Final Draft

SOURCE PROTECTION PLANNING

Lakehead Source Protection Area – Water Budget and Water Quantity Stress Assessment

Prepared for
Lakehead Region Conservation Authority

Submitted by
Gartner Lee Limited

November, 2007

Gartner Lee

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Reference: **GLL 60-795**

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Executive Summary

final draft

The Ontario government has introduced legislation to protect drinking water at the source, as part of an overall commitment to human health and the environment. A key focus of the legislation is the production of locally developed, science-based source water assessment reports and protection plans. The Lakehead Region Conservation Authority (LRCA) is participating in this initiative.

The Water Budget is one in a series of Technical Guidance Modules that was mandated to help watershed communities develop the Assessment Report. A water budget is a process that identifies how much water is available in the watershed, and illustrates how water moves through the watershed (lakes, streams, and under the ground). The water budget takes into account all the activities that require water, including both the needs of people and the environment. It also accounts for anticipated future water needs.

The Lakehead Region Conservation Authority has prepared this water budget 'conceptual understanding' on a watershed basis. The conceptual understanding provides an overview of how the groundwater and surface water interact and move through the watershed. This understanding has enabled the LRCA to determine if there is a need for, and level of, water budget assessment through numeric modeling.

The Kaministiquia River and its tributaries form the most significant drainage system in the Lakehead Source Protection Area (Lakehead SPA). Other major rivers in the Lakehead SPA area are the Neebing, Current, McIntyre and Wolf Rivers. The major urban centre in the Lakehead SPA area is the City of Thunder Bay, which has a total population of approximately 110,000, comprising about 90% of the total population of the Lakehead SPA. The Municipalities of Oliver Paipoonge, Neebing, and the Township of Shuniah have a combined total population of approximately 10,000. The Townships of Conmee, O'Connor, Gillies and Dorion have a combined total population of about 3,000.

Within the Lakehead SPA, there are 21 quaternary watersheds with a total drainage area of approximately 11,526 km^2. The Kaministiquia River and its tributaries form the major watershed in the study area and drain an area of approximately 7,812 km^2 (approximately 68% of the total watershed area). The remaining smaller watersheds comprise 3,714 km^2 (approximately 32%) of which the most important are: Current River watershed (663 km^2), Neebing River watershed (232 km^2), McIntyre River watershed (210 km^2), and the Wolf River watershed (730 km^2). All of the 21 quaternary watersheds eventually drain to Lake Superior via the Kaministiquia River, Neebing River, McIntyre River, Current River, Wolf River, McVicar Creek, Whiskeyjack Creek and Lomond River, as well as some other minor creeks and streams northwest and south of the City of Thunder Bay.

The Lakehead SPA is characterized largely by shallow soils over bedrock with sporadic occurrences of deeper overburden in the area of Kaministiquia River Valley, Whitefish and Slate River Valleys and the area south of the Dog Lake moraine. Another isolated area of thick overburden occurs in the area of Dorion, in the northeast part of the study area. The overburden is mostly sand and gravel, through which, infiltration of precipitation readily occurs. There are areas with thicker more fine grained deposits and while these accept less water, there is still significant ground water recharge. The underlying Precambrian bedrock is comparatively impermeable and therefore deflects groundwater flow laterally to the streams, wetlands and lakes. Most of the shallow private wells are located within the area of thicker overburden.

In the past the City of Thunder Bay has obtained its drinking water from Lake Superior and Loch Lomond. However, Loch Lomond will likely be decommissioned by the end of 2007 and then all surface water supplies for the City of Thunder Bay will come from Lake Superior. In addition to the City of Thunder Bay, the hamlet of Rosslyn Village is also supplied with municipal water supply from a well field (the Rosslyn well field) utilizing one ground water well for potable water. Within the City of Thunder Bay, 8% of the population obtain drinking water from private wells. Approximately 13,000 people within the rural population get their water supply from domestic wells.

The water balance was calculated based on the six meteorological stations within and in the vicinity of the Lakehead SPA. An assessment of soils, topography, and landcover was compared to the average annual streamflow of twelve gauging stations within the SPA. This was conducted for the period of 1970 to 1994, when the meteorological records were most coincident with existing streamflow records. Measured meteorological data and related calculations (like actual evapotranspiration) were interpolated for the Lakehead SPA from values measured (or calculated) at six meteorological stations. Individual month and annual interpolations were made using an Inverse Distance Weighting formulation. This interpolation is dependent on the variation between observed data points.

The interpolated average annual precipitation for the Lakehead SPA during this period was approximately 843 mm/yr. The interpolated actual evapotranspiration and surplus were estimated to be 508 mm/yr and 335 mm/yr, respectively. This surplus is then available for surface runoff and groundwater recharge. The average recharge for the area was approximately 168 mm/yr and average surface runoff was 167 mm/yr. Since the recharge ultimately reaches the watercourses in this shallow flow system, it generates baseflow. The combination of surface runoff and baseflow is generally within 10% of the observed streamflow for smaller watersheds. For larger watersheds like the Kaministiquia River (02AB006) and Shebandowan River (02AB009) the deviation becomes larger and is in the range of 20 to 28%.

When considering the entire Lakehead SPA, consumptive surface and groundwater takings equal 61.17 and 3.75 mm/yr, respectively, for a total of approximately 65 mm/yr. Compared with the available surplus, there are ample drinking water supplies within the Lakehead SPA. On a regional basis, there is low water use, low growth and minimal land use changes. There are no known water quality issues. Therefore, the team has selected a simple analytical modelling approach to conduct a Tier 1 water budget assessment.

The Tier 1 water quantity stress assessment relied on the Water Budget Conceptual Understanding. A Tier 1 Water Budget and Water Quantity Stress Assessment were performed for Loch Lomond (surface water based former municipal drinking water supply) and the Rosslyn Wells (groundwater-based drinking water supply). Although Loch Lomond will likely be decommissioned as the source of drinking water supply but may be used in the future for other purposes. Analysis was performed for both of the watersheds and identified a Low Level of stress for both existing and future conditions.

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1. Introduction

A water budget analysis measures and characterizes the contribution of each component of the hydrologic cycle. A water budget should provide both a quantitative measure of various components of the hydrologic cycle (precipitation, runoff, evapotranspiration, etc.) and an understanding of the pathways that water takes through a watershed. The focus of the water budgeting activities carried out for the Lakehead Source Protection Area (hereafter referred to as Lakehead SPA) is restricted to municipal drinking water systems only. These include the ground water supply in Rosslyn, the Lake Superior intake for Thunder Bay, and the former intake in Loch Lomond for Thunder Bay (which is technically no longer classified as a municipal system). This water budget is linked to the Watershed Characterization (LRCA, 2006), but provides a conceptual quantitative look at the watershed.

1.1 Water Budget

Water budget is the component of the Assessment Report where water supply and demand are quantified and where water movement within the watershed is understood. The level of water budgeting required in any specific watershed will depend on a number of factors, in particular water-taking or water-quality stresses, or both. The objective of a water budget analysis is to provide a technically sound basis for managing the quantity of existing and future sources of drinking water.

1.2 Water Budget Requirements

A water budget is an understanding and accounting of the movement of water and the uses of water over time on, through and below the surface of the earth. In the Lakehead SPA there are 21 watersheds that all drain ultimately to Lake Superior. Each is analyzed in a similar fashion which addresses some or all of the following four main questions:

1. Where is the water? (i.e., where are the surface water and groundwater reservoirs located?);
2. How does the water move between those reservoirs? (i.e., what are the pathways through which the water travels?);
3. What and where are the stresses on the water? (i.e., where are the takings and assimilative needs?); and,
4. What are the trends? (i.e., are water levels declining, increasing, or remaining constant over time?).

The water budget developed in each watershed accommodates some or all of the following considerations:

a) The amount of water within the various reservoirs of the hydrologic cycle, including precipitation, evapotranspiration, groundwater inflow and outflow, surface water inflow and outflow, change in storage, water withdrawals and water returns.

b) A description of groundwater and surface water flow pathways, and temporal (seasonal and annual) changes in water quantities within each reservoir.

c) Identification of:
   - areas of key hydrologic processes (e.g., recharge and discharge areas); and
   - the availability of potential water sources (aquifers and unused surface water sources).

d) Support for predicted changes in the hydrologic cycle due to trends in climate, land use and additional takings.

1.3 The Lakehead Source Protection Area Watersheds

Water budget studies are conducted on a watershed basis. There are 18 independent quaternary watersheds and 3 partial watersheds (2AA03, 2AC01 and 2AC09) within the Lakehead SPA. Some of these drain into others, for example the Kashabowie flows into the Shebandowan, which ultimately joints the Kaministiquia before entering Lake Superior. Figure 1 shows the locations of the quaternary watersheds, and Table 1 presents the drainage area of each watershed.

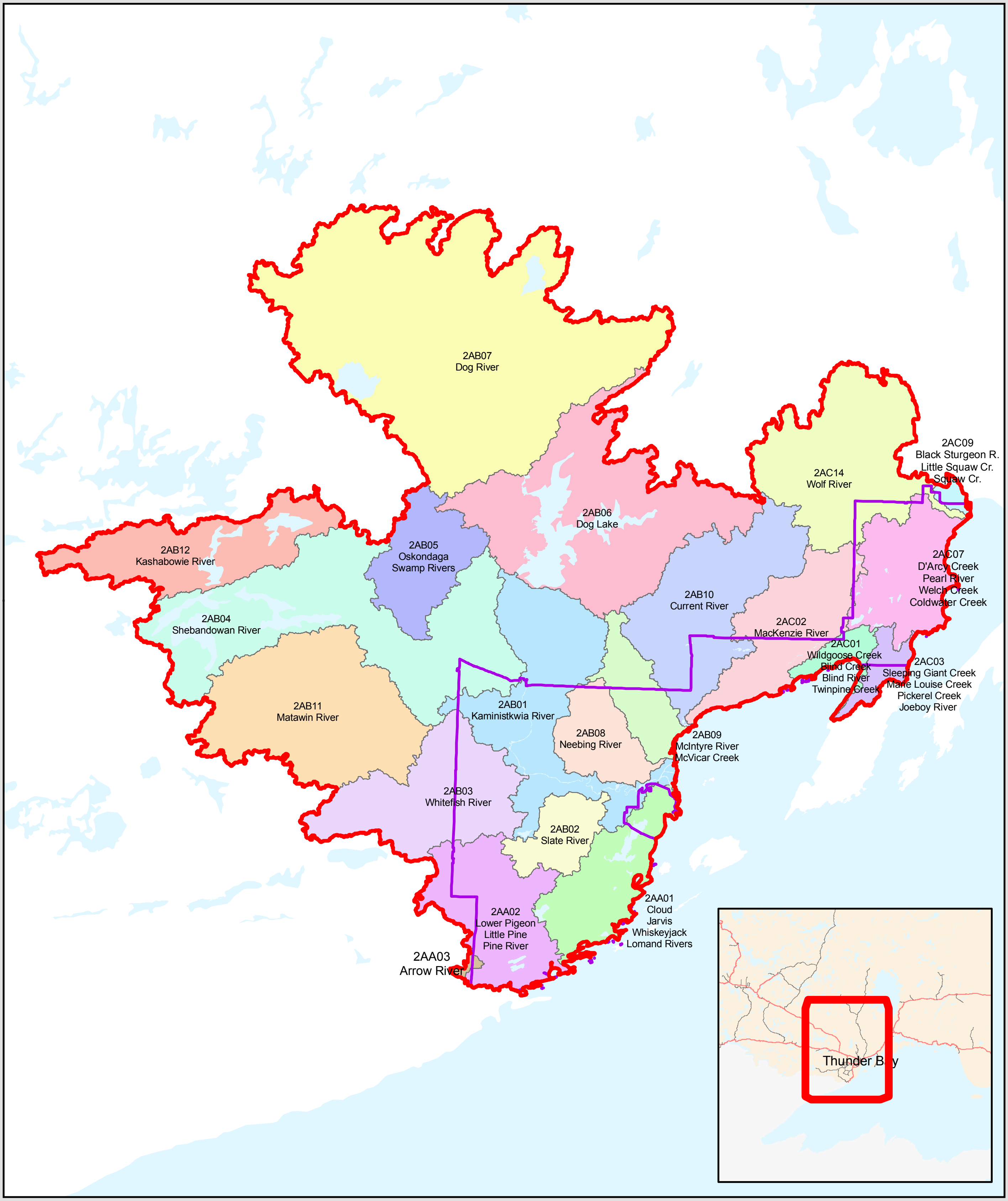
The watershed area considered within the Lakehead SPA area has been estimated at 11,526 km^2. The entire watershed area ultimately drains to Lake Superior via the Kaministiquia River, Neebing River, McIntyre River, Current River, Wolf River, McVicar Creek, Whiskeyjack Creek and Lomond River, as well as some minor creeks and streams northwest and south of the City of Thunder Bay. Therefore, these river systems can be considered as independent watersheds.

The Kaministiquia River with its tributaries forms a major drainage system within the Lakehead SPA. It covers a total drainage area of approximately 7,812 km^2 and includes a number of watercourses within the basin, the most important of which are the Dog, Kaministiquia, Matawin, Shebandowan, Whitefish and Kashabowie Rivers. The Kaministiquia River flows from Dog Lake in the northern part of the basin in a southward direction until it reaches Kakabeka Falls. At that point the river turns eastward and flows to Thunder Bay and Lake Superior. Downstream from Kakabeka Falls, the Whitefish and Slate Rivers flow into the Kaministiquia River. Two other tributaries (Matawin River and Shebandowan River) enter the Kaministiquia River from the west. The water released from the Shebandowan Dam flows approximately 15 km southeast to the confluence of the Matawin River and flows into the Kaministiquia River above Kakabeka Falls. Figure 2 shows a schematic of the drainage basins of the Kaministiquia River System. As shown in Figure 2, flow in the Kaminstiquia River system is controlled by a number of dams and generating stations.

Table 1. Lakehead SPA Quaternary Watersheds and Drainage Areas

Major Watershed	Quaternary Watershed	IWD #	Drainage Area* (km^2)
Kaministiquia River Watershed	Kaministiquia River	2AB01	723
	Shebandowan River	2AB04	1177
	Kashabowie River	2AB12	527
	Whitefish River	2AB03	586
	Slate River	2AB02	182
	Matawin River	2AB11	864
	Oskondaga - Swamp Rivers	2AB05	341
	Dog Lake	2AB06	1132
	Dog River	2AB07	2280
Neebing River Watershed	Neebing River	2AB08	232
McIntyre River Watershed	McIntyre River - McVicar Creek	2AB09	210
Current River Watershed	Current River	2AB10	663
Wolf River Watershed	Wolf River	2AC14	730
Arrow River Watershed	Arrow River	2AA03	12
Pigeon River Watershed	Lower Pigeon - Little Pine - Pine River	2AA02	474
Cloud River Watershed	Cloud - Jarvis – Whiskeyjack Creek - Lomand River	2AA01	373
Black Sturgeon River Watershed	Black Sturgeon River - Little Squaw Creek - Squaw Creek	2AC09	27
MacKenzie River Watershed	MacKenzie River	2AC02	443
Sleeping Giant Creek Watershed	D'Arcy Creek - Pearl River - Welch Creek - Coldwater Creek- Old John Creek Laurie	2AC07	381
	Sleeping Giant Creek - Marie Louise Creek - Pickerel Creek- Joeboy River - Portag	2AC03	90
	Wildgoose Creek - Blind Creek - Blend River - Twinpine Creek	2AC01	79
		Total	**11,526 km^2**

*Note: * Each area does not include upstream watersheds. e.g., Shebandowan does not include Kashabowie.*



Basemapping from Ontario Ministry of Natural Resources

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Legend

- Lakehead Region Conservation Authority
- Lakehead Source Protection Area

Lakehead Source Protection Area

Watersheds

October 2007
Project 60795

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Figure 1

Map Document: (N:\Projects\2006\60795\2007\Final\GISSpatial\ReportMaps\60795LRCAWatershedFigure1.mxd)
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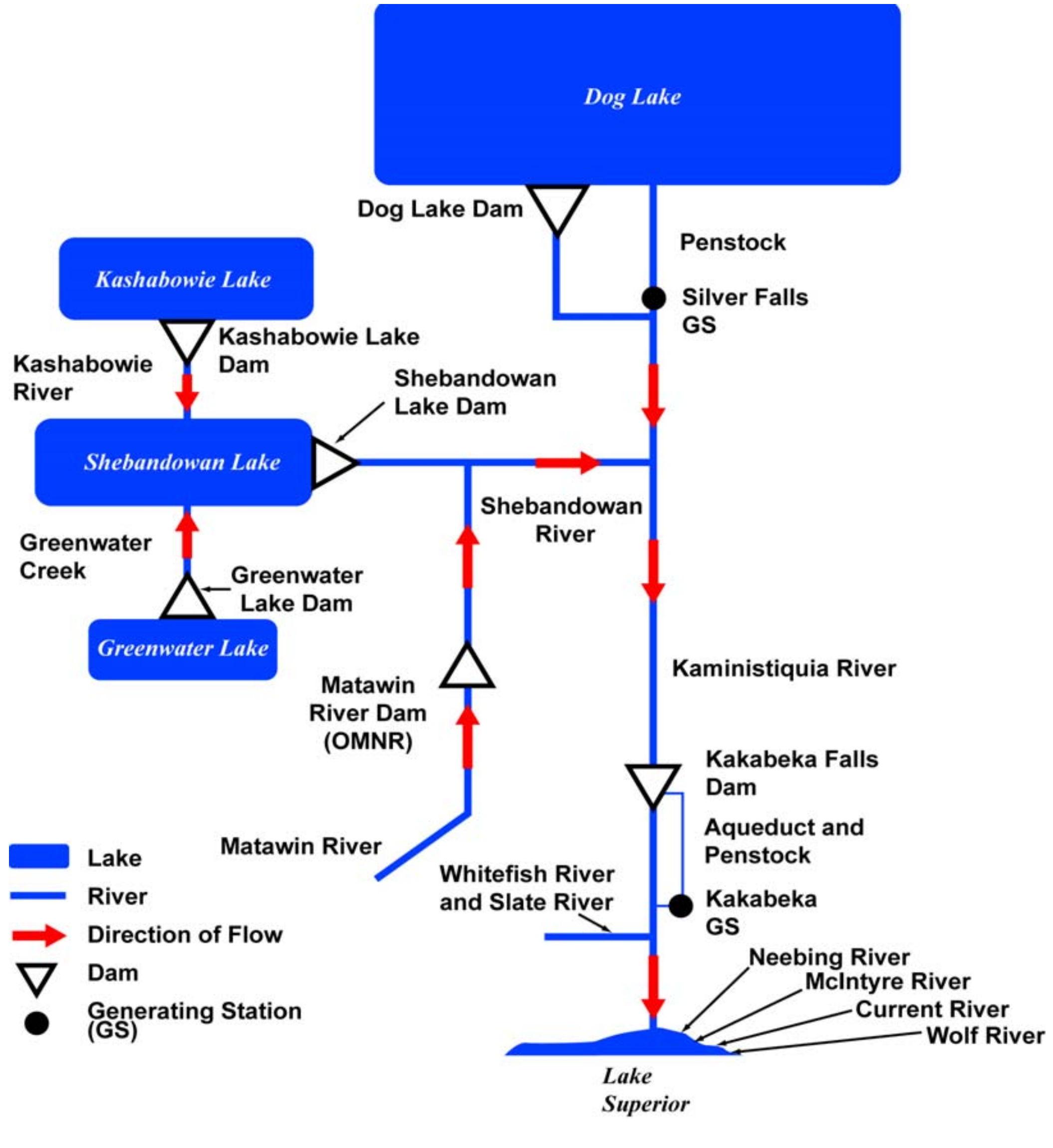

Note: (Adapted and modified from Acres International Limited, 1990)

Figure 2. Schematic of the Kaministiquia River System Drainage Basins and Control Structures

The Neebing, Current and McIntyre Rivers are some smaller independent watersheds in the Lakehead SPA, and drain 232 km^2, 663 km^2 and 210 km^2 respectively, to Lake Superior. The Pigeon River including the Little Pine and Pine Rivers forms the southwest boundary of the watershed, flowing along the Ontario-Minnesota border and draining lands on both sides. The watershed area also contains Wolf River, which drains an area 730 km^2, located west of Lake Nipigon and flowing into Black Bay through part of Dorion Township.

The Lakehead SPA watershed is characterized largely by shallow soils over bedrock, particularly along the Kaministiquia River Valley and the area immediately north of the valley and south of the Dog Lake Moraine. In addition, thicker overburden underlies the Whitefish River and Slate River valleys to the south and west. An isolated area of thick overburden occurs in the area of Dorion, in the northeast part of the study area. The majority of these areas are underlain by less than 15 m of overburden. The overburden is mostly outwash sand and gravel, which readily accepts the infiltration of precipitation. Portions that are more fine grained (lacustrine silt deposits) exhibit lower yet still significant infiltration capacity. The underlying Precambrian bedrock is comparatively impermeable and therefore deflects groundwater flow laterally to the streams, wetlands and lakes.

The major urban centre in the Lakehead SPA area is the City of Thunder Bay, which has a population of approximately 110,000 and accounts for approximately 90% of the total population of the Lakehead SPA. Previously, the City of Thunder Bay was dependent on its water supply from surface water takings from Lake Superior and Loch Lomond. The City of Thunder Bay intends to draw its entire municipal potable water supply from Lake Superior by the end of 2007. Thereafter, the Loch Lomond water supply may have alternate uses (e.g. a source of potable water for the Fort William First Nation or the City of Thunder Bay for power generation and/or an industrial grade water supply). The municipal water supply system in Rosslyn Village draws its water from groundwater sources. In Rosslyn, there is a confined aquifer of limited proportions that supplies the small community of about 30 homes. The rural homes located in the SPA are dependent on shallow domestic wells. Based on MOE (Ontario Ministry of Environment and hereafter referred to as MOE) Water Well Records, there are about 3,000 drilled wells[1] in the study area, of which 81% are drilled in overburden and the rest are in bedrock. Well completion depths are highly variable with 75% of wells completed at depths of 60 m or less.

1.4 Water Budget Maps

The MOE Interim Water Budget Technical Direction document (MOE, 2007) suggests up to 27 different maps could be used to present the results of the water budget exercise. The Lakehead SPA study area is relatively straightforward from an analytical point of view, having a relatively uniform terrain. This coupled with the spread-out nature of the data stations in comparison to other watersheds, means that the proposed maps have been consolidated to 17 (including maps 14b and 14c). These are foldout maps presented together in Appendix B, and may be kept folded out. In this way the reader can conveniently reference the maps as they proceed through the report. Appendix B also includes a summary of what information is on each map, and how the original 27 maps were consolidated.

1. *It has been our experience that there are typically up to 30% more wells than reported in the official water well records, largely because many pre-date record keeping, or were unreported at the time of drilling.*

2. Objectives of Source Protection Planning of Lakehead SPA

Water budget prepared for the Lakehead SPA will be used for the following purposes in watershed planning:

a) to set quantitative hydrological targets (e.g., water allocation, recharge rates, etc.) within the context of (sub) watershed plans;
b) as a decision-making tool to evaluate, relative to established targets, the implications of existing and proposed land and water uses within (sub) watersheds;
c) to evaluate the cumulative effects of land and water uses within (sub) watersheds;
d) to provide a (sub) watershed-scale framework within which site-scale studies (e.g., hydrological evaluations, sewage treatment plans, water supply plans) can be undertaken;
e) to help make informed decisions regarding the design of environmental monitoring programs;
f) to assist in setting targets for water conservation;
g) to assist in establishing long-term water supply plans;
h) for the SPA, these objectives will answer four main questions posed in Section 1.2 above; and
i) to identify data and knowledge gaps and to investigate climate change scenarios.

3. Conceptual Understanding of the Water Balance

This section gives a general overview of the components in the hydrologic water balance in a watershed to provide the reader with a basic understanding of the physical processes that characterize the available water resources within the Lakehead SPA. For a more complete understanding of the processes involved in the water balance of a watershed, please refer to some of the key textbooks on this subject (e.g., Chow, 1964; Viessman and Lewis, 1996; Linsley *et al.*, 1982).

Figure 3 displays a conceptual diagram of the major components within the hydrologic cycle (or water balance) within a watershed. The hydrologic cycle is the cycle of water movement through the earth-ecologic-atmosphere system. Water vapour accumulates in the atmosphere by evaporation from surface water and transpiration from plants, forming clouds. When it condenses, it falls to the land surface as precipitation (rain and snow). This precipitation is stored on the surface (e.g., lakes, ponds and marshes), or at depth (groundwater). From there it is evaporated (from the surface) or transpired (from the shallow subsurface) to repeat the next cycle. The following paragraphs provide further detail.

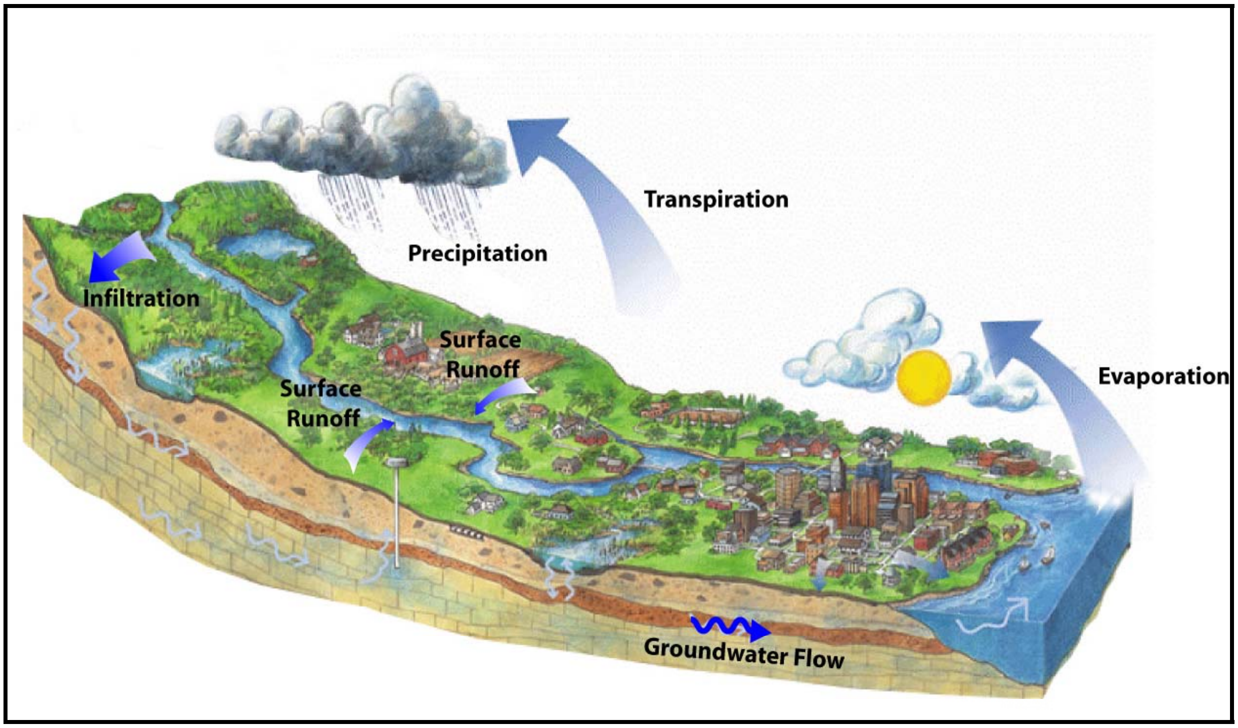

Figure 3. Conceptual Representation of the Hydrologic Cycle in a Watershed (Source: Conservation Ontario)

The hydrologic cycle begins with precipitation falling on the ground. The amount and rate of precipitation that actually arrives at the ground surface is controlled by the prevailing weather system that generated the precipitation on a regional scale. At the more localized scale, topography and land cover influence the actual precipitation amounts arriving at the ground surface.

This water (as rain or snowmelt) can have three pathways. It either runs off across the ground surface directly to a surface watercourse, infiltrates into the ground to recharge groundwater storage, or goes back to the atmosphere by evaporation or plant transpiration[2].

The amount of water that actually infiltrates the ground surface is controlled by the rate of precipitation input (rainfall or snowmelt), soil type (e.g., clay, silt, sand or gravel), ground surface conditions (e.g., slope, frozen, cracking) and vegetative cover (e.g., pasture, forests). In some areas (e.g., hummocky ground), the surface topography has created large depressions, which require several metres of water to pond before overland flow occurs. Consequently, water in these depressions either infiltrates downward and contributes to groundwater and subsurface storage, or evaporates back to the atmosphere. The recharge to the groundwater system creates a groundwater pressure that causes it to flow slowly through the ground. In the Lakehead SPA, these pathways are localized and groundwater discharges over short distances back into the watercourses as baseflow. The travel time of groundwater flow is governed by the porosity and permeability of the soil or rock, the driving head or groundwater pressure and the geometry of the pathways.

Surface runoff collects in stream channels that lead to larger channels or discharge to ponds, wetlands or lakes. While in these ponds or lakes, part of this water returns to the atmosphere by evaporation. It may also infiltrate into the ground, or spill to downstream channels. The travel time of flow in these stream channels is governed by the length, slope, roughness, and cross-sectional shape of these channels. If the flow is high and fast enough, water may overtop the channel banks, flooding the adjacent land area subjecting it to further evaporation or infiltration.

Evapotranspiration is a function of multiple factors including temperature, wind, humidity and radiation. Potential evapotranspiration (PET) is the amount of water that could be evaporated and transpired if there was sufficient water available. PET can be measured indirectly from other climatic factors, but it also depends on the surface type, such as free water (for lakes and oceans), the soil type for bare soil and the species of vegetation.

Actual evapotranspiration (AET) is the actual amount of water evaporated to the atmosphere by evaporation and transpiration. In wet months, when precipitation exceeds potential evapotranspiration, actual evapotranspiration is equal to potential evapotranspiration. In dry months, when potential evapotranspiration exceeds precipitation, actual evapotranspiration is equal to precipitation plus the absolute value of the change in soil moisture storage (in these cases AET < PET).

2. *Henceforth we use the term "evapotranspiration" to couple the processes of evaporation and transpiration (plant uptake). Keep in mind that transpirative losses include temporary storage in the plant body and subsequent release to the air.*

4. Water Budget Elements

The purpose of this chapter is to describe the dominant watershed characteristics, features or factors that influence the water balance (or budget) within the Lakehead SPA. Its secondary purpose is to summarize the available data used to measure or monitor those particular factors, highlighting (where possible) any gaps in the required databases.

Water in the river/stream is the result of precipitation that has fallen on the watershed over time. Water resulting from precipitation gains entry to the creek following three main paths: by directly falling on the creek surface, by running over the land surface to the streams/water bodies (surface runoff), or by infiltrating into the ground and later reappearing as groundwater discharge (springs or seeps) along the streams.

It is important to note that not all of the precipitation that falls on the watershed makes its way to the water system. A portion of the precipitation that falls returns to the atmosphere by evaporation from open water surfaces (including sublimation in the winter from the snow covered surfaces) or is used by plants through transpiration. The other portion of this water infiltrates into the ground, and may leave the watershed by discharge to streams/rivers or is used by plants (and other activities) in an adjacent watershed.

The path water that follows in a watershed, will determine to a great extent how the watershed responds to precipitation (the ‘water balance’). The local climate, physiography (surficial geology, topography and land use) are dominant factors that influence how water is delivered to the streams and rivers that drain a watershed. In the Lakehead SPA study area, consumptive activities (e.g., drinking water, irrigation etc.) are locally dominant, but minor in comparison to the availability of water. Streamflow is the response to how water is delivered to the streams and creeks, forming the drainage network of a watershed. Each of these factors must be considered when describing the water balance within a watershed.

To develop a conceptual understanding for the Lakehead SPA, the following elements will be considered, utilizing available data:

a) climate;
b) land cover;
c) geology/physiography;
d) groundwater;
e) surface water (including reservoirs and major discharges); and
f) water use.

4.1 Climatic Setting

The climate of northern Ontario is characterized as having warm wet summers, cold dry winters, a short growing season and usually reliable precipitation. The climate within northern Ontario differs somewhat from one location to the other and from one year to the next. Spatial variations are caused by the topography and varying exposure to the prevailing winds in relation to the Great Lakes such as Lake Superior to the south and to a lesser extent, Hudson Bay to the north. The constant influence of several air masses, including moist subtropical air, dry arctic air and dry continental air masses, makes the area susceptible to extreme and rapid variations in weather throughout the year. These variations are especially prevalent during the summer months when warm humid air mixes with dry cool air, resulting in moderate to severe thunderstorms. This mechanism creates an enhanced effect when storms approach the region close to the shore of Lake Superior; the weather systems, filled with warmer inland air, clash with cold air over Lake Superior. In the winter, Lake Superior is usually entirely ice-covered and thus the City of Thunder Bay is not affected by open water influences. As a result, there is a substantial decrease in snow flurry activity during late winter.

The climate of Northern Ontario is described in “The Climate of Northern Ontario” by Chapman and Thomas (1968). The south part of the Lakehead SPA lies in the Rainy River-Thunder Bay region, and the north part in Height of Land climatic region (Chapman and Thomas, 1968). Given that this region is in the southern part of Northern Ontario, it is about 8 degrees warmer than beside Hudson Bay to the north. The average annual temperature is about 2 degrees warmer at the south edge of the Lakehead compared to the north edge SPA. Frost-free days vary across the SPA with approximately 100 near Thunder Bay, reducing markedly to 70 days to the northwest. From a moisture point of view this region has 10 to 30% lower precipitation in comparison to other Northern Ontario regions to the east and west, and experiences a correspondingly lower surplus. These relatively cooler and drier conditions are understandable given the fact that the region is upwind of large water bodies. It is even cooler and drier inland to the western edge of the Lakehead SPA.

Over the past 120 years, climate observations comprising maximum and minimum daily air temperature and daily precipitation (as rainfall and snowfall) totals have taken place within and around, the study area at 49 meteorological stations. These measurements however, have been made over different time periods. Only two of these meteorological stations (Cameron Falls and Upsala, both of which are located outside of the Lakehead SPA) meet the World Meteorological Organization standards. At a few of these locations there are recording rain gauge (e.g., tipping-bucket) measurements and in others, snow depth on the ground measurements. At other stations, snow course measurements have been made on a twice monthly schedule during the winter months. For the most part, these climate observations have been carried out by a number of agencies, including: Environment Canada’s Atmospheric Environment Service (AES), the Ontario Ministry of Natural Resources (OMNR), LRCA, Ontario Power Generation (OPG), some mining companies and regional municipalities. A list of the climate stations located within and in the vicinity of the Lakehead SPA where historical measurements have been made and recorded is provided in Appendix A.

Using a data fill-in technique to account for missing values in the record developed by Schroeter *et al.,* (2000), daily meteorological data were processed for six selected stations in and around the Lakehead SPA for the period 1970-1994. This period was chosen to keep consistency with HYDAT data for estimating water balance for the same interval. Climate normals as well as daily climate data can be obtained from Environment Canada's web site (www.climate.weatheroffice.ec.gc.ca). Table 2 provides a summary of mean annual values for air temperature, rainfall, snowfall, and total precipitation at six selected climate stations at and in the vicinity of the study area. (To aid the reader, the station values given in Table 2 are deliberately grouped according to geographical location and then listed in a north to south orientation for each group.)

Table 2. Climate Summary for Selected Stations at and in the Vicinity of Lakehead SPA (Data of 1970-1994)

Climate Stations Name		ID	Mean Annual Air Temp. (°C)	Mean Annual Rainfall Depth (mm)	Mean Annual Snowfall Depth (cm)	Mean Annual Total Precip. Depth (mm)
Stations Located Within the Lakehead SPA	*Flint*	6042MJ7	2.19	588.3	217.1	805.3
	Thunder Bay	6048261	2.52	573.8	197.7	771.5
	Whitefish	6049466	1.74	603.9	303.7	907.7
	Tranquillo Ridge	6048864	2.56	629.1	255.1	884.2
Stations Located North of the Lakehead SPA	*Upsala**	6049095	0.78	601.3	249.8	851.1
	Cameron Falls	6041110	1.80	643.8	241.5	885.3

*Note: * This station cannot be seen on the Map 2 as it is situated 30 km to the northwest of the northern boundary of the study area.*

Generally speaking, there is an obvious north to south trend in the mean annual air temperature, with the northern part being cooler than southern part. For example, Cameron Falls located 100 km northeast of Thunder Bay is 0.7°C cooler than Thunder Bay. Upsala, which is the furthest north and most inland, is the coolest (on average) being 1.7°C cooler than Thunder Bay. The spatial distribution of mean rainfall and snowfall amounts in the Lakehead SPA tends to be related to the distance from Lake Superior as well as to the relative topography of the area. In general, the highest total precipitation is associated with the highest topography and longest distance north of Lake Superior (for example, compare Thunder Bay station[3] to Whitefish, Flint, and Upsala stations).

The average precipitation (arithmetic average) for all of the six stations is 851 mm/yr. Map 1 in Appendix B displays the total precipitation across the study area, contoured using an inverse distance weighting formulation. Within the Lakehead SPA, the contours range from 775 mm/yr at Thunder Bay Airport in the east, increasing towards the southwest to a value of 900 mm/yr near Whitefish Lake. The average precipitation inland to the north of Lakehead SPA is 850 to 885 mm/yr.

3. *The reader will be aware that the Thunder Bay meteorological station may be considered to be influenced by Lake Superior, because of its close proximity to the lake.*

Given the relatively few meteorological stations in the Lakehead SPA and its great spatial extent, total precipitation varies between stations as well. Variations in climatic data between watershed meteorological stations result from differences in elevation, the rain shadow effect of topography, the moderating effect of large water bodies and the moderating effect of large urbanized areas. Dominant weather modifiers in the Lakehead SPA include:

a) the modifying effect of Lake Superior;

b) the rain shadow effect of the Height of Land (Atlantic/Arctic watershed division) in the northern part of the SPA, which is an area of great local variation resulting in a difference in total precipitation over the entire watershed area;

c) the rain shadow effect of the Height of Land, west of Thunder Bay resulting in higher precipitation at Tranquillo Ridge and in Whitefish, than that at the Thunder Bay Airport;

d) the rain shadow and temperature inversions which occur between the Height of Land and the shore of Lake Superior;

e) the urban heat island effect that occurs over urban Thunder Bay;

f) on-shore winds from Lake Superior at the Thunder Bay Airport; and

g) the down-slope effect created by prevailing westerlies, which tends to minimize cloud formation over the airport weather office.

For discussion purposes, 55 year (1950-2005) mean values of air temperature and precipitation (as rainfall and snowfall) for the Thunder Bay Airport climate station are summarized in Table 3.[4] This particular station was selected for discussion because it has the longest period of record and is still in operation. From the table, one can see that the mean annual total precipitation is about 728.5 mm, of which 27% (assuming 199 cm snow = 199 mm of water[5]) appears as snowfall, and 73% as rainfall (or 529 mm). The highest average monthly snowfall amounts occur in December and January (41 and 46 cm, respectively). The total precipitation is distributed such that May through October are the wettest months, likely due to the presence of the many upwind lakes. December, January and February are the three driest months, because ice cover removes the upwind lakes as a source of moisture. The lowest average monthly precipitation (30.6 mm) occurs in February, whereas the highest precipitation without snowfall occurs in either July (79.7 mm) or August (80.2 mm).

4. As will be seen in Section 5, this is not the period selected for the water balance, but is used here as it provides representative conditions on average for a longer period.

