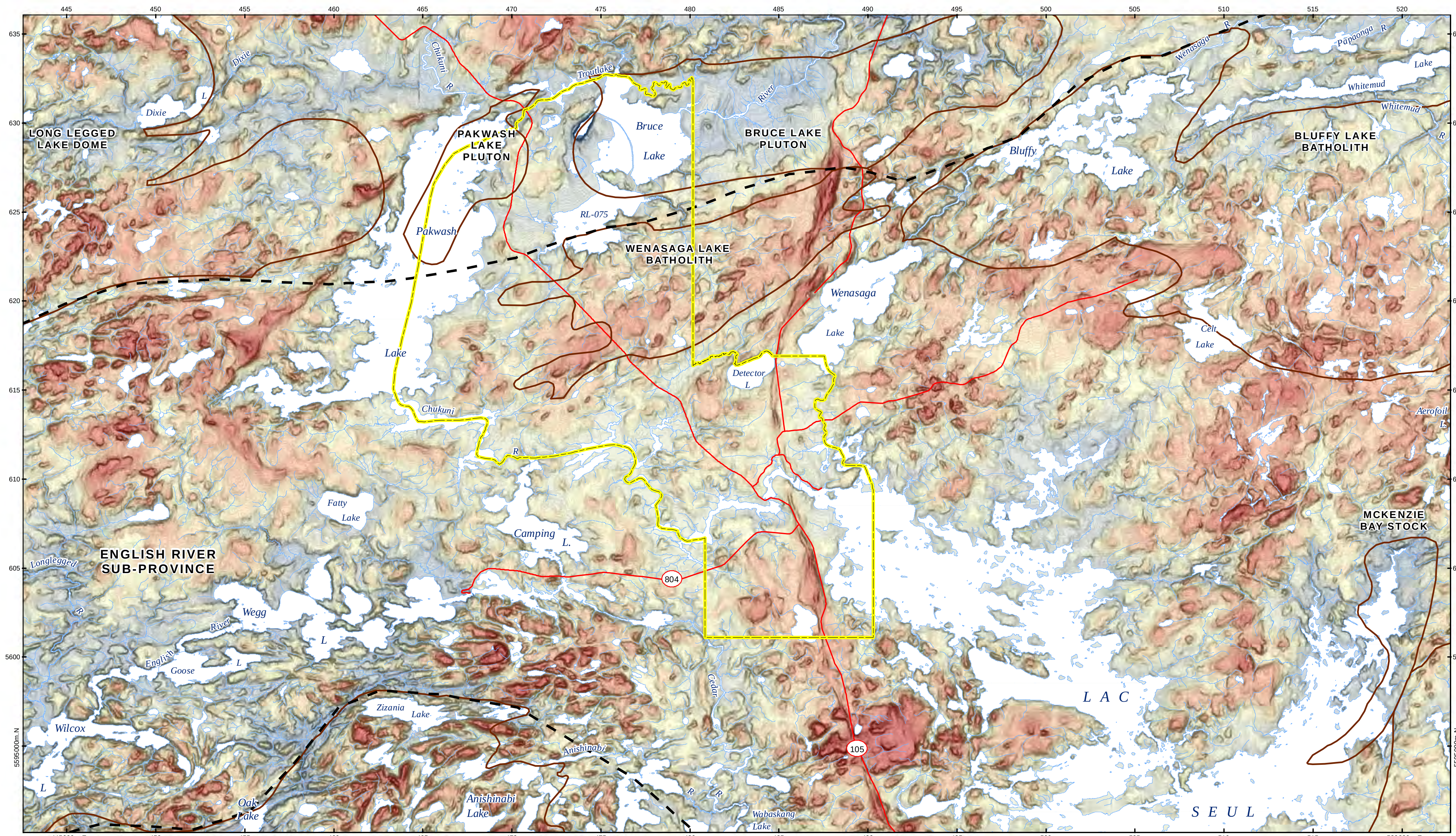
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

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

TITLE
Elevation and major topographic features

DESIGN	DVZ	14 SEP 2012	FIGURE 5	REVISION 3
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	JIC	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:275,000



LEGEND

- Township of Ear Falls
- Sub-province boundary
- Selected batholiths
- Main road
- Waterbody
- Watercourse

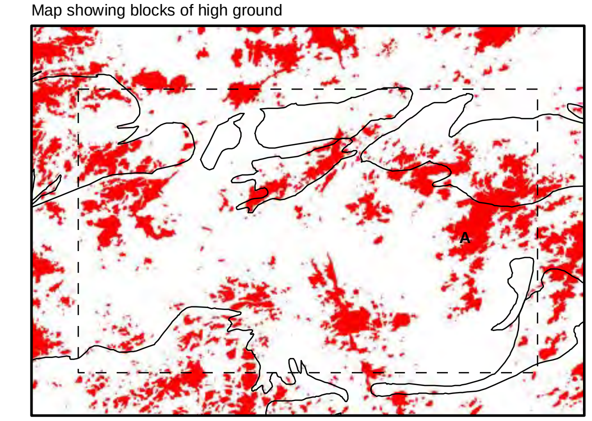
Relief (m)

- -77.6 - -48.9
- -48.8 - -40.4
- -40.3 - -31.9
- -31.8 - -23.5
- -23.4 - -15
- -14.9 - -6.5
- -6.4 - 1.9
- 2 - 10.4
- 10.5 - 18.9
- 19 - 27.3
- 27.4 - 35.8
- 35.9 - 44.3
- 44.4 - 80.5

Slope (°)

- 0 - 0.3
- 0.4 - 1.4
- 1.5 - 2.6
- 2.7 - 3.8
- 3.9 - 5
- 5.1 - 6.2
- 6.3 - 7.3
- 7.4 - 29

