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SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Phase 1 Geoscientific Desktop Preliminary Assessment of Potential Suitability for Siting a Deep Geological Repository for Canada's Used Nuclear Fuel

TOWNSHIP OF WHITE RIVER, ONTARIO

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Township of White River, Ontario

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Executive Summary

In January 2013, the Township of White River, Ontario expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process, and requested that a preliminary assessment be conducted to assess potential suitability of the White River area for safely hosting a deep geological repository (Step 3). This request followed successful completion of an initial screening conducted during Step 2 of the site selection process. The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessment are reported in an integrated preliminary assessment report (NWMO, 2014).

This report presents the results of a desktop geoscientific preliminary assessment to determine whether the White River area contains general areas that have the potential to meet NWMO's geoscientific site evaluation factors. The assessment builds on the work previously conducted for the initial screening and focuses on the Township of White River and its periphery, which are referred to as the "White River area".

The geoscientific preliminary assessment was conducted using available geoscientific information and a subset of key geoscientific evaluation factors that can be realistically assessed at this early stage of the site evaluation process. These include: geology; structural geology; interpreted lineaments; distribution and thickness of overburden deposits; surface conditions; and the potential for economically exploitable natural resources. The desktop geoscientific preliminary assessment included the following review and interpretation activities:

- Detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology, overburden deposits;
- Interpretation of available geophysical surveys (magnetic, electromagnetic, gravity, radiometric);
- Lineament studies using available satellite imagery, topography and geophysical surveys to provide information on the characteristics such as location, orientation and length of interpreted structural bedrock features;
- Terrain analysis studies to help assess factors such as overburden type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones; and
- The identification and evaluation of general potentially suitable areas based on key geoscientific characteristics and the systematic application of NWMO's geoscientific site evaluation factors.

The desktop geoscientific preliminary assessment showed that the White River area contains at least four general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. Two of these areas are within the Anahareo Lake pluton, one is located in the Pukaskwa batholith and one is located in the Strickland pluton.

The Pukaskwa batholith, Anahareo Lake pluton and Strickland pluton hosting the four identified potentially suitable areas appear to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. They all appear to have sufficient depth and extend over large areas. The four general areas identified in the White River area have good bedrock exposure, low potential for natural resources and contain limited surface constraints.

While the identified general potentially suitable areas appear to have favourable geoscientific characteristics for hosting a deep geological repository, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. Main uncertainties include the low resolution of available geophysical data over most of the potentially suitable areas, the influence of regional structural features and the presence of numerous dykes.

The identified potentially suitable areas are located away from regional structural features, such as the Quetico-Wawa Subprovince boundary. However, the potential impact of these regional features on the suitability of the four areas would need to be further assessed. The area contains numerous dykes. While the spacing between mapped and interpreted dykes and lineaments within the four potentially suitable areas appears to be favourable, the potential presence of smaller dykes not identifiable on geophysical data, and potential damage of the host rock due to the intrusion of dykes would need to be assessed.

Should the community of White River be selected by the NWMO to advance to Phase 2 study and remain interested in continuing with the site selection process, several years of progressively more detailed geoscientific studies would be required to confirm and demonstrate whether the White River area contains sites that can safely contain and isolate used nuclear fuel. This would include the acquisition and interpretation of higher resolution airborne geophysical surveys, detailed field geological mapping and the drilling of deep boreholes.

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Appendices

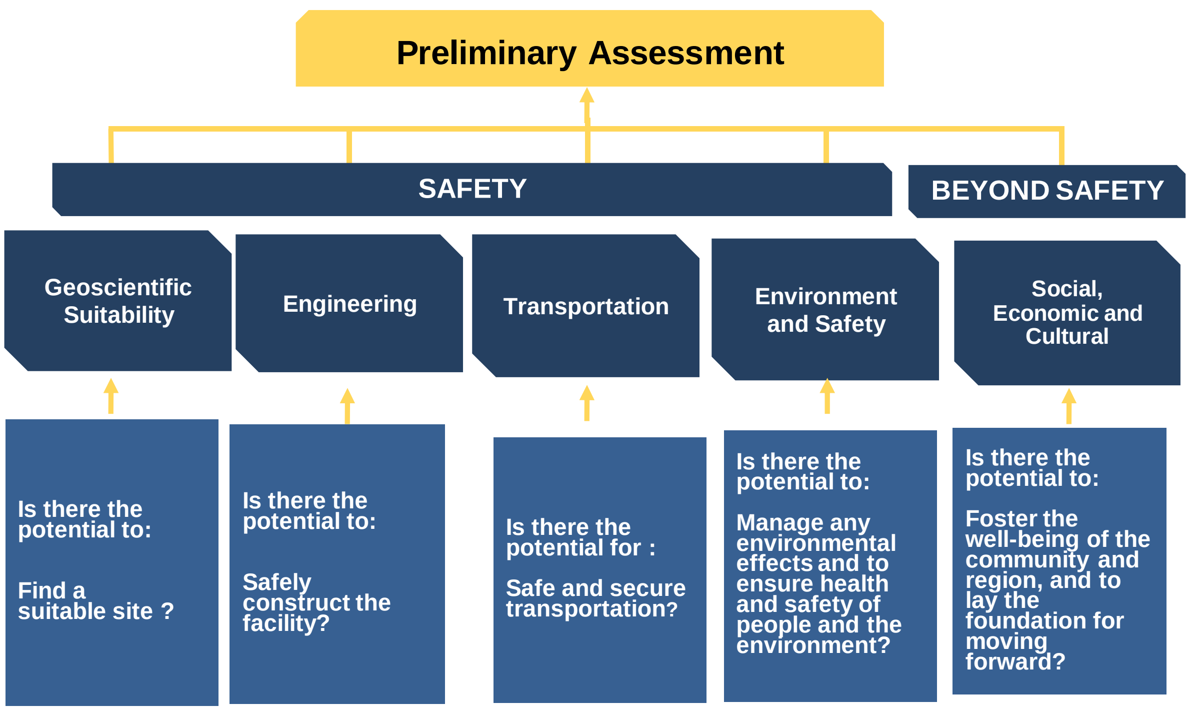
Appendix A. Geoscientific Factors
Appendix B. Geoscientific Data Sources

1. Introduction

1.1 Background

In January, 2013, the Township of White River, Ontario, expressed interest in continuing to learn more about the Nuclear Waste Management Organization (NWMO) nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess the potential suitability of the White River 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 (Golder, 2012a).

The overall preliminary assessment is a multidisciplinary study integrating both technical and community well-being assessments as illustrated in the diagram below. The five components of the preliminary assessment address geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. A brief description of the project, the assessment approach, and findings of the preliminary assessment are documented in an integrated preliminary assessment report (NWMO, 2014).



The objective of the geoscientific preliminary assessment is to assess whether the White River area contains general areas that have the potential to meet NWMO's site evaluation factors. The preliminary assessment is conducted in two phases:

- ***Phase 1 - Desktop Study.*** For all communities electing to be the focus of a preliminary assessment. This phase involves desktop studies using available geoscientific information and a set of key geoscientific characteristics and factors that can be realistically assessed at the desktop phase of the preliminary assessment.

- ***Phase 2 - Preliminary Field Investigations.*** For a subset of communities selected by the NWMO, to further assess potential suitability. This phase will involve a site investigation that includes high resolution geophysical surveys, geological mapping and the drilling of deep boreholes.

The subset of communities considered in Phase 2 of the preliminary assessment will be selected based on the findings of the overall desktop preliminary assessment considering both technical and community well-being factors presented in the above diagram.

1.2 Desktop Geoscientific Preliminary Assessment Approach

The objective of the Phase 1 desktop geoscientific preliminary assessment is to assess whether the White River area contains general areas that have the potential to satisfy the geoscientific evaluation factors outlined in the site selection process document (NWMO, 2010). The location and extent of identified potentially suitable areas would be confirmed during subsequent site evaluation stages.

The desktop preliminary assessment built on the work previously conducted for the initial screening (Golder, 2012a) and focused on the Township of White River and its periphery, which are referred to as the “White River area” in this report (Figure 1.1). The boundaries of the White River area were defined to encompass the main geological features within the Township of White River and its surroundings. The Phase 1 Desktop Geoscientific Preliminary Assessment included the following review and interpretation activities:

- Detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology, overburden deposits;
- Interpretation of available geophysical surveys (magnetic, electromagnetic, gravity, radiometric);
- Lineament studies using available satellite imagery, topography and geophysical surveys to provide information on the characteristics such as location, orientation and length of interpreted structural bedrock features;
- Terrain analysis studies to help assess overburden type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones; and
- The identification of general potentially suitable areas based on key geoscientific characterizations and the systematic application of NWMO’s geoscientific site evaluation factors.

The details of these various studies are documented in three supporting documents: Terrain Analysis (AECOM, 2014), Geophysical Interpretation (PGW, 2014), and Lineament Interpretation (SRK, 2014). Key findings from these studies are summarized in this report.

1.3 Geoscientific Site Evaluation Factors

As discussed in the NWMO site selection process, the suitability of potential sites will be evaluated in a staged manner through a series of progressively more detailed scientific and technical assessments using a number of geoscientific site evaluation factors, organized under five safety functions that a site would need to ultimately satisfy in order to be considered suitable (NWMO, 2010):

- ***Safe containment and isolation of used nuclear fuel:*** Are the characteristics of the rock at the site appropriate to ensuring the long-term containment and isolation of used nuclear fuel from humans, the environment and surface disturbances caused by human activities and natural events?

- ***Long-term resilience to future geological processes and climate change**:* Is the rock formation at the general potentially suitable area geologically stable and likely to remain stable over the very long-term in a manner that will ensure the repository will not be substantially affected by geological and climate change processes such as earthquakes and glacial cycles?

- ***Safe construction, operation and closure of the repository**:* Are conditions at the site suitable for the safe construction, operation and closure of the repository?

- ***Isolation of used fuel from future human activities:*** Is human intrusion at the site unlikely, for instance through future exploration or mining?

- ***Amenable to site characterization and data interpretation activities:*** Can the geologic conditions at the site be practically studied and described on dimensions that are important for demonstrating long-term safety?

The list of site evaluation factors under each safety function is provided in Appendix A.

The assessment was conducted in two steps. The first step assessed the potential to find general potentially suitable areas within the White River area using key geoscientific characteristics that can realistically be assessed at this stage of the assessment based on available information (Section 7.2). The second step assessed whether identified potentially suitable areas have the potential to meet all the safety functions outlined above (Section 7.3).

1.4 Available Geoscientific Information

Geoscientific information for the White River area was obtained from many data sources, including maps, reports, databases, and technical papers. In summary, the review of existing information identified that there was sufficient geoscientific information available to conduct the Phase 1 preliminary assessment studies and to identify general potentially suitable areas within the White River area. Key geoscientific information sources are summarized in this section, with a complete listing provided in Appendix B.

1.4.1 Airborne Geophysics, Digital Elevation Model, Satellite Imagery and Aerial Photography

Geophysical data for the White River area were obtained from available public-domain sources, particularly the Ontario Geological Survey (OGS) and the Geological Survey of Canada (GSC) (Table 1.1, Table B.1). Figure 1.2 shows the outline of the available airborne geophysical surveys for the White River area.

Low-resolution magnetic data from the GSC (Ontario #8 and #17) provides complete coverage of the entire White River area (GSC, 2013). Magnetic data from these surveys form part of the GSC Regional Magnetic Compilation data and were flown at a terrain clearance of 305 m and flight line spacing of 805 m, providing them with a relatively low spatial resolution. Higher resolution geophysical surveys from the OGS (Oba-Kapuskasing Survey, Manitouwadge Survey and Hemlo Survey) provide coverage for the area, and consist of three magnetic and frequency-domain (FDEM) surveys. These were flown at a lower terrain clearance (45 and 55 m) compared to the GSC surveys, and with flight line spacing of 200 m and 100 m (OGS, 2002a; 2002b; 2003). One covers the northwest part of the White River area, and two additional surveys extend into the area to the northeast and southwest, focused on greenstones. These surveys focused on areas with mineral exploration potential, covering the greenstone belts and also the adjacent intrusive and metasedimentary rocks.

In addition, the OGS Assessment File Research Imaging (AFRI) database was queried for airborne geophysical surveys located within the White River area and 23 files were downloaded for review. Six files provided useful maps, one of which (MNDM, 2013a; AFRI No. 20004804) included maps that were incorporated into the geophysical assessment. These assessment file maps (AFRI No. 20004804) provided additional high-resolution magnetic and FDEM coverage over the Dayohessarah greenstone belt in the central part of the White River area.

The electromagnetic coverage consists of frequency-domain electromagnetic (FDEM) surveys that form part of the high-resolution surveys discussed above. The electromagnetic data grids provided from the OGS surveys are as follows:

- GDS1024 (Oba-Kapuskasing): apparent resistivity grid from the 4,186 Hz coplanar coil pair;
- GDS1205 (Manitouwadge): apparent resistivity grid from the 900 Hz, 7,200 Hz, and 56,000 Hz coplanar coil pairs;
- GDS1207 (Hemlo): apparent resistivity grid from the 4,500 Hz coaxial coil pair and VLF total field grid.

In addition, each FDEM survey included an EM anomaly database with the sources classified as bedrock, surficial, or cultural.

The GSC radiometric and gravity coverage for the White River area is the typical regional coverage available for most of the country. The GSC radiometric data sets show the distribution of natural radioactive elements at surface: uranium (eU), thorium (eTh) and potassium (K), and provide complete coverage of the White River area (GSC, 2013). This survey was flown at 5,000 m line spacing at a terrain clearance of 123 m above the surface. The gravity data provide complete coverage of the White River area (GSC, 2013), consisting of an irregular distribution of 32 station measurements within the White River area, comprising roughly a station every 5 to 15 km.

Data sets containing remote sensing data were available for use in the White River Phase 1 Desktop Geoscientific Preliminary Assessment. The digital elevation model (DEM) data for the White River area, referred to as the Canadian Digital Elevation Data (CDED), consists of a 1:50,000 scale, 20 m resolution elevation model (Table 1.1; GeoBase, 2013a). SPOT multispectral/panchromatic orthoimagery (20 m / 10 m resolution, respectively) were also available for the White River area as was Landsat 7 orthoimages (30 m resolution) (Table 1.1; GeoBase, 2013b).

Aerial photographic coverage of the White River area from 1978, at a scale of 1:54,000 was obtained from the archives of the Ontario Geological Survey. The images, part of the OGS's Northern Ontario Engineering Geology Terrain Study (NOEGTS) collection, were captured during seasons with limited vegetation cover thus permitting the identification of topographic features.

Each of the remotely-sensed data sets covers the entire White River area and all have a good level of resolution in relation to the scope of the project allowing the interpretation surficial geology. In addition, meaningful and accurate bedrock structural information could be gained from each of the data sets for the majority of the area. The only areas where this was not the case was in the northeastern portion of the White River area and, to a lesser degree, the northwest corner of the White River area where significant deposits of Quaternary sediments are present.

Table 1.1: Summary of Satellite, Airborne and Geophysical Source Data Information for the White River Area

Data Set	Product	Source	Resolution	Coverage	Acquired	Additional Comments
DEM	Canadian Digital Elevation Data (CDED); 1:50,000 Scale	Geobase	8-23 m (0.75 arc seconds) depending on latitude	Entire White River area	1995 (published in 2003)	Hillshade and slope rasters used for mapping
Aerial Photography	Images	OGS	1:54,000 scale	Entire White River area	1978	
Satellite Imagery	Spot 4/5; Orthoimage, multispectral/ panchromatic	Geobase	10 m (panchromatic) 20 m (multispectral)	Entire White River area	2009	
	Landsat 7 orthorectified imagery	Geobase	30 m (multispectral)	Entire White River area	2001-2002	
Geophysics	Ontario #8 Fixed wing magnetic	GSC	805 m line spacing; Sensor height 305 m	West part of White River area	1959	Locally superseded by higher resolution coverage.
	Ontario #17 Fixed wing magnetic	GSC	805 m line spacing; Sensor height 305 m	East part of White River area	1963	Little overlap with high-resolution coverage.
	Manitouwadge Area magnetic and electromagnetic data (Block H) (GDS1205)	OGS	200 m line spacing; Sensor height MAG 45 m FDEM 30 m	Covers 160 km^2 (~3%) of White River area, located in northwest corner	1989 (published in 2002)	4-frequency Dighem IV system, flown for Noranda Exploration Company, Ltd.
	Hemlo Area magnetic and electromagnetic data, (GDS1207-Rev)	OGS	100 m line spacing; Sensor height MAG 55 m FDEM 40 m VLF-EM 55 m	Covers 140 km^2 (~3%) of White River area, located along the western boundary	1983 (published in 2002)	3-frequency Aerodat system

Table 1.1: Summary of Satellite, Airborne and Geophysical Source Data Information for the White River Area

	Oba-Kapuskasing area, magnetic and electromagnetic data (GDS1024-Rev)	OGS	200 m line spacing; Sensor height MAG 45 m FDEM 30 m VLF-EM 45 m	Covers 75 km^2 (~1.5%) of White River area, located in northeast corner	1986 (published in 2003)	3-frequency Aerodat system
	AFRI No. 20004804 Helicopter magnetic, FDEM	OGS Assessment Files	100 m line spacing; Sensor height MAG 30 m FDEM 30 m	Dayohessarah greenstone belt; Central White River area	2008	5-frequency Dighem system, flown for Corona Gold Corp.
	Ground Gravity Measurements (CGDB, SEP 2010)	GSC	5 to15 km Station Spacing	Stations sparsely located over White River area	1946- 2001	Good data quality, limited numbers of data points
	North Shore Lake Superior, section 1 (East), Fixed wing magnetic, radiometric	GSC	5,000 m line spacing; Sensor height 123 m	Entire White River area	1982	Only radiometric survey available.

1.4.2 Geology

Precambrian geologic mapping in the White River area and surrounding region has been conducted over the last century (Table B.2). A number of early reconnaissance and mineral exploration mapping initiatives (Parsons, 1908; Maynard, 1928; 1929; Barkley, 1957; Page, 1958) were followed by township-scale mapping conducted by the Ontario government in the 1960s (Fenwick, 1966; 1967; Milne, 1968). This mapping led to the creation of regional-scale compilation map (1:253,440) for the area in the 1970s (Milne *et al.,* 1972).

Subsequent field investigations in the White River area focussed on the greenstone belts with the Kabinakagami belt being mapped by Siragusa (1977; 1978) at a scale of 1:63,360, and the Dayohessarah belt by Stott *et al.* (1995a; 1995b; 1995c) at a scale of 1:20,000. The results of this mapping have been incorporated into updated regional and provincial compilations at scales of 1:250,000 (Santaguida, 2001; Ontario Geological Survey, 2011) and 1:1,000,000 (Ontario Geological Survey, 1991; 1997), respectively. A provincial-scale tectonic assemblage map was also generated from an interpretation of this latest generation of mapping (Ontario Geological Survey, 1992). Wilson (1993) reviewed the geology and mineral occurrences of the Kabinakagami greenstone belt. Figure 1.2 illustrates the recent bedrock geological map coverage in the White River area.

More recent mapping of the White River area, largely completed by the Ontario Geological Survey (OGS) and the Geological Survey of Canada (GSC), is of varying detail depending on scale, but is considered to be of high quality (e.g., Williams, 1989; Card, 1990; Williams *et al.*, 1991; Muir, 2000; 2003). The focus of most of the bedrock mapping in the region was on defining the lithologies, structural controls, and mineral potential of the greenstone belts. The mapping has resulted in the definition of assemblages within the Dayohessarah greenstone belt (Stott,

1999) and understanding of regional lithotectonic relationships (Muir, 2003). It should be noted, however, that the mapping and study of the batholiths and plutons in the area is notably less comprehensive and detailed.

Bedrock maps covering the White River area have identified the position and orientation of a number of large scale faults and lineaments. The density of the structural data is greatest within the greenstone belts, due to their known and potential mineral endowment and complex tectonic history. With the exception of Stott (1999), limited information is available on the structural history of the White River area. The eastern portion of the Schreiber-Hemlo greenstone belt, notably the area surrounding the Hemlo gold mines, has been studied in detail (e.g., Lin, 2001; Muir, 2003). As such, it is inferred that events recognized in Hemlo area also occurred to the east. Additional field studies would be required to confirm the nature and timing of major events affecting the structural history of the White River area.

Several geochronological investigations have been completed that assist in determining the age of bedrock units within and surrounding the White River area (Corfu and Muir, 1989; Jackson *et al.*, 1998; Beakhouse, 2001). This research has principally focused on defining the age of greenstone rocks and the alteration halos surrounding mineral deposits (e.g., Hamilton *et al.*, 2002; Davis and Lin, 2003; Lin and Beakhouse, 2013). Dates of the granitoid rocks surrounding the greenstone belt are far fewer and show greater variability in ages. In general, the quality of geochronological data is high, especially for dates generated within the past few decades. A database of geochronological dates is maintained by the GSC.

Information on the geochemical analysis of bedrock samples collected from the 1970s to the early 1990s is contained in the OGS lithogeochemistry (formerly Petroch) database (MNDM, 2013a). The majority of the results in this database are of supracrustal greenstone rocks with far fewer analyses of felsic intrusive rocks. In general, the quality of the analytical results is dependent on when the analyses were conducted, since modern analytical equipment tends to have better detection levels. Furthermore, the location information recorded for samples taken prior to modern GPS technology may be less reliable in some cases.

A provincial compilation of Quaternary geology at the scale of 1:1,000,000 includes the White River area (Barnett *et al.*, 1991). This is complemented by detailed mapping (1:100,000) of the surficial sediments from airphoto interpretation with limited ground checking, completed during the Northern Ontario Engineering Geology Terrain Study (NOEGTS; Gartner and McQuay, 1979a; 1979b; 1980a; 1980b; OGS *et al.*, 2005). The mapping is of sufficient quality to illustrate the distribution of glacial materials and to determine that they are generally thin over the majority of the White River area. Exceptions include some bedrock controlled valleys and pockets of land along the northern edge of the area. Data on overburden thickness are also available from well records in the Ontario Ministry of Environment Water Well Information Systems database (Ontario Ministry of Environment, 2013) and from the OGS drill hole database (MNDM, 2013a) discussed in Section 1.5.4.

The glacial history for the area is reasonably well-understood having been constructed on the basis of detailed mapping in surrounding areas and regional studies assessing glaciation events (e.g., Geddes *et al.*, 1985; Geddes and Kristjansson, 1986; 2009; Barnett, 1992; Kettles and Way Nee, 1998). Research on glacial lake levels in the Superior Basin has allowed an understanding of isostatic recovery rates in the area (Farrand and Drexler, 1985; Barnett, 1992; Lee and Southam, 1994; Mainville and Craymer, 2005).

Several databases contain records of publications with information on the White River area's bedrock geology, geological history, structural evolution and economic potential (Table B.3). The most relevant databases to the Desktop Preliminary Assessment are referenced and/or available through GEOSCAN and Geology Ontario (OGS publications).

National seismicity data sources were used to provide an indication of seismicity in the White River area (Hajnal *et al*., 1983; Hayek *et al*., 2011; Natural Resources Canada, 2013).

1.4.3 Hydrogeology and Hydrogeochemistry

The Land Information Ontario (LIO) data warehouse, held by the Ontario Ministry of Natural Resources, contains a database of tertiary and quaternary level watersheds (LIO, 2013) and lakes, including flow direction of all waterways. Shallow groundwater flow is expected to mimic the pattern of surface flow suggested by the configuration of these watersheds. Limited stream/river flow data are available for the region surrounding the White River area (Environment Canada, 2013).

Data on the hydrogeology of the White River area are largely lacking. The reliance on surface water sources and the very limited number of water wells recorded in the Ministry of Environment's Water Well Information System (Ontario Ministry of Environment, 2013) results in only a basic and localized understanding of surficial and shallow bedrock flow systems. The completeness of the information in the few water well records for the White River area, most of which are located in and around the settlement area of White River, is uneven.

Groundwater flow regimes and the positions of recharge and discharges areas are inferred from other bedrock-dominated areas and the type and distribution of surficial materials. The absence of information in the area on deep aquifers or groundwater geochemistry necessitates inferring conditions from similar geologic settings elsewhere in the Canadian Shield. Specific reports/studies include Gascoyne (1994; 2000; 2004), Everitt *et al. (*1996), Gascoyne *et al*. (1996), Ophori *et al. (*1996), and Everitt (1999).

1.4.4 Natural Resources – Economic Geology

The White River area has had an extended history of mineral exploration mainly focused on precious and base metals. Exploration in the Kabinakagami greenstone belt resulted in the discovery of a number of mineral occurrences and the brief operation of a gold mine in the 1930s. Exploration in the Dayohessarah greenstone belt became active after the discovery of the Hemlo gold deposits to the west in 1981. The mineral potential of the Dayohessarah and Kabinakagami greenstone belts has resulted in bedrock geological mapping being concentrated on these rocks and the majority of geologic maps and reports noted in Section 1.5 containing information relevant to assessing the mineral potential of the area. The various types of precious and base metal deposits in the White River area are described in Fenwick (1967), Siragusa (1978), Wilson (1993), McKay (1994) and Stott (1999). The mineral resource potential for other commodities is described by Springer (1977), Gartner and McQuay (1979a; 1979b; 1980a; 1980b), Hinz *et al*. (1994) and Breaks *et al.* (2003).

Several databases resulting from mineral exploration and/or mining activities in the White River area are held by the MNDM/OGS and contain information useful to understanding the area's resource potential. The largest of these is the Assessment File Research Imaging (AFRI) database which consists of technical results of exploration programs on Crown Land (MNDM, 2013a). The AFRI database outlines the type of geoscience investigations completed and a summary of findings. The quality and usefulness of the files is highly variable; information varies from site-specific to regional and the level and/or amount of information from low to very high.

The OGS drill hole database is a collection of surface and underground drilling data compiled from some of the AFRI records (MNDM, 2013a). The database includes several fields including drill hole location, drill hole orientation and depth, overburden depth, and the presence of assay results, if available.

The Mineral Deposits Inventory (MDI) database contains a record of base, precious, and industrial mineral deposits, occurrences, and showings in the White River area and beyond (MNDM, 2013a). The level of information in each

MDI record is highly variable, notably for small occurrences. In general, information is available on geological structure, lithology, minerals, and mineral alteration, in addition to production and reserve data. Information quality is variable as the data are compiled from a range of sources, and may not always be verified.

The Abandoned Mines Information System (AMIS) contains the location of past-producing mines sites in the area and augments mineral potential evaluations (MNDM, 2013a). The database has records on mining-related features including mining hazards and abandoned mines and is generally considered to be accurate.

Regional-scale geochemical sampling of lake sediments and lake waters has been conducted by the GSC and reported on for the White River area by Friske *et al.* (1991). The sampling, conducted in the late 1970s, is useful in defining mineral potential and can play a role in establishing environmental baseline conditions. The geochemical data from this survey, while of high quality, is reflective of the methods and analytical capacities of the time. Lake and water sampling was conducted by Jackson (2002a; 2002b; 2003a; 2003b) in the area of the Dayohessarah and Kabinakagami greenstone belts primarily to identify mineral exploration targets.

1.4.5 Geomechanical Properties

Available geotechnical studies in the area are restricted to near-surface investigations involving surficial materials and the upper few metres of bedrock. The geotechnical investigations in the area, especially the more recent ones, are of high quality but add little to the understanding of conditions at depth.

While a large amount of mineral exploration drilling has been completed in the area, some to considerable depths, the bulk of the boreholes are within the metavolcanic units associated with the Dayohessarah and Kabinakagami greenstone belts. While numerous boreholes have high quality information on lithology variations, and some geophysical logs, geotechnical testing on core is largely absent.

As geotechnical information on the felsic intrusive bodies at repository depth is lacking, it must be inferred from studies completed on other locations. As such, inferences have been made from geomechanical information derived from sites elsewhere in the Canadian Shield with similar types of rock, the majority of which was completed under the auspices of Atomic Energy of Canada Ltd. (AECL) in the 1980s and 1990s as part of the Canadian Nuclear Fuel Waste Management Program. Information on the geomechanical properties of granitic rocks with conditions ranging from intact rock to highly fractured fault zones is available from AECL's Underground Research Laboratory (URL) near Pinawa, Manitoba, and the Atikokan research area in Ontario (Brown *et al*., 1989; Stone *et al.*, 1989).

2. PHYSICAL GEOGRAPHY

2.1 Location

The White River area is located northeast of Lake Superior approximately 295 km east of Thunder Bay, and 240 km north-north west of Sault Ste. Marie (all straight-line distances). The area covered by this report, referred to herein as the White River area, contains approximately 4,991 km^2 (Figure 1.1). The Township of White River occupies 102.2 km^2 in the southwest corner of the area and contains a population centre of the same name. The only other population centre in the area is the small settlement of Amyot, located along the rail line southeast of the Township at the eastern end of Negwazu Lake. Other nearby towns are Wawa, 93 km to the southeast, Marathon, 95 km to the west, and Hornepayne, 110 km to the northeast (road distances).

A Landsat colour composite image of the White River area is presented as Figure 2.1. The composite image was created by assigning a primary colour (red, green and blue) to three of the Landsat multispectral bands. Different materials reflect and absorb solar radiation differently at different wavelengths and therefore have varying intensities within each of the Landsat bands. When combined into a single image, the chosen colour scheme approaches a “natural” representation, where, for example, vegetation appears in shades of green. Exposed soil or rock can appear in lighter tones of green that can, in some cases, have a pinkish hue. On Figure 2.1, the widespread whitish patches represent where the vegetation has been disturbed, most commonly by forestry operations, although areas of recent forest fires show-up in a similar manner. A notable burnt area can be seen on Figure 2.1 immediately northwest of the Township of White River, north of Highway 17. This area is within the boundary of the Kwinkwaga Ground Moraine Conservation Reserve (Figure 1.1).

Access to the White River area is via Ontario King’s Highway 17 (the Trans-Canada Highway), which enters the area along its southern boundary and trends northwest, exiting at the mid-point of the western side (Figure 1.1). Provincial Highway 631 runs east from White River before turning northward to Hornepayne. Good access to the interior of the White River area is provided by a network of secondary roads and trails connecting to the two provincial highways. A rail line operated by Canadian Pacific Railways closely follows the route of Highway 17 west of White River, before trending eastward along the southern boundary of the White River area. A rail line operated by the Algoma Central Railway that trends northeast from Dubreuilville to Hearst crosses the extreme southeast corner of the White River area.

2.2 Topography and Landforms

A detailed terrain analysis was completed as part of the preliminary assessment of potential suitability for the White River area (AECOM, 2014). This section provides a summary of this analysis.

The White River area is located within the Abitibi Upland physiographic region (Thurston, 1991), a subdivision of the extensive James physiographic region (Bostock, 1970). The region is generally characterized by abundant bedrock outcrop with shallow drift cover and a rugged topography.

The topography of the White River area is presented on Figure 2.2. Bedrock-controlled terrain dominates the majority of the area and results in significant differences in elevation over short distances; the maximum relief within the White River area is approximately 311 m (Figure 2.2). The highest point of land within the area, 622 masl, occurs approximately 13 km northeast of the settlement area of White River, and the lowest point (311 masl) is the level of Kabinakagami Lake in the northeast corner of the White River area. Notable variations in elevation caused by the relief of the bedrock surface are prevalent throughout the majority of the White River area. The White River area can be viewed as consisting of a broad, dissected plateau which has higher elevations in the western and southern regions and a lower ground surface along its northern boundary.

Across expanses in the southern and north-central parts of area, the elevation of hills and intervening valleys is commonly above 400 m (Figure 2.2). Localized areas with elevations over 500 m are present in the areas surrounding the Township of White River, as well as in several of the townships along the southern boundary of the White River area, east of Highway 631.

Elevations of 320 to 400 m occur as a band of varying width across the northern and eastern boundaries of the area as well as a large portion of the northeast quadrant (Figure 2.2). All significant glaciolacustrine and organic deposits occur within this range of elevation.

Within the White River area, the upland regions, consisting of bedrock hills and ridges, are typically characterized by moderate relief (approximately 60 to 80 m) over distances of hundreds of metres to a few kilometres. The uplands are scattered throughout the area and form the dominant terrain type. Glaciolacustrine, organic, and to a lesser degree, glaciofluvial deposits and ground moraine, represent areas of limited relief, although many of these deposits are characterized by protrusions of bedrock. The glaciolacustrine deposits in the northern third of the area display relief in the range of 20 to 40 m over the majority of their surface area. Limited relief is present within organic deposits, except where their surface is disrupted by hummocks of bedrock.

Approximately 17.4 percent (867 km^2) of the White River area is represented by slopes greater than 6 degrees. These steep slopes generally occur in areas of bedrock terrain and there is a correlation with areas of higher relief (Figure 2.2). A concentration of steep slopes occurs in a southeast-trending belt that arches north of the Township of White River from Highway 17 in the west to the mid-point of the southern boundary of the White River area. A high number of steep slopes are also present either side of Esnagi Lake in the southeast corner of the White River area.

The rugged character of the land immediately north of the Township of White River is caused by the fact that the steep slopes make up the majority of the land surface. Elsewhere the terrain has a more distinctively knobby nature; here the tops of the knobs, and occasional ridges, frequently have lower slopes than the surrounding terrain. Often, the steep slopes form northeastern-facing cuestas. The north-central and northeastern corner of the White River area has a paucity of steep slopes, as does the area east of White Lake in the northwest corner.

It is assumed that steep slopes are indicative of areas with no or limited overburden, where observations on the character of the bedrock can be more easily discerned. Conversely, areas of gentler slopes may be indicative of somewhat thicker overburden that may obscure the surface expression of bedrock structures.

2.3 Watersheds and Surface Water Features

The White River area straddles the Atlantic and Arctic watershed divide; the watersheds drain via the Lake Superior/Great Lakes/St. Lawrence River and James/Hudson Bay water systems, respectively (Figure 2.4) (LIO, 2013). Drainage to Lake Superior is through the Michipicoten-Magpie and White tertiary watersheds; the overall flow direction in the former is southward, while the general drainage direction of the latter is westward toward White Lake (Figure 2.4, inset map). The Arctic watershed is represented in the White River area by two tertiary level watersheds, the Nagagami and the Upper Kabinakagami, which drain the majority of the land in the eastern half of the area.

Major drainage in Michipicoten-Magpie watershed is via Esnagi Lake which flows into the Magpie River south of the White River area. Significant rivers in the White watershed include the Shabotik, Bremner, and White, although these are fed by numerous smaller waterways. The Beaton and Kabinakagami are the principal rivers in the White River area draining the Nagagami and the Upper Kabinakagami watersheds, respectively.

The orientation of the drainage network within the White River area is largely controlled by bedrock structural features (faults and lineaments) and the irregular topography of the terrain. Due to this control, the majority of waterways, including lakes, have, in order of dominance, a northeast, north or northwest orientation. While the overall drainage direction in the Atlantic and Arctic watersheds are southwest and northeast, respectively, the catchment areas of individual lakes within the watersheds have stream segments with multiple flow directions (Figure 2.4).

The larger rivers draining the White River area are fed by numerous smaller creeks and streams that effectively drain all parts of the area. While there is generally a high density of stream and rivers in the White River area, it is somewhat lower in the region surrounding Kabinakagami Lake where glaciolacustrine, glaciofluvial and organic deposits occupying a significant percentage of the landscape.

Typically, segments of the waterways in the White River area are on the order of 2 to 10 km, as they flow into and out of lakes occurring along the drainage paths. A relationship exists between the length of stream segments and relief: shorter segments are present in highland regions, and longer segments in lower relief regions associated with glaciolacustrine deposits. Gradients of the watercourses vary; those of smaller streams are generally moderate, while longer rivers, such as the, Kabinakagami, Shabotik and White rivers, have lower gradients. Rapids and small waterfalls are common in the White River area.

The numerous lakes within the White River area occupy approximately 10 percent (514 km^2) of the land surface. While the lakes are widespread, lake density is greatest in areas of high elevation and relief (Figure 1.1) and, as such, more lakes occur in bedrock-dominated terrain in the southern and west-central portions of the area. Lower lake density is present in a large zone to the north of an arching line that runs from Matthews Lake on the northern boundary, to north of Oba Lake in the east. This zone corresponds with the most extensive deposits of glaciolacustrine, glaciofluvial and organic sediments. Local concentrations of small lakes, however, are present in this zone within some large glaciofluvial deposits. Notable examples occur in Bayfield Township immediately west of Highway 631, in an esker-outwash complex, and in Derry and Ermine townships east of Kabinakagami Lake, where the lakes are associated with a southward-trending esker system (Figure 1.1).

In general, the lakes are of a modest size with the majority having a surface area of less than 2 km^2. The larger water bodies (>2.5 km^2) in the White River area are listed in Table 2.1.

Table 2.1: Size of lakes larger than 2.5 km^2 in the White River area.

Lake	Area (km^2)	Perimeter (km)
Kabinakagami*	123.2	374.4
White*	60.9	182.8
Esnagi*	46.0	254.6
Oba*	25.5	110.0
Negwazu	14.3	43.0
Nameigos	13.5	47.8
Dayohessarah	11.2	44.9
Gourlay	9.9	31.1
Mosambik	9.8	19.5
Pokei	8.7	22.4
Kwinkwaga	8.6	53.5
Anahareo	8.5	19.2
Matthews	6.1	16.3
Duffy	4.9	20.3
Hambleton	3.5	19.0
Caribou	3.4	28.5
Tukanee	3.2	13.1
Upper Duffy	2.7	18.3
Round	2.6	7.4
Pike	2.6	16.2

* Lake extends beyond boundary of White River area

A lake sediment sampling survey conducted by the GSC recorded lake depths at approximately 355 locations in the White River area (Friske *et al.*, 1991). While it was the intent of this survey to sample the deepest part of the lakes, this cannot be confirmed. Nevertheless, the lake sediment survey data do provide a general picture of minimum lake depths. Bathometric surveys have been conducted by the MNR for 59 lakes in the White River area; however, the accuracy of these surveys is deemed as questionable (C. Bolton, written comm., 2013). Lake-depth data in the areas of the Dayohessarah and Kabinakagami greenstone belts is also available as a result of lake and water sampling conducted by Jackson (2002a; 2002b; 2003a; 2003b).

No correlation between lake size and depth can be determined based on the available data. Deeper lakes are concentrated in the western and southeastern parts of the area were bedrock terrain is prevalent. This area is largely underlain by the Black-Pic batholith, the Denny Lake stock and the informally named Anahareo Lake pluton.

Table 2.2 indicates that approximately 60 percent of the sample sites measured by Friske *et al.* (1991) have a water depth of less than 5 m and nearly 86 percent are less than 10 m deep. Lakes deeper than 20 m account for only 3.7 percent of the sites sampled.

Table 2.2: White River area lake-depth data (from Friske *et al.*, 1991).

Lake Depth (m)	Number of Lake Sites	Percentage
<5.0	210	59.1
5.1 – 10.0	95	26.8
10.1 – 15.0	19	5.3
15.1 – 20.0	18	5.1
>20.1	13	3.7

Generally, shallower lake depths in the northeastern corner of the White River area likely reflect infilling of bedrock basins by glaciolacustrine sediments. Significant bedrock units in the White River area are the Strickland pluton, the Kabinakagami greenstone belt, an area of foliated tonalite, and a relative limited portion of the Anahareo Lake pluton.

2.4 Land Use and Protected Areas

Figure 2.5 shows a summary of land disposition and ownership within the White River area, including known protected areas (Golder Associates, 2014).

2.4.1 Land Use

The vast majority of the White River area is undeveloped Crown Land with privately held residential and business properties located almost exclusively within the settlement area of White River. Private land, held as mineral patents, also occurs in Lizar Township, west of Kabinakagami Lake, and in Derry Township, in the northeast corner of the White River area. Several small parcels of land designated as Crown Reserves are scattered across the area (Figure 2.5).

Mineral exploration is active in the area; numerous active mining claims and a small number of patents are held by prospectors and mining companies (MNDM, 2013b). The majority of the mining claims occur in three areas: a large rectangular shaped block centred on Dayohessarah Lake (primarily over the Dayohessarah greenstone belt); a northeast trending group between Nameigos Lake and Kabinakagami Lake (over the central part of the Kabinakagami greenstone belt); and west of White River, south of Highway 17. A range of exploration work is conducted on the claims to assess the mineral potential including geologic mapping, drilling, and geochemical and geophysical surveys. A number of aggregate operations are extracting sand and gravel in the area (MNR, 2013a). The majority of the pits are located adjacent to the routes of Highways 17 and 631. Natural resources are discussed further in Section 5.

Forestry is a long-standing use of the land and has been an economic mainstay of the White River area. The area falls within MNR's Magpie, Nagagami and White River forestry management units (MNR, 2013b). The northeast corner of the White River area is located within the Hearst Forest (MNR, 2013b). Timber harvesting has occurred over large expanses of the White River area.

Forestry sector activities result in the development of an extended road and/or trail network, although some of this access is of a temporary (e.g., open only while logging is on-going) or seasonal nature (e.g., winter roads). Access to the many lakes and remote areas within the White River area allows use of the land for hunting and fishing by the local population and visitors to the region.

2.4.2 Parks and Reserves

Seven protected areas are located completely or partially within the White River area, including two Forest Reserves within the Kwinkwaga Ground Moraine Conservation Reserve (Figure 2.5).

The Pokei Lake/White River Wetlands Provincial Nature Reserve occupies 17.68 km^2, in the townships of McDowell and Memaskwosh, south of White River and west of Highway 17. The Park area includes riparian wetlands, including marsh, fen and swamp, in the floodplain of the White River (MNR, 2013c). A candidate Life Science, Areas of Natural and Scientific Interest (ANSI) (White River Wetland) is located within and to the west of this park.

The Kakakiwibik Esker Conservation Reserve protects a distinct steep-sided esker ridge, associated tributary esker ridges, kettle lakes, kames and shoreline features (MNR, 2013c). The Conservation Reserve encompasses 5.21 km^2 in Abraham and Vasiloff townships. An area to the west of the Conservation Reserve is a candidate Life Science ANSI (Kakakawibik Esker).

The Strickland River Mixed Forest Wetland Conservation Reserve is described as land that has strongly broken ground moraine with areas of mixed forest consisting of mainly coniferous, sparse forest, and wetlands (MNR, 2013c). The Conservation Reserve has an area of 16.38 km^2 within Strickland Township.

The Kwinkwaga Ground Moraine Conservation Reserve is a 126.5 km^2 area of rugged topography with many hills and numerous lakes and creeks that was burned over by a forest fire in 1999 (MNR, 2013c). The land is described as being dominated by moderately to weakly broken ground moraine. Kwinkwaga Ground Moraine Conservation Reserve contains two small areas classified as Forest Reserve that will become part of the Kwinkwaga Ground Moraine Uplands Conservation Reserve if the mining claims that currently share their boundaries are retired.

The White Lake Peatlands Provincial Park was established to protect a large peatland bog and several other supporting features including a sand beach and backshore lagoon, and a low levee ridge on the west bank of the Shabotik River (MNR, 2013c). The Park has an area of 9.92 km^2 of which roughly half falls within the northwestern corner of the White River area. A candidate Life Science ANSI is associated with this park (White Lake Peatland).

A candidate Life Science ANSI site, the Bremner River Wetland, occupies 23 km^2 in the southwestern corner of the area.

There are three Life Science Sites and three Earth Science Sites within the White River area. The three Life Science Sites in the White River area are: Kawapitapika Lake Park Reserve, Kawaweagama Lakes – Jack Pine Forest, and Bremner Watershed. There are three Earth Science Sites in the White River area, including a meandering stream in the Kakakiwibik Lake Park Reserve, an esker in the Kakakiwibik Lake Park Reserve, and an esker at Kaginagakog Lake.

2.4.3 Heritage Sites

Information on archaeological sites in Ontario is provided by the Ontario Ministry of Tourism and Culture, through their Archaeological Sites Database (Ontario Ministry of Tourism and Culture, 2013).

Within the White River area a single archaeological site has been discovered approximately 15 km east of the Town of White River in Abraham Township. Referred to as the Caribou Lodge site, it is a pre-contact Aboriginal campsite of an undetermined culture and time period (R. von Bitter, written comm., 2013). Locations of known archaeological sites are not shown in maps within this report to comply with the Ministry of Tourism and Culture publication guidelines.

Archaeological potential is established by determining the likelihood that archaeological resources may be present on a subject property. In archaeological potential modelling, a distance to water criterion of 300 m is generally employed for primary water courses, including lakeshores, rivers and large creeks, as well as secondary water sources, including swamps and small creeks (Government of Ontario, 2011).

The Canadian Pacific Railway Station in the Town of White River has been classified as a National Historic Site (Parks Canada, 2013). In close proximity, Canadian Pacific Railway Superintendent's House is listed in the provincial historic site properties database (Ontario Heritage Trust, 2013).

Additional First Nation and/or Metis-related archaeological and/or sacred sites may exist within the White River area, notably along lake shores and water ways, given the length of time the region has been inhabited by First Nation and/or Métis peoples. The presence of locally protected areas and heritage sites would need to be further confirmed in discussion with the community and First Nation and Métis communities in the vicinity during subsequent evaluation stages, if the community is selected by the NWMO, and remains interested in continuing in the site selection process.

3. GEOLOGY

3.1 Regional Bedrock Geology

3.1.1 Geological Setting

The Canadian Shield forms the stable core of the North American continent and is dominated by the Superior Province comprising ca. 3.0 to 2.6 billion-year-old (Ga) bedrock. The Superior Province is a stable craton created from a collage of ancient plates and accreted juvenile arc terranes that were progressively amalgamated over a period of more than 2 billion years (Figure 3.1) (e.g., Percival *et al.*, 2006). The Superior Province covers an area of approximately 1,500,000 km^2 stretching from the Ungava region of northern Québec through the northern part of

Ontario and the eastern portion of Manitoba, and extending south to Minnesota and the northeastern part of South Dakota. It is divided into subprovinces: medium- to large-scale regions that are each characterized by their similar rock types, structural style, isotopic age, metamorphic grade and mineral deposits (Figure 3.1).

The White River area is within the Wawa Subprovince, which is a volcano-sedimentary-plutonic terrane bounded to the east by the Kapuskasing structural zone and to the north by the metasedimentary-dominated Quetico Subprovince (Figures 3.1 and 3.2). The Wawa Subprovince is composed of well-defined greenstone belts of metamorphosed volcanic rocks and associated metasedimentary rocks, separated by granitoid rock units (Figures 3.3 to 3.4). The granitoids that separate the greenstone belts comprise 20 to 30 percent of the landmass of the Wawa Subprovince, and consist of massive, foliated, and gneissic tonalite-granodiorite, which is cut by massive to foliated granodiorite and granite. The majority of the granitoids were emplaced during or after the deposition of the greenstone belts with which they are associated (Williams *et al.,* 1991).

The Quetico Subprovince, occurring to the north of the White River area (Figures 3.2 to 3.4), consists of migmatitic metasedimentary rocks (Zaleski *et al.,* 1995). Granitic intrusions are widely present while mafic to ultramafic intrusions occur sporadically (Williams, 1989; Sutcliffe, 1991).

In more recent years, a tectonic subdivision of the Superior Province into lithotectonic terranes and domains has been developed (Percival *et al*., 2006; Percival and Easton, 2007; Stott, 2010; Stott *et al*., 2010). Terranes are defined as regions with tectonic boundaries with distinct characteristics, whereas domains refer to lithologically distinct portions within a terrane (Stott, 2010; Stott *et al.,* 2010). The White River area is located in the Wawa-Abitibi terrane, a region composed of a series of plutonic and gneissic rocks interspersed with greenstone belts (Figure 3.2), which corresponds to the Wawa and Abitibi subprovinces. This terrane has a length of approximately 2,200 km, stretching westward from central Québec, across the width of Ontario and into northern Minnesota. Within Ontario, the terrane is juxtaposed to the north by the Quetico Basins terrane and to the south by overlying Paleoproterozoic basins (the rocks of the Southern Province dominantly comprising the Animikie foreland basin and the Huronian Supergroup (Ojakangas *et al.,* 2001).

Within the Wawa Subprovince there are two semi-linear zones of greenstone belts, the northern of which includes the Shebandowan, Schreiber-Hemlo, Manitouwadge-Hornepayne, Dayohessarah, and Kabinakagami greenstone belts. The southern zone comprises the Michipicoten, Mishibishu, and Gamitagama greenstone belts which are located west of the Kapuskasing structural zone, well southeast of the White River area (Figure 3.2) The Dayohessarah greenstone belt and the western portion of the Kabinakagami belt are within the White River area (Figure 3.3); a small portion of the Schreiber-Hemlo belt is located along the western boundary of the White River area, while the Michipicoten greenstone belt is situated approximately 25 km to the southeast (Figures 3.3 and 3.4). The Dayohessarah and Kabinakagami greenstone belts have been interpreted by Williams *et al.* (1991) and Stott (1999) as being part of a once continuous supracrustal belt now represented by the Manitouwadge-Hornepayne and the Black River assemblage of the Schreiber-Hemlo belts.

In the Wawa Subprovince, large granitoid bodies, commonly composed of tonalite to granodiorite, surround the greenstone belts and occur as intrusions within them. Such bodies in the White River area include the Black-Pic and Pukaskwa batholiths, the Strickland and Anahareo Lake (informal name) plutons, and the Danny Lake Stock (Figure 3.3). Several generations of Paleoproterozoic diabase dyke swarms, ranging in age from ca. 2.473 to 1.141 Ga, cut all bedrock units in the White River area (Krogh *et al*., 1987; Ernst and Buchan, 1993; Hamilton *et al*., 2002; Buchan and Ernst, 2004; Halls *et al*., 2006).

No large scale faults or shear zones have been recorded in the White River area, with the only nearby regional feature being the Wawa-Quetico Subprovince boundary, approximately 30 km to the north (Figure 3.3). Published bedrock geological maps of the region surrounding White River area (e.g., Santaguida, 2001; Johns and McIlraith

2003) indicate a number of mapped, but unnamed faults that range in length from a few kilometres to several tens of kilometres (Figure 3.3). The majority of the faults are highly linear with northeast or northwest trends that are coincident with the primary orientations of mapped dykes. In addition, a series of arcuate, semi-circular faults occur in an area centred approximately 23 km north of White River.

Faulting in the White River area occurred over a protracted period of time as it began during the formation of the greenstone belts and continued to be active until after the accretion of the Wawa and the Quetico subprovinces (i.e., ca. 2.7 to 2.68 Ga, Williams *et al.*, 1991; Corfu and Stott, 1996). It is possible that fault reactivation may have occurred during Proterozoic events such as development of the ca. 1.9 Ga Kapuskasing structural zone (e.g., Percival and West, 1994) or the ca. 1.1 Ga Midcontinent Rift event (Van Schmus, 1992). Additional fault movement may also have occurred as a result of Phanerozoic tectonism.

3.1.2 Geologic History

The initial development of the Wawa-Abitibi terrane took place during the period between ca. 2.89 and 2.77 Ga through progressive accretion of rock assemblages produced in several geological environments. A collage of intraoceanic fragments, including remnants of volcanic arcs, backarcs, and oceanic plateaus, assembled in a migrating subduction-accretion complex (Kerrich *et al.*, 1999; Kerrich *et al.*, 2008), ultimately forming an emerging land mass. Accretion was followed by calc-alkalic volcanism and emplacement of major batholithic complexes (Williams *et al.*, 1992; Corfu and Stott, 1998; Polat, 1998).