5. For the sake of this conceptual water budget we have assumed a 10:1 ration for the depth of snow to the equivalent depth of water. In reality, the ratio is somewhat less, however such a detailed assessment is beyond the scope of this conceptual exercise.

Table 3. Summary of Climate Data for Thunder Bay Airport (1950-2005)

Month	Average Maximum Daily Temp. (°C)	Average Minimum Daily Temp. (°C)	Average Daily Temp. (°C)	Mean Total Rainfall (mm)	Mean Total Snowfall (cm)	Mean Total Precipitation (mm)
JAN	-8.8	-21.0	-14.9	1.2	46.6	47.8
FEB	-5.3	-18.6	-12.0	2.3	28.3	30.6
MAR	0.2	-11.8	-5.8	13.3	28.7	42.0
APR	8.6	-3.2	2.7	34.1	16.7	50.8
MAY	15.7	2.2	9.0	68.6	2.6	71.2
JUN	20.8	7.5	14.2	79.5	0.0	79.5
JUL	24.3	11.0	17.6	79.7	0.0	79.7
AUG	23.2	10.2	16.7	80.2	0.0	80.2
SEP	17.6	5.6	11.6	79.4	0.3	79.7
OCT	10.8	0.0	5.4	58.8	4.8	63.6
NOV	1.9	-7.1	-2.6	27.9	30.4	58.3
DEC	-5.4	-16.5	-10.7	4.1	41.0	45.1
Annual Mean or Total	**8.6**	**-3.5**	**2.6**	**529.1**	**199.4**	**728.5**

The daily average minimum temperature ranges from –14.9°C in January to an average maximum of 17.6°C in July, with an annual mean daily temperature of 2.6°C. Extreme temperatures as high as 40°C can occur in summer and as low as -41°C in winter.

Monthly water balance calculations for potential evapotranspiration at the six meteorological stations show that actual evapotranspiration is greater than the total precipitation input for June July and August, relying in part on soil moisture uptake. Therefore, during the summer period there is a net deficit in the water balance. The loss of recharge causes water tables to drop during this period.

The influence of climate on the region’s physical and economic development is significant in that it affects the scope and intensity of certain land use activities either directly or indirectly. A short growing season together with cool temperatures influence the intensity of agricultural activity, while long cold winters have a certain impact on outdoor recreational patterns. In terms of potential flooding, the amount of snowfall, depth and extent of frost and the precipitation levels in the spring all contribute significantly to how the watershed reacts during the spring runoff.

In the following sections the Thunder Bay Airport meteorological station is relied upon to discuss trends. For the purposes of the water budget calculations undertaken later in Section 4.4, spatially distributed climate data between the six meteorological stations within and in the vicinity of the Lakehead SPA have been used. Map 1 in Appendix B shows the precipitation distribution determined by the IDW (Inverse Distance Weighted) interpolation technique. This technique described in Appendix C is more heavily weighted to the measured values closest to the location, than those further away.

4.1.1 Temperature Trends

The temperatures within the LRCA study area vary with yearly climatic cycles and geographic location. Based on historical data at the Thunder Bay Airport location for the period 1950 to 2005, the highest air temperatures (above 9°C) occur between mid-May and mid-October and start to significantly decrease in late October, when the lowest air temperatures (less than -5°C) occur regularly between November through February. Typically, summer mean monthly high temperatures are 14.2 to 17.6°C. Winter mean monthly temperatures are in the range of -2.6 to -12.0°C (see Table 3). Figure 4 shows the monthly distribution of average daily, average maximum, and average minimum air temperatures at the Thunder Bay Airport climate station.

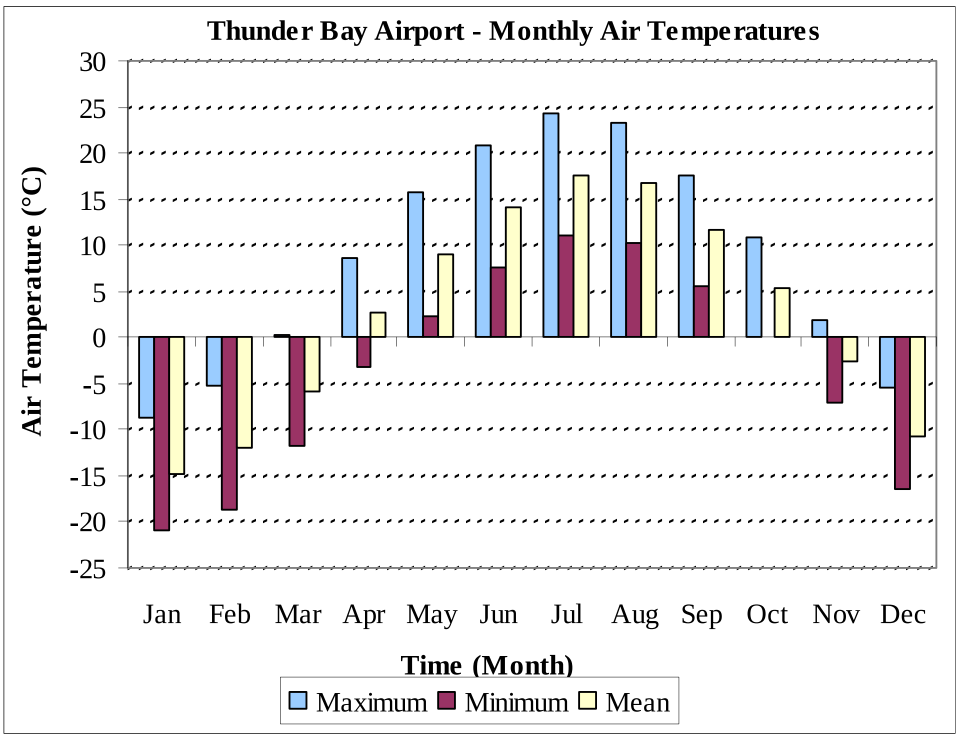

Figure 4. Mean Monthly Temperature at Thunder Bay Airport (1950 – 2005 normals)

The time-series of average annual, minimum and maximum daily air temperatures for the 1950 to 2005 period are plotted in Figure 5 along with a three-year moving average trend line (shown in brown),) representing the average daily temperature. It suggests that there has been a mild warming trend, which has also been noticed in most locations throughout Canada but does not indicate a significant variation from the long-term average. Nonetheless, the years from 1998 to 2002 have been above average.

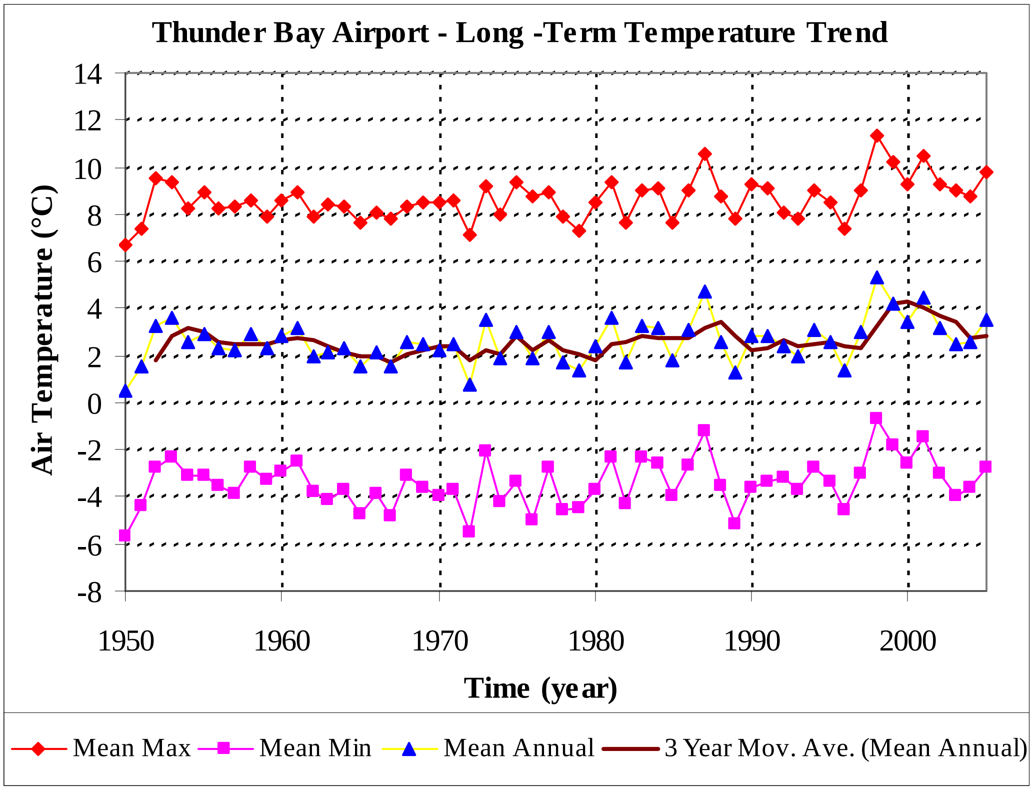

Figure 5 Time-Series of Annual Temperatures at Thunder Bay Airport for 1950 to 2005

Of the 55 years shown in Figure 5, the year with highest mean daily temperature of 5.3°C occurred in 1998, whereas the year with the lowest mean daily temperature of 0.5°C occurred in 1950. The absolute highest maximum daily temperature of 40.3°C occurred on July 7, 1983, where the lowest minimum daily temperature of -41°C happened on January 30, 1951.

4.1.2 Precipitation Trends

Precipitation, like temperature, varies with yearly climatic cycles, geographic location, and elevation. Figure 6 gives the mean monthly distribution of precipitation occurring at the Thunder Bay Airport climate station for the period 1950 to 2005.

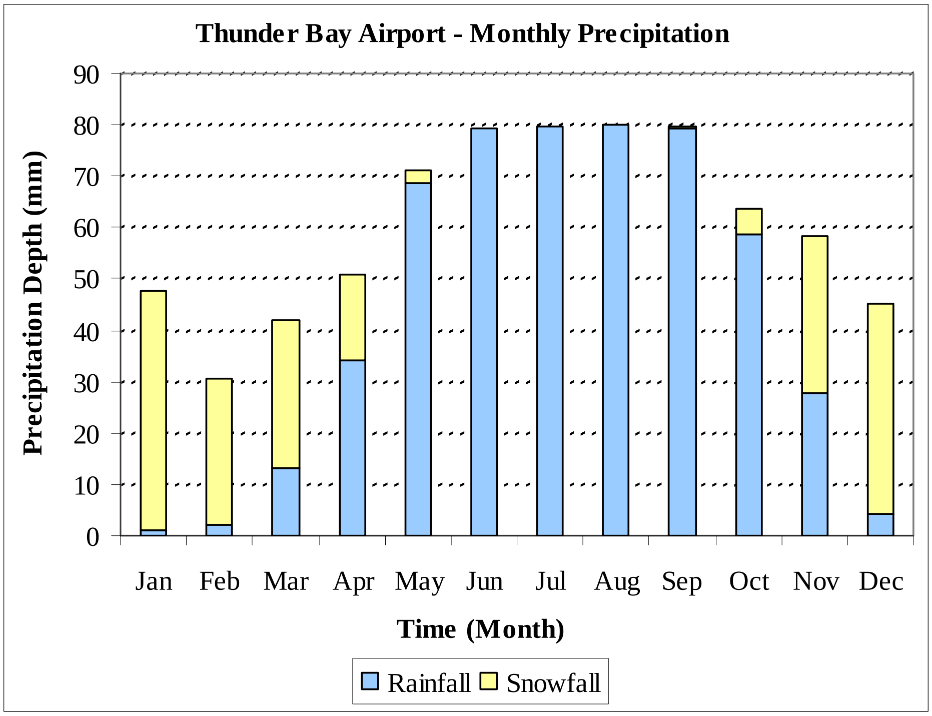

Figure 6. Mean Monthly Precipitation at Thunder Bay Airport for 1950 to 2005

Figure 6 is given as a stacked histogram graph so the contributions from rainfall and snowfall can be illustrated concurrently (snowfall is given in equivalent millimetres of water). From Figure 6, we see that the maximum precipitation occurs in the summer months when all of it appears as rainfall. (The high summer rains have much to do with the proximity of Lake Superior at this particular meteorological station.) In winter, most of the total precipitation falls as snowfall in the Thunder Bay area. Snowfall can occur as early as early October, and extend throughout April in small quantities. There has also been some snowfall observed in early May.

Figure 7 illustrates the annual time-series of total precipitation, rainfall and snowfall occurring at Thunder Bay Airport from 1950 to 2005. Generally speaking, there has been a constant trend in the precipitation totals since the early 1950s. From Figure 7, it appears that the wettest period in terms of total precipitation occurred in the early and late 1970s, whereas the driest period took place during the early 1960s and early 2000s. The highest annual total precipitation of 1,072 mm occurred in 1977, whereas the lowest total of 483 mm occurred in 2003. In terms of mean annual rainfall totals, the highest total of 872 mm also occurred in 1977, whereas the lowest amount of 317 mm occurred in 1976. The highest total snowfall of 416 cm (which equals 416 mm equivalent water) occurred in 1950, whereas the lowest total of 90 cm occurred in 2003.

The greatest 24-hour rainfall total of 131.1 mm took place on July 8, 1977, and the highest 24-hour snowfall total of 61.5 cm took place on January 18, 1996.

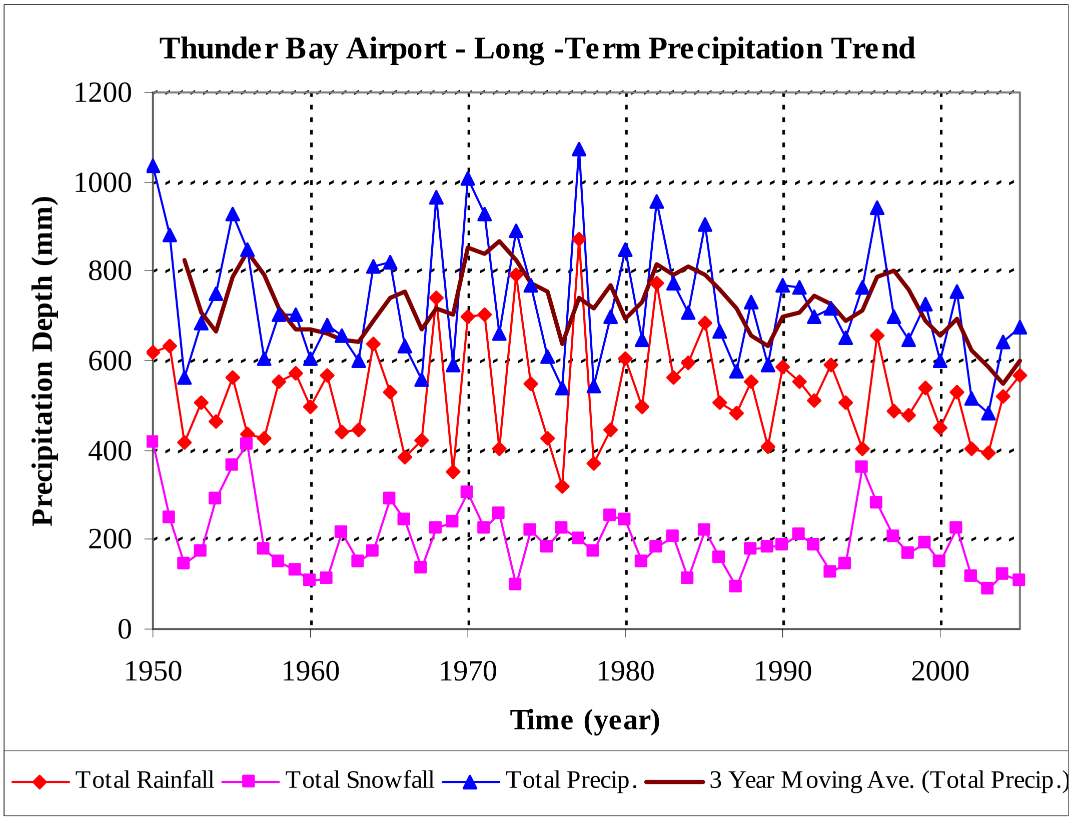

Figure 7. Time-Series of Annual Precipitation at Thunder Bay Airport for 1950-2005

4.1.3 Snow Courses

At the present time there are three snow course survey locations (see Table 4) in the Lakehead SPA. All of the snow courses are monitored by the Lakehead Region Conservation Authority. The location of the snow course stations are shown on Map 1, Appendix B.

Table 4. Lakehead SPA Snow Course Data

Station	Data Record Available	Source	Easting	Northing	Elevation (mASL)
Current River-1401	1974-2006	LRCA	336,539	5,384,171	438.6
Pennock Creek-1601	1974-2006	LRCA	319,173	5,361,296	221.5
McVicar Creek-1501	1974-2006	LRCA	334,784	5,368,865	232.2

Figure 8 shows the temporal distribution of snow water equivalent at three snow courses for a high snow winter (1995-1996). The maximum snow water equivalent tends to occur in early March. However, Figure 9 provides similar information for a low snow winter (2002-2003), when the maximum snow water equivalent also tends to take place in early to mid-March. During the spring freshet most of the runoff is generated by the melting snowpack because the frozen ground inhibits infiltration.

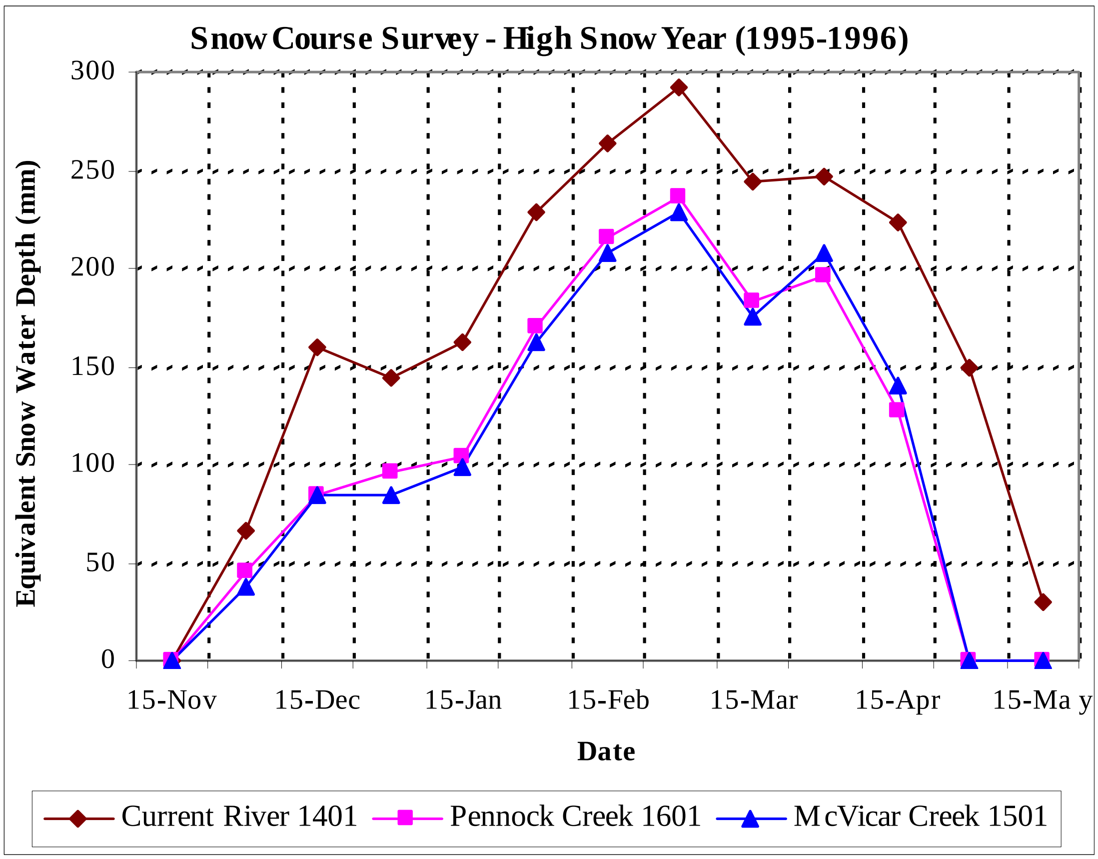

Figure 8. Temporal Distribution of Snow Water Equivalent for a High Snow Year (1995-1996)

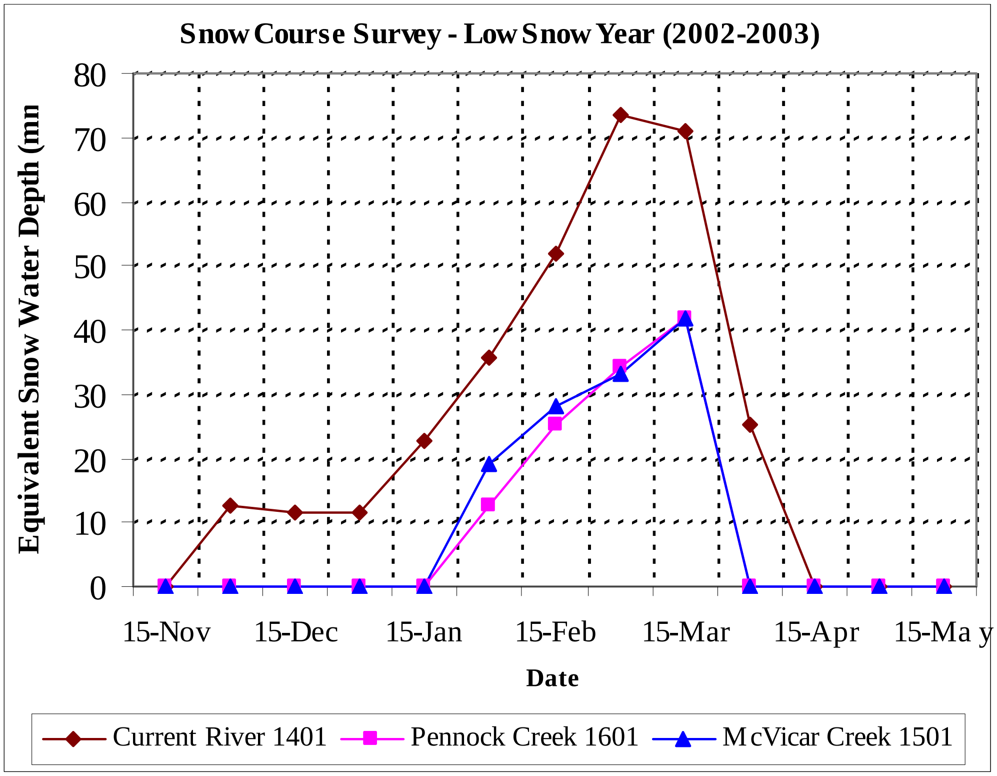

Figure 9. Temporal Distribution of Snow Water Equivalent for a Low Snow Year (2002-2003)

4.1.4 Evaporation and Potential Evapotranspiration

None of the climate stations in the general vicinity of the Lakehead SPA, as listed in Appendix A, have been equipped with pan evaporation measurements to permit estimates of lake evaporation. Calculated lake evaporation amounts may be used to provide estimates of the available evaporation/ evapotranspiration potential in an area. Historically, the closest available evaporation measurements for Northern Ontario have been made by Environment Canada[6] in Cameron Falls, close to the northeastern boundary of the Lakehead SPA. Although these measurements have not occurred within the Lakehead SPA, they are sufficiently close to provide some indication of the pattern of evaporation potential that can occur within the study area. Typically, the annual total potential (or lake) evaporation ranges between 570 to 650 mm. Given the fact that the Lakehead SPA is further south, one would expect these values to be higher (annual total estimated Lake evaporation in Cameron Falls is 379.4 mm), because the sun is at a higher angle of incidence throughout the year.

6. *Environment Canada measures pan evaporation using a Class A evaporation pan and provide calculated lake evaporation (which is always less than pan evaporation) for different regions of Canada. The calculations are based on the work of Kohler, Nordenson and Fox as reported in U.S. Weather Bureau Research Paper No. 38*

Figure 10 shows the distribution of mean monthly potential evaporation for Cameron Falls, as taken from the 1951-1980 climate normals. Range bars represent the standard deviation calculated from the monthly lake evaporation totals for the available data during the 1951-1980 period. The highest potential amount occurs in July. When these values (~120 mm) are compared with the precipitation amounts (~80 mm) given in Table 3, it can be seen that the potential evaporation amounts are higher than the precipitation totals. In order to satisfy the deficit between the potential evaporation and precipitation totals, water is consumptively withdrawn from the lake into the atmosphere.

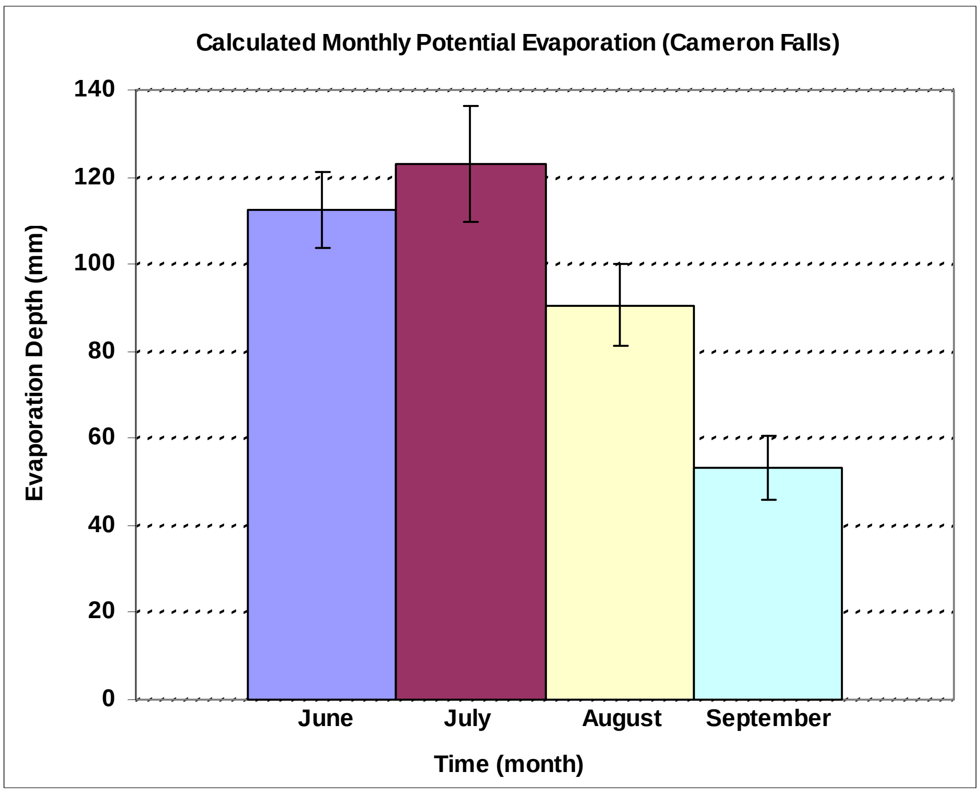

Figure 10. Mean Monthly Potential Evaporation at Cameron Falls (1951 – 1980 Normals)

4.2 Land Cover

The Lakehead Region includes the urban areas of Thunder Bay, Municipalities of Oliver Paipoonge Neebing, Shuniah and some other small townships and rural populations. Settlement and infrastructure are concentrated on these urban areas. The census data taken from the Statistics Canada website for the years 1991 and 2001 in the study area shows a population decline from 124,000 to 122,000 people. Assuming this trend continues or simply stabilizes, water use is not expected to increase significantly over the next 15 years.

Land cover influences the distribution of surface runoff and infiltration to the subsurface. Land cover throughout the study area is presented in Map 8 (Appendix B). Information to produce this map was completed using the 2000 Edition of the Ontario Land Cover Database, the second edition of this provincial land cover classification. The coverage is derived wholly from Landsat-7 Thematic Mapper (TM) satellite data frames recoded between 1999 and 2002, with most from 2000 onward.

Table 5 presents a breakdown of land cover type by percentage in the SPA. As Map 8 (MOE specified WB Map 15) and Table 5 show, the vast majority of the Lakehead SPA is covered by woodland (about 86%). Generally, the watershed lies within two major forest regions, the Great Lakes-St. Lawrence Forest Region and the Boreal Forest Region. Lakes and rivers/streams are densely distributed within this area. These water bodies comprise, on average, approximately 9% of the land surface. There are also wetlands that cover approximately 2.5% of the SPA. Settlement and agriculture covers only a small portion that amounts to approximately 2.5% of the SPA.

Several different species of plants grow annually without cultivation within the Lakehead SPA. Dominant species in the watershed include different varieties of pine (red, white, jack pine), yellow and white birch, white and black spruce, poplar etc. The area supports a variety of trees, shrubs and herbaceous species.

Agriculture is limited within the study area and is mainly composed of food crops, hay, and cattle farms. Agricultural land cover primarily includes the land along the Slate, Neebing and the Kaministiquia River watersheds.

Available information shows that some physical and biological features of the Lakehead SPA have been altered from human land use since pre-development conditions. Pre-development conditions are not fully documented, nonetheless significant alterations can be identified that affect water resources including populated areas, dams, forestry, and mine sites. Notwithstanding this, the majority of the watershed is unaltered in any significant way.

Generally speaking, the Lakehead SPA has an extensive forest, wetland and water cover (97.6%) with the rest under some form of land use. Of interest, human settlement is less than 2% of the 11,526 km^2 area, the highest density being observed in the Neebing and McIntyre River watersheds. Projections of land cover and its type area are listed in Table 5 on a watershed basis.

4.3 Geology

Although many geological studies have been completed for the study area, much of the following description has come from the Thunder Bay Regional Aquifer Characterization, Groundwater Management and Protection Study Report (Burnside and Amec, 2005). The following sections describe the physiography, bedrock and overburden geology of the study area.

Table 5. Land Cover Types and their Percentages in the Lakehead SPA[1]

Watershed	Open Water	Settle-ment	Mine/ Taili.	Forest 1	Forest 2	Forest 3	Forest 4	Forest Total	Wet-land	Agri cult.
Kaministquia River	3.5	4.3	0.0	29.0	27.8	1.2	28.3	86.4	0.3	5.6
Shebandowan River	13.4	0.6	0.1	23.9	29.3	7.2	22.5	83.7	3.1	0.0
Kashabowie River	21.8	0.0	0.0	17.1	32.5	11.3	14.6	76.1	2.6	0.0
Whitefish River	1.4	0.0	0.0	25.4	27.6	1.9	42.6	97.5	0.8	0.3
Slate River	1.1	0.9	0.0	14.0	27.4	0.1	35.6	77.2	0.1	20.8
Matawin River	8.4	0.0	0.0	19.6	29.2	14.5	22.9	88.3	5.4	0.0
Oskondaga - Swamp Rivers	0.8	1.3	0.0	14.8	23.8	9.0	46.9	95.6	3.4	0.0
Dog Lake	19.3	0.0	0.0	13.5	28.2	10.7	27.2	79.9	1.0	0.0
Dog River	9.1	0.0	0.4	8.1	20.6	18.6	36.5	86.1	6.6	0.0
Neebing River	0.5	17.8	0.0	20.0	17.2	3.6	36.9	77.7	0.6	3.4
McIntyre River - McVicar Creek	1.2	20.4	2.9	17.3	26.1	4.1	28.0	75.5	0.0	0.0
Current River	6.6	0.5	0.0	24.5	37.2	7.4	22.9	92.1	0.9	0.0
Wolf River	7.7	0.1	0.1	18.7	35.9	7.7	29.1	91.6	0.6	0.0
Lower Pigeon - Little Pine - Pine River	3.5	0.0	0.0	13.9	34.9	4.4	42.7	96.0	0.3	0.2
Cloud - Jarvis - Whiskeyjack - Lomand Rivers	8.4	0.8	0.0	18.7	31.8	1.8	38.4	90.7	0.2	0.0
Black Sturgeon R. - Little Squaw Cr. - Squaw Cr.	1.1	5.1	0.1	27.4	32.3	13.7	20.2	93.6	0.1	0.0
MacKenzie River	3.2	2.1	0.2	34.3	27.3	2.9	29.8	94.3	0.1	0.0
D'Arcy Creek - Pearl River - Welch Creek - Coldwater Creek- Old John Creek Laurie	5.0	1.9	0.6	40.0	29.6	3.6	18.7	92.0	0.6	0.0
Sleeping Giant Creek - Marie Louise Creek - Pickerel Creek- Joeboy River – Portage Creek [2]	4.7	2.6	0.0	32.4	41.8	4.0	14.4	92.6	0.0	0.0
Wildgoose Creek - Blind Creek - Blende River - Twinpine Creek	2.6	5.4	0.0	32.7	35.6	3.9	19.7	92.0	0.0	0.0
Study Area Average	**8.7**	**1.4**	**0.2**	**86.4**					**2.5**	**0.8**

Notes: 1. The land cover classification was produced by the digital analysis of spectral reflectance data recorded in Landsat-7 satellite images. For Details see Spectranalysis Inc. 2004.
2. Only Portage Creek is within the watershed, others outside boundary

Forest 1: Deciduous forest
Forest 2: Mixed forest
Forest 3: Conifer forest
Forest 4: Sparse/Cuts/Burns

4.3.1 Topography and Physiography

Northwestern Ontario belongs to the Precambrian Shield Region. The earliest known Precambrian sediment was deposited on a surface of rugged topography. At a later time, the area underwent prolonged volcanic activity. As the volcanic activity subsided, the land mass started to form and underwent intermittent submergence. During its last stage of development, the region continued in its shallow submergence to form a low topographic relief. Topographic relief in the study area is largely the result of glacial deposition (moraines, eskers) and bedrock erosion (river valleys) during the Quaternary Period. Map 7 (Appendix B) is a map of ground surface elevation generated using the Digital Elevation Model (DEM) provided by the Ministry of Natural Resources.

The northern and western portions of the Lakehead SPA generally consist of higher elevations. Low lying areas predominantly occur along the Kaministiquia Rivers below Kakabeka Falls, along the Neebing, McIntyre and Slate Rivers, in the vicinity of Thunder Bay and in the northern portion of the Sibley Peninsula along the western shore of Black Bay. The elevated areas are directly underlain by Precambrian rocks of various types and formations, while the low lying areas are typically underlain by thicker sequences of surficial or glacial material, particularly in the Kaministiquia River valley. Ground surface elevations in the study area range from approximately 500 mASL in the north, to 183 mASL at Lake Superior. One localized high area reaching 667 mASL occurs north of Whitefish lake. Watercourses in the northern portion of the study area appear to reflect some of the major structural features in the underlying bedrock terrain and drain toward Lake Superior.

Two physiographic subdivisions of the James Bay Region exist within the study area. The Severn Upland, a physiographic subdivision of the James Bay Region of the Precambrian Shield makes up the northern portion of the study area. This area is dominated by the rolling surface of the Precambrian bedrock that is exposed at the surface or is only shallowly covered over much of the area. The southern boundary of this subdivision extends from Whitefish Lake in the west, through Kakabeka Falls, and extends east sub-parallel to the shore of Thunder Bay itself. South of this line is the Nor'Westers and Mount McKay. In general, these hills consist of southward dipping Proterozoic sills and underlying metasediments. The relatively flat plain lying to the west of the City of Thunder Bay is occupied by the valley, floodplain and delta of Kaministiquia River and those of the Neebing and McIntyre Rivers. Several large end moraine segments (such as Dog Lake Moraine, MacKenzie Moraine and Marks Moraine), drumlins, eskers, kames, deltas and beaches are important elements of the surface topography in the study area

4.3.2 Bedrock Geology

Understanding the bedrock geology is a key component to understanding groundwater movement within a study area. Information on the bedrock geology is compiled from numerous sources, including Ontario Geological Survey mapping (OGS, 1993), geological reports on Palaeozoic geology from various authors, a review of well records, etc. Map 3 is found in Appendix B, and shows the bedrock geology of the area.

The majority of the study area is found within the Superior Province of the Canadian Shield, which was formed in the Precambrian period of Archean age. The bedrock of the Superior Province is generally characterised by Metavolcanics/granites and metasedimentary rock types as well as gneissic/plutonic and high-grade gneiss rock types (metamorphosed rocks). These rock types are generally crystalline in structure and massive (and therefore not easily eroded).

The Thunder Bay area consists mostly of Archean rocks, which are in excess of 2.5 Ga (billion years) in age (Ontario Geological Survey Report GR164, 1977). These rocks have been extensively deformed through metamorphism, with erosional and intrusional contacts further complicating the local geology. In general, the oldest rocks are made up of metavolcanics/granites and metasediments, with this sequence locally intruded by smaller ultramafic and felsic units. These metavolcanic and metasediments are most prominent in the northern portion of the study area (North of Thunder Bay) and make up three distinct belts. To the east of Thunder Bay, a younger sequence of rocks generally overly these Archean rocks. To the south they are made up of the Animikie Group (circa 1.8 Ga), which are comprised of the Gunflint and Rove Formations. These formations are made up of a complex variety of rock types, ranging from cherts to conglomerates, with interbedded argillites and carbonates. To the east they are made up of the Sibley group (circa 1.6 Ga), which consists mainly of sedimentary rocks of the Karma Hill, Ross Port and Pass Lake formations (Mudstones/Shale, Dolostone and sandstone). The youngest of the Precambrian rocks in the Lakehead region are the Logan Sills, which were formed approximately 1.1 Ga ago during the period of Keweenwan intrusion. These sills are essentially sheets of diabase (granitic) rock up to 60 m thick (Ontario Geological Survey Report GR164, 1977). These diabases and associated dykes in the area, were formed through the intrusion of igneous (granitic) rocks into the surrounding sedimentary rocks, and as such have created erosionally resistant cap rocks. Subsequently erosional Mesa landforms were formed that created the Norwesters, the highest hills in the area located immediately south of the City of Thunder Bay, of which Mount McKay is best known.

From a hydrogeologic perspective, these metamorphosed and granitic rocks are very hard and erosion resistant. However, continental tectonic forces (which formed the rocks of this region) had caused significant deformation resulting in paleo faulting, fracturing and jointing, providing minor pathways for groundwater movement. These features could provide minor aquifers that can be tapped if a water well is fortuitously placed and intersects one. On the whole, the bedrock surface is relatively impermeable, although some weathering would have occurred in areas where the rock surface was exposed for significant periods. Therefore, groundwater preferentially flows through the overlying materials, but may also be found in limited areas in the upper bedrock.

Bedrock surface elevation data are presented in Map 5. In general, the bedrock topography closely reflects the ground surface elevations when compared to Map 7. The highest bedrock surface elevations correspond to areas having thin covers of surficial material overlying the Precambrian bedrock (Map 6). These correspond to the northern and western parts of the study area, and the area around the Nor'Westers. Bedrock elevations of approximately 550 mASL occur in the area north of Whitefish Lake, with elevations decreasing toward Lake Superior. A comparison of the bedrock surface elevation (Map 5) and the ground surface elevation (Map 7) confirms that there is very little overburden over (most of the areas) areas dominated by Precambrian granitic rocks. This is confirmed by Map 6 where much of the study area is shown as bedrock plateaus, knobs, ridges and plains and is described as thin drift over bedrock. The lowest bedrock elevation within the study area underlies the Kaministiquia River valley and the City of Thunder Bay, where the bedrock surface is at approximately 150 mASL. This elevation is approximately 30 m below the elevation of the surface of Lake Superior. Two bedrock valleys trend westward from the Kaministiquia bedrock valley, and underlie the Whitefish and Slate River valleys to the north and south respectively. In addition, bedrock valleys underlie Hawkeye Lake and the area to the east, the Current River valley, and the Greenwich Lake and the MacKenzie River valley, likely indicating structural bedrock control at the location of these surficial drainage features.