Map showing blocks of high ground



- Selected batholiths

Relief (m)

- -78 - 15
- 16 - 110

Data sources:
DEM: CDED (1:50,000)
Main road: MNR Road Segment
Local road (MNR): MNR Road Segment
Local road (JDMA): Infill mapping by JDMA
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Selected batholiths: OGS MRD 126-REV1

NORTH

5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

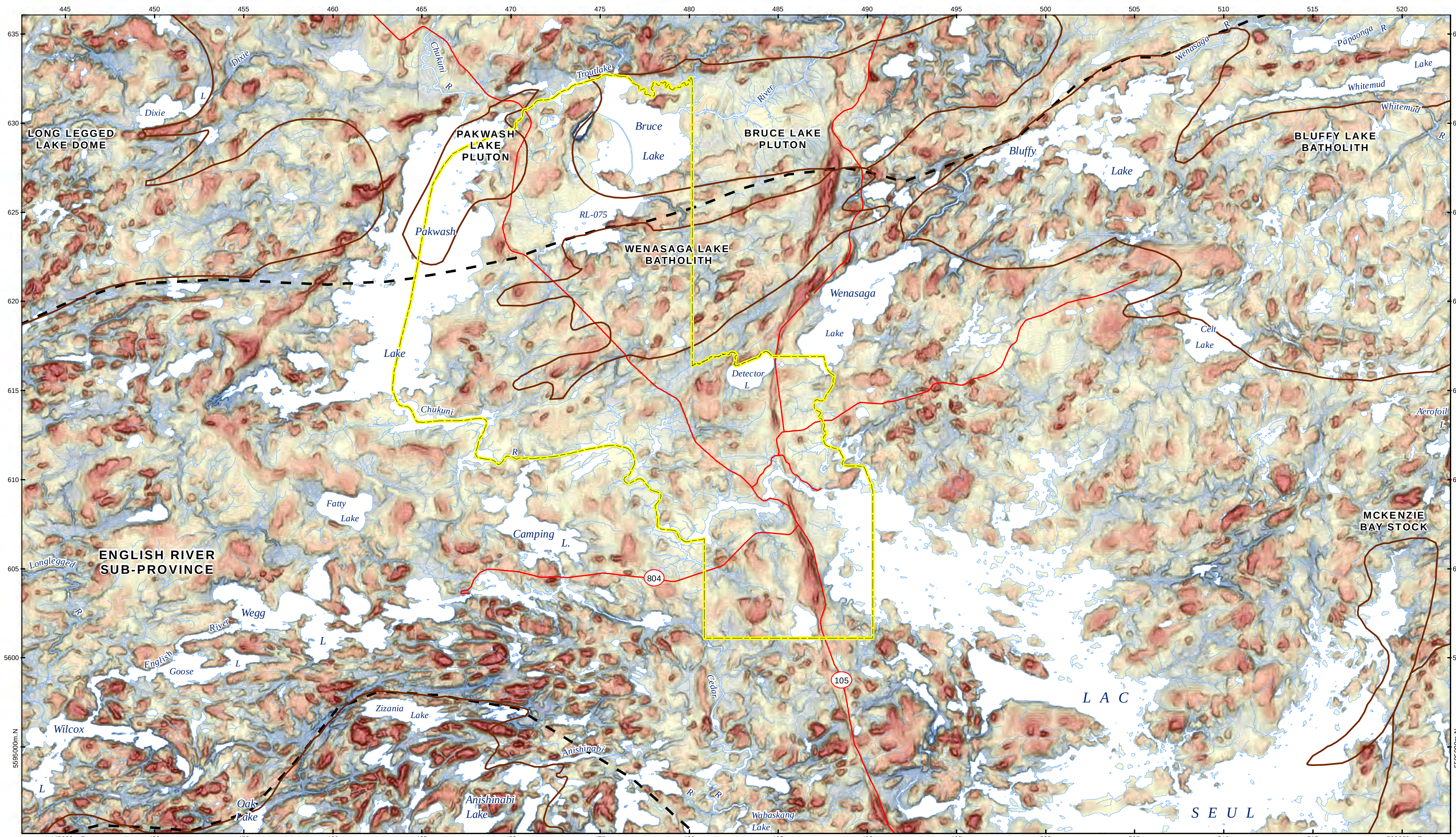
PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, EAR FALLS AREA, ONTARIO

TITLE

Departure from average elevation within 20 km radius

DESIGN	DVZ	14 SEP 2012	FIGURE 6	REVISION 3
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	JIC	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:275,000



LEGEND

- Township of Ear Falls
- Selected batholiths
- Sub-province boundary
- Main road
- Waterbody
- Watercourse

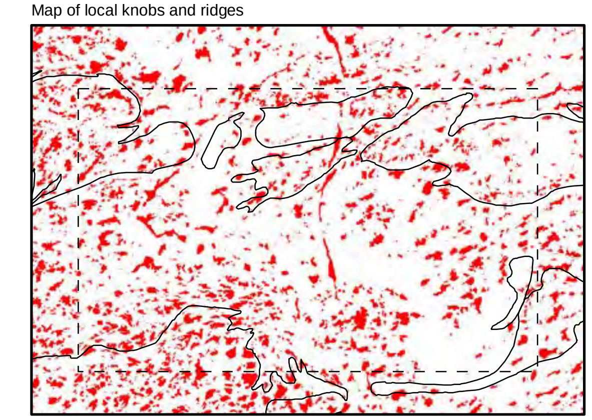
Relief (m)