The development of the portion of the Wawa-Abitibi terrane that comprises the Dayohessarah and Kabinakagami greenstone belts began at ca. 2.770 Ga and continued to as late as ca. 2.678 Ga (Williams *et al*., 1991; Stott, 1999; Muir, 2003). These greenstone belts are considered to be remnants of broader volcanic and sedimentary domains, which are now highly deformed and metamorphosed to upper amphibolite facies and separated by synorogenic plutons. It is suggested that the belts may possibly be correlative with the Black River assemblage of the Schreiber-Hemlo greenstone belt and the Manitouwadge-Hornepayne greenstone belt, and as such they would represent dismembered parts of a once continuous greenstone terrane (e.g., Stott, 1999). Stott (1999) noted that the tectonostratigraphy of the Dayohessarah belt bears similarities to the Hemlo greenstone belt, south of the Dotted Lake batholith, suggesting that a correlation can be made with the northeastern Hemlo strata dated at <2.697 Ga by Jackson *et al.* (1998).

The volcanic activity that occurred in the White River area, and which extended to Wawa and Hornepayne, was accompanied by intense plutonic activity, as attested by the emplacement of the Pukaskwa and Black-Pic gneissic complexes at around ca. 2.719 and 2.72 Ga (e.g., Turek *et al*., 1982; 1984; Corfu and Muir, 1989; Jackson *et al.*, 1998; Davis, 2003; Beakhouse *et al.*, 2011). These major batholiths reflect a long and perhaps complex history of intrusion and subsequent deformation in the White River area and its regional surroundings (e.g., Lin and Beakhouse, 2013).

In the White River area the timing of the emplacement of late-stage granite-granodiorite intrusions, of which there are several, is not well constrained, with only the Dotted Lake batholith having been dated at ca. 2.697 Ga (Jackson *et al*. (1998). Regional studies suggest that most of these granitic bodies may have been intruded between ca. 2.697 and 2.678 Ga (Corfu and Muir, 1989). In the White River area the youngest intrusions are the Tedder granite and the unmetamorphosed, late tectonic Danny Lake stock, which are positioned immediately south and west of the Dayohessarah belt, respectively.

The geological history of the White River area during the Proterozoic Eon (i.e., after 2.5 Ga) is enigmatic. At the beginning of the Proterozoic Eon, an Archean supercontinent (Williams *et al*., 1991) began fragmentation into several continental masses, including the Superior craton, caused by a widespread and voluminous magmatic event that took place in the Lake Superior region (Heaman, 1997). The rift setting ultimately evolved into a passive margin setting, allowing development of intracratonic basins in many areas across the Lake Superior region, including deposition of the Huronian Supergroup between ca. 2.497 Ga and ca. 2.22-2.10 Ga (Corfu and Andrews, 1986; Rainbird *et al*., 2006) along the north shore of Lake Huron. While it is likely that Huronian strata once covered a much larger area than their present distribution there is no direct evidence to indicate the former existence of Huronian rocks in the White River area. However, the occurrence of tillites in the Huronian package elsewhere in Ontario points to the occurrence of several glaciations periods (Young *et al.,* 2001), which may suggest that at least one period of glaciation could have affected the White River area. If this were the case, any deposits related to this glacial event have been removed by subsequent erosion.

The most prominent indicators of Proterozoic tectonic activity in the White River area are the well-defined swarms of diabase dykes that have intruded the White River area. These include the northwest-trending Matachewan swarm, emplaced ca. 2.473 Ga (Buchan and Ernst, 2004); the Biscotasing swarm, dated at ca. 2.167 Ga (Hamilton *et al.*, 2002), which trends northeast through the area; the north-trending Marathon dykes, dated ca. 2.121 Ga (Buchan *et al*., 1996; Hamilton *et al*., 2002); the Sudbury swarm dated at ca. 1.238 Ga (Krogh *et al.*, 1987); and the infrequently occurring northeast-trending Abitibi swarm dated at ca. 1.14 Ga (Ernst and Buchan, 1993). In addition, there are several mapped north-northeast-trending mafic dykes that occur along the northern boundary of the White River area that have not been associated with any specific swarm.

During the middle Paleoproterozoic Era, two more major tectonic events occurred south of the White River area, in the Lake Superior-Lake Huron area: the ca. 1.89 to 1.84 Ga (Sims *et al.*, 1989) Penokean Orogeny and the younger ca. 1.75 Ga Yavapai Orogeny (Piercey, 2006). Though there is no evidence of these two orogenies on rocks of the White River area, the development of the ca. 1.9 Ga Kapuskasing structural zone may have left a tectonic imprint in the form of a regional deflection in the trend of northwest-trending Matachewan dykes across the White River area (Figure 3.3),

Around ca. 1.1 billion years ago, a continental-scale rifting event in the Lake Superior area, to the southwest of the White River area, produced the Midcontinent Rift structure (Van Schmus, 1992) that extends southward via an eastern branch down through Minnesota, and via a western branch from Sault Ste. Marie to central Michigan. The rifting event included deposition of large volumes of volcanic rocks and voluminous emplacement of mafic intrusions (Heaman *et al.,* 2007). In spite of the proximity of the White River area to the Midcontinent Rift structure, no related tectonic activity has yet been documented to have occurred in the White River area.

At the start of the Paleozoic Era (ca. 540 Ma), a large portion of Ontario was covered by seas in which carbonate and clastic sedimentary units were deposited. Whilst it can be inferred that Cambrian to Devonian sedimentary rocks once covered large portions of the Canadian Shield between Hudson Bay and Lake Ontario (Johnson *et al.*, 1992), there is no direct evidence that they were present in the White River area. It is also possible that the primary control on deposition of these rocks might be largely epeirogenic (e.g., infilling of the Michigan Basin to the south and that of the Moose River Basin to the northeast).

Erosion is believed to have been the dominant geological process affecting the White River area from the late Paleozoic Era until at least the late Mesozoic (Johnson *et al.*, 1992). Sedimentary deposits resulting from this erosional event have not been documented in the White River area. Marine and terrestrial deposits of Cretaceous age are found in the Moose River Basin, James Bay Lowland area, ~230 km to the northeast of White River; rocks of similar age have not been documented in the White River area.

Erosion is also thought to have been the dominant process affecting the White River area during the Paleocene and Neogene Periods (ca. 66 to 2.6 Ma; Johnson *et al.*, 1992), but no sedimentary deposits of this age have been recorded in the White River Area. During the Quaternary Period (2.6 Ma to present), large parts of North America were covered by continental ice sheets. In the White River area, glacial and interglacial deposits, associated with the most recent ice advance during the Late Wisconsinan glaciations (ca. 30 to 10 Ka), have been recorded.

Table 3.1 outlines the major events in the geological history of the White River area.

Table 3.1: Summary of the Geological and Structural History of the White River Area

Approximate Time period (years before present)	Geological Event
2.89 to 2.77Ga	Progressive growth and early evolution of the Wawa-Abitibi terrane by collision, and ultimately accretion, of distinct geologic terranes.
2.770 – 2.673 Ga	- ca. 2.720 Ga: Onset of volcanism and subordinate sedimentation associated with the formation of the Dayohessarah and Kabinakagami greenstone belts. - ca. 2.720 Ga: Emplacement of oldest recognized phase of Black-Pic batholith. - ca. 2720-2.703 Ga: Emplacement of oldest lithologic association of Pukaskwa batholith. - ca. 2703-2.686 Ga: Emplacement of second lithologic association of Pukaskwa batholith. - ca. 2.697 Ga: Intrusion Dotted Lake pluton, and possibly of Strickland pluton. - ca. 2.689 Ga: Emplacement of younger recognized phase of Black-Pic batholith. - ca. 2.677 Ga: Emplacement of Bremner pluton. - ca. 2.719 to 2.677 Ga: Four periods of ductile-brittle deformation (D_1-D_4). - D_1: ca. 2.719 – 2.691 Ga - D_2: ca. 2.691 – 2.683 Ga → Main phase of coalescence of the Wawa and Quetico subprovinces (Corfu and Stott, 1996) - D_3: ca. 2.682 – 2.679 Ga → sinistral transpressive deformation, structural domal uplift of Pukaskwa Batholith - D_4: ca. 2.679 – 2.673 Ga - ca.2.688 to 2.675: Regional metamorphism (Muir, 2003)
2.675 and 2.669 Ga	Peak metamorphism of regional greenstone belts.
2.667 Ga	Youngest lithologic association of Pukaskwa Batholith.
2.5 to 2.1 Ga	- ca. 2.5 Ga: Supercontinent fragmentation and rifting in Lake Superior area. Development of Southern Province. - ca. 2.473 Ga: Emplacement of the Matachewan dyke swarm. - ca. 2.167 Ga: Emplacement of Biscotasing dyke swarm. - ca. 2.121 Ga: Emplacement of the Marathon dyke swarm.
1.9 to 1.7 Ga	Penokean Orogeny in Lake Superior and Lake Huron areas; possible deposition and subsequent erosion in the White River area.

Table 3.1: Summary of the Geological and Structural History of the White River Area

1.238 Ga	- ca. 1.238 Ga emplacement of the Sudbury dyke swarm.
1.150 to 1.090 Ga	Rifting and formation of the Midcontinent Rift. - ca. 1.14 Ga: Emplacement of the Abitibi dyke swarm.
540 to 355 Ma	Possible coverage of the area by marine seas and deposition of carbonate and clastic rocks subsequently removed by erosion.
145 to 66 Ma	Possible deposition of marine and terrestrial sediments of Cretaceous age, subsequently removed by erosion.
2.6 to 0.01 Ma	Periods of glaciation and deposition of glacial sediments.

3.1.3 Regional Structural History

Information on the structural history of the White River area is based predominantly on insights derived from structural investigations of the Manitouwadge and Dayohessarah greenstone belts (Polat, 1998; Zaleski *et al.*, 1994; Peterson and Zaleski, 1999) and the Hemlo gold deposit and surrounding region (Muir, 2003). Additional studies by Lin (2001), Percival *et al*. (2006), Williams and Breaks (1996) and Lin and Beakhouse (2013) have also contributed to the structural understanding of the White River area. These studies were performed at various scales and from various perspectives. Consequently, the following summary of the structural history of the White River area should be considered as a “best-fit” model that incorporates relevant findings from all studies.

Few detailed investigations of the structural history of the White River area have been completed; however, the structural history of the Manitouwadge and nearby Schreiber-Hemlo greenstone belts are generally well characterized and suggests up to of six phases of deformation (Polat, 1998; Peterson and Zaleski, 1999; Lin, 2001; Muir, 2003). Polat *et al*. (1998) interpreted that the Schreiber-Hemlo and surrounding greenstone belts represent collages of oceanic plateaus, oceanic arcs, and subduction-accretion complexes amalgamated through subsequent episodes of compressional and transpressional collision. On the basis of overprinting relationships between different structures Polat *et al*. (1998) suggested that the Schreiber-Hemlo greenstone belt underwent at least two main episodes of deformation. This can be correlated with observations from Peterson and Zaleski (1999) and Muir (2003), who reported at least five and six generations of structural elements, respectively. Two of these generations of structures account for most of the ductile strain and, although others can be distinguished on the basis of crosscutting relationships, they are likely the products of progressive strain events. Integration of the structural histories detailed in Williams and Breaks (1996), Polat (1998), Peterson and Zaleski (1999), Lin (2001), and Muir (2003) suggests that six deformation events occurred within the White River area. The first four deformation events (D_1-D_4) were associated with brittle-ductile deformation and were typically associated with deformation of the greenstone belts. D_5 and D_6 were associated with a combination of brittle deformation, and fault propagation through all rock units in the White River area. The main characteristics of each deformation event are summarized below.

The earliest recognizable deformation phase (D_1) is associated with rarely preserved small-scale isoclinal folds, ductile faults that truncate stratigraphy and a general lack of penetrative foliation development. Peterson and Zaleski (1999) reported that planar D_1 fabrics are only preserved locally in outcrop and in thin section. Locally in the White River region, D_1 deformation may have produced a strain aureole within the margins of the Pukaskwa batholith and surrounding country rocks which formed a local S_1 fabric. D_1 deformation is poorly constrained to between ca. 2.719 and ca. 2.691 Ga (Muir, 2003).

D_2 structural elements include prevalent open to isoclinal F_2 folds, an axial planar S_2 foliation and mineral elongation L_2 lineations (Peterson and Zaleski, 1999). Muir (2003) interpreted D_2 to have resulted from progressive north-northeast- to northeast-directed compression that was coincident with the intrusion of various plutons, including phases of the Pukaskwa batholith. The S_2 foliation is the dominant meso- to macro-scale regional fabric evident across the White River area. Ductile flow of volcano-sedimentary rocks between more competent batholiths (e.g., Pukaskwa) may also have occurred during this deformation phase (e.g., Lin and Beakhouse, 2013). D_2 deformation is constrained to between ca. 2.691 and ca. 2.683 Ga (Muir, 2003).

D_3 deformation comprised northwest-southeast shortening as a result of on-going regional-scale dextral transpression and produced macroscale F_3 folds, and local shear fabrics that exhibit a dextral shear sense and overprint of D_2 structures (Peterson and Zaleski, 1999; Muir, 2003). D_3 deformation did not develop an extensive penetrative axial planar and (or) crenulation cleavage. D_3 deformation is constrained to between ca. 2.682 and ca. 2.679 Ga (Muir, 2003).

D_4 structural elements include isolated northeast-plunging F_4 kink folds with a Z-asymmetry and a moderate, northeast plunge, and associated small-scale fractures and faults overprinting D_3 structures. D_3-D_4 interference relationships are best developed north of the White River area in the Manitouwadge greenstone belt and in rocks of the Quetico Subprovince. D_4 deformation is roughly constrained to between ca. 2.679 and ca. 2.673 Ga (Muir, 2003).

Details of structural features associated with the D_5 and D_6 deformation events are limited in the literature; however, where described, they manifest as brittle and brittle-ductile faults of various scales and orientations (Lin, 2001; Muir, 2003). Within the Hemlo greenstone belt, Muir (2003) suggested that local D_5 and D_6 faults offset the Marathon, and Biscotasing dyke swarms (all ca. 2.2 Ga), and as such suggested that in the Hemlo region, D_5 and D_6 faults propagated after ca. 2.2 Ga. However, since there are no absolute age constraints on specific events, the entire D_5-D_6 interval of brittle deformation can only be constrained to a post-2.673 Ga timeframe that may include many periods of re-activation attributable to any of several post-Archean tectonic events, as described above and summarized in Table 3.1.

3.1.4 Mapped Regional Structure

In the White River area, a limited number of unnamed faults are indicated on public domain geological maps (Fenwick, 1966; Siragusa, 1977; 1978; Stott, 1995a; 1995b; 1995c; OGS, 2011); the largest of these parallels the axis of Esnagi Lake in the east-central part of the White River area (Siragusa, 1978; Figure 3.4). Mapped faults generally have either a northwest- or northeast-trending orientation, although a grouping of semi-circular faults is present west of Dayohessarah Lake (OGS, 2011). The origin and geologic description of these semi-circular features is largely unknown.

Stott (1999) found that fault displacements in the Dayohessarah greenstone belt were not significant but noted that additional faults (i.e., unmapped) may exist along the narrow, northeast-trending bay of Strickland Lake and along a northwest-trending lineament through Strickland Lake (Stott, 1995b); however, no lateral offsets along these features could be confirmed. In the Kabinakagami greenstone belt, Siragusa (1977) reported that it is likely that northeast-trending strike-slip fault with horizontal displacement of 240 m is present in a narrow valley, to the north of the inlet of Kabinakagami River.

Fenwick (1967) and Siragusa (1977) noted that lineaments parallel the trend of two sets of diabase dykes, which strike either northeast or northwest, and assumed that the lineaments formed from the weathering of diabase dykes or from vertical joints. It is also noteworthy that there is a clear southerly deflection in the northwesterly trend of Matachewan dykes, across a mapped northeast-trending fault, in the southeastern corner of the White River area (Figure 3.4). This may be related to a regional scale pattern of crustal deformation and faulting associated with the development of the Kapuskasing structural zone.

3.1.5 Metamorphism

Studies on metamorphism in Precambrian rocks across the Canadian Shield have been summarized in a few publications since the 1970s (e.g., Fraser and Heywood,1978; Kraus and Menard, 1997; Menard and Gordon, 1997; Berman *et al.*, 2000; Easton, 2000a; 2000b; and Berman *et al*., 2005) and the thermochronological record for large parts of the Canadian Shield is documented in a number of studies (Berman *et al*., 2005; Bleeker and Hall, 2007; Corrigan *et al*., 2007; and Pease *et al*., 2008).

The Superior Province of the Canadian Shield largely preserves low pressure – high temperature Neoarchean (ca. 2.710-2.640 Ga) metamorphic rocks. The relative timing and grade of regional metamorphism in the Superior Province corresponds to the lithological composition of the subprovinces (Easton, 2000a; Percival *et al*., 2006). Subprovinces comprising volcano-sedimentary assemblages and synvolcanic to syntectonic plutons (i.e., granite-greenstone terranes) are affected by relatively early lower greenschist to amphibolite facies metamorphism. Subprovinces comprising both metasedimentary- and migmatite-dominated lithologies, such as the English River and Quetico, and dominantly plutonic and orthogneissic domains, such as the Winnipeg River, are affected by relatively late middle amphibolite to granulite facies metamorphism (Breaks and Bond, 1993; Corfu *et al*., 1995). Subgreenschist facies metamorphism in the Superior Province is restricted to limited areas, notably within the central Abitibi greenstone belt (e.g., Jolly, 1978; Powell *et al*., 1993). Most late orogenic shear zones in the Superior Province and Trans-Hudson Orogen experienced lower to middle greenschist retrograde metamorphism. Post-metamorphic events along faults in the Abitibi greenstone belt show a drawn-out record through Ar/Ar dating to ca. 2.500 Ga the value of which remains unclear (Powell *et al.,* 1995).

A widespread Paleoproterozoic tectonothermal event, the Trans-Hudson Orogeny, involved volcanism, sedimentation, plutonism and deformation that affected the Churchill Province through northernmost Ontario, western Manitoba, northern Saskatchewan and Nunavut (e.g., Skulski *et al.*, 2002; Berman *et al.,* 2005). This event was associated with ca. 1.84 to 1.8 Ga collisional convergence of the Archean Hearne domain and Superior Province (Kraus and Menard, 1997; Menard and Gordon, 1997; Corrigan *et al*., 2007). Associated metamorphism at moderate to high temperatures and low to moderate pressures resulted in amphibolite facies metamorphism that overprinted Archean metamorphic signatures in Archean rocks of the Churchill Province, and a complex brittle overprint in Archean rocks of the Superior Province (e.g., Kamineni *et al*., 1990)

Along the eastern flank of the Canadian Shield, the Grenville Province records a complex history of episodic deformation and subgreenschist to amphibolite and granulite facies metamorphism, from ca. 1.300 Ga to 950 Ma (Easton, 2000b; Tollo *et al*., 2004 and references therein). Lower greenschist metamorphism was documented along faults in the vicinity of Lake Nipigon and Lake Superior and is inferred to be the result of ca. 1 Ga far-field reactivation during the Grenville Orogeny (Manson and Halls, 1994).

In northwestern Ontario, the concurrent post-Archean effects, including the Trans-Hudson Orogen, are limited to poorly documented reactivation along faulted Archean terrane boundaries (e.g., Kamineni *et al*., 1990 and references therein). Most late orogenic shear zones in the Superior Province and Trans-Hudson Orogen experienced lower to middle greenschist retrograde metamorphism (e.g., Kamineni *et al*., 1990 and references therein).

Overall, most of the Canadian Shield preserves a complex episodic history of Neoarchean metamorphism overprinted by Paleoproterozoic tectonothermal events culminating at the end of the Grenville orogeny ca. 950 Ma. The distribution of contrasting metamorphic domains in the Canadian Shield is a consequence of relative uplift, block rotation and erosion resulting from Neoarchean orogenesis, subsequent local Proterozoic orogenic events and broader epeirogeny during later Proterozoic and Phanerozoic eons.

All Precambrian rocks of the White River area display some degree of metamorphism. The Dayohessarah greenstone belt is typically characterized by amphibolite facies metamorphism (Stott, 1999). This amphibolite facies metamorphic grade may be a manifestation of an amphibolite grade contact metamorphic aureole bordering the Strickland pluton (Stott, 1999). Little information regarding the metamorphic grade of the exposed rocks of the Kabinakagami greenstone belt is available in the reviewed literature. Based on ages obtained from metamorphic monazites, Zaleski *et al.* (1995; 1999) suggested that near-peak metamorphism of the Manitouwadge-Hornepayne greenstone belt occurred between 2.675 and 2.669 Ga. It can be inferred that the Dayohessarah and Kabinakagami belts may have been subjected to metamorphism during this period, as the age constraints given by Zaleski (1995; 1999) correspond well with the ca. 2.675 ±1 and 2.661 ±1 Ga periods of regional metamorphism recognized by Schandl *et al.* (1991) and Davies *et al.* (1994).

Typical metamorphic grades in plutonic rocks within the White River area are variable from non-metamorphosed to amphibolite grade in metamorphic contact aureoles. No records exist that suggest that rocks in the White River area may have been affected by thermotectonic overprints related to post-Archean events.

3.1.6 Erosion

There is no specific information on erosion rates for the White River area. Past studies reported by Hallet (2011) provide general information on erosion rates for the Canadian Shield. The average erosion rate from wind and water on the Canadian Shield is reported to be a few metres per 100,000 years. Higher erosion rates are associated with glaciation. The depth of glacial erosion depends on several regionally specific factors, such as the ice-sheet geometry, topography, and history (occupation time and basal conditions: temperature, stress, and amount of motion), as well as local geological conditions, such as overburden thickness, rock type and pre-existing weathering.

Flint (1947) made one of the first efforts to map and determine the volume of terrestrial glacial sediment in North America, on the basis of which he inferred that the Plio-Pleistocene advances of the Laurentide ice-sheet had accomplished only a few tens of feet of erosion of the Canadian Shield. White (1972) pointed out that Flint's (1947) study ignored the much larger quantity of sediment deposited in the oceans, and revised the estimate upward by an order of magnitude. Subsequently, Laine (1980; 1982) and Bell and Laine (1985) used North Atlantic deposits and all marine sediment repositories of the Laurentide ice-sheet (excluding the Cordilleran Ice Sheet), respectively, to calculate a minimum value for erosion of 120 m averaged over the ice-sheet over 3 million years. Hay *et al.* (1989) contended that the depth of sediment of Laurentide provenance in the Gulf of Mexico was greatly overestimated by Bell and Laine (1985) and reduced the estimate of regional erosion to 80 m over the same period.

3.2 Local Bedrock and Quaternary Geology

3.2.1 Bedrock Geology

The main geological units in the White River area include the Black-Pic and Pukaskwa batholiths, several granitoid intrusions (e.g., Strickland, Anahareo Lake plutons), the supracrustal rocks of the Dayohessarah and Kabinakagami greenstone belts, and several suites or swarms of mafic diabase dykes (Figures 3.3 and 3.4). Each of these sets of rock units is discussed in more detail below. The reduced to pole residual magnetic field and its first vertical derivative over the White River area are shown in Figures 3.5 and 3.6, respectively, and regional Bouguer gravity data are shown on Figure 3.7. A detailed interpretation of geophysical data was carried out as part of this preliminary assessment (PGW, 2014) and is also summarized in this section.

3.2.1.1 Granitoid Intrusive Rocks

Black-Pic Batholith

The Black-Pic batholith is a large, regionally-extensive intrusion that encompasses a roughly 3,000 km^2 area within the Wawa Subprovince (Figure 3.3). The batholith underlies the northwest portion of the White River area (Figure 3.4). It is bounded to the south by the Pukaskwa batholith and the Danny Lake stock, and to the east by the Dayohessarah greenstone belt.

The Black-Pic batholith comprises a multi-phase suite that includes hornblende-biotite, monzodiorite, foliated tonalite, and pegmatitic granite with subordinate foliated diorite, granodiorite, granites and crosscutting aplitic to pegmatitic dykes (Williams and Breaks, 1989; Zaleski and Peterson, 1993). In the White River area the batholith is described as a gneissic tonalite in a compilation map of Santaguida (2001); however, Fenwick (1967), similarly to Milne (1968), mapped the batholith as uniform, biotite granitic gneiss and biotite granite which becomes gneissic near the boundary with the Dayohessarah greenstone belt (noting that terminology used was before Streckeisen's (1976) standard classification). Fenwick (1967) also noted the occurrence of migmatites (noting that terminology used was prior to either Mehnert's (1968) or Sawyer's (2008) classifications) composed of highly altered remnants of pre-existing volcanic and sedimentary rocks mixed with variable amounts of granitic material. The migmatites occur either as a breccia type, in which fragments of the older rocks are cemented by dykes; or veins of granitic rock or a banded type, in which layers of the older material alternate with layers of granitic material.

Several generations of intrusions are present within the batholith, yielding geochronological ages ranging from ca. 2.720 Ga (Jackson *et al.,* 1998) for the earliest recognized phase to ca. 2.689 Ga for a late-stage recognized monzodioritic phase located in the Manitouwadge area, about 70 km northwest of the White River area (Zaleski *et al.*, 1999). In addition, there are also younger granitic phases within the Black-Pic batholith in the Manitouwadge area which, despite a lack of geochronological information, are thought to be part of the regional suite of ca. 2.660 Ga, post-tectonic "Algoman granites" (Zaleski *et al*., 1999). Within the batholith, intrusive relationships are typically destroyed, and only metamorphic textures and associated mineral assemblages are preserved. Inclusions of relatively melanocratic members of the suite occur as foliated inclusions within later, leucocratic members (Williams and Breaks, 1989; 1996).

The Black-Pic batholith is interpreted as containing regional scale domal structures with slightly dipping foliations radiating outward from its centre (Williams and Breaks, 1989; Lin and Beakhouse, 2013). At least one such smaller-scale structure potentially exists in the White River area immediately north of the Danny Lake stock where semi-circular faults outline the position of a possible dome several kilometres in width (Figure 3.4).

Structurally deeper levels of the tonalite suite in the Black-Pic batholith are strongly foliated with a sub-horizontal planar fabric that exhibits a poorly developed, north-trending rodding and mineral-elongation lineation (Williams and Breaks, 1989). Upper structural levels of the tonalite suite are cut by abundant granitic sheets of pegmatite and aplite, and are more massive (Williams and Breaks, 1989; Zaleski and Peterson, 1993). Just to the north of the White River area are zones of migmatized volcanic rocks, and zones of massive granodiorite to granite embodied in the Black-Pic batholith. The contact between these rocks and the tonalitic rocks of the Black-Pic batholith is relatively gradational with extensive sheeting of the tonalitic phase (Williams and Breaks, 1989; Williams *et al*., 1991).

Fairly uniform and weaker background magnetic responses responses tend to be predominant throughout most of the Black-Pic batholith in the White River area and may be attributed to a lack of dyke response present in these areas, as well as a decrease in magnetic minerals of the bedrock lithology (PGW, 2014; Figures 3.5 and 3.6). An elevated magnetic response north of Danny Lake stock and west of the Dayohessarah greenstone belt, matches a similar magnetic response to that over the Strickland pluton to the east on the opposite side of the Dayohessarah greenstone belt (PGW, 2014). The higher magnetic responses may reflect an abundance of magnetic minerals of the bedrock lithology, as well as an increased presence of diabase dykes. In general, much of the variability in magnetic responses shown within the Black-Pic batholith presumably corresponds to numerous generations of intrusions as well as younger granitic rock phases identified within the batholith (Jackson *et al*., 1998; Zaleski *et al*., 1999).

The eastern boundary of the Black-Pic batholith tends to be clearly bounded by the Dayohessarah greenstone belt, in which the edge of the greenstone belt units correspond to a weak response in the reduced to pole magnetic data, as well as low variability in the vertical derivatives (PGW, 2014; Figures 3.5 and 3.6). Locally, highly altered remnants of greenstone belt units are variability mixed within the Black-Pic batholith (Fenwick, 1967), which tend to show elongated higher magnitude responses. These responses in the magnetic data are broadly coincident with thin greenstone units shown on the bedrock geology map (PGW, 2014; Figure 3.4).

The gravity response over the Black-Pic batholith is relatively flat with moderate amplitude, in contrast to the high associated with the Dayohessarah greenstone belts and the lows over the Strickland pluton, Anahareo Lake pluton and parts of the Pukaskwa batholith (PGW, 2014; Figure 3.7). This suggests that the Black-Pic batholith may be composed of denser rock or may reflect a thinner intrusive unit compared to others in the White River area (PGW, 2014). Additionally, the Black-Pic batholith generally shows low radioelement responses, at least partly due to lower elevation, resulting in more wetlands and drainage. The minimal FDEM coverage over the batholith shows it to be of uniformly low conductivity, with local higher conductivities associated with water bodies, drainage features and overburden units (PGW, 2014).

Pukaskwa Batholith

The Pukaskwa batholith (also referred to as the Pukaskwa gneissic complex) is a large, regionally-extensive intrusion covering an area of at least 5,000 km^2 in the Wawa subprovince (Figure 3.3). Mapping of the intrusion in the White River area was completed at a reconnaissance scale resulting in crudely defined boundaries of the batholith (Milne *et al.,* 1972; Santaguida, 2001). As mapped by Santaguida (2001), the batholith is bounded to the north by the Strickland pluton, the Danny Lake stock and the Black-Pic batholith. The contact with the Black-Pic batholith is located along a line extending from the west end of the Danny Lake stock running northwest to White Lake. The Pukaskwa batholith surrounds the western extent of the Anahareo Lake pluton and west-trending septa of the Dayohessarah greenstone belt.

The Pukaskwa batholith extends over a large portion of the south-central portion of the White River area (Figure 3.4) and is described in the compilation map as comprising foliated tonalite and gneissic tonalite suites (Santaguida, 2001). Regionally, the Pukaskwa batholith is a multi-phased intrusion emplaced over an extended period of time (Stott, 1999; Beakhouse and Lin, 2006; Beakhouse *et al.,* 2011).

Knowledge of the Pukaskwa batholith is primarily obtained from regional studies conducted to the west, in the vicinity of the Hemlo greenstone belt. An investigation of the batholith by Beakhouse *et al.* (2011) identified a number of lithologic associations (rock groupings) based on petrological and geochemical characteristics, three of which were volumetrically significant.

The oldest association and most abundant of the three are a group of gneissic, well-foliated tonalite to granodioritic rocks. The gneissic nature of these rocks is a composite fabric formed by flattening or transposition of heterogeneities, metamorphic segregation or partial melting, and emplacement of sheet-like intrusive phases controlled by pre-existing anisotropy (Beakhouse *et al.*, 2011). This lithologic association is interpreted to represent rocks derived from melting of a mafic crust and emplaced during the period ca. 2.720 to 2.703 Ga (Corfu and Muir, 1989; Jackson *et al.,* 1998; Stott, 1999; Beakhouse *et al.*, 2011; Lin and Beakhouse, 2013). It is likely that the foliated tonalite and gneissic tonalite suites as described by Santaguida (2001) in the White River area are part of this rock group.

The Pukaskwa batholith's second lithologic association, emplaced in the period between ca. 2.703 and 2.686 Ga, consists of foliated granodiorite to quartz-monzodiorite that is widespread but volumetrically limited (Beakhouse *et al.*, 2011). Corfu and Muir (1989) reported a weakly foliated granodiorite from the Pukaskwa batholith having an inferred magmatic crystallization age of ca. 2.688 Ga. Geochemical analysis indicates that the rocks of the lithological association were derived from, or due to some sort of interaction with, an ultramafic source. These rocks cut the older lithologic association described above and have a weakly to moderate foliation which is generally sub-parallel to parallel to pre-existing rock units. The geometrical, age, and field relationships are interpreted as indicative of a syn-tectonic emplacement of the second lithologic association of the Pukaskwa batholith (Beakhouse *et al.*, 2011). Following the emplacement of the syn-tectonic phases, the Pukaskwa batholith was uplifted at approximately ca. 2.680 Ga as a structural regional dome relative to flanking greenstone belts synchronously with ongoing regional sinistral transpressive deformation (Beakhouse *et al.*, 2011; Lin and Beakhouse, 2013).

The youngest lithologic association comprises a group of granodioritic to granitic units that form large, homogeneous plutons and small dykes; the geochemical signature of the rocks suggests that they are derived from melting of older intermediate to felsic crust (Beakhouse *et al.*, 2011). The rocks are dated at ca. 2.667 Ga and, therefore, are interpreted as late to post-tectonic intrusions (Davis and Lin, 2003; Beakhouse *et al.*, 2011).

As a result of mapping in the Hemlo area to the west, Jackson *et al.* (1998) and Muir (2000) have identified an intrusion termed the Bremner pluton and indicated that it may extend into the White River area south of where Highway 17 crosses the western boundary of the White River area. Muir's mapping (Muir, 2000) does not delineate an eastern boundary of the pluton and, although Jackson *et al.* (1998) do outline the pluton, they note that the geometry of the intrusion should be regarded as preliminary. As the boundary of the pluton is uncertain and it is likely to extend only a limited distance into the White River area, it is not depicted on Figure 3.4 (i.e., the area is shown as being within the Pukaskwa batholith). Muir (2000) described the pluton near the boundary of the White River area as consisting of biotite-hornblende tonalite and biotite-hornblende granodiorite. Jackson *et al.* (1998) dated the Bremner pluton at ca. 2.677 Ga.

A fairly uniform and weak background magnetic response exists within the northern Puskawa batholith that is indistinguishable from the response over the southern Black-Pic batholith (PGW, 2014; Figure 3.5). Within the Pukaskwa batholith, this response correlates fairly well with the mapped foliated tonalite suite. A distinct magnetic response does not exist over most of the Danny Lake stock and the nearby Tedder granite pegmatite intrusion located northeast of White River (Stott, 1999).

To the east, a large area of fairly uniform and low background magnetic response is associated with the gneissic tonalite suite that extends east and northeast of White River within the Pukaskwa batholith (PGW, 2014: Figure 3.5). A band of east-west striking metasediments (south of Round Lake) are also part of this geophysical unit, which shows a generally flat response and low amplitude (Figure 3.4). These metasediments are reflected by a slightly lower magnetic response with a strike that cuts the northwest-oriented magnetic responses associated with the dykes. The contacts between the geophysical units in the eastern Pukaskwa batholith do not correspond particularly well with the boundaries of the mapped geological units (PGW, 2014). This discrepancy may partially result from the crudely defined boundaries of the batholith that have been mapped at a reconnaissance scale (Milne *et al*., 1972; Santaguida, 2001). The slightly higher magnetic responses within the Pukaskwa batholith at the southern edge of the White River area may reflect a subtle increase in background magnetic response reflecting the increased presence of magnetic minerals of the bedrock lithology, as well as locally an increased response from the diabase dykes present. The distribution of geophysical units throughout the Pukaskwa batholith may broadly reflect the distribution of multi-phased intrusions that comprise the entire batholith body (Stott, 1999; Beakhouse and Lin, 2006; Beakhouse *et al*., 2011).

Along the northern part of the Pukaskwa batholith, a relatively strong magnetic response extends over the mapped boundary into the Black-Pic batholith (PGW, 2014; Figure 3.5). This response is associated with both the high and low resolution geophysical data. This unit is much more magnetic than the remainder of either the Pukaskwa or Black-Pic batholith. This may reflect variations in the degree of metamorphism preserved in the bedrock, or changes in lithology (PGW, 2014).

A discrete gravity low occurs over a significant portion of the Pukaskwa batholith (PGW, 2014; Figure 3.7). This gravity response may reflect a thicker portion of the batholith. In places, due to the limited distribution of gravity stations, this gravity low also extends well into the Anahareo Lake pluton.

The radiometric responses are relatively high in all three radioelements over the Pukaskwa batholith, which tends to partially correspond to higher elevation resulting in more exposed bedrock. Although the data is of low resolution, the radiometric responses are broadly coincident with the mapped portion of the Pukaskwa batholith. The FDEM coverage in the Pukaskwa batholith is extremely limited and indicates a fairly uniform low conductivity response, whereas the local high conductivity responses are generally associated with overburden deposits and drainage features (PGW, 2014).

Strickland Pluton

The Strickland pluton occurs in the northeast portion of the White River area bordering the Dayohessarah and Kabinakagami greenstone belts. The pluton occupies an area of approximately 600 km^2 and has maximum dimensions in the area of 34 km north-south and 55 km east-west (Figure 3.4). Stott (1999) described the Strickland pluton as a relatively homogeneous, quartz porphyritic granodiorite, although near the outer margin of the pluton, adjacent to the greenstone belt, granodiorite to tonalite and diorite are present. In the area west of the Kabinakagami greenstone belt, Siragusa (1977) noted that massive quartz monzonite (i.e., monzogranite in modern terminology) intrudes the granodioritic and trondhjemitic rocks in the form of medium-grained to pegmatitic dykes and small sills and irregular bodies.

Some degree of post-emplacement deformation and metamorphism of the Strickland pluton is indicated by the observed presence of fine- to medium-grained titanite and the widespread presence of hematite-filled fractures and weak alteration of silicate minerals (Stott, 1999). Stott (1999) noted that the pluton is petrographically similar to the ca. 2.697 Ga Dotted Lake batholith located in the northwestern corner of the White River area and suggested that these plutons are members of an intrusive suite commonly found along the margins of greenstone belts in this part of the Wawa Subprovince.

The Dayohessarah greenstone belt is located to the west of the Strickland Pluton and the Kabinakagami greenstone belt is to the southeast. These greenstone units tend to show a well defined magnetic response that allows these geological contacts as well as the adjacent Strickland pluton contacts to be interpreted without great difficulty (PGW, 2014). The Strickland pluton is dominated by a moderate to strong magnetic response, where individual units are predominantly characterized by variations in magnetic intensity, as well as variations in limited foliation and dyke intensity (PGW, 2014; Figure 3.5). The major portion of the mapped Strickland pluton shows a high background magnetic intensity and the magnetic field decreases gradationally to the southwest which reflects, at least partially, a reduced number of northwest-striking dykes. The southern portion of the pluton shows the lowest magnetic intensity which tends to represent a gradational change from the central portion of the pluton into the gneissic tonalite of the Pukaskwa batholith to the south. The higher magnetic response, present in the area of high resolution geophysical survey in the northeast extent of the White River area, may indicate that it incorporates slivers of metavolcanic rocks associated with the Kabinakagami greenstone belt. Most if this unit lies over Kabinakagami Lake. Although the Kabinakagami and Dayohessarah greenstone belts tend to show fairly distinct magnetic low responses along their boundaries, their responses do not precisely coincide with the mapped geological contacts on the bedrock geology maps (PGW, 2014). The distributions of the geophysical units throughout the Strickland pluton are assumed to reflect changes of lithology and associated mineralogy.

Gravity data over the Strickland pluton do not show a correspondence to the geometry shown on the bedrock geology map (PGW, 2014; Figure 3.7). A regional gravity low over the Anahareo Lake pluton extends northwards through the centre of the Strickland pluton, possibly reflecting a thickening of the latter at that location. The radioelement concentrations are generally low other than towards the southwest, perhaps reflecting inhomogeneities within the pluton. There is no FDEM coverage over this pluton.

Anahareo Lake Pluton

The Anahareo Lake pluton (informal name adopted in this report) is a large felsic intrusion of which approximately 690 km^2 is located within the southern and southeastern parts of the White River area (Figure 3.4). The pluton extends over 51 km north-south and 71 km east-west. The intrusion was mapped by Siragusa (1977; 1978) as being dominantly granodiorite and quartz monzonite (i.e., monzogranite in modern terminology). Distal from the contact with the Kabinakagami greenstone belt, these rock types are relatively uniform and appear to represent multi-phase intrusions. Migmatites of trondhjemitic composition, the least dominant granitic rock within the intrusion, are present along the pluton’s boundaries and as syntectonic intrusive sheets that locally exhibit a variably developed cataclastic fabric (Siragusa, 1978).

Quartz monzonite is the youngest recognized phase of the Anahareo Lake pluton and commonly intrudes the granodioritic and trondhjemitic rocks in the form of large, coarse-grained pegmatitic dykes, sills and discordant bodies of variable size (Siragusa, 1977; 1978). This phase of the pluton is described as massive, which prompted Siragusa (1978) to suggest that these young intrusive phases post-date the major period of tectonism in the White River area. However, no geochronological information is currently available to test this interpretation and the age of the pluton is unknown.

The bedrock geology of the Anahareo Lake pluton shows a fairly uniform distribution of weak magnetic response (PGW, 2014; Figure 3.5). Foliation is evident at a few locations but is generally lacking due to the low-resolution data and ubiquity of dyke responses. The easternmost portion of the Anahareo Lake pluton in the White River area shows increased variability in the northwest trending dyke responses. Additionally, this response contrasts sharply with those to the west and south, which show pronounced magnetic lows with weaker dyke responses present. Although the dyke responses in the extreme eastern portion of the White River study area are elevated in magnitude, the background magnetic responses of the pluton tend to be weak (PGW, 2014; Figure 3.5). The area of higher background magnetic response near Anahareo and Esnagi lakes represent a contrast that is better defined immediately south of the White River area (PGW, 2014). The magnetic amplitude in this area increases gradually towards the southeast, reflecting a greater number of dykes present. Siragusa (1977, 1978) suggest that the Anahareo Lake pluton bedrock is relatively uniform and appears to represent multi-phase intrusions. The lower responses within the pluton, could reflect different phases of the pluton in addition to the variability introduced by the northwest trending dykes (PGW, 2014).

A regional gravity low correlates well with the granite-granodiorite of the Anahareo Lake pluton (PGW, 2014; Figure 3.7). The strongest low is centred 25 km east of White River, suggesting that the Anahareo Lake pluton thickens in that area. The exposed southern part of the Anahareo Lake pluton, other than over the lakes, shows relatively high radioelement responses, whereas the subdued responses further north occur in areas of overburden cover. There is no FDEM coverage over this pluton.

Danny Lake Stock

The Danny Lake stock is an east-west-elongated intrusion (5 km wide by 22 km long) located approximately 4 km north of the Township of White River (Figure 3.4). The Danny Lake stock consists of hornblende porphyritic quartz monzonite to quartz monzodiorite, and is classified by Stott (1999) as a probable sanukitoid suite. Crosscutting relationships suggest that this intrusion is the youngest intrusion in the White River area, although no absolute age is available. The Danny Lake stock locally crosscuts tonalite gneiss and envelopes amphibolite slivers that outline a tonalite gneiss dome west of Dayohessarah greenstone belt.

The Danny Lake stock cannot be distinguished by its magnetic response from the neighbouring batholiths and plutons, although there is a contrast with the lower response of the Dayohessarah greenstone belt along its eastern contact, as well as locally, high magnetic responses from greenstone slivers within the northern portion of the Danny Lake stock (PGW, 2014; Figure 3.5).

Gravity data over the Danny Lake stock are extremely sparse, with only a single station measurement located along the northern contact (PGW, 2014; Figure 3.7). The gravity response tends to be relatively flat and represents regional changes between a gravity high associated with the Dayohessarah greenstone belt to the northeast and a gravity low in the northern part of the Pukaskwa batholith to the southwest. The stock is located where the radioelement responses transition from higher concentrations in the southern part of the White River area to lower concentrations in the north (PGW, 2014).

Foliated Tonalite Suite

On the southeast side of Kabinakagami Lake, Santaguida (2001) outlined two packages of rock, bisected by greenstone, described as a foliated tonalite suite that occur between the Kabinakagami greenstone belt and the Anahareo Lake pluton (Figure 3.4). The tonalite packages extends over a distance of 29 km north-south and 25 km east-west. This suite of rocks is similar to the Anahareo Lake pluton mapped by Siragusa (1977; 1978). Siragusa (1977) described outcrops of the foliated tonalite suite within the White River area as consisting of biotite trondhjemite, trondhjemite, granodiorite and biotite granodiorite. Biotite trondhjemite is the dominant granitic rock in contact zones between the granitic and supracrustal rocks of the Kabinakagami greenstone belt and also occurs as syntectonic intrusive sheets concordant to the foliations observed in the metavolcanic rocks. The biotite trondhjemite appears as strongly gneissic, grey to brownish grey, medium-grained rock and is locally porphyritic owing to the presence of eye-shaped quartz and feldspar porphyroblasts (Siragusa, 1977).

The foliated tonalite suite displays a moderate to low magnetic response not dissimilar to the Anahareo Lake pluton, which abuts it to the southeast (PGW, 2014; Figures 3.5 and 3.6). No absolute age is available for this foliated tonalite suite, although it may be of the same age as other lithologically similar intrusions in the region. No information is available regarding the thickness of the suite.

Dotted Lake Batholith

The Dotted Lake batholith (referred to in some literature as a pluton) is located north of White Lake and straddles the western boundary of the White River area; only a small portion of the batholith is within the White River area (Figure 3.4). The Dotted Lake batholith is of irregular shape, approximately 20 km long and 10 km wide; no information exists on the depth to which the pluton extends. The batholith is primarily a coarse-grained, homogeneous, biotite leucotonalite to leucogranodiorite that is massive to weakly foliated to lineated away from its margin (Milne, 1968; Beakhouse, 2001). The margin of the batholith is highly strained with a well-developed penetrative fabric. Localized narrow zones of high strain also occur in the interior of the batholith associated with narrow, brittle-ductile shear zones. The Dotted Lake batholith has been dated at ca. 2.697 Ga (Beakhouse, 2001), and is interpreted to pre-date the imposition of the regional deformational fabric (Jackson *et al.*, 1998).

Tedder Granite Pegmatite

Immediately south of the Dayohessarah greenstone belt, in the area surrounding Round Lake, Stott (1999) identified an intrusive body he termed the Tedder granite pegmatite. This late stage intrusive body is a massive pegmatite containing local amphibolite and clastic metasedimentary inclusions, and very local tonalite gneiss inclusions. The tonalite gneiss inclusions are similar to the gneiss present to the west and southwest of the greenstone belt suggesting a wider distribution of this unit prior to the emplacement of the pegmatite (Stott, 1999).

The amphibolite inclusions appear to be structurally non-rotated relative to the orientation of the schistosity in the greenstone belt. Based on regional deformation patterns in the surrounding tonalite gneiss and the Dayohessarah greenstone belt, Stott (Written comm., 2014) interpreted the pegmatite to post-date at least the main phase of regional deformation and noted that there exists no evidence of subsequent regionally related penetrative deformation within the pegmatite. Consequently, it appears that the pegmatite is a late phase that intruded after the granodiorite plutons were emplaced into the regional tonalite gneisses and adjacent to the greenstone belt.

The extent of Tedder granite pegmatite is likely minor and only the northern boundary, adjacent to the greenstone belt, has been defined. Mapping by Stott (1999) has shown that the intrusion has dimensions of greater than 8 km east-west and 3 km north-south. The Tedder granite pegmatite is not represented by a distinct magnetic response (PGW, 2014). Due to the small size and undefined shape, the outline of the pegmatite is not shown on Figure 3.4.

3.2.1.2 Greenstone Belts

Dayohessarah Greenstone Belt

The Dayohessarah greenstone belt is centred on Dayohessarah Lake in the north-central part of the White River area, and forms a narrow, north-trending arcuate belt, approximately 36 km in length and from 1.5 to 5 km in width (Figure 3.4).

The Archean-aged greenstone belt has been mapped by Fenwick (1967), Stott *et al.* (1995a; 1995b; 1995c) and Stott (1999). The following description of the greenstone belt is taken from Stott (1999). The greenstone belt is a south-plunging syncline composed of a basal sequence of massive to pillowed basalt overlain in succession by:

- A local unit of komatiitic flows, typified by spinifex-texture, and accompanying gabbro to peridotite bodies;
- Dacite to rhyolite flows and pyroclastic units; and
- A metasedimentary sequence centered on Dayohessarah Lake.

The metasedimentary assemblage of the Dayohessarah greenstone belt is the youngest supracrustal sequence in the greenstone belt and unconformably overlies the ultramafic flow sequence. This metasedimentary package is composed of basal metaconglomerate, containing metavolcanic and metasedimentary clasts, overlain by metamorphosed wacke-siltstone beds. The metasedimentary rocks appear to be derived from volcanic, sedimentary and felsic plutonic sources.

The structure of the belt appears to be dominated by the strain regime related to the emplacement of the syn-tectonic Strickland Pluton to the east (Stott, 1999). The southern end of the belt transitions into amphibolite inclusions within granite pegmatite and granodiorite intrusions, one of which trends westward toward the settlement area of White River.

No published information on the thickness of the Dayohessarah greenstone belt is available; however, exploration drilling has shown it extends to a depth of greater than 400 m (MNDM, 2013a; AFRI file 42C15SW2003). It is likely that the belt may extend to a depth of 2 to 3 km (G. Stott, Pers. Comm, 2013).

Kabinakagami Greenstone Belt

The Kabinakagami greenstone belt occurs in the northeastern part of the White River area as a northeast-trending irregularly shaped body between the Anahareo Lake and Strickland plutons (Figure 3.4). Within the White River area the belt has a length of approximately 40 km and varies in width from 4 to 23 km. General lithological descriptions of the Kabinakagami greenstone belt can be found in Siragusa (1977; 1978) and Wilson (1993). No internal subdivision of the belt has been completed (Williams *et al.*, 1991).

The belt is a metavolcanic-metasedimentary belt dominated by mafic metavolcanic rocks locally interbedded with mafic pyroclastic rocks and minor thin, felsic metavolcanic units, and subordinate clastic metasedimentary rocks. Locally, massive metagabbro, metapyroxenite, and minor peridotite are in contact with the mafic metavolcanic rocks. These rocks were intruded, and locally assimilated, by trondhjemitic intrusions (Siragusa, 1977; 1978).

The metasedimentary rocks include metaconglomerate, metasandstone and paragneiss. The principal sources of clasts within the metasedimentary rocks are local metavolcanic rocks, suggesting that metasedimentary rocks were derived from a source proximal to where they were deposited (Siragusa, 1977). Metasandstones and associated paragneiss flank the east side of the metavolcanic rocks. Minor occurrences of pyrite-bearing biotite-rich paragneiss and hornblende-biotite paragneiss are found at several localities along the eastern shore of Kabinakagami Lake near the boundary of the greenstone belt and are interpreted as sulphide facies iron formation bands. At the southern end of Kabinakagami Lake, the fine- and medium-grained metasedimentary rocks grade along strike into metaconglomerate (Siragusa, 1977).

The supracrustal rocks in the Kabinakagami greenstone belt were metamorphosed to middle-greenschist to upper amphibolite facies conditions. The rocks were uplifted, deformed, and partially assimilated by the emplacement of granodioritic plutons at their margins. Subsequently, both the supracrustal and the granitic rocks were intruded by numerous diabase dykes (Siragusa, 1977, 1978). The main mapped structural feature of the belt is a northeast-trending syncline, immediately west of Kabiskagami Lake (Siragusa, 1978, Santaguida, 2001). Siragusa (1977) also noted, but did not delineate, the axis of another northeast-trending syncline between Nameigos Lake and the northeastern corner of the White River area.

The Dayohessarah and Kabinakagami greenstone belts in the White River area generally show moderate to high curvilinear magnetic anomalies at their core, reflecting intermediate to mafic metavolcanic horizons (PGW, 2014). The extent of the mafic metavolcanics may be less than indicated by the published maps, but incorporating the adjacent magnetic lows, which likely reflect intermediate to felsic metavolcanics and/or metasedimentary rocks, the contacts between the greenstone belts and adjacent rocks correlate well (Figures 3.5 and 3.6). The gravity data show a prominently response associated with the Kabinakagami greenstone belt and smaller amplitude anomaly over the Dayohessarah greenstone belt (Figure 3.7).

3.2.1.3 Other Units

Numerous small lenses of mafic metavolcanic rock occur in the area to the west of the Dayohessarah greenstone belt from the northern boundary of the White River area southward to the Ruthie Lake area (Fenwick, 1967; Santaguida, 2001; Figure 3.4). These supracrustal rocks are surrounded by the Black-Pic batholith or the Danny Lake stock and likely represent remnant fragments of what was once a far more extensive greenstone terrain.