4.3.3 Surficial Geology

Overlying most of the bedrock of the watershed are unconsolidated Quaternary Age sediments and organic materials of varying depth deposited during a complex sequence of glacial advances and retreats that have occurred over the past million years. The last glacial advance, known as the Laurentide Ice Sheet, occurred during the Wisconsin Age approximately 10,000-25,000 years ago and deposited sand till on the bedrock surface. The most common materials resulting from this glaciation are till, glaciofluvial material and glaciolacustrine sediments deposited within glacial lakes. Map 6 in Appendix B shows the distribution of Quaternary Age deposits.

As warming climactic conditions set in, about 12,000 years ago, deglaciation commenced and the ice sheet margin retreated northward (the ice did not physically retreat, rather it melted depositing its contents on the ground surface). It was during this time that the watershed was reshaped by meltwaters and residual soil materials into a number of varying landforms and soil types, as described below.

The term "overburden" is used to group the unconsolidated soil deposits lying on the bedrock. Overburden in the study area is variable in thickness and composition. There are substantial areas where there is less than a metre of overburden, however this area also includes zones with more than 40 m of overburden overlying the bedrock. The overburden thickness map (Map 4) was prepared by subtracting the bedrock surface elevation (Map 5) from the DEM (or the ground surface elevation (Map 7) within the SPA area. This information was then contoured and is presented on Map 4, which shows the interpreted distribution[7] of overburden thickness across the study area. The resulting figure shows that the thickest overburden typically occurs within the bedrock valleys, with up to 30 m of overburden at the mouth of the Kaministiquia River, and 20 to 25 m underlying both the Whitefish River and Slate River valleys. Isolated areas of thicker (15 to 20 m) overburden also occur at Cloud Bay, Jarvis River, and Shabaqua Corners. Another area of thick overburden is located in the area of Dorion, and reaches depths of more than 30 m over a small area. A mantle of thin overburden covers the remainder of the study area, typically ranging from 0 to 10 m locally.

Deposits formed by, or in connection with, continental glaciers are of particular hydrogeologic importance in the Lakehead region. Continental scale glaciers repeatedly advanced over the study area in recent geologic history (within Quaternary Period), leaving behind a variety of glacial deposits. The following paragraphs identify these surficial geologic deposits in the context of their hydrogeologic properties.

Till Deposits

A large area of till occurs west of the City of Thunder Bay and north of the Kaministiquia River, and is subdivided into stoney sand till, clay till and silt till units. These typically contain a significant

7. *Caution should be exercised in interpreting Map 7 as it is only representative in areas where there are sufficient water well records. Actual overburden thickness will vary from that shown on the map, particularly in areas where no wells have been drilled.*

proportion of fine-grained material. Additional fine-grained material was deposited in glacial meltwater lakes, ponding behind the Superior ice lobe that flooded the area to an elevation of at least 260 mASL (77 m above the present Lake Superior elevation of 183 mASL). Lacustrine deposits from earlier intervals of glacial retreat occur at elevations up to 366 mASL and are noted in logs of water wells northwest of Kakabeka Falls.

Deltaic Deposits

A major surface feature within the study area is the Kaministiquia River delta, which extends for approximately 20 km west from the shore of Lake Superior to Kakabeka Falls. It is divided into two distinct physiographic units, the deltaic upland and the lower deltaic plain. The deltaic upland extends from the village of Rosslyn approximately 15 km upstream to Kakabeka Falls, encompassing an elevation rise from 230 mASL to 260 mASL. A wave-cut bluff forms the eastern face of this upland feature and gravel and sand form the core of the upland. Between the upland and Lake Superior is the lower deltaic plain, which is more extensive than the deltaic upland, being 24 km long and varying from 6.5 km to 21 km wide. Surface elevations within the deltaic plain drop 43 m across this length, with no major topographic breaks in the general slope. Underlying this plain at the north end of McKellar Island is a bedrock high, with elevations of 198 mASL on the bedrock surface (Ontario Geological Survey Report GR164, 1977). Ontario Geological Survey Map 2372 also illustrates glaciofluvial and deltaic sediments bordering each side of the Kaministiquia River approximately 10 km from the shore of Lake Superior, with finer grained lacustrine deposits extending up the valley to Rosslyn Village. This sequence is bordered on the south by the bedrock uplands of the Nor'Westers and on the north by older tills deposited by the Superior Ice Lobe.

Glaciofluvial Deposits

Locally, there are extensive but typically thin deposits of outwash sand that have been reworked by the action of glacial lakes. Evidence of this reworking is visible up to heights of 56 m above the present level of Lake Superior. Additional discontinuous glaciofluvial deposits are located in a number of places. For example: north of the Kaministiquia River; in the upper reaches of the Dog River watershed; and adjacent to the present Lake Superior shoreline near Dorion (Ontario Geological Survey Map 2372). A large number of sand and gravel extractive operations are associated with the coarse grained glaciofluvial sediments located between Rosslyn Village and Kakabeka Falls, as well as with the discontinuous glaciofluvial deposits north of the city

Moraines

Three major moraines occur in the north-central portion of the study area, as illustrated by Ontario Geological Survey Map 2203. The Dog Lake Moraine was established by a readvance of the Dog Lake ice lobe from the northeast following the late-Wisconsinan glaciation. This moraine consists of a stony loam till, and extends in a NW-SE orientation from the southern shore of Dog Lake. The Dog Lake Moraine extends to the SE until it intersects the MacKenzie and Marks Moraines at the present location of the Current River. Marks Moraine consists of silt and clay till, and was established by the westerly readvance of the Superior ice lobe at the same time as the Dog Lake Moraine. Glacial Lake Kaministiwia was dammed in the angle of the Superior and Dog Lake ice lobes. The MacKenzie Interlobate Moraine was also formed between the Superior and Dog Lake ice lobes prior to 10,200 years BP. Useable gravel and sand deposits reportedly occur within the ice-contact deposits and the interlobate deposits of the Marks Moraine.

Alluvial Deposits

Modern alluvial deposits, with a composition controlled by the underlying glacial material, mixed with recent organic sediment, are found in the local streambeds throughout the study area.

4.4 Groundwater

A groundwater study report was prepared for the LRCA by R.J. Burnside & Associates Limited in association with AMEC Earth & Environmental in July 2005 (Burnside and Amec, 2005). Although that study area is not entirely coincident with the present limits of the SPA, it provides an overview of groundwater conditions. The study was completed using compiled regional geologic and hydrogeologic data sets and information from previous hydrogeologic studies. In addition, information from many data sources, including the OMOE, OMNR, Ministry of Northern Development and Mines, Ontario Geological Survey, the Water Survey of Canada, and the LRCA was incorporated into a project database and GIS layers.

The Lakehead SPA is characterized largely by shallow soils over bedrock. There is only a thin overburden covering much of the northern part of the study area. As such, overburden aquifers do not generally exist in these areas, with the exception of locations associated with glacial moraines, or where overburden sand and gravel deposits exist. However, the majority of thicker overburden material occurs in the general vicinity of the Kaministiquia River valley and the area immediately north of the valley and south of the Dog Lake Moraine. In addition, thicker overburden underlies the Whitefish River and Slate River valleys to the south and west. An isolated area of thick overburden occurs in the area of Dorion in the northeast part of the study area. However, the majority of these areas are underlain by less than 15 m of overburden. In terms of potential water supply, the areas mentioned above offer the best opportunity for groundwater-based supply in the overburden. But as the remaining area has limited overburden, it is less likely to provide sufficient water yields.

Groundwater recharge occurs through all surficial geology units, with the coarse-grained esker and outwash materials having the highest recharge rates. Groundwater discharge occurs mainly along the numerous lakes and streams. In general, groundwater recharge from direct infiltration of precipitation over the till and glaciolacustrine surface deposits is slower than that of the coarser deposits, but given the large surface exposure of the till and glaciolacustrine deposits, the volume of water supplied to the regional groundwater regime is significant.

Regional aquifers in the overburden are difficult to characterize as the majority of the overburden aquifers within the study area are associated with glacial or periglacial landforms. Based on MOE water well records, 91% of the wells in the Lakehead SPA area are domestic wells and the rest are either industrial/commercial or not used (Burnside and Amec, 2005). Well completion depths are highly variable with 75% of the wells completed at depths of 60 m or less. Overburden wells dominate the study area, as extensive and/or discrete bedrock aquifers are not identified within the study area. Moreover, most crystalline bedrock formations in the study area have very little inherent or primary porosity and are considered impermeable.

The Municipal water supply system of Rosslyn village in the Municipality of Oliver-Paipoonge utilizes groundwater. This water supply system consists of two groundwater supply wells drilled in 1974, which currently service approximately 30 homes in Rosslyn. The source water for the system is a basal sand and gravel aquifer approximately 5 m thick immediately above the bedrock, confined beneath approximately 35 m of clay and silt rich material. Water is pumped from the two wells on an alternating basis to a single water treatment plant. Average daily water use is approximately 35 m^3/d, with maximum usage of approximately 50 m^3/d recorded (Burnside and Amec, 2005).

4.4.1 Water Table

A water table elevation map is presented in Map 13. WWIS (Water Well ***I***nformation System) data provided the depth to water for wells within the Lakehead SPA area. At each well, the static water level that was recorded when the well was drilled was used to interpolate groundwater levels throughout the study area. Although static water levels may change over time, groundwater extractions have not changed dramatically and therefore the static water levels are considered acceptable for the purpose of mapping regional water table elevations. All wells completed to less than 15 m depth were considered in this analysis. This was done to limit the misleading effects of deeper wells that may not measure the groundwater table, but actually a potentiometric head.[8] In general, a few reliable water wells records are available only in the central part of the study area. Because of sparse data over the northern portion of the study area where overburden is thin or discontinuous, a large number of data points were introduced using surficial water body features. It was assumed that the water table would coincide with the water levels in the surface water bodies and streambeds.

Generally, the water table follows the surface topography. The shallow groundwater flow system is entirely local, largely due to the presence of the many streams and lakes. Precipitation that is not taken up by evapotranspiration will either runoff to the local watercourses or will recharge the water table. Because of the low permeability of the bedrock, much of this recharge is deflected laterally through the relatively more permeable overburden. It discharges as baseflow in the local watercourses, which then flows out of the highlands in the north and south, draining to the different

8. In short, a deeper well in a recharge area will have a measured static level lower than the water table. The converse is true in a discharge area where the measured level will be higher than the actual water table.

rivers such as Kaministiquia and eventually into Lake Superior. The existence of numerous lakes is suggestive of shallow groundwater flow discharge into those water bodies. In general, the elevation of the shallow groundwater table closely reflects the ground surface elevation (compare Map 7 and Map 13). Water table elevations range from 183 mASL at the shore of Lake Superior to 618 mASL in the western part of the study area, west of the Whitefish River watershed.

In general, groundwater flows from the northern uplands area toward Lake Superior or the east-west Kashabowie/Shebandowan/Kaministiquia River valley. It is unlikely that there is significant ground water flow between major watersheds for the following reasons. Locally, the shallow groundwater flow is influenced by the thickness and distribution of coarser sand and gravel units within the overburden and topographic highs in the surface of the underlying bedrock. Groundwater flow divides likely occur along the bedrock highs. Lateral groundwater movement will also occur in the shallow bedrock where fractures exist. There are no appreciable deep groundwater flow systems on the regional scale, although some pathways are longer where the overburden is deepest.

4.4.2 Quantification of Groundwater Recharge

Recharge is defined as the process by which water moves from the ground surface, through the unsaturated zone, to arrive at the water table[9] (MOE, 2007). This provides the driving force that causes groundwater to flow, and ultimately discharge as baseflow to wetlands, watercourses and lakes. Historically, groundwater recharge has been estimated by calculating the “missing” water from surface water calculations. Hydrogeologists need to estimate recharge as that which is the source and driving force for groundwater flow systems. As described in Section 3, recharge of the water table is accomplished by the infiltration of precipitation and snowmelt that is not taken up again by plants or evaporation. In 1995, the Ministry Of Environment and Energy (MOEE, 1995) established a method to estimate recharge based on topography, soils and plant cover. This method relied on applying a partitioning coefficient (F) to the annual surplus (S) to separate it into runoff (RO) and recharge (R) by the following relationships: $R = F \times S$; and, $RO = S – R$.

Evapotranspiration is a large component of the water balance. This is a function of the vegetative cover as well as soil and climatic conditions. As described earlier, evapotranspiration includes the amount of moisture lost to the atmosphere through transpiration by plants and evaporation from the soil, tree canopy and other surfaces. Evapotranspiration can be affected by the removal of vegetation and will result in a reduction of evapotranspiration losses, higher runoff and a smaller loss of soil moisture. The net result will favour the retention of groundwater. The mean annual water surplus (the difference between mean precipitation and evapotranspiration) is therefore derived.

9. *Not all water that infiltrates into the ground ends up as recharge. Some is lost to plant uptake and is subsequently transpired by the plants. In this report, recharge is thus defined, and infiltration is used to describe the initial egress of water into the subsurface.*

The first step is to prepare a water budget for existing conditions from the meteorological data at each meteorological station. The average annual precipitation for the period 1970 to 1994 was selected as it can be directly compared to the period of streamflow record. Using the method of Thornthwaite and Mather (1957) the actual evapotranspiration was calculated for each station. (This method is an empirical technique that quantifies monthly inflow (precipitation) and outflow (baseflow plus runoff = streamflow) for many watersheds, and thus calculated the actual evapotranspiration as the difference, which followed a predictable pattern.) This method uses precipitation, temperature, site latitude, surficial soil, and vegetation cover to calculate the actual evapotranspiration. The surplus is determined by subtracting the actual evapotranspiration from the average annual precipitation. Soil moisture storage, used to buffer evapotranspirative losses, was assumed to be 100 mm based on the generally sandy soil type. The results of this analysis are presented in Table 6 below.

Table 6. Summary of Water Balance for the Selected Meteorological Stations (1970-1994)

Climate stations name		Precipitation (mm/yr)	Actual ET (mm/yr)	Water Surplus (mm/yr)
Stations Located Within the Lakehead SPA	Flint	805.3	505.5	299.8
	Thunder Bay	771.5	498.7	272.8
	Tranquillo Ridge	884.2	511.4	372.8
	Whitefish	907.7	524.2	383.5
Stations Located Outside the Lakehead SPA	Upsala	885.3	496.5	388.8
	Cameron Falls	851.1	501.0	350.1

As discussed in Section 4.1, the precipitation values are shown on Map 1, Appendix B. Evapotranspiration is shown the same way on Map 2. The actual evapotranspiration ranges over a narrow band of approximately 496 to approximately 524 mm/yr, a much more narrow variation in comparison to precipitation which had a variance of 136 mm. The difference between the precipitation and the actual evapotranspiration is termed the surplus, which is available for runoff and infiltration (recharge). The surplus is shown on Map 14c (Appendix B), and ranges approximately between 273 and 388 mm/yr, being greatest at the locations where the highest precipitation occurs.

The next step in determining recharge is to partition the surplus, using the following methodology. The partitioning of the water surplus between runoff and infiltration depends on four main factors: 1) topography; 2) soil texture, 3) cover type, and 4) available water. The MOEE (1995) method relies on calculating “infiltration factors” composed of the first three factors that are applied to the fourth factor, average annual water surplus. These factors are tabulated in Table 2 (Infiltration Factors) of the MOEE manual (MOEE, 1995) on page 4-62, and is reproduced here in Table 7 for the reader’s convenience.

Table 7. Infiltration Factors

Table 2: Infiltration Factors	
Description of Area/Development Site	**Value of Infiltration Factor**
TOPOGRAPHY	
1. Flat and average slope not exceeding 0.6 m per km	0.30
2. Rolling land, average slope of 2.8 m to 3.8 m per km	0.20
3. Hilly land, average slope of 28 m to 47 m per km	0.10
SOIL	
1. Tight impervious clay	0.10
2. Medium combinations of clay and loam	0.20
3. Open sandy loam	0.40
COVER	
1. Cultivated lands	0.10
2. Woodlands	0.20

Reproduced from MOEE (1995), Technical Guidelines for the Preparation of Hydrogeological Studies for Land Development Applications.

For this study, topographic factors were calculated based on actual slope. Application of the generalized infiltration factors recommended by MOEE (1995), were refined by developing a relationship between the infiltration factor and degree of slope. For the categories where slope ranges were given, the appropriate slope (in degrees) was calculated for the mid-point of the range. The resulting relationship is shown in Figure 11.

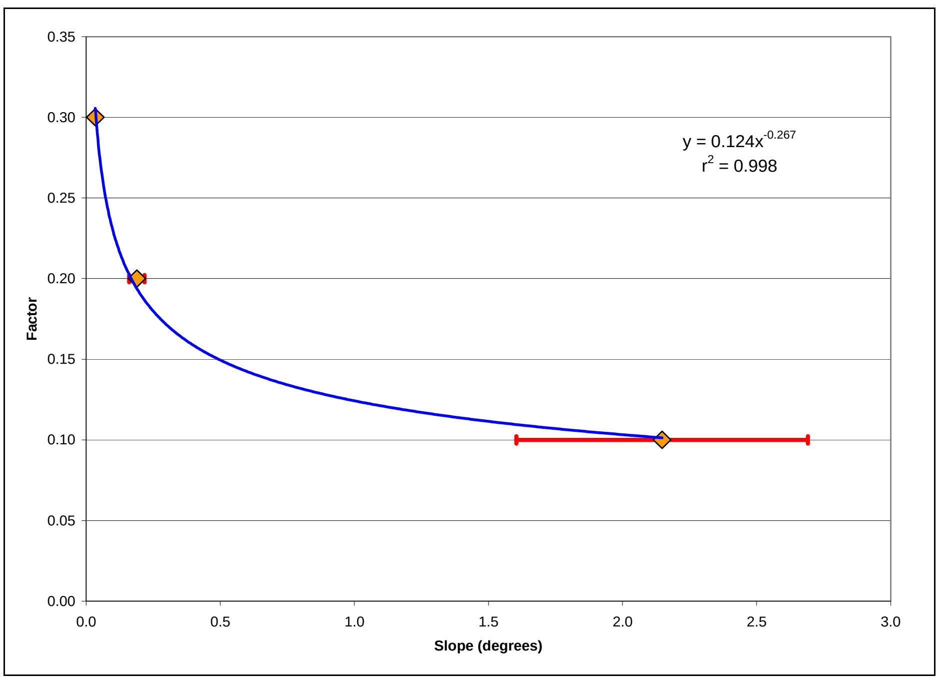

Figure 11. Relationship Between Infiltration Factor and Slope

The MOEE (1995) method is based on the principle that water will infiltrate more easily through:

a) sands compared to clays;
b) on flat slopes compared to steep slopes; and,
c) through vegetated soils compared to areas which have less moisture interception.

An infiltration factor, for example, of 0.4 means that 40% of the water surplus will infiltrate into the ground while the remaining 60% will become runoff. The method is applied on a long-term basis (annually) and is not related to individual precipitation events.

The horizontal range bars in Figure 11 show the range of slope associated with the guidelines in the MOEE (1995) report. The points were best described by a power fit (the equation is shown in Figure 11). This relationship was used to derive an infiltration factor based on slope. For slopes less than 0.03°, the infiltration factor was assigned to 0.3. Slope factors ranged from 0.1° to 0.3° with the higher values in the flat lying areas.

The soil factor is based on the geologic mapping for the area. Factors of between 0.1 for tight impervious soils or bedrock, to 0.4 for permeable aeolian sands were selected and applied to the digital geologic map in a GIS platform. Bedrock was assumed to be very tight, and was assigned an infiltration factor of 0.1. Some rock is marginally more weatherable than others and was given an infiltration factor of 0.2.

The final factor in the MOEE (1995) methodology is based on land cover. In this case, there are two factors applied, based on whether or not the area is wooded or cultivated. Wooded areas were assigned an infiltration factor of 0.2, and cultivated areas (including lawns) were given an infiltration factor of 0.1. To estimate this factor, a grid of the study area was constructed in the GIS platform based on the vegetation coverage obtained from OMNR. That vegetation coverage is based on the interpretation of air photos during the development of the Ontario Base Mapping series. For all open water, the infiltration factor was set to 0, as all this water contributes to runoff.

The method is best described by a sample calculation. For a given 20 m square polygon in the GIS platform, the slope is calculated. In this example the slope is 2°. The factor may be calculated using the equation in Figure 11:

$$Y = 0.124 \times (\mathbf{2^o})^{-0.267} = 0.103$$

The slope factor is therefore 0.103, which is reasonable since it is relatively steep and the runoff is increased, meaning there is less opportunity for infiltration. Assuming that the bedrock is near the surface, but of the more weathered variety, a factor of 0.2 is used. This indicates that relatively more water will be captured by open fractures, leaking to depth. Finally, there is little vegetation except grasses and mosses on the slope, so retention of runoff is minimal and therefore a factor of 0.1 is selected. These are summed together to determine the partitioning coefficient of 0.103 + 0.2 + 0.1 = 0.403 for this example polygon.

The final step is to apply the partitioning coefficient to the surplus. We have assumed the polygon lies in an area just south of Dog Lake. The surplus from Map 14c is about 320 mm/yr. Therefore, infiltration equals 0.403 X 320 mm = 129 mm/yr. This infiltration, which contributes to groundwater recharge, is shown on Map 14a. The remaining water (191 mm/yr in this case) is runoff, (the difference between the surplus and the infiltration). Map 14b shows the average annual runoff for the watershed of between 160 and 200 mm/yr. In this example, the runoff is greater than the infiltration, which would be expected for a slope of 2° or more.

It is useful to examine the water budget on a watershed scale. Here we report the water balance as an example for the HYDAT catchment station (02AB006) of the Kaministiquia River Watershed covering an area of 6,455 km^2 (see Table 8)[10]. The following average values were obtained from the GIS platform after interpolation. They are derived by multiplying their cell values by the cell areas, summed as a total volume, and then divided by the total area. The average precipitation for the watershed is approximately 846 mm/yr; actual evapotranspiration is approximately 509 mm/yr, and the surplus is approximately 337 mm/yr. This surplus has been partitioned into runoff and recharge with a value of 166 mm/yr and 171 mm/yr, respectively. By way of comparison, the streamflow gauge on the Kaministiquia River at Kaministiquia estimates a total flow (including both runoff and baseflow[11]) of 287.3 mm/yr, which is about 85.3% of the surplus value of 337 mm/yr at the same location. The close agreement (± 15% difference) of these two independent methods provides some degree of confidence in the water balance.

4.4.3 Baseflow Separation

As the watershed region is composed of numerous lakes and wetlands and its soil structure is mostly of silt, sand and gravel, there is a significant interaction between surface water and groundwater in terms of baseflow contribution to the streams. Baseflow is defined as that portion of the total streamflow that occurs when there is no contribution from rainfall or runoff. In addition, any precipitation that does not runoff and infiltrate into ground and later returns to the watercourse, would be referred to as 'baseflow'. Generally, infiltrated water that returns to the stream rapidly (say in less than 24 hours) is referred to as 'subsurface flow' and sometimes as interflow, and is usually considered as part of the 'storm flow'. In agricultural watersheds that are drained by subsurface tiles, the flow in the tiles (hence, 'tile flow') is considered part of the 'rapid subsurface flow' (or the 'slow' storm flow). Water that infiltrates deeper into the ground and returns to the stream much later, say in a period of greater than 2 days, would be considered as the 'baseflow'.

Therefore, baseflow comprises the accumulated subsurface or groundwater discharge to the watercourses. This is important for the natural function of the ecosystem, providing clean water and sustaining streamflow and wetlands in dry periods. In particular, it provides the cold water that allows for thermal buffering in headwater streams, sustaining fish habitat. The accumulation of baseflow throughout the watershed sustains the river system and lakes in the Lakehead SPA.

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10. The entire Kamnistiquia watershed is 7,812 km^2, of which this 6,455 km^2 catchment above HYDAT catchment station #02AB006 at Kamnistiquia is the major portion.

11. Since it can be assumed that groundwater storage changes are negligible over the 24 years of record, the total infiltration should equal the baseflow into the river and its' tributaries. Therefore the annual average stream flow should theoretically be equal to the surplus.

Baseflow analyses were carried out using an automated baseflow separation program as described by Arnold *et al.*, 1995. This program uses a digital filter technique and calculates baseflow from stream flow data. This filter method has proven to be comparable to other automated techniques in its ability to reproduce the results produced from graphical separation techniques. This method calculated baseflow, on average, of over 50% of the stream flow. On the other hand, values of 20 to 30% based upon surficial geology (e.g., soils information) considerations are given in OMNR (1984) and Singer *et al.* (2002). Using the Kaministiquia River watershed example discussed in Section 4.4.2 above, a value of 49% was derived (166 mm / 337 mm = 0.49). This would seem to indicate the Arnold *et al.* (1995) derivation is more in agreement for this northern watershed. Table 12 in section 5.2.1 provides the calculated baseflow for some of the watersheds of the Lakehead SPA.

4.5 Surface Water

The Kaministiquia River and its tributaries form the most significant surface water system in the Lakehead SPA. Figure 2 provides a schematic of the Kaministiquia River and its tributaries. Other major rivers in the Thunder Bay area include; Neebing River, Pennock Creek, McIntyre River, Current River, Wolf River, McVicar Creek, and Mosquito Creek. All of these rivers drain into Lake Superior. In the following sections some of these major rivers are briefly discussed.

4.5.1 Kaministiquia River System

The Kaministiquia River (locally also called the Kam River) covers a drainage basin of 7,812 km^2. There are a number of watercourses within the basin, the most important of which are Kashabowie, lake and River, Shebandowan Lake and River, Matawin River, Dog Lake, Kaministiquia River, Whitefish River and Slate River etc. These are shown in Figure 2.

The headwaters of the Kashabowie river are the furthest west portion of the study area. The Kashabowie Lake drains the eastern half of this subwatershed (Figure 1). A dam on Kashabowie Lake discharges into the river from the north, which then reaches Shebandowan Lake.

The Shebandowan River originates in three large lakes in the extreme northwestern area of the basin – namely, the Greenwater, Kashabowie and Shebandowan Lakes. All three lakes are controlled to varying degrees by OPG dams. The Kashabowie Lake has limited control over the upstream catchment area and is controlled by a structure having a weir and a stoplog control gate. The Greenwater Lake also has limited control over the upstream catchment area... However, the Shebandowan Lake has more live storage and it has a greater regulating capability on the catchment runoff. Lake discharge is also controlled using a stop log control structure. The water released from Shebandowan dam flows about 15 km southeast to the confluence with the Matawin River and flows into the Kaministiquia River above Kakabeka Falls.

The Matawin River originates in a number of small, unregulated lakes in the western area of the basin and flows eastward to the middle reach of the Shebandowan River. Near its confluence with the Shebandowan River, there is a small weir owned by MNR, but it is operated only to maintain water levels and does not significantly regulate flow.

The Kaministiquia River flows from Dog Lake in the northern area of the basin, in a southward direction until it reaches Kakabeka Falls, due west of Thunder Bay. At that point the river turns eastward and flows to Thunder Bay and Lake Superior. Dog Lake is the largest lake in the basin, and is controlled by the Silver Falls Hydroelectric Project and two stop log structures owned and operated by Ontario Power Generation (OPG).

Downstream from Kakabeka Falls, Whitefish River, Oliver Creek, Corbett Creek and Slate River are some of the waterways that flow into the Kaministiquia River. These are all uncontrolled watercourses.

The Kaministiquia River floodplain mapping study covered 30 km of the river, which was found to exhibit two distinctly different flow characteristics. In the lower reaches, the river bed cuts a gently sloping channel through alluvium. The channel ranges from 100 to 200 m in width and 7 to 9 m in depth under normal low flow conditions, with an average gradient of 0.06%. In upstream reaches the flow is quite shallow and much faster, with an average bed slope of 0.2% and a series of very steep, shallow rapids. High flows are experienced during spring and early summer due to heavy rainfall and high spring runoff, and have resulted in flooding along some lower portions of the river.

There are six water control structures/facilities on the Kaministiquia River system, shown on Figure 2 and in Map 9 (Water Control Structures) in Appendix B. Two of these facilities (Silver Falls and Kakabeka Falls) are used to generate hydroelectricity, three dams (Kashabowie, Greenwater and Shebandowan) serve to store and release water as required for a variety of purposes (e.g., flood control or low flow augmentation) and MNR Matawin River dam creates waterfowl habitat.

4.5.2 Current River

The main branch of the Current River originates at Current Lake northeast of Thunder Bay, passes successively through Ray, Kingfisher, Onion and Boulevard Lakes and falls over 304 m on its 64 km journey to Lake Superior. The lower branch of the river drops 274 m over its 38.4 km length from the headwaters in Kingfisher Lake area to just north of Boulevard Lake, where it joins the main branch. Through the last 800 m, the river cascades steeply down to Lake Superior. The total watershed area is 663 km^2 (see Table 1). The river valley cuts through bedrock and the adjacent soils are very thin and undifferentiated.

Current River has a history of severe floods that have resulted in damage to crossings, water control structures and loss of life. Historically, extreme flood flows have occurred in mid-April to mid-May due to precipitation coincident with snow melt. Primary areas endangered by high flooding are the Boulevard Lake dam, the Cumberland Street and the railway crossings below the dam.

Downstream restrictions to the river at the C.N.R. and C.P.R. Railway bridge crossings are a major cause of increased water levels during severe flooding. The Onion Lake dam which has already been removed by MNR represented a hazard since failure of the dam and released some 17 Mm^3 (million cubic metres) of stored water in addition to any flood through the City of Thunder Bay. The MNR Ray Lake dam, upstream of Highway 527, also represents a hazard since failure of the dam would result in washout of the Highway 527 culverts and a logging road crossing further downstream. However, the presence of a large number of lakes tends to mitigate flood peaks by providing natural storage capacity. The major land use around the Current River is recreational.

4.5.3 Neebing River

The Neebing River watershed contains an area of approximately 232 km^2. The main branch of the Neebing is 39 km long with an average gradient of 0.74%. It has two large tributaries, namely Pennock Creek (21 km) and the Northwest tributary which is slightly shorter. The main channel flows through undulating till plains of stratified sands and gravel and then through flat deltaic deposits that are imperfectly drained in numerous sections and contain deep peat bogs. The river falls only about 15 m in the last 13 km and for its last 3.25 km, the Neebing is at the same level as Lake Superior.

There is extensive urban development along the lower portions of the Neebing and approximately 30 to 40% of the land has been cleared. This watershed is the most heavily farmed in the region. Because of the gradient and the influence of the lake, the natural river channel has a low capacity estimated at 42.5 m^3/s maximum without flooding. In the early 1980's the Neebing-McIntyre Floodway was constructed to divert excess flood flows into an enlarged channel formerly carrying the McIntyre River. This work has alleviated the previous high river levels and floods that used to occur regularly along the lower Neebing River causing sewer and property damage in the past. Erosion of riverbanks is a serious problem as well.

4.5.4 McIntyre River

The McIntyre River with its headwaters at Trout Lake drains an area of 210 km^2 and falls a total of 320 m along its length to Lake Superior. The upper reaches of the river are located in undifferentiated soils overlying bedrock and through flatter sand and gravel plains in the urban area. The lower reaches of this watercourse are also heavily developed with residential as well as some industrial uses. Only 10-20% of the land within the watershed is cleared with the remainder being forest covered. The problem of stream bank erosion is much less severe on the McIntyre as compared to the Neebing River. Flooding along the lower reaches was a recurring problem along both the Neebing and McIntyre Rivers prior to the construction of the Neebing-McIntyre Floodway in 1984. The natural channel of the McIntyre River, upstream of the Neebing-McIntyre Floodway, has a maximum capacity of about 63 m^3/s without flooding.

4.5.5 Wolf River

The Wolf River drains an area of rural and forested land, encompassing 730 km^2. The river originates in Upper Wolf Lake, generally flowing in a southerly direction and draining into Lake Superior at Black Bay. Approximately 64 km in length, the river is fed by numerous lakes and streams along its course, including Venice, Anders, Hicky, Greenwich, Furcate, Wolf, Pringle, Wolfpup, and Cavern Lakes. In its upper reaches, the river tends to be very steep, creating hazardous slopes and sites with active erosion. Many of the areas along the river currently experiencing erosion occur in the bends of the river where water flow has caused undercutting, slumping and bank instability. Dense vegetation, including mature trees and shrubs, cover the river banks. The lower portion of the river becomes less steep as it approaches Lake Superior. The majority of Wolf River is contained within the Township of Dorion, while the rest of the river lies completely in unorganized territory. Provincial Highway 11/17 crosses Wolf River at one point along the lower reach. Along the course of the river there are no identified wetlands larger than 40 ha, only small areas developing through natural succession in the oxbow lakes adjacent to the meandering river channel.

4.5.6 Streamflow Gauges

Within the Lakehead SPA, there are twenty-five streamflow gauges/hydrometric stations, which contain an extensive record of flow dating back from 1923 until the year 2003. Of these twenty-five, some measure stream flow continuously, some measure only water level and some were in operation for only a short period of time. Water levels in most of the rivers vary depending on the control dams, lakes and reservoirs. The Kaministiquia River is the largest river within the Lakehead SPA. Table 8 summarizes information such as station ID, drainage area, location, and period of record for available data for fourteen stations that have a period of record that matches with the precipitation records. These stations are also shown on Map 10 in Appendix B.

4.5.7 Streamflow Response

Figure 12 shows as an example the time-series of mean annual, minimum and maximum daily flows for the Kaministiiquia River at Kakabeka Falls Powerhouse gauge (02AB006) for the period 1970 to 1994. For the period represented by Figure 13, the computed mean annual discharge was found to be 58.81 m^3/s, the mean maximum daily flow was 194.39 m^3/s, and the mean minimum daily flow was 18.73 m^3/s. The highest mean annual flow of 83.90 m^3/s occurred in 1970, whereas the lowest value of 28.40 m^3/s took place in 1987. For the past 24 years, the mean annual flow has been quite steady.

Table 8. Summary of Continuous Streamflow Gauge Stations Within the Lakehead SPA (data from 1970-1994)

Station Name	Station ID	Drainage Area[1] (km^2)	Latitude	Longitude	Period of Records	Number of Years	Mean Annual Flow rate (m^3/S)	Max. Annual Flow rate (m^3/S)	Min Annual Flow rate (m^3/S)
Pigeon River at Middle Falls	02AA001	1550	48°0'44"N	89o36'58"W	1924-1999	75	15.08	40.65	2.03
Kaministiquia River at Outlet of Dog Lake	02AB004	3760 (3397)	48°42'30"N	89°38'0"W	1923-1994	71	30.19	61.96	6.79
Kaministiquia River at Kaministiquia	02AB006	6475 (6455)	48°31'58"N	89°35'39"W	1926-2003	77	58.81	121.64	18.13
Neebing River near Thunder Bay Airport	02AB008	187 (205)	48°22'56"N	89°18'28"W	1953-2003	50	1.80	5.87	0.15
Shebandowan River at Sunshine	02AB009	2800 (2852)	48°33'20"N	89°40'55"W	1957-1994	37	24.09	60.45	4.67
Kaministiquia River at Kakabeka Falls Powerhouse	02AB010	6710 (6746)	48°24'56"N	89°37'51"W	1923-1994	71	54.46	121.71	16.73
Shebandowan River at Outlet of Shebandowan Lake	02AB011	ND (1159)	48°37'11"N	90°3'42"W	1924-1994	70	6.14	21.41	0.24
Kashabowie River at Outlet of Kashabowie Lake	02AB013	526 (514)	48°39'25"N	90°25'3"W	1951-1994	43	3.87	11.09	0.21
North Current River near Thunder Bay	02AB014	111 (116)	48°30'4" N	89°10'47"W	1972-2003	31	1.22	3.58	0.20
Current River near Stepstone	02AB015	492 (499)	48°32'10"N	89°14'10"W	1972-1986	14	5.32	12.77	1.44
Current River at Stepstone	02AB021	392 (404)	48°33'45"N	89°14'27"W	1989-2003	14	3.92	7.78	1.77
McIntyre River at Thunder Bay	02AB016	145 (137)	48°25'7" N	89°15'55"W	1972-1986	14	4.01	1.26	0.15
McIntyre River above Thunder Bay	02AB020	90 (80)	48°28'57"N	89°19'31"W	1987-2003	16	2.36	0.82	0.14
Wolf River at Highway No. 17	02AC001	736 (716)	48°49'19"N	88°32'7"W	1971-2003	22	6.78	17.09	1.28

Note: 1. Drainage area is from HYDAT database; Drainage area in the parenthesis was calculated using Archydro and used for water budget analysis.

Within the year, variations in the maximum daily, mean daily, and minimum daily flows are exhibited in Figure 13. Generally speaking, the highest flows occur in the spring freshet months of April, whereas the lowest flows occur in the late summer or early fall month of August and in March. The highest maximum mean monthly flow of 144 m^3/s occurred in April, whereas the lowest maximum mean monthly flow of 58 m^3/s occurred in March. For the record shown, the lowest minimum mean monthly flow value of 26 m^3/s occurred in August, while the highest minimum mean monthly flow of 46 m^3/s took place in February. Although the month of February would not normally be a time of high minimum flows, Kaministiquia River flows are regulated for hydroelectricity production and February is a month of peak demand.

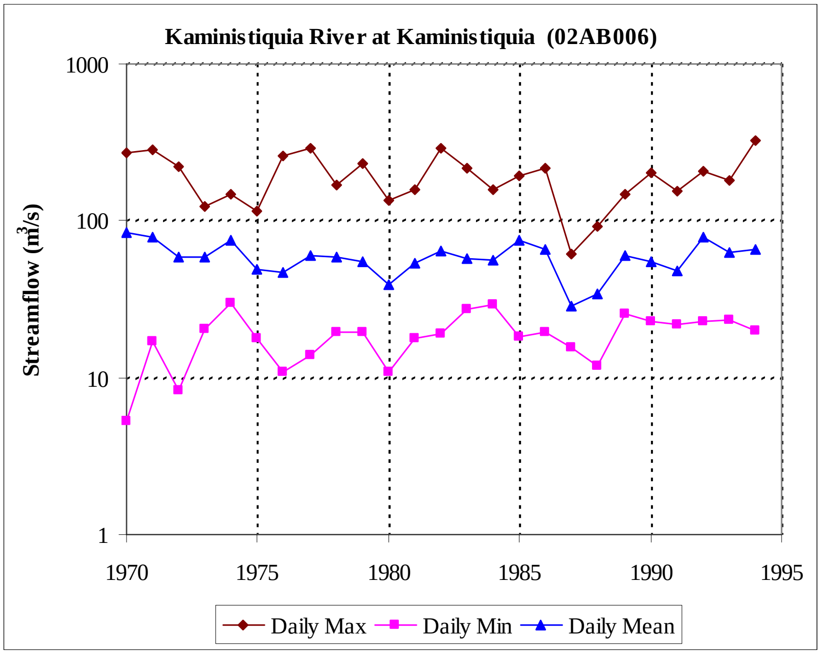

Figure 12. Time-Series of Annual Flows on the Kaministiquia River at Kaministiquia (02AB006)

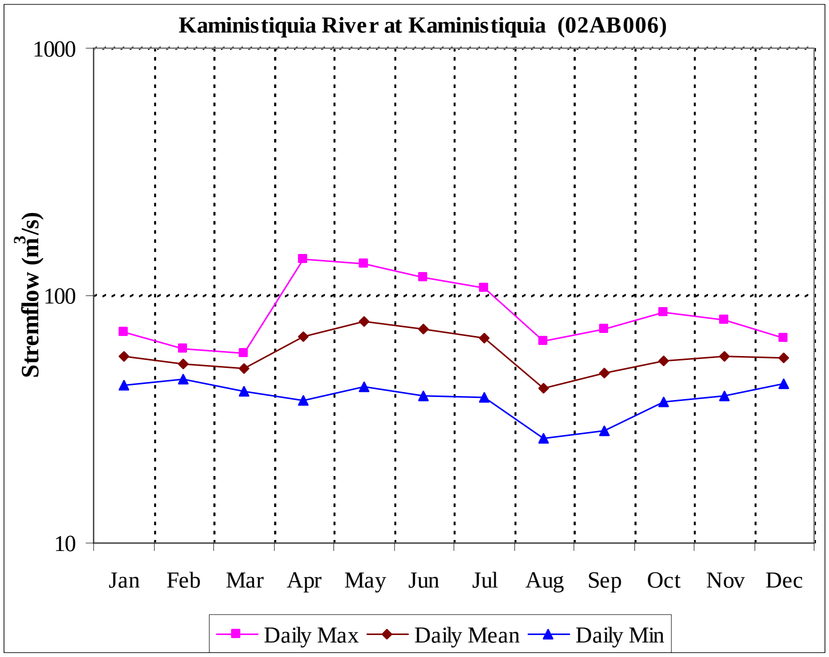

Figure 13. Monthly Flow Distribution of the Kaministiquia River at Kaministiquia (02AB006)

4.5.8 Surface Water Nodes (Points of Interest) for Watershed Catchment Delineation

The Ministry of Natural Resources maintain dams throughout the watershed to regulate water levels for recreational users and to support MNR facilities (e.g. Wolf Lake Dam assists in providing groundwater flow to the Dorion Fish Culture Station). OPG dams at Kakabeka Falls and Silver Falls on the Kaministiquia River are utilized to generate electricity. The dam at Boulevard Lake was used to produce electricity until 1972. OPG also operates control dams on Dog Lake, Shebandowan Lake, Greenwater Lake, and Kashabowie Lake. Map 9 (Water Control Structures) shows the water control facilities that are constructed on the different rivers/streams, lakes of Lakehead SPA. Some of the major dams are discussed in the following paragraphs.