- -53.3 - -25.9
- -25.8 - -21.2
- -21.1 - -16.6
- -16.5 - -11.9
- -11.8 - -7.2
- -7.1 - -2.6
- -2.5 - 2.1
- 2.2 - 6.8
- 6.9 - 11.4
- 11.5 - 16.1
- 16.2 - 20.7
- 20.8 - 25.4
- 25.5 - 59.3

Slope (°)

- 0 - 0.3
- 0.4 - 1.4
- 1.5 - 2.6
- 2.7 - 3.8
- 3.9 - 5
- 5.1 - 6.2
- 6.3 - 7.3
- 7.4 - 29

Map of local knobs and ridges



- Selected batholiths

Relief (m)

- -53 - 10
- 11 - 86

Data sources:
DEM: CDED (1:50,000)
Main road: MNR Road Segment
Local road (MNR): MNR Road Segment
Local road (JDMA): Infill mapping by JDMA
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Selected batholiths: OGS MRD 126-REV1

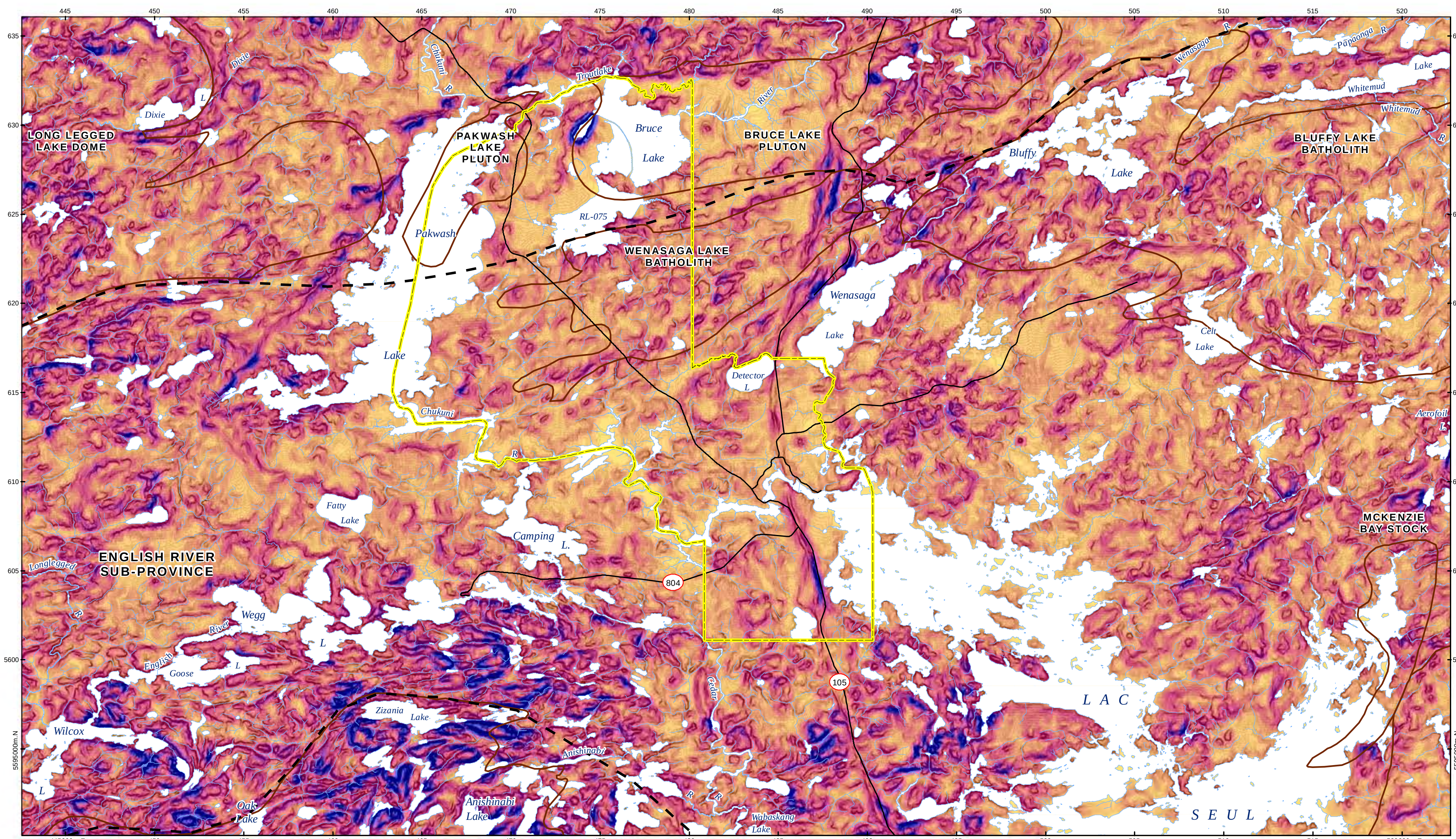
NORTH
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

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

TITLE
Departure from average elevation within 2 km radius

DESIGN	DVZ	14 SEP 2012	FIGURE 7	REVISION 3
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	JIC	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:275,000



LEGEND

- Township of Ear Falls
- Main road
- Sub-province boundary
- Selected batholiths
- Waterbody
- Watercourse

Relief (m)

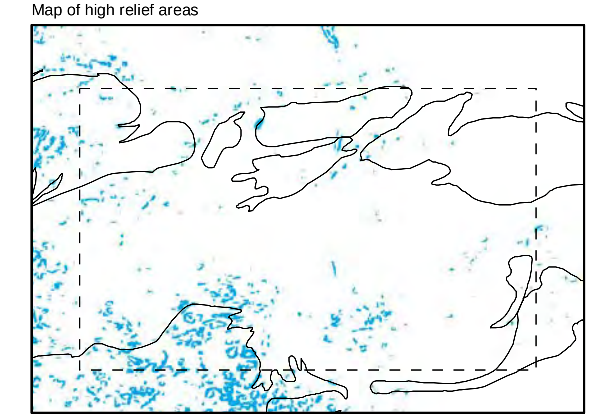
Value

- 0 - 1.8
- 1.9 - 7.9
- 8 - 14
- 14.1 - 20.1
- 20.2 - 26.3
- 26.4 - 32.4
- 32.5 - 38.5
- 38.6 - 44.6
- 44.7 - 98