A gabbroic body, the mapped boundaries of which are geophysically defined, is interpreted as being located in the Bulldozer Lake area in the northwestern corner of the White River area (Santaguida, 2001). Mineral exploration mapping and drilling suggest that additional, smaller gabbroic intrusions are present to the south of this unit. Approximately 5 km southeast of the intrusion, eight boreholes encountered units described variously as mafic to ultramafic dykes and hornblende-quartz biotite gabbro which occurred as thin dykes to intrusions >60 m thick (MNDM, 2013a; AFRI files 42C14NW0003 and 42C14NW0007). The dykes were observed as being hosted by granite-tonalitic gneiss.

3.2.1.4 Mafic Dykes

Several generations of Paleoproterozoic and Mesoproterozoic diabase dyke swarms crosscut the White River area (Figure 3.4), including:

- Northwest-trending Matachewan Suite dykes (ca. 2.473 Ga; Buchan and Ernst, 2004). This dyke swarm is one of the largest in the Canadian Shield and most predominant of all dyke swarms recognized in the White River area. Individual dykes are generally up to 10 m wide, and have vertical to subvertical dips. The Matachewan dykes comprise mainly quartz diabase dominated by plagioclase, augite and quartz (Osmani, 1991);
- North-trending Marathon Suite dykes (ca. 2.121 Ga; Buchan *et al*., 1996; Hamilton *et al*., 2002). These form a fan-shaped distribution pattern around the northern, eastern, and western flanks of Lake Superior, and are fairly minor in the White River area. The dykes vary in orientation from northwest to northeast, and occur as steep to subvertical sheets, typically a few metres to tens of metres thick, but occasionally up to 75 m thick (Hamilton *et al*., 2002). The Marathon dykes comprise quartz diabase (Osmani, 1991) dominated by equigranular to subophitic clinopyroxene and plagioclase;
- Northeast-trending Biscotasing Suite dykes (ca. 2.167 Ga; Hamilton *et al*., 2002). These dykes are not numerous in the White River area;
- West-northwest-trending Sudbury Suite dykes (ca. 1.238 Ga; Krogh *et al*., 1987). These dykes are not numerous in the White River area; and
- Northeast-trending Abitibi Suite dykes (ca. 1.14 Ga; Ernst and Buchan, 1993). These dykes are not numerous in the White River area.

The five dyke swarms in the White River area are generally distinguishable by their unique strike directions, crosscutting relationships and, to a lesser extent, by magnetic amplitude. SRK (2014) notes that several of the dykes occupy faults, some of which show offsets along strike.

One aspect of uncertainty is the likelihood that thin dykes, while known to be present in the host rock, could be too small to be identified with any confidence from the geophysical data. For example, Halls (1991) characterized the Matachewan dykes as having a median width of ca. 20 m, but also described minor dykelets as narrow as several cm in width that were recognized during detailed field mapping. West and Ernst (1991) suggested further that narrow dykes may produce anomalies of insufficient magnetic intensity to be traced with any confidence. Halls

(1982) discussed the bifurcating and branching geometry of the Matachewan dykes which was also determined based on detailed field mapping. In addition, it is well understood, but not easily quantifiable from geophysical data alone, that dyke propagation could induce damage to the host rock within an envelope around the dyke that varies with the size of the intrusion (e.g., Meriaux *et al*., 1999). The presence of smaller dykes and the potential for damage to the host rock between dykes would need to be evaluated at later stages of the assessment, through the collection of site-specific information.

3.2.2 Quaternary Geology

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

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

All glacial landforms and related materials within the White River area are associated with the Late Wisconsinan glaciation (30,000 to 10,000 years ago). The Quaternary (i.e., surficial) geology of the area has been mapped at different scales as discussed in AECOM, 2014.

Geddes *et al.* (1985) and Geddes and Kristjansson (1986) reported that glacial striae in the White River area reveal an early north to south ice movement that was followed by a strong, regional flow of approximately 220°. Bedrock erosional features indicate that ice flow, likely in the waning stage of glacial cover, was influenced by local topographic conditions as demonstrated by striae measurements ranging from 180° to 245°. For the large parts of the White River area, drift thickness over bedrock is limited and the ground surface reflects the bedrock topography (Kristjansson and Geddes, 1985). Over the majority of the area, bedrock outcrops are common, and the terrain is classified, for surficial mapping purposes, as a bedrock-drift complex, i.e., thin drift cover that only locally achieves thicknesses that mask or subdue the bedrock topography (Figure 2.3). Valleys and lowland areas typically have extensive and thicker surficial deposits that frequently have a linear outline.

The remote sensing and terrain evaluation completed as part of the Phase 1 preliminary assessment (AECOM, 2014) provides a detailed assessment of the type, distribution and thickness of surficial deposits in the White River area (Figure 2.3).

The most common glacial deposit in the White River area is stony, sandy till (ground moraine) which forms a veneer in rocky upland areas. In the White River area the till composition is variable and two types are regionally recognizable (Geddes *et al.*, 1985; Geddes and Kristjansson, 1986). A moderately loose, very stony variety with a sandy texture that is of local derivation dominates in areas of thin till cover in the western part of the White River area. A calcareous, silty till, rich in "exotic" carbonate lithologies derived from the James Bay Lowland, is common in the northern part of the White River area (Geddes and Kristjansson, 1986). This latter till occurs in two facies, one of which is stone poor, massive, silty and quite dense. The other more dominant facies is less compact and slightly sandier, and has a variable stone content. In some areas, the calcareous till is capped by coarser, locally derived till or till-like material. Geddes and Kristjansson (1986) noted that in areas where there is little relief on the land surface, the calcareous till is usually prominent, especially in areas on the leeside of significant topographic features. It is typical of the stony till to have a more hummocky, or moranic surface expression.

Till thickness is variable; while depths of several metres are present locally, thicknesses are typically less than 3 m (A. Bajc, pers. comm., 2013). Gartner and McQuay (1980a; 1980b) reported that the till is seldom more than 1 m thick on the crests of the hills, but can thicken to 5 m or more on the flanks and in the valleys between the bedrock hills.

Areas of ground moraine shown in Figure 2.3 are zones of lesser relief indicating that the till thickness may be sufficient to subdue the bedrock topography. In the area south and west of Dayohessarah Lake, the till forms a patchy blanket over highland areas (OGS, 1997) and is, in places, gently fluted (Kristjansson and Geddes, 1986). Although the ruggedness of the surface in this area suggests that the till thickness is generally of limited depth, it may locally mask the relief of the underlying bedrock surface.

Two types of glaciofluvial deposits are present in the White River area, ice-contact stratified drift deposits (ICSD) and outwash deposits. The ICSDs deposits are associated with a number of esker-kame complexes that trend in a south-southwest direction across the area (Figure 2.3). All the complexes have a well-developed, if discontinuous, central esker ridge(s) which is frequently flanked by kettled kame terraces and occasionally by outwash (Geddes and Kristjansson, 1986). The ICSDs consist primarily of stratified, well to poorly sorted sand and gravel that locally can achieve thicknesses of several tens of metres, as evidenced by the logs of exploration overburden drill holes (MNDM 2013a, assessment file 42C11SE0010).

Glaciofluvial outwash deposits in the White River area occur as areas of limited relief along the esker-kame complexes and within the larger modern drainage systems, such as the Gum, Kwinkwaga, Shabotik and White rivers (Figure 2.3). Smaller deposits, occupying topographic lows and bedrock valleys, are scattered across the area. The thickness of the outwash deposits are likely to be variable, but may be substantial where they are proximal to ICSD features. Deposits are generally well-sorted and consist predominantly of stratified sand with a low clast content; however, locally they are coarser-grained and gravel-rich (Geddes and Kristjansson, 1986).

Glaciolacustrine sediments in the area consist of fine sand, silt, and minor clay deposited in shallow lakes within bedrock controlled basins (Figure 2.3). The largest of these deposits are located: south and east of White Lake; northeast of Dayohessarah Lake; and in the northeast corner of White River area (Gartner and McQuay, 1980a, 1980b). Other small deposits, such as those around Picnic Lake, occur throughout the area (Geddes and Kristjansson, 2009).

Based on the logs of water wells and surficial mapping in surrounding areas, the glaciolacustrine deposits can achieve a thickness of over 20 m. The larger glaciolacustrine deposits are likely to be of variable thickness, as is indicated by the occurrence of outcrops and rock knobs (Gartner and McQuay, 1980a; 1980b).

Bogs and organic-rich alluvial deposits, consisting of sand, silt and organic debris, are present along several of the water courses in the White River area (Figure 2.3). These deposits tend to be relatively narrow (<200 m), although their width can increase notably where they surround lakes. Larger expanses of organic terrain, some of several square kilometres in size, are present in the north-central and northeastern parts of the White River area. These deposits may be developed on finer-grained glaciolacustrine deposits and/or outwash which occupy lowland areas. Smaller occurrences of organic terrain exist in bedrock-controlled basins throughout the White River area.

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

Eolian deposits of fine- to medium-grained sand, are present as parabolic dunes developed on some outwash plains (Geddes and Kristjansson, 1986). Dunes, formed in post-glacial time, have heights of only a few metres in the White River area.

3.2.3 Lineament Investigation

A detailed lineament investigation was conducted for the White River area (SRK, 2014) using publicly available remote sensing data sets, including airborne geophysical data, digital elevation model data, and satellite imagery data. Lineaments are linear features that can be observed on remote sensing and geophysical data and which may represent geological structures (e.g., fractures). However, at this stage of the assessment, it is uncertain if interpreted lineaments are a reflection of real geological structures, and whether such structures extend to depth. The assessment of these uncertainties would require detailed geological mapping and borehole drilling.

The lineament investigation identified interpreted brittle structures, dykes, and ductile lineaments in the White River area, and evaluated their relative timing relationships within the context of the local and regional geological setting. A detailed analysis of interpreted lineaments is provided by SRK (2014), and key aspects of the lineament investigation are summarized in this section.

At this desktop stage of the investigation, the remotely-sensed character of interpreted features allows only for their preliminary categorization, based on expert judgement, into three general lineament classes, including ductile, brittle, and dyke lineaments. Each of these three lineament categories is described in more detail below in the context of its usage in this preliminary desktop study.

- **Ductile lineaments**: Features which were interpreted as being associated with the internal fabric to the rock units (including sedimentary or volcanic layering, tectonic foliation or gneissosity, and magmatic foliation) were classified as ductile lineaments. This category also includes recognizable penetrative shear zone fabric;
- **Brittle lineaments:** Features interpreted as fractures (joints or joint sets, faults or fault zones, and veins or vein sets), including those that offset the continuity of the ductile fabric described above, were classified as brittle lineaments. This category also includes brittle-ductile shear zones, and brittle partings interpreted to represent discontinuous re-activation parallel to the ductile fabric. At the desktop stage of the investigation, this category also includes features of unknown affinity. This category does not include interpreted dykes, which are classified separately (described below).
- **Dyke lineaments**: For this preliminary desktop interpretation, any features which were interpreted on the basis of their distinct character, e.g., scale and composition of fracture in-fill, orientation, geophysical signature and topographic expression were classified as dykes. Dyke interpretation is largely made using the aeromagnetic data set, and is often combined with pre-existing knowledge of the bedrock geology of the White River area.

For each data set, brittle lineaments were interpreted by two independent experts using a number of attributes, including certainty and reproducibility (SRK, 2014). The certainty attribute describes the clarity of the lineament within each data set based on the expert judgement and experience of the interpreter (i.e., with what certainty is a feature interpreted as a lineament). Reproducibility was assessed in two stages (RA_1 and RA_2). Reproducibility assessment RA_1 reflects the coincidence between lineaments interpreted by the two experts within a data set. Reproducibility assessment RA_2 reflects the coincidence of interpreted lineaments between the three data sets used (magnetic, satellite imagery, topographic data). Combined surficial and geophysical lineaments are presented in Figure 3.8 and 3.9, respectively. In addition, ductile features (i.e., magnetic form lines) were identified from the geophysical data set (Figure 3.10). These features are included to provide context to our understanding of the tectonic history of the White River area, but were not included in the merged lineament sets or statistical analyses.

A detailed description of the lineament investigation workflow, and discussion of the results of the analysis, is provided by SRK (2014).

The resolution of each available data set has a strong impact on the resolution and number of interpreted lineaments. The GDS1025, GDS1207-REV, GDS1024-REV and AFRI No. 20004804 data sets have a high resolution (100 to 200 m line spacing; ~30 m grid cells) and cover approximately 11% of the White River area (Figure 1.2; Table 1.1). The remainder of the White River area is covered by the lower resolution SMGA (GDS1036) data set (805 m line spacing; 200 m grid cells). In the areas covered by the high-resolution data sets, it is considered that other available data sets with lower resolution were not favorable for use in the lineament analysis.

The Spot 4/5 satellite and Landsat 7 satellite images cover the entire White River area and have resolutions of 20 m and 30 m, respectively (Figure 2.1). The CDED topography data covers the entire area with a resolution of 8 to 23 m (Figure 2.2). However, the bedrock structural information available from these three data sets is limited in various sectors of the White River area due to Quaternary cover (Figure 2.3). The sectors of the White River area where bedrock structures are concealed by Quaternary cover include a large area in the northeast of the White River area and significant portions of the northeast corner and north boundary of the White River area (Figure 2.3). The total area of Quaternary cover where the satellite (SPOT and Landsat) and CDED topography data were of limited use is roughly 1,000 km^2 or approximately 20% of the White River area. In addition, a large majority of the area affected by Quaternary cover is not covered by high resolution geophysics. Consequently, in this area, few lineaments associated with bedrock features were identified with certainty, resulting in a low lineament density.

Combined, the CDED and satellite data sets yielded 2,809 surficial lineaments, 2,733 interpreted brittle lineaments and 76 as dyke lineaments (Figure 3.8; SRK, 2014). A total of 756 surficial lineaments (27%) were coincident in both the CDED and satellite imagery data.

The surficial lineaments range in length from 220 m to 83.5 km, with a geometric mean length of 3.5 km and a median length of 2.3 km (SRK, 2014). Surficial brittle lineament orientations exhibit three dominant orientations trending to the northwest, north, and northeast, and one minor orientation trending east-northeast. All orientations are sharply defined, with the exception of the northeast trend, which is somewhat more diffuse. Surficial lineaments interpreted as dykes exhibit two dominant orientations trending to the northwest and northeast, and one very minor orientation trending to the north-northeast. All orientations of dyke lineaments are well defined (Figure 3.8 inset).

On the basis of their orientation, the 76 dyke lineaments in the White River area were divided into four groups (SRK, 2014):

- 42 dyke lineaments are interpreted to belong to the northwest-trending Matachewan dyke swarm;
- 16 dyke lineaments are interpreted to belong to the northeast-trending Biscotasing dyke swarm;
- 14 dyke lineaments are interpreted to belong to the north-trending Marathon dyke swarm; and
- 4 dyke lineaments are interpreted to belong to the northeast-trending Abitibi dyke swarm.

Interpretation of geophysical data allows for the distinction between lineaments associated with ductile fabrics, dykes and brittle faults. Interpretation of the geophysical magnetic data resulted in a data set containing 762 geophysical lineaments of which 330 are interpreted as brittle lineaments and 432 as dyke lineaments (Figure 3.9; SRK, 2014). The length of the aeromagnetic lineaments ranges from 180 m up to 83.5 km, with a geometric mean length of 5.6 km and a median length of 3.3 km. Azimuth data, weighted by length, for the aeromagnetic lineaments interpreted as brittle and dyke lineaments exhibit a dominant orientation to the northwest. Azimuth data, weighted by length, for the aeromagnetic lineaments interpreted as brittle lineaments exhibit two dominant orientations trending to the northwest and northeast, and two minor orientations trending to the north and east-northeast. All orientations are sharply defined, with the exception of the northeast trend, which is slightly diffuse (SRK, 2014; Figure 3.9 inset).

Lineaments interpreted as dykes exhibit one dominant orientation trending to the northwest, one minor orientation trending to the northeast, and one very minor orientation trending to the north.

Based on the geophysical data (magnetic with the support of electromagnetic), 432 of the total 762 interpreted lineaments in the White River area are interpreted as dyke lineaments. On the basis of their orientation the 432 dyke lineaments were divided into four groups (SRK, 2014):

- 284 dyke lineaments are interpreted to belong to the northwest-trending Matachewan dyke swarm. This group of dykes may also contain west-northwest-trending dykes of the Sudbury dyke swarm; however, Sudbury dykes could not be determined from the lineament analysis and therefore all dykes of similar orientations are grouped together;
- 80 dyke lineaments are interpreted to belong to the northeast-trending Biscotasing dyke swarm. This group of dykes may also contain northeast-trending dykes of the Abitibi dyke swarm; however, Abitibi dykes could not be determined from the lineament analysis and, therefore, all dykes of similar orientations are grouped together;
- 58 dyke lineaments are interpreted to belong to the north-trending Marathon dyke swarm; and
- 10 dyke lineaments are interpreted to belong to the northeast-trending Abitibi dyke swarm. These dykes share the same orientation as the Biscotasing dyke swarm and were identified based on coincident Abitibi aged dykes identified on the OGS (2011) bedrock compilation map.

The final merged data set (Figure 3.11) containing both surficial and geophysical lineaments contained 3,281 lineaments, 2,839 of these lineaments were interpreted as brittle lineaments, while 442 were interpreted as dyke lineaments. Figure 3.11 contains all lineaments, regardless of how their reproducibility was attributed. The orientation data for the brittle and dyke lineaments (Figure 3.11 inset; Figure 3.12) show three dominant orientations trending to the northwest, north and northeast, and one minor orientation trending east-northeast.

The lineaments in the merged data set range in length from 180 m to 83.5 km. The geometric average length of these lineaments is 3.7 km and the median length is 2.5 km. Of all merged lineaments, 180 lineaments are greater than 10 km in length (6%), 504 lineaments are equal to or between 5 to 10 km in length (15%), 2,227 lineaments are between 1 to 5 km in length (68 percent), and 370 lineaments are equal to or less than 1 km in length (11%). It should be noted that the rose diagrams for the brittle and dyke lineaments (Figure 3.11 inset; Figure 3.12) are weighted by lineament length and, thus, these orientations are influenced by longer lineaments.

SRK (2014) noted the following trends in the final merged lineament data set:

- The resolution of each available data set has a strong impact on the reproducibility and number of interpreted lineaments. The higher resolution of the surficial data sets over the entire White River area may explain why a larger number of lineaments are identified from the combination of these data sets compared to the geophysical data sets;
- Longer lineaments generally have a higher certainty and reproducibility;
- There is a higher confidence that the longer features that were identified are related to bedrock structures;
- The observed overlap in dominant lineament orientation between all data sets (Figures 3.8, 3.9 and 3.12) suggests that all data sets are identifying the same regional sets of structures;
- Resolution and distribution of the data sets used form a suitable basis to conduct a robust lineament interpretation in the White River area.

The drawing of ductile features (i.e., stratigraphic and structural form lines) was completed using first vertical-derivative magnetic data. These lineaments are shown in Figure 3.10 and were not used in lineament statistics (e.g., rose diagrams, density plots). The form lines trace the geometry of magnetic high lineaments and represent the geometry of stratigraphy within metavolcanic and metasedimentary rocks or the internal fabric (foliation) within granitoid batholiths and gneissic rocks. This process highlighted discontinuities between form lines, particularly in stratigraphic form lines (e.g., intersecting form lines) that represent structural lineaments (e.g., faults, folds, unconformities, or intrusive contacts).

Of the 762 lineaments observed in magnetic data, 289 lineaments (38%) were reproduced in at least one surficial data set. The coincidence between these data sets is in part explained by the fact that lineaments are related to significant bedrock structure and are, therefore, observed in multiple data sets. The lack of coincidence between the magnetic data and the surficial data is largely due to the contrast in resolution between data sets. Additional factors contributing to the lack of coincidence between data sets include deeper structures identified in geophysics that may not have a surface expression, surficial features that may not extend to great depth, and structural features that may not possess a magnetic susceptibility contrast with the host rock.

In particular, geophysical data were very effective in identifying dykes, whereas surficial data sets were rarely able to identify dyke lineaments. Of the 442 dykes interpreted from all data sets 376 dykes (85%) were only observed in the magnetic data. A total of 43 dyke lineaments (10%) were coincident with a lineament from one other data set, and 23 lineaments (5%) were coincident in all three data sets.

The total density of lineaments in the White River area (surficial and geophysical) is presented as Figure 3.13. This figure was constructed using all lineaments regardless of how their reproducibility was attributed. The density of lineaments in the White River area is highly variable, primarily due to the limited distribution of high resolution geophysical data and Quaternary and lake cover (Figures 1.2 and 2.3). Lineament density is low throughout a large area covering the northeastern sector of the White River area and in smaller areas in the northwest corner and near the central southern boundary of the area. The majority of low lineament density areas are likely due to low resolution geophysics and Quaternary and lake cover which decreases the density of lineaments interpreted from geophysical and surficial data sets, respectively. In particular, the northeastern quadrant of the White River area has more extensive Quaternary and lake cover (Figure 2.3), resulting in the interpretation of very few lineaments related to bedrock structures. Conversely, several low lineament density areas are present in zones with significant bedrock exposure and are interpreted to represent areas with low densities of bedrock structures. Such areas are located in the Pukaskwa batholith, near the southwestern corner of the White River area; the Black-Pic batholith in the northwestern corner of the White River area; the Strickland pluton between the Dayohessarah and Kabinakagami greenstone belts; and along the boundary of the Anahareo pluton near the southern border of the White River area.

As a means of evaluating the influence of lineament length on lineament density across the White River area, the results of progressive “filtering” by lineament length are shown in Figures 3.14 to 3.16. These figures illustrate only lineaments >1 km, >5 km, and >10 km, respectively. This process allows longer lineaments to be viewed more easily. Limited change in the density pattern exists with the exclusion of the <1 km lineaments (Figure 3.14) and areas of low lineament density remain unchanged. A notable decrease in lineament density occurs when only those lineaments of >5 km are considered (Figure 3.15). While this decrease in density is primarily due to the exclusion of a large percentage of surficial lineaments, a significant number of geophysical lineaments that occurred in “clusters”, such as those in the vicinity of the Dayohessarah greenstone belt, were also removed. The result is that only scattered pockets of moderate lineament density remain (Figure 3.15).

When lineaments >10 km are plotted, density across the area is generally low (Figure 3.16). Despite the fact that the majority of the White River area has low resolution geophysical coverage, geophysical lineaments slightly outnumber surficial lineaments when only >10 km features are considered.

Figure 3.17 shows the combined data sets (i.e., mapped regional faults, brittle lineaments, dykes and ductile features), which helps provide a structural understanding of the White River area. Most of the mapped faults, along all or part of their length, were coincident with surficial lineaments while the coincidence of mapped faults with geophysical lineaments was notably poorer. The curvilinear mapped faults in the Black-Pic batholith west of the Dayohessarah greenstone belt were not identified in the surficial or geophysical data; it is interesting to note that field studies in the area did not identify these features (Fenwick, 1967).

The orientation of the dense network of lineaments in the White River area provides a framework to interpret the geological history of the area by linking the lineaments with the structural history of the White River area. This was accomplished by defining the age relationships of the interpreted lineaments on the basis of crosscutting relationships between different generations of brittle lineaments.

3.2.3.1 Relative Age Relationships of Lineaments

The structural history of the White River area, outlined in Section 3.1.3, provides a framework that may aid in constraining the relative age relationships of the interpreted bedrock lineaments. Previous work in and around the White River area has identified six regionally distinguishable deformation episodes (D_1 – D_6) that are inferred to have overprinted the bedrock geological units of the area. The lineament interpretation is fairly consistent with regional observations, however, the D_5 and D_6 events interpreted from the lineament analysis differ from the D_5 and D_6 events described in the literature.

Consistent with existing literature, D_1 is interpreted as compositional layering and isoclinal folds between ca. 2.719 and ca. 2.691 Ga. D_2-D_4 produced the dominant brittle-ductile structures observed within the greenstone belts, including steeply dipping foliations, isoclinal folds, and thrust faults prior to ca. 2.680 Ga. D_5 was a brittle deformation event that involved the activation and possible re-activation of major regional faults sub-parallel to S_2 between ca. 2.680 and ca. 1.100 Ga. D_6 represents another regional brittle deformation event that occurred between ca. 2.680 and 1.100 Ga.

The 2,839 brittle lineaments identified in the White River area are interpreted to represent successive stages of brittle-ductile and brittle deformation. These lineaments can therefore be classified into three main stages based on relative age and in consideration of the structural history described above: 76 D_2-D_4 lineaments, 1,035 D_5 lineaments, and 1,728 D_6 lineaments. D_2-D_4 brittle lineaments are interpreted as Archean brittle-ductile faults characterized as zones of pervasive foliation and phyllonite development, potentially with hydrothermal veining. D_5 and D_6 brittle lineaments are interpreted as brittle faults characterized as zones of pseudotachylite, gouge and (or) breccia. Limited information exists on the character of each interpreted fault set. At the desktop stage of preliminary assessment, it is still uncertain whether or not each interpreted lineament is in fact an actual brittle-ductile or brittle geological feature with a significant expression at depth.

Four populations of dykes have been identified in the lineament interpretation that appear to correspond to the: ca. 2.473 Ga., northwest-trending Matachewan dyke swarm (Buchan and Ernst, 2004), the ca. 2.167 Ga., northeast-trending Biscotasing dyke swarm (Hamilton *et al*., 2002), the ca. 2.121 Ga., north-trending Marathon dyke swarm (Buchan *et al*., 1996; Hamilton *et al*., 2002), and the ca. 1.14 Ga northeast-trending Abitibi dykes (Ernst and Buchan, 1993). Regional geological maps also identify isolated northwest-trending Sudbury dykes (ca. 1.24; Krogh *et al.,* 1987); however, the lineament analysis did not identify any lineaments consistent with this dyke swarm. The lineament analysis could not differentiate these dykes from the more numerous and similarly oriented Biscotasing and Matachewan dyke swarms. The timing between D_6 faults and the Marathon dyke swarm (~2.1 Ga) appears ambiguous. D_6 faults can be coincident with Marathon dykes such that earlier structures can appear offset along the trend of an individual dyke. Elsewhere, Marathon dykes are observed to crosscut D_6 faults with no observable offset. Biscotasing or Marathon dykes were not observed to be offset by D_6 faults. As such, it is thought that D_6

faults likely formed prior to emplacement of the Marathon dyke swarm and that the dykes exploited pre-existing weaknesses along the D_6 faults. However, it is also possible that some fault reactivation may have occurred coeval with, or after dyke emplacement, and this could account for the apparent offset of structures observed along dykes. Apart from these timing constraints, there are no additional absolute age constraints for these phases of deformation.

No information is available on the depth of fault penetration in the White River area; however, brittle lineament strike length may be a proxy for the depth extent. In general, D_6 faults have the longest strike length (3.9 km average length, 2.6 km median length), followed by D_5 faults (3.3 km average length, 2.2 km median length) and D_2-D_4 faults (2.4 km average length, 1.7 km median length).

3.2.3.2 Lineament distribution in batholiths and plutons

As described in Section 3.2.1, the bedrock geology of the White River area is dominated by large granitic intrusive bodies that intrude older metavolcanic and metasedimentary rocks associated with the Dayohessarah and Kabinakagami greenstone belts. The following subsections describe the characteristics of the interpreted lineaments for select lithological units, consisting of the: Black-Pic batholith, Pukaskwa batholith, Anahareo Lake pluton, and Strickland pluton. Lineament orientation trends for these units are presented in Figure 3.12 and discussed below.

3.2.3.3 Black-Pic Batholith

A total of 789 lineaments (673 brittle and 116 dyke) were interpreted in the Black-Pic batholith, an area that covers the northwest portion of the White River area (Figures 3.12 and 3.17; SRK, 2014). These lineaments include all lineaments that are contained within and crosscutting the boundary of the batholith. Of the 673 brittle lineaments, 8 are interpreted as D_2-D_4 faults, 206 as D_5 faults, and 459 as D_6 faults. The interpreted lineaments within the Black-Pic batholith range in strike length from 180 m to 83.5 km. Interpreted brittle and dyke lineaments exhibits a dominant orientation to the northwest and an additional minor northeast trend (Figure 3.12).

Much of the Black-Pic batholith in the White River area is obscured by Quaternary cover; however, local areas of relatively low lineament density and exposed bedrock are present throughout the batholith (Figure 3.17).

3.2.3.4 Pukaskwa Batholith

The characteristics of the interpreted lineaments for two areas of the Pukaskwa batholith are described separately. The first area is the foliated tonalite suite, and lesser areas of gneissic tonalite, located west of the settlement area of White River and south of the Anahareo pluton (referred to as the “main zone”). The second area is the gneissic tonalite suite east of White River (referred to as the “east zone”; Figures 3.4 and 3.12). The lineament orientation trends for the zones are discussed separately to determine whether the east zone has been affected by the emplacement of the surrounding late stage intrusions (i.e., the Anahareo Lake and Strickland plutons, Danny Lake stock, Tedder pegmatite).

Main Zone - foliated tonalite

A total of 595 lineaments (523 brittle, 72 dyke) were interpreted in the Pukaskwa batholith, an area that covers the southwest portion of the White River area (Figures 3.12 and 3.17; SRK, 2014). These lineaments include all lineaments that are contained within and crosscutting the boundary of the batholith in this area. Of the 523 brittle lineaments, 225 are interpreted as D_5 faults and 298 as D_6 faults. The interpreted lineaments within the Pukaskwa batholith range in strike length from 270 m to 49.8 km. Interpreted brittle and dyke lineaments exhibit a dominant orientation to the northwest and additional minor northeast and north trends (Figure 3.12).

Locally, areas of low lineament density are observed throughout the Pukaskwa batholith, in particular in the centre of the mapped foliated tonalite suite (Figure 3.17). These low density areas are present in zones of high bedrock exposure, suggesting that low lineament density is representative of a low concentration of bedrock structures.

East Zone – gneissic tonalite

The east zone of the Pukaskwa batholith, located east of the Township of White River, comprises a gneissic tonalite suite. The zone is bounded by the Anahareo pluton to the south and east, and the Strickland pluton and Danny Lake stock to the north (Figures 3.12 and 3.17; SRK, 2014). A total of 523 lineaments (479 brittle and 44 dyke) were interpreted in the gneissic tonalite unit. These lineaments include all lineaments that are contained within and crosscutting the boundary of the batholith. Of the 479 brittle lineaments, 11 are interpreted as D_2-D_4 faults, 177 as D_5 faults and 291 as D_6 faults. The interpreted lineaments within the gneissic tonalite range in strike length from 290 m to 40.0 km. Interpreted brittle and dyke lineaments exhibit a dominant orientation to the northwest and an additional minor northeast trend (Figure 3.12).

Locally, areas of low lineament density are observed throughout the gneissic tonalite, in particular near the southern and eastern boundaries of the gneissic tonalite (Figure 3.17). These low density areas are present in zones of moderate bedrock exposure, suggesting that low lineament density may be representative of a low concentration of bedrock structures.

3.2.3.5 Anahareo Pluton

A total of 748 lineaments (673 brittle and 75 dyke) were interpreted in the Anahareo pluton, an area that covers the southeast portion of the White River area (Figures 3.12 and 3.17; SRK, 2014). These lineaments include all lineaments that are contained within and crosscutting the boundary of the batholith. Of the 673 brittle lineaments, 3 are interpreted as D_2-D_4 faults, 292 as D_5 faults and 378 as D_6 faults. The interpreted lineaments within the Anahareo Pluton range in strike length from 240 m to 27.5 km. Interpreted brittle and dyke lineaments exhibit a dominant orientation to the northeast, northwest, and additional minor north and east-west trends (Figure 3.12).

Locally, areas of low lineament density are observed throughout the Anahareo pluton, in particular near the western boundary of the pluton and the gneissic tonalite suite to the west (Figure 3.17). These low density areas are present in zones of moderate bedrock exposure, suggesting that low lineament density may be representative of a low concentration of bedrock structures.

3.2.3.6 Strickland Pluton

A total of 415 lineaments (318 brittle and 97 dyke) were interpreted in the Strickland pluton, an area extending from the Dayohessarah greenstone belt in the centre of the White River area to the northeast corner of the White River area (Figures 3.12 and 3.17; SRK, 2014). These lineaments include all lineaments that are contained within and crosscutting the boundary of the batholith. Of the 318 brittle lineaments, 17 are interpreted as D_2-D_4 faults, 88 as D_5 faults and 213 as D_6 faults. The interpreted lineaments within the Anahareo Pluton range in strike length from 340 m to 40 km. Interpreted brittle and dyke lineaments exhibit a dominant orientation to the northwest and northeast.

Areas of low lineament density are observed throughout the Strickland pluton, particularly in the centre of the pluton (Figure 3.17). Although much of the Strickland pluton is covered by lakes and Quaternary cover (Figure 2.3) zones of low lineament density in the centre of the pluton may correspond with exposed bedrock. These low lineament density areas likely represent zones with a low concentration of bedrock structures.

3.3 Seismicity and Neotectonics

3.3.1 Seismicity

The White River area lies within the Superior Province of the Canadian Shield where large parts have remained tectonically stable for the last 2.5 billion years (Percival and Easton, 2007). Figure 3.18 illustrates the location of earthquakes with a magnitude 3 or greater that are known to have occurred in Canada from 1627 until 2010 (Earthquakes Canada, 2013). The Canadian Shield is considered the least seismically active portion of the North American continent (Maloney *et al.*, 2006). Hayek *et al.* (2011) indicate that the general western Superior Province has experienced a number of low magnitude, shallow seismic events, with all recorded earthquakes since 1982 being of a magnitude less than 3 (Earthquakes Canada, 2013).

Within the White River area, for the period 1985 to present, three earthquakes with magnitudes between 2.2 and 2.5 have been recorded; two were centred west of Kabinakagami Lake and the other along Highway 17 west of the Township (Figure 3.19). Other seismic events in close proximity to the area have epicentres approximately 12 km to the north, (magnitude 2.6) and 27 km to the west (magnitude 2.1). A number of low magnitude earthquakes with magnitudes between 1 and 3 have occurred in scattered locations in the region surrounding White River.

In summary, available literature and recorded seismic events indicate that the White River area is located within a region of low seismicity, the tectonically stable Superior Province of the Canadian Shield.

3.3.2 Neotectonic Activity

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 horizontal principal stress orientation in central North America, based on the World Stress Map (Zoback, 1992) is northeast (63° ±28°). This orientation coincides roughly with both the absolute and relative plate motions of North America (Zoback, 1992; Baird and McKinnon, 2007), and is controlled by the present tectonic configuration of the North Atlantic spreading ridge (Sbar and Sykes, 1973) which has likely persisted since the most recent Paleocene-Eocene plate reorganization (Rona and Richardson, 1978; Gordon and Jurdy, 1986).

The geology of the White River area is typical of many areas of the Canadian Shield, which has been subjected to numerous glacial cycles during the last million years, resulting in post-glacial isostatic rebound in the northern portion of the North America plate. During the maximum extent of the Wisconsinan glaciation, approximately 21,000 years ago (Barnett, 1992), the Earth's crust was depressed by more than 340 m in the Minnesota/North Dakota area (Brevic and Reid, 1999), due to the weight of glacial ice. The amount of crustal depression in the White River area would be of a somewhat greater magnitude, due to its closer proximity to the main centre of glaciation located over Hudson's Bay.

Post-glacial isostatic rebound began with the waning of the continental ice sheets and is still occurring across most of Ontario. Vertical velocities show present-day uplift of about 10 mm/a near Hudson Bay, the site of thickest ice at the last glacial maximum (Sella *et al*., 2007). The uplift rates generally decrease with distance from Hudson Bay and change to subsidence (1-2 mm/a) south of the Great Lakes. The ‘‘hinge line’’ separating uplift from subsidence is consistent with data from water level gauges along the Great Lakes, showing uplift along the northern shores and subsidence along the southern ones (Mainville and Craymer, 2005). Current rates of isostatic uplift in the White River area are not precisely known, although Lee and Southam (1994) estimated that the land is rising at a rate of 2.9 mm/a at Michipicoten, Ontario, some 80 km to the southeast.

As a result of the glacial unloading, acting along with tectonic stresses, principal stress magnitudes and orientations are changed. Seismic events could be associated with these post-glacial stress changes as a result of reactivation of existing fracture zones. In addition, natural stress release features can include elongated compressional ridges or pop-ups such as those described by McFall and Allam (1990), McFall (1993) and Karrow and White (2002).

No neotectonic structural features are known to occur within the White River area. It is therefore useful to review the findings of previous field studies involving fracture characterization and evolution as it pertains to glacial unloading. McMurry *et al*. (2003) summarized several studies conducted in a number of plutons in the Canadian Shield and in the crystalline basement rocks in western Ontario. These various studies found that fractures below a depth of several hundred metres in the plutonic rock were ancient features. Early-formed fractures have tended to act as stress domain boundaries. Subsequent stresses, such as those caused by plate movement or by continental glaciation, generally have been relieved by reactivation along the existing zones of weakness rather than by the formation of large new fracture zones.

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

4. HYDROGEOLOGY

4.1 Groundwater Use

The Township of White River obtains its municipal water supply from Tukanee Lake, located 5 km north of the settlement area, and from groundwater sources. The Ontario Ministry of the Environment categorizes the supply network as a large municipal residential system.

There is limited information on the depth of overburden for the White River area in the Ontario Ministry of Environment Water Well Database (2013) as only 33 wells are in the database after removal of duplicate records and wells deemed to have incorrect geographic co-ordinates (Figure 4.1). The vast majority of the water wells are located within the community of White River, in close proximity to Highways 17 or 631. Of the five water wells located outside of the Township of White River, four are located west of the settlement area, along Highway 17; the records for two of these wells contain no information beyond geographic coordinates. A single well is positioned in Gourlay Township, approximately 45 km northeast of White River (Figure 4.1). Records indicate 16 of the wells in the area draw water from bedrock, 15 wells are developed in overburden, and no data exists for two wells.

A summary of water well data derived from the MOE database is provided in Table 4.1.

Table 4.1: Water Well Record Summary for the White River Area

Water Well Type	Number of Wells	Total Well Depth (m)	Average Well Depth (m)	Static Water Level (mbgs)	Tested Well Yield (L/min)	Depth to Top of Bedrock (m)
Overburden	15	4.6 to 38.7	16.5	0.9 to 3.0	4.5 to 909	NR
Bedrock	16	15 to 99.1	36.8	1.2 to 8.5	4.5 to 1,250	1.5 to 27.1
Unknown	2					

NR = Bedrock not reached Blank Fields – data not reported

4.2 Overburden Aquifers

There are 15 water well records in the White River area that extract groundwater from an overburden aquifer. Water wells confirmed to be developed in overburden are largely within glaciolacustrine deposits in the central portion of the Township of White River and have depths of between 4.6 and 38.7 mbgs indicating that bedrock is at a greater depth (MOE, 2013). Wells terminating in sand and gravel have reported test pumping rates of 4.5 to 909 L/min; however, these yields may not be reflective of aquifer capacity, as the wells primarily supply residences with limited demand. Static water levels in the wells are shallow, ranging from 0.9 to 3.0 mbgs. The limited number of well records limits the interpretation of available information regarding the extent and characteristics of overburden aquifers in the White River area.

4.3 Bedrock Aquifers

No information was found on deep bedrock groundwater conditions in the White River area at a typical repository depth of approximately 500 m. Within the White River area 16 water wells are recorded as being developed in bedrock (MOE, 2013). These wells encountered bedrock at depths ranging from 1.5 to 27.1 mbgs and have maximum depths of between 15.0 and 99.1 mbgs. Tested yields range from 4.5 to 1,250 L/min with static water levels ranging from 1.2 to 8.5 mbgs.

The reported well test yields reflect the purpose of the wells (i.e., private residential supply) and do not necessarily reflect the maximum sustained yield that might be available from the shallow bedrock aquifers. Long-term groundwater yield in fractured bedrock will depend on the number and size of fractures, their connectivity, transmissivity, storage, and on the recharge properties of the fracture network in the wider aquifer.

The MOE water well records indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the White River area or anywhere else in Northern Ontario.

4.4 Regional Groundwater Flow

In many shallow groundwater flow systems the water table is generally a subdued replica of the topography (AECOM, 2014). The variation of the water table elevation across an area reflects the changes in hydraulic head, the driving force within the flow system. However, the pattern of groundwater flow will also be influenced by horizontal and vertical variations in the hydraulic properties of the medium, for example associated with interbedding of sand and clay layers in overburden sediments and the presence of fracture networks in bedrock. As a general concept, shallow groundwater flow in Canadian Shield terrain will tend to be directed from areas of higher hydraulic head, such as highlands, towards areas of lower hydraulic head such as adjacent or nearby valleys and depressions. The extent of these localized flow systems are defined by local, topography-controlled, drainage divides across which flow will not readily occur. However, the geometry of shallow flow systems can be more complex in the presence of permeable fracture zones and more complex topography.

Within the White River area, it is believed that groundwater flow divides mimic the boundaries of surface watersheds (Figure 2.4) due to the fact that large areas are characterized by the presence of bedrock at or near the surface. Groundwater recharge in these areas is through an interconnected fracture network present in the bedrock. Recharge can be rapid but is largely restricted to a near surface zone. Groundwater flow is directed towards flanking valleys and depressions where the bulk of the groundwater discharges either directly to waterways or into surficial deposits occupying the lower ground. Surficial deposits on the highland bedrock areas, most commonly till, are usually thin and relatively coarse-grained, allowing downward infiltration to the bedrock surface. These higher relief areas can have higher hydraulic gradients that may impact the depth extent of shallow flow systems. Site-specific, subsurface characteristics such as hydraulic conductivity and groundwater density variations, will also influence flow system geometry. No information was found in the available literature regarding groundwater recharge rates and temporal patterns in the White River area; however, it is expected to be typical for the shield region with elevated recharge in spring and fall, reduced recharge in late summer, and essentially no recharge during frozen winter conditions.

Coarse-grained glaciofluvial deposits, mainly outwash, found along the major bedrock valleys in the White River area (Figure 2.3) are recharged by overland and subsurface storm flow from the bedrock highlands and direct precipitation (rain and snow). Groundwater discharge from these deposits is as baseflow to streams and rivers which transect them. The presence of a shallow water table in many of the valley outwash deposits is suggested by the fact that the elevation of the dissecting waterway is often close to that of the surrounding ground surface.

The large glaciofluvial esker deposits that trend south and southwest across the area are also zones of significant groundwater recharge (Figure 2.3). Creeks and streams are generally lacking over these glaciofluvial systems; however, the water level in kettle lakes associated with some of these systems indicates a generally shallow water table. The influence of regional bedrock structures, such as the mapped faults in the area, on the rate and volume of groundwater flow is not known at present.

There is little known about the hydrogeologic properties of the deep bedrock in the White River area, as no deep boreholes have been advanced for this purpose. Experience from other areas in the Canadian Shield with similar rock types has shown that active groundwater flow in bedrock is generally confined to shallow fractured localized systems and is dependent on the secondary permeability associated with the fracture networks (Singer and Cheng, 2002). For example, in Manitoba’s Lac du Bonnet batholith, groundwater movement is largely controlled by a fractured zone down to about 200 m depth (Everitt *et al*., 1996).

The low topographic relief of the Canadian Shield tends to result in low hydraulic gradients for groundwater movement in the shallow active region (McMurry *et al.*, 2003). In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson *et al*., 1996; McMurry *et al*., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures thereby reducing permeability (Stevenson *et al*., 1996; McMurry *et al*., 2003). Rock mass hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell and Atikokan research areas range from approximately 10^{-10} to 10^{-15} m/s (Ophori and Chan, 1996; Stevenson *et al*., 1996). Another example is data reported by Raven *et al.* (1985) which shows that the rock mass hydraulic conductivity of the East Bull Lake pluton decreases from an average near-surface value of 10^{-8} m/s to less than 10^{-12} m/s below a depth of 400 to 500 m.

As the fracture frequency in a rock mass tends to decline with depth, eventually the movement of ions becomes diffusion-dominated. However, fracture networks associated with deep faults and shear zones will influence advective groundwater flow around bodies of rock characterized by diffusion-controlled conditions. The orientation of these fracture networks relative to the *in situ* stress field may influence their hydraulic properties. For example, in the fractured crystalline rock at SKB's Forsmark site, Follin and Stigsson (2014) documented that the transmissivities of large-scale, fracture zones generally decreased with depth by four orders of magnitude from ground surface to nearly 800 m, but specifically-orientated fracture zone groupings tended to have different ranges of transmissivities. The s ub-vertical fracture zones orientated at high angles (near perpendicular) to the northwest-southeast, maximum horizontal compressive stress direction tended to have a greater frequency of low transmissivities compared to sub-vertical fracture zones oriented at low angles to the maximum horizontal stress direction. Notably, the sub-horizontal fracture zones had even higher transmissivities regardless of depth, presumably because of the lower normal effective stresses acting across these zones as a result from their preferential orientation to the minimum vertical stress.

Horizontal stress measurements from various locations in the Canadian Shield (Kaiser and Maloney, 2005; Maloney *et al.*, 2006) indicate that the axis of maximum horizontal stress is oriented predominantly in the west-southwest-trending direction. However, due to lack of data in the White River area, caution is warranted in extrapolating the west-southwest stress orientations without site-specific data.

There is no site-specific information on the hydraulic characteristics of the dykes interpreted for the White River area. Information from mines in the Canadian Shield (Raven and Gale, 1986) and other geological settings shows that dykes may act as either pathways or barriers for groundwater flow in a host rock. Their hydraulic characteristics depend on a wide range of factors that include their frequency and location within the host rock, their orientation with respect to the direction of groundwater flow, their mineralogical composition, degree of alteration, and their potential association with brittle deformation structures (e.g., Ryan *et al*., 2007; Svensson and Rhén, 2010; Gupta *et al*., 2012; Holland, 2012), including both pre-existing structures and those developed as a result of dyke emplacement.

The exact nature of deep groundwater flow systems in the White River area would need to be evaluated at later stages of the site evaluation process through collection of site-specific information.

4.5 Hydrogeochemistry

Lake sediment and water geochemical surveys of the areas surrounding the Dayohessarah and Kabinakagami greenstone belts have been conducted by Jackson (2002a; 2003a). These surveys determined the average values for pH and electrical conductivity (EC) for the Dayohessarah area to be 7.71 and 121.8 μS/cm, respectively. Values for the Kabinakagami area were 7.87 and 117.4 μS/cm, respectively.

Jackson (2002a; 2003a) observed that most of the more alkaline lakes with high EC values occur in areas underlain by glaciofluvial deposits. He attributed this to the waters having dissolved carbonate minerals derived from the underlying surficial deposits. In these surveys, most of the lakes with low pH were underlain by felsic intrusive rocks in regions of thin drift cover.

There is a lack of information or studies on groundwater hydrogeochemistry for the White River area. Existing literature, however, has shown that groundwater within the Canadian Shield can be subdivided into two main hydrogeochemical regimes: a shallow, generally fresh groundwater flow system, and a deep, typically saline flow system (Singer and Cheng, 2002).

Gascoyne *et al*. (1987) investigated the saline brines found within several Precambrian plutons and identified a chemical transition at around 300 m depth marked by a uniform, rapid rise in total dissolved solids (TDS) and chloride. This was attributed to advective mixing above 300 m, with a shift to diffusion-controlled flow below that depth. It was noted that major fracture zones within the bedrock can, where present, extend the influence of advective processes to greater depths and hence lower the transition to the more saline conditions characteristic of deeper, diffusion-controlled conditions.

In the deeper regions, where groundwater transport in unfractured or sparsely fractured rock tends to be very slow, long residence times on the order of a million years or more have been reported (Gascoyne, 2000; 2004). Groundwater research carried out in AECL's Whiteshell Underground Research Laboratory (URL) in Manitoba found that crystalline rocks from depths of 300 to 1,000 m have TDS values ranging from 3 to 90 g/L (Gascoyne *et al*. 1987; Gascoyne, 1994; 2000; 2004). However, TDS exceeding 250 g/L have been reported in some regions of the Canadian Shield at depths below 500 m (Frape *et al*., 1984).

Site-specific conditions will influence the depth of transition from advective to diffusion-dominated flow, which may occur at a depth other than the typical 300 m reported by Gascoyne *et al.* (1987). Such conditions will need to be evaluated during subsequent site evaluation stages.

5. NATURAL RESOURCES – ECONOMIC GEOLOGY

Mineral exploration in the White River area has historically focused on metals, especially gold, within the Dayohessarah and Kabinakagami greenstone belts. This is illustrated by the distribution of active mining claims in the area, the bulk of which are located over the two volcanic belts (Figure 5.1). The greenstone belts host the majority of mineral occurrences, a historic mining operation (Figure 5.1), and exploration diamond drilling activity.

There are currently no producing metallic mineral mines in the White River area. There is the potential for economically exploitable base and precious metal mineralization within the greenstone belts and mineral exploration is active (MNDM, 2013a).

5.1 Petroleum Resources

The Archean suites of felsic intrusive and metavolcanic rocks found in the White River area are unfavourable host rocks for petroleum generation and/or containment. For this reason there is negligible potential for hydrocarbon reserves in the area and no records exist of exploration for oil or gas.

5.2 Metallic Mineral Resources

<u>*Gold*</u>

Gold exploration in the White River area dates to the early part of the 20th century. The only mine to briefly operate in the area was the Hiawatha Gold Mine, located in the Kabinakagami greenstone belt, which in 1939 produced 179 ounces of gold from a 1,931 tons of extracted rock (Wilson, 1993). The mine had a three-compartment shaft that was sunk to 299 feet (91 m) with workings established at the 150 (45 m) and 275 foot (84 m) levels.

Stott (1999) and Mineral Deposit Inventory files (MNDM, 2013a) suggest that favourable environments for gold mineralization in the White River area are:

- Auriferous quartz-veins and quartz-stringers in shear zones and faults in mafic metavolcanic rocks;

- Quartz veins in shear zones in metavolcanic rocks close to the contact strain aureoles of felsic intrusions;
- Veins either inside or in the border zone of the granitic rocks

At the Hiawatha Gold Mine property, located in Lizar Township on the west side of Kabinakagami Lake, an auriferous quartz vein occurs along the edge of a narrow quartz porphyry dyke. Siragusa (1977) and Wilson (1993) reported that gold mineralization occurs as a series of quartz veins in a silicified shear within a granodioritic sill and a narrow sheared quartz vein along the contact of a quartz porphyry.

Gold mineralization at the Sugar Zone property in the Dayohessarah belt appears to be related to the contact aureole of the Strickland pluton. At this site, gold mineralization mostly occurs in quartz veins, stringers, and quartz-flooded zones predominantly associated with porphyry zones, porphyry contact zones, hydrothermally altered basalts and, rarely, weakly altered or unaltered basalt. The quartz veins of the Sugar Zone occur in strongly foliated amphibolitized basaltic flows injected by abundant felsic sills that are either very fine-grained or contain quartz or feldspar phenocrysts. This weathered suite of sills is intruded and accompanied by narrow, pyritic quartz veins (Stott, 1999; MNDM, 2013a). The Sugar Zone property is undergoing advanced exploration.

Numerous gold showings and occurrences are reported southwest of Kabinakagami Lake in the greenstone belt of the same name and a lesser number of showings in the Dayohessarah greenstone belt. For most of these, the geological setting is poorly described or unknown (MNDM, 2013a). Within the greenstone belts in the White River area the potential for economic deposits of gold is deemed to be high.