The major surface water nodes (dams and generating stations) on the Kaministiquia River System are shown on Figure 2. Discharges into the Kaministiquia from Shebandowan Lake and Dog Lake are regulated through the operation of control dams, several of which have aided in minimizing the effects of flooding. Control dams exist on Greenwater Lake, Kashabowie Lake, Shebandowan Lake and Dog Lake. Despite partial control exerted by these dams, high flows are experienced during spring and early summer.

In the past, repeated flooding by the Neebing and McIntyre Rivers brought damage and disruption in the central areas of the city of Thunder Bay. The development of the Neebing McIntyre Floodway involved the re-routing of flood flows to alleviate the annual flooding problems in this part of the city. The diversion involved the construction of a floodway from the Neebing River at Ford Street, through the Chapples Golf Course to existing McIntyre River to the east of Fort William Road, and redirecting the flow in the Neebing River, meeting Lake Superior south of the Keefer Terminal. West of Ford Street, minor improvements to the Neebing River channel are required where erosion and sloughing of banks have occurred. Peak flows are 156 m^3/s for the Neebing River, and 127 m^3/s for the McIntyre River. Flows of 28 m^3/s are diverted down the existing Neebing River since the floodway has been constructed, leaving 255 m^3/s and 283 m^3/s to be carried by the floodway during peak flows. Construction of the floodway began in 1980 and was completed in 1984. Since the construction of the floodway there has been no further flooding in this part of the city. As a result, this area of the city has gone through a great deal of commercial development and expansion since the mid-1990s and is now the largest retail sector in the entire city.

In the first decades of the 1900's the Port Arthur Hydroelectric Commission (now Thunder Bay Hydro) constructed Boulevard Lake Dam and its nearby generating station. Upstream on the Current River storage dams were built at Stepstone, Hazelwood Lake, Onion Lake and Ray Lake to retain the spring runoff and other flood peaks for later release. The generating station below Boulevard Lake was removed in 1972. The City of Thunder Bay took over Boulevard Lake Dam. The MNR took over Onion Lake Dam and Ray Lake dam. The Lakehead Region Conservation Authority took over the Hazelwood Lake Dam and the lake itself below the high water level. The Stepstone Dam had washed out decades earlier and no longer exits. The flood control role of the dam is perceived to have only a secondary role, with its primary function as part of an urban recreational complex that manages the water levels in the man-made Boulevard Lake. The dam can pass a flow of 518 m^3/s, which constitutes the Regional Flood parameters.

Onion Lake Dam at the outlet of Onion Lake was originally constructed to store water for the hydro generating facilities at the Boulevard Lake dam. Once the generating station was removed and Boulevard Lake was dredged to create a larger lake, which created an increased discharge capacity, the need for flood storage at Onion Lake was reduced. The dam regulates runoff for an area of 370 km^2 in the upper drainage basin of the Current River. A fire in September 1980 left the gate completely destroyed and caused serious structural damage to the overflow wall. At this time a temporary remedial action consists of excavating a breach in the dam to create an opening of sufficient width and depth to handle the highest historical flows without failure. This dam is outside of the legal jurisdiction of the Lakehead Region Conservation Authority and falls under the jurisdiction of the Ontario Ministry of Natural Resources. However, it does fall within the area delineated as the scientific watershed boundary for the purpose of determining a water budget for the Lakehead SPA. At the time this was produced the Ontario Ministry of Natural Resources had slated this dam for decommissioning and was moving through the official process.

Hazelwood Lake Dam was originally constructed in about 1905 and was intended for water control in the production of hydro-electric power at Boulevard Lake. In the late 1970s, deterioration of the dam necessitated that it be rebuilt to a safe state so that desirable water levels could be maintained. Completed late in 1980, the reconstruction was carried out under the authority of the LRCA and included the installation of an impervious membrane along the old dam and construction of a new spillway with a walkway above.

Other dams and/or control structures in the study area include a dam located on the property of Lakehead University, at a narrowing in the McIntyre River, to impound water and create a small lake known as Lake Tamblyn. A small dam is located on Pennock Creek to the west of Thunder Bay, at the Ontario Ministry of Natural Resources Science and Information Unit. A control dam regulates the natural discharge from Loch Lomond. Dams are also located at Wolf Lake, Ray Lake, Marie Louise Lake, Pine River, Matawin River, Neebing River, Wolf River, Dog River and others. The Neebing weir in the City of Thunder Bay maintains water levels and is a Sea Lamprey barrier.

4.6 Water Use

The LRCA Groundwater Management and Protection Study Report (Burnside and Amec, 2005) identifies the basic water uses within the Lakehead SPA. These are summarized below, and where data gaps are identified by that study, estimates have been provided. Potable water is provided by a variety of sources such as from the municipality. Table 9 provides a summary of water users in the City of Thunder Bay and surrounding areas.

Table 9. Water Users and Estimated Population in the Lakehead SPA (Source: Statistics Canada, 2001)

Water Users	Service Type	Population
City of Thunder Bay	Municipal + Private	109,016
Municipality of Oliver Paipoonge	Private	5,749
Rosslyn Village	Municipal + Private	90[1]
Municipality of Neebing	Private	2,049
Township of Shuniah	Private	2,466
Township of Conmee	Private	748
Township of O'Connor	Private	724
Township of Gillies	Private	522
Fort William	Private	599
Township of Dorion	Private	382
Total Population in 2001		**122,345**

Note: 1. Based on personal communication with Steve Suke, LRCA

Maximum allowable surface water takings, based on the Ministry of Environment (MOE) PTTW (Permit To Take Water) database (shown only active permits) are presented on Table 10. Figure 14 provides the relative consumptive and non-consumptive surface water takings for power generation, municipal, industrial, and irrigation purposes from the SPA based on PTTW. The bold and italicized values in Table 10 are non-consumptive surface water takings that include power generation, dams, and reservoirs, totalling approximately 480 Mm^3/yr, most of which is returned to the source after use. Permitted total consumptive surface water takings is 210 Mm^3/yr, which in this case consists of three things: permitted industrial volumes total approximately 161 Mm^3/yr, permitted irrigation volumes total approximately 21 Mm^3/yr and the permitted municipal takings from Loch Lomond for the City of Thunder Bay is approximately 28 Mm^3/yr [12.] Together, these account for approximately 31% of the total water taking, and are probably lower based on the fact that water takings from the MOE PTTW database do not report actual takings, just maximum permitted amounts.

Table 10. Surface Water Takings According to PTTW Database (only active permits)

Permit No	Easting	Northing	Water Use	Source (River, Lake, Creek)	Takings (Mm^3/yr)
00-P-6024	318033	5359040	Field and Pasture Crops	Kaministiquia River	0.24
01-P-6047	309300	5431490	Pits and Quarries	Open Pit	10.95
01-P-6057	307850	5431495	Other - Industrial	Lac Des Illes	12.78
02-P-6057	321809	5356238	Field and Pasture Crops	Kaministiquia River	0.60
03-P-6040	309583	5362370	Aggregate Washing	Spring Few Tributary to Kaministiqua River	0.08
04-P-6027	336256	5360704	Other - Industrial	On-site Storage Ponds	1.08
3628-6BCQJR	335528	5358534	Other - Industrial	Mission River	0.10
67-P-511	331304	5361895	Dams and Reservoirs	Neebing River	***5.84***

12. As mentioned previously in Section 1.3, The City of Thunder Bay intends to draw its entire potable municipal water supply from Lake Superior by the end of 2007. If not used for other purposes, Loch Lomond water takings should be subtracted from the given calculation. Permitted municipal water takings from the Lake Superior is not accounted in this calculation as this takings is considered not from the watershed.

Table 10. Surface Water Takings According to PTTW Database (only active permits)

Permit No	Easting	Northing	Water Use	Source (River, Lake, Creek)	Takings (Mm^3/yr)
70-P-429	332375	5365608	Dams and Reservoirs	McIntyre River	***0.02***
73-P-112	326816	5379309	Aggregate Washing	Pond on Trib. to McIntyre #1	0.64
73-P-112	326816	5379309	Aggregate Washing	Pond on Trib. to McIntyre #2	0.96
74-P-6015	328578	5360692	Golf Course Irrigation	Creek	0.10
75-P-6007	384101	5410724	Aquaculture	Wolf River	5.52
76-P-6011	382393	5410921	Aquaculture	Spring Creek	14.32
77-P-6001	334501	5359024	Power Production	Mission Island	***474.50***
82-P-6004	384069	5410868	Other - Industrial	Wolf River	6.69
84-P-6006	310703	5378970	Aggregate Washing	Strawberry Creek	2.39
86-P-6024	322497	5349921	Snowmaking	SW Quarter of Section 6	0.20
87-P-6015	329009	5357256	Manufacturing	Water Intake #1 Upstream Intake (Kraft)	78.84
91-P-6015	329000	5349213	Municipal	Loch Lomond	28.21
96-P-6013C	320606	5354884	Field and Pasture Crops	Slate River	0.20
97-P-6023	329001	5357254	Other - Industrial	Water Intake No. 2, Downstream Intake	52.56
97-P-6045	322500	5349912	Snowmaking	McQuaig Lake, Section 6	0.17
98-P-6094	319000	5355718	Field and Pasture Crops	Slate River	0.04
98-P-6893	321001	5356724	Field and Pasture Crops		0.05
Total					**690.36**
Non-consumptive (Power generation, Dams/Reservoirs)					***480.36***
Total Consumptive (Industrial, Municipal, Irrigation (Field and Pasture crops, aqua culture etc.))					**210.00**
Industrial					**160.74**
Municipal					**28.21**
Irrigation (Field and Pasture crops, aqua culture etc.)					**21.05**

Note: *Bold and Italicized values represent non-consumptive uses*

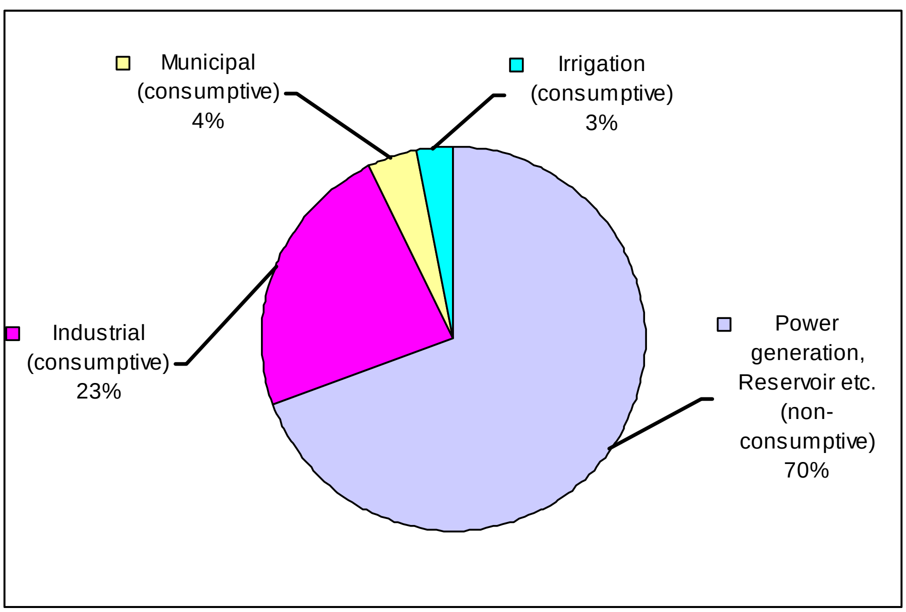

Figure 14. Breakdown of Surface Water Takings from the Lakehead SPA According to PTTW Database

The largest demand for potable water is in the City of Thunder Bay, where water is currently drawn from Lake Superior supplied through the Bare Point Water Treatment Plant (on Lake Superior) and formerly the Loch Lomond Plant (on Mount McKay). The Bare Point water treatment plant is located in the northern part of the City with the intake pipe located approximately 750 m offshore from Bare Point. The Loch Lomond water supply is located south of the city limits, on Mount McKay Lookout. The water intake extends 220 m into the lake (Lomond) and once supplied water by gravity distribution through the city's system. According to the Thunder Bay City Water Department, Bare Point (Lake Superior) supplies 64 million litres per day and Loch Lomond supplied 28 million litres per day for a total of 92 million litres per day (33.6 Mm^3/yr) for a population of 109,016. Data from the same source indicates that this water supplies approximately 92% of the population of the City of Thunder Bay. The rest of the 8% of the population within the city uses private/domestics wells for satisfying their water demand. Based on the PTTW database, the city is permitted to draw a maximum of 61 Mm^3/year while in actuality it draws a little less than half of it.

Maximum allowable groundwater takings, based on the MOE PTTW database are presented on Table 11. Figure 15 provides the relative consumptive groundwater takings for municipal, industrial, and irrigation purposes from the SPA. Based on the PTTW database, the water supply system in Rosslyn Village in the Municipality of Oliver Paipoonge serves a population of 90. It is permitted to draw a maximum of 0.9 Mm^3/yr of water from two groundwater wells according to the PTTW database (Table 11). Based on Burnside and Amec (2005), the average daily and maximum daily groundwater use for the Rosslyn Village are 35 m^3/d and 50 m^3/d, respectively.

Table 11. Groundwater Takings According to PTTW Database (only active permits)

Permit No	Easting	Northing	Water Use	Source (River, Lake, Creek)	Takings (Mm^3/yr)
00-P-6073	318409	5359730	Municipal	North Well	0.045
00-P-6073	318410	5359716	Municipal	South Well	0.045
01-P-6047	309300	5431490	Pits and Quarries	Open Pit	10.948
02-P-6021	366394	5358749	Campgrounds	Visitor Centre Well	0.051
02-P-6055C	320606	5354884	Field and Pasture Crops	Groundwater pond	0.119
03-P-6021	335314	5377732	Communal	Wet Well	0.079
03-P-6021	335314	5377732	Communal	3 Wells	0.070
03-P-6043	324651	5355621	Snowmaking	Dug Reservoir	0.105
1373-6CSQ6P	320606	5354884	Fruit Orchards	Groundwater Storage Pond	0.119
92-P-6018	328501	5358424	Other - Industrial	Dug Well	0.097
Total					**11.68**
Other Industrial					**11.35**
Municipal					**0.09**
Irrigation					**0.24**

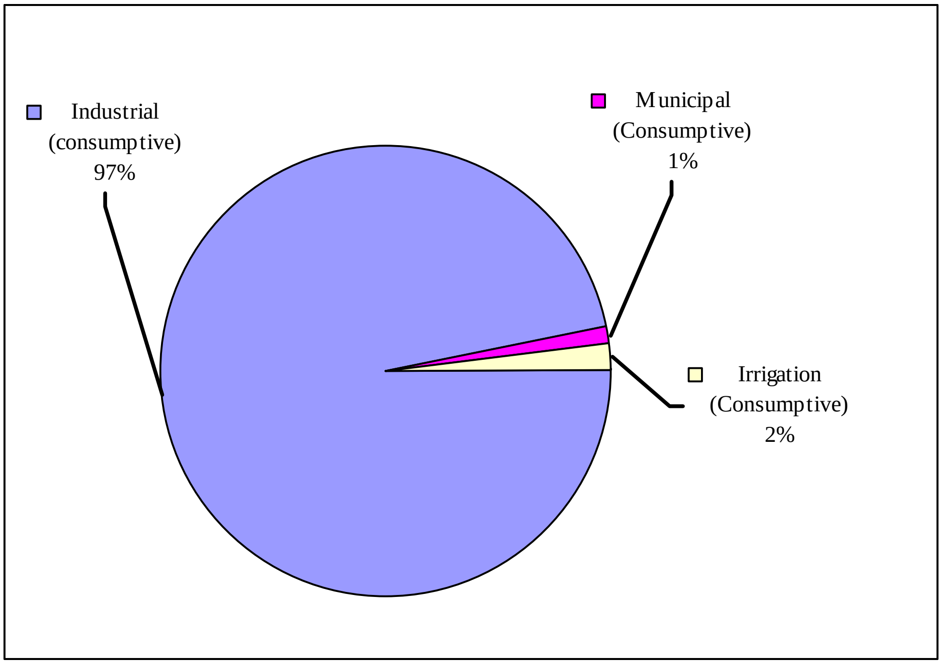

Figure 15. Breakdown of Groundwater Takings According to PTTW Database

In rural areas and in municipal areas where people receive no service from municipal supplies, private wells are used to draw groundwater for their domestic uses. Within the city limits, the 8% of the population (8,721) that use private wells draw approximately 1.07 Mm^3/yr (based on the consumption rate of 335 L/day/capita, (Module 7, MOE, 2007).

Within the surrounding municipalities and townships, the primary source of water is groundwater from private wells. Based on the assumption that each resident uses 335 L/day/capita and with of total population of 13,239, water demand is estimated at 1.62 Mm^3/yr. Analysis of the MOE water well record data on wells in the area indicates that approximately 91% of the over 3,000 wells evaluated in this study are noted as being used for domestic purposes (Burnside and Amec, 2005).

Because of shallow overburden and bedrock outcrops, the study area does not support any large-scale agricultural (irrigation and livestock) activities. The PTTW database was evaluated to estimate the proportion of agricultural water use derived from either surface or groundwater. The current database indicates that there is only one groundwater PTTW for agricultural use, and that all agricultural demands are satisfied with surface water takings.

Table 14, in Chapter 5, summarizes the volume of actual consumptive surface water and groundwater demand from the watershed. Actual consumptive surface water takings that include water takings for industrial supply, municipal water supply, and agricultural (irrigation, livestock etc.)

use are about 62.85 Mm^3/yr, which is only about 9.0% of the values reflected in the PTTW database[13]. Similarly, the actual consumptive groundwater demand from the watershed is about 3.78 Mm^3/yr, which is approximately 32% of the peak takings listed in the PTTW database.

In calculating the actual consumptive water takings provided in Table 14 of Chapter 5, the following assumptions were made:

a) consumptive water loss for power generation is 0%. That is, all of the water drawn from the watershed is returned to the watershed;
b) consumptive water loss for industrial water use is 25% and the rest is returned to the watershed through drains;
c) consumptive water loss for municipal water use is 20% and the rest is returned to the watershed through residential septic tanks; and,
d) consumptive water loss for irrigation water use is 90% through evapotranspiration etc., and the rest is returned to the watershed through infiltration into the ground or runoff to the ditches.

4.7 Report on Quality and Quantity of Available Data

4.7.1 Climate Data

As far as the quantity of data are concerned, there have been 49 climate stations operating in and around the Lakehead SPA that have been recording data over the past 120 years. These stations have been identified and are operated by different agencies like Ontario Power Generation, the Ontario Ministry of Natural Resources, and Environment Canada's Atmospheric Environment Service (AES). Many of these climate stations are no longer active. Historical data that date as far back as the early 1900s are available through Environment Canada's Canadian Climate Centre website. At present, the only long-term climate stations still collecting data are Thunder Bay Airport (#6048261/6048264, since 1941), Whitefish (#6049466, since 1917) and Flint (# 6042MJ7 since 1979).

Although 47 stations[14] have operated in the vicinity of the Lakehead SPA over the years, most of them only recorded daily precipitation (as rainfall and snowfall depths), with a handful of them including daily maximum and minimum air temperatures as part of their climate observation program. An even smaller number of stations have included recording rainfall (tipping-bucket) data, and some have included relative humidity and windspeed measurements. There have been no pan evaporation measurements in the study area from which to estimate lake evaporation. The availability of climate data in the region can be classified as sparse at best. Few stations were in operation for more than 25 years, although a sufficient number have been open long enough to make some general conclusions about the overall climate of the region. In some stations there are also data gaps for a significant period of time.

13. This is because the PTTW database only lists maximum takings and not actual takings.
14. Only 2 of the 47 stations have data quality that meets the WMO standard.

Climate averages, means, or normals refer to the arithmetic computations based on the observed meteorological values for a given location over a specified time period and are used to describe the climatic characteristics of the location. The averages can be used to describe a "typical" climate pattern for a specific location. Real daily meteorological data can be used to describe how unusual or how great departure/deviation from the average scenario is.

The World Meteorological Organization (WMO) considers thirty years long enough to eliminate year-to-year variations. Thus the WMO climatological standard period for normals calculation are defined as "averages of climatological data computed for a consecutive period of thirty years as follows: 1 January 1901 to 31 December 1930, 1 January 1931 to 31 December 1960, etc." Additionally the WMO established that normals should be arithmetic means calculated for each month of the year from daily data. To qualify, temperature data, temperatures and evaporation must fit the 3/5 rule: if more than three consecutive daily values are missing or more than five daily values in total in a given month are missing, the monthly mean should not be computed and the year-month mean should be considered missing. For total precipitation, degree-days, and "days with" calculations, no missing days are allowed. Obviously the ideal averages can only be calculated when enough historically recorded data are available.

Once the months that qualify are determined, a similar 3/5 rule is also applied to the number of monthly average or total values in the thirty-year period. For example, to meet this WMO standard, the "normal" value of a monthly element, such as the normal rainfall amount for May, can have no more than three consecutive, or five in total, missing rainfall values in any month of May from 1971 to 2000.

Normals for some elements are derived from less than thirty years record. The minimum number of years used are indicated by a code defined as:

- "A": No more than three consecutive or five total missing years from 1971 to 2000;
- "B": At least 25 years of record from 1971 to 2000;
- "C": At least 20 years of record from 1971 to 2000;
- "D": At lease 15 years of record from 1971 to 2000.

The climatic data we have used was calculated using the approach given by Schroeter *et al.,* (2000). This approach uses data fill-in techniques to account for missing values in the record; daily meteorological data were processed for seven selected stations in and around the Lakehead SPA for the period of 1970-1994.

4.7.2 Streamflow Data

The availability of streamflow data is much better than climate data, because of the need for operators to use these data for the direct operation of reservoirs and other control structures. Complete annual records of daily flows are available for fourteen useable locations within the watershed, of which ten of these have been in operation for more than 20 years. This amount of available streamflow data are sufficient to make general conclusions about the water resources in the Lakehead SPA.

Despite the better coverage of streamflow records it was not possible to completely match the climate data. Where the period of record did not completely match, data were extrapolated by doing a simple pro rata based calculation (see also section 5.2.3 for details). For example, for the Current River Watershed this was done for the years 1970 to 1972 and from 1986-1994. This estimated data represents about 2-5% of the overall available record and assuming an error of 25%, the overall water balance would only be out by 2.0%. Therefore this approach was deemed acceptable for the purpose of this report in order to extend the period of record to match the meteorological period of record.

Water budget calculations were performed for twelve HYDAT catchment areas out of fourteen. The HYDAT catchment 02AA001 (Pigeon River at Middle Falls) was excluded from calculation as a portion of the watershed lies in the USA and there is no complete data coverage for the station. The HYDAT catchment 02AB011 (Shebandowan River at the outlet of Shebandowan Lake) was also excluded from the water budget calculation because the measured flow at this station is known to be inaccurate due to significant leakage through the dam (personal communication, Karl Piirik, OPG).

4.7.3 Groundwater Information

A recent groundwater study report was produced for the City of Thunder Bay and surrounding municipalities and townships by R.J. Burnside and Associates Ltd. in partnership with Amec Earth and Environmental Limited (Burnside and Amec, 2005). This report presents an extensive compilation and evaluation of regional and local water resources information including groundwater and aquifer characterization, groundwater management and protection and groundwater use assessment etc. It did not cover the full extent of the Lakehead SPA, because of sparse data over the northern portion of the area where the overburden is thin or discontinuous. The corresponding gaps in water table information were estimated by introducing data points from surface water bodies, assuming that the water table would coincide with the water levels in the surface water bodies and stream beds.

However, it is important to understand that the number of available wells, over a wide and relatively uninhabited area, do not provide complete coverage. It would not be possible to have enough wells to cover each of the small local groundwater flow systems around each creek and portion of every subwatershed, nor is it necessary. Rather, a few well-placed sentinel wells (unused for pumping), in typical settings, equipped with daily level recorders would suffice to characterize the area. When specific undertakings are necessary, then site-specific installations could be made and compared to the greater period of record.

5. Integrated Conceptual Understanding

5.1 Water Budget on a Watershed Basis

5.1.1 Spatial Scale

The Lakehead SPA consists of a large number of surface water river systems – the most important within the Lakehead SPA are Kaministiquia River, Neebing River, Current River, McIntyre River, and Wolf River. All the river systems drain ultimately to Lake Superior. The Kaministiquia River watershed is the largest watershed in the study area, covering a drainage area of approximately 7,812 km^2. Several large lakes feed the river and the river flow is controlled by a large number of dams constructed on the river. Groundwater flow is localized towards the surface water system. In the study area it is assumed that the surface drainage watershed or subwatershed boundaries correspond to the groundwater flow divides. Given the shallow nature of the groundwater system this is a reliable assumption. The Lakehead SPA subwatershed study includes a large enough area that cross-boundary groundwater flow is not an issue. Topography is therefore one of the key drivers of the groundwater flow system.

Groundwater takings for drinking water consist of two wells operating alternately in Rosslyn Village for a small community of approximately 90 people. Groundwater is also the source for private domestic water supply for the area (such as surrounding townships and municipalities of the City of Thunder Bay) that receive no service from the municipality. Approximately 22,000 people use groundwater from individual private wells. There were approximately 3,000 private wells listed in the MOE water well database, spread over the 11,526 km^2 of watershed area. These takings will not induce changes that will extend beyond the surface watershed or subwatershed boundaries, primarily because they are returned to the ground very close to where they are taken.

In the Lakehead SPA, the City of Thunder Bay obtains all of its water supply from Lake Superior and Loch Lomond[15]. The City of Thunder Bay draws 33.6 Mm^3/yr (see section 4.6 for details) of water for a population of 109,016. It is also reported that within the city limit approximately 8% of the population use individual domestic wells for their water demand. Most of the treated wastewater is ultimately discharged into Lake Superior via the lower reach of the Kaministiquia River. In total, twenty-one independent quaternary watersheds (Figure 1) are identified within the Lakehead SPA. There are 13 useable HYDAT stations within the SPA which measure flow and water level for a specified drainage area. To better understand the overall movement of water in the large subwatersheds, our water budget will be calculated on the subwatershed scale (based on the upstream catchment area at streamflow gauge stations) for the conceptual understanding and for Tier 1.

15. The City intends to draw its entire municipal potable water supply from the Lake Superior by the fall of 2007.

5.1.2 Annual Temporal Scale

Hydrologic patterns can be subdivided into four general periods throughout the year. The actual length of each period can differ between particular locations, on an annual basis, and depending on climate.

Period 1 occurs from approximately mid-November to the late part of March. Precipitation is generally in the form of snow (Figure 6) with the thickness of the snowpack increasing. The temperature is generally below freezing (Figure 4). Evaporation from the snowpack is minimal and the recharge to the water table is almost zero, due to the frozen ground. The exception would be for periodic melting events before the ground is completely frozen. In the absence of recharge during this time, groundwater storage may deplete. Streamflow is primarily composed of groundwater discharge.

Period 2 runs from late-March to May. The rise in temperature to above freezing means that most precipitation is in the form of rain. With the melting of the snowpack, this leads to high streamflow and flooding. This is enhanced by the fact that the ground is still frozen in March and early April, and the snowmelt cannot infiltrate. Streamflow runoff is generally the highest in April/May. Percolating water exceeds the field capacity or wet limit of the soil, as suggested by a rise in the water table. In this period, evapotranspiration is not significant because the temperature is still low and plant growth minimal. This is a period of rapid transition from no groundwater recharge to significant groundwater recharge as the ground thaws.

Period 3 occurs from June to September, and is characterized by high temperatures and evapotranspirative uptake due to plant growth. Precipitation occurs in the form of rain, and the majority of it is retained by the surficial soil to satisfy an increasing moisture deficiency created by evapotranspiration. The water only soaks through to the groundwater when the field capacity (wet limit) of soil is exceeded. Limited groundwater recharge can occur during periods of soil moisture deficit through such features as fractures, and by runoff that collects in ditches (or dry kettles and swales) and may reach the water table. However, the water table is steadily declining, as groundwater discharge to streams is greater than recharge to groundwater.

Period 4 occurs from October to early December. Precipitation comes from rain and some snow. The growing season is finished and transpiration is low and evaporation declines as temperatures drop. The soil moisture has returned to field capacity as shown by the water table rise. This is the second major period of the year when groundwater recharge exceeds discharge. The December period more closely resembles Period 1 in the study area, as the frost sets into the ground.

Water availability within the various components of the hydrologic cycle also varies on longer than seasonal scales. For example, there are periodically 2- to 3-year periods of above average precipitation or below average precipitation. The vertical position of the water table can vary by 2 m over a year, but can vary by another 2 m from year to year, depending upon the availability of recharge from precipitation. The climatic information used for the Lakehead SPA water budgeting purposes has been taken over a 25-year period to be representative of average conditions. Water management decisions will be more effective if the water budget is considered within a temporal climatic framework, however site specific water management will have to consider the extremes as well.

5.1.3 Water Budget Approach

In initiating the water budget analyses for the Lakehead SPA watershed, the following approach has been used:

1. Consideration of a long enough period of time, in which storage changes and natural inter-basin flows can be safely assumed to be minimal.
2. Use of average saturation state conditions, where input data and calibration targets represent average climate conditions, average groundwater levels, and average streamflow conditions.
3. Selection of the period of 1970 to 1994, as this is the period where complete streamflow and precipitation records are coincident.

The question then became: What scale one needs to consider when conducting calculations? The answer was: Whatever scale is necessary depending on the application and local sensitivity. For the purposes of this conceptual water balance study, a subwatershed scale was considered large enough to balance the water budget. It is also necessary to understand the saturation state of the study area required for a particular application. As discussed above, streamflow and groundwater levels vary seasonally, but at different rates (streamflow being much more dynamic, and groundwater being attenuated by soil permeability). For this reason a long, 25 year period was deemed appropriate.

To summarize, the design of water budget investigations must incorporate:

a) climate data representative of the geographic area of concern;
b) an area large enough to balance the water budget (a more regional understanding of the flow system must account for estimates of groundwater transfers); and,
c) data from a period covering a range in saturation states, both annually and long-term (drought versus non-drought conditions).

To calculate the simple water balance/budget for the subwatershed, a simple empirical water balance equation will be used to conceptualize the water available and the water being used to supply drinking water in the watershed. The approach is expressed as follows (MOE, 2007):

$$P + Sw_{in} + Gw_{in} + ANTH_{in} = ET + Sw_{out} + Gw_{out} + ANTH_{out} + \Delta S \qquad \textit{Equation (1)}$$

Where:

P	=	Precipitation
Sw_{in}	=	Surface water inflow into the system from outside
Gw_{in}	=	Groundwater inflow into the system from outside
$ANTH_{in}$	=	Anthropogenic or human inputs
ET	=	Evapotranspiration losses
Sw_{out}	=	Surface water outflow from the system
Gw_{out}	=	Groundwater outflow from the system
$ANTH_{in}$	=	Anthropogenic or human removals
ΔS	=	Change in storage (both surface and groundwater)

Equation (1) applies to the entire watershed. Internal to the watershed the precipitation follows a more intricate pathway. The evapotranspiration is derived from surface water and groundwater. The groundwater recharge is only a portion of the actual infiltration, some of it being lost to transpiration. Evaporation comes from both open water ways, canopy interception and temporary puddle storage. Streamflow is made up of both runoff and groundwater discharge (called baseflow). Hydrologists have simplified the Precipitation Equation, expressed at a local scale, to:

$$\mathbf{P = AET+S} \qquad \textit{Equation (2)}$$

Where:
- **P** = Precipitation
- **AET** = Actual Evapotranspiration
- **S** = Surplus (difference between P and AET)

The surplus is further broken down into runoff (RO) and recharge (R) by:

$$\mathbf{S = RO + R} \qquad \textit{Equation (3)}$$

Therefore Equation (2) can be restated as:

$$\mathbf{P = AET+ RO + R} \qquad \textit{Equation (4)}$$

For the preliminary estimation of the water balance components (i.e., actual evapotranspiration, surface runoff and recharge for equation (4) above), the climactic data as determined in Section 4.4.2 was used for the periods 1970-1994 for all stations.

It should be noted that one of the objectives of the water budget exercise in terms of the Source Water Protection Program is to determine the available water in the stream and ground, as well as the water being used for drinking purposes, and water lost through evapotranspiration from the basin. The groundwater recharge (**R**) is available to wells and for ultimate discharge into the watercourses as baseflow. Coupled with runoff (**RO**) these represent the water surplus (**S**) as derived in Section 4.4, and given in Equation (3). For the recharge component of the above equation, it is safely assumed that the recharge water is not leaving the basin. Based on the deflection of this water by the low permeability bedrock, recharge is ultimately discharged to the surface water as baseflow into a stream. The water taken from the basin will be calculated from the Permit to Take Water information.

Attention has been paid to consumptive versus non-consumptive use. The surplus in Equation (3) simply represents the available water to which consumptive use factors may be applied.

5.2 SPA Water Budget Calculations

In calculating the water budget, measured meteorological data and related parameters (like evapotranspiration, water surplus) were interpolated for the Lakehead SPA from values measured (or calculated) at six meteorological stations.

Individual month and annual interpolations were made using an inverse distance weighting technique. Inverse Distance Weighting (IDW) interpolation determines intermediate values by using a linearly weighted combination of the set of observed weather data. The weighting function was selected as the inverse of the square of the distance from the weather stations. Once the interpolation was completed for each parameter, an average value for the study area (or watershed) was determined from mean of the interpolated values over the area of interest. In plain language, the water amounts (expressed as depths for each cell in the grid) were multiplied by the area to derive an annual volume of water for each cell. These were summed and then divided by the entire area to obtain an average value for the entire area of interest.

5.2.1 Precipitation

In Section 4.1, it was noted that climate data for six stations within and surrounding the Lakehead SPA were calculated for the period 1970 to 1994 (see Table 2). The mean annual precipitation for each of these six stations was computed for that time period to agree with the time frame for streamflow records available in the Lakehead SPA.

The point observations of mean annual precipitation for the six climatic stations were entered into the GIS database and the mean annual precipitation was interpolated over the entire study area with IDW (Inverse Distance Weighted) formulation technique as mentioned previously. The interpolated annual precipitation is presented in Map 1 in Appendix B and calculated monthly and annual precipitation for each station is presented in Appendix A. Table 12 presents annual average precipitation estimated by this method for the different watersheds (above specific stream gauges) in the Lakehead SPA. Among the six selected meteorological stations, precipitation ranges from 771 mm/yr to 908 mm/yr (see Table A4 in Appendix A) with an arithmetic average annual precipitation of 850.8 mm/yr. An area weighted interpolated annual average for the entire study area is approximately 843 mm/yr, which is used in the following analyses.

Table 12 was compiled for the twelve watersheds with gauges, with consistent periods of record (1970-1994). As noted previously (Section 4.7.2), a water budget was not completed for gauge stations 02AA001 and 02AB011 because of lack of information and flow measurement inaccuracy.

Table 12. Summary of Water Budget on Sub-watershed Basis

Catchment Name	Area (km^2)	Average Annual Precip (mm)	Average Annual Actual ET (mm)	Average Annual Surplus (mm)	Average Annual Runoff (mm)	Average Annual Recharge (mm)	Annual Stream-flow (mm)	Baseflow (mm)[1]
Kaministiquia River at Outlet of Dog Lake	3397	841.5	507.2	334.4	158.6	175.8	280.3	ND
Kaministiquia River at Kaministiquia	6455	846.4	509.4	337.0	166.0	171.0	287.3	201
Neebing River near Thunder bay Airport	205	798.7	502.7	296.0	135.1	160.9	277.0	140
Shebandowan River at Sunshine	2852	853.4	512.2	341.2	173.9	167.3	266.4	118
Kaministiquia River at Kakabeka Falls Powerhouse	6746	845.3	509.3	336.0	165.9	170.1	254.6	ND
Kashabowie River at Outlet of Kashabowie Lake	514	852.2	511.3	341.0	193.0	148.0	237.6	ND
North Current River near Thunder Bay	116	815.3	504.1	311.2	174.9	136.2	332.0	ND
Current River near Stepstone	499	825.6	504.7	320.9	171.5	149.4	336.3	138
McIntyre River at Thunder Bay	137	804.3	503.4	300.9	139.5	161.3	289.8	ND
McIntyre River above Thunder Bay	80	811.1	504.3	306.8	150.1	156.6	321.5	141
Current River at Stepstone	404	828.0	504.7	323.4	172.4	150.8	306.3	ND
Wolf River at Highway No. 17	716	856.1	501.8	354.2	175.6	178.5	298.5	154

Note: 1. Baseflow was calculated using an automated baseflow separation program described by Arnold et al.*, 1995, ND: Not determined*

5.2.2 Evapotranspiration

Actual evapotranspiration (AET) losses were calculated using the Thornthwaite and Mather (1957) method, which takes into consideration the average monthly temperature and the hours of daylight, as well as soil moisture storage. This method is very widely used in water balance estimates and was chosen here for its simplicity and its ability to directly utilize the available climate data. This method produces an estimate of the potential evapotranspiration (PET) and calculates AET by considering soil moisture storage. Based on the application of this method, AET estimated for the six stations ranges from 496 mm to 524 mm, with an arithmetic average of 506 mm annually. An areally-weighted mean annual AET total of 508 mm is derived and used in Table 13 (found in Section 5.2.4)[16].

As noted in Section 5.2.1, the interpolated annual AET is presented in Map 5 in Appendix B, and calculated monthly and annual AET for each station is presented in Appendix A.