Slope (°)

- 0 - 0.3
- 0.4 - 1.4
- 1.5 - 2.6
- 2.7 - 3.8
- 3.9 - 5
- 5.1 - 6.2
- 6.3 - 7.3
- 7.4 - 29

Map of high relief areas



- Selected batholiths

Relief (m)

- 0 - 40
- 40.1 - 98

Data sources:
DEM: CDED (1:50,000)
Main road: MNR Road Segment
Local road (MNR): MNR Road Segment
Local road (JDMA): Infill mapping by JDMA
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Selected batholiths: OGS MRD 126-REV1

NORTH

5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

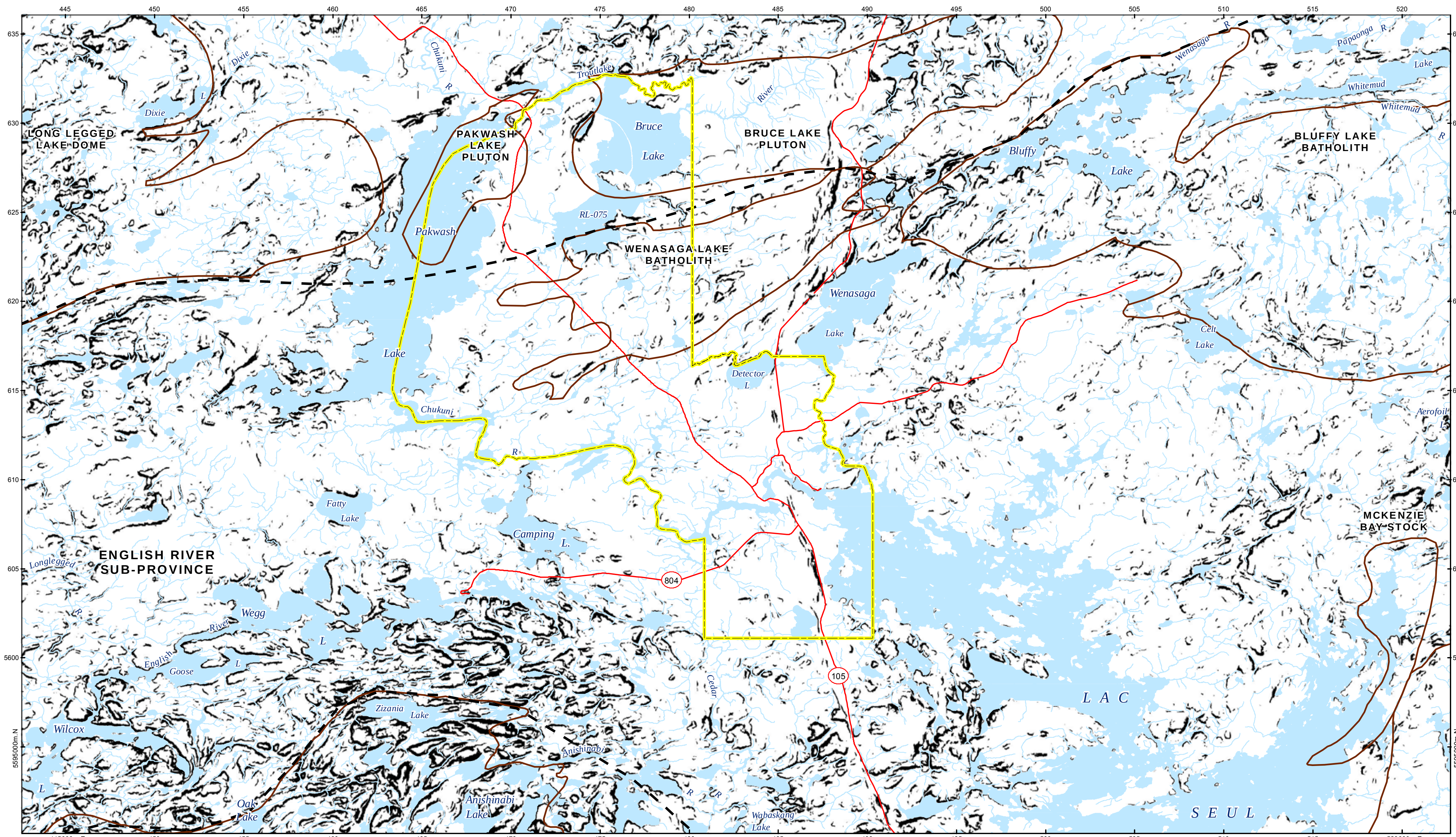
PROJECT

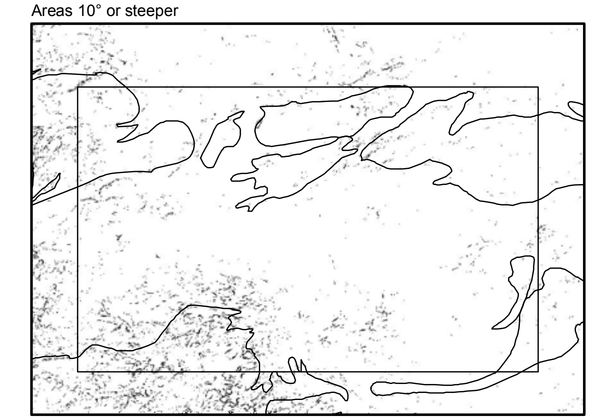
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, EAR FALLS AREA, ONTARIO