Base metals

A limited number of base metal occurrences exist in the White River area. Approximately 5 km north of Dayohessarah Lake, elevated zinc and copper values were reported in sheared intermediate metavolcanics or metasedimentary rocks interbedded with mafic metavolcanic rocks. On the eastern side of Dayohessarah Lake, a 1.5 m section of cherty iron formation interbedded with fine-grained mafic metavolcanic rocks and quartz-feldspar porphyry intrusions had elevated assays levels of zinc, copper and silver. A number of mafic intrusion-hosted Cu-Ni-PGE are located near the northwest corner of the map area (Schnieders *et. al.*, 2000).

Minor zinc mineralization is present in the vicinity of Nameigos Lake where the host rock is a thick assemblage of pillowed mafic flows containing a 2 to 3 m thick interflow horizon consisting of strongly foliated chloritic bands, chert, recrystallized quartz, felsic ash tuff and sulphide mineralization.

While there is a possibility of a base metal deposit(s) in the Dayohessarah and/or Kabinakagami greenstone belts, the potential for an economic deposit in the area is considered as modest.

Rare earth metals

Rare earth elements (REE) mineralization has not been identified in the White River area. Jackson (2003a) noted that REEs were enriched in lake sediment samples collected over a large east-trending belt between White River in the south and the Dayohessarah greenstone belt to the north. The area is underlain by a gneissic tonalite suite referred to by Stott (1999) as the Tedder granite pegmatite. In general, the potential for REE mineralization in the White River area is low.

Platinum Group Elements

A single PGE occurrence has been recorded in the in south-central Shabotik Township where copper-nickel-PGE mineralization has been found on a property predominantly underlain by felsic intrusive rocks and gneisses. Intruded into the felsic intrusive complex are one or more mafic intrusive units of variable composition. The economic potential of the occurrence is limited by its small size and apparent lack of continuity with depth (MNDM, 2013a). Other mafic intrusion-hosted Cu-Ni-PGE are located near the northwest corner of the map area (Schnieders *et. al.*, 2000).

The possibility for PGE mineralization in the White River area does exist mainly in the ultramafic and mafic-ultramafic intrusive rocks, most of which are small bodies of limited areal extent. Stott (1999) noted the presence of spinifex-textured komatiitic flows and differentiated mafic intrusions in the north of Dayohessarah Lake that may have potential for nickel and platinum; however, the potential for an economic PGE deposit in the White River area is considered as modest.

Uranium

No uranium mineralization has been identified within the White River area. The closest recorded uranium occurrence is located approximately 3 km west of the White River area, at the south end of White Lake adjacent to the CPR railway line (MNDM, 2013a). Little is known of the mineralization as it is only described as being underlain by felsic igneous rocks of early Precambrian age. The potential for an economic deposit in the White River area is considered to be low.

5.3 Non-metallic Mineral Resources

Sand and Gravel

The Ontario Ministry of Natural Resources (MNR, 2013a) records indicate that 21 sand and gravel pits are licensed under the Aggregate Resources Act in the White River area. Seven of the pits are located in the vicinity of the settlement area of White River or along Highway 17 to the west of the town. The remainder of the aggregate operations are located across the White River area, and are used as a source of material for the construction and maintenance of forestry roads. A number of small, unpermitted pits have been developed along forestry roads and trails.

Sand and gravel operations, largely developed in glaciofluvial material, are utilized on an as-needed basis to meet demand. The majority of aggregate license owners are forestry companies with a lesser number held by local construction companies.

Aggregate – Crushed Stone

The Ontario Ministry of Natural Resources (MNR, 2013a) records indicate no active quarry permits for the White River area. Highway construction in the area has, however, used the “cut and fill” method, whereby excavated rock along the right-or-way has been used as fill in lower areas.

Building Stone

The potential for a building stone extraction in the White River area has been recognized, and regional investigations of the bedrock have been conducted and reported on by the Ontario Geological Survey (Hinz *et al.*, 1994). The investigations focussed on a suite of felsic lithologies which are all considered “granite” in construction terminology. While the potential for a building stone quarry in the White River area exists, past exploration activity has been limited. A site within the Dotted Lake batholith, described as a grey granite, has been sampled and tested as a potential stone source; however, no development has occurred (Hinz *et al.*, 1994). Stott (1999) noted that the Danny Lake stock, a hornblende-bearing syenite to granodiorite body, may be a potential dimension stone source. The rock is fresh, unmetamorphosed, and locally contains widely spaced joints.

Regionally, in the Marathon area to the west, a number of quarries have seen extractive activity; however, none are currently operating. Some of these quarries appear to have been developed to supply stone for the construction of the CPR railway. All quarries were developed in iron-rich syenite with the rock being described as black granite (Hinz *et al.*, 1994).

Diamonds (kimberlite)

To date no reports of kimberlite intrusions, with which diamonds are associated, have been reported in the White River area. Sage (1982) suggested that a north-trending corridor between Marathon and Terrace Bay is more prospective for diamond exploration. To the south, in the Michipicoten greenstone belt, diamond-bearing rocks of Precambrian age have been discovered, and Schnieders *et al.* (2005) noted that some rocks in the Hemlo greenstone belt have similar characteristics to these. Given the similarity in age of the greenstone belts, there is a possibility that diamond-bearing rocks may occur in the Dayohessarah and Kabinakagami greenstone belts; however, the likelihood of this is considered low.

Diamond exploration activity is occurring immediately west to the White River area, where an MNDM Exploration Permit has been issued (Ontario Environmental Registry, 2014).

Peat

No record of peat extraction exists for the White River area. Organic deposits in the White River area are of small to moderate size and appear to hold limited potential for development (Monenco Ontario Limited, 1981). A regional evaluation of peat deposits to the northwest of White River area was conducted by Dendron Resource Surveys Limited (1986). Their findings indicated that large peat deposits developed on poorly drained glaciolacustrine and till substrates; however, the deposits are generally thin and largely unsuitable for commercial development.

Other Industrial Minerals

The felsic intrusive bodies within and surrounding the White River area are recognized as having three primary settings with potential for non-metallic/metallic mineralization (Springer, 1977). These are:

- Vein infillings - amethyst, barite and fluorite mineralization;
- Migmatite contact zones - uranium, thorium mineralization;
- Pegmatitic zones - lithium, beryllium, cesium, molybdenum and rare earth elements.

A beryl-lithium occurrence associated with a calcite-quartz-feldspar vein or dyke within granite gneisses in the Strickland pluton is present in Nameigos Township (MNDM, 2013a). The occurrence is described as consisting of considerable lepidolite or lithium mica, plus a weathered spodumene crystal. Another lithium occurrence is reported in Mosambik Township within a calcite-quartz feldspar vein or dyke. Neither occurrence is currently considered economic.

A number of molybdenite occurrences are reported in the Mineral Deposits Inventory of the White River area (MNDM, 2013a). The mineralization is commonly associated with pegmatite dykes and within and the margins of felsic intrusive bodies.

6. GEOMECHANICAL AND THERMAL PROPERTIES

Geomechanical information including intact rock properties, rock mass properties, and *in situ* stresses are needed to design stable underground openings, predict the subsequent behaviour of the rock mass around these openings and predict the response of the groundwater flow system. As such, geomechanical information associated with a potential host rock can be used when addressing several geoscientific, safety-related factors defined in the site selection process document (NWMO, 2010).

There is limited geomechanical information on the granitic intrusions in the White River area. Table 6.1 summarizes all available geomechanical information from the granitic intrusions elsewhere in the Canadian Shield with rock types similar to those of interest in the White River area. These sites are the Lac du Bonnet granite at AECL's Underground Research Laboratory (URL) in Manitoba and the Eye-Dashwa granite near Atikokan, Ontario. The majority of the geomechanical characterization work for the URL in Pinawa, Manitoba, was conducted on these rocks as part of AECL's Nuclear Fuel Waste Management Program in the 1990s.

Table 6.1: Summary of Intact Rock Properties for Selected Canadian Shield Rocks

Property	Lac du Bonnet Granite	Eye-Dashwa Granite
Uniaxial Compressive Strength (MPa)	185 ±24[a]	212 ±26[b]
Split Tension Strength (Brazilian) (MPa)	4 to 9[c]	NA
Porosity (%)	0.35[a]	0.33[b]
P-wave velocity (km/s)	3220 (±100) - 4885 (±190)[d]	NA
S-wave velocity (km/s)	2160 (±55) - 3030 (±115)[d]	NA
Density (Mg/m^3)	2.65[a]	2.65[a]
Young's Modulus (GPa)	66.8[a]	73.9[a]
Poisson's Ratio	0.27[a]	0.26[a]
Thermal Conductivity ($W/(m^0K)$)	3.4[a]	3.3[a]
Coef. Thermal Expansion ($x10^{-6}/^0C$)	6.6[a]	15[a]

NA = Not Available; [a]Stone *et al*., 1989; [b]Szewcyk and West, 1976; [c]Annor *et al.*, 1979; [d]Eberhardt *et al*., 1999

6.1 Intact Rock Properties

Intact rock properties tabulated in Table 6.1 are based on laboratory testing of rock core specimens from boreholes. The table includes basic rock properties such as density, porosity, uniaxial compressive strength, and tensile strength for use in engineering design and structural analyses. These parameters feed into the rock mass classification schemes, and *in situ* stress determination.

There is a general paucity of information on the geomechanical properties of the granitic intrusive bodies in the White River area. A limited amount of construction and development has taken place in the area that required near surface investigation of the batholiths' engineering properties, and no deep subsurface investigations have been conducted. No specific information is available for the Black-Pic or Pukaskwa batholiths or the plutons present (e.g., Anahareo Lake, Strickland, Denny Lake) within the White River area.

At this stage of the site evaluation process, it is reasonable to assume that the geomechanical properties of intact rock in the White River area may resemble those of the similar rock types elsewhere in the Superior Province. The rock property values presented in Table 6.1 are consistent with the values selected for numerical modeling studies conducted to evaluate the performance of hypothetical repository designs in a similar crystalline rock environment (SNC-Lavalin Nuclear Inc., 2011; Golder Associates, 2012a; 2012b). Site-specific geotechnical assessment will be conducted during later stages of site evaluation.

6.2 Rock Mass Properties

Rock mass properties address the behaviour of a body of rock, including its fracture or joint network. The presence of fractures changes the strength and hydraulic behaviour of a rock mass compared to what would be measured on small intact samples of the rock. For example, the strength of a rock mass containing a network of joints will be lower than the uniaxial compressive strength of a core sample measured in a laboratory. One would also expect the permeability of a rock mass to be greater than what would be measured on an intact core sample.

Fracture spacing, orientation and condition (width or aperture, mineral fill, evidence of relative displacement, etc.) of the fractures tend to influence the overall mechanical response of the rock mass. There is no information available on rock mass properties of the granitic intrusions in the White River area; however, it is known that crystalline rock of the Canadian Shield can have a spectrum of fracture conditions at a given site. In general, there will be a downward decreasing fracture density from highly fractured rocks in shallow horizons (ca. <300 m below ground surface) to sparsely fractured intact rock at greater depths as experienced at other shield sites (e.g., Everitt, 2002). Fractures observed on surface bedrock exposures may occur as well-defined sets of geological discontinuities, or as randomly oriented and variably-dipping features. Based on observations from other shield sites (e.g., Everitt, 2002) and stress measurement data (e.g., Maloney *et al*., 2006), one could infer that a shallowly-dipping to sub-horizontal fracture set may exist as a result of either strain releasing during the rebound from the last glacial cycle or the presence of pre-existing fabric anisotropy (e.g., bedding, tectonic foliation) in the rock structure. Rock mass properties for the White River area would need to be determined at later stages of the assessment.

6.3 *In situ* stresses

Knowledge of the *in situ* stress at a site is required to model the stress concentrations around underground excavation designs. These stress concentrations are ultimately compared to the strength of a rock mass to determine whether conditions are stable or the excavation design needs to be modified. This is particularly important in a repository design scenario, where minimization of excavation induced rock damage is required.

No site-specific information is available regarding the *in situ* stress conditions within the White River area; however, in eastern North America the current stress orientation is approximately east-northeast (Heidbach *et al*., 2008). Horizontal stress conditions are difficult to estimate; over-coring or hydraulic fracturing methods can be used to determine the stresses on a plane at depth and resolve the horizontal *in situ* stress conditions (or resolve inclined principal stresses). A large set of such horizontal stress measurements is available from various locations in the Canadian Shield (Kaiser and Maloney, 2005; Maloney *et al*., 2006). These data are presented on Figure 6.1.

The nearest *in situ* stress measurements were taken in rocks at depths of 1,000 mbgs at the David Bell Mine located southwest of the White River area at Marathon, Ontario (Kaiser and Maloney, 2005). The reported maximum principal stress data available from two sets of tests were 34.7 and 44.6 MPa oriented south, with the minimum principal stress being subvertical.

The observation that the stress state is neither constant nor linear (Maloney *et al*., 2006) suggests that variability should be expected in the Canadian Shield. Based on the available stress measurement data, Maloney *et al.* (2006)

developed a conceptual model that describes the variable stress state in the upper 1,500 m of the Canadian Shield. The conceptual model identifies a shallow stress-released zone from surface to a depth of 250 m, a transition zone from 250 to 600 m and an undisturbed stress zone below 600 m. The undisturbed stress zone can be expected to be representative of far-field boundary stress conditions whereas stresses within the shallow zone tend to be lower as they have been disturbed through exhumation and influenced by local structural weaknesses such as faults (Maloney *et al*., 2006).

Typical repository depths of approximately 500 m fall within the transition zone, where the maximum principal stress may range from approximately 20 to 50 MPa (Maloney *et al*., 2006). The data presented by Maloney *et al.* (2006) indicate an average southwest orientation for the maximum horizontal stress. This orientation is consistent with the World Stress Map, although anomalous stress orientations have been identified in northwest Ontario and southern Manitoba; for example, a 90° change in azimuth of the maximum compressive stress axis which was identified in the near surface of the Whiteshell area of Manitoba (Brown *et al.*, 1995). In addition, a roughly north-south orientation of maximum horizontal compressive stress was found for the Sioux Falls Quartzite in South Dakota (Haimson, 1990).

Local stress relief features such as faults and shear zones can be expected to locally affect the stress regime. For example, thrust faults at the Lac du Bonnet batholith were shown to be boundaries between significant changes in the magnitude and orientation of the principal stresses. Above a major thrust fault, located at a depth of 270 m, the magnitude was close to the average value for the Canadian Shield and the orientation of the maximum horizontal stress was consistent with the average predicted by the World Stress Map (i.e., southwest) (Zoback, 1992). Below the same thrust fault, the stress magnitudes are much higher than the average data for the Canadian Shield, and the maximum principal stress rotates approximately 90° to a northwest orientation (Martino *et al*., 1997). The principal maximum horizontal stress magnitude below the Fracture Zone 2 thrust fault remains relatively constant around 55-60 MPa, which is more typical of the values found at greater depths. The southeast orientation of the maximum principal horizontal stress is consistent with the data presented by Herget (1980) for the area, which indicates maximum compression clustered in the southwest and southeast for the Canadian Shield.

In addition to loading history and geologic structure, *in situ* stress conditions are further influenced by rock mass complexity (i.e., jointing, heterogeneities and mineral fabric). As such, local stresses may not resemble the average stress state for a region (Maloney *et al*., 2006). The conceptual model presented by Maloney *et al.* (2006) is considered appropriate for sub-regional modelling activities. Due to wide scatter in the data (Figure 6.1), site-specific measurements would be required during detailed site investigations for application to more detailed design activities.

6.4 Thermal Conductivity

Thermal conductivity values for potential host rocks provide information on how effectively the rock will transfer heat from the repository and dissipate it into the surrounding rock. The thermal conductivity of a rock is in part dependent on its mineral composition, with rocks composed of higher quartz content generally having higher thermal conductivities. The thermal conductivity of quartz (7.7 W/(m˚K)) is greater than that of other common rock-forming minerals such as feldspars (1.5 to 2.5 W/(m˚K)) or mafic minerals (2.5 to 5 W/(m˚K)) (Clauser and Huenges,1995).

There are no site-specific thermal conductivity values or detailed quantitative mineral compositions for the White River area. Available information indicates that the dominant compositions of the intrusions are granite, granodiorite and tonalite in the Black-Pic and Pukaskwa batholiths; granodiorite and quartz monzodiorite in the Anahareo Lake pluton; and granodiorite in the Strickland pluton. The Danny Lake stock consists of monzonite to quartz monzodiorite. The quartz mineral content of granite and granodiorite rock types can range from approximately 20% to 60% by volume (Streckeisen, 1976). The range of measured thermal conductivity values for granite, granodiorite and tonalite found in the literature are presented in Table 6.2; data for monzonite was not found. At this desktop stage of the investigation, there is additional uncertainty as to whether the existence of dykes will have a positive or negative impact on the thermal conductivity of the surrounding host rocks. The potential heterogeneity in thermal conductivity associated with the presence and nature of dykes is difficult to quantify at the desktop stage of the investigation and would need to be studied in further detail.

Table 6.2: Thermal Conductivity Values for Granite, Granodiorite, and Tonalite

Rock type	Average thermal conductivity (W/(m˚K))	Minimum thermal conductivity (W/(m˚K))	Maximum thermal conductivity (W/(m˚K))
Granite[a,b,c,d,e,f,g]	3.15	2.60	3.63
Granodiorite[a,f,g]	2.69	2.44	2.86
Tonalite[h,i]	3.01	2.95	3.14

[a]Petrov *et al*., 2005; [b]Kukkonen *et al.*, 2011; [c]Stone *et al*., 1989; [d]Back *et al.*, 2007; [e]Liebel *et al*., 2010; [f]Fountain *et al*., 1987; [g]Fernandez *et al.*, 1986; [h]de Lima Gomes and Mannathal Hamza 2005; [i]Kukkonen *et al.*, 2007.

Although no thermal conductivity values are available for the White River area, some useful comparisons are provided by Stone *et al.* (1989) in their summary of thermal conductivity values for two late Archean granitic intrusions of the Superior Province of the Canadian Shield, the Lac du Bonnet Batholith and the Eye-Dashwa Pluton (Table 6.1). Both intrusions were described by Stone *et al.* (1989) as having similar mineralogical compositions. The average thermal conductivity for the Eye-Dashwa Pluton was 3.3 W/(m˚K) based on 35 samples. The average thermal conductivity for the Lac du Bonnet Batholith was 3.4 W/(m˚K) based on 227 samples.

The above literature values for thermal conductivity are considered useful for general comparison purposes as part of this preliminary assessment. However, actual values would need to be determined at later stages of the assessment.

7. POTENTIAL GEOSCIENTIFIC SUITABILITY OF THE WHITE RIVER AREA

7.1 Approach

The objective of the Phase 1 geoscientific preliminary assessment was to assess whether the White River area contains general areas that have the potential to satisfy the geoscientific site evaluation factors outlined in NWMO's site selection process document (NWMO, 2010). The location and extent of general potentially suitable areas would be refined during the second phase of the preliminary assessment through more detailed assessments and field evaluations.

The repository is expected to be constructed at a depth of about 500 mbgs. The surface facilities will require a dedicated surface area of about 600 x 550 m for the main buildings and about 100 x 100 m for the ventilation exhaust shaft (NWMO, 2013). The actual underground footprint at any particular site would depend on a number of factors, including the characteristics of the rock, the final design of the repository and the inventory of used fuel to be managed. For the purpose of this preliminary assessment, it is assumed that the repository would require a footprint in the order of 2 x 3 km.

The geoscientific assessment of suitability was carried out in two steps. The first step (Section 7.2) was to identify general potentially suitable areas using the key geoscientific characteristics described below. The second step (Section 7.3) was to verify that identified general areas have the potential to meet all NWMO's geoscientific site evaluation factors (NWMO, 2010). The potential for finding general areas that are potentially suitable for hosting a deep geological repository was assessed using the following key geoscientific characteristics:

- **Geological Setting**: All areas of unfavourable geology identified during the initial screening (Golder, 2012a) were not considered. Such areas include rocks of the Dayohessarah and Kabinakagami greenstone belts and detached fragments, which were not considered suitable due to their heterogeneity, structural complexity and potential for mineral resources. Areas containing small greenstone and gabbroic bodies were also not considered due to their small size and/or potential geological heterogeneity/structural complexity. In the White River area, the Black-Pic batholith, Pukaskwa batholith, Anahareo pluton and Strickland pluton were considered as potentially suitable host rocks. Within these intrusions, the geophysical data were examined (PGW, 2014), such that areas with "quiet" aeromagnetic signatures were favoured. These intrusions were further evaluated on the basis of the subsequent considerations.

- **Structural Geology**: Areas within or immediately adjacent to regional faults were considered unfavourable. Published bedrock geology maps of the area indicate a limited number of faults in the area that generally trend either northwest or northeast. A group of semi-circular faults that occurs west of Dayohessarah Lake (Figure 3.4) was avoided. The thicknesses of the batholiths and plutons in the White River area are unknown and were therefore not a differentiating feature.

- **Lineament Analysis**: In the search for potentially suitable areas, there was a preference to select areas that have a relatively low density of lineaments, particularly a low density of longer lineaments as they are more likely to extend to greater depth than shorter lineaments (Section 3.2.3). For the purpose of this assessment, all interpreted lineaments (fractures and dykes) were conservatively considered as conductive (permeable) features. In reality, many of these interpreted features may be sealed due to higher stress levels at depth and the presence of infilling.

- **Overburden**: The distribution and thickness of overburden cover is an important site characteristic to consider when assessing amenability to site characterization of an area. For practical reasons, it is considered that areas covered by more than 2 m of overburden deposits would not be amenable for the purpose of structural mapping. This consideration is consistent with international practices related to site characterization in areas covered by overburden deposits (e.g., Andersson et al., 2007). At this stage of the assessment, preference was given to areas with greater bedrock exposures (Figure 2.3). Areas mapped as bedrock terrain are assumed to be covered, at most, with a thin veneer of overburden and are therefore considered amenable to geologic mapping.

- **Protected Areas**: Provincial parks and conservation reserves were excluded from consideration. Five protected areas were identified as being completely or partially within the White River area. These features occupy a combined total of approximately 175.7 km^2 (Figure 2.5). The Kwinkwaga Ground Moraine Conservation Reserve accounts for the majority of this total as it covers an area of 126.5 km^2.

- **Natural Resources**: The potential for natural resources is shown in Figure 5.1. Areas with known exploitable natural resources were excluded from further consideration. As noted above, the Dayohessarah and Kabinakagami greenstone belts have known potential for exploitable natural resources and were not considered due to its unfavourable geology. Gabbroic bodies were also excluded from consideration based on their potential to host base metal and/or PGE mineralization. The mineral potential of the potentially suitable geological units identified above is considered to be low. At this stage of the assessment, areas of active mining claims located in geologic environments judged to have low mineral resource potential were not systematically excluded.

- **Surface Conditions**: Areas of obvious topographic constraints (e.g., density of steep slopes) and large water bodies (wetlands, lakes) were considered in the identification of potentially suitable areas. The White River area is moderately rugged as bedrock dominated regions have a knobby topography with local areas of significant relief present across the area (Figure 2.2). While the lakes are widespread, lake density is greatest in areas of high elevation and relief and, as such, more lakes occur in bedrock dominated terrain in the southern and west-central portions of the area. Only in a few areas does size of water bodies or the concentration of smaller lakes affect the placement of general potentially suitable areas. Large organic deposits are found only in the north-central portion of the area where it is presumed they are underlain by fine-grained sediments (Figure 2.3). For the identification of potentially suitable areas, the principle factors considered were the size and location of water bodies and wetlands.

7.2 Potential for Finding General Potentially Suitable Areas

The consideration of the above geoscientific evaluation factors and constraints revealed that the White River area contains at least four general areas that have the potential to satisfy NWMO's site evaluation factors. These general areas are located within the Pukaskwa batholith and the Anahareo Lake and Strickland plutons. Figure 7.1 shows features illustrating some of the key characteristics and constraints used to identify general potentially suitable areas, including: bedrock geology; protected areas; areas of thick overburden cover; surficial and geophysical lineaments, existing road network, the potential for natural resources and mining claims. Zoomed-in views of the Pukaskwa batholith, Anahareo Lake pluton and Strickland pluton are shown on Figure 7.2 to 7.4, respectively. The boundaries of the zoomed-in views are shown on the inset of each figure. The legend of each figure also includes a 2 km by 3 km box to illustrate the approximate extent of suitable rock that would be needed to host a repository.

The following sections provide a summary of the key geoscientific characteristics of the four identified general potentially suitable areas. At this early stage of the assessment, the boundaries of these general potentially suitable areas are not yet defined. The location and extent of general potentially suitable areas would be further refined during subsequent site evaluation stages.

7.2.1 Pukaskwa Batholith (Figure 7.2)

The Pukaskwa batholith is a ca. 2.720-2.680 Ga gneissic complex covering 1,392 km^2 of the southwest quadrant of the White River area. As discussed in Section 3.2.1.1, the batholith consists of gneissic, well-foliated tonalite to granodioritic rocks (Figure 3.4). The thickness of the batholith in the White River area is not known, but it is expected to be greater than 3 km based on the interpretation of regional gravity data (PGW, 2014) and the regional geological model for the area (Beakhouse *et al.*, 2011). The northern boundary of the Pukaskwa batholith with the Black-Pic batholith is arbitrarily placed at the mapped contact of the gneissic and foliated tonalite suites north of the Trans-Canada Highway (Highway 17) (Figure 3.4). The gneissic tonalite suite east of the settlement area of White River, between the Anahareo Lake and Strickland plutons, is considered to be part of the Pukaskwa batholith, although its boundaries are poorly mapped.

The Pukaskwa batholith has low potential for natural resources and is mostly free of significant surface constraints (i.e., topography and large water bodies). Three protected areas overlie parts of the batholith: the Pokei Lake/White River Wetlands Provincial Nature Reserve, the Kakakiwibik Esker Conservation Reserve and the Kwinkwaga Ground Moraine Conservation Reserve. Identification of potentially suitable areas outside of protected areas within the Pukaskwa batholith was mainly based on geological setting, lineament analysis and overburden cover.

The assessment of the key geoscientific characteristics identified one general potentially suitable area, referred to herein as the southwest Pukaskwa area, which is entirely within the Pukaskwa batholith's foliated tonalite suite (Figure 3.4). The general potentially suitable area is located southwest of the settlement area of White River and extends from Lost Lake in the north to the southern boundary of the area with Pickerel and Whitefish lakes being the approximate western and eastern limits, respectively (Figure 7.2). The magnetic signature over the southwest Pukaskwa area, while moderately noisy, is more active in the southern half of the area (Figures 3.5 and 3.6). As the area is only covered by a low-resolution geophysical survey (805 m line spacing), detail is lacking in the processed magnetic images. A regional gravity low is present across the southwest Pukaskwa area (Figure 3.7) suggesting that the batholith may extend to a considerable depth (PGW, 2014). The general potentially suitable area has good bedrock exposure, contains no mapped faults and is distal to major regional structures; the Wawa-Quetico Subprovince boundary is approximately 78 km to the north and the Agawa Canyon Fault, 63 km to southeast.

The general area identified in the Pukaskwa batholith was based, in part, on the analysis of interpreted lineaments (Figure 3.11) completed by SRK (2014). Figure 3.9 shows a limited number of geophysical lineaments throughout those parts of the batholith. The low density of geophysical lineaments, however, is presumably due in a large part to the low resolution of the available aeromagnetic data rather than the absence of brittle structures. The spacing between the longer geophysical lineaments (i.e., >10 km) in the general potentially suitable area ranges from approximately 1.5 to 6 km (SRK, 2014). Virtually all the geophysical lineaments in the southwest Pukaskwa area exceed 10 km in length and most likely represent dykes (Figures 3.8 and 7.2). Interpreted dykes within the area are generally consistent with those mapped by the Ontario Geological Survey (Figure 3.4). The dominant orientation of longer geophysical lineaments in the Pukaskwa batholith is northwest, with a far lesser number trending northeast.

The assessment of potentially suitable areas within the Pukaskwa batholith also took into consideration interpreted surficial lineaments. Thin overburden cover and areas of outcrop enabled a detailed assessment of the bedrock structure of the southwest Pukaskwa area and indicated it has a low to moderate density of surficial lineaments. At the desktop stage, it is uncertain whether surficial lineaments represent real bedrock structure and how far they extend to depth, particularly in the shorter lineaments.

The distribution of total lineament density as a function of lineament length is shown on Figures 3.14 to 3.16 for lengths greater than 1 km, 5 km, and 10 km, respectively. The density of lineaments in the southwest Pukaskwa area decreases only slightly when the <1 km long lineaments are filtered out indicating their small population (Figure 3.14). A notable decrease in density occurs when the lineament <5 km in length are removed (Figure 3.15). The filtering out of the <10 km long features results in another visible, but less dramatic, decrease in density (Figure 3.16).

The current assessment revealed that dykes tend to have well-defined orientations, consistent with the geological history of the area (SRK, 2014). There remain some uncertainties, however, regarding the nature and distribution of the dykes. For example, the potential existence of thin dykes, which are too small to be identified with any confidence from the geophysical data, cannot be ruled out. Another aspect of uncertainty associated with the presence of dykes relates to understanding the extent of damage to the host rock as a result of dyke emplacement. It is well understood, but not easily quantifiable from geophysical data alone, that dyke propagation will induce damage to the host rock within an envelope around the dyke that varies with the size of the intrusion (e.g., Meriaux et al., 1999).

The southwest Pukaskwa batholith general potentially suitable area consists entirely of Crown Land (Figure 2.5) and does not contain any protected areas. The mineral potential of the southwest Pukaskwa area is considered to be low based on the geologic setting and a lack of recorded mineral occurrences. A number of recently staked mining claims are present in the batholith west of the Township of White River; however, no information exists on the commodity of interest (Figure 5.1 and 7.1). These mining claims are not thought to impact the potential suitability of the southwest Pukaskwa area, as they are located in a geological environment considered to have a low mineral resource potential.

The southwest Pukaskwa area is well-drained by numerous streams, rivers and lakes. This general potentially suitable area drains to Lake Superior, through the White tertiary watershed, and has permanent water bodies that occupy approximately 7% of the land surface (AECOM, 2014). Although the great majority of the southwest Pukaskwa area is classified as bedrock terrain (Figure 2.3) with thin overburden cover, local accumulations of till can reach several metres. Relief in this general potentially suitable area is modest; however, steep slopes of varying heights frequently occur in areas of bedrock dominated terrain. The thickness of glaciofluvial deposits is highly variable, but can achieve depths of up to several tens of metres. The southwest Pukaskwa area is easily accessible by two local roads and a number of trails that branch off from them (Figure 1.1).

In summary, the general area located in the southwest Pukaskwa batholith (Figures 3.4 and 7.2) appears to be potentially suitable based on its favourable geology, structural geology and lineament density. The general potentially suitable area: is within a large tonalitic intrusion, contains no mapped faults, has a low to moderate interpreted lineament density, and has low potential for economically exploitable natural resources. In addition, the area has good bedrock exposure making it amenable to site characterization.

Inherent uncertainties associated with the general area in the Pukaskwa batholith relate to lack of detailed geologic mapping, the low resolution of available geophysical data, the potential presence of smaller-scale dykes not identifiable on aeromagnetic data and the potential damage of the host rock due to dyke emplacement. In addition, uncertainty remains in relation to the lithologic homogeneity at a local scale, to the indigenous fracture pattern within and adjacent to each dyke, and to the related effects on the bulk thermal conductivity of the bedrock.

7.2.2 Anahareo Lake Pluton (Figure 7.3)

The Anahareo Lake pluton is a relatively uniform felsic intrusion of which approximately 891 km^2 is located within the southern and southeastern parts of the White River area (Figure 3.4). The multi-phase pluton primarily consists of granodiorite and quartz monzonite. No age date is available for the pluton, and it is assumed, based on regional studies, that it was emplaced in between 2.697 and 2.680 Ga. However, if, as Siragusa (1978) suggests, it post-dates the major period of tectonism in the area, it may be somewhat younger. The thickness of the Anahareo Lake pluton is not known; however, its size and gravity signature (Figure 3.7) suggest a thickness of several kilometres, far exceeding that required for the construction of a waste repository.

The Anahareo Lake pluton has low potential for natural resources, and is mostly free of protected areas and significant topographic constraints. The percentage of water cover is limited despite the presence of a few larger lakes (e.g., Anahareo, Esnagi and Oba). Identification of potentially suitable areas within this intrusion was mainly based on geological setting, structural geology, lineament analysis and overburden cover.

Two general potentially suitable areas were identified within the Anahareo Lake pluton and small parts of adjacent Pukaskwa batholith. One potentially suitable area was identified in the southeast of the Township of White River (referred to herein as the Negwazu Lake area) extending from the Negwazu Lake northward to just south of Highway 631, between the Trans-Canada Highway (Highway 17) and the White River area boundary east of Negwazu Lake (Figure 7.3). Approximately the northern third of the general potentially suitable area is within the Pukaskwa batholith. The other potentially suitable area located mainly within the Anahero Lake pluton, east of the Anahareo Lake area (referred to herein as the Anahareo Lake area). The area extends from the southern boundary of the White River area, northwest to the boundary of the pluton and the Pukaskwa batholith. The northeast and southwest edges of the block parallel and are equidistant from a mapped fault south of Anahareo Lake; the northeast boundary is placed just north of Anahareo Lake.

Both general potentially suitable areas have relatively good bedrock exposure with the terrain in a large portion of both areas consisting of bedrock-drift complex (Figure 2.3). The resource potential of both general potentially suitable areas is considered to be low as neither have any mineral occurrences of mining claims despite the fact that the areas are proximal to either or both of the Dayohessarah and Kabinakagami greenstone belts. The Negwazu Lake area contains no mapped faults; a single fault of limited length is present in the Anahareo Lake general potentially suitablearea (Figure 7.3). Major regional structures are removed from the areas with closest one being the Agawa Canyon Fault to the southeast.

The magnetic signature is relative quiet for the Negwazu Lake and moderately noisy for the Anahareo Lake general potentially suitable areas (Figures 3.5 and 3.6). Detail in the magnetic signature of the two areas is limited as the areas are covered by low resolution geophysical surveys. The fact that the general potentially suitable areas are positioned within a negative gravity anomaly (Figure 3.7), which includes most of both the Anahareo Lake pluton and the Pukaskwa batholith, suggests that the intrusions have a considerable thickness, perhaps of several kilometres (PGW, 2014).

The analysis of interpreted lineaments enables additional insight to be gained into the potential suitability of the two general potentially suitable areas identified. The Negwazu Lake and Anahareo Lake areas both have a low apparent geophysical lineament density as interpreted from the regional scale magnetic coverage (Figure 3.9). The low density of geophysical lineaments, however, is presumably due in a large part to the low resolution of the available aeromagnetic data rather than the absence of brittle structures. The majority of the geophysical lineaments identified within the general potentially suitable areas have a length of >5 km and have a northwest orientation. The spacing between the longer geophysical lineaments (i.e., >10 km) in the two general potentially suitable areas ranges between approximately 2 and 8 km; shorter lineaments have a closer spacing (SRK, 2014). In the Negwazu Lake area the longer geophysical lineaments have both northwest and northeast orientations, while in the Anahareo Lake area lineaments of this length only trend northwest.

Surficial lineaments density in the Negwazu Lake and Anahareo Lake areas is low and low to moderate, respectively (Figures 3.8 and 7.3). Outcrops and broad expanses of thin overburden cover allow an assessment of the bedrock structure of those portions of the Anahareo Lake pluton and Pukaskwa batholith within the general potentially suitable areas (Figure 3.11). A zone with a slightly lower density of surficial lineaments, located northwest of Anahareo Lake, is likely due to the presence of a broad area of glaciofluvial sediments the thickness of which masked the bedrock and hindered the identification of lineaments. As is previously noted, there is a degree of uncertainty as to whether the surficial lineaments represent bedrock structures extending to depth.

Figures 3.14 to 3.16 illustrate the distribution of total lineament density as a function of lineament length for lengths greater than 1 km, 5 km and 10 km, respectively. The filtering out of <1 km long lineaments results in a negligible decease in density for the Negwazu Lake and Anahareo Lake general potentially suitable areas (Figure 3.14). A notable decrease in density takes place when the <5 km lineaments are removed (Figure 3.15) and another marked, but less significant, drop occurs with the filtering out the <10 km long features (Figure 3.16). With the removal of the <10 km lineaments, the two general potentially suitable areas in the Anahareo pluton and adjoining portions of the Pukaskwa batholith have very low lineament densities.

As noted in the discussion of the Pukaskwa batholith, all of the White River area, including the Anahareo Lake pluton, contains numerous mapped and interpreted dykes as the area is within regional dyke swarms (Figures 3.3, 3.4 and 3.11). Within the two general potentially suitable areas northwest oriented dykes interpreted from the surficial data were generally consistent with mapped dykes. Although a small number of northeast trending dykes were identified from the surficial data sets, the agreement with mapped dykes was poor (Figure 3.4 and 7.3). The previously noted uncertainties regarding the identification, distribution and structural impact of the dykes would need to be assessed during subsequent site evaluation stages. This would include an understanding of the indigenous fracture pattern within and adjacent to each dyke and the related effects on the bulk thermal conductivity of the bedrock.

The general potentially suitable areas identified in the Anahareo Lake pluton and small areas of the Pukaskwa batholith consists entirely of Crown Land (Figure 2.5) and do not contain any protected areas. The areas are deemed to have low potential for natural resources as no mineral occurrences or mining claims are documented near the areas (Figure 5.1). The Negwazu Lake and Anahareo Lake general potentially suitable areas are well-drained by numerous streams, rivers and lakes, with permanent water bodies occupying approximately 13 and 10% of the surface area, respectively. The Negwazu Lake area straddles the continental divide with the great majority of the potential potentially suitable area being within the White tertiary watershed and draining to Lake Superior. The remainder of the Negwazu Lake and all of Anahareo Lake area drains northeast through the Upper Kabinakagami tertiary watershed to James Bay (AECOM, 2014). Relief in both general potentially suitable areas is modest; however, the ground surface is rugged with steep slopes (>6°) occupying approximately 30% of the land surface.

The Negwazu Lake general potentially suitable area is accessible by trails and logging roads branching off the Trans-Canada Highway to the west of area and Highway 631 parallels the northern edge of the area at a reasonably close distance. Additional access is provided by the rail line that traverses the south edge of the area (Figure 1.1). Access can be gained to the Anahareo Lake general potentially suitable area via a major logging road that approaches Anahareo Lake from the south and forest resource roads that enter the area.

In summary, the two general areas located largely within the Anahareo Lake pluton (Figures 3.4 and 7.3) appear to be potentially suitable based on their favourable geology, structural geology and lineament density. The general potentially suitable areas: are within a large granitic intrusion, contain few mapped faults, have a low interpreted lineament density, and have low potential for economically exploitable natural resources. In addition, the areas have good bedrock exposure making them amenable to site characterization.

The uncertainties associated with the two general areas identified in the Anahareo Lake pluton relate to the lack of detailed geologic mapping, low resolution of available geophysical data, the potential presence of smaller-scale dykes not identifiable on aeromagnetic data and the potential damage of the host rock due to dyke emplacement. In addition, uncertainty remains in relation to the litholithic homogeneity and contacts at a local scale. The potential impact of mapped faults in/near the areas would require further assessment.

7.2.3 Strickland Pluton (Figure 7.4)

The Strickland pluton, located in the north-central portion of the White River area occupies approximately 783 km^2 of land in the White River area between the Dayohessarah and Kabinakagami greenstone belts (Figure 3.4). The pluton is a relatively homogeneous, quartz porphyritic granodiorite that displays a degree of post-emplacement deformation. Although no age date is available for the pluton, its petrographic similarity to the Dotted Lake batholith suggests it may be of the same age, that is, ca. 2.697 Ga. The thickness of the pluton is unknown; however, a large part of the intrusion occupies a gravity low indicating it extends to a considerable depth (Figure 3.7).

The Strickland pluton has low potential for natural resources, and is mostly free of protected areas and significant surface constraints (i.e., topography and large water bodies). Identification of potentially suitable areas within this intrusion was mainly based on geological setting, structural geology, lineament analysis and overburden cover.

One general potentially suitable area was identified in the Strickland pluton, herein referred to as the Nameigos Lake area. The area is bounded by Nameigos and Gourlay lakes to the southeast and northwest, respectively, and extends northeast from the Strickland River Mixed Forest Wetland Conservation Reserve to the Beaton Lake area (Figure 7.4). The Nameigos Lake area has a quiet aeromagnetic signature (Figures 3.5 and 3.6) and forms part of a large gravity low that extent northward from the Pukaskwa batholith (Figure 3.7) indicating that the pluton likely extends well below the planned repository depth of approximately 500 m in this general area (PGW, 2014). The general potentially suitable area is midway between the Wawa-Quetico Subprovince boundary to the north and the Agawa Canyon fault to the south, each of which is roughly 40 km distant (Figure 3.3). A short west-northwest trending mapped fault is present immediately north of Nameigos Lake.

The identification of the Nameigos Lake area general potentially suitable area was based, in part, on the analysis of interpreted lineaments. Apparent geophysical lineament density is also low for the general potentially suitable area (Figures 3.9 and 7.4) with the longer geophysical lineaments (i.e., >10 km), having a spacing of between 1.5 and 7 km, and only a limited number of shorter geophysical lineaments are recognized in the area. However, the low density of geophysical lineaments may be due to, in a large part, the low resolution of the available aeromagnetic data rather than the absence of brittle structures. Most geophysical lineaments identified in the Nameigos Lake area general potentially suitable area have a northwest orientation.

The general potentially suitable area has a low apparent surficial lineament density (Figure 3.8), such that virtually all mapped dykes are being identified in the surficial data sets (Figures 3.8 and 7.4). At the desktop stage, it is uncertain whether surficial lineaments represent real bedrock structures and how far they extend to depth, particularly in the shorter lineaments.

The distribution of total lineament density for the Nameigos Lake area as a function of lineament length is shown on Figures 3.14 to 3.16 for lengths greater than 1 km, 5 km and 10 km, respectively. As is the case with other general potentially suitable areas in the White River area, the removal of the <1 km lineaments has little effect on the density given the low number of features of this length (Figure 3.14). Lineament density decreases significantly after the filtering of the lineaments of <5 km (Figure 3.15) with a further slight reduction with the removal of the lineaments <10 km in length (Figure 3.16). The progressive filtering indicates that the Strickland pluton in the Nameigos Lake area achieves a low lineament density once lineaments <5 km are removed.

A number of northwest and northeast trending dykes have been interpreted as crossing the Nameigos Lake area general potentially suitable area (Figure 3.11). Uncertainties exist in relation to the number, size and an understanding of possible damage to the host rock resulting from dyke emplacement that would need to be assessed during subsequent site evaluation stages. This would include an understanding of the indigenous fracture pattern within and adjacent to each dyke and the related effects on the bulk thermal conductivity of the bedrock.

The Nameigos Lake area general potentially suitable area consists entirely of Crown Land (Figure 2.5) and contains no protected areas, although a conservation reserve is located immediately to the south. No mineral occurrences are present in the general potentially suitable area, but parts of four mining claims cover a minor amount of land in the eastern portion (Figure 5.1). The Nameigos Lake area is generally well-drained by streams and rivers, although small wetlands occur in bedrock basins; approximately 11% of the surface area is covered by permanent water bodies. The potential potentially suitable area lies astride the continental divide with over 75% draining to James Bay through either the Nagagami or Upper Kabinakagami tertiary watersheds. The southwestern part of the area drains to Lake Superior via the White tertiary watershed (AECOM, 2014). The terrain over nearly three-quarters of the Strickland pluton in the Nameigos Lake area is classified as bedrock-drift complex indicating that the overburden is generally thin and outcrops are common (Figure 2.3). Steep slopes account for a very small percentage (~7%) of the surface area (AECOM, 2014). Access to the potential potentially suitable area is excellent as Highway 631 traverses the area and forest resource roads are present in the northern portion of the area (Figure 1.1).

In summary, the Nameigos Lake general potentially suitable area in the Strickland pluton appears to be potentially suitable based on its favourable geology, structural geology and lineament density. The potentially suitablearea is within a massive intrusion of suitable lithology, contains sufficient area for a repository, has a low interpreted lineament density, and has low potential for economically exploitable natural resources (Figures 3.4 and 7.4). The terrain in the area consists primarily of bedrock outcrop or thin drift allowing for site characterization.

The uncertainties associated with the general area identified in the Strickland pluton relate to the lack of detailed geologic mapping, the low resolution of available geophysical data, the potential presence of smaller-scale dykes not identifiable on aeromagnetic data and the potential damage of the host rock due to dyke emplacement. The potential impact of a mapped fault in the area would require further assessment.

7.2.4 Other Areas

The Black-Pic batholith occupies a large area in the northwest quadrant of the White River area. Geological mapping (Figure 3.4) and mineral exploration have shown that the batholith contains numerous small fragments of greenstone and gabbroic intrusions in the White River area. Given the geographic extent of this batholith in the White River area, it may be possible to identify additional general potentially suitable areas; for example, along Kabossakwa and Matthews lakes, there may be areas with potential, considering the low lineament density and bedrock at or near surface around those lake areas. Nevertheless, the four general areas identified are those judged to best meet the preferred geoscientific characteristics outlined in Section 7.1, based on available information.

7.2.5 Summary of Geoscientific Characteristics of the General Potentially Suitable Areas

Table 7.1 provides a summary of the key geoscientific descriptive characteristics of the general potentially suitable areas identified in the White River area.

Table 7.1 Summary Characteristics of the General Potentially Suitable Areas – White River Area

Geoscientific Descriptive Characteristic	**General Potentially Suitable Areas**			
	Pukaskwa batholith – foliated tonalite (SW Pukaskwa area)	**Anahareo Lake pluton and gneissic tonalite (Negwazu Lake area)**	**Anahareo Lake pluton (Anahareo Lake area)**	**Strickland pluton (Nameigos Lake area)**
Composition	Gneissic tonalite-granodiorite	Granite-granodiorite and gneissic tonalite	Granite-granodiorite	Granite-granodiorite
Age	2.720-2.680 Ga	ca.2.720 - 2.680 Ga	ca.2.720 - 2.680 Ga	ca.2.720 - 2.680 Ga
Inferred host rock thickness	Unknown - Likely several kilometres	Unknown	Unknown	Unknown
Extent of geologic unit in the White River area	1,392 km^2	891 km^2	891 km^2	783 km^2

Table 7.1 Summary Characteristics of the General Potentially Suitable Areas – White River Area

Relative proximity to mapped structures (faults, shear zones, subprovince boundaries, etc)	Wawa-Quetico Subprovince boundary - 78 km to north Agawa Canyon Fault - 63 km to southeast Unnamed northeast-trending fault - 45 km to southeast No mapped faults in area Nearest mapped fault - 16 km to northwest	Wawa-Quetico Subprovince boundary - 74 km to north Agawa Canyon Fault - 37 km to southeast Unnamed northeast-trending fault – 20 km to southeast No mapped faults in area Nearest mapped fault - 12 km to north	Wawa-Quetico Subprovince boundary - 64 km to north Agawa Canyon Fault - 19 km to southeast Unnamed northeast-trending fault – 9 km to southeast One mapped northwest trending fault in area	Wawa-Quetico Subprovince boundary - 40 km to north Agawa Canyon Fault - 41 km to southeast Unnamed northeast-trending fault - 29 km to southeast One mapped northwest trending fault in area
Structure: faults, foliation, dykes, joints	Low to moderate apparent surficial lineament density Low apparent geophysical lineament density No mapped faults in area Several mapped dykes – well defined orientations	Low apparent surficial lineament density Low apparent geophysical lineament density No mapped faults in area Several mapped dykes – well defined orientations	Low to moderate apparent surficial lineament density Low apparent geophysical lineament density One mapped northwest-trending fault in area Several mapped dykes – well defined orientations	Low apparent surficial lineament density Low apparent geophysical lineament density One mapped northwest-trending fault in area Several mapped dykes – well defined orientations
Aeromagnetic characteristics and resolution	Moderately noisy	Quiet	Moderately noisy	Quiet
Terrain: topography, vegetation	Moderate relief, boreal forest; logged areas; bedrock-drift complex and glaciofluvial terrain	Moderate relief, boreal forest; bedrock-drift complex and glaciofluvial terrain	Low to moderate relief, boreal forest; logged areas; bedrock-drift complex and glaciofluvial terrain	Low to moderate relief, boreal forest; logged areas; bedrock-drift complex, minor glaciofluvial and glaciolacustrine terrain
Access	Two local roads provide access to southern half of area. Numerous forest resource roads throughout area	Trans-Canada Highway 1 km to west of area Highway 631 parallels northern boundary 3 km to north of area Rail line traverses southern part of area Few forestry trails	Highway 631 7 km to northeast of area Numerous forest resource roads throughout area	Highway 631 traverses western side of area Forest resource roads provide access to northern portion of area
Resource potential	Low	Low	Low	Low
Overburden cover *	~16%	~24%	~17%	~28%

Table 7.1 Summary Characteristics of the General Potentially Suitable Areas – White River Area

Drainage	Good; Area within White tertiary watershed; drains to Lake Superior	Good; straddles continental divide Western ~80% of area drains to west; within White tertiary watershed; drains to Lake Superior Eastern ~20% of area drains to northeast; within Upper Kabinakagami tertiary watershed; drains to James Bay	Good; Area within Upper Kabinakagami tertiary watershed; drains to James Bay	Good; straddles continental divide Southwestern 20% of area drains northwest; within White tertiary watershed; drains to Lake Superior Northwestern 25% of area drains to north; within Nagagami tertiary watershed; drains to James Bay Eastern ~55% of area drains to northeast; Kabinakagami tertiary watershed; drains to James Bay

*Estimated percentage of area outside of bedrock terrain, as mapped on Figure 2.3.

7.3 Evaluation of the General Potentially Suitable Areas in the White River Area

This section provides a brief description of how the identified potentially suitable areas were evaluated to verify whether they have the potential to satisfy the geoscientific safety functions outlined in NWMO's site selection process (NWMO, 2010). At this early stage of the site evaluation process, where limited geoscientific information is available, the intent is to assess whether there are any obvious conditions within the identified potentially suitable areas that would fail to satisfy the geoscientific safety functions. These include:

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

The evaluation factors under each safety function are listed in Appendix A. An evaluation of the four general potentially suitable areas in the White River area is provided in the following subsections.

7.3.1 Safe Containment and Isolation of Used Nuclear Fuel

The geological, hydrogeological, chemical and mechanical characteristics of a suitable site should promote long-term isolation of used nuclear fuel from humans, the environment and surface disturbances; promote long-term containment of used nuclear fuel within the repository; and restrict groundwater movement and retard the movement of any released radioactive material.

This requires that:

- The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events;
- The volume of available competent rock at repository depth should be sufficient to host the repository and provide sufficient distance from active geological features such as zones of deformation or faults and unfavourable heterogeneities;
- The hydrogeological regime within the host rock should exhibit low groundwater velocities;
- The mineralogy of the rock, the geochemical composition of the groundwater and rock porewater at repository depth should not adversely impact the expected performance of the repository multiple-barrier system;
- The mineralogy of the host rock, the geochemical composition of the groundwater and rock porewater should be favourable to retarding radionuclide movement; and
- The host rock should be capable of withstanding natural stresses and thermal stresses induced by the repository without significant structural deformations or fracturing that could compromise the containment and isolation functions of the repository.

The above factors are interrelated as they contribute to more than one safety function. The remainder of this section provides an integrated assessment of the above factors based on information that is available at the desktop stage of the evaluation.