5.2.3 Streamflow

The annual flow volumes (when divided by the catchment area are expressed as equivalent annual depths) for the twelve sub-watershed/catchment areas are provided in Table 12, with the annual mean streamflow variances from 237.6 mm to 336.3 mm. The mean annual water balance for the entire Lakehead SPA is summarized in Table 13 (found in Section 5.2.4). The average stream flow

16. Areally-weighted mean annual AET values were also reported for different watersheds in the SPA in Table 12.

for the entire watershed in this exercise was calculated on a pro rata basis: that is, the flow rate of each individual watershed was divided by the corresponding watershed area, all of which were summed and then multiplied by the total area of the watershed.

5.2.4 Summary of the Lakehead SPA Water Budget

Table 13 below provides a summary of the integrated water budget for the entire Lakehead SPA area. The description column of the table provides some insight as to assumptions and limitations of the analysis.

Table 13. Summary of the Conceptual Water Budget of the Lakehead SPA (Total Drainage Area: 11,526 km^2)

Parameters	Annual Depth (mm)	Annual Volume (106 m^3)	Description
Precipitation	842.8	9,714	➢ Interpolated and area averaged annual mean precipitation. Precipitation calculated by arithmetic average of the six stations is 850.8 mm
Actual Evapotranspiration (AET)	508.0	5,855	➢ Interpolated and area averaged annual average AET. (Arithmetic average of AET calculated using Thornthwaite and Mather (1957) is 506.2 mm/yr)
Surplus	334.8	3,859	➢ Spatially distributed average value. ➢ (Arithmetic average value is 344.6 mm/yr)
Recharge	167.8	1,934	➢ Determined in GIS platform
Runoff	167.0	1,925	➢ Determined in GIS platform
Mean Streamflow	290.6	3,350	➢ Area weighted mean annual streamflow
Max Streamflow	748.4	8,626	➢ Area weighted maximum annual streamflow
Min Streamflow	62.3	718	➢ Area weighted minimum annual streamflow
Consumptive SW Takings	5.3	61.2	➢ According to PTTW Database Provided in Table 14--. See also Table 10
Non-consumptive SW Takings	54.6	629	➢ Total Surface water takings-consumptive surface water takings
Consumptive Groundwater Takings	0.32	3.7	➢ According to PTTW database provided in Table 14 and including water takings from private wells for about 22,000 people consuming water at a rate of 335 L/day/capita
Non-consumptive GW Takings	0.69	8.0	➢ Total groundwater water takings-consumptive groundwater takings

To simplify the interpretations of Table 13, the following narrative is meant to assist the reader. It is expressed solely in terms of average annual amounts. All values are expressed in terms of a volume of water, expressed in “million cubic metres per year (Mm^3/yr)”.

A total of 9,714 Mm^3/yr falls as precipitation, of which 5,855 Mm^3/yr is returned to the atmosphere by evapotranspiration (that is, about 60% is lost). This leaves 3,859 Mm^3/yr as a surplus, available for runoff or recharge. By way of comparison, the average streamflow out of the watershed is 3,350 Mm^3/yr, which is made up of both runoff and baseflow. There is about a 13% difference in these values, with the measured streamflow being lower than the calculated surplus. This difference is considered to be an acceptable margin of variance, given the uncertainties in parameter estimation, measurement error, and meteoric distribution of precipitation.

The surplus of 3,859 Mm^3/yr is partitioned between runoff and recharge in the following way. About 50% of the surplus, or 1,925 Mm^3/yr directly runs off, where as the remaining 1,934 Mm^3/yr infiltrates into the ground and recharges the water table (expressed as a Baseflow Index this is 1,925/3,859 = 0.50 for the entire watershed).

The present use of this surplus total of 3,859 Mm^3/yr is 702 Mm^3/yr, of which 637 Mm^3/yr (SW: 629 Mm^3/yr; GW: 8.0 Mm^3/yr see also Table 14 for details) is comprised of non-consumptive uses[17.] As previously defined, non-consumptive uses involve the use of the water that is returned to the local watershed of origin in a reasonable time frame. Consumptive uses do not return this water directly to the watershed of origin. The consumptive use, including Thunder Bay's withdrawal only from Loch Lomond), is about 65 Mm^3/yr (SW: approximately 61 Mm^3/yr; GW: approximately 4 Mm^3/yr: see also Table 14 for details), or 1.68% of the surplus. The total use (consumptive and non-consumptive) is about 18% of the surplus.

Table 14. Consumptive Surface Water and Groundwater Use/Demand in the Lakehead SPA

Water Use	Water Takings (Mm^3/yr)	Consumptive Factor	Consumptive Use (Mm^3/yr)
Surface Water			
Total Surface Water Takings according to PTTW	690.36		
Permitted Takings: Power Generation, Dam/Reservoirs	480.36	0.0	0.0
Permitted Takings: Other- Industrial	160.74	0.25	40.18
Permitted municipal water takings (only from Loch Lomond)	10.22	0.2	2.04
Permitted Takings: Agriculture (Irrigation, Livestock)	21.05	0.9	18.95
Total Consumptive Surface Water Use/Demand			**61.17**
Groundwater			
Total Groundwater Takings according to PTTW	**11.68**		
Permitted Takings: Other- Industrial	**11.35**	**0.25**	**2.84**
Permitted Takings: Municipal Water Supply	**0.09**	**0.20**	**0.02**
Permitted Takings: Agriculture (Irrigation, Livestock)	**0.24**	**0.90**	**0.22**
Water Takings: Private wells	**2.69**	**0.25**	**0.67**
Total Consumptive Groundwater Use/Demand			**3.75**

5.3 Water Use Percentage

As per the Interim Water Budget Technical Direction document, the percentage of water used in the watershed region was also calculated. Table 13 gives the summary of the conceptual water budget of the Lakehead SPA. Stream flow volumes are compared to the water use to estimate the "Percent Of Water Use" for the whole SPA and these are presented in Table 15.

17. For the purpose of this summary, both ground and surface water sources are considered together.

Table 15. Stream Flow Volume Versus Surface Water Use Scenarios

Streamflow	Volume (Mm^3/yr)	Water Use[1] (Mm^3/yr)	% Water Use
Mean Streamflow Volume	3,350	61.17	1.83
Minimum Streamflow Volume	718	61.17	8.52
Maximum Streamflow Volume	8,626	61.17	0.71

Note: 1. Consumptive surface water use/demand (for details see Table 14)

Table 15 shows that on average, consumptive surface water demand is 1.83% for the entire study area and is used for different purposes, including drinking water. These values are based on the PTTW database for surface water takings and include only the actual water takings from Loch Lomond as reported in Table 14. Surface water takings from Lake Superior are not considered in this calculation as the water is not taken from the watersheds. These consumptive water demands are also compared to the minimum and maximum stream flow volumes. The percentage of water use versus the water available will be assessed using the Tier 1 Water Quantity Risk Assessment guidelines. These scenarios are presented to understand the water use, with respect to the water available, which is very low. This information will be used in Section 6 to assess the water demand against the supply (taking into account a reserve) to determine whether the watershed is under a significant, moderate or low stress.

Overall, the water balance summary for the Lakehead SPA illustrates that the flow at the selected long-term gauge stations appears reasonable with respect to the climate data on an annual basis. It also indicates that the consumptive water use, on average, in the watershed is relatively small (only 1.83%). For the worst-case scenario of a minimum stream flow volume of 718 Mm^3/yr, the water use is still only approximately 8.5% of the water available.

Table 16 provides a groundwater use scenario and compares consumptive groundwater demand/use with groundwater recharge. Annual groundwater recharge is calculated based on the estimated annual average recharge of 167.8 mm, determined in GIS, and multiplied with the area where most of the wells are concentrated. This area is estimated to be about 4,395 km^2. According to the PTTW database and based on the assumption that approximately 22,000 people use 335 L/day/capita, the total consumptive groundwater demand in the entire Lakehead SPA is about 3.75 Mm^3/yr, which represents less than 1% of recharged water in the selected portion of the study area. These are just estimated values. Further detailed studies on the delineation of actual recharge area are required in order to more accurately compare groundwater recharge with groundwater use.

Table 16. Groundwater Recharge Versus Groundwater Use Scenarios

Parameters	Amount
Recharge Area (km^2)	4,395
Recharge Rate (mm/yr)	167.8
Total Groundwater Recharge (Mm^3/yr)	737.5
Consumptive Groundwater Use (Mm^3/yr)	3.75
% Consumptive Groundwater Use	0.51

5.4 Summary

The conceptual understanding can be summarized as follows:

1. Surface water plays a vital role in the watershed region and most of the drinking water is supplied from surface water sources. Lake Superior is the only source of municipal drinking water in the City of Thunder Bay area after the decommissioning of the Loch Lomond water intake pipe and water filtration plant. However, Lake Superior does not constitute a part of the watershed.
2. The geologic framework of the area governs the surface and subsurface groundwater pathways. The area is dominated by shallow permeable soils overlying low permeability bedrock. Infiltrating water recharges the local water table and is deflected by the bedrock to local watercourses, wetlands and streams and finally to Lake Superior. Maximum determined overburden thicknesses occur in the City of Thunder Bay near the mouth of the Kaministiquia River.
3. Water movement is dominantly by surface water, flowing south and east towards Lake Superior.
4. Groundwater studies were conducted in 2005 for the LRCA covering the City of Thunder Bay and extended from Whitefish Lake in the west to the head of Black Bay in the east, Lake Superior in the south, to Dog Lake in the north. These studies, however, did not cover the whole SPA region. The hamlet of Rosslyn Village within the Municipality of Oliver-Paipoonge uses strictly groundwater for their Municipal Drinking Water System, obtaining it from a basal sand and gravel aquifer approximately 5 m thick immediately above the bedrock. Many rural residents rely on residential private wells, from groundwater.
5. It is expected that the Loch Lomond supply will be converted to industrial supply and power generation by the year 2008. Discharge of the used water would be into the lower reaches of the Kaministiquia River. This would minimize the water transfer from the watershed and thereby reduce the overall water demand in the Lakehead SPA
6. From a water quantity perspective, the amount of water moving through the watershed greatly outweighs present and future anticipated uses and the quality is reliable.
7. Water management decisions will be more effective if the water budget is considered within a temporal climatic framework, however site specific water management will have to consider the climatic extremes as well.

6. Tier 1 Water Budget and Water Quantity Stress Assessment

6.1 Introduction

This Water Quantity Stress Assessment process is dependent on the water budget and provides a framework to evaluate the sustainability of drinking water supply systems in the context of the local watershed. The objective of the framework is to help managers identify drinking water sources that may not be able to meet current or future demands. Those sources identified to have potential problems meeting demand will be subject to risk management initiatives designed to help reduce demand and to make more efficient use of available supplies.

Water Budgets and the linked Water Quantity Stress Assessment are those components of the Assessment Report where water supply and demand are quantified, where water movement within the watershed is understood and where the sustainability of the Province's Municipal drinking water sources are evaluated. The level and complexity of water budget assessments required in any specific watershed will depend on a number of factors, in particular water-taking or water-quality stresses. The stress assessment components (the Water Quality Stress Assessment and Water Quantity Stress Assessment) are both strongly linked to water budgeting and, at successive stages, will dictate the need to loop back for additional higher level water budget investigations if necessary.

The Province has prescribed a minimum level of effort - that all regions within the Province need a basic understanding to effectively address issues and prepare source water protection plans. This minimum level of effort requires each region to complete a Conceptual Understanding and a Tier 1 Simple Approach for all watersheds in the Source Water Protection Area.

In the Tier 1 Simple Approach, estimates are made of the various climate components, including precipitation, evapotranspiration, runoff and recharge. These are distributed within the watershed according to land use, surficial geology, (and perhaps slope). The estimates of the components are performed using either simple numerical analysis or, where necessary, GIS techniques are used to assist with this process. For the watersheds of the Lakehead SPA, which contain a few small communities, two municipal drinking water supplies (one surface water and one groundwater), minimal growth, and small land use change, the Tier 1 Simple Approach is all that is required. Within the Lakehead SPA, the pathways that the water takes and the connections between groundwater and surface water are not significant in managing the water quantity and quality stresses on drinking water supplies.

This Tier 1 Water Quantity Stress Assessment analysis largely utilized the available data, collected and analyzed in the Conceptual Understanding phase, to evaluate the cumulative stress within each watershed/subwatershed. As a part of the process, an overall water takings stress limit within the Lakehead SPA was evaluated. Accordingly, the water demand was assessed against the water supply to determine whether the watershed was under significant, moderate or low stress. The Water Demand for the watersheds of the Lakehead SPA was estimated from the Ministry of the Environment Permit To Take Water (PTTW) for both surface water and groundwater (see Map 15). The surface water supply was determined from the available streamflow data (1970-1994). The municipal groundwater supply for the Rosslyn Village was calculated from the available groundwater study report.

A water quantity stress assessment is conducted for the Loch Lomond water supply plant. This is a surface water intake that is located on Loch Lomond (see Map 16). Another water quantity stress assessment is conducted for the Rosslyn Village municipal water well (see Map 15) to determine if there are any concerns regarding the sustainability of the Municipal drinking water supply for the Rosslyn Village. Some parts from the Conceptual Water Budget has been used and may be repeated while evaluating water quantity stress assessment in this section.

6.2 Water Budget Elements

The Tier 1 water budget and stress assessment is designed to screen out the unstressed watersheds, utilizing existing information collected during the Conceptual Understanding phase. The level of water budget understanding necessary in the Tier 1 level is a simple approach that estimates the various elements of the hydrologic cycle, including precipitation (P), actual evapotranspiration (AET), recharge (R) and runoff (RO). These were calculated during the Lakehead SPA Conceptual Water Budget Understanding phase using climate data (1970-1994). The recharge was estimated using the GIS techniques presented in Section 4.4.2.

The estimated/calculated P, AET, R and RO were distributed within the watershed according to land use, surficial geology and slope. GIS techniques were used to assist with this process. This approach includes a soil moisture budget or climate estimating procedure using established methods. The calculations were conducted on a monthly basis to allow for monthly and annual summations to be used in the Tier 1 stress assessment. Water surplus was calculated (precipitation minus actual evapotranspiration) according to the methodology of Thornthwaite and Mather (1957). This calculation took into account monthly mean temperature and precipitation for six climate stations within or near the Lakehead SPA. The next step was to calculate runoff and infiltration according to the coefficient method outlined by the Ministry of the Environment (1995) using soil characteristics, topography and vegetative cover.

6.2.1 Water Supply Estimation

6.2.1.1 Surface water Supply Evaluation

The main source of Municipal water supply in the Lakehead SPA area is Lake Superior and Loch Lomond. However, Lake Superior is not considered a part of the Lakehead SPA and given its tremendous storage volume is not considered in the analysis. Currently Loch Lomond supplies municipal drinking water from the Loch Lomond water treatment plant. As mentioned in the Conceptual Understanding of Water Budget, the City of Thunder Bay intends to draw its entire potable municipal water supply from Lake Superior by the fall of 2007. Thereafter, the Loch Lomond water supply is available for other uses at the discretion of the stakeholders, and subject to appropriate regulatory approval.

There are two discharge points for Loch Lomond. The main discharge is the Lomond River,. The former water taking from the lake to the City of Thunder Bay is the other one. For this evaluation the water feeding Loch Lomond must be determined. Presently, there is no gauge station for the measurement of streamflow at Loch Lomond. The gauge station 02AB008 located on Neebing River at Thunder Bay is identified as the closest to Loch Lomond. Therefore, streamflow (or water supply) at Loch Lomond is estimated using the data from gauge station 02AB008 and applying the pro rata area of the two watersheds. This calculation involves determining the monthly average streamflow at 02AB008 from the years 1970-1994. The calculated monthly average data are multiplied by the ratio of the catchment area of Loch Lomond to the catchment area of Neebing Watershed.

Figure 16 depicts the mean monthly flow distribution at Loch Lomond. From Figure 16 it is seen that the highest flow occurs in April with a value of approximately 2.53 m^3/s, whereas the lowest flow month is February with a mean flow of approximately 0.06 m^3/s. The mean annual flow at Loch Lomond is 0.68 m^3/s. From the flow distribution, it appears that the highest flow in Loch Lomond or alternatively at gauge 02AB008, is associated with snowmelt in the spring, whereas the lowest flow occurs in January-February when most of the water remains frozen. It must however be noted that low discharge in February may not be a limiting factor given the available storage in the lake and replenishment in the spring.

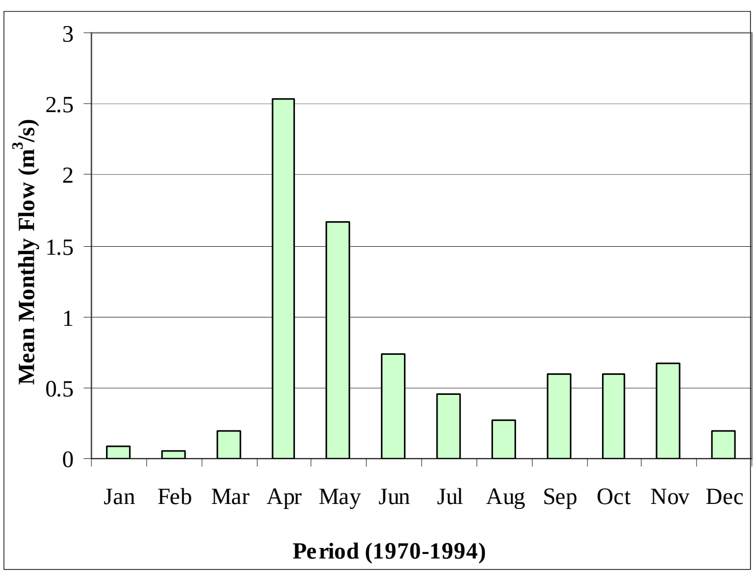

Figure 16. Mean Monthly Flow (Water Supply) at Loch Lomond

6.2.1.2 Groundwater Supply Evaluation

Within the Lakehead SPA, the only groundwater-based municipal water supply system is in Rosslyn Village. There are two wells in the Rosslyn Village; one is the production well and the second is used as standby. The following paragraphs summarize the results of a groundwater modelling study on the Rosslyn Water Well system study conducted by R.J. Burnside in association with Amec Earth & Environmental (Burnside and Amec, 2005).

According to the groundwater study report, the overburden material at the site is identified as being primarily comprised of surficial sands, till, silty clay, and basal sand and gravel units. The subject wells are reportedly screened in the water bearing basal sand and gravel unit. The basal sand and gravel unit was interpreted to extend over a distance of about 1,200 m to 1,800 m away from the Kaministiquia River in a northwesterly direction. The clay unit, overlying the aquifer, was interpreted to extend for a distance of about 2,000 m from the river. Undifferentiated till deposits were interpreted to extend down to the bedrock surface north of the surficial clay zone. Total thickness of the overburden material in the Rosslyn Village area is about 40 m. Bedrock underlying the overburden material is described as sedimentary rock of the Animikie Group. According to the pumping test data analyzed by Waters Environmental Geosciences Ltd. (Waters, 2003) transmissivity of the basal sand and gravel aquifer is expected to be about 66 m^2/d. Based on this transmissivity value and taking into account that the basal unit thickness is about 3 m to 6 m, the hydraulic conductivity of the basal unit is expected to be in the order 10^{-4} m/s. Apparent transmissivity of the bedrock aquifer was estimated to be in the range of 0.08 m^2/d to 82.3 m^2/d, with a geometric mean of 2.8 m^2/d (Waters, 2003). The average penetration depth of wells in the area into this aquifer is about 37 m.

The groundwater flow direction in the shallow and deep overburden and bedrock aquifers was interpreted to be primarily south to southeast, towards the Kaministiquia River. Close to the river, hydraulic heads in the shallow overburden appear to be higher than in the deep system (basal unit and bedrock aquifer). This can be attributed to the fact that water level in the Kaministiquia River (about 195 mASL) appears to be below the bottom of the shallow sand unit. Further north of the river there is no indication of significant differences between hydraulic heads in various aquifer units.

Recharge of the aquifer within the study area was assumed to be coming from precipitation only. Note that recharge of the deep aquifer zones is expected to occur primarily in the undifferentiated till zone located in the northern portion of the study area (Burnside and Amec, 2005*).*Groundwater from both overburden and bedrock units is expected to discharge into the Kaministiquia River and into several permanent streams located north of Rosslyn Village.

Some of Rosslyn Village[18] is supplied from a Municipal groundwater well under MOE's PTTW (# 00-P-6073) with the maximum allowable water takings of 124.4 m^3/day for each pump. Based on a groundwater flow model conducted for the Rosslyn Water Supply Well field, the total groundwater supply or inflow in the basal sand and gravel unit and further upgradient is about 6,431 m^3/day most of which comes from recharge.

6.2.2 Water Demand Estimation

Within the current methodology, water demand will only relate to water taken as a result of an anthropogenic activity (e.g., municipal supply water takings, private water well takings as well as other permitted takings), that is, a consumptive use. In a strict sense, consumptive water demand refers to water taken from surface or groundwater and not returned locally in a reasonable period of time.

Referring to the Conceptual Water Budget part of this report, the consumptive surface water and groundwater use/demand was quantified based on the MOE's PTTW in the Lakehead SPA (see Table 14). The quantities of permitted water takings as reported in the PTTW database are generally presented as maximum takings over a period of time and do not usually reflect the actual takings. Consequently, using permitted water takings to estimate water demand generally far overestimates the actual demand. For the purpose of the more detailed Tier 1 analysis, the present water demand for surface or groundwater in the Lakehead SPA is calculated based on the actual water takings from the watershed.

6.2.2.1 Surface water Demand

The actual monthly surface water taking from Loch Lomond at the Loch Lomond Water Treatment Plant in the year 2002 is shown in Table 17 and in Figure 17. The 2002 monthly water takings data are used, as it was not possible to obtain the most current water supply data from the treatment plant.

Table 17. Summary of Quantity of Water Supplied by the Loch Lomond Water Treatment Plant in the Year 2002 (Data source: City of Thunder Bay website)

Period	Water Takings (m^3/month)	Average Daily Takings (m^3/day)
January	848,470	27,370
February	767,820	27,422
March	849,250	27,395
April	868,980	28,966
May	942,950	30,418
June	922,840	30,761
July	946,330	30,527
August	900,700	29,055
September	850,370	28,346
October	872,170	28,135
November	684,690	22,823
December	698,230	22,524
Total (m^3/yr)	**10,152,800**	
Permitted Water Takings (m^3/yr)	**28,207,930**	

The total actual water takings are about 10 Mm^3/yr, which is about 36% of the maximum allowable takings according to the PTTW database. Table 17 also shows that the maximum monthly water takings is in the month of July.

18. Some residents choose to use their own wells.

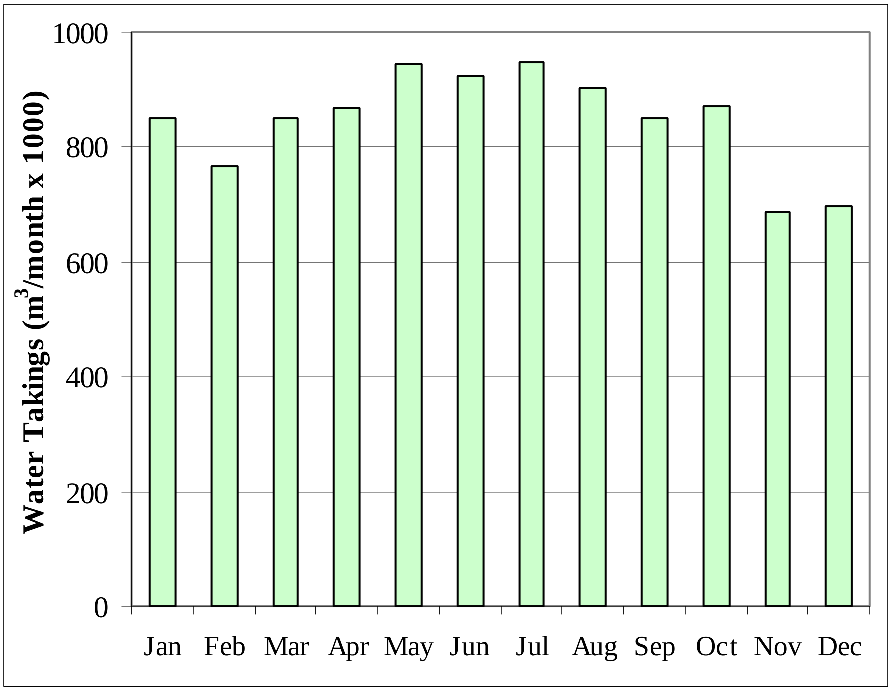

Figure 17. Monthly Water Takings from Loch Lomond Water Treatment Plant

6.2.2.2 Groundwater Demand

Calculated water takings from the Rosslyn municipal groundwater supply well are provided in Table 19 and graphically shown in Figure 18. As only daily average water takings data (35 m^3/day, Burnside and Amec, 2005) were available for the Rosslyn Water Supply Well, monthly water takings were determined using a comparison to the monthly water takings patterns at Loch Lomond Water Treatment Plant and using the following procedure:

a) the actual monthly takings from the Loch Lomond Water Treatment Plant were summed to get an annual total of 10,152,800 m^3(Table 18);

b) This annual total was divided by 12 to get an average monthly taking of 846,067 m^3 (Table 18);

c) the actual given monthly takings (column b in Table 18) were divided by the arithmetically averaged monthly takings (b, above) to get a coefficient for each month (column c in Table 18); and

d) The coefficient, which is variable for each month, was then multiplied by the given monthly average takings from the Rosslyn Water Supply Well to get monthly water takings for the Rosslyn Water Supply Well (Table 19).

Table 18. Estimation of Coefficient Used for Calculating Monthly Water Takings from the Rosslyn Water Supply Well

Period	Loch Lomond Water Takings (m^3/month)	Coefficient
January	848,470	1.003
February	767,820	0.908
March	849,250	1.004
April	868,980	1.027
May	942,950	1.115
June	922,840	1.091
July	946,330	1.119
August	900,700	1.065
September	850,370	1.005
October	872,170	1.031
November	684,690	0.809
December	698,230	0.825
Total (m^3/yr)	**10,152,800**	
Average Monthly Taking (Total/12)	**846,067**	

The annual water demand for the Rosslyn Village is approximately 12,800 m^3 with the highest water demand observed in the months of May and July.

Table 19. Summary of Water Takings Calculated for the Rosslyn Water Supply Well

Period	Days of the Month	Monthly Water Takings (m^3/month)*		Coefficient **		Monthly Water Takings (m^3/month)***
January	31	1085	**X**	1.003	**=**	1088
February	28	980	**X**	0.908	**=**	889
March	31	1085	**X**	1.004	**=**	1089
April	30	1050	**X**	1.027	**=**	1078
May	31	1085	**X**	1.115	**=**	1209
June	30	1050	**X**	1.091	**=**	1145
July	31	1085	**X**	1.119	**=**	1214
August	31	1085	**X**	1.065	**=**	1155
September	30	1050	**X**	1.005	**=**	1055
October	31	1085	**X**	1.031	**=**	1118
November	30	1050	**X**	0.809	**=**	850
December	31	1085	**X**	0.825	**=**	895
Total (m^3/yr)		**12,787**				

Notes: * *calculated by multiplying the reported average daily water takings (35 m^3/day) with the days of a corresponding month*

** *coefficient was calculated based on the procedure described above*

*** *monthly water takings in column three multiplied with the coefficients in column five*

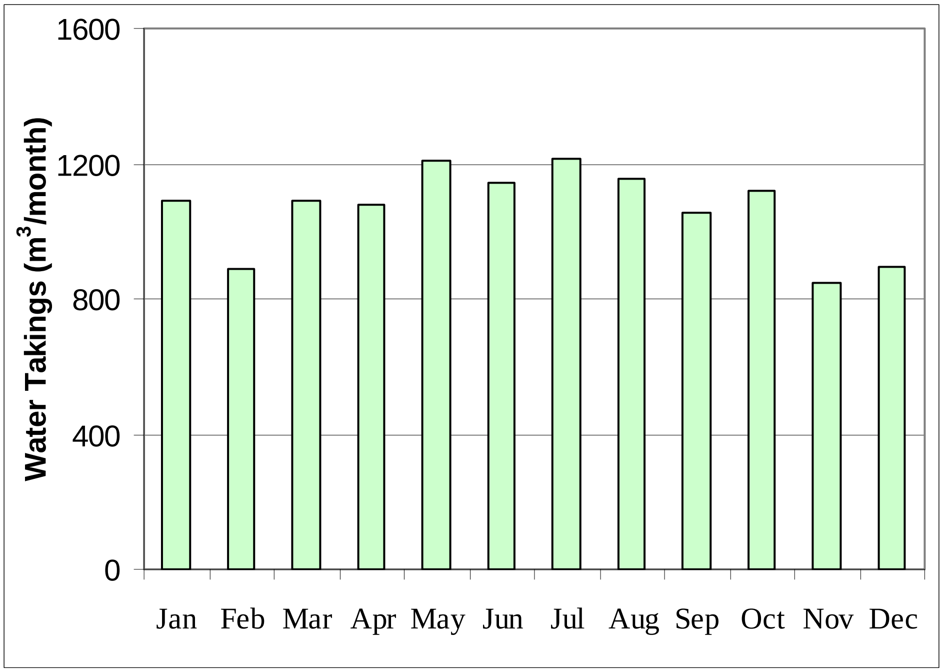

Figure 18. Calculated Monthly Water Takings from the Rosslyn Water Supply Well

6.2.3 Water Reserve Estimation (Surface Water and Groundwater)

Water reserve is an estimate of the amount of streamflow that needs to be reserved to support other uses of water within the watershed including both ecosystem requirements (instream flow needs) as well as other human uses, both future permitted uses and current and future non-permitted uses.

For the Tier 1 assessment of the Loch Lomond watershed (surface water source) in the Lakehead SPA, the water reserve will be estimated using the nearby streamflow data for the Neebing River at Thunder Bay gauge stations (1977-1994). This will estimate the monthly water reserve in Loch Lomond, which is stipulated by the MOE Guidance Module 7 as 10% of the total supply. For groundwater, the reserve quantity is also estimated as 10% of the estimated groundwater supply (recharge plus groundwater inflow). The water reserve in either case will be used as a threshold level in comparison to the percentage water demand.

6.2.4 Water Budget Summary

In addition to providing an integrated water budget summary for the entire Lakehead SPA, water budgets were calculated for twelve subwatersheds under the Conceptual Water Budget section of the report. As the watershed region is composed of numerous lakes and wetlands and its soil structure is mostly of silt, sand and gravel, there is a significant interaction between surface water and groundwater in terms of baseflow contribution to the streams. For example, for the Kaministiquia River Watershed at Kaministiquia, a total of about 50% of surplus water was identified as baseflow.

Considering Loch Lomond's water use in the future, a detailed water budget analysis for Loch Lomond was conducted for its contributing watershed as a part of Tier 1 analysis. The total contributing catchment area for Loch Lomond (including the lake itself) is estimated to be 76.7 km^2. The mean monthly and annual water balances for Loch Lomond are summarized in Table 20.

As shown in Table 20, the annual total precipitation applied to Loch Lomond is approximately 63.5 Mm^3. Approximately 39 Mm^3 (or approximately 61% of annual precipitation) is lost through evapotranspiration. Approximately 25 Mm^3 (or approximately 39% of annual precipitation) of water remains as surplus. The amount of surplus is assumed to reach the lake through groundwater flow and runoff. Out of 25 Mm^3 of surplus water, approximately 10 Mm^3 has typically withdrawn from Loch Lomond for municipal water supply. As mentioned previously in Section 4, the total stream flow should theoretically be equal to the surplus, given that groundwater storage changes are negligible over longer periods of time. In this watershed, estimated surplus matches with streamflow within ± 15%. A breakdown of water surplus, streamflow, and water takings on a monthly basis is shown on Figure 19 graphically.

Table 20. Monthly and Annual Water Budget for the Loch Lomond Watershed

Month	Precipitation (Mm^3)	Actual ET (Mm^3)	Surplus (Mm^3)	Streamflow [1] (Mm^3)	Water Takings (Mm^3)
January	4.05	0.00	4.05	0.24	0.85
February	2.60	0.00	2.60	0.14	0.77
March	3.90	0.00	3.90	0.51	0.85
April	3.78	1.55	2.23	6.56	0.87
May	5.89	5.39	0.50	4.47	0.94
June	6.59	7.89	Deficit (-1.30)	1.92	0.92
July	7.42	9.11	Deficit (-1.69)	1.21	0.95
August	6.71	7.59	Deficit (-0.88)	0.73	0.90
September	7.24	5.02	2.22	1.54	0.85
October	5.36	2.18	3.18	1.61	0.87
November	4.95	0.00	4.95	1.74	0.68
December	5.01	0.00	5.01	0.53	0.70
Total	**63.50**	**38.74**	**24.76**	**21.20**	**10.15**

Note: 1. Mean streamflow data from Neebing River near Thunder Bay Airport (02AB08) and later calculated on areal proportional basis.

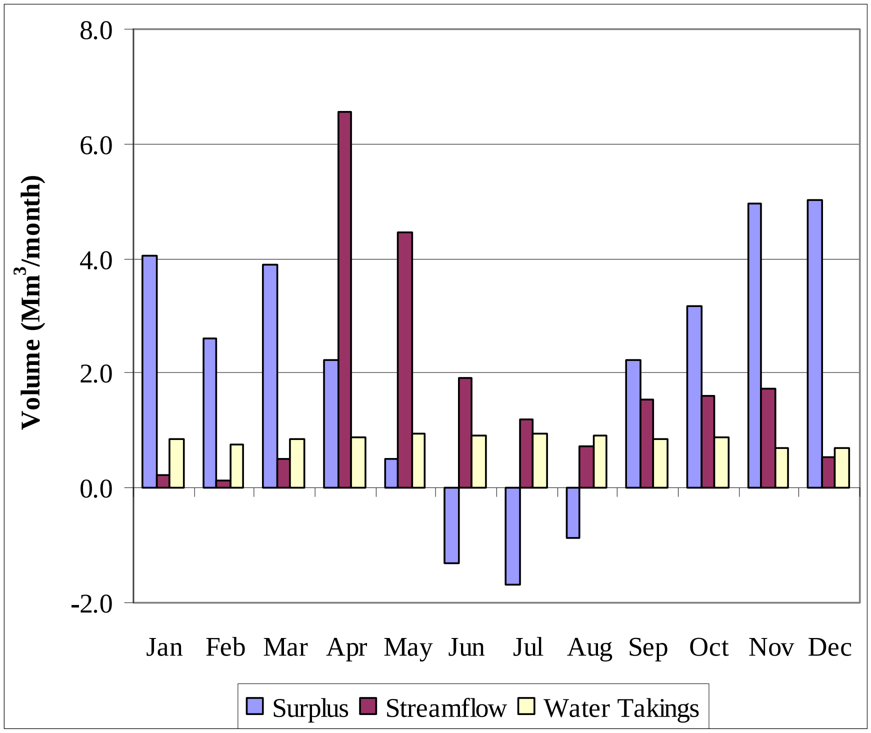

Figure 19. Water Surplus, Streamflow and Water Takings in the Loch Lomond Watershed

When comparing water surplus with water takings, it appears that May through August are the months when water takings exceed the surplus and theoretically, lake discharge goes to zero and the water levels begin to decline. This is not observed in practice indicating that some of the recharge from earlier months may be reaching the lake as baseflow, supplementing the water supply.

6.3 Subwatershed Stress Assessment

The Tier 1 stress assessment is designed to efficiently screen out safe subwatersheds and highlight those where the degree of stress warrants refined water budget efforts for stress characterization. The stress assessment evaluated the ratio of the consumptive water demand for permitted and non-permitted users to the available water supplies, minus water reserves within the subwatershed. For groundwater, a calibrated numerical model exists and was used for the Tier 1 stress assessment, whereas for the Loch Lomond surface water source, available existing data were used for the stress assessment.

At Tier 1, for each drinking water supply, two scenarios were evaluated: i) current conditions; and ii) 25-year future demand.

The % Water Demand was evaluated independently for groundwater and surface water. The subwatershed stress level was then determined based on the greater level of stress evaluated for either the groundwater or surface water system in question.

Table 21. Tier 1 Stress Assessment Scenarios (MOE, 2007)

Time Period	Average Annual % Water Demand	Highest Monthly % Water Demand
Current Conditions	Groundwater Supplies	Groundwater and Surface Water Supplies
25-Year Future Demand	Groundwater Supplies	Groundwater and Surface Water Supplies

Table 21 presents the list of scenarios for groundwater and surface water supplies. As this table indicates, groundwater systems are evaluated for both average annual and monthly conditions, whereas surface water conditions are evaluated monthly. The reason for this is that the rate of groundwater flow is so slow that there are only subtle differences between months, whereas monthly flow in surface water varies widely.

Based on percentage Water Demand (which will be compared to prescribed thresholds, discussed below), each subwatershed was assigned a stress level for groundwater and for surface water. Based on MOE Module 7, those subwatersheds receiving a low level of stress will require no further water budgeting or water quantity stress assessment work. Monitoring is still anticipated to occur within these areas, and databases should be maintained in an up-to-date manner. This is considered necessary in case future conditions change within the watershed, and the stress needs to be reassessed.

Tables 22 and 23 identify the Tier 1 stress thresholds for surface and for groundwater, respectively.

Table 22. Tier 1 Stress Thresholds (Surface Water) (MOE, 2007)

Surface Water Quantity Stress Level Assignment	Maximum Monthly % Water Demand
Significant	> 50%
Moderate	20% - 50%
Low	<20%

Table 23. Tier 1 Stress Thresholds (Groundwater) (MOE, 2007)

Groundwater Quantity Stress Assignment	Average Annual	Monthly Maximum
Significant	> 25%	> 50%
Moderate	> 10%	> 25%
Low	0-10%	0-25%

For surface water, stress categories are assigned to each subwatershed by comparing their maximum calculated monthly stress to the thresholds listed above. These thresholds apply to both current and future conditions. The resulting surface water stress level assignment is the maximum of the current and future assessment values.

For groundwater, the thresholds for monthly maximum conditions are higher than average annual thresholds because groundwater systems can typically tolerate short-term water demands that may not be sustainable over the entire year. The resultant groundwater stress level assignment is the maximum of the current and future assessment values for both annual and monthly conditions.

6.3.1 Inland Surface Water Source – Loch Lomond Water Supply

The only municipal water supply in the Lakehead SPA was Loch Lomond, which will soon be decommissioned. Despite this, a surface water stress calculation was performed for Loch Lomond considering that its water is still in use.

The following equation was used to calculate water quantity stress. However, for surface water, the annual average flow does not have practical significance and the percentage Water Demand is calculated on a monthly basis:

$$\%\ \text{Water Demand (Surface Water)}\ \frac{Q_{DEMAND}}{Q_{SUPPLY} - Q_{RESERVE}} \times 100$$

The terms of the equation were determined as follows:

- ***Q_{Supply}* (Surface Water Supply):**
  Calculated on monthly basis using the measured streamflow data (1970-1994) of a nearby station and applying the pro rata of catchment area of two subwatersheds. Monthly lake reserve is calculated based on a lake area of 20 km^2, and a lake depth of 10 m, and dividing the total volume by 12 (see also Section 6.2.4);
- ***Q_{Demand}* (Surface Water Demand):**
  Taken as the estimated water takings from Loch Lomond in the latest year available, 2002;
- ***$Q_{Reserve}$* (Surface Water Reserve):**
  Calculated as 10 % of the lake reserve;
- ***% Surface Water Demand*:**
  Calculated using the expression mentioned above.

Table 24 provides monthly percentage surface water demand calculated using the above expression. Also shown in Table 24 is the monthly stress level assignment based on the threshold values listed in Table 22.