TITLE

Range in elevation within 250 m radius

DESIGN	DVZ	14 SEP 2012	FIGURE 8	REVISION 3
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	JIC	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:275,000





LEGEND

- Township of Ear Falls
- Sub-province boundary
- Selected batholiths
- Main road
- Waterbody
- Watercourse

Slope (°)

- 0 - 6
- 6.1 - 29

Areas 10° or steeper

- Selected batholiths

Slope (°)

- 0 - 9.9
- 10 - 38

Data sources:
DEM: CDED (1:50,000)
Main road: MNR Road Segment
Local road (MNR): MNR Road Segment
Local road (JDMA): Infill mapping by JDMA
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Wetland: LIO Wetland Unit
Selected batholiths: OGS MRD 126-REV1

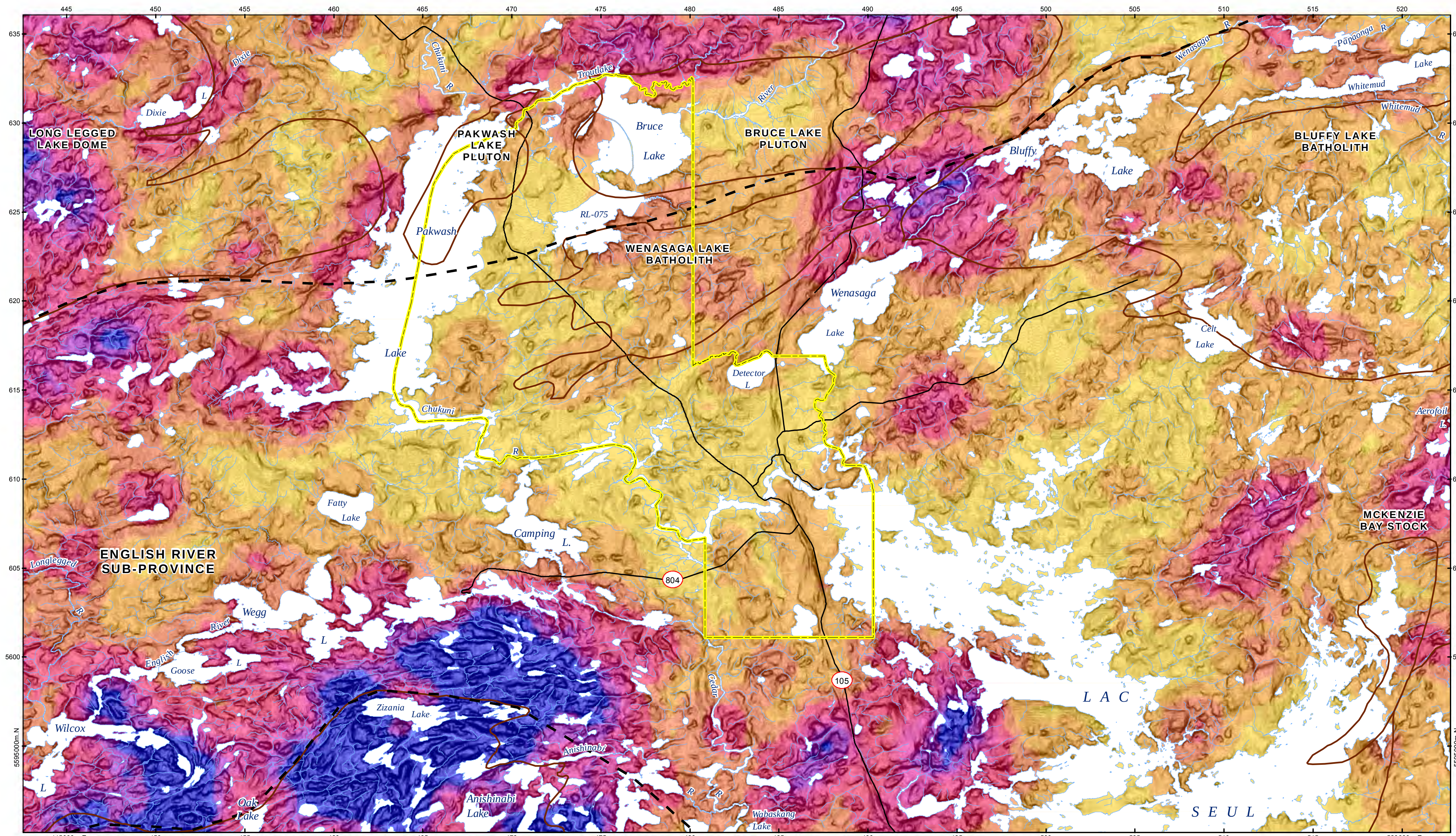
NORTH
5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

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

TITLE
Areas 6° or steeper in the Ear Falls area

DESIGN	DVZ	14 SEP 2012	FIGURE 9	REVISION 3
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	JIC	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:275,000



LEGEND

- Township of Ear Falls
- Sub-province boundary
- Selected batholiths
- Main road
- Waterbody
- Watercourse