As discussed in Section 3 and summarized in Table 7.1, available information reviewed as part of this preliminary assessment indicates that the thickness of the Pukaskwa batholith, and Anahareo Lake and Strickland plutons in the White River area are unknown but are estimated to be well in excess of 1 km. The Pukaskwa batholith is believed to extend to a depth of >3 km based on its size and an understanding of the regional geologic history and structure. No information exists on the thickness of the Anahareo Lake and Strickland plutons, but their areal extent and late stage emplacement suggest that these intrusions are likely to extend below typical repository depth (approximately 500 m). Therefore, the depth of the rock in the four potentially suitable areas would contribute to the isolation the repository from human activities and natural surface events.

Analysis of lineaments interpreted during this preliminary assessment (Section 3.2.3 and SRK, 2014) indicates that the four areas in the White River area warrant further consideration as they have the potential to contain rock volumes of sufficient size to host a deep geological repository. Given the potential for lithological homogeneity of the Pukaskwa batholith and the Anahareo Lake and Strickland plutons, zones of lower lineament density were the favoured locations for the identified general areas. Within the four general areas, the spacing between longer lineaments (>10 km) was an additional consideration since these were most likely to appear in multiple data sets, and hence most likely to represent real features with a potential to extend to repository depth. In these general potentially suitable areas, longer lineaments occurred with spacing on the order of 1.5 to >6 km, suggesting there is potential for sufficient volumes of structurally favourable rock at typical repository depth.

The hydrogeological regime at repository depth should exhibit low groundwater velocities and retard the movement of any potentially released radioactive material. There is no information on the hydrogeologic properties of the deep granitic bedrock in the White River area. It is therefore not possible at this stage of the evaluation to predict the nature of the groundwater regime at repository depth in the four areas. The potential for groundwater movement at repository depth is, in part, controlled by the fracture frequency, the degree of interconnection, and the extent to which the fractures are sealed due to higher stress levels and the presence of mineral infilling. Deeper into the bedrock, fracture frequency in a mass of rock will tend to decline, and eventually, the groundwater movement will be diffusion-dominated. However, fracture networks associated with deep faults and shear zones will influence advective groundwater flow around bodies of rock characterized by diffusion limited conditions. As such, in the White River area, it can be expected that features such as long regional faults will be important in the deep groundwater flow system.

Experience from other areas in the Canadian Shield indicates that ancient faults, similar to those in the White River area, have been subjected to extensive periods of rock-water interaction resulting in the long-term deposition of infilling materials that contribute to sealing and a much reduced potential for groundwater flow at depth. Site-specific conditions that can influence the nature of deep groundwater flow systems in the White River area would need to be investigated at later stages of the site evaluation process through site characterization activities that include drilling and testing of deep boreholes.

As discussed in Section 4.4, available information for other granitic intrusions (plutons and batholiths) within the Canadian Shield, indicates that active groundwater flow within structurally-bounded blocks tends to be generally limited to shallow fracture systems, typically less than 300 m. In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson *et al*., 1996; McMurry *et al*., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson *et al*., 1996; McMurry *et al*., 2003). Hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell Research Area and Atikokan range from approximately 10^{-10} to 10^{-15} m/s (Stevenson *et al*., 1996; Ophori and Chan, 1996). Data reported by Raven *et al*. (1985) show that the hydraulic conductivity of the East Bull Lake pluton decreases from an average near-surface value of 10^{-8} m/s to less than 10^{-12} m/s below a depth of 400 to 500 m.

Information on other geoscientific characteristics relevant to the containment and isolation functions of a deep geological repository, such as the mineralogy of the rock, the geochemical composition of the groundwater and rock porewater, and the thermal and geomechanical properties of the rock is largely lacking for the White River area. The review of available information from other locations, with similar geological settings, did not reveal any obvious conditions that would suggest unfavourable mineralogical or hydrogeochemical characteristics for the granitic plutonic rocks characterizing the four areas identified within the White River area (Sections 4.0 and 7.2). Mineralogical and hydrogeochemical characteristics, including pH, Eh, and salinity would need to be assessed during subsequent site evaluation stages. Similarly, it is expected that the geomechanical and thermal characteristics of the granitic intrusions within the White River area may resemble those of other granitic bodies (i.e., the Lac du Bonnet batholith) elsewhere in the Superior Province (Section 6.0) with no obvious unfavourable conditions known at present. These characteristics would need to be assessed during subsequent site evaluation stages.

Dykes associated with Matachewan, Biscotasing and Marathon dyke swarms have been mapped and/or were identified during the lineament analysis of the White River area. At this desktop stage of the investigation, information about the hydraulic and thermal conductivity properties is lacking, and there is uncertainty as to whether the existence of dykes will have a positive or negative impact on the thermal conductivity of the surrounding host rocks. In addition, the potential existence of thin/narrow dykes, which are too small to be identified with any confidence from the geophysical data, or the presence of damage to the host rock (i.e., additional smaller lineaments) associated with dyke emplacement cannot be ruled out at this time. These aspects of uncertainty will need to be studied in further detail at later stages if the community remains in the site selection process.

In summary, the review of available geoscientific information, including completion of a lineament analysis and geophysical interpretation of the area, did not reveal any obvious conditions that would cause the rejection of any of the four identified areas on the basis of them not satisfying the containment and isolation requirements demanded of a repository. Potential suitability of these areas would have to be further assessed during subsequent site evaluation stages.

7.3.2 Long-term Resistence to Future Geological Processes and Climate Change

The containment and isolation functions of the repository should not be unacceptably affected by future geological processes and climate changes, including earthquakes and glacial cycles.

The assessment of the long-term stability of a suitable site would require that:

- Current and future seismic activity at the repository site should not adversely impact the integrity and safety of the repository system during operation and in the very long-term;
- The expected rates of land uplift, subsidence and erosion at the repository site should not adversely impact the containment and isolation functions of the repository;
- The evolution of the geomechanical, hydrogeological and geochemical conditions at repository depth during future climate change scenarios such as glacial cycles should not have a detrimental impact on the long-term safety of the repository; and
- The repository should be located at a sufficient distance from geological features such as zones of deformation or faults that could be potentially reactivated in the future.

A full assessment of the above factors requires detailed site-specific data that would be typically collected and analyzed through detailed field investigations. The assessment would include understanding how the site has responded to past glaciations and geological processes and would entail a wide range of detailed studies involving disciplines such as seismology, hydrogeology, hydrogeochemistry, paleohydrogeology and climate change. At this desktop preliminary assessment stage of the site evaluation process, the long-term stability factor is evaluated by assessing whether there is any evidence that would raise concerns about the long-term stability of the four general potentially suitable areas identified in the White River area. The remainder of this section provides an integrated assessment of the factors listed above.

The White River area is located in the Superior Province of the Canadian Shield, where large portions of land have remained tectonically stable for the last 2.5 billion years (Percival and Easton, 2007). Although a number of low magnitude seismic events (i.e., less than magnitude 3) have been recorded in the surrounding region, there are no recorded earthquakes with the White River area (Figure 3.19).

A significant nearby regional feature is the east trending Wawa-Quetico subprovince boundary, located approximately 30 km north of the area (Figure 3.3). In addition, several mapped faults are present within the White River area (Figure 3.4). There is no evidence to suggest these faults have been tectonically active within the past 1.100 Ga. The youngest major event of brittle fault displacement is constrained by the ca. 1.100 Ga Keweenawan dykes that transect the White River area with no apparent fault offset. This suggests that only limited displacement could have occurred along the interpreted fault network since the intrusion of these dykes. The structural geology of the White River area and associated fracture network will require additional assessments and field evaluations.

The geology of the White River area is typical of the Canadian Shield, which has been subjected to numerous glacial cycles during the last million years. Glaciation is a significant past perturbation that could occur again in the future. However, findings from studies conducted in other areas of the Canadian Shield suggest that deep crystalline units, particularly plutonic intrusions, have remained largely unaffected by past perturbations such as glaciation (e.g., Laine, 1980; 1982; Bell and Laine, 1985). Findings of a comprehensive paleohydrogeological study of the fractured crystalline rock at the Whiteshell Research Area, located within the Manitoba portion of the Canadian Shield (Gascoyne, 2004), indicated that the evolution of the groundwater flow system was characterized by periods of long-term hydrogeological and hydrogeochemical stability. Furthermore, there is evidence that only the upper 300 m shallow groundwater zone has been affected by glaciations within the last million years. McMurry *et al.* (2003) summarized several studies conducted in a number of plutons in the Canadian Shield and in the crystalline basement rocks of western Ontario. These various studies found that fractures below a depth of several hundred metres in the plutonic rock were ancient features. Subsequent geological processes such as plate movement and continental glaciation have typically caused reactivation of existing zones of weakness rather than the formation of large new zones of fractures.

The White River area is still experiencing isostatic rebound following the end of the Wisconsinan glaciations. Current rates of isostatic uplift in the White River area are not precisely known, although Lee and Southam (1994) estimated that the land is rising at a rate of 2.9 mm/a at Michipicoten, Ontario, some 150 km to the southeast.

There is no site-specific information on erosion rates for the White River area. However, as discussed in Section 3.1.6, the erosion rates from wind, water, and past glaciations on the Canadian Shield are reported to be low, and are unlikely to affect the integrity of a deep geological repository in the White River area in the long-term.

In summary, available information indicates that the identified areas in the White River area have the potential to meet the long-term stability factor. The review did not identify any obvious conditions that would cause the performance of a repository to be substantially altered by future geological and climate change processes, or prevent the identified areas from remaining stable over the long-term. The long-term stability factor would need to be further assessed through detailed multidisciplinary site specific geoscientific and climate change site investigations.

7.3.3 Safe Construction, Operation and Closure of the Repository

The characteristics of a suitable site should be favourable for the safe construction, operation, closure, and long-term performance of the repository.

This requires that:

- The available surface area should be sufficient to accommodate surface facilities and associated infrastructure;
- The strength of the host rock and *in-situ* stress at repository depth should be such that the repository could be safely excavated, operated and closed without unacceptable rock instabilities; and
- The soil cover depth over the host rock should not adversely impact repository construction activities.

There are few surface constraints that would limit the construction of surface facilities in the four general potentially suitable areas identified in the White River area. These areas are characterized by low to moderate relief and each contains enough surface land outside protected areas and major water bodies to accommodate the required repository surface facilities.

From a constructability perspective, limited site-specific information is available on the local rock strength characteristics and *in-situ* stresses for the White River area. However, there is abundant information at other locations of the Canadian Shield that could provide insight into what might be expected for the White River area in general. As discussed in Section 6.0, available information suggests that granitic and gneissic crystalline rock units within the Canadian Shield generally possess good geomechanical characteristics that are amenable to the type of excavation activities involved in the development of a deep geological repository for used nuclear fuel (Arjang and Herget, 1997; Everitt, 1999; McMurry *et al*., 2003; Chandler *et al*., 2004).

The four general potentially suitable areas are situated in areas having a reasonable amount of outcrop exposure. At this stage of the site evaluation process it is not possible to accurately determine the exact thickness of the overburden deposits in these areas due to the low resolution of available data. However, it is anticipated that overburden cover is not a limiting factor in any of the identified general potentially suitable areas.

In summary, the four general potentially suitable areas in the White River area have good potential to meet the safe construction, operation, closure and long-term performance factors required of a repository.

7.3.4 Isolation of Used Fuel from Future Human Activities

A suitable site should not be located in areas where the containment and isolation functions of the repository are likely to be disrupted by future human activities.

This requires that:

- The repository should not be located within rock formations containing economically exploitable natural resources such as gas/oil, coal, minerals and other valuable commodities as known today; and
- The repository should not be located within geological formations containing groundwater resources at repository depth that could be used for drinking, agriculture or industrial uses.

In the White River area, the Dayohessarah and Kabinakagami greenstone belts have the greatest mineral potential, with the bedrock comprising the felsic batholiths and plutons having low potential (Section 5.0). No known or significant economic mineralization has been identified to date in the Pukaskwa batholith, the Anahareo Lake pluton, and the Strickland pluton within the White River area. Active mining claims exist over the Pukaskwa batholith in area west of the settlement of White River; however, these claims have been staked only relatively recently and there is no history of exploration for the ground or reported mineral occurrences.

The review of available information did not identify any groundwater resources at repository depth for the White River area. As discussed in Section 4.0, water wells in the White River area obtain water from overburden or shallow bedrock sources with well depths ranging from 4.6 to 99.1 m. Experience from other areas in the Canadian Shield has shown that active groundwater flow in crystalline rocks is generally confined to shallow fractured localized systems (Singer and Cheng, 2002). Records contained in the Ontario Ministry of Environment databases indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the White River area or anywhere else in northern Ontario. Groundwater at such depths is generally saline and very low groundwater recharge at such depths limits potential yield, even if suitable water quality were to be found.

In summary, the potential for groundwater resources and economically exploitable natural resources at repository depth is considered low in the four identified areas within the White River area although this conclusion would be subjected to further confirmation if the community advances in the site selection process.

7.3.5 Amenability to Site Characterization and Data Interpretation Activities

In order to support the case for demonstrating long-term safety, the geologic conditions at a potential site must be amenable to site characterization and data interpretation. Factors affecting the amenability to site characterization include: geological heterogeneity; structural and hydrogeological complexity; accessibility, and the presence of lakes or overburden with thickness or composition that could mask important geological or structural features.

As described in Section 3, the bedrock in the two general potentially suitable areas largely within the Anahareo Lake pluton and the single area in the Strickland pluton is relatively homogeneous granite-granodiorite that will not be difficult to characterize. Similarly, the well-foliated tonalite to granodioritic rocks bedrock in the general potentially suitable area in the Pukaskwa batholith should not pose an impediment to site characterization.

Interpreted lineaments described in Section 7.1, represent the observable two-dimensional expression of three-dimensional features. The ability to detect and map such lineaments is influenced by topography, the character of the lineaments (e.g., their width, orientation, age, etc.), and the resolution of the data used for the mapping. The two factors that significantly influenced the lineament interpretation for the White River area are the low resolution magnetic geophyisical survey coverage for the majority of the area and the large extent of bedrock at or near surface across the area. The low resolution geophysical coverage is compensated, in part, by the thin overburden that enables the recognition of lineaments from satellite imagery and by the topographic data.

In the White River area, future mapping of geology and identification of geological structures will be strongly influenced by the extent and thickness of overburden cover and large lakes. Information on the thickness of overburden deposits within the White River area is derived from a terrain evaluation (AECOM, 2014), data within the MOE's water well records and MNDM's exploration drill hole database. These data indicate that the majority of the White River area has thin, but variable, drift cover. Extensive overburden deposits in the White River area are found in scattered pockets along the northern edge of the area, where glaciolacustrine and organic materials occupy lowland basins, and in south to southwest trending bedrock valleys that host glaciofluvial esker-outwash complexes.

Lakes in the White River area, while frequent, show a high density only in a limited number of local areas. In addition, lakes in the White River area are generally of modest size. The identified potentially suitable areas contain sufficient areas with exposed bedrock and limited surface water cover which would allow for surface bedrock mapping as part of a detailed site characterization.
Access to the four general potentially suitable areas ranges from good to excellent. In the case of the south western part of the Pukaskwa batholith local roads and forest roads cross the general potentially suitable area. The potentiallysuitable areas located mainly within the Anahareo Lake pluton area and in the Negwazu Lake area are accessible by trails branching off the Trans-Canada Highway to the west and Highway 631 to the north, in addition to a rail line that traverses southern part of area. The Anahareo Lake general potentially suitable area can be reached via numerous forest resource roads. The general potentially suitable area located within the Strickland Pluton is traversed by Highway 631 and a number of logging roads are present in the northern portion of the area.

The review of available information did not indicate any obvious conditions which would make the rock mass in the four identified areas unusually difficult to characterize. All areas have a high percentage of outcrop allowing for detailed surface mapping to support site characterization. No conditions were identified that would make site characterization unusually difficult at either of the areas.

8. GEOSCIENTIFIC PRELIMINARY ASSESSMENT FINDINGS

The objective of the Phase 1 geoscientific preliminary assessment was to assess whether the White River area contains general areas that have the potential to satisfy the geoscientific site evaluation factors outlined in NWMO's site selection process document (NWMO, 2010).

The preliminary geoscientific assessment built on the work previously conducted for the initial screening (Golder, 2012a) and focused on the Township of White River and its periphery, which are referred to as the "White River area" (Figure 1.1) in this report. The geoscientific preliminary assessment was conducted using available geoscientific information and key geoscientific characteristics that can be realistically assessed at this early stage of the site evaluation process. These include: geology; structural geology; interpreted lineaments; distribution and thickness of overburden deposits; surface conditions; and the potential for economically exploitable natural resources. For the White River area much of the geological mapping and geophysical survey are of regional scale and lack detail. Where information for the White River area was limited or not available, the assessment drew on information and experience from other areas with similar geological settings on the Canadian Shield. The desktop geoscientific preliminary assessment included the following review and interpretation activities:

- Detailed review of available geoscientific information such as geology, structural geology, natural resources, hydrogeology, and overburden deposits;
- Interpretation of available geophysical surveys (magnetic, electromagnetic, gravity, radiometric);
- Lineament studies using available satellite imagery, topography and geophysical surveys to provide information on the characteristics such as location, orientation, and length of interpreted structural bedrock features;
- Terrain analysis studies to help assess factors such as overburden type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones; and
- The identification and evaluation of general potentially suitable areas based on key geoscientific characteristics and the systematic application of NWMO's geoscientific site evaluation factors.

The desktop geoscientific preliminary assessment showed that the White River area contains at least four general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. Two of these areas are within the Anahareo Lake pluton, one is located in the Pukaskwa batholith, and one is located in the Strickland pluton.

The Pukaskwa batholith, Anahareo Lake pluton, and Strickland pluton hosting the four identified potentially suitable areas appear to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. They all appear to have sufficient depth and extend over large areas. The four general areas identified in the White River area have good bedrock exposure, low potential for natural resources and contain limited surface constraints.

While the identified general potentially suitable areas appear to have favourable geoscientific characteristics for hosting a deep geological repository, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. Main uncertainties include the low resolution of available geophysical data over most of the potentially suitable areas, the influence of regional structural features, and the presence of numerous dykes.

The identified potentially suitable areas are located away from regional structural features, such as the Quetico-Wawa Subprovince boundary. However, the potential impact of these regional features on the suitability of the four areas would need to be further assessed. The area contains numerous dykes. While the spacing between mapped and interpreted dykes and lineaments within the four potentially suitable areas appears to be favourable, the potential presence of smaller dykes not identifiable on geophysical data, and potential damage of the host rock due to the intrusion of dykes would need to be assessed.

Should the community of White River be selected by the NWMO to advance to Phase 2 study and remain interested in continuing with the site selection process, several years of progressively more detailed geoscientific studies would be required to confirm and demonstrate whether the White River area contains sites that can safely contain and isolate used nuclear fuel. This would include the acquisition and interpretation of higher resolution airborne geophysical surveys, detailed field geological mapping, and the drilling of deep boreholes.

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APPENDIX A

Geoscientific Factors

Safety Factors Performance Objectives Evaluation Factors to be Considered

Table 1: Safety Factors, Performance Objectives and Geoscientific Factors

Safety Factors	Performance Objectives	Evaluation Factors to be Considered
Containment and isolation characteristics of the host rock	1. The geological, hydrogeological and chemical and mechanical characteristics of the site should: • Promote long-term isolation of used nuclear fuel from humans, the environment and surface disturbances; • Promote long-term containment of used nuclear fuel within the repository; and • Restrict groundwater movement and retard the movement of any released radioactive material.	1.1 The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events. 1.2 The volume of available competent rock at repository depth should be sufficient to host the repository and provide sufficient distance from active geological features such as zones of deformation or faults and unfavourable heterogeneities. 1.3 The mineralogy of the rock, the geochemical composition of the groundwater and rock porewater at repository depth should not adversely impact the expected performance of the repository multi-barrier system. 1.4 The hydrogeological regime within the host rock should exhibit low groundwater velocities. 1.5 The mineralogy of the host rock, the geochemical composition of the groundwater and rock porewater should be favourable to retarding radionuclide movement. 1.6 The host rock should be capable of withstanding natural stresses and thermal stresses induced by the repository without significant structural deformations or fracturing that could compromise the containment and isolation functions of the repository.
	2. The containment and isolation functions of the repository should not be unacceptably affected by future geological processes and climate changes.	2.1 Current and future seismic activity at the repository site should not adversely impact the integrity and safety of the repository system during operation and in the very long-term. 2.2 The expected rates of land uplift, subsidence and erosion at the repository site should not adversely impact the containment and isolation functions of the repository. 2.3 The evolution of the geomechanical, hydrogeological and geochemical conditions at repository depth during future climate change scenarios such as glacial cycles should not have a detrimental impact on the long-term safety of the repository. 2.4 The repository should be located at a sufficient distance from geological features such as zones of deformation or faults.

Table 1: Safety Factors, Performance Objectives and Geoscientific Factors

Repository construction, operation and closure	**3.** The surface and underground characteristics of the site should be favourable to the safe construction, operation, closure and long-term performance of the repository.	3.1 The strength of the host rock and in-situ stress at repository depth should be such that the repository could be safely excavated, operated and closed without unacceptable rock instabilities. 3.2 The soil cover depth over the host rock should not adversely impact repository construction activities. 3.3 The available surface area should be sufficient to accommodate surface facilities and associated infrastructure.
Human intrusion	4. The site should not be located in areas where the containment and isolation functions of the repository are likely to be disrupted by future human activities.	4.1 The repository should not be located within rock formations containing economically exploitable natural resources such as gas/oil, coal, minerals and other valuable commodities as known today. 4.2 The repository should not be located within geological formations containing exploitable groundwater resources (aquifers) at repository depth.
Site characterization	5. The characteristics of the site should be amenable to site characterization and site data interpretation activities.	5.1 The host rock geometry and structure should be predictable and amenable to site characterization and site data interpretation.

APPENDIX B

Geoscientific Data Sources

Table 1: Summary of Geophysical Mapping Sources for the White River Area

Product	Source	Type	Line spacing / Sensor Height	Coverage	Acquired	Additional comments
Ontario #8	GSC	Fixed wing magnetic	805 m / 305 m	West part of White River area	1959	Incorporated into SMGA
Ontario #17	GSC	Fixed wing magnetic	805 m / 305 m	East part of White River area	1963	Incorporated into SMGA
Single master gravity and aeromagnetic data for Ontario (SMGA; GDS 1036)	OGS	Fixed wing magnetic	805m / 305m	Entire study area	1959	Reduced and leveled to common datum magnetic data. Data reprocessed in 1999.
GDS1205 Manitouwadge	OGS	Helicopter magnetic, FDEM	150 and 200m / 45m	Covers 160 km^2 (~3%) of White River area, located in northwest corner	1989 (published in 2002)	4-frequency Dighem IV system, flown for Noranda Exploration Company, Ltd.
GDS1207- Rev Hemlo Area	OGS	Helicopter magnetic, FDEM, VLF	100m /45m	Covers 140 km^2 (~3%) of White River area, located along the western boundary	1983 (published in 2002)	
GDS1024 - Rev Oba-Kapuskasing area, Ontario	OGS	Airborne magnetic and electromagnetic surveys	200 m / 45 m	Covers 75 km^2 (~1.5%) of White River area, located in northeast corner	1986 (published in 2003)	3-frequency Aerodat system
Ground Gravity (CGDB, SEP 2010)	GSC	Ground Gravity Measurements	5 to 15 km	Stations sparsely located over entire area	1946-2001	Good data quality, limited number of stations
AFRI No. 20004804	OGS Assessment Files	Helicopter magnetic, FDEM	100 m / 30m	Dayohessarah greenstone belt; Central White River area	2008	5-frequency Dighem system, flown for Corona Gold Corp.

Table 2: Summary of Geological Mapping Sources for the White River Area

Map Product	Title	Author	Source	Scale	Date	Coverage	Comments
Map 2022A	Diabase dyke swarms and related units in Canada and adjacent regions	Buchan, K.L. and Ernst, R.E.	Geological Survey of Canada	1:5,000,000	2004	Full	Large scale
Map 2129	Geology of the Dayohessarah Lake area, District of Algoma	Fenwick, K.G.	Ontario Department of Mines	1:26,720	1967	Partial	Accompanies ODM Geologic Report 49
Map 2355	Geology of the Kabinakagami Lake area, District of Algoma	Siragusa, G.M	Ontario Division of Mines	1:63,360	1977	Partial	Accompanies ODM Geologic Report 159
Map 2382	Geology of the Esnagi Lake area, District of Algoma	Siragusa, G.M	Ontario Geological Surveys	1:63,360	1978	Partial	Accompanies OGS Geologic Report 176
Map 2518	Surficial geology of northern Ontario	Sado,E.V. and Carswell, B.F	Ontario Geological Survey	1:1,200,000	1987	Full	Based on compilation of NOEGTS maps
Map 2543	Bedrock geology of Ontario, east-central sheet	Ontario Geological Survey	Ontario Geological Survey	1:1,000,000	1991	Partial	Geology of Ontario series
Map 2555	Quaternary geology of Ontario, east-central sheet	Barnett, P.J.,Henry,A.P. and Babuin,D.	Ontario Geological Survey	1:1 000,000	1991	Full	Based on compilation of NOEGTS maps
Map 2577	Tectonic assemblages of Ontario, east-central sheet	Ontario Geological Survey	Ontario Geological Survey	1:1,000,000	1992	Partial	Geology of Ontario series
Map 2614	Geological Compilation of the Eastern Half of the Schreiber-Hemlo greenstone belt	Muir, T.L.	Ontario Geological Survey	1:50,000	2000	N/A	West of Study Area
Map 2666	Precambrian geology compilation series – White River sheet	Santaguida, F.	Ontario Geological Survey	1:250,000	2001	Partial	OGS Compilation map
Map 2668	Precambrian geology compilation series - Hornepayne sheet	Johns, G.W., and McIlraith, S.	Ontario Geological Survey	1:250,000	2003	Partial	OGS Compilation map
Map 38c	Oba area, District of Algoma	Maynard, J.E.	Ontario Department of Mines	1:126,720	1928	Partial	Accompanies ODM Report, Vol. 38, pt. 6

Table 2: Summary of Geological Mapping Sources for the White River Area

Map 5094	Northern Ontario Engineering Geology Terrain Study, Data Base Map White River area	Gartner, J.F. an McQuay, D.F.	Ontario Geological Survey	1:100,000	1980	Partial	Map accompanies Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 61
Map 5095	Northern Ontario Engineering Geology Terrain Study, Data Base Map Kabinakagami Lake area	Gartner, J.F. an McQuay, D.F.	Ontario Geological Survey	1:100,000	1980	Partial	Map accompanies Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 62
Map 5096	Northern Ontario Engineering Geology Terrain Study, Data Base Map Pukaskwa Rive area	Gartner, J.F. an McQuay, D.F.	Ontario Geological Survey	1:100,000	1979	Partial	Map accompanies Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 72
Map 5097	Northern Ontario Engineering Geology Terrain Study, Data Base Map Goudreau area	Gartner, J.F. an McQuay, D.F.	Ontario Geological Survey	1:100,000	1979	Partial	Map accompanies Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 73
Map S265	Surficial geology of the Thunder Bay map area	Zoltai, S. C.	Ontario Department of Lands and Forests	1:506,880	1965	Full	Regional scale surficial map
P.1519	Ontario Mineral Potential, White River Sheet, Districts of Algoma and Thunder Bay	Springer, Janet	Ontario Geological Survey, Mineral Deposits Ser.	1:250,000	1977	Full	Black/white - some lineaments
P.3309	Precambrian geology of the Dayohessarah Lake area (north)	Stott, G., Mahoney, K.L. and Zwiers, W.G.	Ontario Geological Survey	1:20,000	1995	Partial	Covers Dayohessarah greenstone belt
P.3310	Precambrian geology of the Dayohessarah Lake area (central)	Stott, G., Mahoney, K.L. and Zwiers, W.G.	Ontario Geological Survey	1:20,000	1995	Partial	Covers Dayohessarah greenstone belt
P.3311	Precambrian geology of the Dayohessarah Lake area (south)	Stott, G., Mahoney, K.L. and Zwiers, W.G.	Ontario Geological Survey	1:20,000	1995	Partial	Covers Dayohessarah greenstone belt

Table 3: Summary of Geoscientific Databases for the White River Area

Database	Source / Description	Scale (Regional/Local)	Used? (Yes/No)
Abandoned Mines	Ministry of Northern Development and Mines. 2013. Abandoned Mines Inventory (AMIS).	Regional	No
Aggregate Data	Ontario Ministry of Natural Resources, Licence and permit list, 2013	Site	No
Bedrock Geology	Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release–Data 126 - Revision 1.	Site	Yes
Earthquake Data	Earthquakes Canada, 2013. Earthquake Search (On-line Bulletin). Natural Resources Canada, Geologic Survey of Canada	Regional	Yes
Exploration Data (Assessment Files)	Ministry of Northern Development and Mines. 2013. Assessment Files.	Site	Yes
Exploration Drill holes	Ministry of Northern Development and Mines. 2013, Diamond Drill Hole Database.	Site	Yes
Geochemical lake sediment and water data	Jackson, J.E. 2003. Ontario Geological Survey, Miscellaneous Release-Data Sets 110 and 116.	Regional	No
Geochemical lake sediment and water data	Friske, P.W.B., Hornbrook, E.H.W., Lynch, J.J., McCurdy, M.W., Gross, H., Galletta, A.C., Durham, C.C. 1991. National Geochemical Reconnaissance lake sediment and water data, northwestern Ontario (NTS 42C and 42F south). Geological Survey of Canada, Open File 2362.	Regional	Yes
Geochron	Geological Survey of Canada 2013. Geochron Database	Site	Yes
Geophysical Data	Natural Resources of Canada, 2013. Aeromagnetic and Electromagnetic data, Canadian Aeromagnetic Data Base, http://gdr.nrcan.gc.ca/aeromag/about_e.php	Regional	Yes

Table 3: Summary of Geoscientific Databases for the White River Area

Geophysical Data	Ontario Geological Survey, 2013. Geophysical Atlas of Ontario,	Regional	Yes
Geoscience Data	Natural Resources Canada. 2013. Geoscience Data Repository (GDR),	Regional	Yes
Geotechnical Records	Ontario Ministry of Transportation, 2013. GeoCres Files; Downsview, Ontario	Site	No
In-situ ground stresses	Arjang, B. 2004. CANMET Division Report MMSL 01-029 (TR).	Regional	Yes
Lineament Data	Shirota, J. and Barnett, P.J., 2004. Lineament Extraction from Digital Elevation Model (DEM) for the Province of Ontario; Ontario Geological Survey, Miscellaneous Release - Data 142.	Regional	No
Mineral deposits	Ontario Geological Survey 2011. Mineral Deposit Inventory-2011; Ontario Geological Survey, Mineral Deposit Inventory, December 2011 release.	Site	Yes
Mining Claims (CLAIMaps)	Ministry of Northern Development and Mines. 2013. Mining Lands Section: Ontario Mining Land Tenure Spatial Data.	Regional	Yes
Ontario Base Mapping	Land Information Ontario 2013. Ontario Ministry of Natural Resources	Regional	Yes
Quaternary Geology	Ontario Geological Survey, 1997. Quaternary Geology. Seamless coverage of the Province of Ontario: Ontario Geological Survey, Data Set 14.	Regional	Yes
Rock Geochemistry	Ontario Geological Survey. Miscellaneous Release—Data 250 Data from the PETROCH Lithogeochemical	Site	No
Stream Flow Data	Environment Canada. 2013. Water Survey of Canada	Regional	No

Table 3: Summary of Geoscientific Databases for the White River Area

Terrain Map	Ontario Geological Survey, Ministry of Northern Development and Mines, and Northeast Science and Information Section, Ministry of Natural Resources 2005. Digital Northern Ontario Engineering Geology Terrain Study (NOEGTS); Ontario Geological Survey, Miscellaneous Release Data 160.	Regional	Yes
Topographic Data	Natural Resources Canada. 2009. Canadian Digital Elevation Data, Government of Canada, Natural Resources Canada, Earth Sciences Sector, Centre for Topographic Information.	Regional	Yes
Water Information, Basemaps	Ministry of Natural Resources 2013. Land Information Ontario Data Warehouse.	Site	Yes
Water Well Data	Ontario Ministry of Environment. 2013. Water Well Information System (WWIS) Database.	Site	Yes

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Figure 1.2: Geoscience Mapping and Geophysical Coverage of the White River Area
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Figure 2.2: Elevation and Major Topographic Features of the White River Area
Figure 2.3: Terrain Features of the White River Area
Figure 2.4: Drainage Features of the White River Area
Figure 2.5: White River Area Land Ownership
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Figure 3.2: Terrane Subdivision of North Central Ontario
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Figure 3.4: Local Bedrock Geology of the White River Area

Figure 3.5: Geophysical Data Analysis Reduced to Pole Residual Magnetic Field in the White River Area
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Figure 3.7: Geophysical Data Analysis Bouguer Gravity Field with Station Locations in the White River Area
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Figure 3.9: Geophysical Lineaments of the White River Area
Figure 3.10: Ductile Features of the White River Area
Figure 3.11: Brittle and Dyke Lineaments of the White River Area
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Figure 3.13: Lineament Density Calculated for Lineaments in the White River Area
Figure 3.14: Lineament Density Calculated for Lineaments (>1 km) in the White River Area
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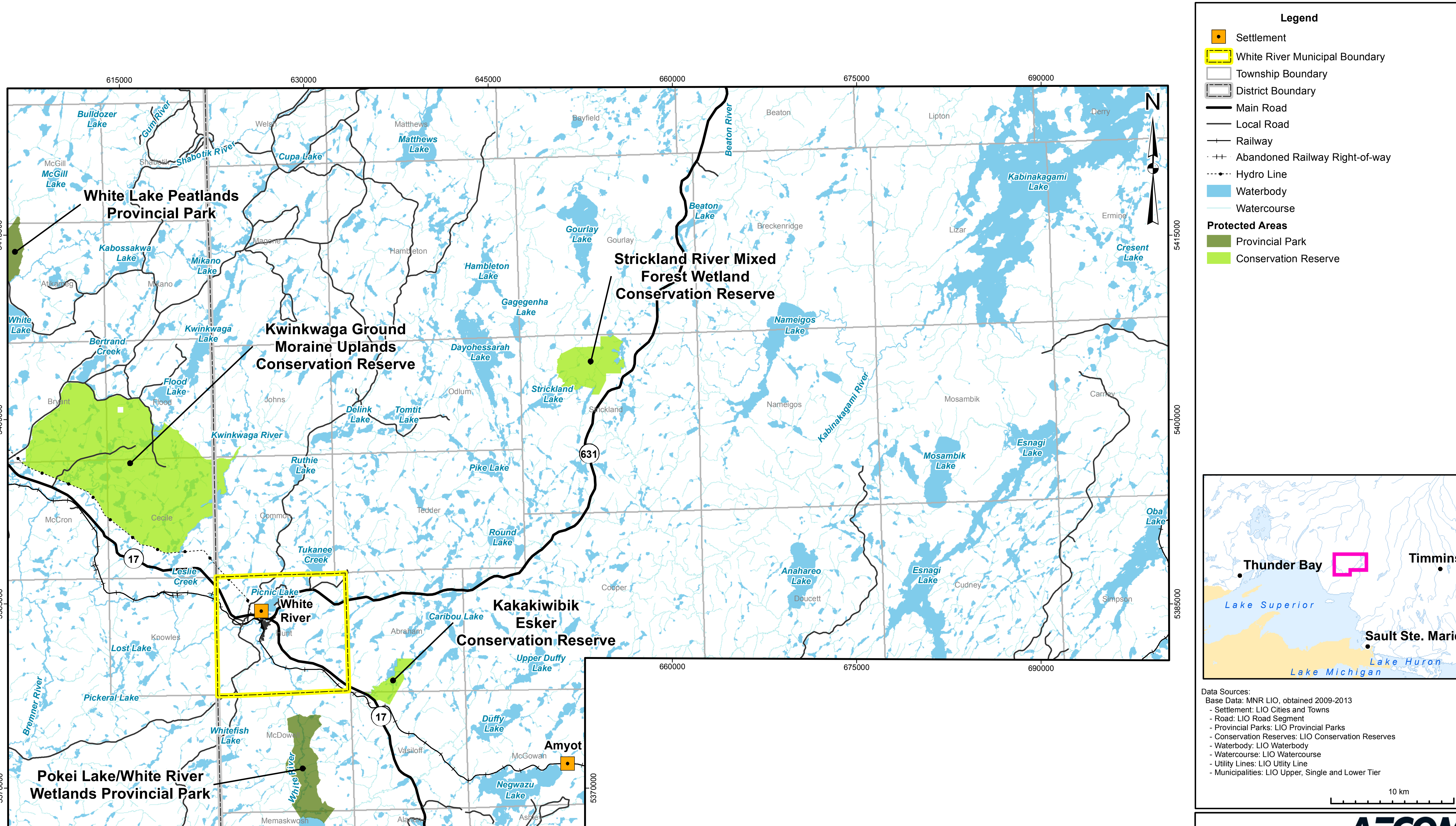
Figure 7.2: Key Geoscientific Characteristic of the Pukaskwa Batholith of the White River Area
Figure 7.3: Key Geoscientific Characteristic of the Anahareo Lake Pluton of the White River Area
Figure 7.4: Key Geoscientific Characteristic of the Strickland Pluton of the White River Area



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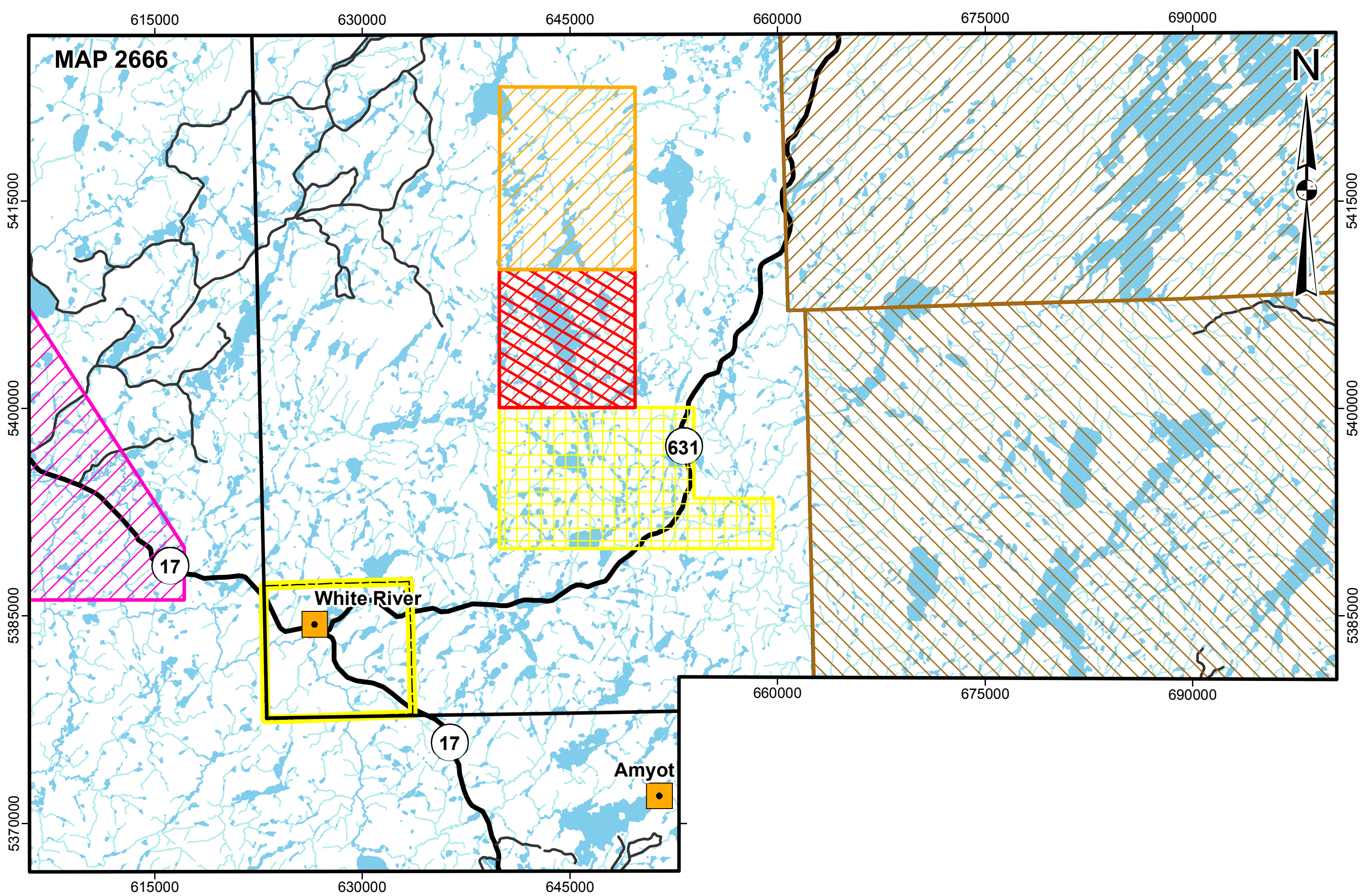
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Township of White River and Surrounding Area

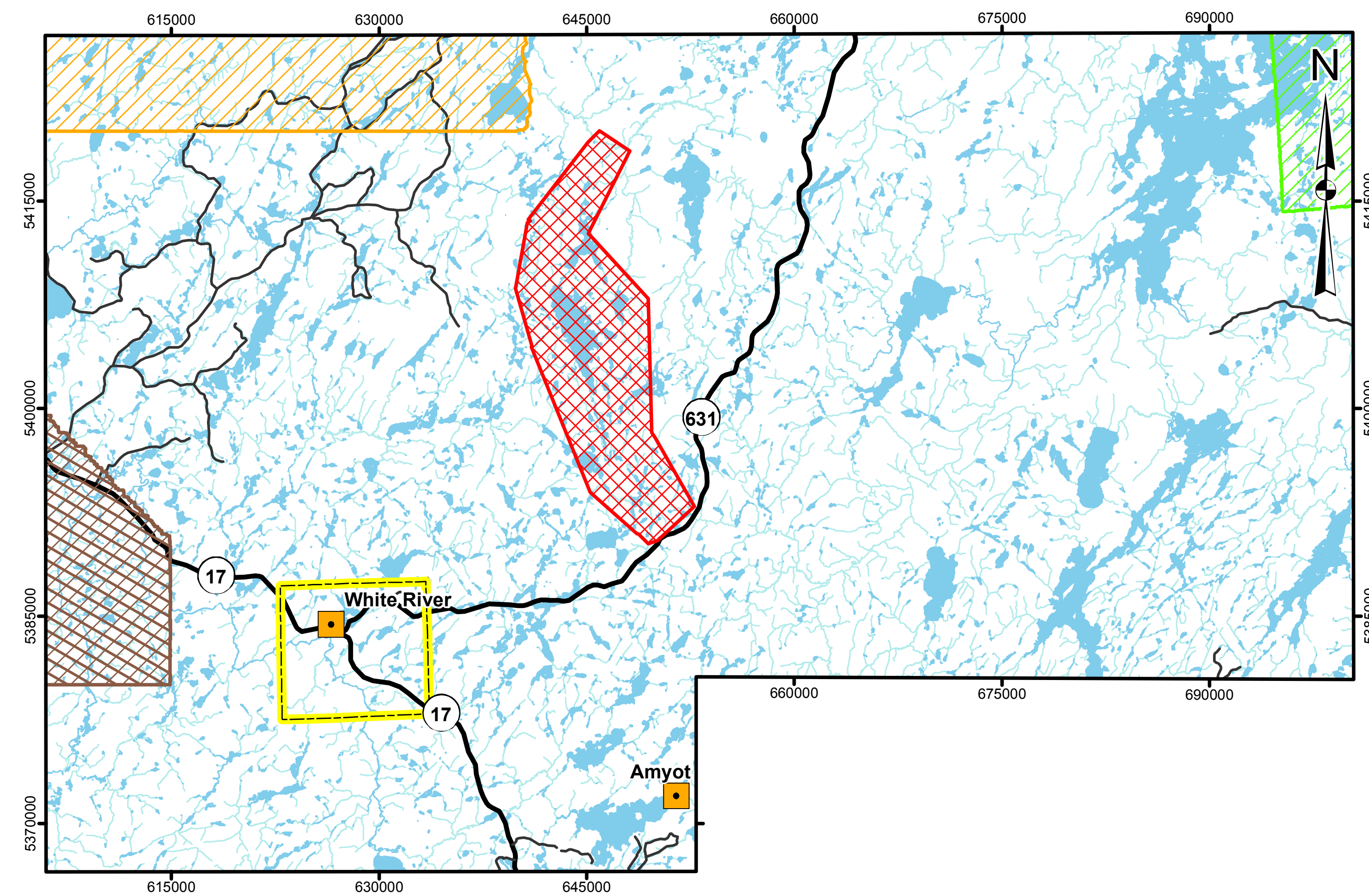
DESIGN	KR	23 AUG 2013	Figure 1.1	REVISION 1
GIS	GF	29 AUG 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 1.1 Township of White River and Surrounding Area.mxd

Geology Mapping Coverage



Geophysics Mapping Coverage



Legend

- Settlement
- White River Municipal Boundary
- Main Road
- Local Road
- Waterbody

Detailed Geological Extent

- Fenwick M2129
- Muir M2614
- Siragusa M2355
- Siragusa M2382
- Stott et al., P3309
- Stott et al., P3310
- Stott et al., P3311

Full Geology Coverage
OGS Bedrock Geology of Ontario 2011 (MRD-126)
OGS Surficial Geology (MRD-160)
OGS M2666 (1:250,000)(

Full Geophysics Coverage
Single Master Gravity and Aeromagnetics:
OGS GDS1036
Gravity Coverage: Canadian Gravity Anomaly Database

Data Sources:
Base Data: MNR LIO, obtained 2009-2013

Legend

- Settlement
- White River Municipal Boundary
- Main Road
- Local Road
- Waterbody

Detailed Geophysical Extent

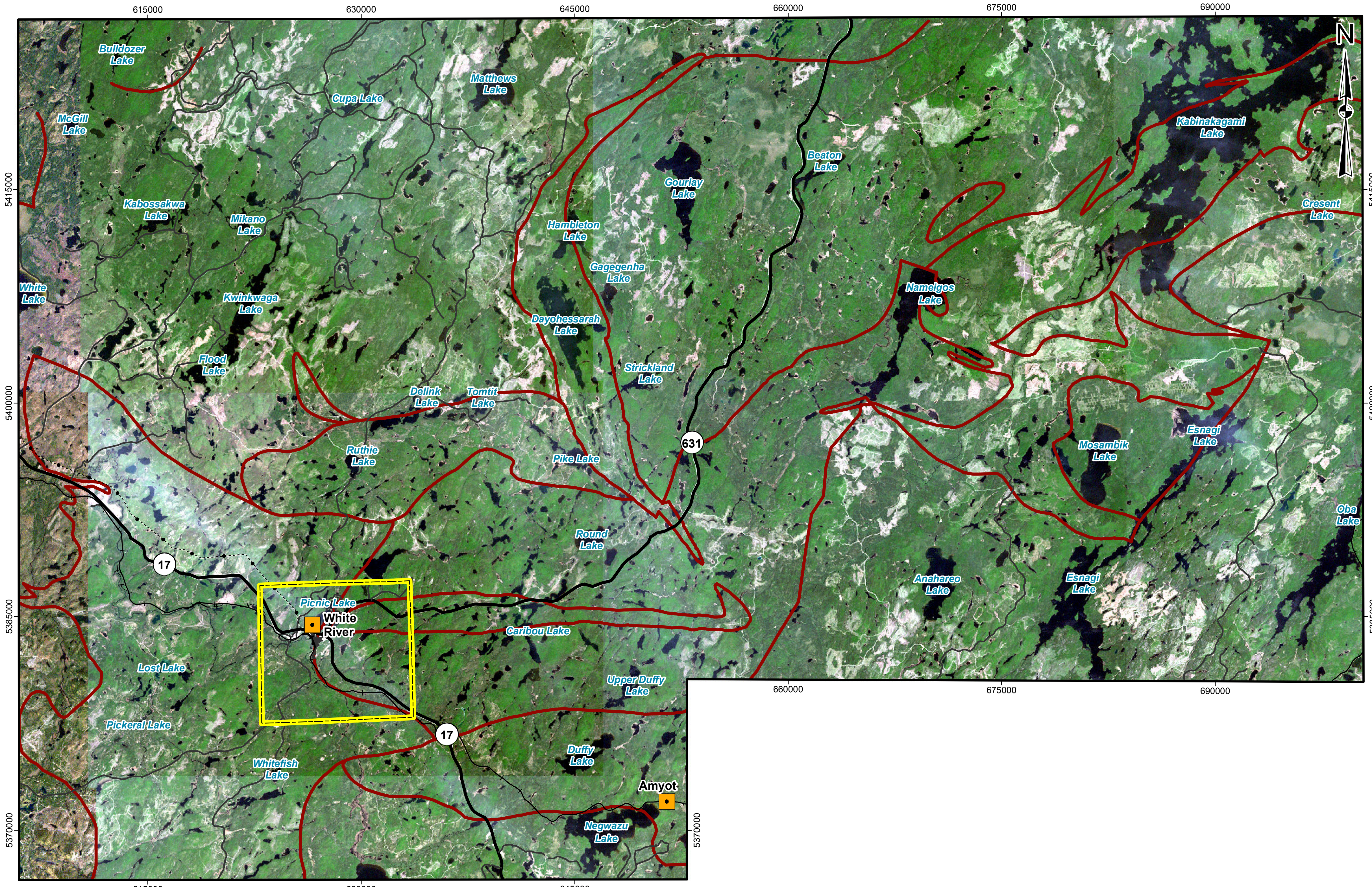
- OGS GDS1024
- OGS GDS1205
- OGS/GSC GDS1207-REV
- Mineral Exploration Survey

10 km

AECOM

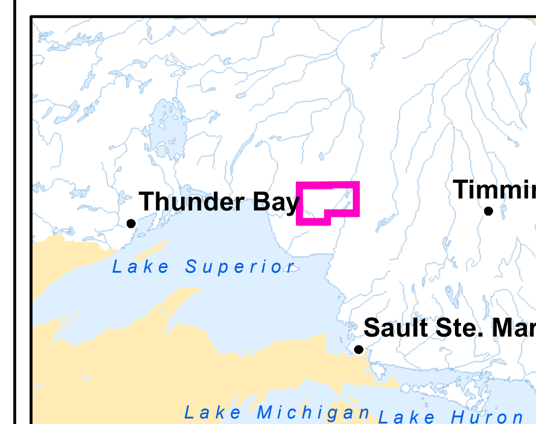
PROJECT	Preliminary Assessment of Geoscientific Suitability Phase 1 Desktop Study			
TITLE	Geoscience Mapping and Geophysical Coverage of the White River Area			
DESIGN	GHF	14 Jun 2013	FIGURE 1.2	REVISION 4
GIS	GHF	24 SEP 2013		UTM ZONE 16
CHECK	CB			NAD 1983
REVIEW	CB			1:500,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 1.2 - Geoscience Mapping and Geophysical Coverage of the White River Area.mxd



Legend

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



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Imagery: NRCAN CanImage - Landsat 7 Orthoimage
Composite of; Band 1 (Blue), Band 2 (Green), Band 3 (Red)
Obtained from GeoGratis (1:50,000)
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)