Table 24. Summary of Tier I Surface Water Stress Assessment for the Loch Lomond

Month	Streamflow (Mm^3)	Lake Reserve (Mm^3)	Inflow into the Lake (Mm^3)	Water Takings (Mm^3)	% Water Demand	Stress Level Assignment
January	0.24	16.67	16.91	0.85	5.57	Low
February	0.14	16.67	16.81	0.77	5.07	Low
March	0.51	16.67	17.18	0.85	5.48	Low
April	6.56	16.67	23.23	0.87	4.03	Low
May	4.47	16.67	21.14	0.94	4.84	Low
June	1.92	16.67	18.58	0.92	5.45	Low
July	1.21	16.67	17.88	0.95	5.84	Low
August	0.73	16.67	17.40	0.90	5.73	Low
September	1.54	16.67	18.21	0.85	5.14	Low
October	1.61	16.67	18.28	0.87	5.25	Low
November	1.74	16.67	18.41	0.68	4.09	Low
December	0.53	16.67	17.20	0.70	4.50	Low

Presently (based on the information provided to calculate the percentage water demand), the maximum monthly surface water demand of approximately 6% is in the month of July. The stress level associated with the percentage water demand is assigned to LOW in accordance with the thresholds as listed in Table 22. Future water demand is not calculated, as the potential water use from the lake is not known and indeed the existing use is expected to stop by the fall 2007.

6.3.2 Groundwater Source – Rosslyn Water Supply Well

In the Lakehead SPA, the only groundwater based municipal water supply system is in the Rosslyn Village in the Municipality of Oliver Paipoonge. Therefore, a groundwater stress calculation is performed and a stress level is assigned for the Rosslyn Village Subwatershed. The Tier 1 groundwater water stress assessment for the Rosslyn Village subwatershed needed to determine the following terms/parameters by using a simple calculation:

$$\textit{\% Water Demand (Groundwater)} \ \frac{Q_{DEMAND}}{Q_{SUPPLY} - Q_{RESERVE}} \times 100$$

- Q_{Supply} ***(Groundwater Supply):***
  Obtained as the combination of groundwater recharge plus the groundwater inflow into the watershed from the calibrated 3-D groundwater flow model developed for the subject well (Burnside and Amec, 2005);
- Q_{Demand} ***(Groundwater Demand):***
  Calculated as the estimated average annual and monthly rate of groundwater takings in the subwatershed. For monthly calculations the average annual recharge is divided by 12 to obtain the monthly water demand;

- **$Q_{Reserve}$ (*Groundwater Reserve):***
  Calculated as 10% of the groundwater recharge (supply);
- ***% Water Demand:***
  Groundwater in the subwatershed is calculated using the expression described above.

The above terms and calculations for Tier 1 of the Rosslyn Village groundwater stress assessment have been summarized in Table 25 below:

Table 25. Summary of Tier 1 Groundwater Stress Assessment for the Rosslyn Water Supply Well

Tier 1 Components	m^3/yr	m^3/month	Comments
Recharge	2,315,560	195,963	From a 3-D GW Flow Model (Burnside and Amec, 2005)
GW Inflow	31,755	2,646	From a 3-D GW Flow Model (Burnside and Amec, 2005)
Water Supply (Recharge + GW Inflow)	2,347,315	195,609	
Maximum Water Takings (Water Demand)	45,398	3,783	PTTW # 00-P-6073
Average Annual Water Takings (Water Demand)	12,787	1,065	Based on daily average water takings
Reserve	234,731	19,561	10% of Water Supply
% Water Demand (Maximum Water Takings	2.15	2.18	Considered Max Water Takings + Reserve; monthly % water demand accounts for only recharge instead of total water supply
% Water Demand (Actual Water Takings	0.60	0.61	Considered Ave Annual Water Takings + Reserve; monthly % water demand accounts for only recharge instead of total water supply
Stress Assessment Assignment	Low	Low	% Demand <10% of threshold level

The above table indicates that currently The Rosslyn Village's water requirement are met with pumping one production well. The consumption rate is far below the maximum allowable water takings (PTTW) and therefore, it is unlikely that the village should exceed its permit allowance.

The annual maximum (based on PTTW database) and average annual percentage groundwater demand is 2.15% and 0.60%, respectively. The stress assessment for either scenario is low (see Table 25) as they are below the threshold value of 10. Since 99% of the water supply consists of recharge, there is no significant difference in the calculation of monthly water demand from the annual demand. There is no 25-year population trend available, however if one assumes an increase of 10% the above figures do not change appreciably (< 1 %) and therefore a Low stress level is determined for the 25 year scenario.

6.3.3 Uncertainty

Uncertainty is inherent in the water budget estimation process. The accuracy of estimates is reliant on the quality of input data. Input data of observations pertaining to climate, streamflow and hydrology may contain errors. All of these factors can lead to uncertainty in the water budget estimates that are then applied to the sub-watershed stress assessment, which may compound the uncertainty. This uncertainty particularly becomes important if a sub-watershed has been assigned a low stress level. Sub-watersheds that are assigned a stress level near the low-moderate threshold of 10% should check all calculations to ensure that all estimates can be considered conservative. This is not the case for the Lakehead SPA where the % Water Demand is generally < 6% (Table 24).

The Tier 1 stress assessment seeks to determine threats to water quantity on a watershed/ subwatershed basis utilizing existing observed data or simple, ideally conservative, estimates of various elements of the hydrologic cycle. In some cases some of these estimates may be subject to considerable uncertainly. For example, for a surface water stress assessment, surface water supply was calculated based on a nearby gauge and the streamflow data was pro-rated to calculate water supply in the lake. In addition, the monthly lake reserve assumed a constant volume of water in the lake throughout the year. Both estimates may contain considerable uncertainty in the calculation of final percentage water demand.

There may also be uncertainty associated with the Tier 1 groundwater stress assessment the for the Rosslyn Village sub-watershed, especially in terms of calibrated water supply estimates from a 3D- groundwater flow model (Burnside and Amec, 2005). Since the consumptive water takings are extremely low compared to its supply and the population is not expected to increase significantly, there is very much less possibility that the sub-watershed will move to a moderate stress level.

6.4 Significant Recharge Areas

As part of the water budgeting exercise recharge rates were determined across the source water protection region. As described in Section 4.4.2, recharge is the process by which water moves from the ground surface, through the unsaturated zone, to arrive at the water table (MOE, 2007). Given that recharge is an integral part of understanding the flow systems across the watershed, it was important for the Water Quantity Stress Assessment Report to address the issue of “significant” recharge areas. As identified in Guidance Module 7, the use here of the term “significant” is different than that used to define a level of risk in the source water protection stress assessment process.

The Lakehead SPA requires only a Tier 1 analysis and significant recharge areas were delineated using the more simple methods outlined in Appendix B of Guidance Module 7.

The identification of the Significant Recharge Areas for any given watershed is considered a two-step process. The first step is to delineate those areas that provide the most volume over the smallest area of recharge to the watershed. These areas are labelled as “High Recharge Volume Areas”. The second step is to consider which of these areas, or other low volume recharge areas might be considered significant within the context of the watershed.

Gartner Lee conducted significant recharge area mapping using the High Volume Recharge Area Delineation method (# 3) described in Guidance Module 7. In this methodology, high volume recharge areas were delineated based on those areas that have a recharge rate of greater than 1.15 times the average annual recharge rate to the watershed under consideration. The high volume recharge areas for the entire source protection region are mapped on Map 17.

The High Volume Recharge Areas delineated above are all certainly strong contenders to be identified as Significant Recharge Areas. However, it should be pointed out that even some areas with a lower recharge rate might be considered significant if they are essential in maintaining an important hydrological or ecological function. One example of this is sub-watershed of the Rosslyn Water Supply Well as described below.

The high volume recharge areas in the Lakehead SPA (Map 17) provides general recharge to subsurface aquifers in areas with little or no water use or no municipal water demand and are thus not deemed significant in the context of this surface water driven system which is highly regulated[19]. The only exception is the subwatershed containing the Rosslyn Water Supply Well. The 25-year time-of-travel area, as defined in the Burnside and Amec (2005) groundwater modelling study report is 0.15 km^2. This is the same as Well Head Protection Area (WHPA). Even though the average recharge rate of approximately 168 mm/yr is less than the 193 mm/yr high volume recharge threshold, it is nonetheless deemed significant because it is in the WHPA. Map 18 shows a conservative estimate of the significant recharge area for the Rosslyn Water Supply Wells of approximately 1 km^2. (This estimate allows for seasonal spreading of the capture zone and must be treated with caution. Should land use regulations be considered, a more detailed analysis is necessary, but is beyond the scope of this undertaking.) Finally, in the Rosslyn Village subwatershed, groundwater ultimately discharges to the stream and river systems.

Although there are some volume high recharge areas within the Rosslyn Village/wells subwatershed, these are not shown in Map 18. The mapping of the high volume recharge areas was conducted at a scale suitable for the entire study area, using map sources that ranged from 1:20,000 to 1:1,000,000. The spatial accuracy is such that it is inappropriate to present at smaller scale.

6.5 Data and Knowledge Gaps

As stated in Section 6.3.3, there is no measured water supply data for Loch Lomond. There is also no climate station near Loch Lomond. Precipitation and temperature data were obtained from Thunder Bay Airport to calculate water budget components for the Loch Lomond subwatershed. Daily usage figures for Rosslyn were unavailable for this work. The significant recharge area for

19. This does not say that the ecologic function is insignificant, however evaluation of this important function is beyond the scope of this document.

Rosslyn has only been conservatively estimated for the purpose of this study, and should be more carefully delineated should land use restrictions be considered. We are unclear if there are recorded groundwater takings for Rosslyn's municipal wells and if not, they should be recorded to facilitate not only source protection, but well operation decisions.

Calculation of the contributing water to Loch Lomond has been undertaken using secondary sources that do not consider its elevation or special geographic relation to Lake Superior. Should this become a municipal drinking water source in future, consideration may be given to acquiring site specific meteorological and streamflow data.

6.6 Summary

The Tier 1 Water Budget and Water Quantity Stress Assessment can be summarized as follows:

a) Tier 1 Water Budget and Water Quantity Stress Assessment were carried out on two municipal drinking water supplies: Loch Lomond (surface water based) and Rosslyn Water Supply Well (groundwater based). However, Loch Lomond has already been decommissioned as the source of drinking water supply and may be used in future for other purposes which are undetermined at his time. Analysis was performed for both current and future conditions;

b) Water quantity stress assessment identified LOW levels of stress for both the Loch Lomond and Rosslyn Water Supply Well watersheds;

c) High volume recharge areas have been mapped for the entire source protection region following MOE Method 3. Low volume recharge areas linked with the Rosslyn Water Supply Well head protection area can be considered significant recharge areas, but may require refinement should land use restrictions be considered; and

d) Based on the Low Stress level assignment it is recommended that there is no need to proceed to Tier 2 for those water supplies in the Lakehead SPA.

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Appendix A

Summary of Climate Data

Appendix A

Summary of Climate Data

Table A1
Available Climate Stations and Periods of Records within the Lakehead SPA

please see next page

Table A1: Available Climate Stations and Periods of Records within the Lakehead SPA

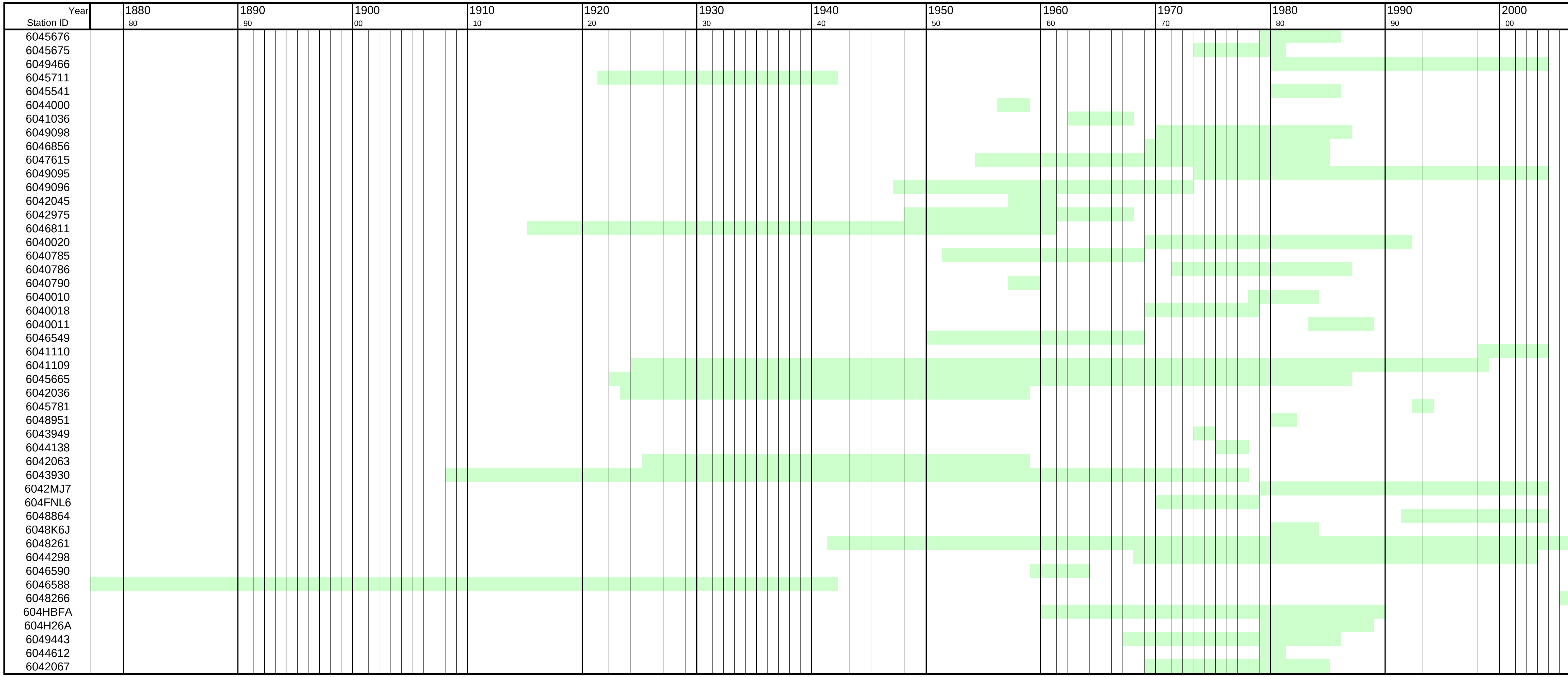
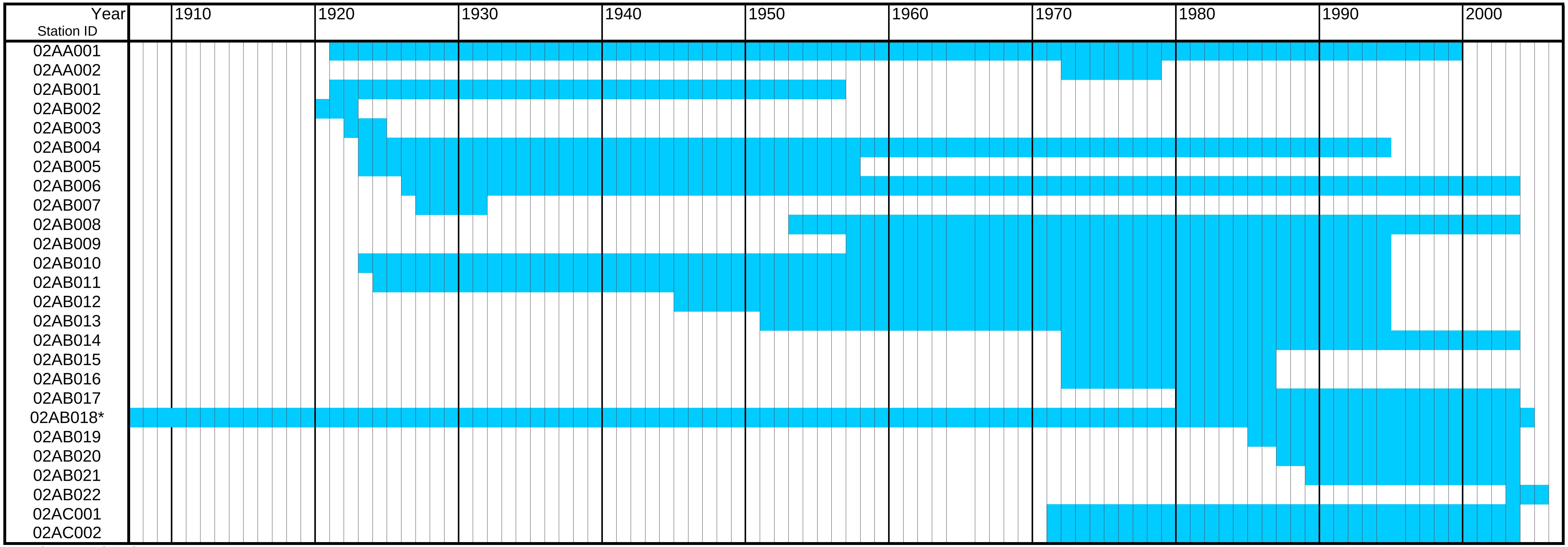


Table A2
Available Hydrometric Stations and Period of Records within the Lakehead SPA

please see next page

Table A2: Available Hydrometric Stations and Period of Records within the Lakehead SPA



* Only water level measurement

Table A3
Summary of Climatic Stations used for Water Balance Analysis (Source: Environment of Canada Website)

Station ID and Name		Latitude	Longitude	Elevation (m)	Period of Record	Data Period Used in Analysis
Stations located Within Lakehead SPA	6042MJ7 – Flint	48° 21' N	89° 40' W	274	1979-2006	1970-1994
	6048264 – Thunder Bay	48° 22' N	89° 19' W	199	1941-2006	1970-1994
	6048864 - Tranquillo Ridge	48° 13' N	89° 13' W	335.3	1991-2006	1970-1994
	6049466 - Whitefish	48° 16' N	89° 55' W	399	1917-1946 1980-2006	1970-1994
Stations Located north of the Lakehead SPA	6041110 - Cameron Falls	49° 9' N	88° 20' W	232.6	1924-2006	1970-1994
	6049095 – Upsala	49° 1' N	90° 28' W	488.5	1947-2006	1970-1994

Table A4
Climatic Stations and Average Precipitation (mm) from 1970-1994 (Data source: Obtained as electronic file from Schroeter, H.O.)

Month/ Station Name	Thunder Bay (6048264)	Tranquillo Ridge (6048864)	Whitefish (6049466)	Flint (6042MJ7)	Upsala (6049095)	Cameron Falls (6041110)
JAN	49.0	56.5	60.1	48.1	32.3	77.7
FEB	32.5	35.2	40.2	33.5	25.5	48.7
MAR	44.2	57.5	57.5	39.8	50.4	48.4
APR	46.6	51.9	61.6	54.8	56.2	43.0
MAY	72.6	81.0	83.4	75.0	73.5	65.4
JUN	84.2	87.6	100.3	93.2	94.4	87.6
JUL	89.3	104.3	105.9	97.2	111.7	87.8
AUG	83.9	90.9	89.6	85.3	105.5	97.7
SEP	90.4	98.5	112.4	91.7	120.2	99.9
OCT	66.6	73.3	69.9	69.0	85.6	93.6
NOV	60.8	68.3	68.0	59.3	56.1	72.0
DEC	51.6	79.1	58.6	58.3	39.7	63.4
Average Annual (mm/yr)	**771.5**	**884.2**	**907.7**	**805.3**	**851.1**	**885.3**

Table A5

Calculated Actual Average Evapotranspiration (mm) at the Selected Climatic Stations (Climatic Data used from 1970-1994)

Month/ Station Name	Thunder Bay (6048264)	Tranquillo Ridge (6048864)	Whitefish (6049466)	Flint (6042MJ7)	Upsala (6049095)	Cameron Falls (6041110)
JAN	0.0	0.0	0.0	0.0	0.0	0.0
FEB	0.0	0.0	0.0	0.0	0.0	0.0
MAR	0.0	0.0	0.0	0.0	0.0	0.0
APR	20.4	20.0	16.9	18.7	13.6	14.0
MAY	70.1	70.5	72.5	70.6	72.7	69.4
JUN	102.2	103.6	112.3	103.2	103.4	100.6
JUL	115.3	122.3	127.9	119.2	119.7	114.8
AUG	96.9	100.9	105.5	100.3	105.5	103.7
SEP	65.8	65.2	63.0	66.5	61.2	65.6
OCT	28.1	28.8	26.1	27.2	24.9	28.4
NOV	0.0	0.0	0.0	0.0	0.0	0.0
DEC	0.0	0.0	0.0	0.0	0.0	0.0
Average Annual (mm/yr)	**498.7**	**511.4**	**524.2**	**505.5**	**501.0**	**496.5**

Table A 6

Estimated Water Surplus (mm) at the selected Meteorological Stations (Data Period: 1970-1994; Soil Moisture Content of 100 mm)

Month/ Station Name	Thunder Bay (6048264)	Tranquillo Ridge (6048864)	Whitefish (6049466)	Flint (6042MJ7)	Upsala (6049095)	Cameron Falls (6041110)
JAN	49.0	56.5	60.1	48.1	32.3	77.7
FEB	32.5	35.2	40.2	33.5	25.5	48.7
MAR	44.2	57.5	57.5	39.8	50.4	48.4
APR	26.1	31.9	44.7	36.2	42.6	29.0
MAY	2.5	10.5	10.8	4.4	0.8	-4.0
JUN	-18.0	-16.0	-12.0	-10.0	-9.0	-13.0
JUL	-26.0	-18.0	-22.0	-22.0	-8.0	-27.0
AUG	-13.0	-10.0	-15.8	-15.0	0.0	-6.0
SEP	24.6	33.3	49.4	25.3	59.0	34.3
OCT	38.5	44.5	43.9	41.9	60.7	65.2
NOV	60.8	68.3	68.0	59.3	56.1	72.0
DEC	51.6	79.1	58.6	58.3	39.7	63.4
Average Annual (mm/yr)	**272.8**	**372.8**	**383.4**	**299.8**	**350.1**	**388.8**

Appendix B

Water Budget Maps

Appendix B

Water Budget Maps

MOE Suggested WB Maps	Lakehead SPA WB Action Maps	Comments
WB Map 1- Climate Stations	**Map 1** Weather Stations and Mean Annual Precipitation	Combined with WB Map 1 and WB Map 2
WB Map 2- Precipitation Distribution		
WB Map 3 – Representative Areas for Climate station (e.g. Theissen Polygons)	Not required	Inverse Distance Weighting Interpolation Technique Used
WB Map 4 – Meteorological Zones	Not required	Only 1 Meteorological zone exists
WB Map 5 - Evapotranspiration	**Map 2** Weather Stations and Mean Annual Actual Evapotranspiration	Actual Evapotranspiration wasdetermined from Thornthwaite and Mather method
WB Map 6 – Bedrock Geology	**Map 3** Bedrock Geology	
WB Map 7 – Sediment Thickness	**Map 4** Overburden Thickness	
WB Map 8 – Geologic Unit Thickness	Not required	- Shallow Overburden - No discrete aquifer/aquitards,
WB Map 9 – Bedrock Topography (elevation)	**Map 5** Bedrock Elevation	
WB Map 10 – Surficial Geology	**Map 6** Surficial Geology	
WB Map - 11 Hummocky Topography		Included in **Map 6**
WB Map 12 – Physiographic Regions		Included in **Map 6**
WB Map 13 – Ground Surface Topography	**Map 7** Surface Topography	
WB Map 14 – Soils Map	Not required	No full coverage. Use of Surficial Geology map and GIS Approach
WB Map 15 – Land Cover Map	**Map 8** Land Cover	
WB Map 16 – Streamflow Gauging Stations	**Map 9** Water Control Structures	Combined with WB Map 16, 18 and 21
WB Map 17 – Flow Distribution	**Map 10** Flow Distribution	
WB Map 18 – Dams, Channel diversions etc.		Included in **Map 9**
WB Map 19 – Fisheries	**Map 11** Fisheries	Very few portions of the watershed covered under this category
WB Map 20 – Surface Water Takings	**Map 12** Surface –and GW takings	Combined with WB Map 25 and WB Map 26
WB Map 21 – Surface Water Nodes		Included in **WB Map 9**
WB Map 22 – Aquifer Extents, GW Flow Directions	**Map 13** Water Table Elevation	Combined with WB map 24
WB Map 23 – Recharge and Discharge Zone	**Map 14a** Recharge Distribution	
WB Map 24 – Depth to Water Table		Included in **Map 13**
WB Map 25 – GW Monitoring Network Locations		Included in **Map 12**
WB Map 26 – Groundwater Takings		Included in **Map 12**
WB Map 27 – Stress Assessment Subwatersheds	**Map 15** Rosslyn Village and Loch Lomond Watershed	

*Note: * "WB Map" # refers to the suggested mapping from the MOE Interim Water Budget Technical Direction Document (Version 3.0, December 21, 2005)*

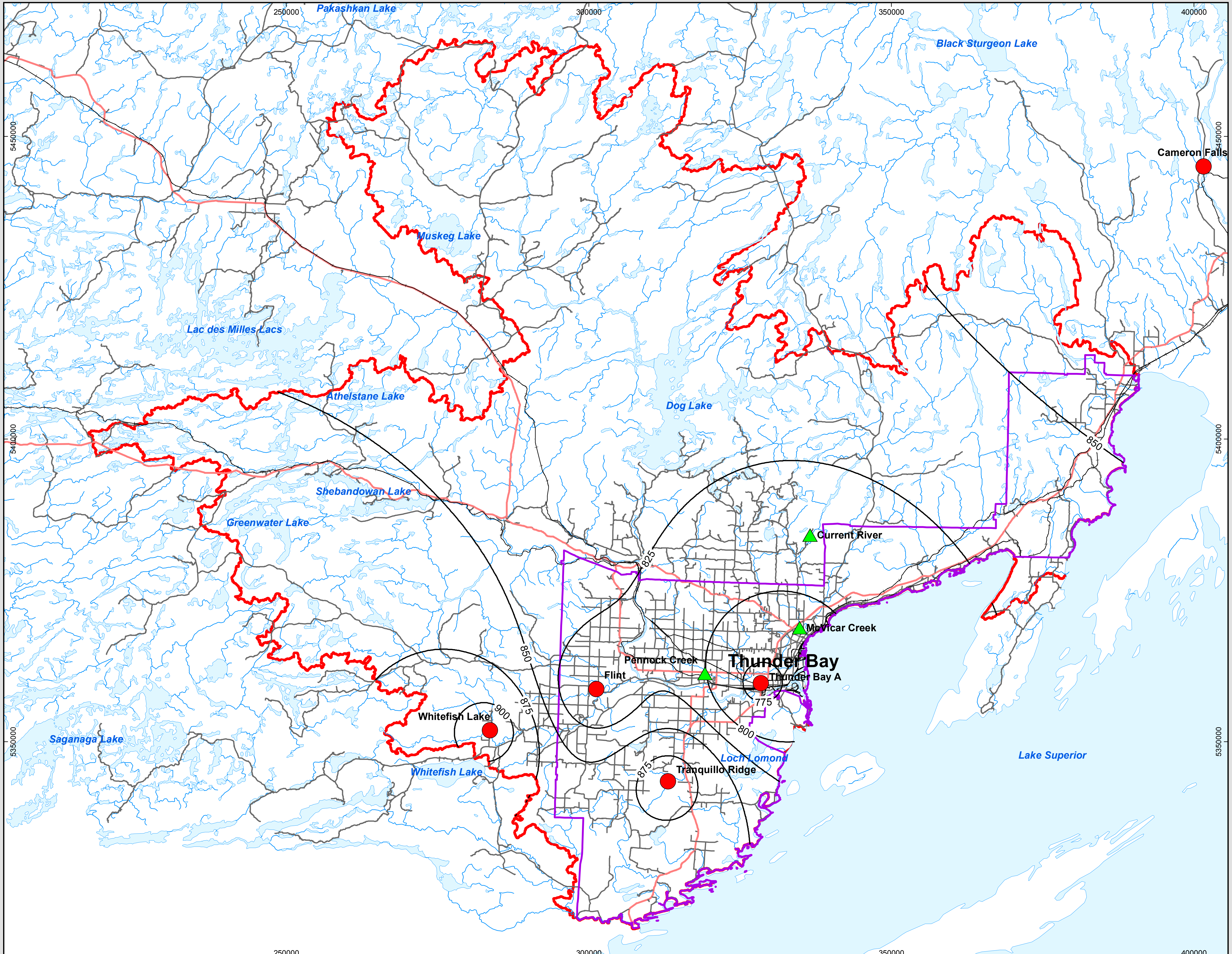
Some of the suggested maps have not been used in this report. WB Map 3 for the Theissen polygons was not included because this was not used in the analysis. Rather an Inverse Distance

Weighting interpolation technique was used to avoid the “steps” that cross the watershed when using the Theissen technique. This was particularly important, as there were no useable meteorological stations in the west, north and east of SPA. WB Map 4 on meteorological zones was also not included because the whole watershed lies in one zone due to the similar physiography. WB Map 8 was intended to identify the unit thicknesses, however given the shallow overburden there are no major aquifer/aquitards or other formations that can be discretely identified.

WB Map 14 was intended to be the pedological soils mapping. Such mapping exists only for a part of the SPA, however much is based on interpretation of high level aerial photography. Since soil properties (from a groundwater recharge perspective) have been obtained from the surficial quaternary mapping, the soils map was deemed redundant. Two (2) maps which are not specified by MOE were prepared for the quantification of run-off (Map 14b) surplus (Map 14c) distribution.

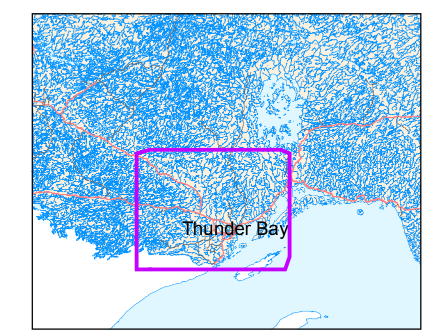
Water Quantity Stress Assessment Maps

Map 16: Loch Lomond Subwatershed
Map 17: High Volume Recharge Areas, Lakehead SPA (MOE Method 3)
Map 18: Significant Recharge Areas (Rosslyn Village/Wells)



Legend

- Snow Course Station
- Weather Stations
- Precipitation Contour
- Lakehead Region Conservation Authority
- Lakehead Source Protection Area



Basemapping from Ontario Ministry of Natural Resources

0 5 10 20 30 Km
1:600,000
UTM Zone 16N, NAD 83

Lakehead Source Protection Area

Weather Stations and
Mean Annual Preciptitation

WB Maps 1 and 2

October 2007
Project 60795

Gartner Lee

Map 1

Map Document: (N:\Projects\2006\60795\2007\Final\GISSpatial\ReportMaps\60795WeatherStationsPrecipMap1.mxd)
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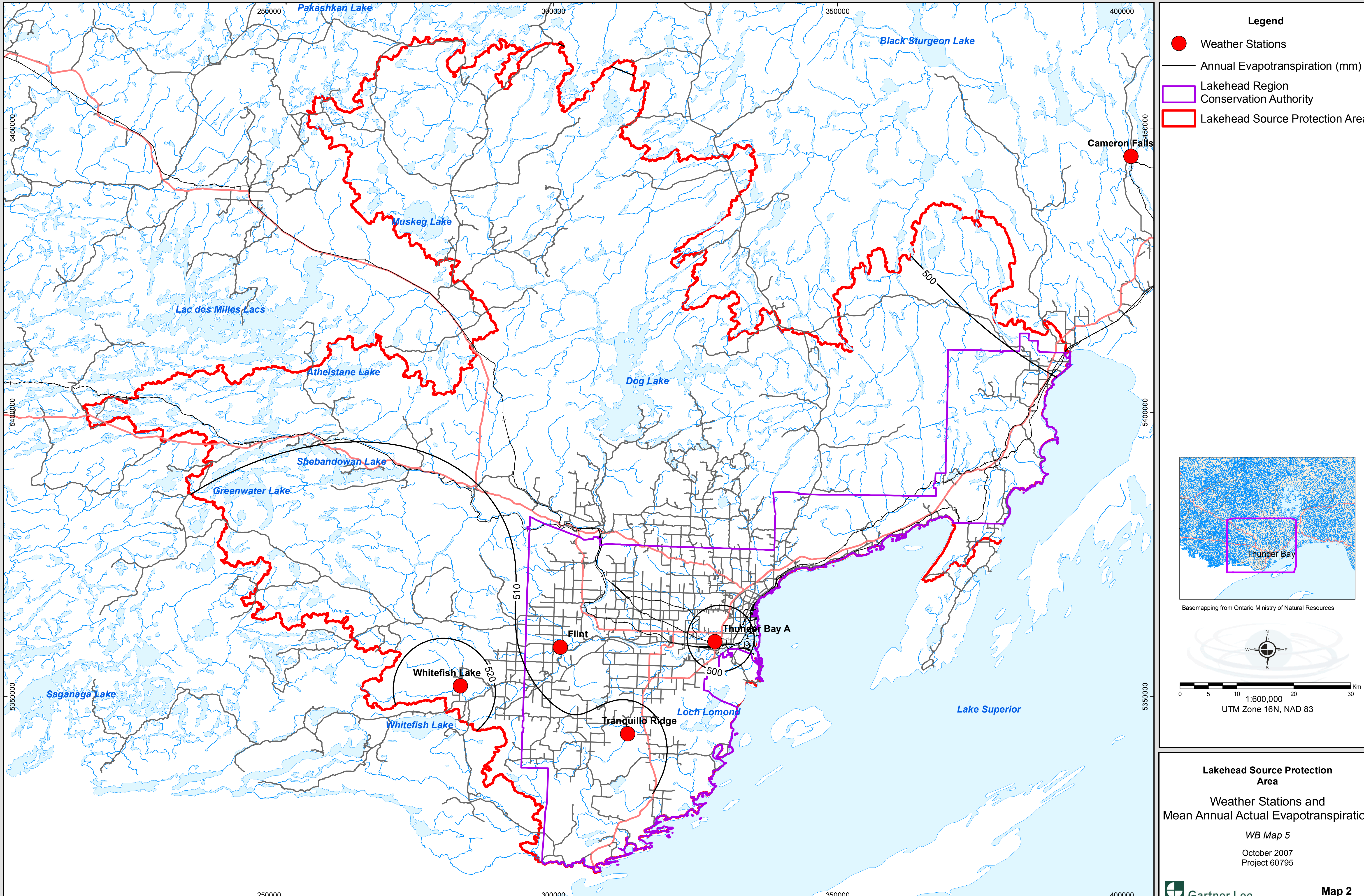

Lakehead Source Protection Area

Weather Stations and
Mean Annual Actual Evapotranspiration

WB Map 5

October 2007
Project 60795

Gartner Lee

Map 2

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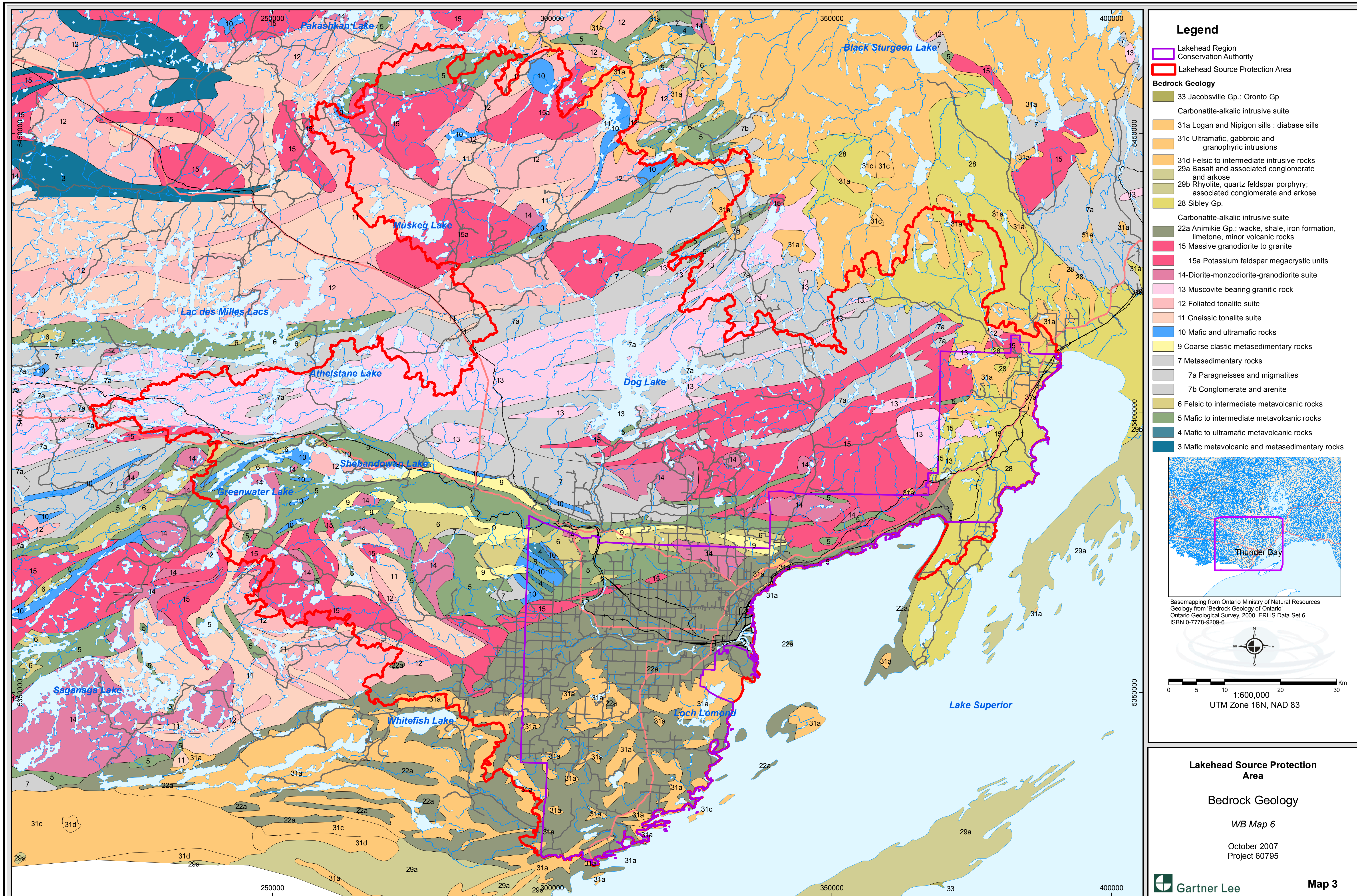