Slope density

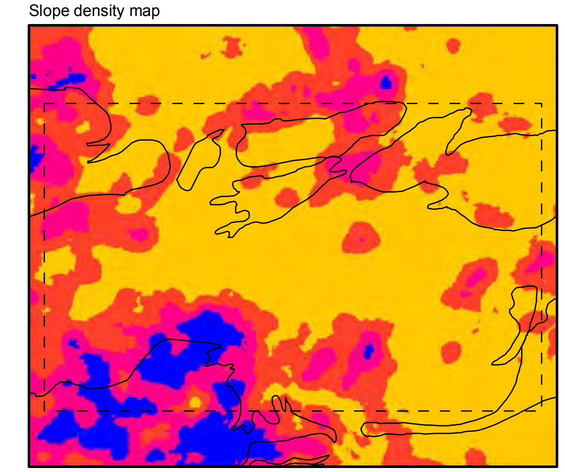
Points\km^2

- 0 - 50.2
- 50.3 - 136.6
- 136.7 - 223.1
- 223.2 - 309.6
- 309.7 - 396
- 396.1 - 482.5
- 482.6 - 569
- 569.1 - 938.3

Slope (°)

- 0 - 0.3
- 0.4 - 1.4
- 1.5 - 2.6
- 2.7 - 3.8
- 3.9 - 5
- 5.1 - 6.2
- 6.3 - 7.3
- 7.4 - 29

Slope density map



- Selected batholiths

Points/km^2

- 0 - 152.3
- 152.4 - 353.9
- 354 - 600.2
- 600.3 - 1,142.2

Data sources:
DEM: CDED (1:50,000)
Main road: MNR Road Segment
Local road (MNR): MNR Road Segment
Local road (JDMA): Infill mapping by JDMA
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Selected batholiths: OGS MRD 126-REV1

NORTH

5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

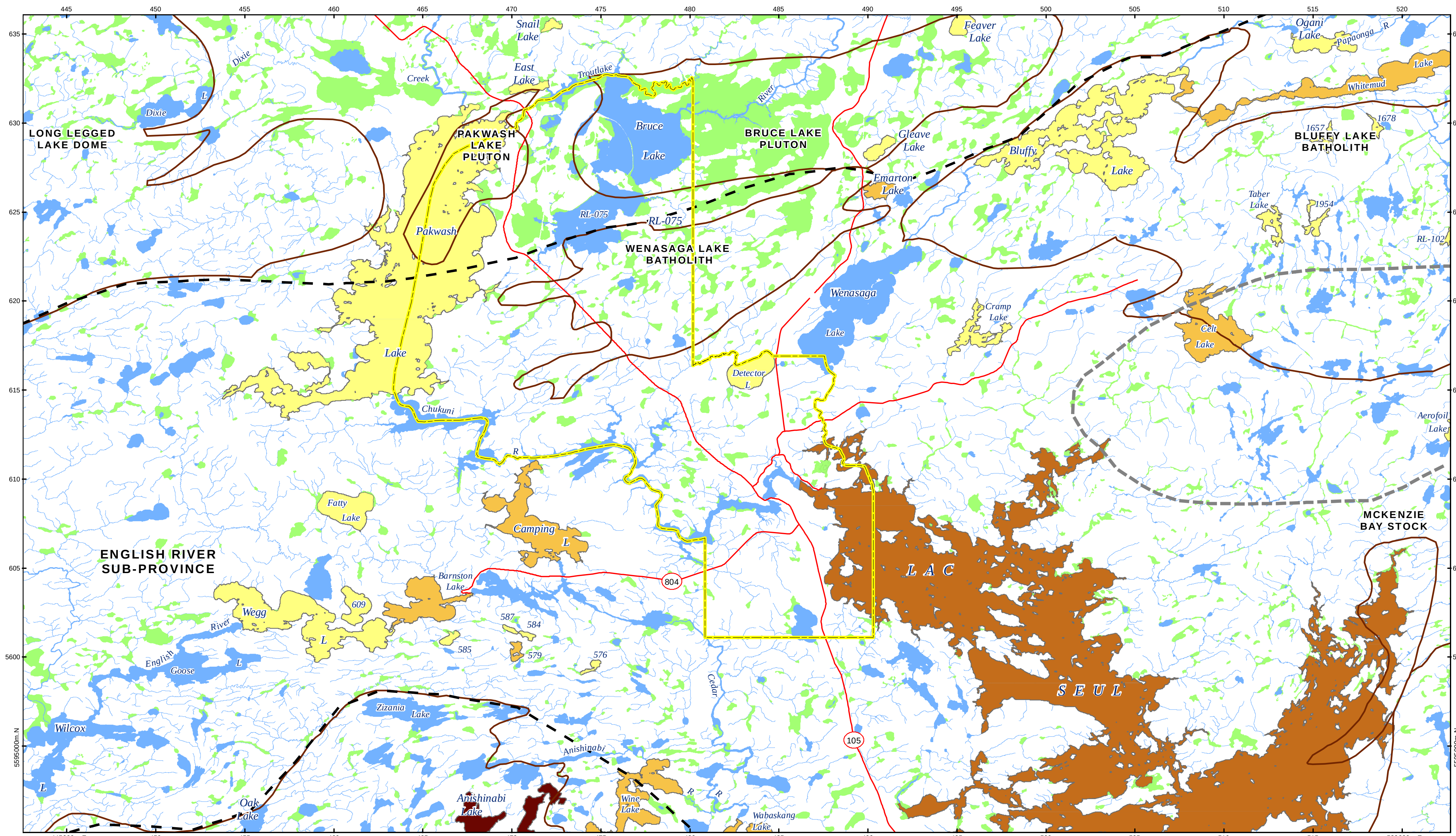
PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, EAR FALLS AREA, ONTARIO

TITLE

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

DESIGN	DVZ	14 SEP 2012	FIGURE 10	REVISION 3
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	JIC	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:275,000



LEGEND

- Township of Ear Falls
- Concentration of unmapped wetlands
- Sub-province boundary
- Selected batholiths
- Main road
- Wetland