10 km

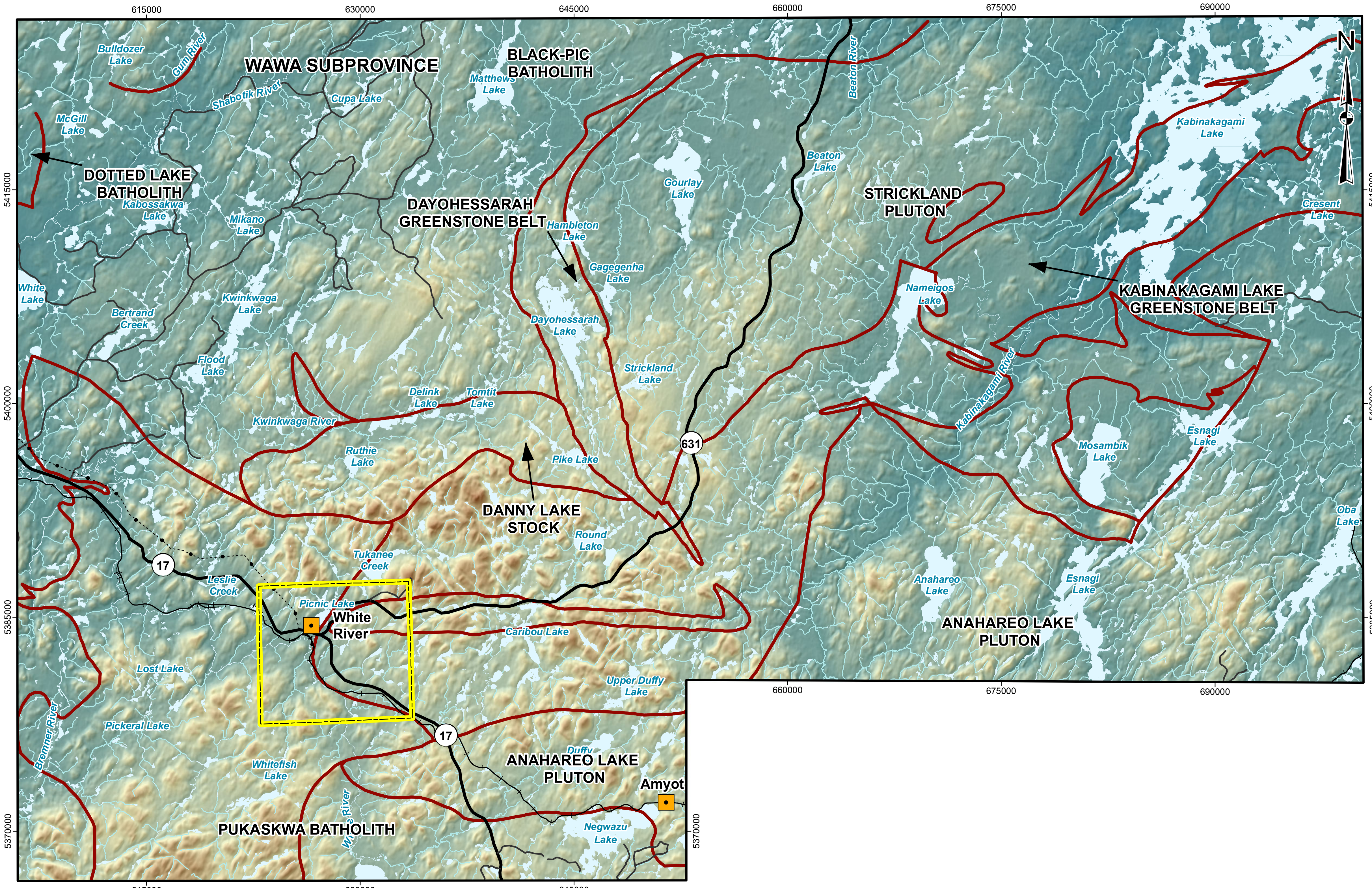
AECOM

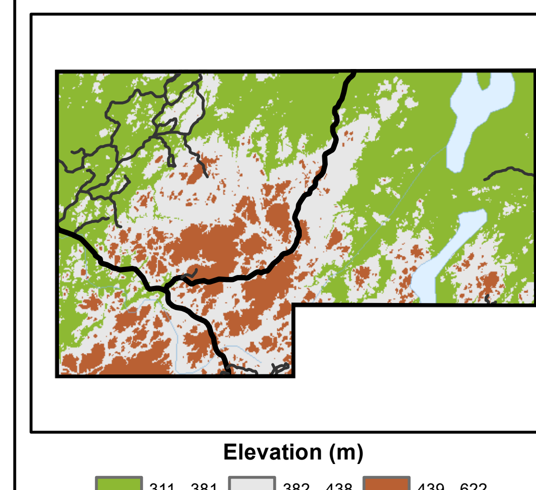
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Satellite Imagery of the White River Area

DESIGN	KR	23 Apr 2013	**Figure 2.1**	REVISION 1
GIS	KR	10 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 2.1 Satellite Imagery of the White River Area.mxd





Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Elevation and Slope: Ontario Ministry of Natural Resources
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)
Underlay: Hillshade DEM, MNR Elevation and Slope

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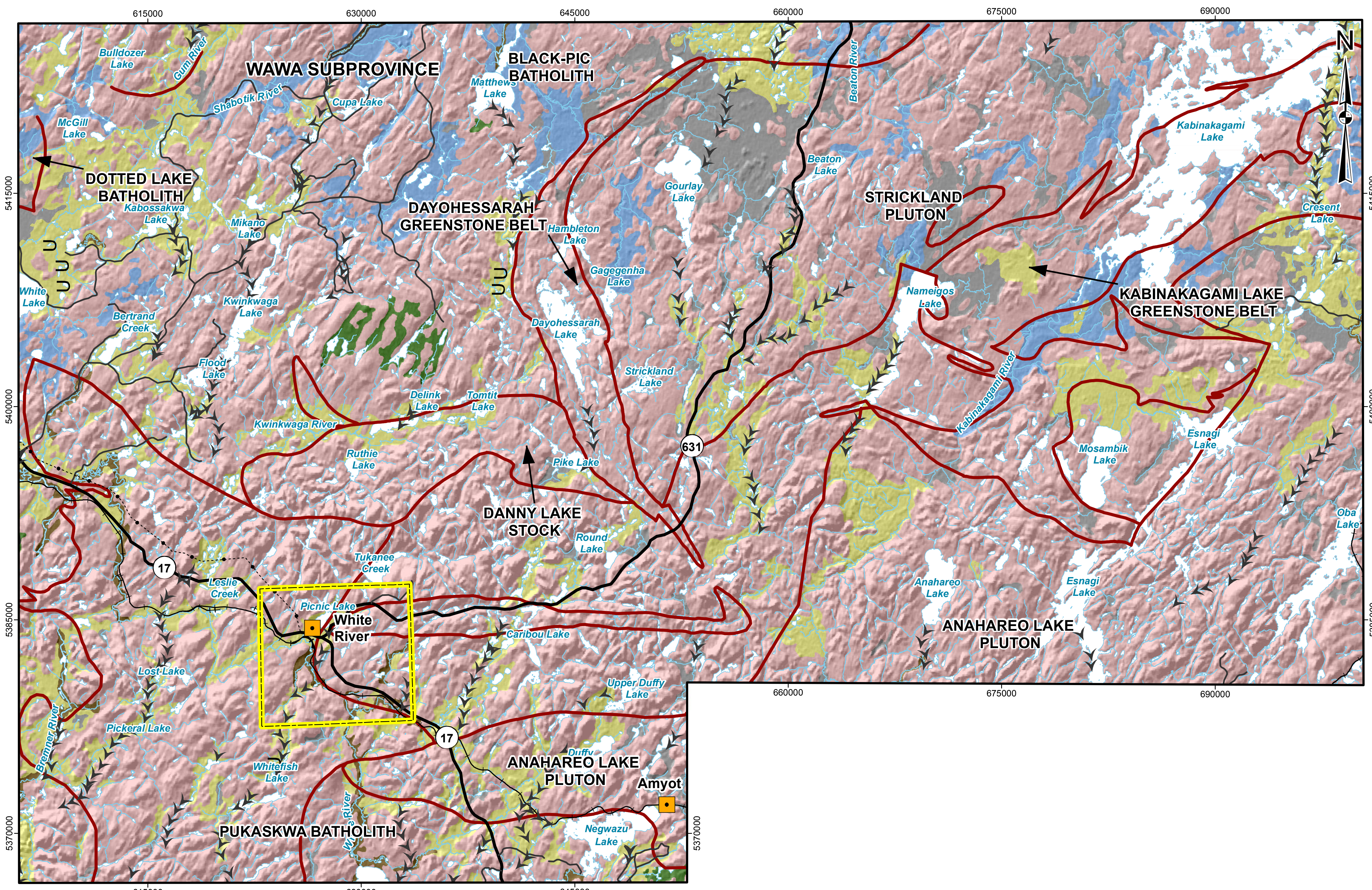
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Elevation and Major Topographic Features of the White River Area

DESIGN	KR	23 APR 2013	**Figure 2.2**	REVISION 1
GIS	GF	16 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 2.2 Elevation and Major Topographic Features of the White River Area.mxd



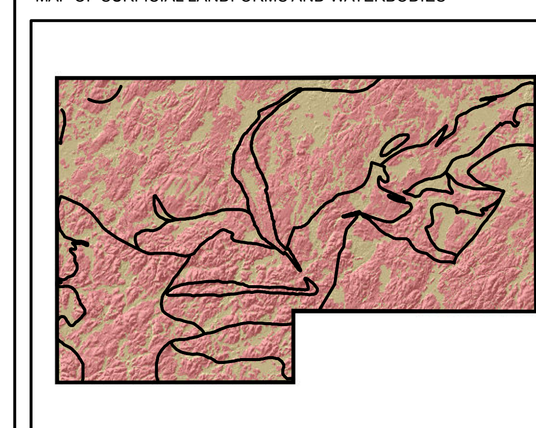
Legend

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

Surficial Geology

- Morainal Terrain
- Glaciofluvial Terrain
- Glaciolacustrine Terrain
- Alluvial Terrain
- Organic Terrain
- Bedrock Terrain
- Sand Dunes
- Eskers

MAP OF SURFICIAL LANDFORMS AND WATERBODIES



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Overburden: OGS MRD-160, NOEGTS 2006
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)
Underlay: Hillshade DEM, MNR Elevation and Slope

10 km

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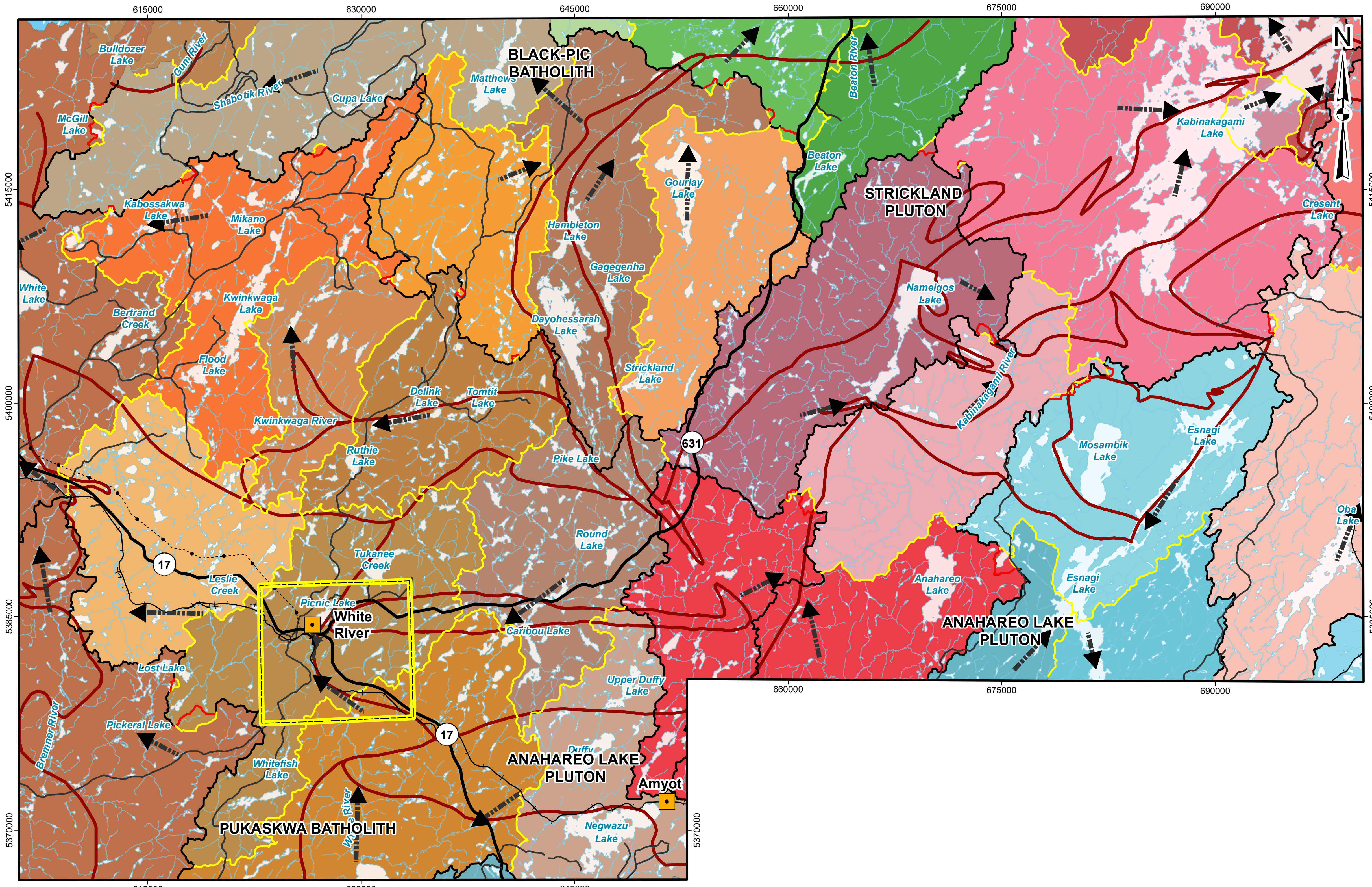
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Terrain Features of the White River Area

DESIGN	KR	23 Apr 2013	Figure 2.3	REVISION 1
GIS	KR	16 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 2.3 Terrain Features of the White River Area.mxd



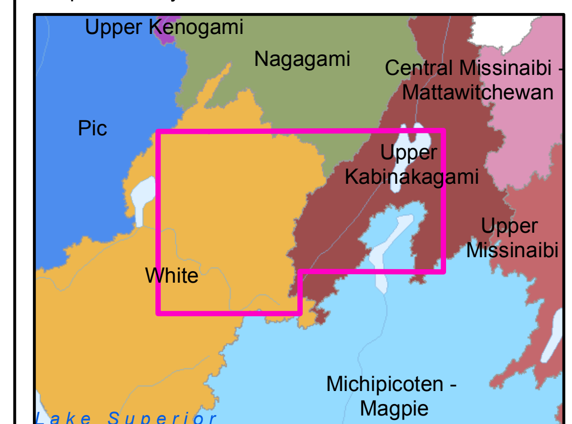
Legend

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

Quaternary Level Drainage Divides

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

Map of Tertiary Watersheds



Tertiary Watershed

- Central Missinaibi - Mattawitchewan
- Michipicoten - Magpie
- Nagagami
- Pic
- Upper Kabinakagami
- Upper Kenogami
- Upper Missinaibi
- White

Data Sources:
Base Map: MNR LIO, obtained 2009-2013
Watersheds: MNR Quaternary, Tertiary Watersheds
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)

10 km

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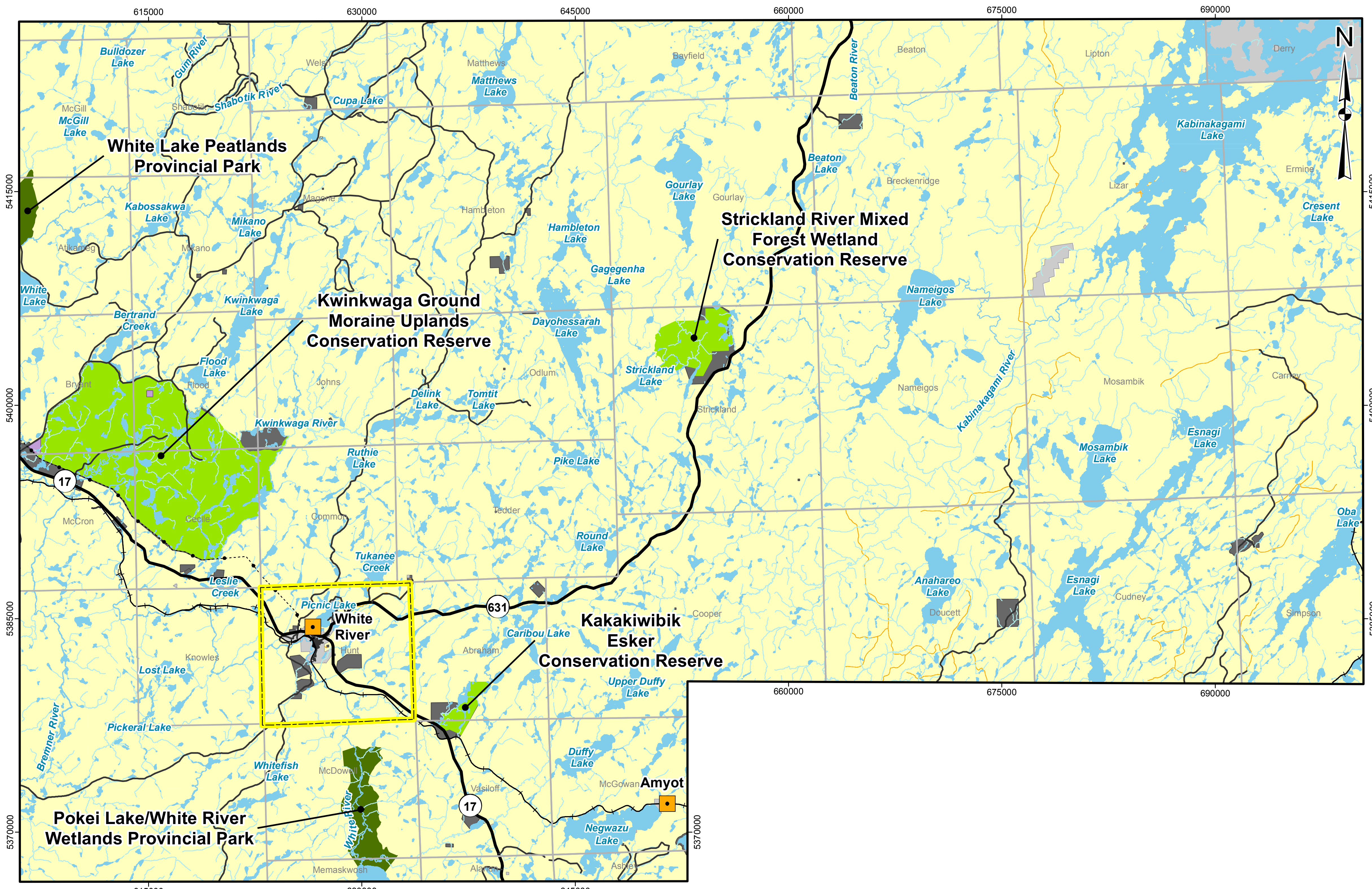
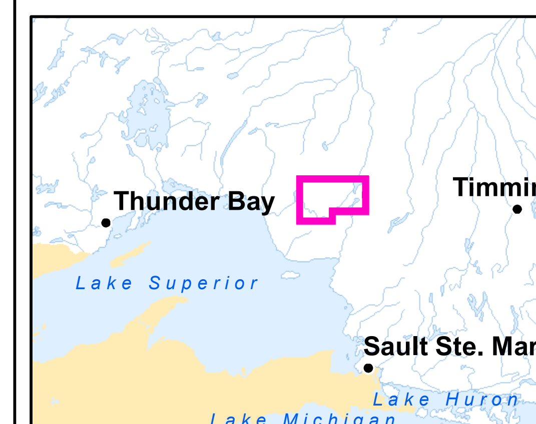
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Drainage Features within the White River Area

DESIGN	KR	23 Apr 2013	Figure 2.4	REVISION 1
GIS	KR	14 Jun 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 2.4 Drainage Features of the White River Area.mxd





Data Sources:
Reproduced from Golder Associates Ltd. (2014)
Base Data: MNR LIO, obtained 2009-2013

10 km

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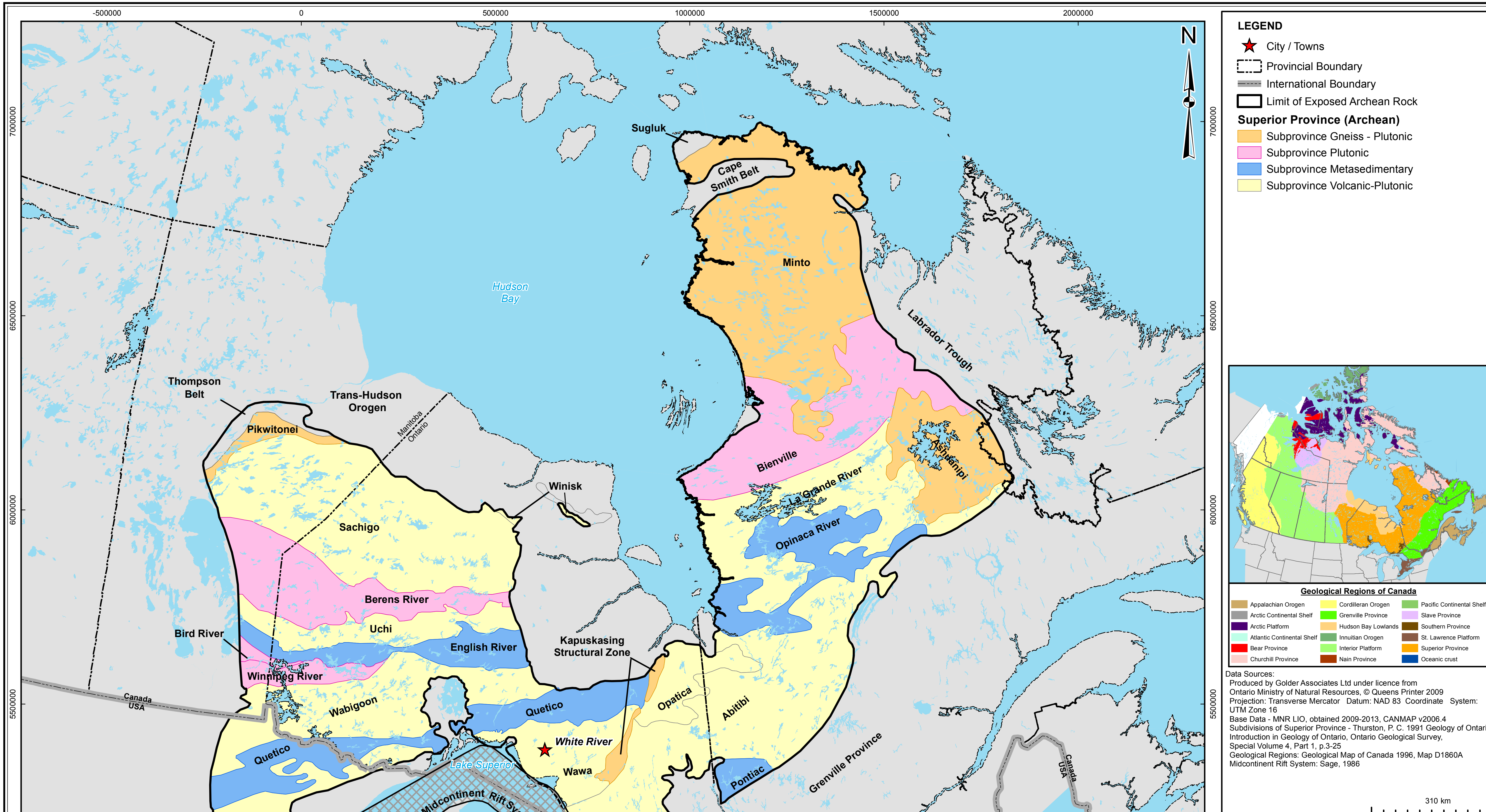
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Land Disposition and Ownerhsip within the White River Area

DESIGN	KR	23 AUG 2013	**Figure 2.5**	REVISION 1
GIS	GF	16 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 2.5 Land Disposition and Ownership within the White River Area.mxd

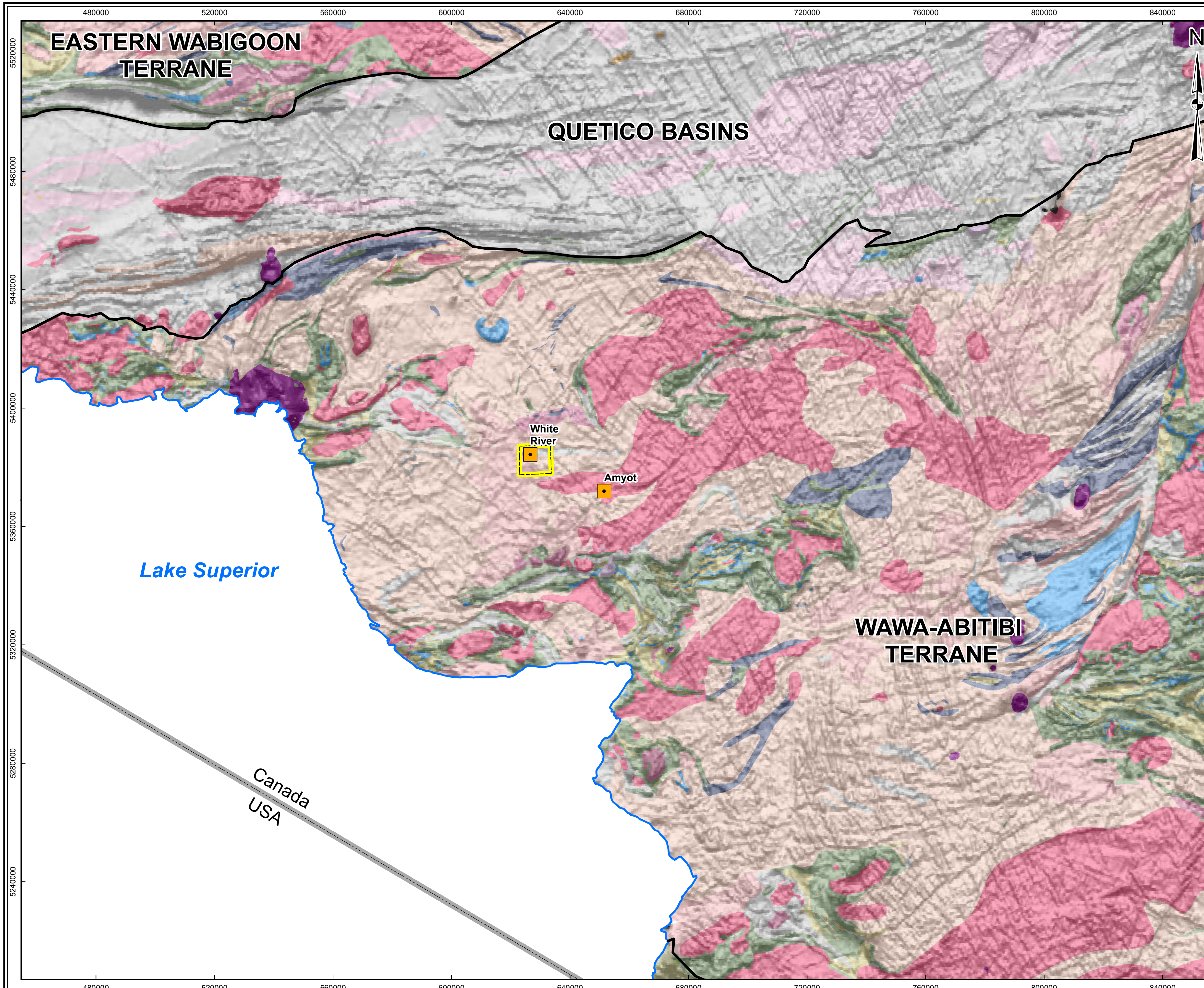


Golder Associates | AECOM

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Subdivision of the Superior Province of the Canadian Shield

DESIGN	PRM	30 Aug 2010	FIGURE 3.1	REVISION 3
GIS	GHF	24 Jan 2013		UTM ZONE 16
CHECK	CB	31 Jan 2013		NAD 1983
REVIEW	CB	31 Jan 2013		1:9,500,000

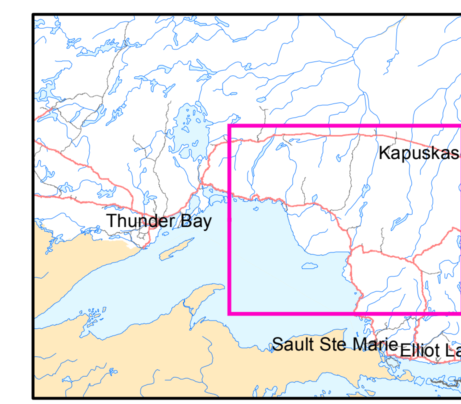


LEGEND

- Settlement
- White River Municipal Boundary
- National Boundary
- Terrane Boundary

Bedrock Geology

- Alkalic Intrusive Suite and Carbonatite
- Mafic intrusive rocks (Keweenawan age)
- Osler Gp., Mamainse Point Fm., Michipicoten Island Fm.
- Sibley Gp.
- Animikie Gp.
- Hornblendite - nepheline syenite suite
- Massive granodiorite to granite
- Diorite-monzodiorite-granodiorite suite
- Muscovite-bearing granitic rocks
- Foliated tonalite suite
- Gneissic tonalite suite
- Mafic and ultramafic rocks
- Coarse clastic metasedimentary rocks
- Migmatized supracrustal rocks
- Metasedimentary rocks
- Felsic to intermediate metavolcanic rocks
- Mafic to intermediate metavolcanic rocks
- Mafic to ultramafic metavolcanic rocks
- Felsic to intermediate metavolcanic rocks



Data Sources:
Bedrock Geology: OGS, MRD 126 - Rev 1 (2011)
Terrane Divisions: MRD 278, Stott (2010)
Cities/Towns: LIO Cities and Towns
Geophysical Underlay: #7 GSC, 800m Line Spacing

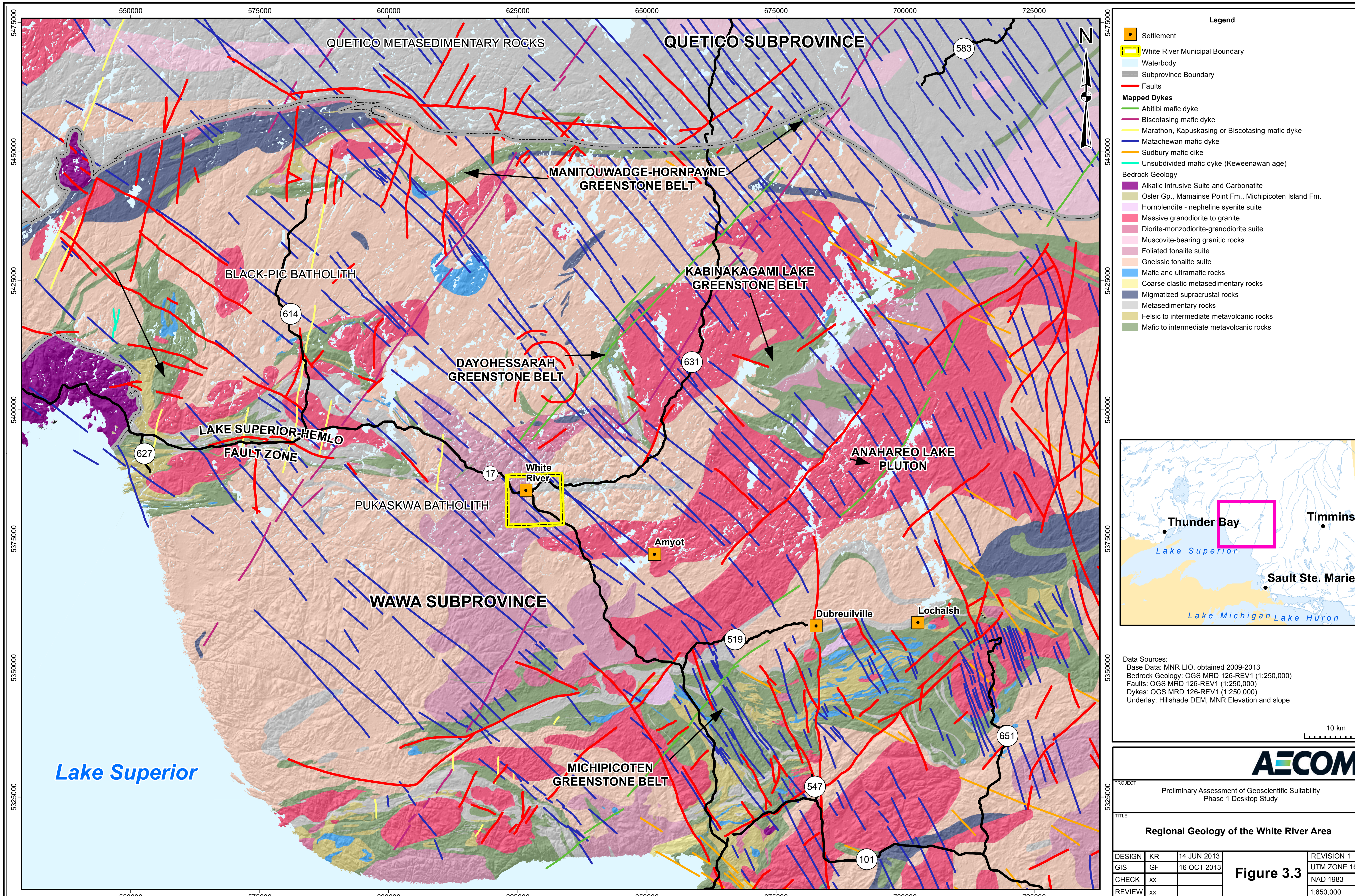
40 km

AECOM

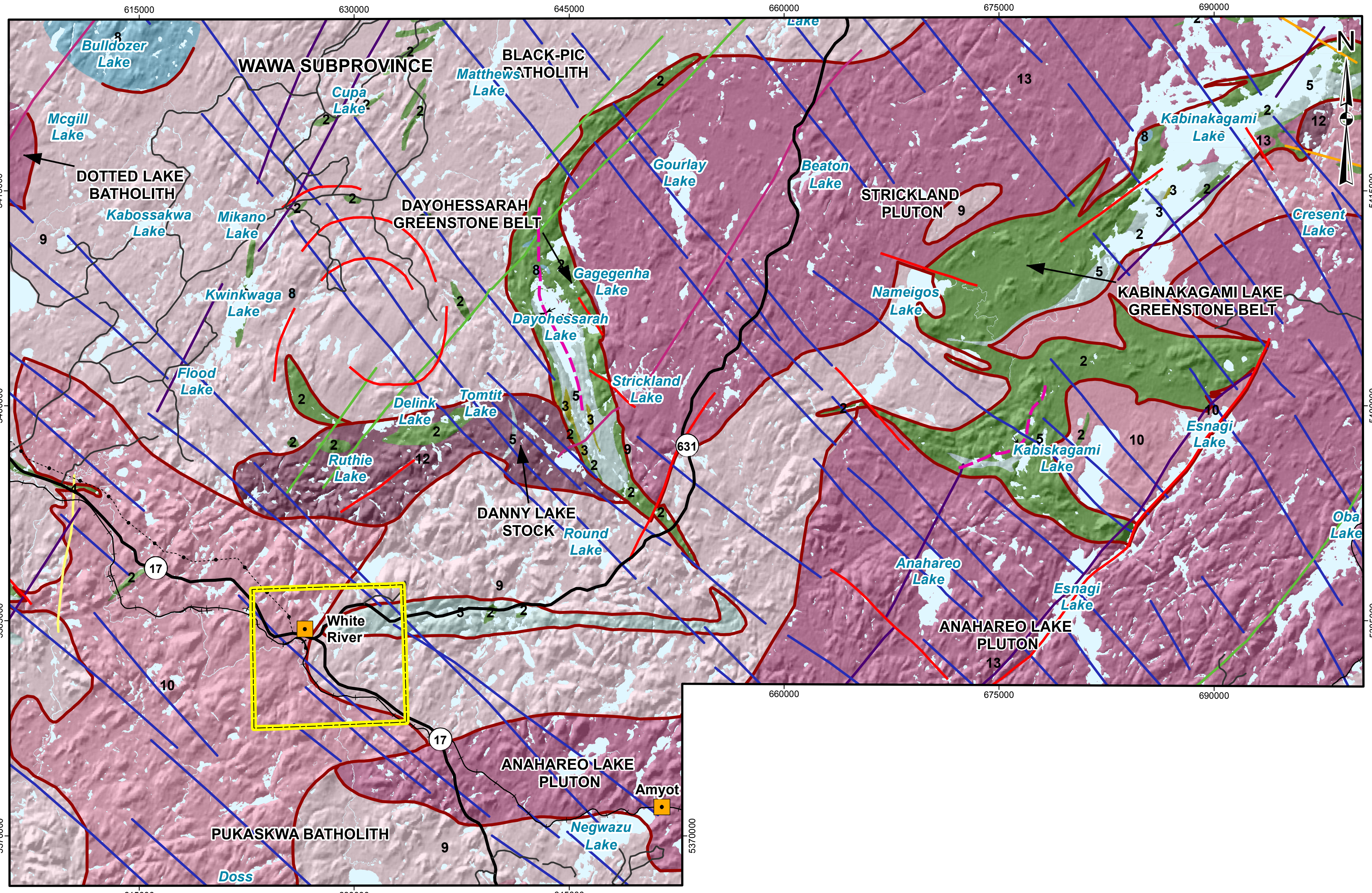
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Terrane Subdivision of North-Central Ontario

DESIGN	GHF	14 Aug 2012	**FIGURE 3.2**	REVISION 3
GIS	GHF	16 OCT 2013		UTM ZONE 16
CHECK	CB			NAD 1983
REVIEW	CB			1:1,250,000



Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 3.3 Regional Geology of the White River Area.mxd



Legend

- Settlement
- White River Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Faults
- Major Fold (Syncline Approximate)
- Bedrock Geology Contact

Mapped Dykes

- Abitibi mafic dyke
- Biscotasing mafic dyke
- Marathon, Kapuskasing or Biscotasing mafic dyke
- Matachewan mafic dyke
- Sudbury mafic dyke
- unknown

Bedrock Geology

- 13: Granite-granodiorite
- 12: Diorite-monzonite- granodiorite
- 10: Foliated tonalite suite
- 9: Gneissic tonalite suite
- 8: Gabbro
- 5: Metasedimentary rocks
- 4: Felsic volcanic rocks
- 3: Felsic and intermediate metavolcanic rocks
- 2: Mafic metavolcanic Rocks

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

10 km

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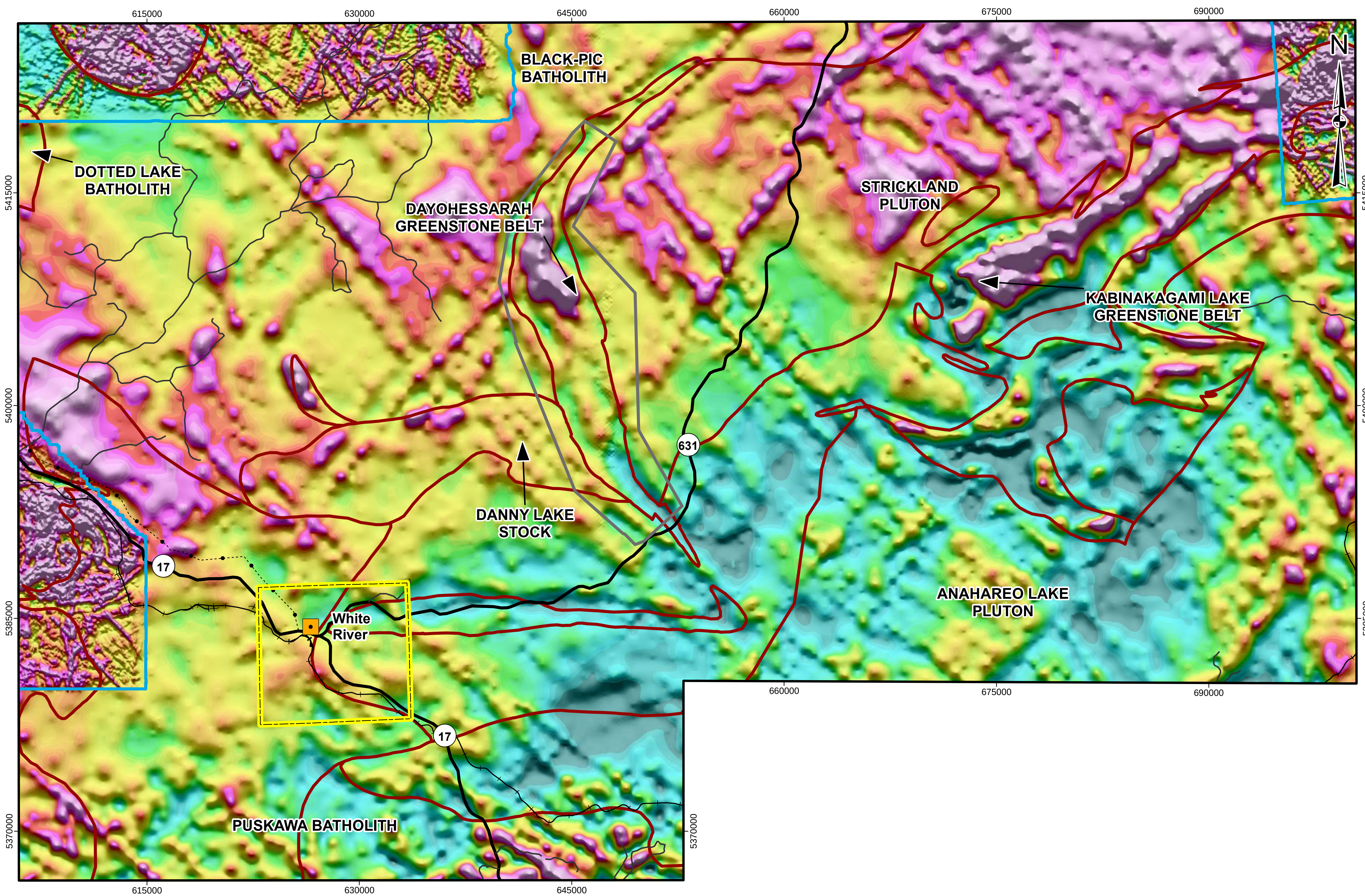
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Bedrock Geology of the White River Area

DESIGN	KR	23 APR 2013	**Figure 3.4**	REVISION 1
GIS	GF	17 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

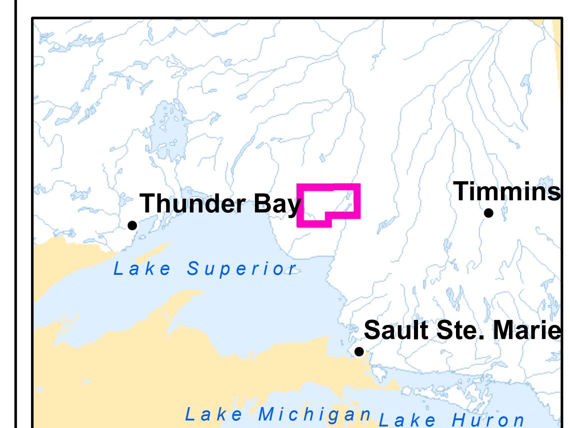


Legend

White River Municipal Boundary
Settlement
Main Road
Local Road
Railway
Abandoned Railway Right-of-way
Hydro Line
Bedrock Geology Contact
High resolution geophysical survey outlines
Industry geophysical survey outlines

Pole-reduced Magnetic Field (nT)

2374
148
100
72
52
38
26
14
4
-4
-12
-20
-28
-36
-44
-50
-58
-68
-76
-84
-92
-102
-112
-122
-132
-146
-160
-176
-200
-370



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Geophysics: Geological Survey of Canada - Aeromagnetic Surveys - Ontario #8, Ontario #17
Ontario Geological Survey - Geophysical Surveys - GDS1024, GDS1205, GDS1207
- Geology Ontario - AFRI no. 20004804
Bedrock Geology: OGS M2666, 2001; M2668, 2003 (1:250,000)

10 km

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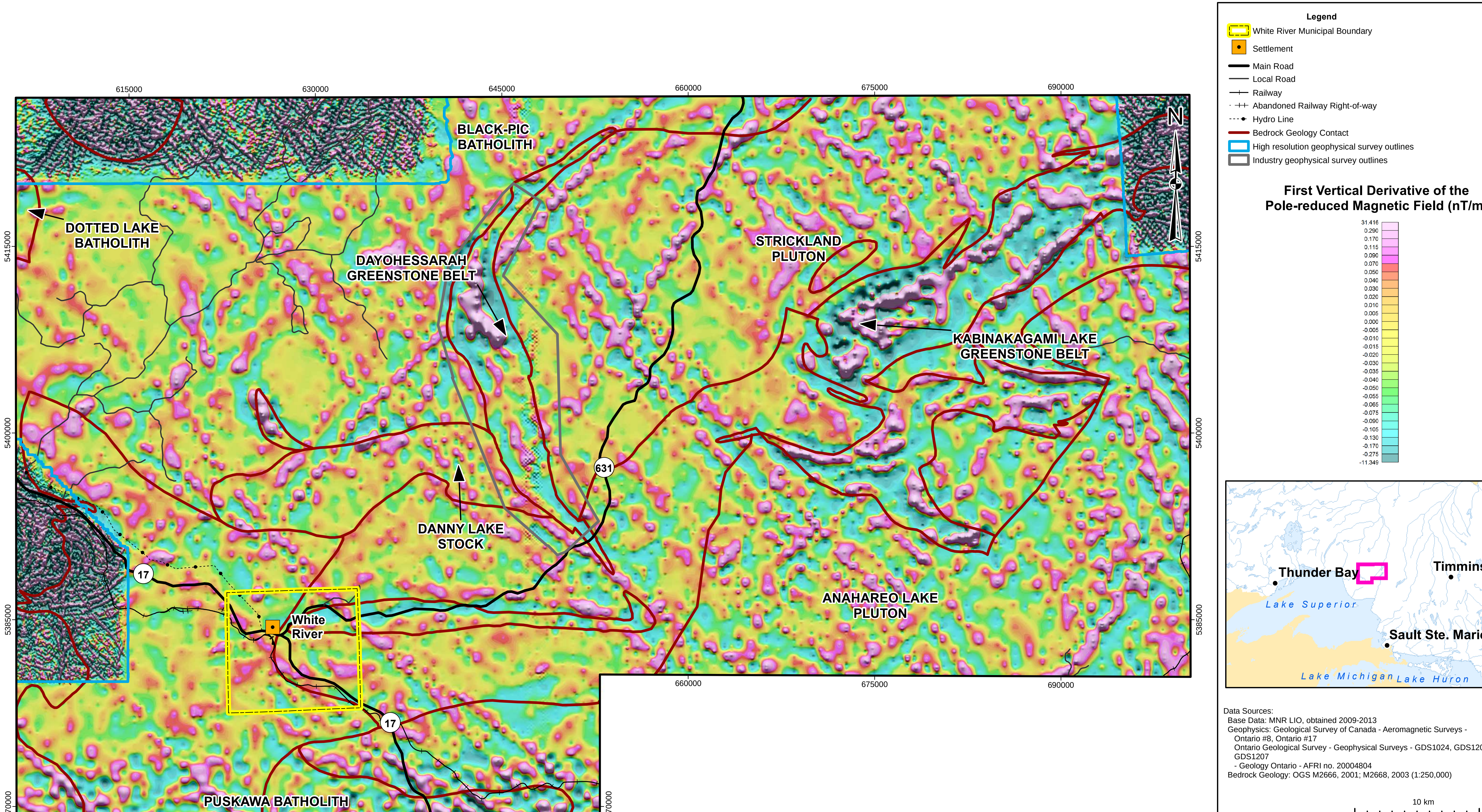
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Geophysical Data Analysis Reduced to Pole Residual Magnetic Field in the White River Area

DESIGN	KR	23 APR 2013	**Figure 3.5**	REVISION 2
GIS	WP	12 SEP 2013		UTM ZONE 16
CHECK	SR	4 FEB 2014		NAD 1983
REVIEW	CB	5 FEB 2014		1:300,000

Path: C:\Users\Stephen\PGW\2013-18\Proc\maps\ArcGIS\Aecom_maps_Jan_2014\Fig3.6_AECOM_White_River_Mag_RTP.mxd



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Geophysics: Geological Survey of Canada - Aeromagnetic Surveys - Ontario #8, Ontario #17
Ontario Geological Survey - Geophysical Surveys - GDS1024, GDS1205, GDS1207
- Geology Ontario - AFRI no. 20004804
Bedrock Geology: OGS M2666, 2001; M2668, 2003 (1:250,000)

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AECOM

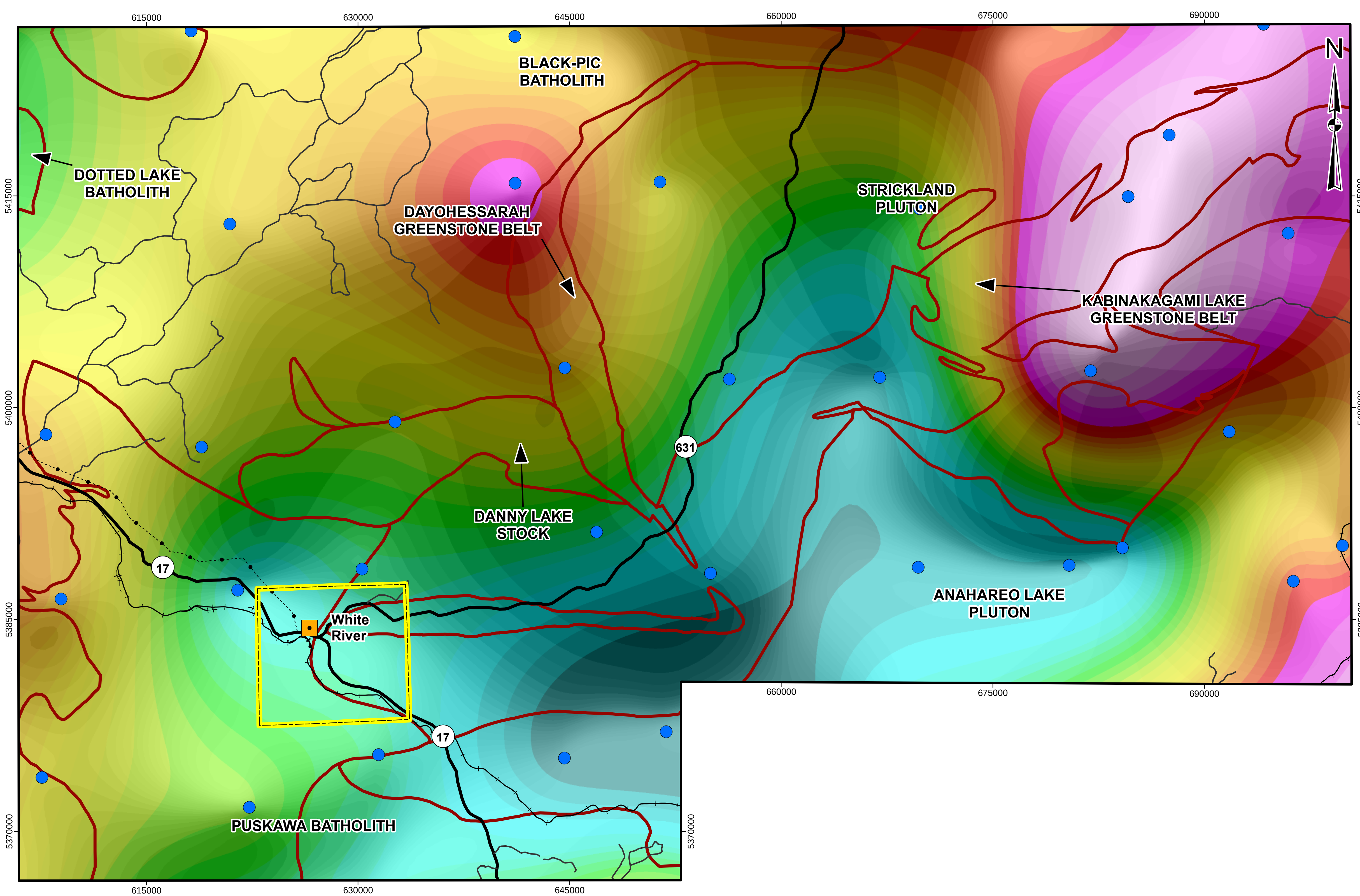
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Geophysics Data Analysis First Vertical Derivative of Reduced to Pole Residual Magnetic Field in the White River Area