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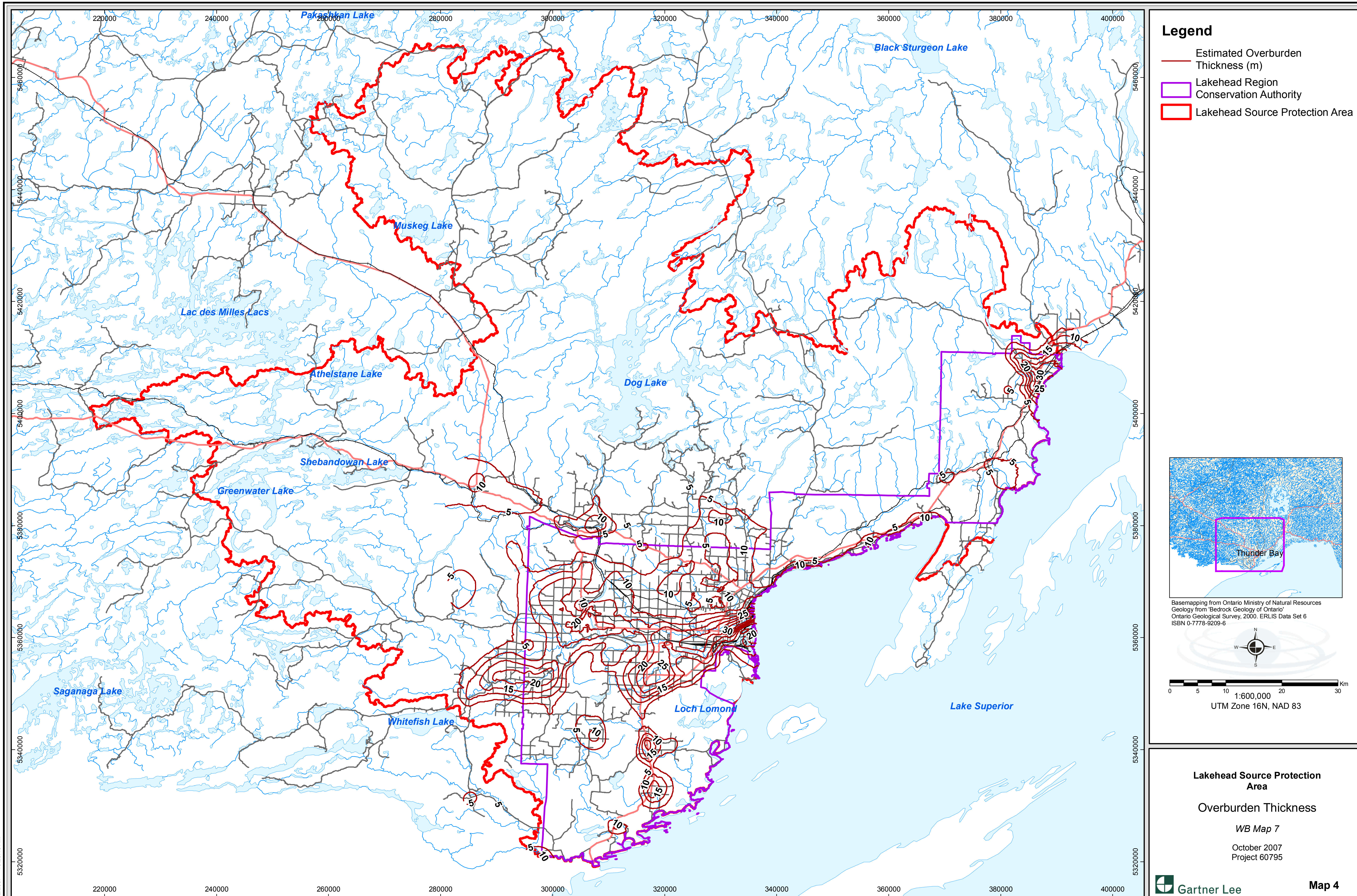


Lakehead Source Protection Area

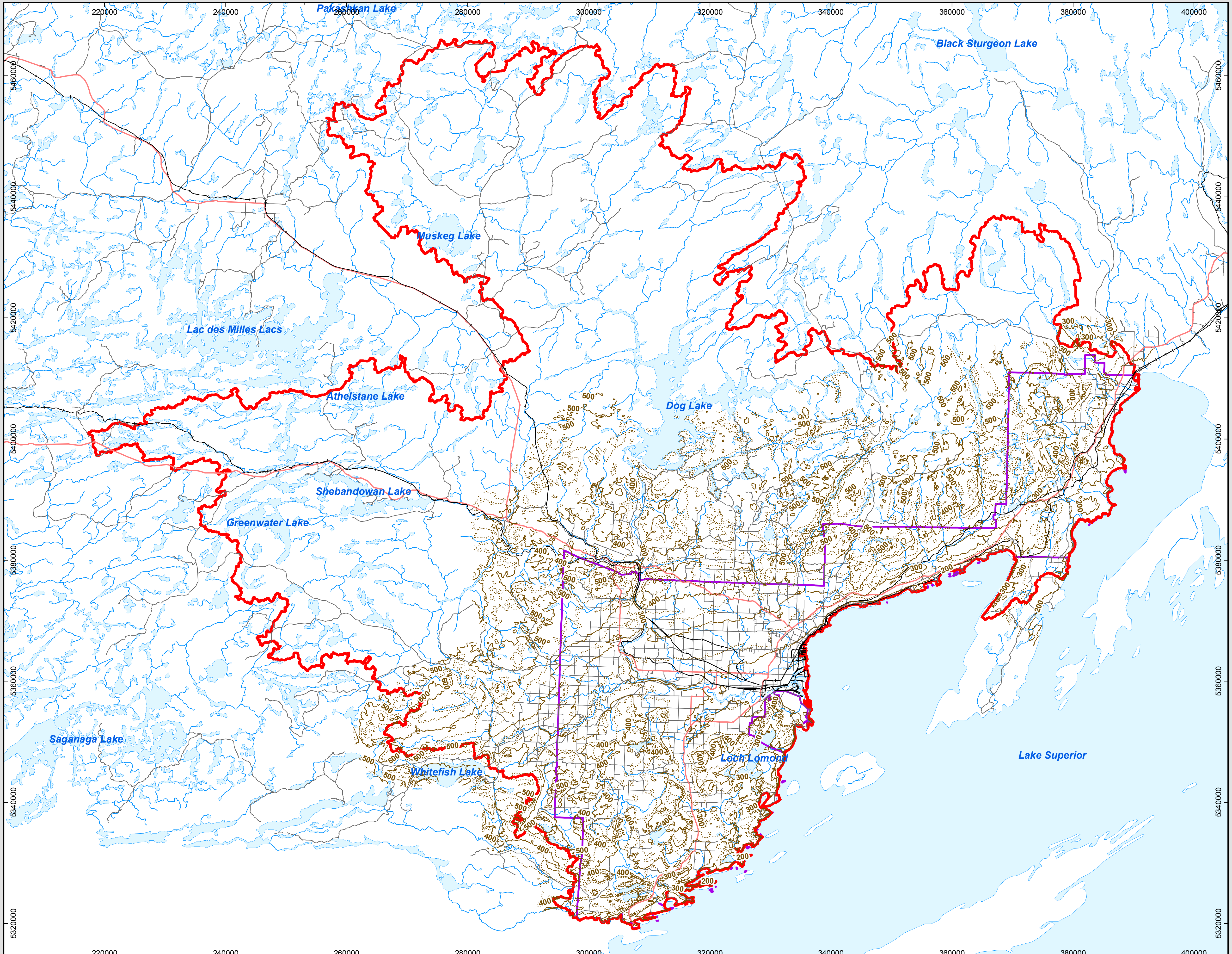
Overburden Thickness

WB Map 7

October 2007
Project 60795

Gartner Lee

Map 4



Legend

- Lakehead Region Conservation Authority
- Lakehead Source Protection Area

Basemapping from Ontario Ministry of Natural Resources
Bedrock elevation mapping from R.J. Burnside

1:600,000
UTM Zone 16N, NAD 83

Lakehead Source Protection Area

Bedrock Elevation (mASL)

WB Map 9

October 2007
Project 60795

Gartner Lee

Map 5

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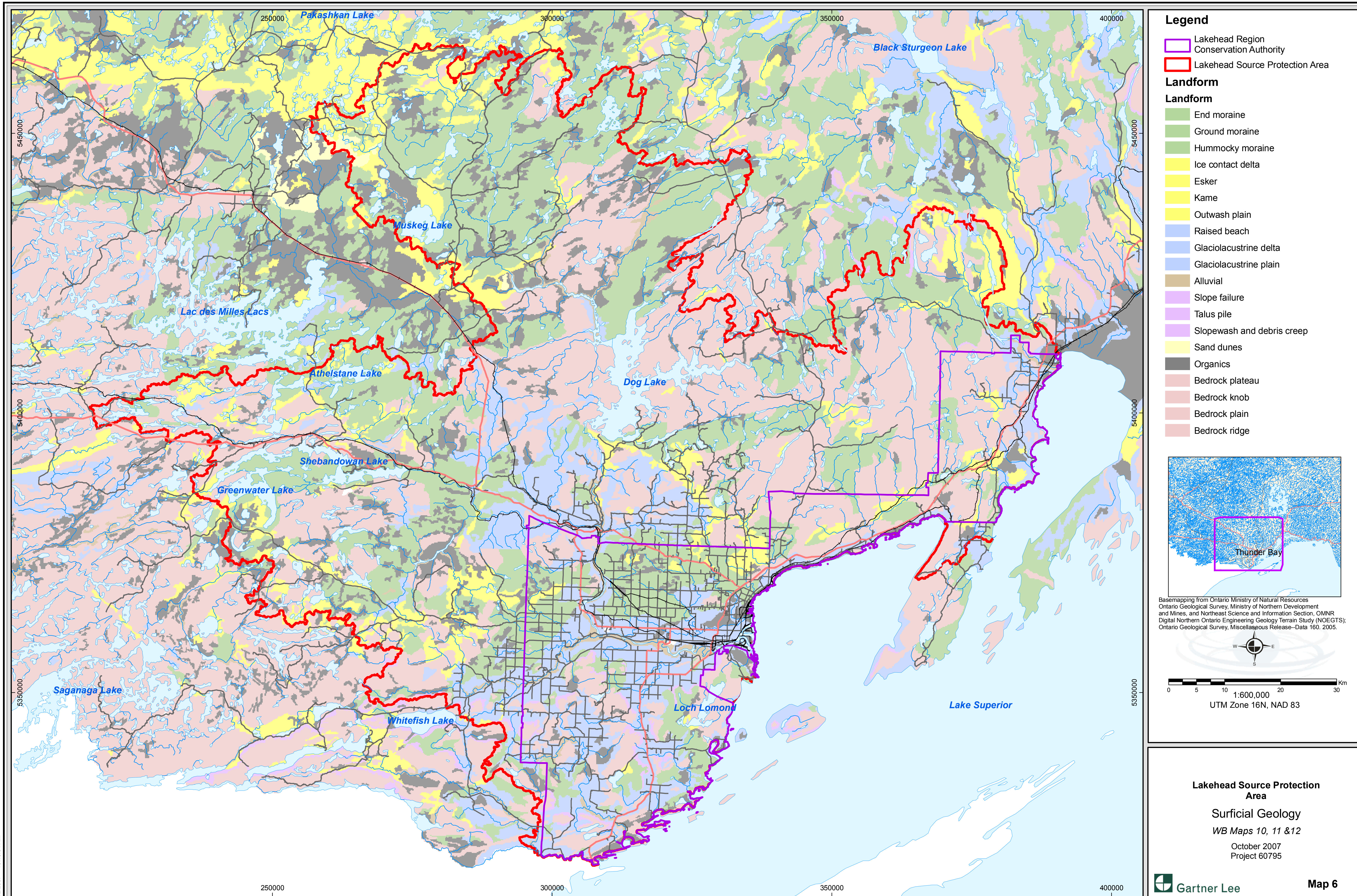

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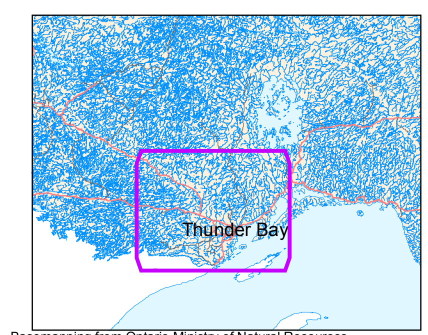
Legend

- Lakehead Region Conservation Authority
- Lakehead Source Protection Area

Elevation (mASL)

High : 675

Low : 175



Basemapping from Ontario Ministry of Natural Resources
Ontario Geological Survey, Ministry of Northern Development and Mines, and Northeast Science and Information Section, OMNR
Digital Northern Ontario Engineering Geology Terrain Study (NOEGTS);
Ontario Geological Survey, Miscellaneous Release--Data 160. 2005.

0 5 10 20 30 Km

1:600,000

UTM Zone 16N, NAD 83

Lakehead Source Protection Area

Surface Topography

WB Map 13

October 2007
Project 60795

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Map 7

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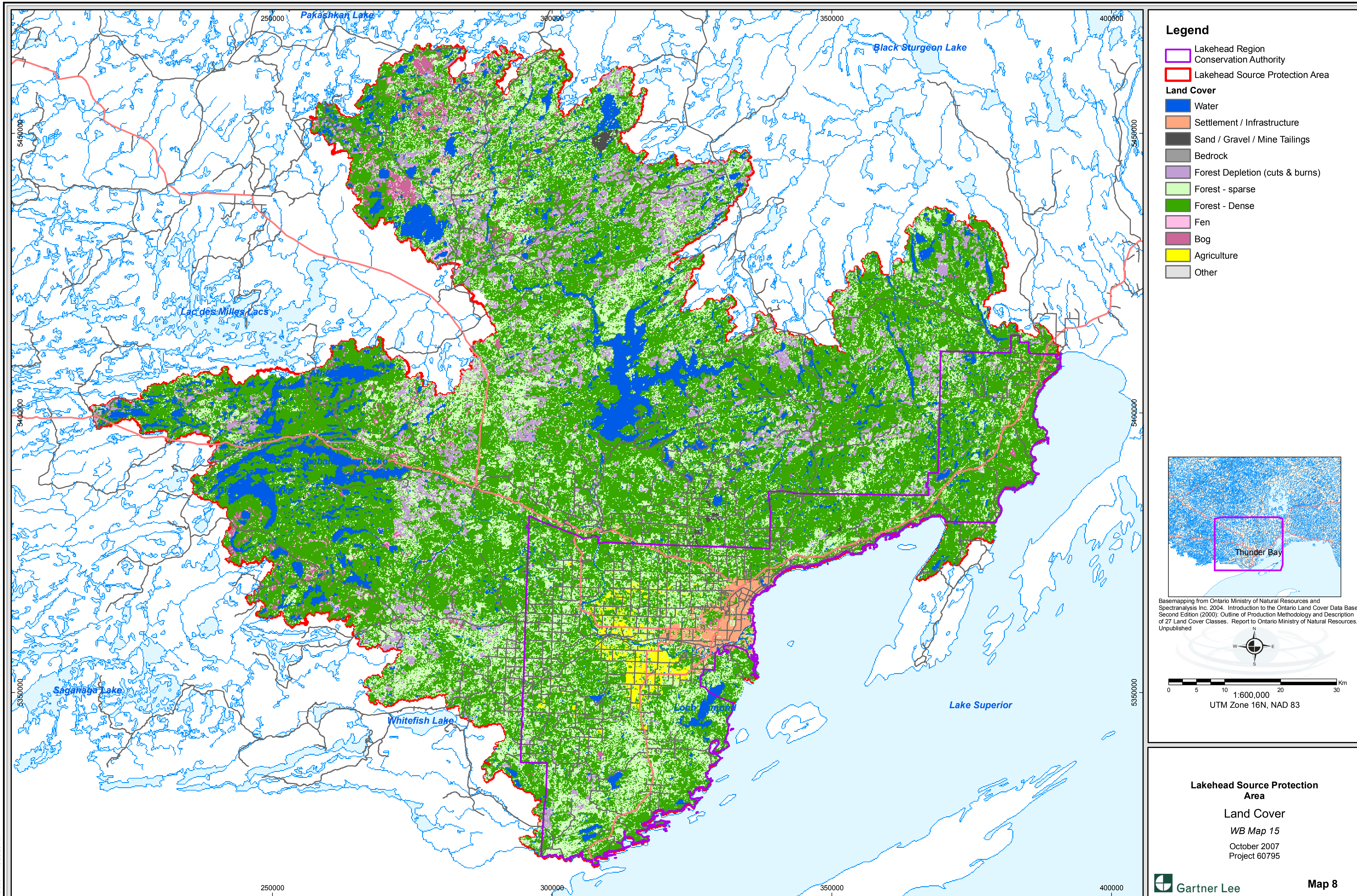

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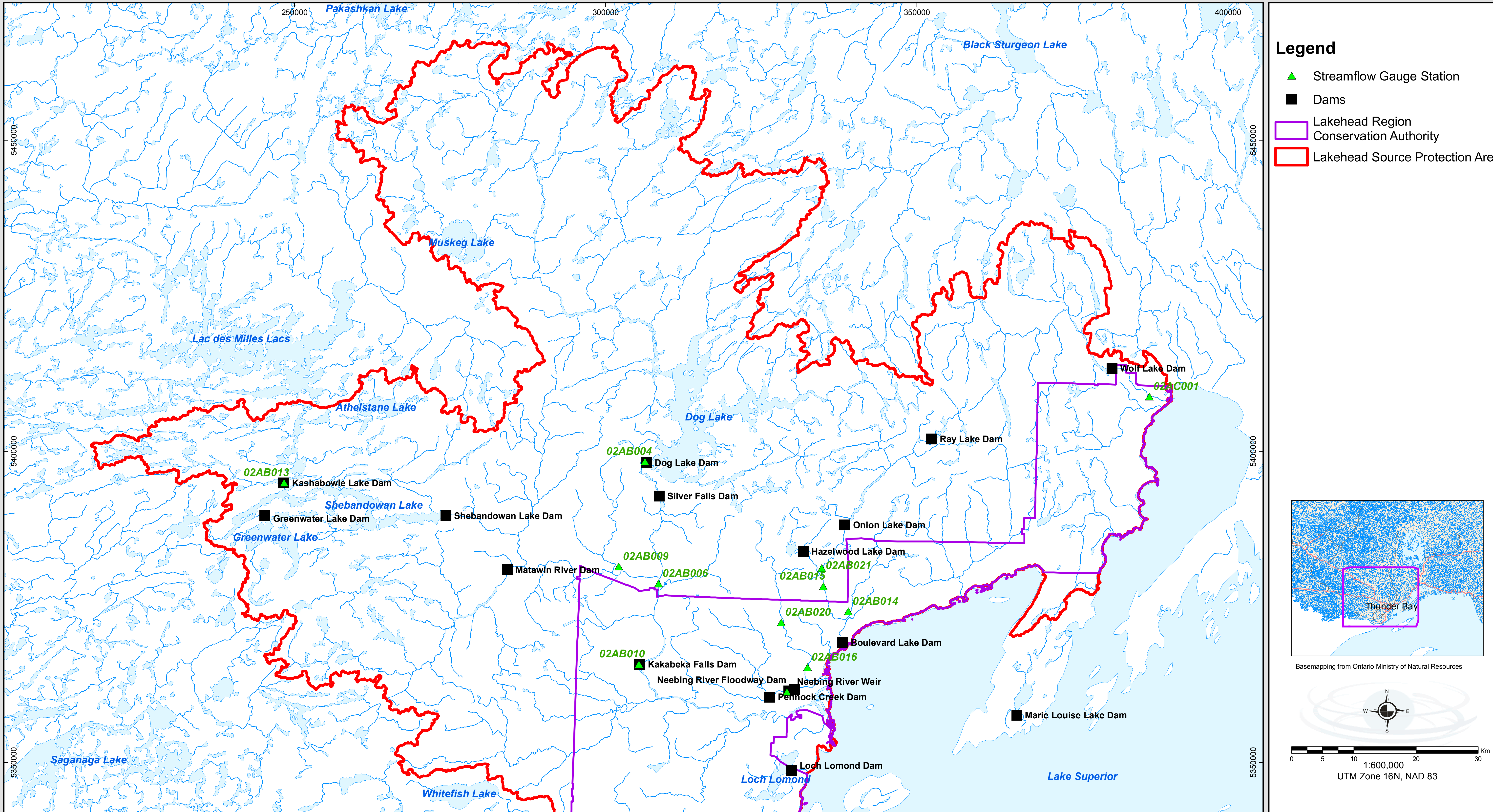

Lakehead Source Protecdtion Area

Water Control Structures

WB Maps 16, 18 & 21

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Project 60795

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Map 9

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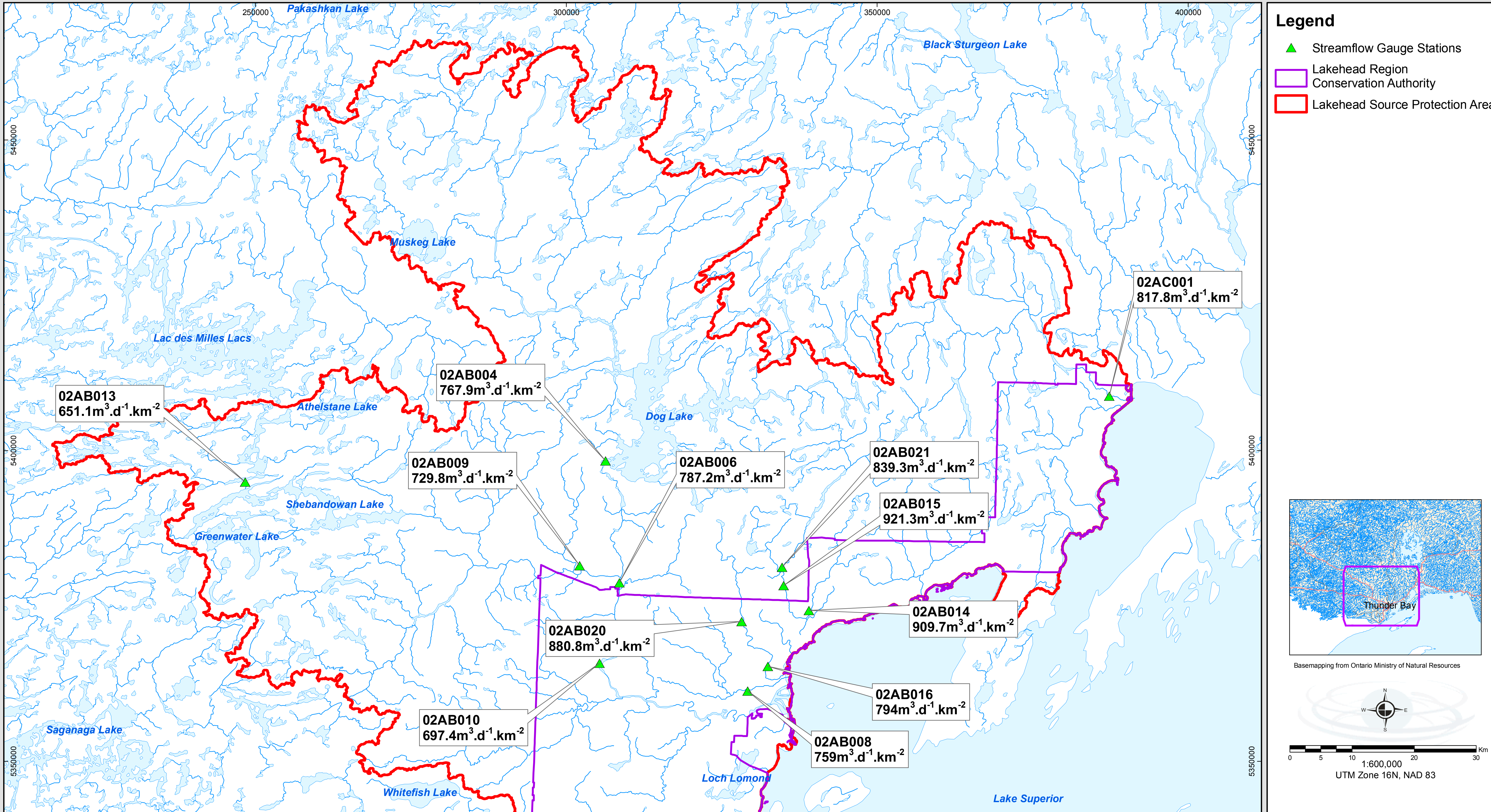

Lakehead Source Protection Area

Flow Distribution

WB Map 17

October 2007
Project 60795

Gartner Lee

Map 10

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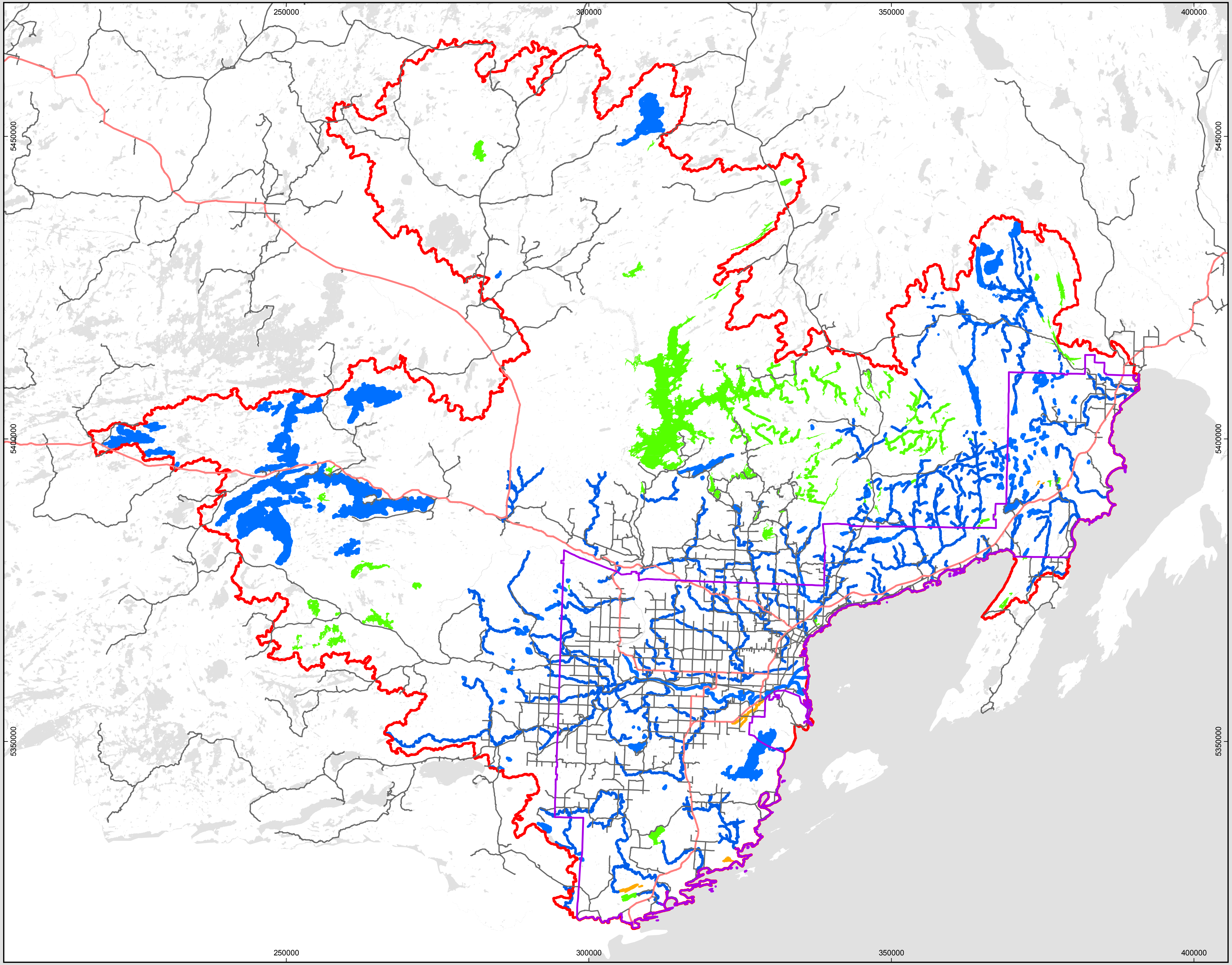


Legend

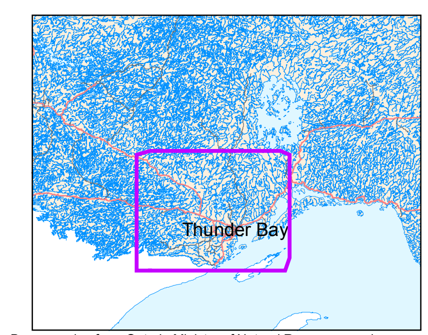
- Lakehead Region Conservation Authority
- Lakehead Source Protection Area

Rivers and Creeks

- Coldwater
- Coolwater
- Warmwater

Lakes

- Coldwater
- Coolwater
- Warmwater
- Unassessed or Out of Study Area



Basemapping from Ontario Ministry of Natural Resources and Spectranalysis Inc. 2004. Introduction to the Ontario Land Cover Data Base, Second Edition (2000): Outline of Production Methodology and Description of 27 Land Cover Classes. Report to Ontario Ministry of Natural Resources. Unpublished

0 5 10 20 30 Km

1:600,000

UTM Zone 16N, NAD 83

Lakehead Source Protection Area

Fisheries

WB Map 19

October 2007

Project 60795

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Map 11

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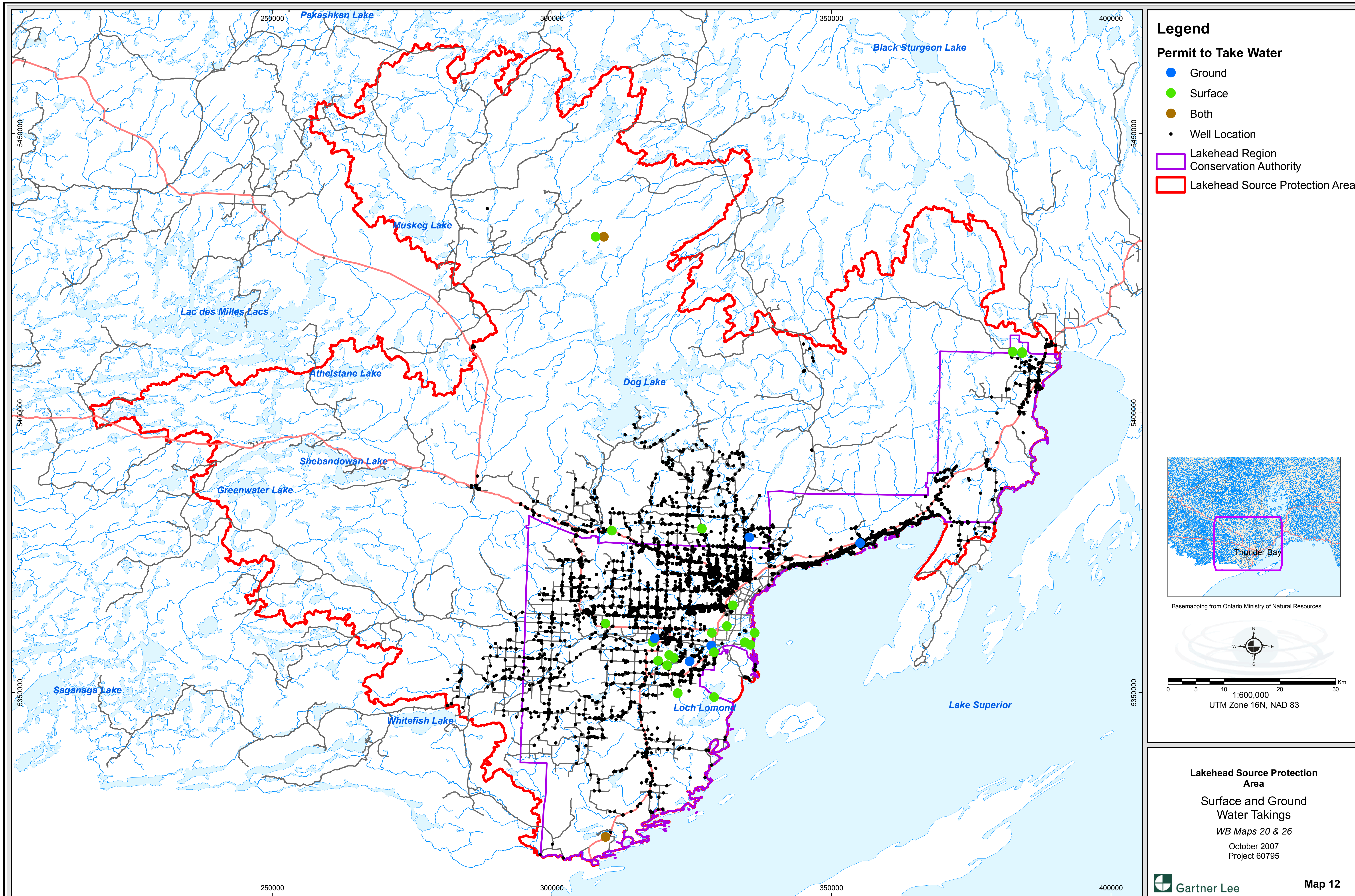

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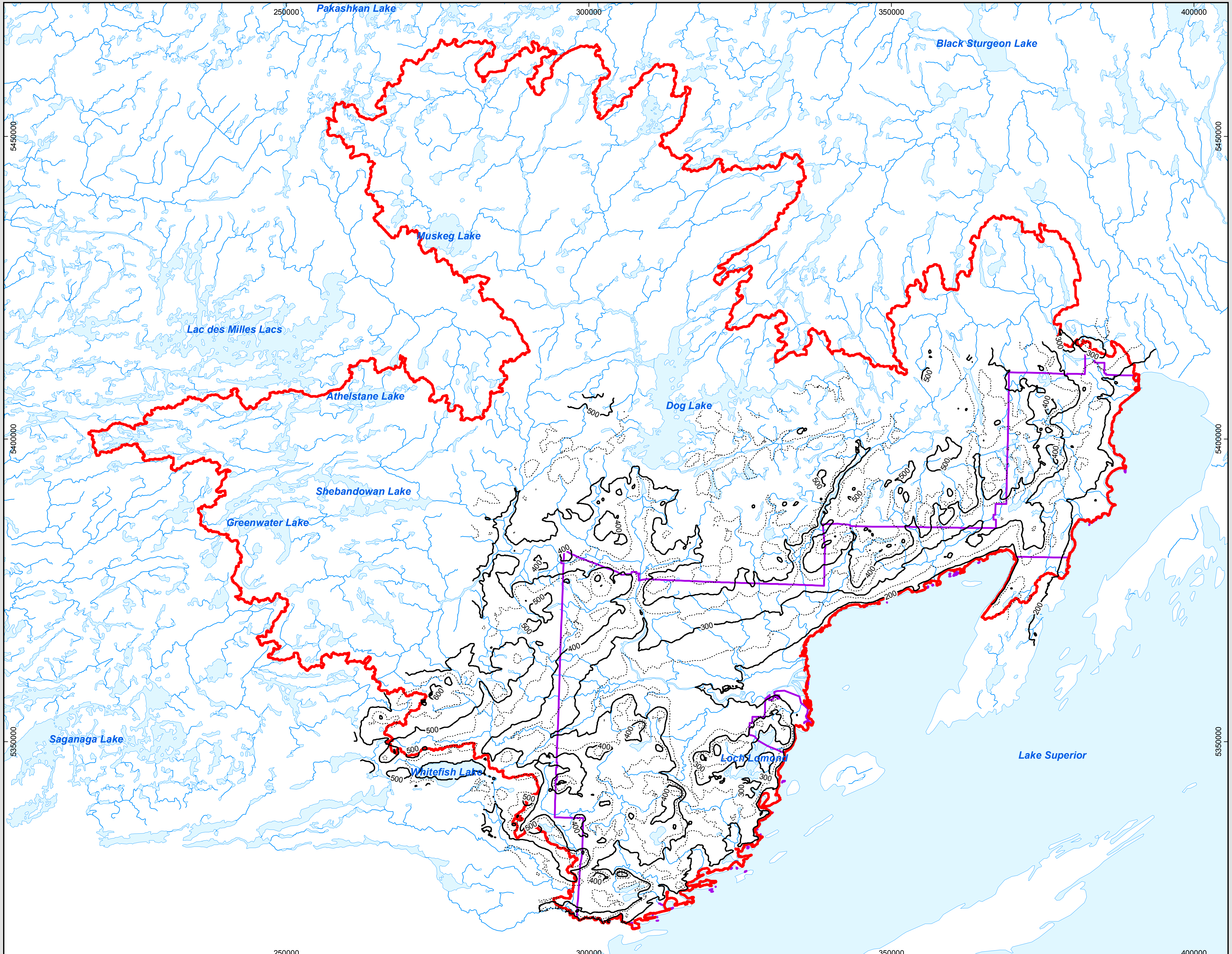
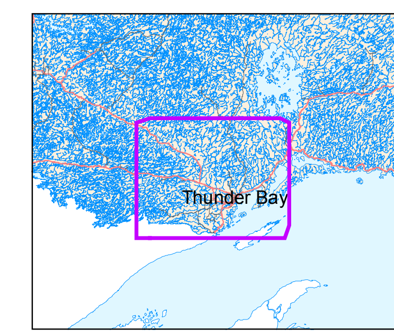


Legend

Potentionmetric Surface Contour

- Minor
- Major
- Lakehead Region Conservation Authority
- Lakehead Source Protection Area



Basemapping from Ontario Ministry of Natural Resources
Water table mapping from R.J. Burnside

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UTM Zone 16N, NAD 83

Lakehead Source Protection Area

Water Table Elevation (mASL)

WB Map 22

October 2007
Project 60795

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Map 13

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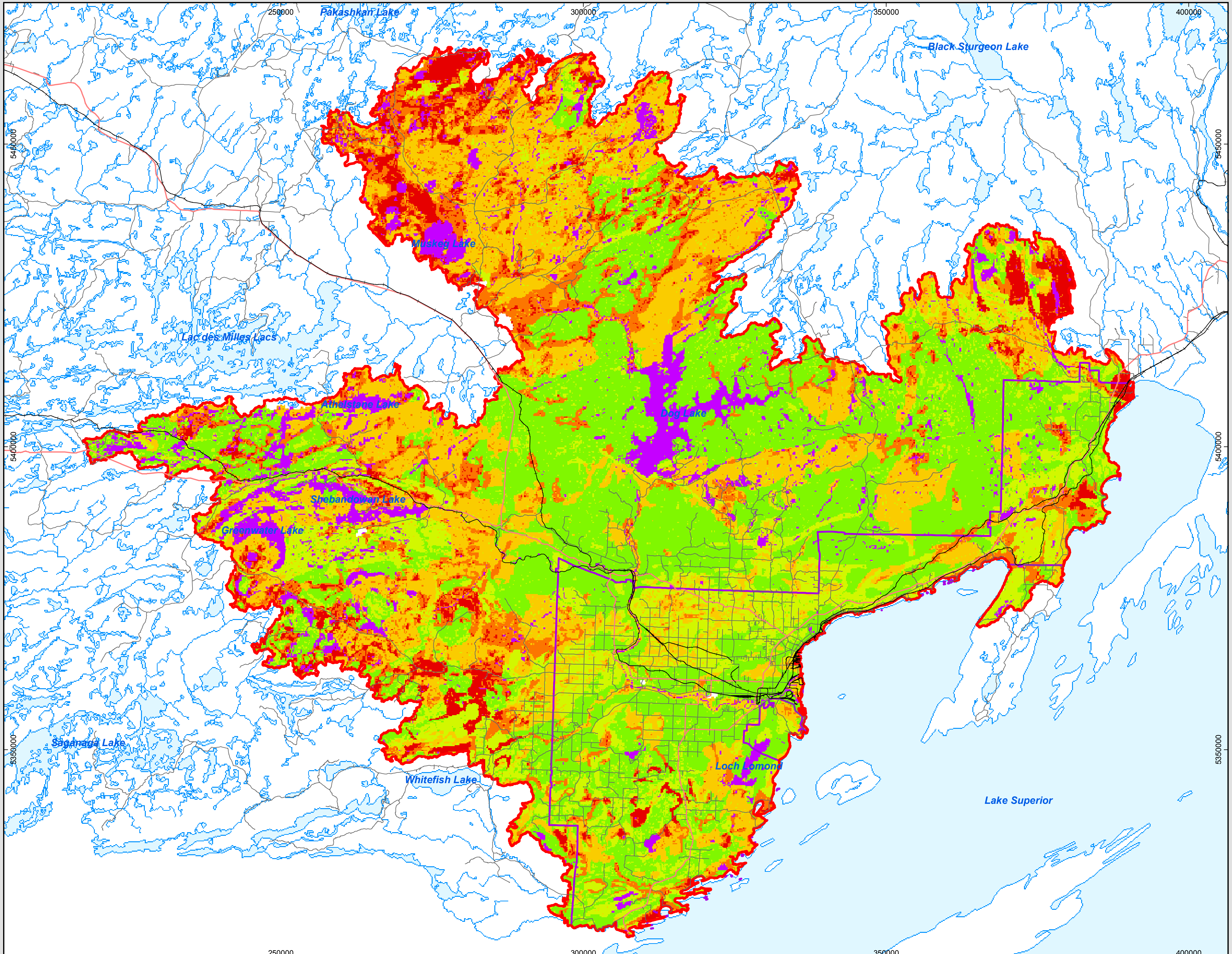