Waterbody

Maximum depth (m)

- 3.0 - 20.0
- 20.1 - 40.0
- 40.1 - 60.0
- 60.1 - 88.8
- No depth data
- Watercourse

Data sources:
DEM: CDED (1:50,000)
Road: Selected for MNR Road Segment
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Wetland: LIO OHN Wetland Unit
Selected batholiths: OGS MRD 126-REV1

NORTH

5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

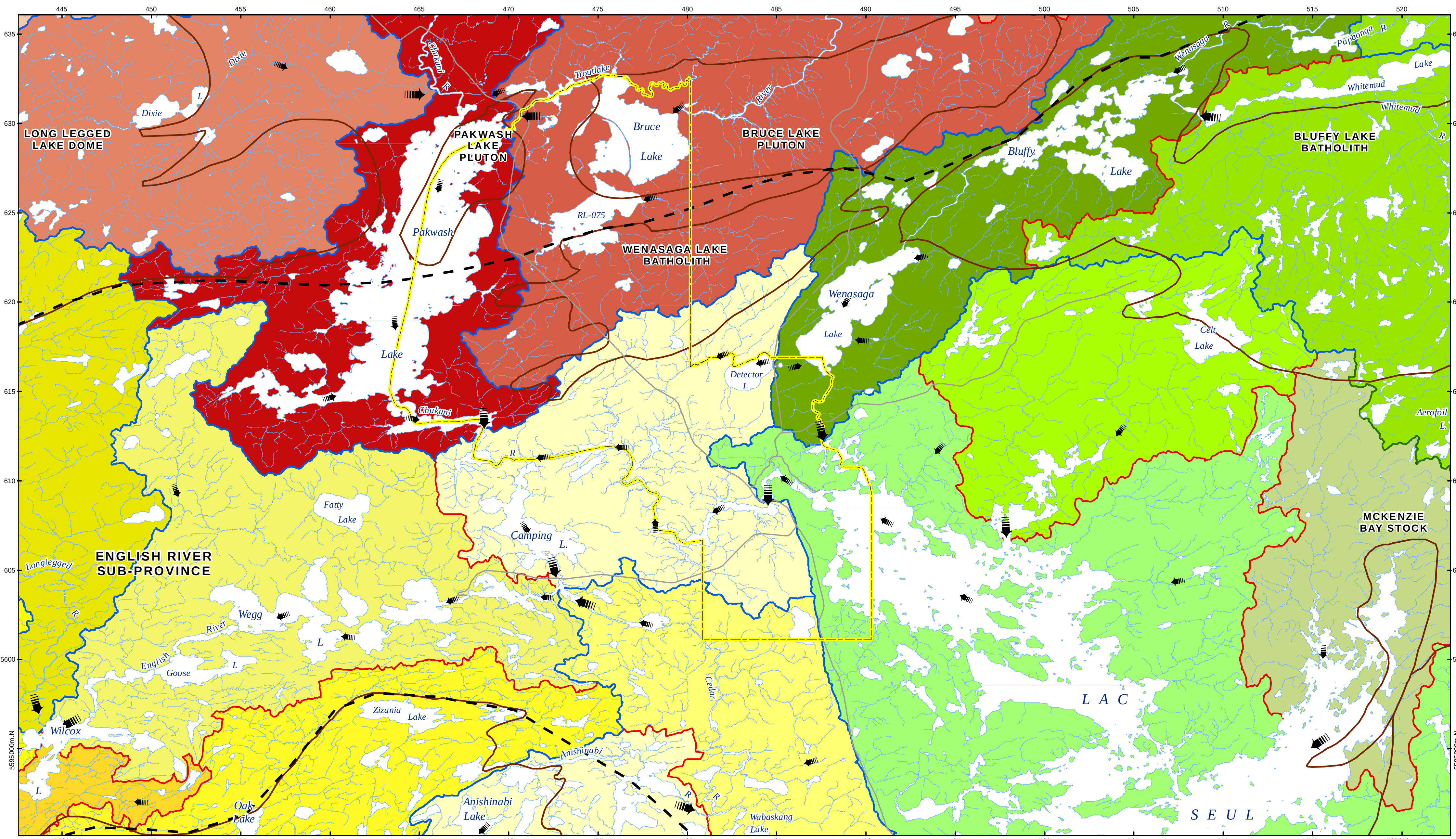
PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, EAR FALLS AREA, ONTARIO

TITLE

Surface drainage features of the Ear Falls area

DESIGN	DVZ	14 SEP 2012	FIGURE 11	REVISION 3
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	JIC	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:275,000

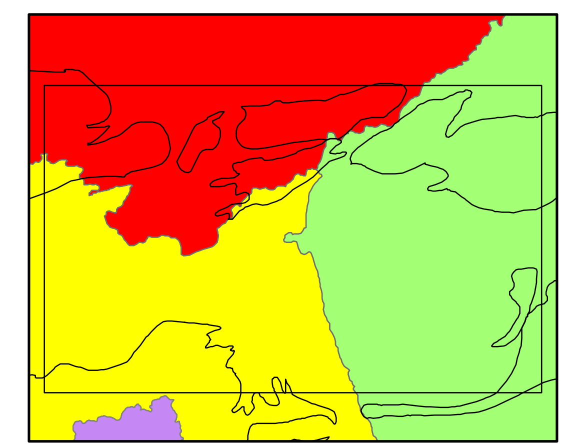


LEGEND

- Watershed outflow
- Flow direction
- Township of Ear Falls
- Main road
- Sub-province boundary
- Selected batholiths
- Waterbody
- Watercourse