DESIGN	KR	23 APR 2013	Figure 3.6	REVISION 2
GIS	WP	12 SEP 2013		UTM ZONE 16
CHECK	SR	4 FEB 2014		NAD 1983
REVIEW	CB	5 FEB 2014		1:300,000

Path: C:\Users\Stephen\PGW\2013-18\Proc\maps\ArcGIS\Aecom_maps_Jan_2014\Fig3.7_AECOM_White_River_Mag_RTP1VD.mxd

Path: C:\Users\Stephen\PGW\2013-18\Proc\maps\ArcGIS\Aecom_maps_Jan_2014\Fig3.8_AECOM_White_River_Grav_Bouguer.mxd

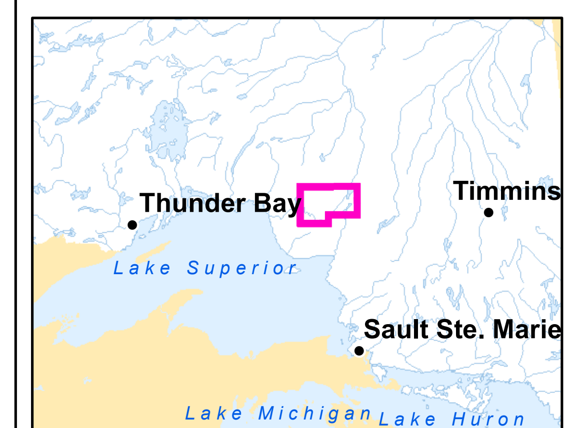


Legend

- White River Municipal Boundary
- Settlement
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Bedrock Geology Contact
- Gravity Stations

Bouguer Gravity Field (mGal)

-50.0, -54.0, -55.8, -57.4, -58.8, -60.0, -60.8, -61.6, -62.4, -63.0, -63.6, -64.0, -64.4, -64.8, -65.2, -65.6, -66.2, -66.8, -67.4, -68.0, -68.6, -69.2, -69.8, -70.4, -70.8, -71.6, -72.6, -73.4, -74.2, -76.4



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Geophysics: Geological Survey of Canada - Nationwide Gravity Compilation
Bedrock Geology: OGS M2666, 2001; M2668, 2003 (1:250,000)

10 km

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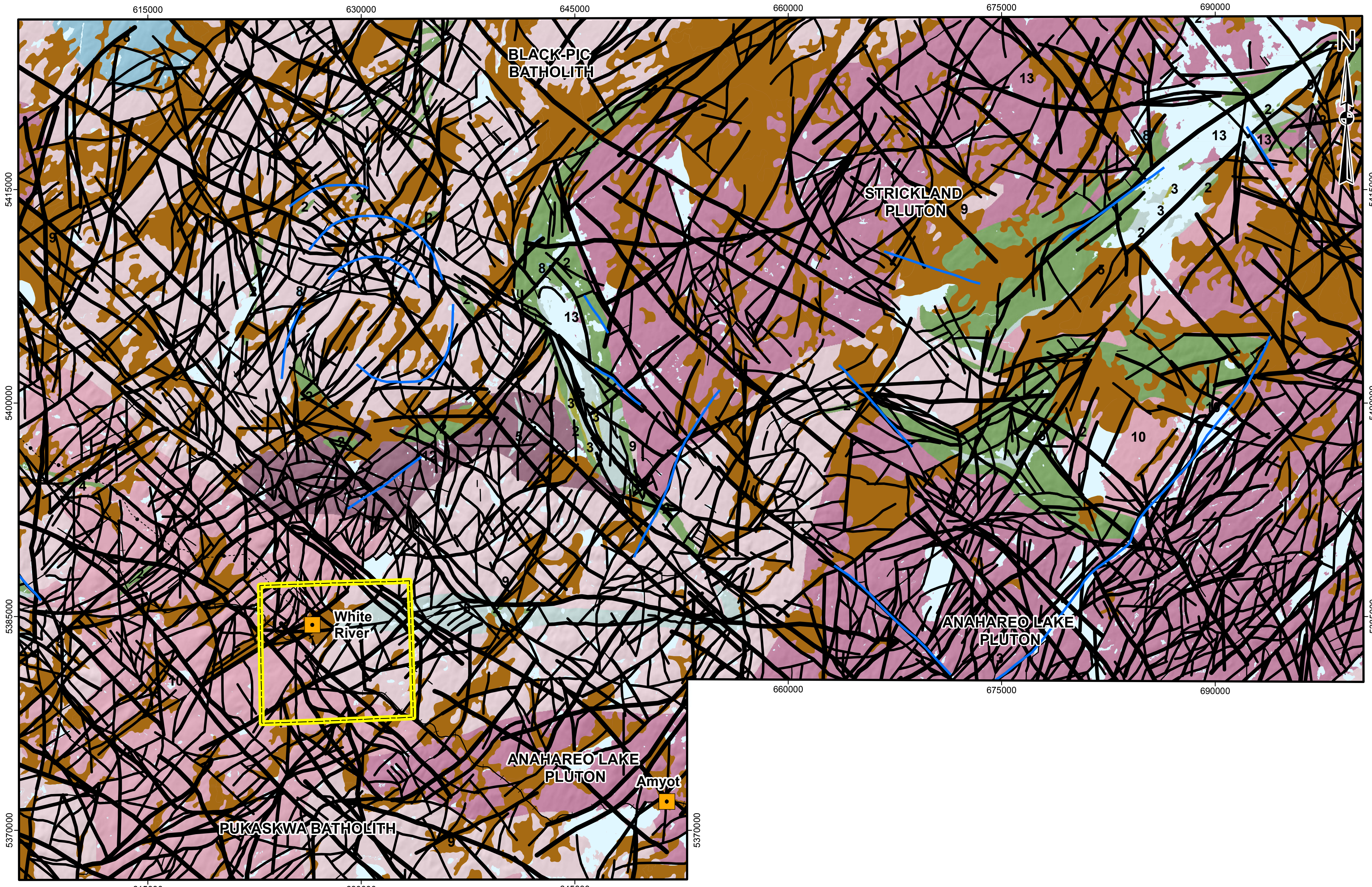
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Geophysical Data Analysis Bouguer Gravity Field with Station Locations in the White River Area

DESIGN	KR	23 APR 2013	**Figure 3.7**	REVISION 2
GIS	WP	12 SEP 2013		UTM ZONE 16
CHECK	SR	4 FEB 2014		NAD 1983
REVIEW	CB	5 FEB 2014		1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 3.8 Surficial Lineaments of the White River Area.mxd



Legend

- Settlement
- White River Municipal Boundary
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Mapped Fault

Surficial Lineaments (DEM and SAT)

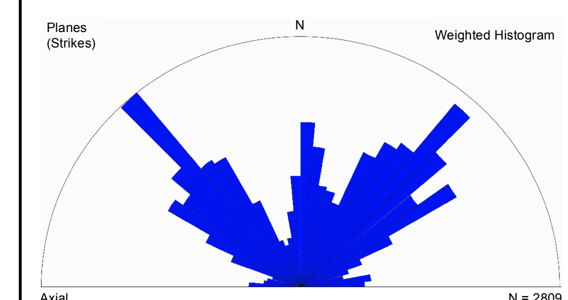
Length

- < 1.00
- 1.01 - 5.00
- 5.01 - 10.00
- > 10.01
- Overburden Cover

Bedrock Geology

- 13: Granite-granodiorite
- 12: Diorite-monzonite- granodiorite
- 10: Foliated tonalite suite
- 9: Gneissic tonalite suite
- 8: Gabbro
- 5: Metasedimentary rocks
- 4: Felsic volcanic rocks
- 3: Felsic and intermediate metavolcanic rocks
- 2: Mafic metavolcanic Rocks

White River Surficial Lineaments - Normalized Length in 5 Degree Azimuth Bins



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)
Overburden: OGS MRD-160, NOEGTS, 2006
Lineaments: SRK, 2014
Underlay: Hillshade DEM, MNR Elevation and Slope

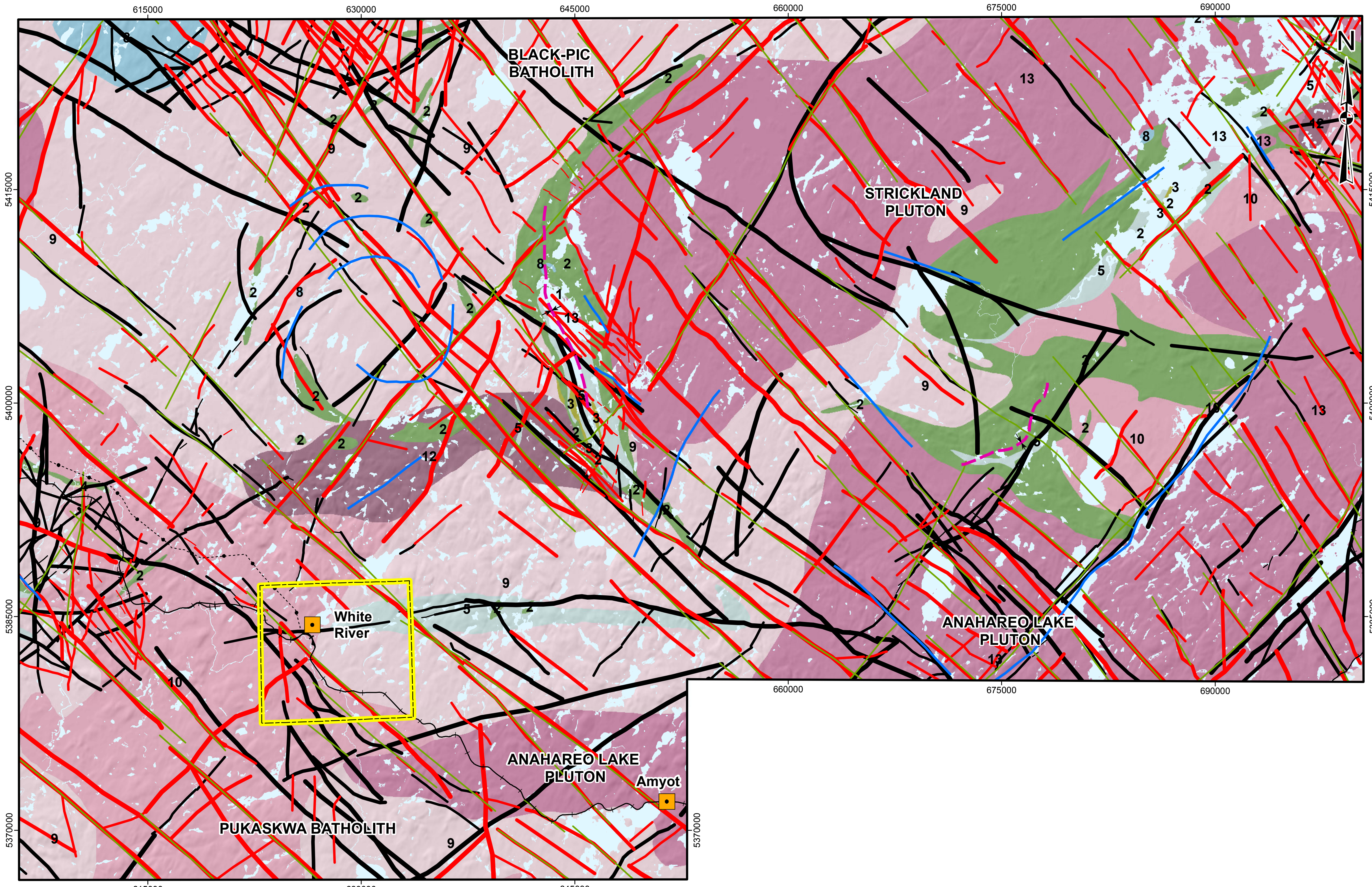
10 km

srk AECOM

PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Surficial Lineaments of the White River Area

DESIGN	KR	23 APR 2013	Figure 3.8	REVISION 1
GIS	GF	17 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

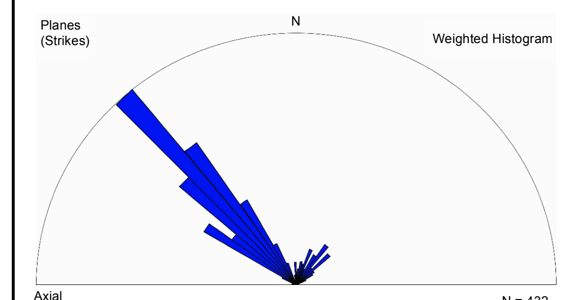


Legend

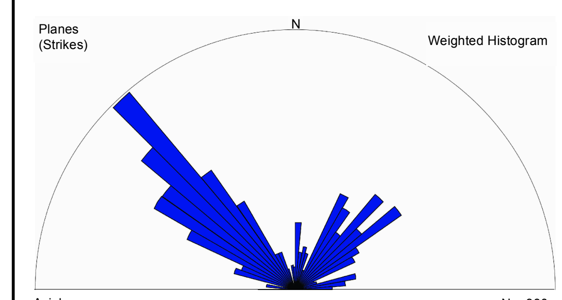
- Settlement
- White River Municipal Boundary
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Mapped Fault
- Mapped Dykes
- Major Fold (Syncline Approximate)

Fracture (length)	Dyke (length)
< 1.00 km	< 1.00 km
1.01 - 5.00 km	1.01 - 5.00 km
5.01 - 10.00 km	5.01 - 10.00 km
> 10.01 km	> 10.01 km

White River Geophysical Dykes - Normalized Length in 5 Degree Azimuth Bins



White River Geophysical Fractures - Normalized Length in 5 Degree Azimuth Bins



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)
Overburden: OGS MRD-160, NOEGTS, 2006
Lineaments: SRK, 2014
Underlay: Hillshade DEM, MNR Elevation and Slope

10 km

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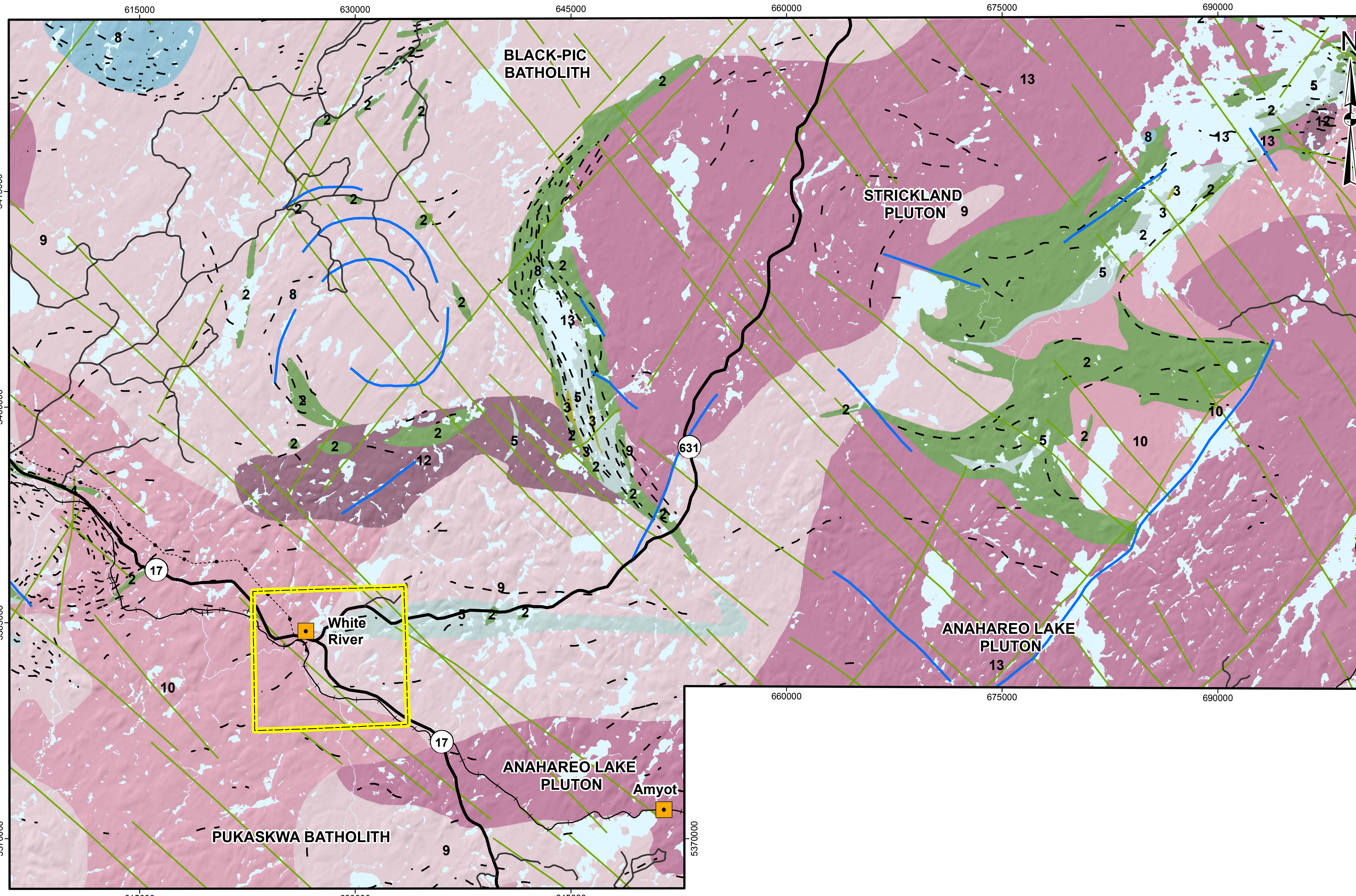
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Geophysical Lineaments of the White River Area

DESIGN	KR	23 APR 2013	**Figure 3.9**	REVISION 1
GIS	GF	30 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 3.9 Geophysical Lineaments of the White River Area.mxd

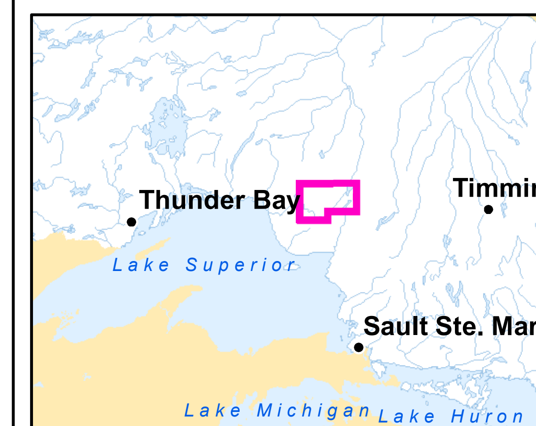


Legend

- Settlement
- White River Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Mapped Fault
- Mapped Dyke
- Ductile Lineament

Bedrock Geology

- 13: Granite-granodiorite
- 12: Diorite-monzonite- granodiorite
- 10: Foliated tonalite suite
- 9: Gneissic tonalite suite
- 8: Gabbro
- 5: Metasedimentary rocks
- 4: Felsic volcanic rocks
- 3: Felsic and intermediate metavolcanic rocks
- 2: Mafic metavolcanic Rocks



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)
Ductile Lineament: SRK, 2014
Underlay: Hillshade DEM, MNR Elevation and Slope

10 km

srk AECOM

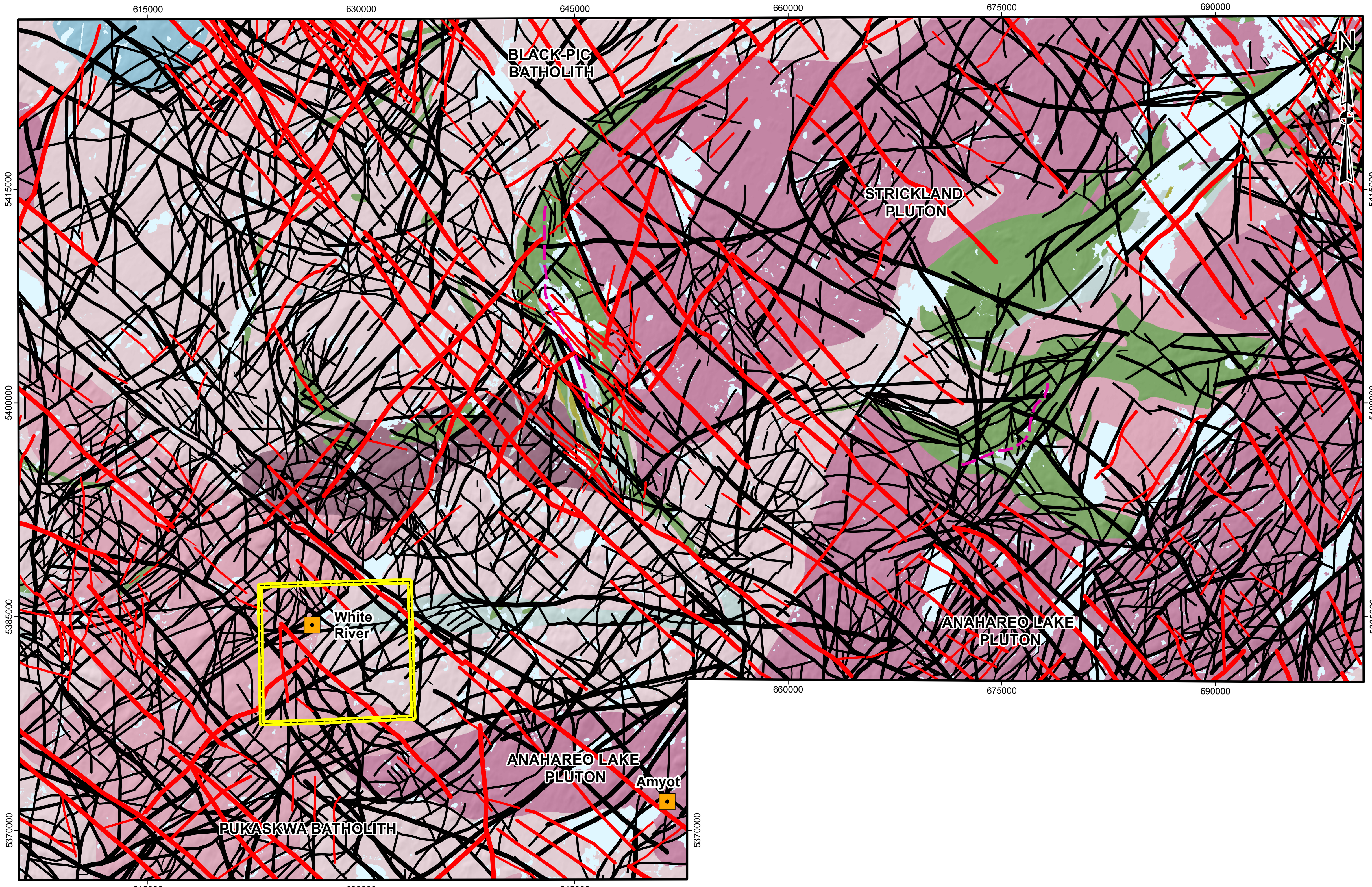
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Ductile Features of the White River Area

DESIGN	KR	23 APR 2013	**Figure 3.10**	REVISION 1
GIS	GF	30 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 3.10 Ductile Features of the White River Area.mxd

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 3.11 Brittle and Dyke Lineaments of the White River Area.mxd

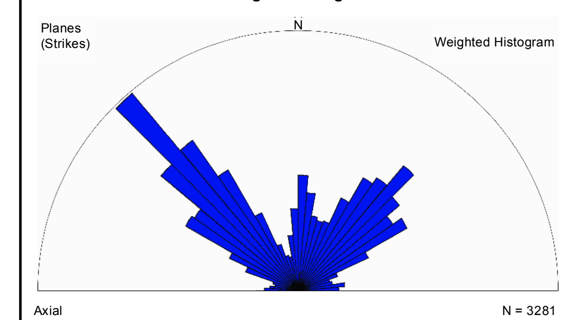


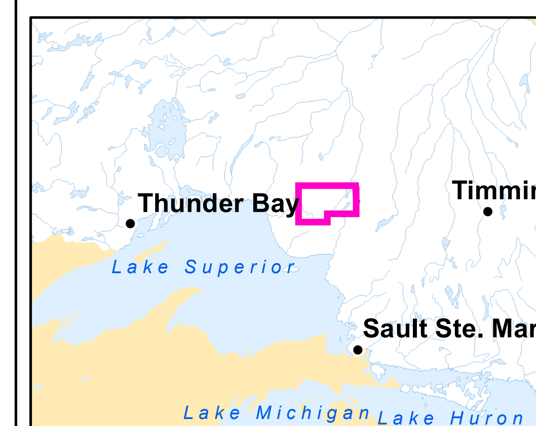
Legend

- Settlement
- White River Municipal Boundary
- Waterbody
- Major Fold (Syncline Approximate)

Brittle Lineament Length	Dyke Lineament Length
< 1.00	< 1.00
1.01 - 5.00	1.01 - 5.00
5.01 - 10.00	5.01 - 10.00
> 10.01	> 10.01

White River All Data -
Normalized Length in 5 Degree Azimuth Bins





Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)
Lineaments: SRK, 2014
Underlay: Hillshade DEM, MNR Elevation and Slope

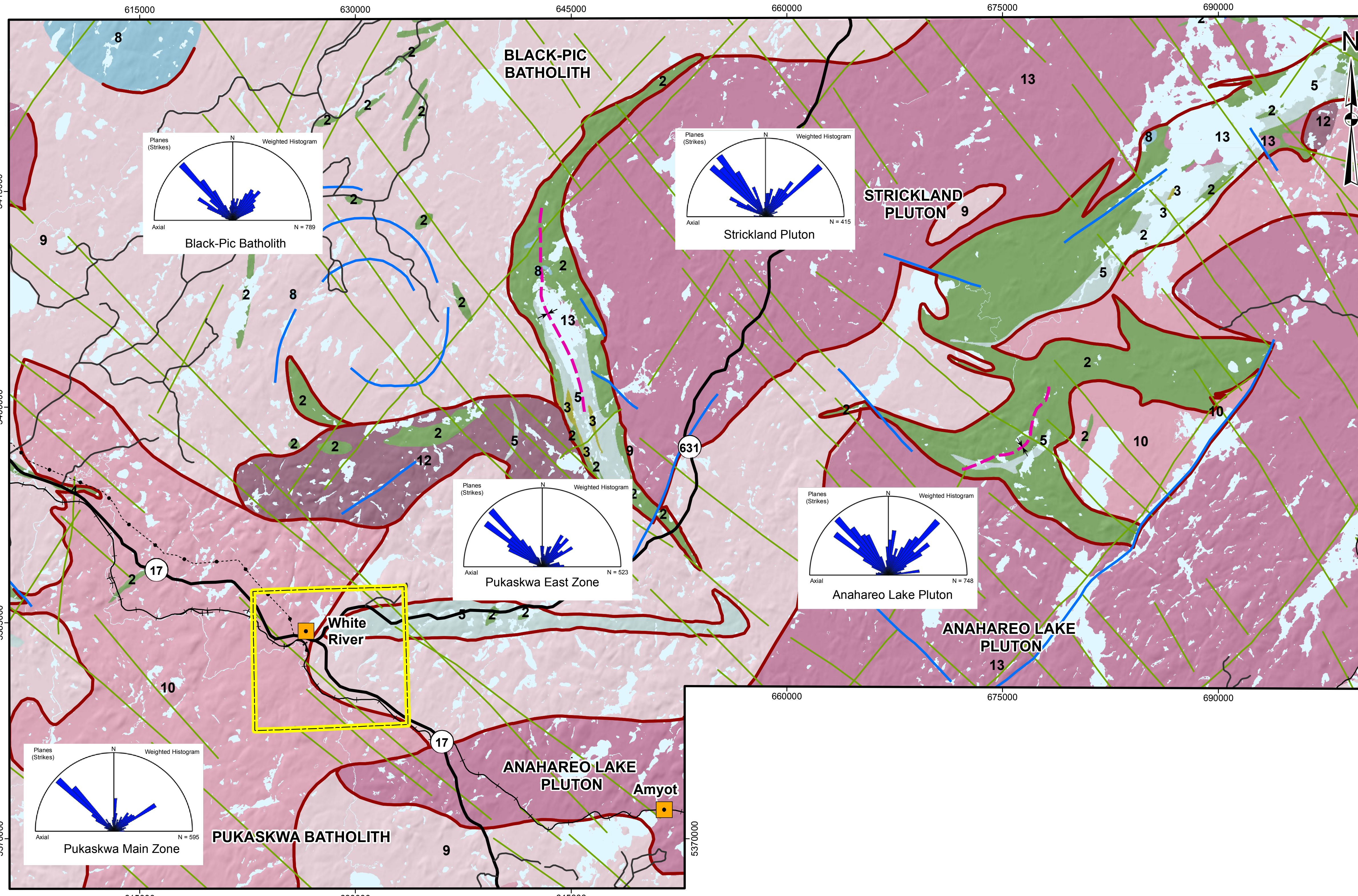
10 km

srk AECOM

PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Brittle and Dyke Lineaments of the White River Area

DESIGN	KR	23 APR 2013	Figure 3.11	REVISION 1
GIS	GF	30 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

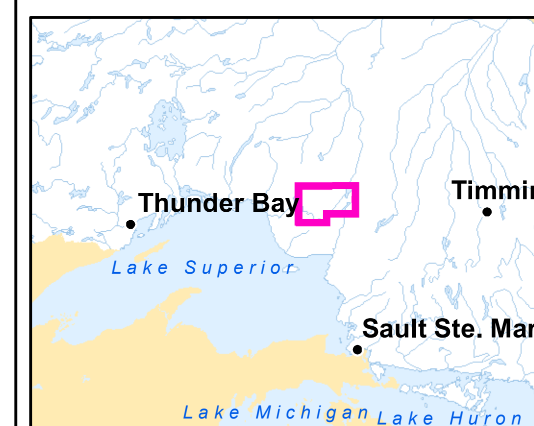


Legend

- Settlement
- White River Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Mapped Fault
- Mapped Dyke
- Major Fold (Syncline Approximate)
- Bedrock Geology Contact

Bedrock Geology

- 13: Granite-granodiorite
- 12: Diorite-monzonite- granodiorite
- 10: Foliated tonalite suite
- 9: Gneissic tonalite suite
- 8: Gabbro
- 5: Metasedimentary rocks
- 4: Felsic volcanic rocks
- 3: Felsic and intermediate metavolcanic rocks
- 2: Mafic metavolcanic Rocks



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)
Lineament Orientations: SRK, 2014
Underlay: Hillshade DEM, MNR Elevation and Slope

10 km

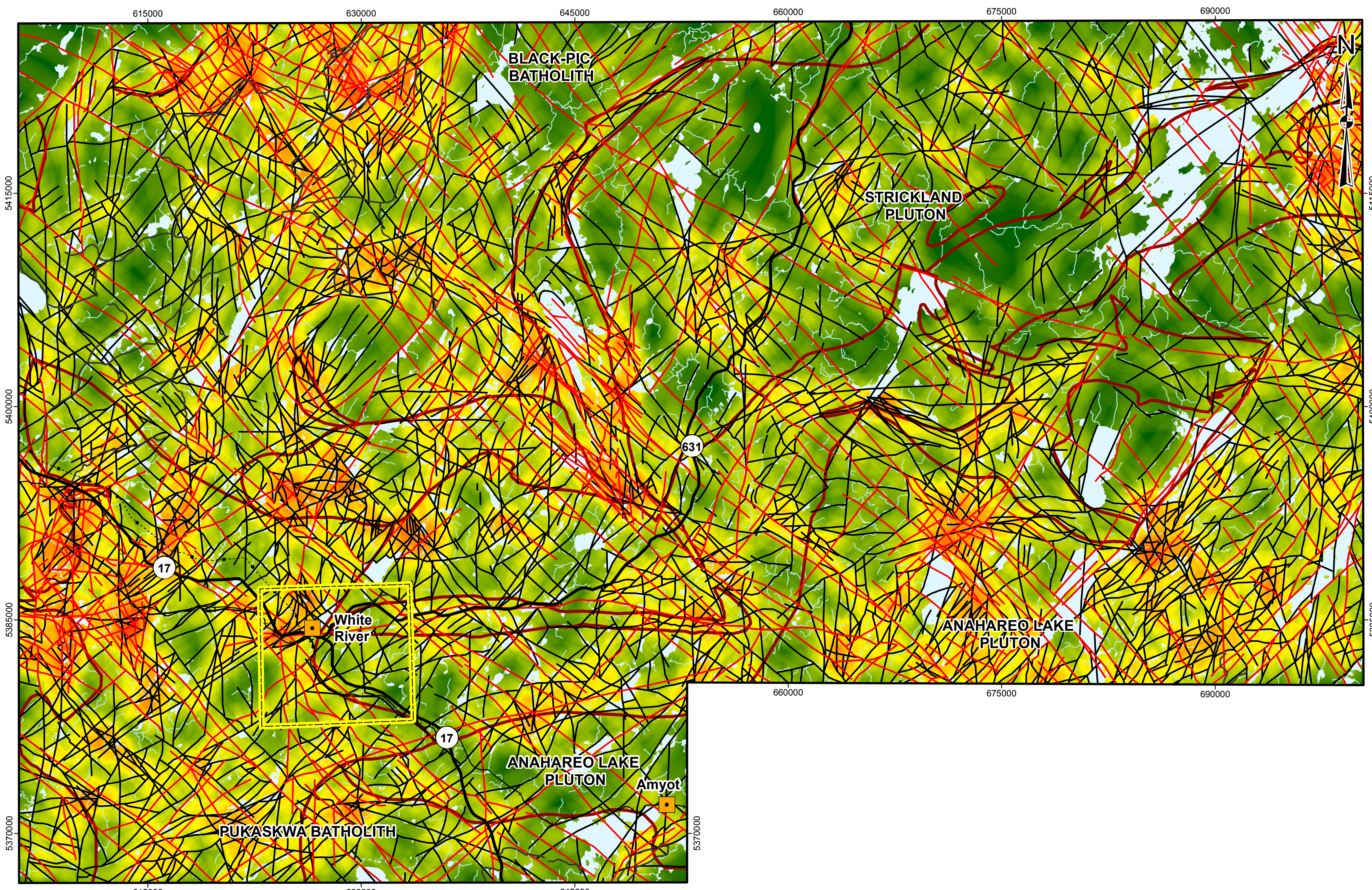
srk AECOM

PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Lineament Orientations of Potentially Suitable Geologic Units of the White River Area

DESIGN	KR	23 APR 2013	Figure 3.12	REVISION 1
GIS	GF	30 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 3.12 Lineament Orientations of Potentially Suitable Geologic Units of the White River Area.mxd



Legend

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

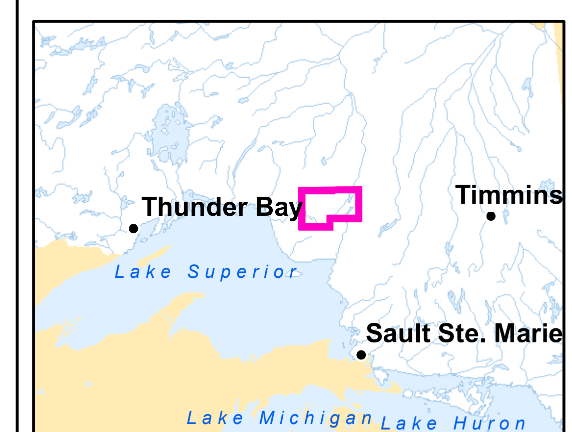
Lineaments

- Geophysical - Fracture and Dyke
- Surficial - Fracture and Dyke

Lineament Density (km/km²)

5.7

0.0



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)
Lineaments: SRK, 2014

10 km

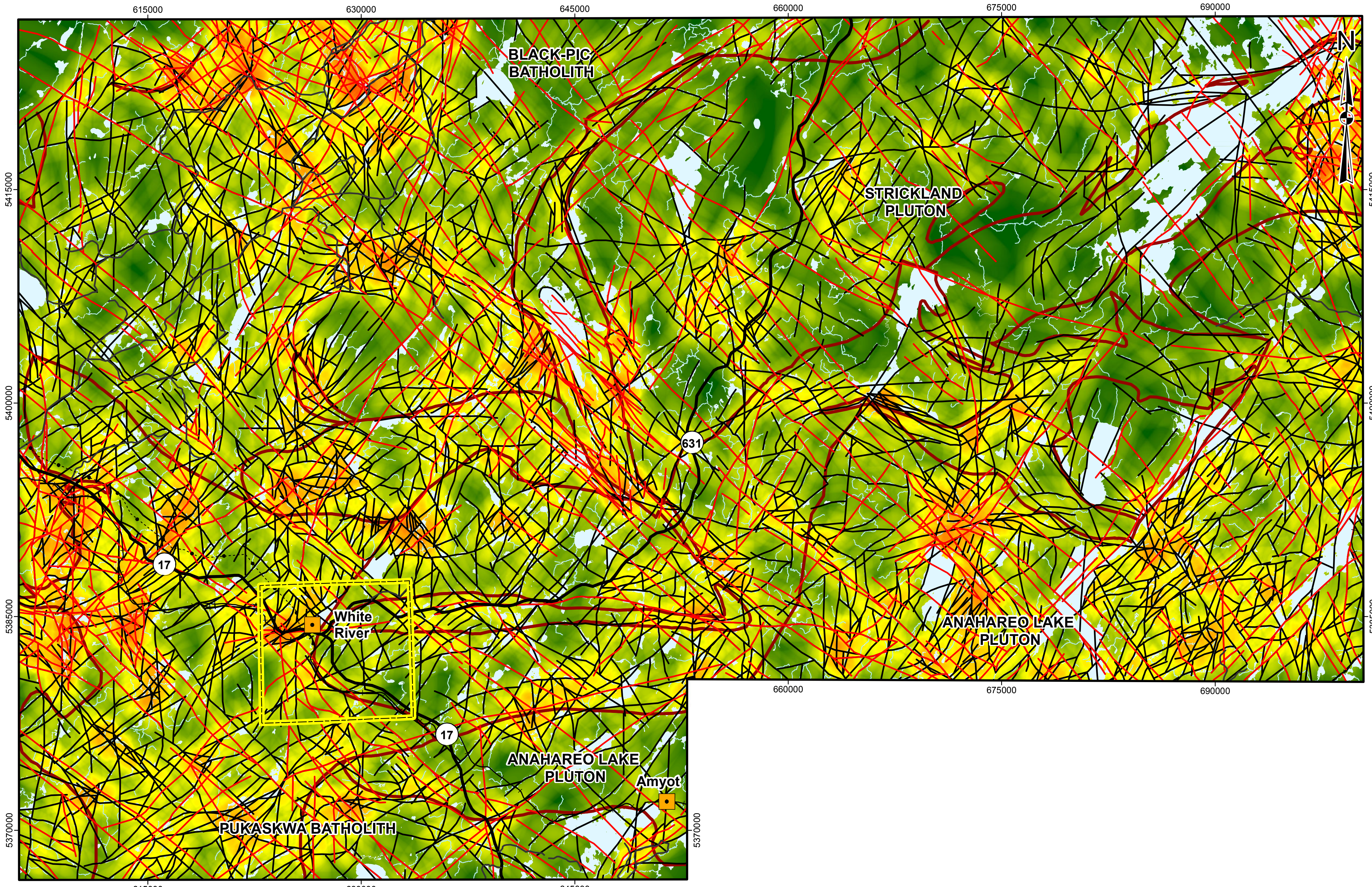
srk AECOM

PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Lineament Density Calculated for Lineaments in the White River Area

DESIGN	KR	23 APR 2013	Figure 3.13	REVISION 1
GIS	GF	30 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 3.13 Lineament Density Calculated for Lineaments in the White River Area.mxd



Legend

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

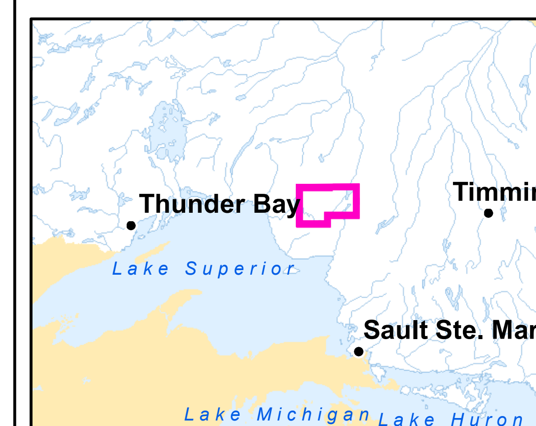
Lineaments

- Geophysical - Fracture and Dyke
- Surficial - Fracture and Dyke

Lineament Density (km/km²)

5.7

0.0



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)
Lineaments: SRK, 2014

10 km

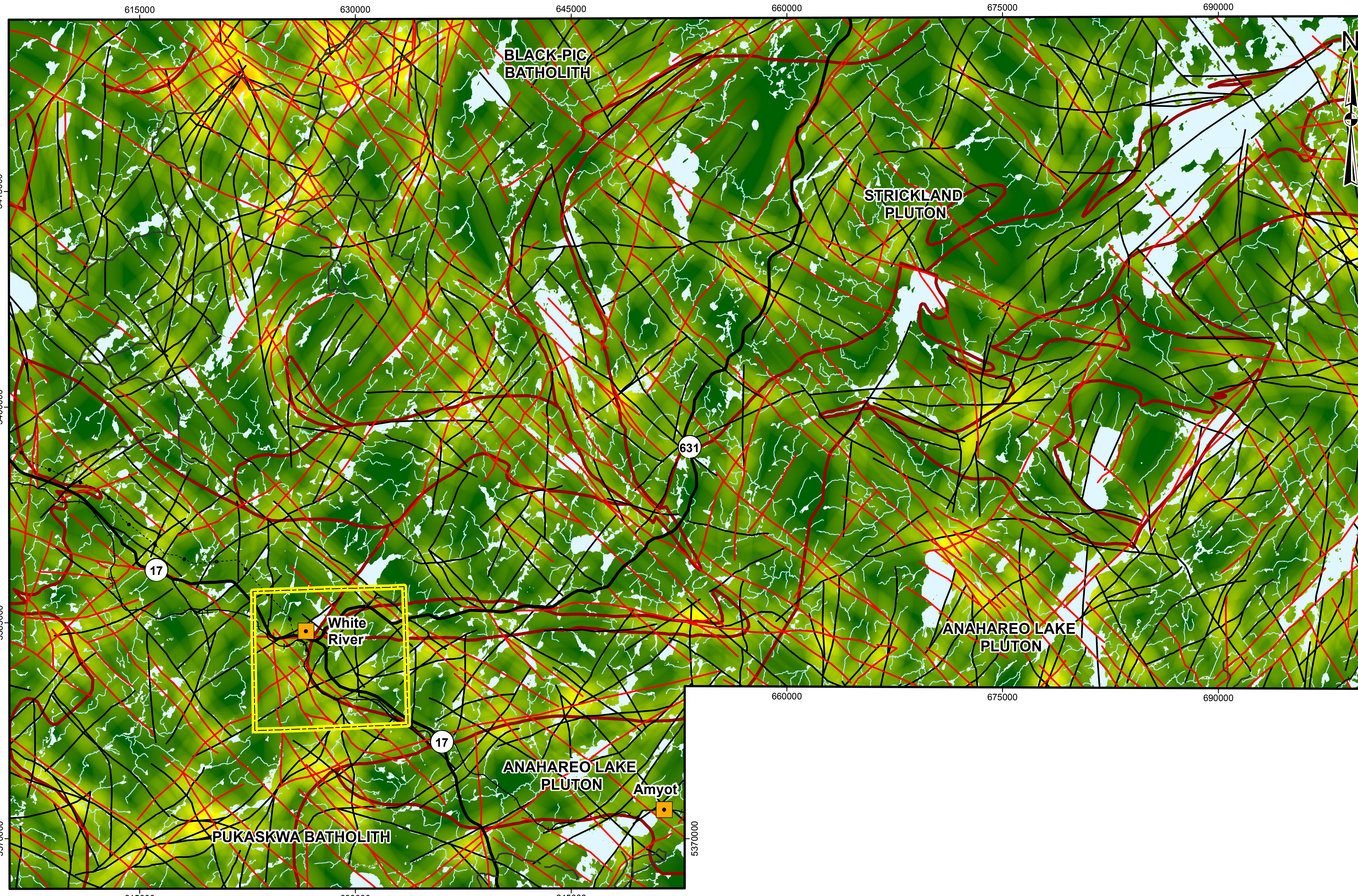
srk AECOM

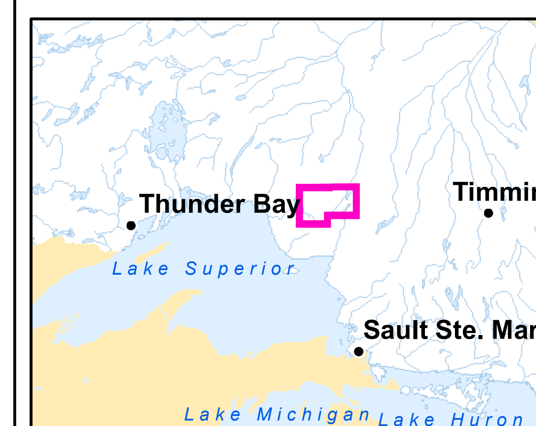
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Lineament Density Calculated for Lineaments (>1 km) in the White River Area

DESIGN	KR	23 APR 2013	Figure 3.14	REVISION 1
GIS	GF	31 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 3.14 Lineament Density Calculated for Lineaments 1kmin the White River Area.mxd





Legend

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

Lineaments

- Geophysical - Fracture and Dyke
- Surficial - Fracture and Dyke

Lineament Density (km/km²)

5.7

0.0

Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)
Lineaments: SRK, 2014

10 km

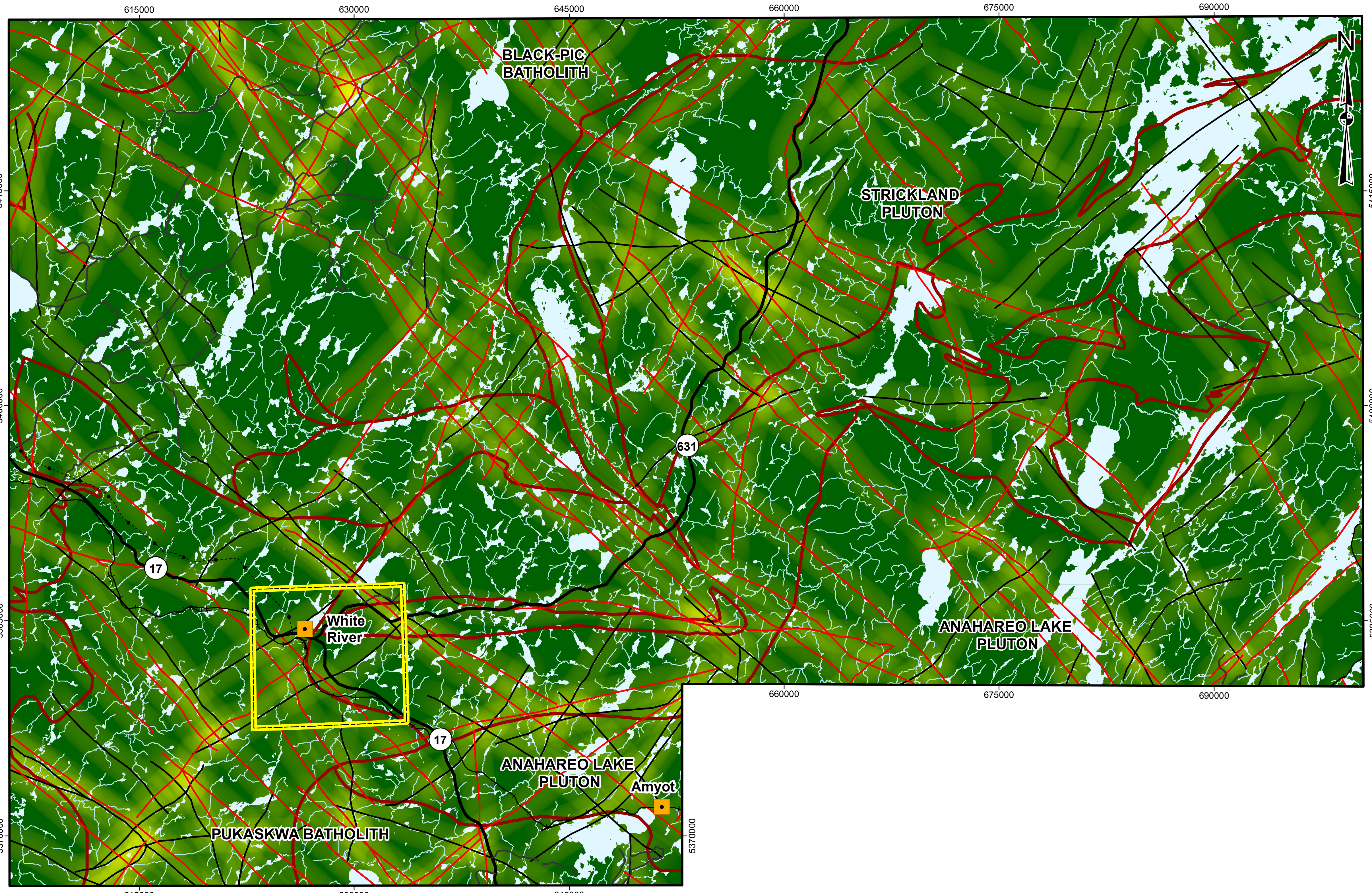
srk AECOM

PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Lineament Density Calculated for Lineaments (>5 km) in the White River Area

DESIGN	KR	23 APR 2013	**Figure 3.15**	REVISION 1
GIS	GF	30 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 3.15 Lineament Density Calculated for Lineaments 5km in the White River Area.mxd



Legend

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

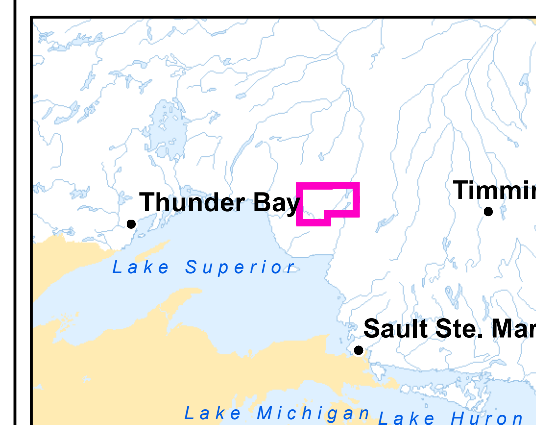
Lineaments

- Geophysical - Fracture and Dyke
- Surficial - Fracture and Dyke

Lineament Density (km/km²)