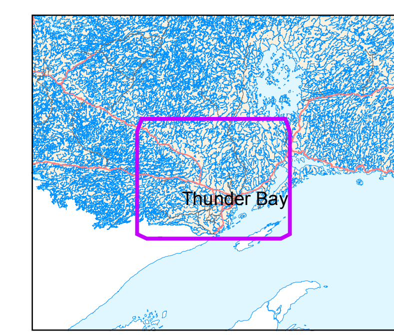
Legend

Lakehead Region Conservation Authority

Lakehead Source Protection Area

Recharge (mm)

- 0 (open water)
- < 150
- 150 - 190
- 190 - 225
- 225 - 255
- > 255



Basemapping from Ontario Ministry of Natural Resources
Water table mapping from R.J. Burnside

0 5 10 20 30 Km

1:600,000

UTM Zone 16N, NAD 83

Lakehead Source Protection Area

Recharge Distribution

WB Maps 2 & 3

October 2007
Project 60795

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Map 14a

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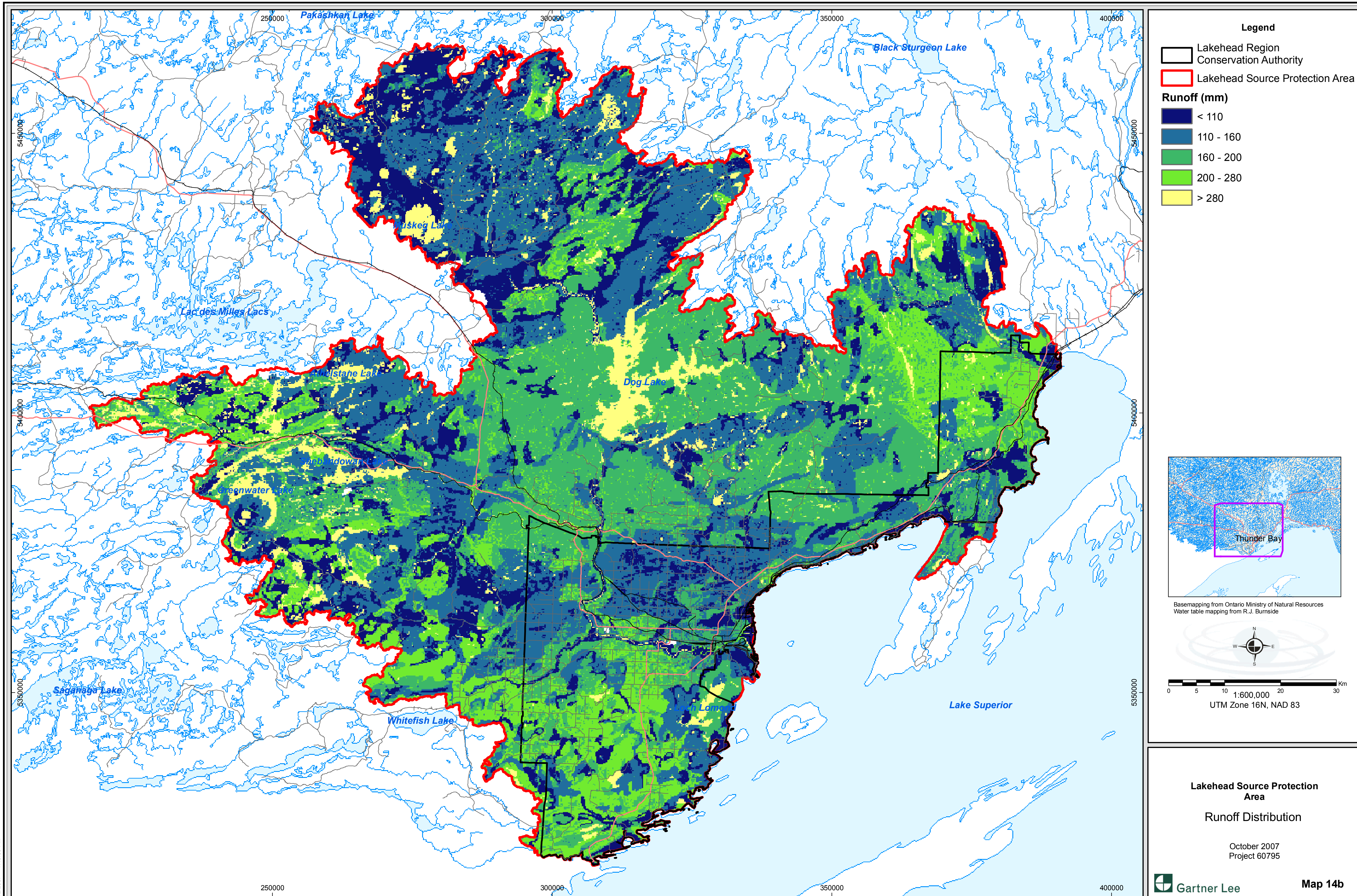

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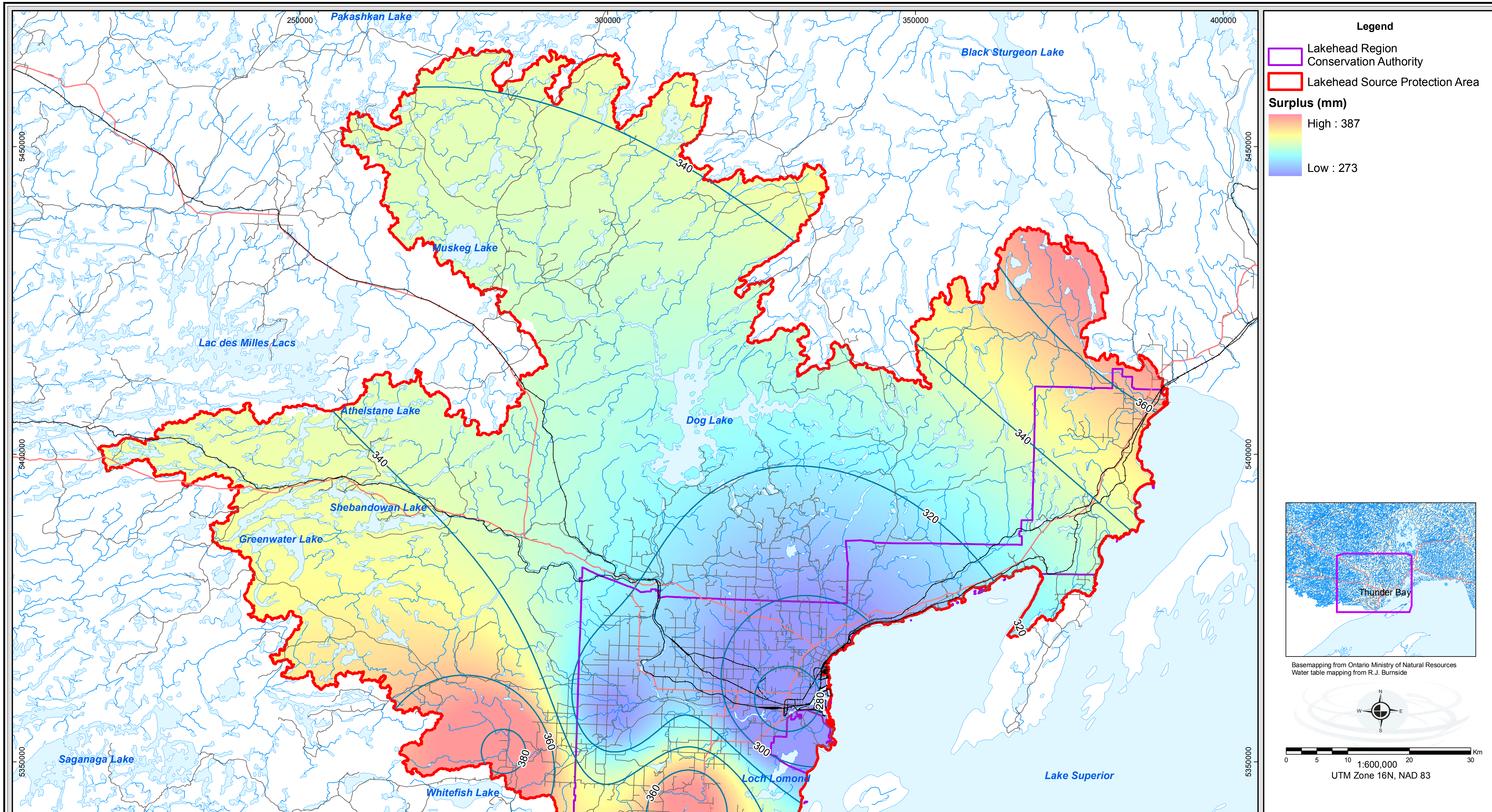

Lakehead Source Protection Area

Surplus Distribution

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Project 60795

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Map 14c

Map Document: (N:\Projects\2006\60795\2007\Final\GISSpatial\ReportMaps\60795SurplusDistributionMap14c.mxd)
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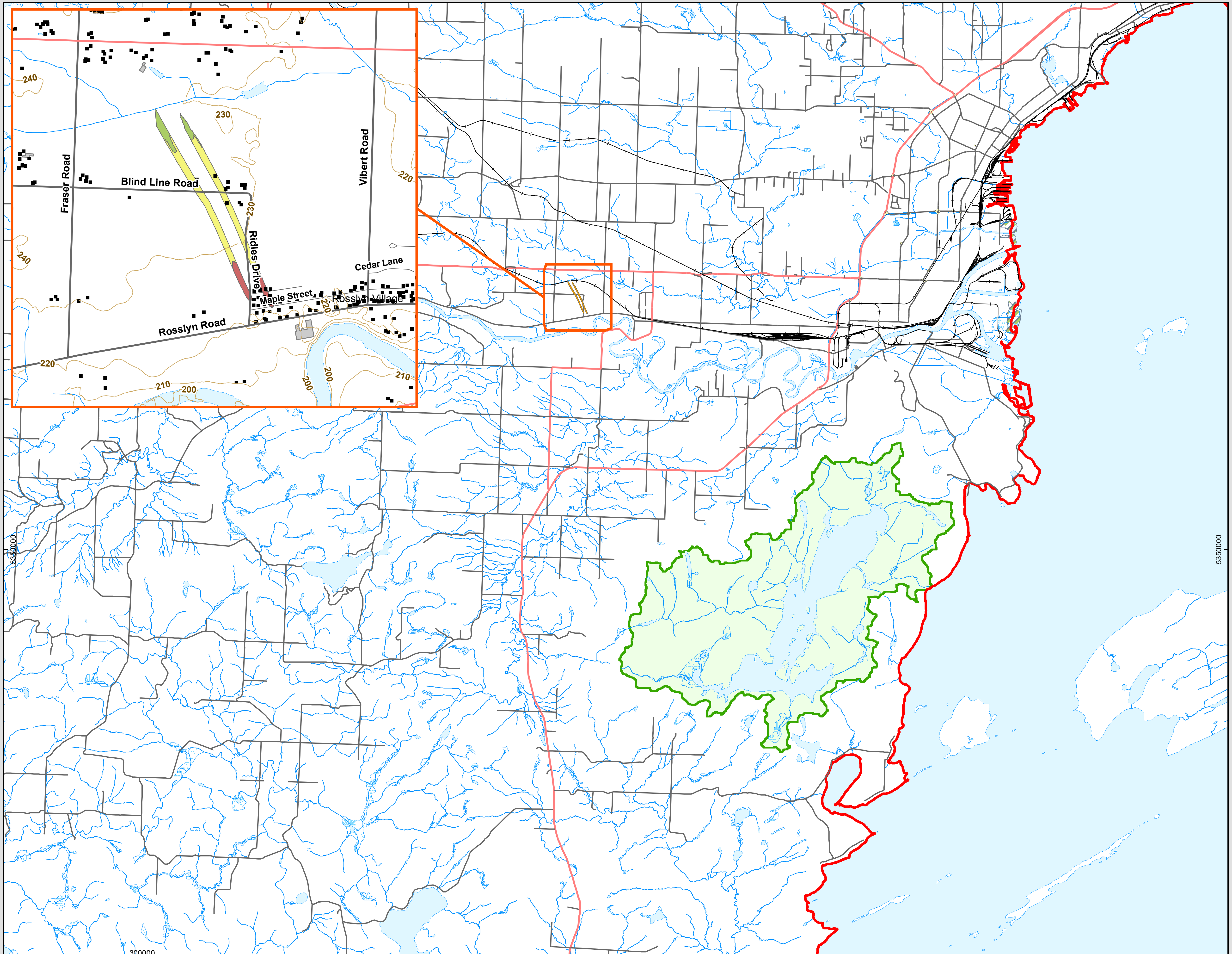

Legend

Rosslyn Wellhead Capture Zones

- 2 year
- 10 year
- 25 year
- Lakehead Source Protection Area
- Loch Lomond Watershed

Thunder Bay

Basemapping from Ontario Ministry of Natural Resources

0 5

1:150,000
UTM Zone 16N, NAD 83

Lakehead Source Protection Area

Rosslyn Village and
Loch Lomond Watershed

WB Map 27
October 2007
Project 60795

Gartner Lee

Map 15

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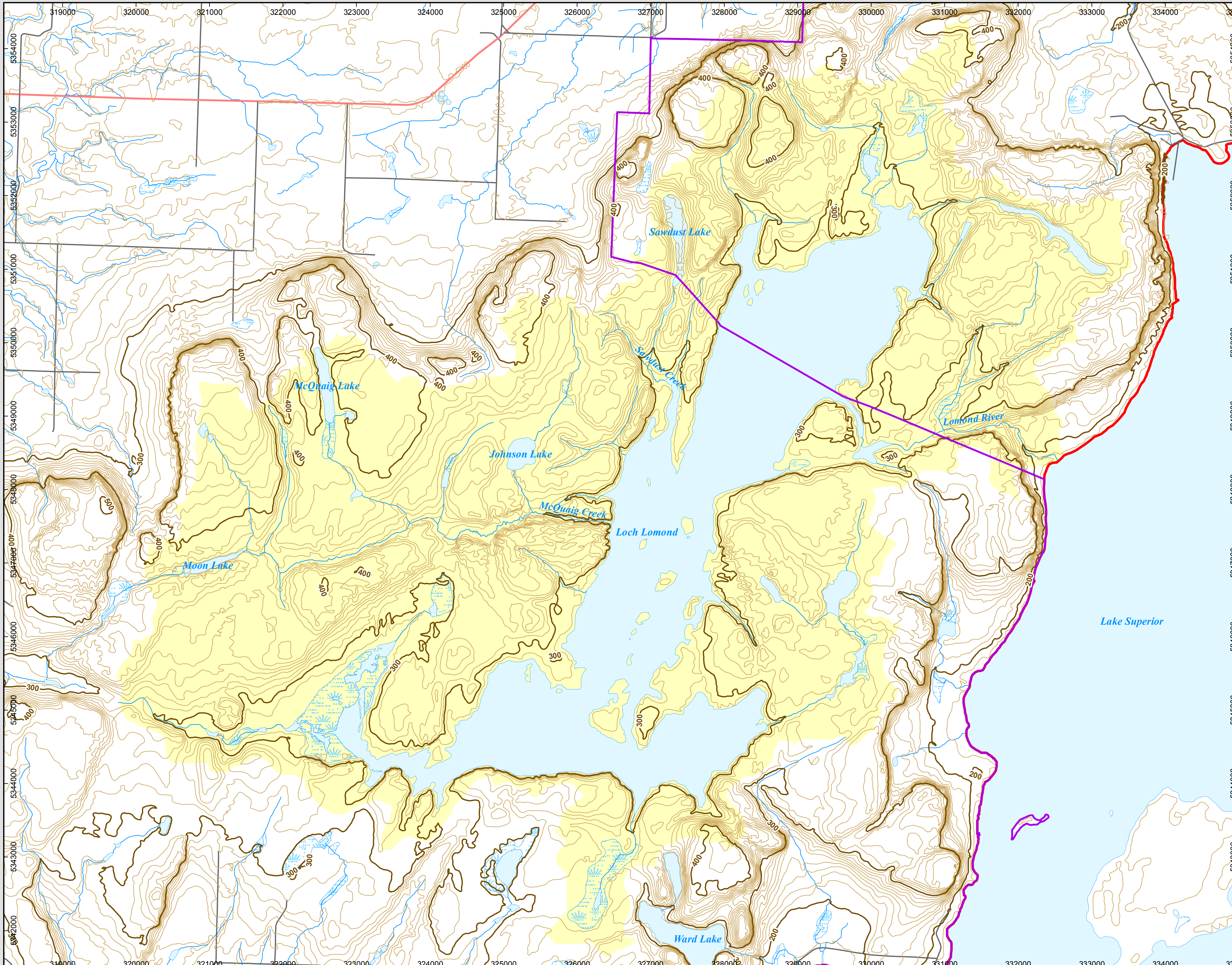
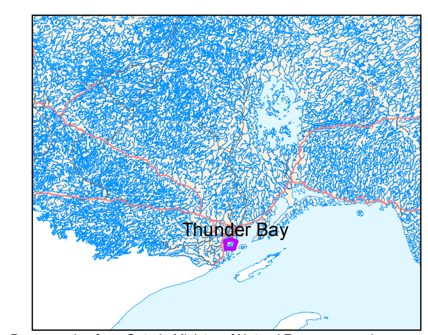


Legend

- Lakehead Region Conservation Authority
- Lakehead Source Protection Area
- Loch Lomond Watershed



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1:50,000

UTM Zone 16N, NAD 83

Lakehead Source Protection Area

Loch Lomond Watershed

October 2007
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Map 16

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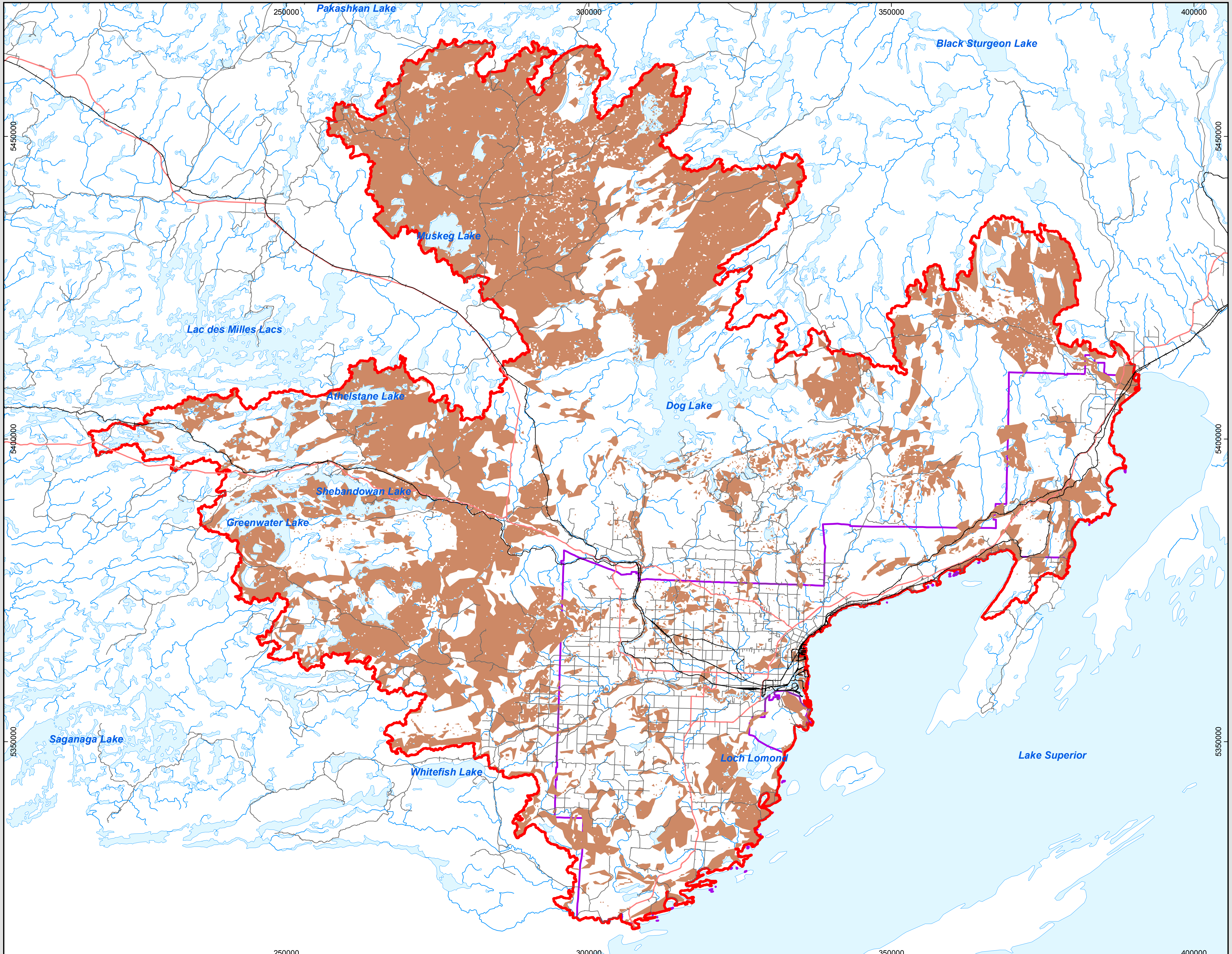
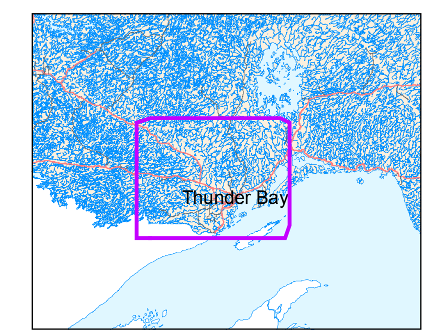


Legend

- Lakehead Source Protection Area
- High Volume Recharge Area
- Lakehead Region Conservation Authority



Basemapping from Ontario Ministry of Natural Resources
High Volume Recharge Areas defined as >1.15 times the average annual recharge rate of 167.8 mm/yr

N W E S

0 5 10 20 30 Km

1:600,000
UTM Zone 16N, NAD 83

Lakehead Source Protection Area

High Volume Recharge Areas

October 2007
Project 60795

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Map 17

Map Document: (N:\Projects\2006\60795\2007\Final\GISSpatial\ReportMaps\60795HighVolumeRechargeAreasMap17.mxd)
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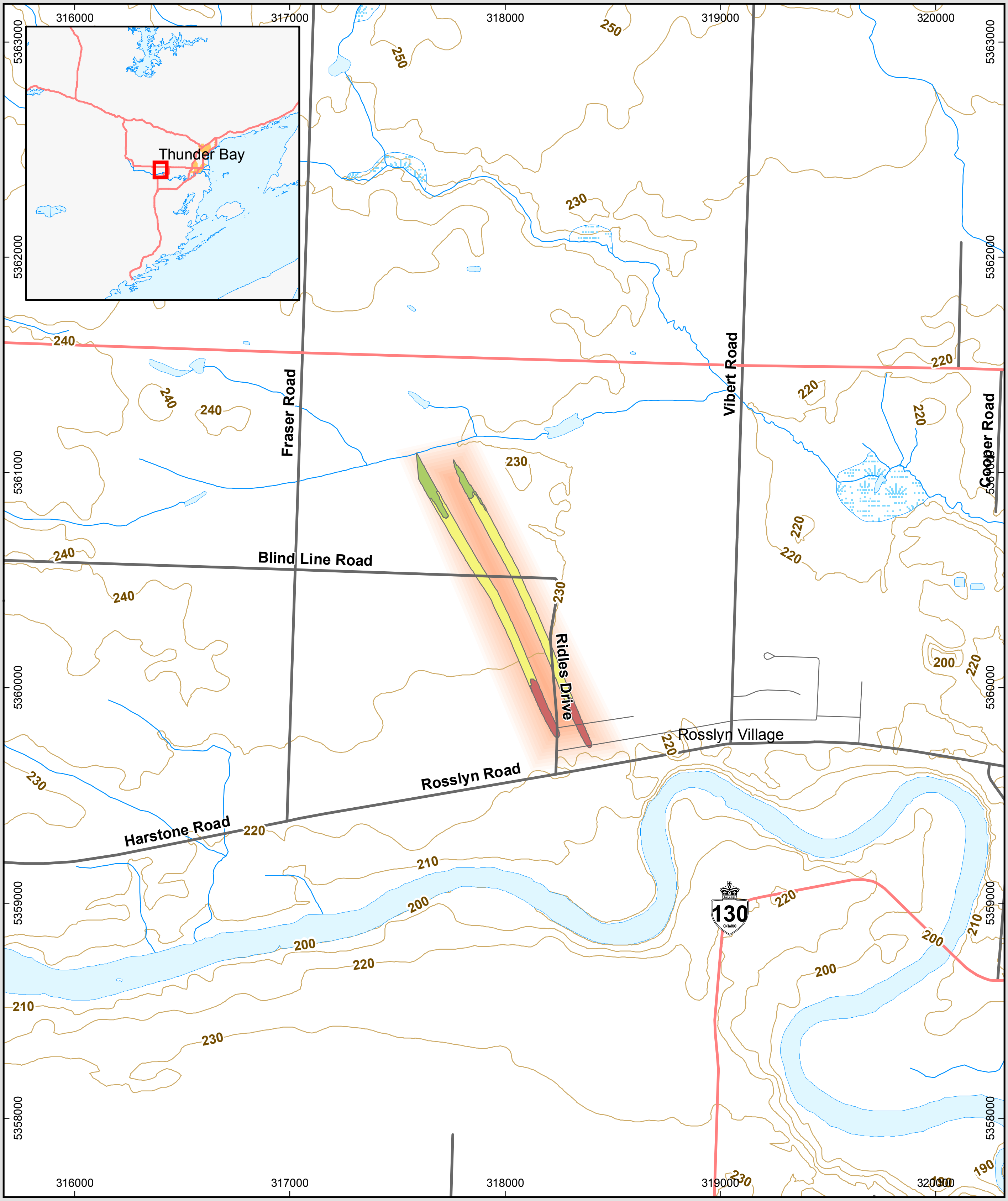

Basemapping from Ontario Ministry of Natural Resources
Capture zones supplied by LRCA

0 100 200 400 600
m
1:25,000
UTM Zone 16N, NAD 83

Legend

Significant Recharge Area (approx)

Capture Zone

- 2 year time of travel
- 10 year time of travel
- 25 year time of travel

Lakehead Source Protection Area

Rosslyn Village Significant Recharge Area

October 2007
Project 60795

Gartner Lee

Map 18

Map Document: (N:\Projects\2006\60795\2007\Final\GISSpatial\ReportMaps\60795SignificantRechargeRosslynMap18.mxd)
10/4/2007 -- 10:58:32 AM

Appendix C

IDW Interpolation Technique

Appendix C

Inverse Distance Weighting (IDW) Interpolation Technique

Using IDW, the formula for the estimation of the value at unsampled point Z from known points z is calculated by:

$$Z = \frac{\sum_{i=1}^{n} \frac{z_i}{d_i^a}}{\sum_{i=1}^{n} \frac{1}{d_i^a}}$$

Where the distance d is calculated as a straight-line or Cartesian distance from each z to Z.

$$d = \sqrt{(x_Z - x_z)^2 + (y_Z - y_z)^2}$$

Where x_Z and y_Z are the UTM coordinates of the unsampled point and x_z and y_z are the coordinates of the known or sampled points.

The influence power is determined by the variable *a*, which in this case was selected to be 2.

"Appendix B (WB Map 1) displays the total precipitation across the study area, contoured using an inverse distance weighting function. Inverse distance weighting is a spatial interpolation technique that allows for estimation of values between measurement points by examining values at measured locations nearby. The technique weights the measurements at close locations more than distant locations. In the case of the precipitation data interpolation, values from all six stations were considered, and the square of the distance was used as the weighting function."

Appendix D

List of Acronyms

Appendix D

List of Acronyms

AES..................... Atmospheric Environment Service
AMEC.................. AMEC Earth and Environmental
mASL.................. Meter Above Sea Level
cm....................... centimetre
GIS...................... Geographic Information System
GW...................... Groundwater
km....................... kilometre
km^2...................... square kilometre
LRCA.................. Lakehead Region Conservation Authority
m......................... metre
mm...................... millimetre
m^{3}s...................... cubic metres per second
Mm^3..................... million metre cubed
OMNR................. Ontario Ministry of Natural Resources
OMOE................. Ontario Ministry of the Environment
MOEE.................. Ministry of the Environment and Energy
OGS.................... Ontario Geologic Survey
OPG.................... Ontario Power Generation
PTTW.................. Permit To Take Water
R.......................... Recharge
RO....................... Run-off
SPA..................... Source Protection Area
WB...................... Water Budget

Appendix E

Glossary

Appendix E

Glossary

Abandoned Well	A well that is deserted because it is dry, contains unpotable water, discontinued before completion, not being properly maintained, constructed poorly, or determined that natural gas may pose a hazard.
Anthropogenic	Influenced by human activity.
Aquifer	A water-bearing layer of soil, sand, gravel, or rock that will yield usable quantities of water to a well.
Baseflow	Baseflow is the portion of streamflow that comes from groundwater and not surface runoff. Baseflow is important for maintaining flow in streams and rivers between rainstorms.
Bedrock	Solid or fractured rock usually underlying unconsolidated geologic materials; bedrock may be exposed at the land surface.
Conceptual Water Budget	A written description of the overall flow system dynamics for each watershed in the Source Protection Area taking into consideration surface water and groundwater features, land cover (e.g., proportion of urban vs. rural uses), human-made structures (e.g., dams, channel diversions, water crossings), and water takings.
Confined Aquifer *(artesian aquifer)*	An aquifer holding water under pressure by a layer above it that does not allow water to pass through. Due to pressure, the water level of a well in a confined aquifer will rise above the top of the aquifer.
Confining Layer *(aquitard)*	Geologic material with little or no permeability or hydraulic conductivity. Water does not rapidly pass through this layer or the rate of movement is extremely slow.
Contaminant *(pollutant)*	Any substance that makes water unfit for a given use.
Data Gaps	The lack of raw information for a specific geological area and/or specific type of information.
Discharge Area	An area where groundwater emerges at the surface; an area where upward pressure or hydraulic head moves groundwater towards the surface to escape as a spring, seep, or base flow of a stream.
Downgradient	A term used in hydrogeology to describe a point at a lower hydraulic head.
Drainage Basin	The land area from which surface runoff drains into a stream or lake.
Eskers	A long winding ridge of post glacial gravel and other sediment; deposited by meltwater from glaciers or ice sheets
Evaporation	The process by which water or other liquids change from liquids to a gas vapour; evaporation can return infiltrated water to the atmosphere from upper soil layers before it reaches groundwater or surface water, and occur from leaf surfaces (interception), water bodies (lakes, streams, wetlands, oceans), small puddled depressions in the landscape.

Evapotranspiration	The sum of evaporation plus transpiration.
Event	Occurrence of an incident (isolated or frequent) with the potential to promote the introduction of a threat into the environment. An event can be intentional as in the case of licensed discharge or accidental as in the case of a spill.
Future Municipal Water Supply Areas	An area corresponding to a wellhead protection area or a surface water intake protection zone, or an aquifer or groundwater area identified for future municipal water supply infrastructure (either a well or a surface water intake pipe).
Karst	Areas that have underlying dissolvable bedrock such as limestone or dolomite. There is generally much more interaction between groundwater and surface water in karst regions than in nonkarst regions.
Geology	The study of science dealing with the origin, history, materials and structure of the earth, together with the forces and process operating to produce change within and on the earth.
Glaciofluvial	Pertaining to rivers and streams flowing from, on or under melting glacial ice, or to sediments deposited by such rivers and streams.
Glaciolacustrine	A term used to describe fine-grained glacial materials deposited in glacial lake environments.
Great Lakes	The five (large) lakes located in Canada and United States: Lake Ontario, Lake Superior, Lake Huron, Lake Eerie, and Lake Michigan.
Great Lakes Connecting Channels	The large rivers that connect the Great Lakes (e.g., St. Clair River, St. Lawrence River).
Groundwater	The portion of rain and snow that soaks through the earth's surface and moves down through the soil – through the unsaturated zone – to the water table. The water table is the top of the saturated zone: the large underground area in which all the interconnected spaces in the rocks and soil are filled with water.
Groundwater Basin	The underground area from which groundwater drains. The basins could be separated by geologic or hydrologic boundaries.
Groundwater Recharge Area	The area where an aquifer is replenished from (a) natural processes, such as the infiltration of rainfall and snowmelt and the seepage of surface water from lakes, streams and wetlands, (b) from human interventions, such as the use of storm water management systems, and (c) whose recharge rate exceeds a threshold specified in the regulations. The Director's rules will specify the acceptable methodologies to determine groundwater recharge rates.
Hydraulic Conductivity	The term used to describe the rate at which water moves through a medium; a controlling factor on the rate at which water can move through a permeable medium.
Hydraulic Gradient	Rate of change of pressure head per unit of distance of flow at a given point and in a given direction.
Hydraulic Head (Head)	The energy that causes groundwater to flow; the total mechanical energy per unit weight; the sum of the elevation head and the pressure head.
Hydrogeology	The study of the interrelationships of geologic materials and processes with water, especially groundwater.

Infiltration	The process of water moving from the ground surface vertically downward into the soil.
Land Use	A particular use of space at or near the earth's surface with associated activities substances and events related to the particular land use designation.
Model	An assembly of concepts in the form of mathematical equations or statistical terms that portrays a behaviour of an object, process or natural phenomenon.
Moraine	An accumulation of earth and stones carried by a glacier and usually deposited into a high point like a ridge.
Municipal Residential System	All municipal drinking-water systems that serve or are planned to serve a major residential development (i.e., five or more private residencies).
Municipal Well *(public or community well)*	A pumping well that serves five or more service connections.
Permeable	A porous surface through which water passes quickly.
Physiography	The study of the landforms – form and process.
Precipitation	Deposition of rain, snow, hail or sleet.
Private Well	A pumping well that serves one home or is maintained by a private owner.
Recharge Areas	Groundwater supplies are replenished, or recharged, when water enters the saturation zone by actions like rain or snow melt.
Runoff-Surface *(overland flow)*	Precipitation that cannot be absorbed by the soil because the soil is already saturated with water (soil capacity); precipitation that exceeds infiltration; the portion of rain, snow melt, irrigation water, or other water that moves across the land surface and enters a wetland, stream, or other body of water (overland flow). Overland flow usually occurs in urban settings (pavement, roofs, etc.) or where the soils are very fine textured or heavily compacted.
Runoff-Total	Includes the sum of surface runoff (overland flow), baseflow, and interflow (subsurface storm flow) that moves across or through the land and enters a stream or other body of water.
Saturation Zone	The portion that's saturated with water is called the zone of saturation. The upper surface of this zone, open to atmospheric pressure, is known as the water table (phreatic surface).
Soil-Water	Water held in a normally unsaturated zone above a perennial water table; water below this level is considered to be groundwater.
Source Water	Untreated water from lakes, rivers, streams or underground aquifers.
Spring	A natural discharge of groundwater at the land's surface.
Static Water Level	The water level in a well that is not being pumped or influenced by pumping.
Stratigraphy	A branch of geology which studies of the formation, composition, sequence, and correlation of the stratified rocks as parts of the earth's crust.
Subwatershed	An area that is drained by an individual tributary into the main watercourse of a watershed.

Thornthwaite Method	A method to estimate soil water balance, based on air temperature, latitude and date.
Threat Assessment – Tier 1	Preliminary examination of a drinking water threat based on readily accessible information.
Threat Assessment – Tier 2	Advanced examination of a drinking water threat through accessing more detailed information, interviews and perhaps when warranted, additional monitoring, modeling or studies.
Tier 1, 2 and 3 Water Budgets	Numerical analysis at the watershed (Tier1), subwatershed (Tier 2) or local (Tier 3) level considering existing and anticipated amounts or water taken from the watershed, as well as quantitative flow between components such as recharge/discharge areas and rates.
Till	Glacier deposits composed primarily of unsorted sand, silt, clay, and boulders laid down directly by the melting ice.
Topographic Divide	A high point in the land surface that provides a boundary between adjacent watersheds or basins.
Topography	The contour of the land surface; the configuration of the land surface including its relief and the position of its natural and man-made features.
Water Cycle *(hydrologic cycle)*	The continuous circulation of water from the atmosphere to the earth and back to the atmosphere including condensation, precipitation, runoff, groundwater, evaporation, and transpiration.
Watershed	Land lying adjacent to water courses and surface water bodies which creates the catchment or drainage area of such water courses and bodies; the watershed boundary is determined by connecting the topographic high point surrounding such catchment or drainage areas.
Water Table	The water surface in an unconfined aquifer; the level below which the pore spaces in the soil or rock are saturated with water; the upper surface of the zone of saturation.
Well	A vertical bore hole in which a pipe-like structure is inserted into the ground in order to discharge (pump) water from an aquifer.
Wetlands	Land such as a swamp, marsh, bog or fen (not including land that is being used for agricultural purposes and no longer exhibits wetland characteristics) that, (a) is seasonally or permanently covered by shallow water or has the water table close to or at the surface, (b) has hydric soils and vegetation dominated by hydrophytic or water-tolerant plants, and (c) has been further identified, by the Ministry of Natural Resources or by any other person, according to evaluation procedures established by the Ministry of Natural Resources, as amended from time to time.
Zone of Saturation *(saturated zone)*	The zone in which the pore spaces between soil and rock particles are completely filled with water. The water table is the top of the zone of saturati on.

Snow-Related Terms	
Snow	Water precipitated in the form of minute ice crystals, and usually falling in irregular agglomerated masses or flakes.
Snowfall	Depth of snow layer produced on the measurement surface by atmospheric precipitation during a given period, measured as accumulated depth above starting plane, at the end of the period.
Snowmelt	Conversion of water from solid (ice) to liquid in the snowpack.
Snowpack	The mass of ice crystals and of liquid water contained within the ice-crystal matrix that is accumulated above the ground surface at a specified place and time.
Snowpack Depth	The vertical distance between the upper surface of a snowpack and the ground surface beneath.
Snow Ablation	The amount of water removed from a snowpack by melting or sublimation.
Snow Cover	A general term for the presence of snow on the surface of a watershed. Use of the term should include acknowledgement of the areal and temporal variation of snowpack amounts on the watershed surface.
Snow Layer	A portion of a snowpack with distinct features in terms of grain size, density, and liquid-water content, which is defined by an upper and a lower surface.
Snow Redistribution	Removal of snow from one location by erosion, with transportation to another location where it is deposited.
Snow Sublimation	Solid to vapour conversion of ice in the snowpack.
Snow Water Equivalent *(also equivalent water content, or total water content)*	Depth of water layer produced, after melting, of snow at a given place.