Drainage divide

- MNR/JDMA
- JDMA
- MNR



- Selected batholiths

Tertiary drainage areas

- Central English - Lac Seul sub-sub basin
- Chukuni sub-sub basin
- Lower English sub-sub basin
- Wabigoon sub-sub basin

Data sources:
Road: LIO Ontario Road Segment
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Watershed: See Section 4.2
Selected batholiths: OGS MRD 126-REV1

NORTH

5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

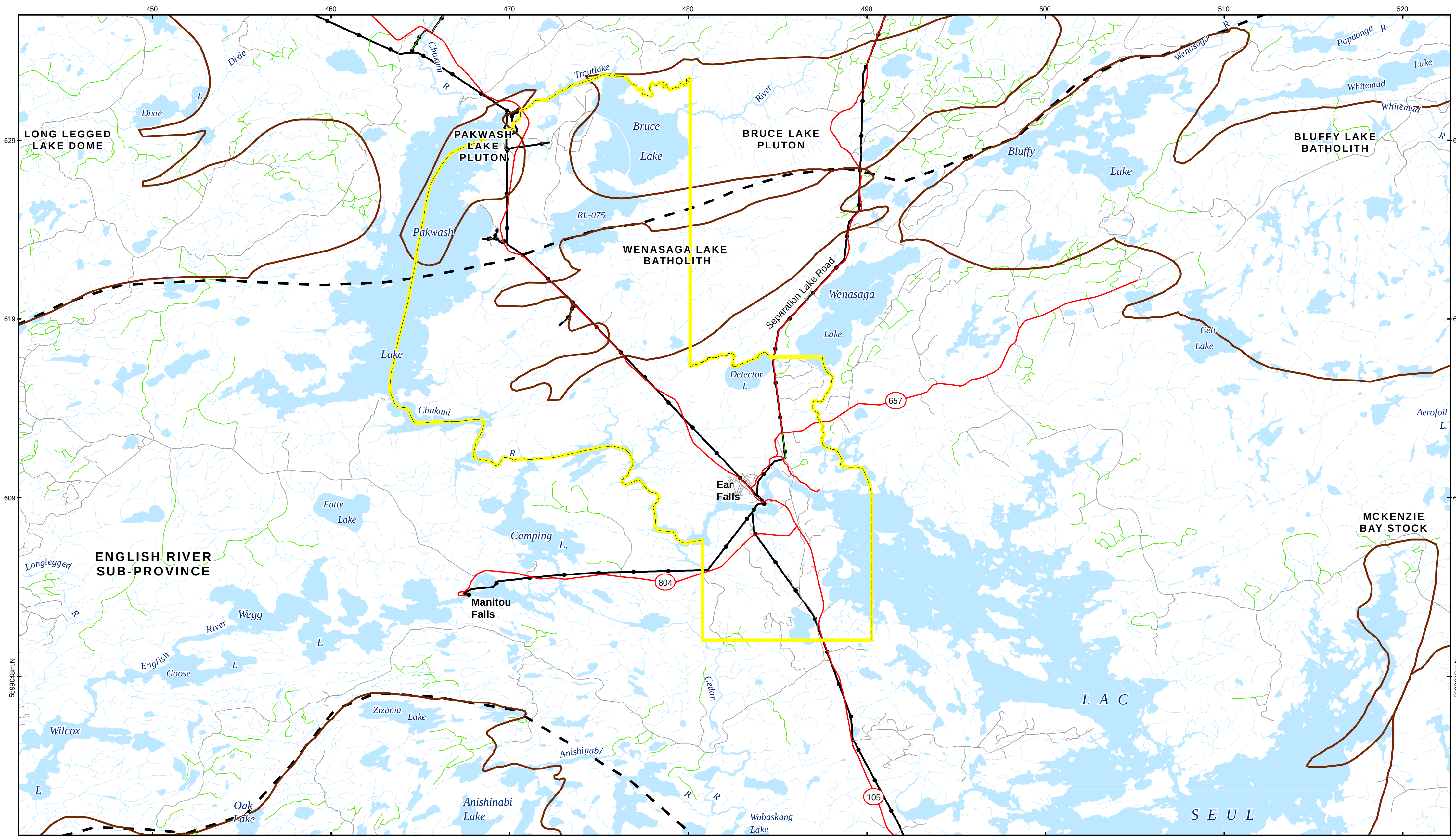
PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, TERRAIN AND REMOTE SENSING STUDY, EAR FALLS AREA, ONTARIO

TITLE

Watersheds within the Ear Falls area

DESIGN	DVZ	14 SEP 2012	FIGURE 12	REVISION 3
GIS	DVZ	01 AUG 2013		UTM ZONE 15
CHECK	JIC	01 AUG 2013		NAD 1983
REVIEW	GS	01 AUG 2013		1:275,000



LEGEND

- Township of Ear Falls
- Selected batholiths
- Sub-province boundary
- Main road
- Local road (MNR)
- Local road (JDMA)
- Transmission line
- Wabauskang First Nation
- Waterbody
- Watercourse

Data sources:
Main road: MNR Road Segment
Local road (MNR): MNR Road Segment
Local road (JDMA): Infill mapping by JDMA
Transmission line: LIO Utility line
Rail: LIO Railway
Waterbody: LIO OHN Waterbody
Watercourse: LIO OHN Watercourse
Selected batholiths: OGS MRD 126-REV1

NORTH

5 km

J D MOLLARD AND ASSOCIATES (2010) LIMITED

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

TITLE
Access roads within the Ear Falls area

DESIGN	DVZ	14 SEP 2012	FIGURE 13	REVISION 4
GIS	DVZ	23 OCT 2013		UTM ZONE 15
CHECK	JIC	23 OCT 2013		NAD 1983
REVIEW	GS	23 OCT 2013		1:275,000