5.7

0.0



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)
Lineaments: SRK, 2014

10 km

srk AECOM

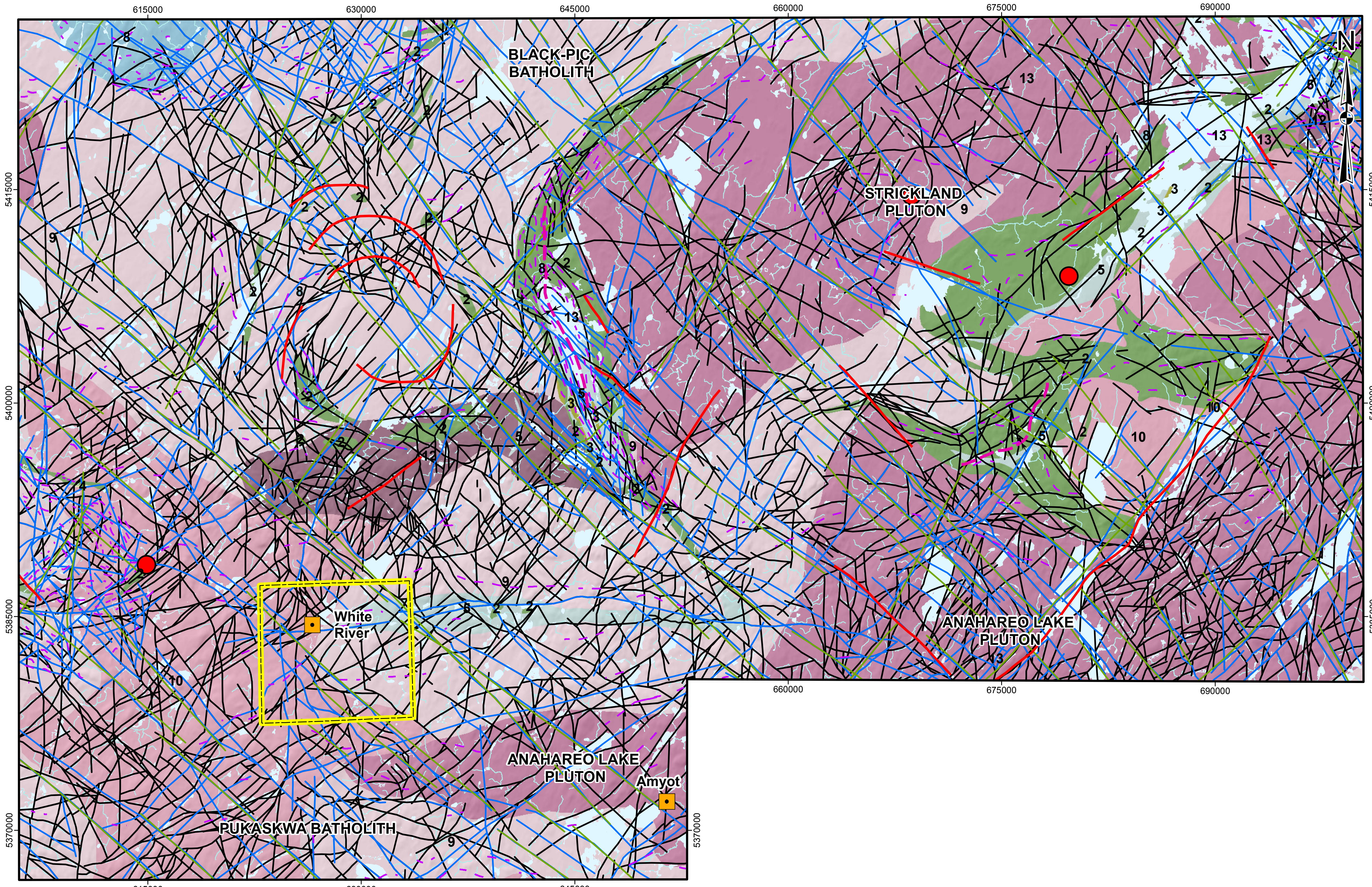
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Lineament Density Calculated for Lineaments (>10 km) in the White River Area

DESIGN	KR	23 APR 2013	Figure 3.16	REVISION 1
GIS	GF	30 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 3.16 Lineament Density Calculated for Lineaments 10km in the White River Area.mxd

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 3.17 Combined Structural Features of the White River Area.mxd



Legend

- Settlement
- White River Municipal Boundary
- Waterbody
- Watercourse
- Mapped Fault
- Mapped Dyke
- Major Fold (Syncline Approximate)
- Ductile Lineament

Lineaments

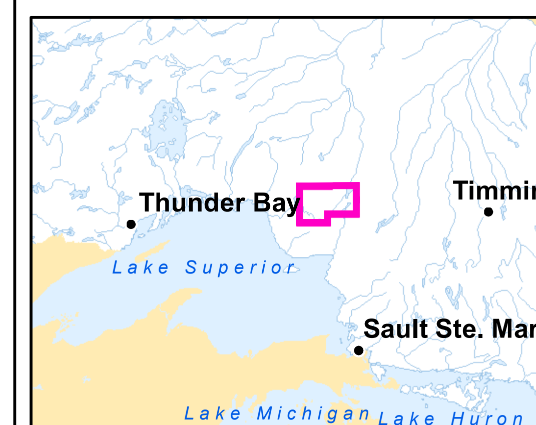
- Geophysical - Fracture and Dyke
- Surficial - Fracture and Dyke

Seismic Events (Magnitude)

- 2.1 - 3.0
  *no events less than 2.0 and greater than 3 within mapping area

Bedrock Geology

- 13: Granite-granodiorite
- 12: Diorite-monzonite- granodiorite
- 10: Foliated tonalite suite
- 9: Gneissic tonalite suite
- 8: Gabbro
- 5: Metasedimentary rocks
- 4: Felsic volcanic rocks
- 3: Felsic and intermediate metavolcanic rocks
- 2: Mafic metavolcanic Rocks



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)
Lineaments: SRK, 2014
Earthquake: NRCAN Earthquake Database (accessed Aug 15, 2013)
Underlay: Hillshade DEM, MNR Elevation and Slope

10 km

srk AECOM

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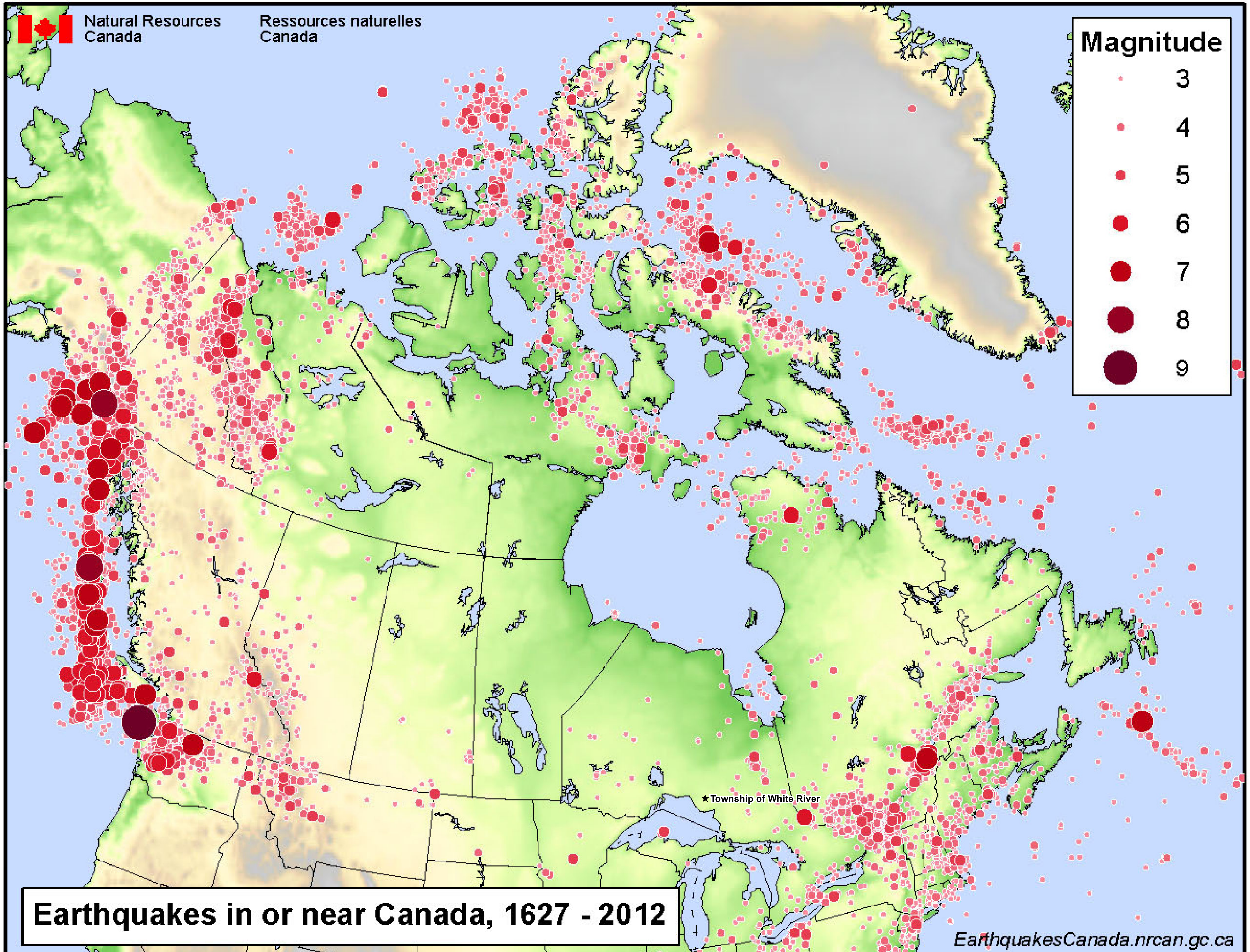
TITLE
Combined Structural Features of the White River Area

DESIGN	KR	23 APR 2013	**Figure 3.17**	REVISION 1
GIS	GF	31 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000



LEGEND

★ Township of White River

Data Sources:
Seismic: NRCAN, Earthquake Map of Canada 1627-2012

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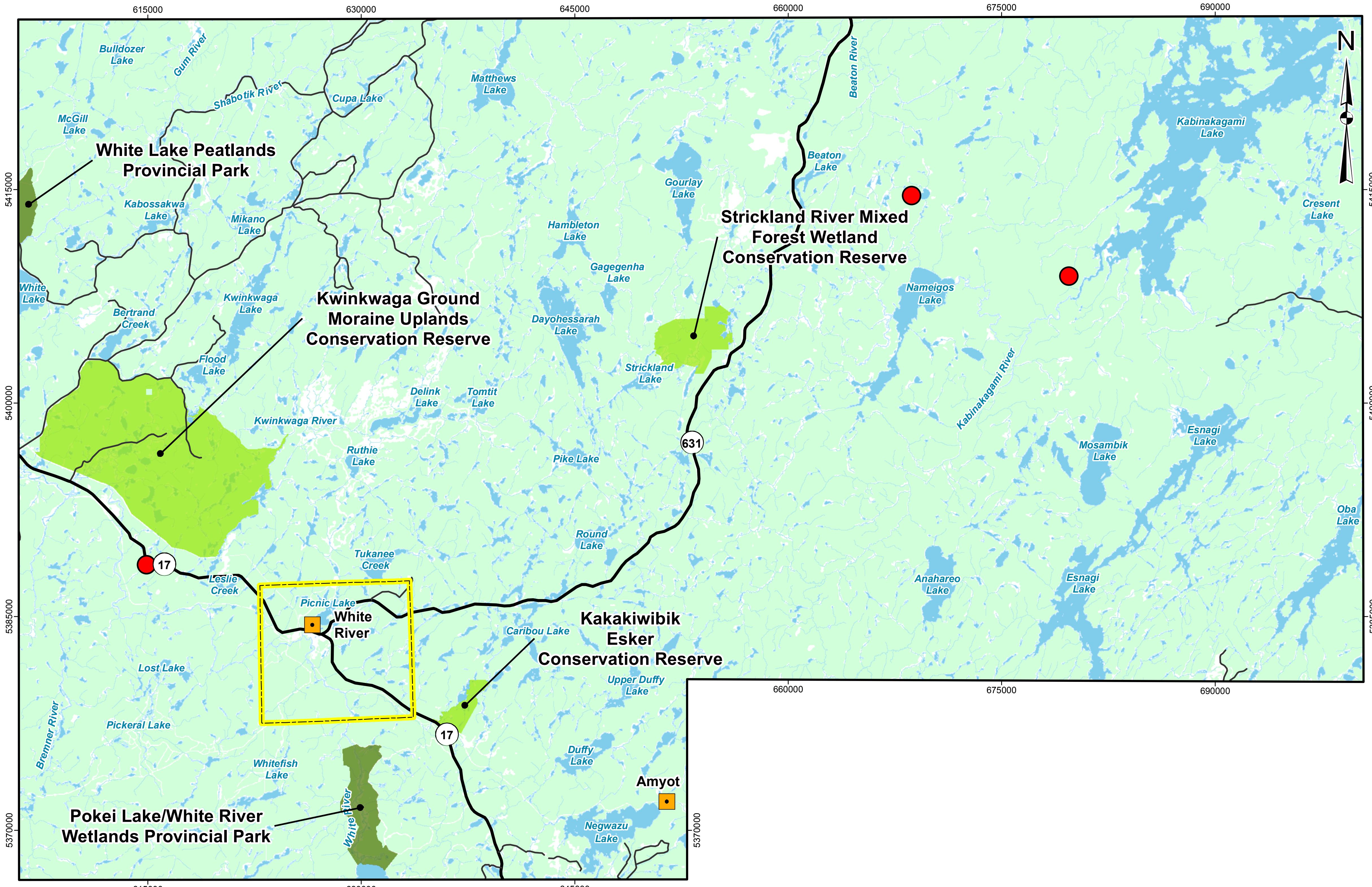
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Earthquakes Map of Canada 1627-2012

DESIGN	GHF	14 Aug 2012	FIGURE 3.18	REVISION 3
GIS	GHF	31 OCT 2013		Scale as Shown
CHECK	CB			
REVIEW	CB			

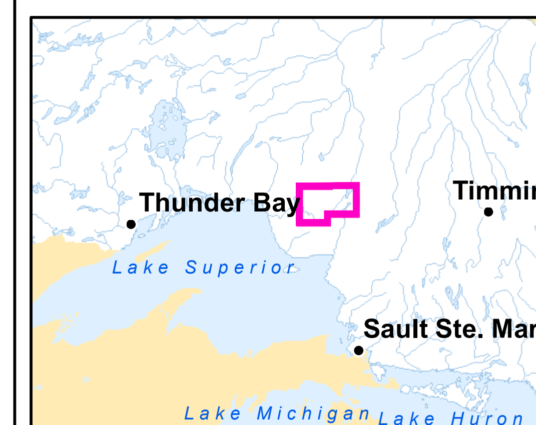


Legend

- Settlement
- White River Municipal Boundary
- Main Road
- Local Road
- Waterbody
- Watercourse
- Wooded Area
- Provincial Park
- Conservation Reserve

Seismic Events (Magnitude)

- 2.1 - 3.0
  *no events less than 2.0 and greater than 3 within mapping area



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Earthquake: NRCAN Earthquake Database (accessed Aug 15, 2013)

10 km

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PROJECT
Preliminary Assessment of Geoscientific Suitability
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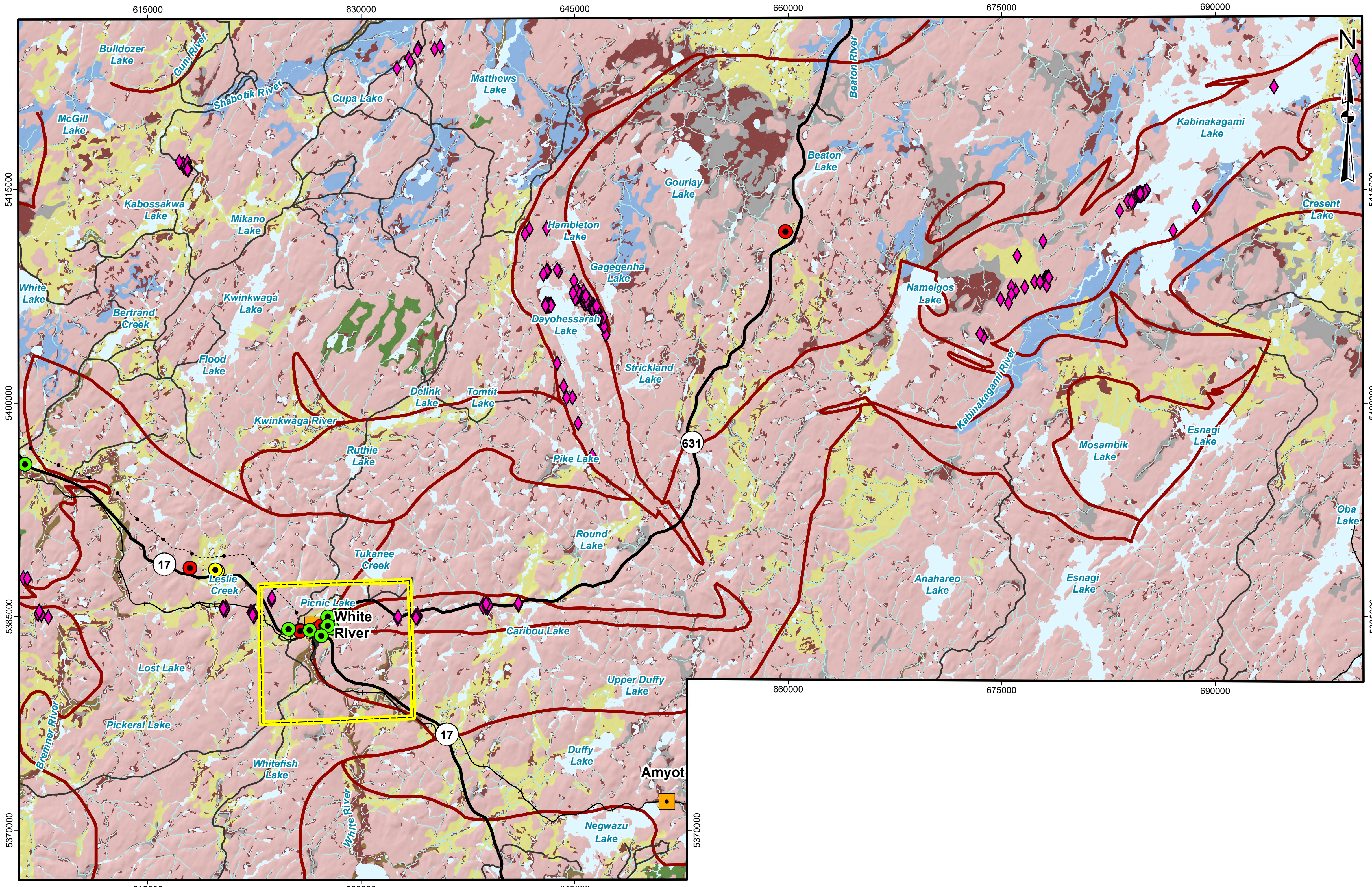
TITLE
Historical Earthquake Records of the White River Area 1985-2013

DESIGN	KR	23 APR 2013	**Figure 3.19**	REVISION 1
GIS	GF	31 OCT 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 3.19 - Historical Earthquake Locations in the Region Surrounding White River.mxd



Legend

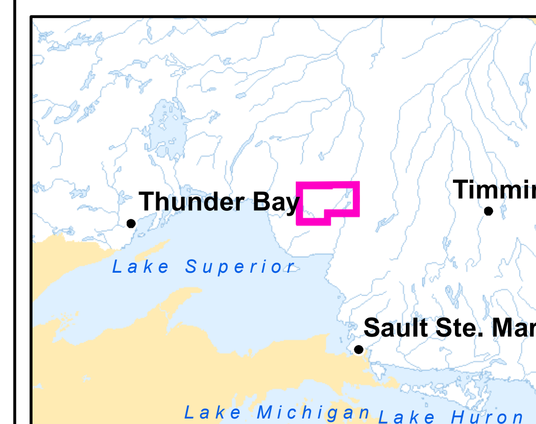
- Settlement
- White River Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Wetlands
- Waterbody
- Watercourse
- Bedrock Geology Contact
- Exploration Drill Holes

Water Well (MOE)

- Reached Bedrock
- Ends in Overburden
- Depth Unknown (incomplete record)

Surficial Geology

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



Data Sources:
Base data: MNR LIO, obtained 2009-2013
Overburden: OGS MRD-160 NOEGTS 2006
Water Well: MOE Water Well Information System
Diamond Drill Holes: Diamond Drill Hole Database, accessed September 2013
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)
Underlay: Hillshade DEM, MNR Elevation and Slope

10 km

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PROJECT
Preliminary Assessment of Geoscientific Suitability
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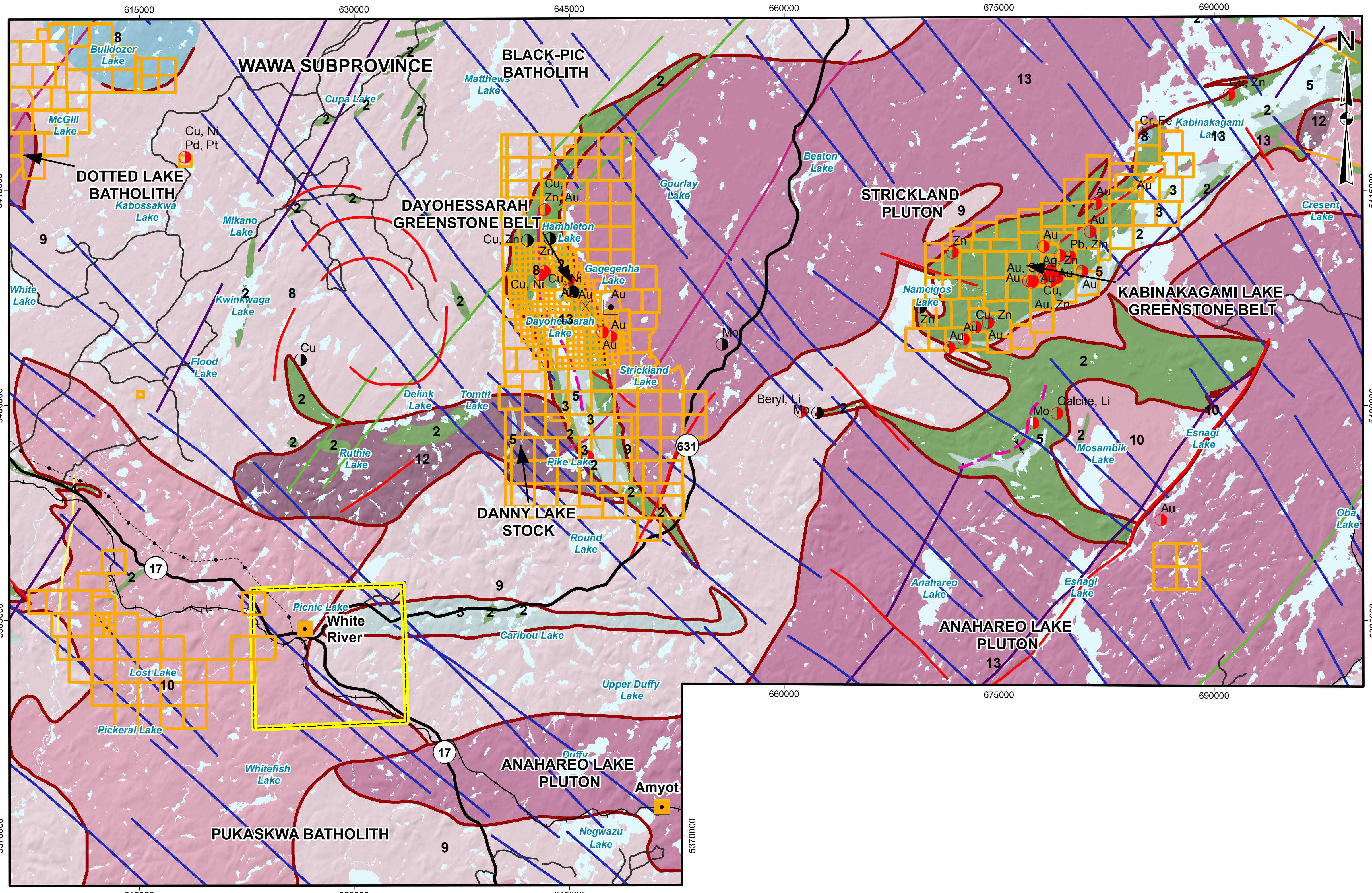
TITLE
Groundwater Wells and Exploration Drill Holes Within the White River Area

DESIGN	KR	23 APR 2013	Figure 4.1	REVISION 1
GIS	GF	04 NOV 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 4.1 Groundwater Well within the White River Area.mxd



Legend

Settlement
White River Municipal Boundary
Main Road
Local Road
Railway
Abandoned Railway Right-of-way
Hydro Line
Waterbody
Developed Prospect With Reserves
Discretionary Occurrence
Mineral Occurrence
Prospect
Faults
Major Fold (Syncline Approximate)
Mining Claims
Bedrock Geology Contact

Mapped Dyke

Abitibi mafic dyke
Biscotasing mafic dyke
Marathon, Kapuskasing or Biscotasing mafic dyke
Matachewan mafic dyke
Sudbury mafic dyke
unknown

Bedrock Geology

13: Granite-granodiorite
12: Diorite-monzonite- granodiorite
10: Foliated tonalite suite
9: Gneissic tonalite suite
8: Gabbro
5: Metasedimentary rocks
4: Felsic volcanic rocks
3: Felsic and intermediate metavolcanic rocks
2: Mafic metavolcanic Rocks

Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)
Active Mining Claims: MNDM, accessed November 1, 2013
Mineral Inventory: OGS MDI-2011
Underlay: Hillshade DEM, MNR Elevation and Slope

10 km

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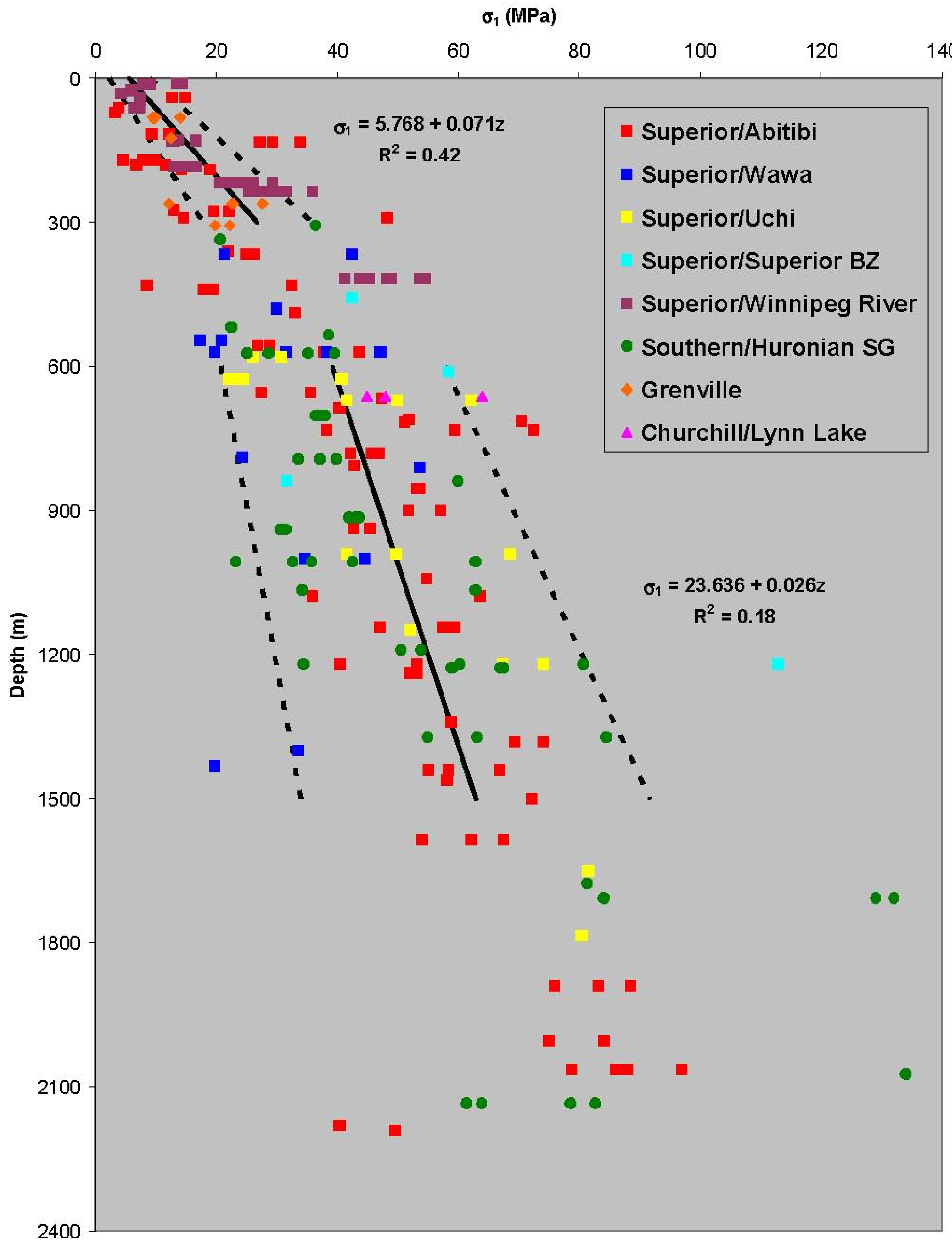
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Mineral Showings and Dispositions of the White River Area

DESIGN	KR	23 APR 2013	**Figure 5.1**	REVISION 1
GIS	GF	01 NOV 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 5.1 Mineral Showing and Dispositions of the White River Area.mxd



Data Sources:
Maloney, Kaiser, and Vorauer, 2006

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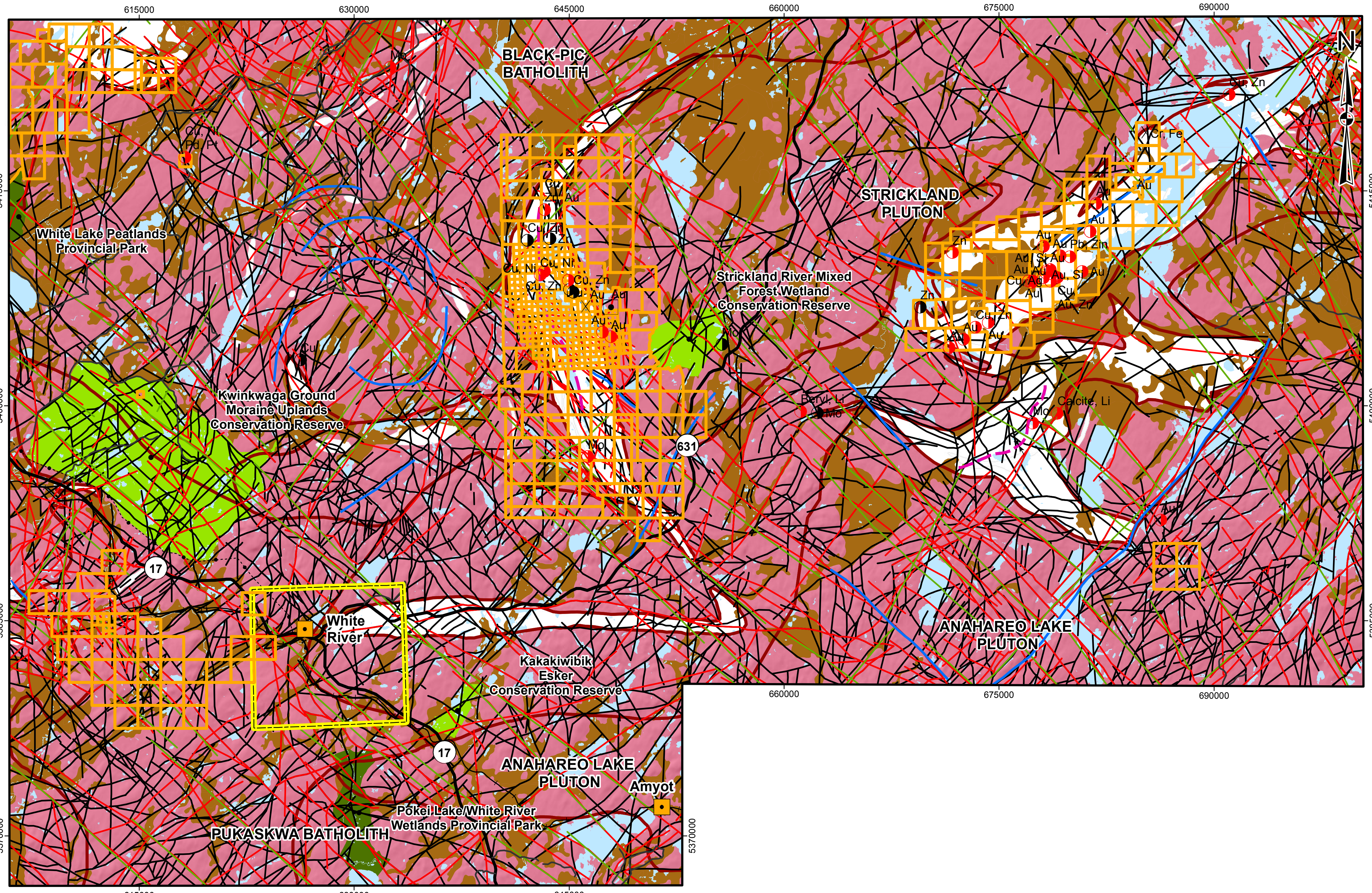
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Maximum Horizontal In Situ Stresses Typically Encountered in Crystalline Rock of the Canadian Shield

DESIGN	GHF	14 Aug 2012	FIGURE 6.1	UTM ZONE 16
GIS	GHF	08 Jan 2013		NAD 1983
CHECK	CB	31 Jan 2013		
REVIEW	CB	31 Jan 2013		



Legend

- Settlement
- White River Municipal Boundary
- Main Road
- Local Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Provincial Park
- Conservation Reserve
- Developed Prospect With Reserves
- Discretionary Occurrence
- Mineral Occurrence
- Prospect
- Mapped Fault
- Mapped Dyke
- Major Fold (Syncline Approximate)
- Mining Claims
- Bedrock Geology Contact
- Overburden Cover
- Unfavourable Geology
- Favourable Geology (exposed or thinly covered)

Brittle Lineaments

- Geophysical - Fracture and Dyke
- Surficial - Fracture and Dyke

Approximate Size of Repository Footprint

2 km
3 km

Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)
Overburden: OGS MRD-160, NOEGTS 2006
Intrusions: Generalized from OGS M2666, 2001 (250,000)
Lineaments: SRK, 2014
Active Mining Claims: MNDM, accessed November 1, 2013
Mineral Inventory: OGS MDI-2011
Underlay: Hillshade DEM, MNR Elevation and Slope

10 km

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PROJECT
Preliminary Assessment of Geoscientific Suitability
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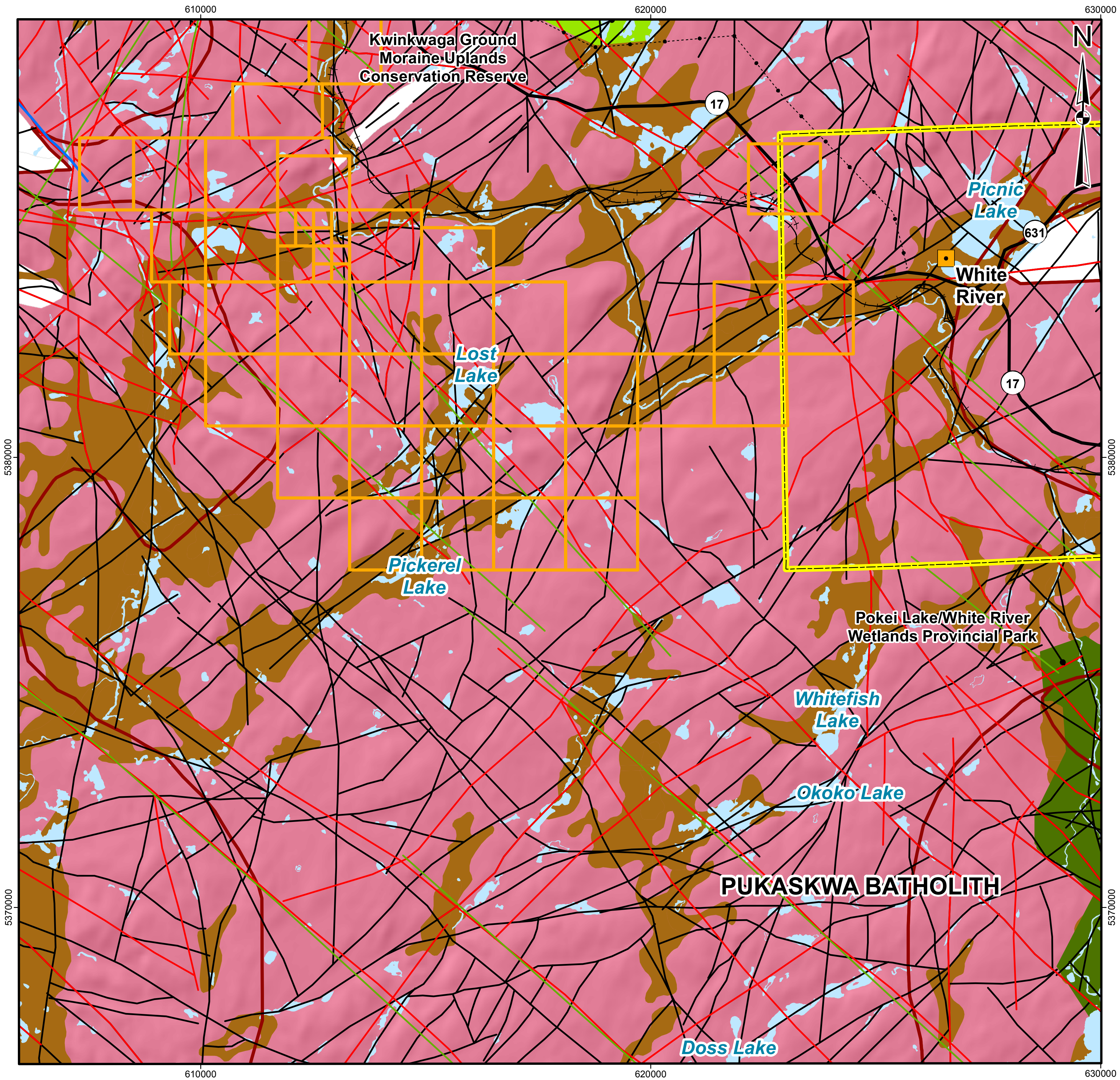
TITLE
Key Geoscientific Characteristics of the White River Area

DESIGN	KR	23 APR 2013	Figure 7.1	REVISION 1
GIS	GF	01 NOV 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:300,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 7.1 Key Geoscientific Characteristics of the White River Area.mxd

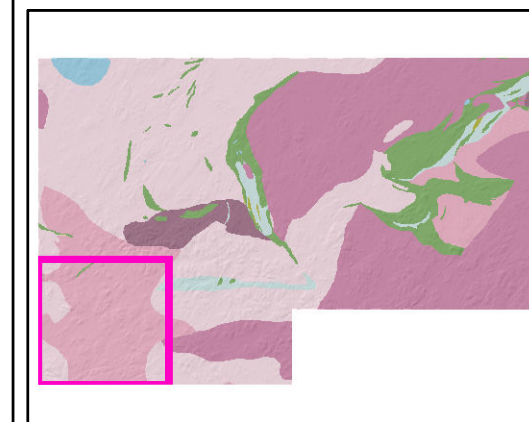


Legend

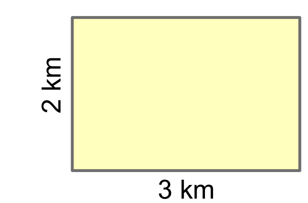
- Settlement
- White River Municipal Boundary
- Main Road
- Railway
- Abandoned Railway Right-of-way
- Hydro Line
- Waterbody
- Provincial Park
- Conservation Reserve
- Mapped Fault
- Mapped Dyke
- Mining Claims
- Bedrock Geology Contact
- Overburden Cover

Brittle Lineaments

- Geophysical - Fracture and Dyke
- Unfavourable Geology
- Favourable Geology (exposed or thinly covered)
- Surficial - Fracture and Dyke



Approximate Size of Repository Footprint



Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)
Overburden: OGS MRD-160, NOEGTS 2006
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)
Lineaments: SRK, 2014
Active Mining Claims: MNDM, accessed November 1, 2013
Underlay: Hillshade DEM, MNR Elevation and Slope

3 km

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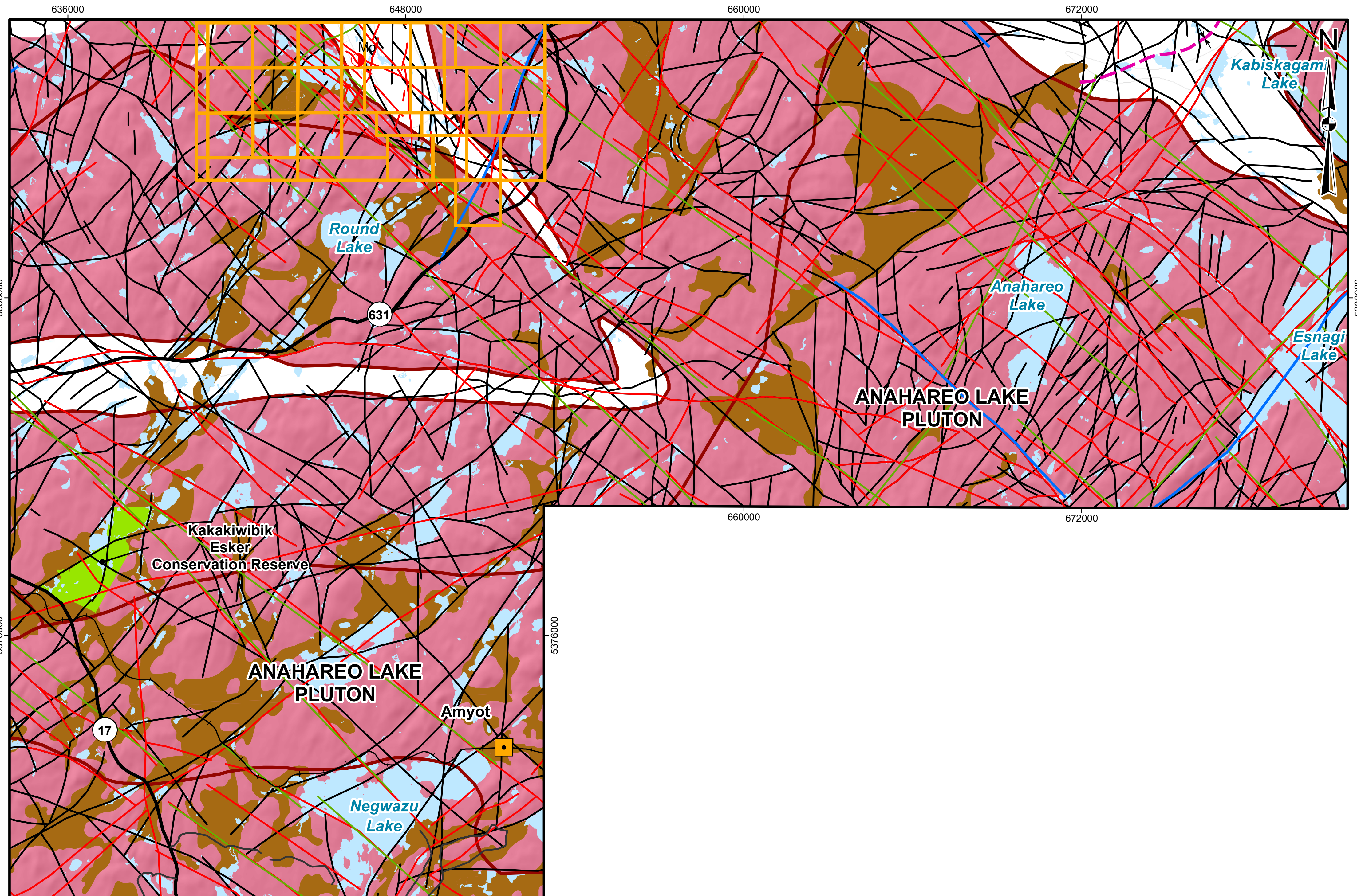
PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Key Geoscientific Characteristics of the Pukaskwa Batholith of the White River Area

DESIGN	KR	23 APR 2013	**Figure 7.2**	REVISION 1
GIS	GF	01 NOV 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:100,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 7.2 Key Geoscientific Characteristics of the Pukaskwa Batholith of the White River Area.mxd



Legend

- Settlement
- Main Road
- Local Road
- Railway
- Waterbody
- Conservation Reserve
- Mineral Occurrence
- Mapped Fault
- Mapped Dyke
- Major Fold (Syncline Approximate)
- Mining Claims
- Bedrock Geology Contact
- Overburden Cover

Brittle Lineaments

- Geophysical - Fracture and Dyke
- Unfavourable Geology
- Favourable Geology (exposed or thinly covered)
- Surficial - Fracture and Dyke

Approximate Size of Repository Footprint

2 km × 3 km

Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)
Overburden: OGS MRD-160, NOEGTS 2006
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)
Lineaments: SRK, 2014
Active Mining Claims: MNDM, accessed November 1, 2013
Mineral Inventory: OGS MDI-2011
Underlay: Hillshade DEM, MNR Elevation and Slope

3 km

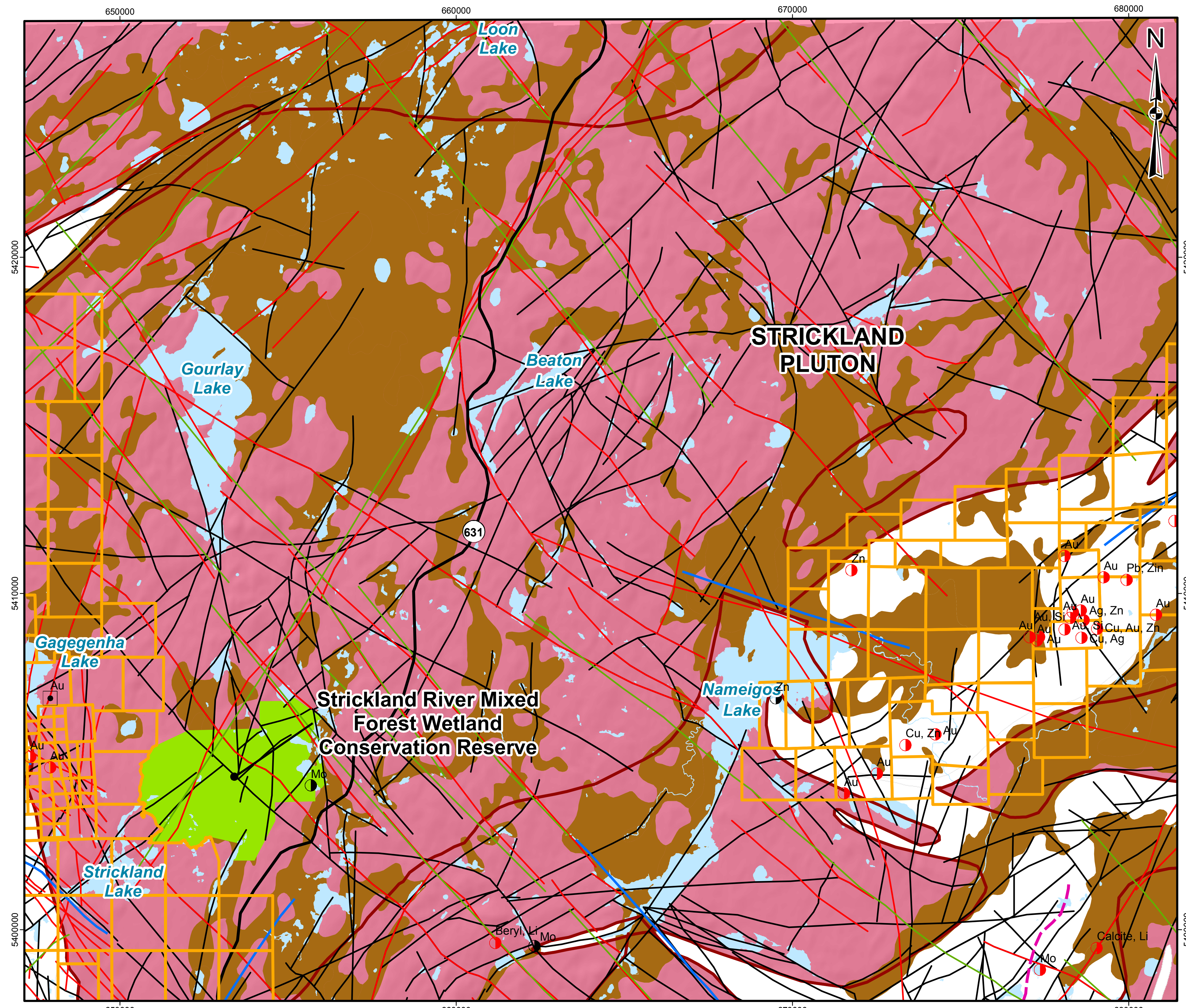
AECOM

PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Key Geoscientific Characteristics of the Anahareo Lake Pluton of the White River Area

DESIGN	KR	23 APR 2013	**Figure 7.3**	REVISION 1
GIS	GF	01 NOV 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:165,000

Path: P:\60297733\900-CAD-GIS\920 GIS-Graphics\Phase 1 Report\ReportMXDs\White River\June 2 2014\60297733_Fig 7.4 Key Geoscientific Characteristics of the Strickland Pluton of the White River Area.mxd



Legend

- Main Road
- Waterbody
- Conservation Reserve
- Discretionary Occurrence
- Mineral Occurrence
- Prospect
- Mapped Fault
- Mapped Dyke
- Major Fold (Syncline Approximate)
- Mining Claims
- Bedrock Geology Contact
- Overburden Cover

Brittle Lineaments

- Geophysical - Fracture and Dyke
- Unfavourable Geology
- Favourable Geology (exposed or thinly covered)
- Surficial - Fracture and Dyke

Approximate Size of Repository Footprint

2 km
3 km

Data Sources:
Base Data: MNR LIO, obtained 2009-2013
Bedrock Geology: OGS M2666, 2001 (1:250,000)
Faults: OGS MRD 126-REV1, 2011 (1:250,000)
Dykes: OGS MRD 126-REV1, 2011 (1:250,000)
Overburden: OGS MRD-160, NOEGTS 2006
Intrusions: Generalized from OGS M2666, 2001 (1:250,000)
Lineaments: SRK, 2014
Active Mining Claims: MNDM, accessed November 1, 2013
Mineral Inventory:OGS MDI-2011
Underlay: Hillshade DEM, MNR Elevation and Slope

3 km

AECOM

PROJECT
Preliminary Assessment of Geoscientific Suitability
Phase 1 Desktop Study

TITLE
Key Geoscientific Characteristics of the Strickland Pluton of the White River Area

DESIGN	KR	23 APR 2013	**Figure 7.4**	REVISION 1
GIS	GF	01 NOV 2013		UTM ZONE 16
CHECK	xx			NAD 1983
REVIEW	xx			1:124,000