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 budgetting 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 groundwater 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 Report (LRCA, 2008), 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 budgetting 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 storages located?);
2. How does the water move between those storages? (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 storages 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 storage.

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 has been estimated at 11,526 km^2. The entire 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 through the City of Thunder Bay and finally to 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

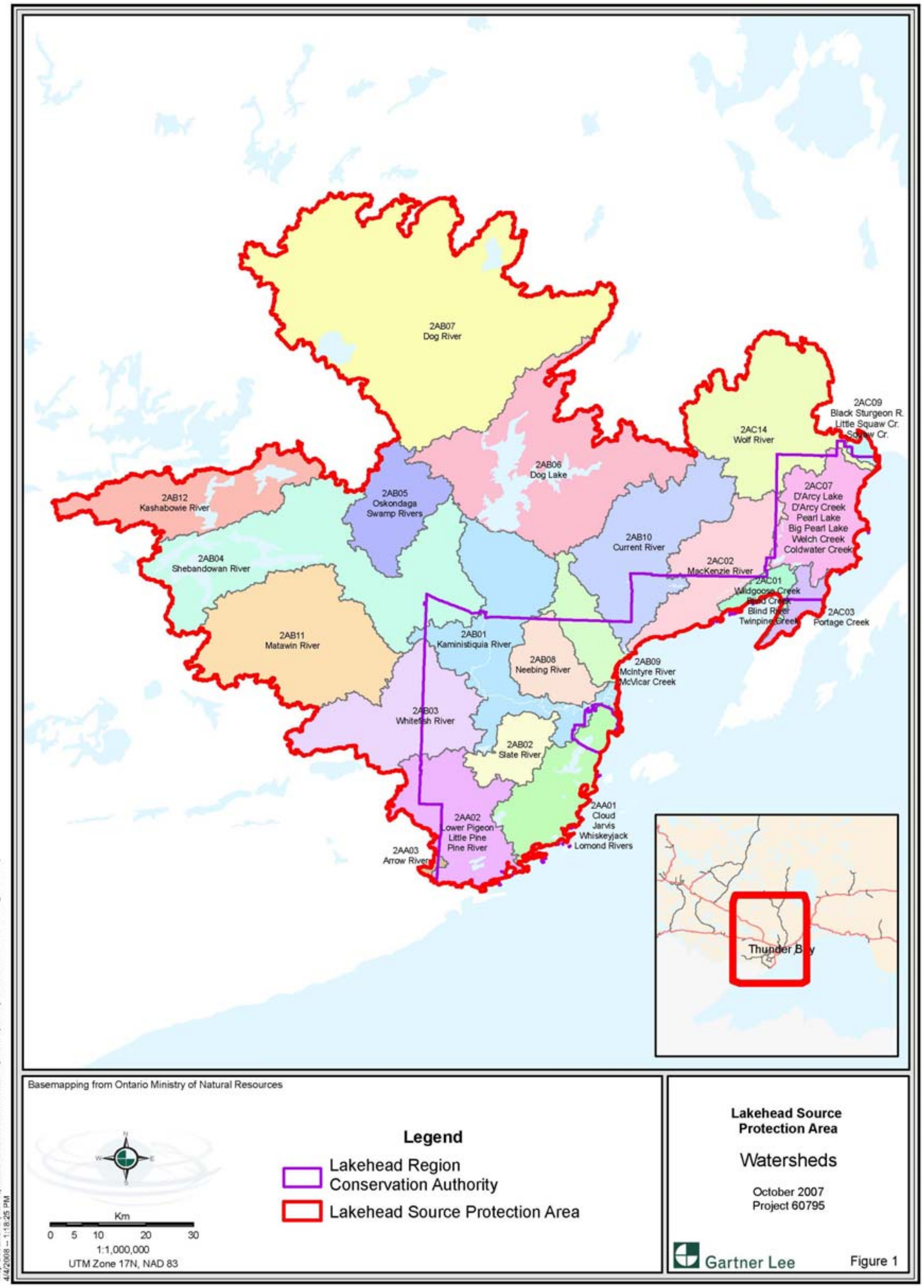


Figure 1. The Watersheds in the Lakehead Source Protection Area

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 Kaministiquia River system is controlled by a number of dams and generating stations.

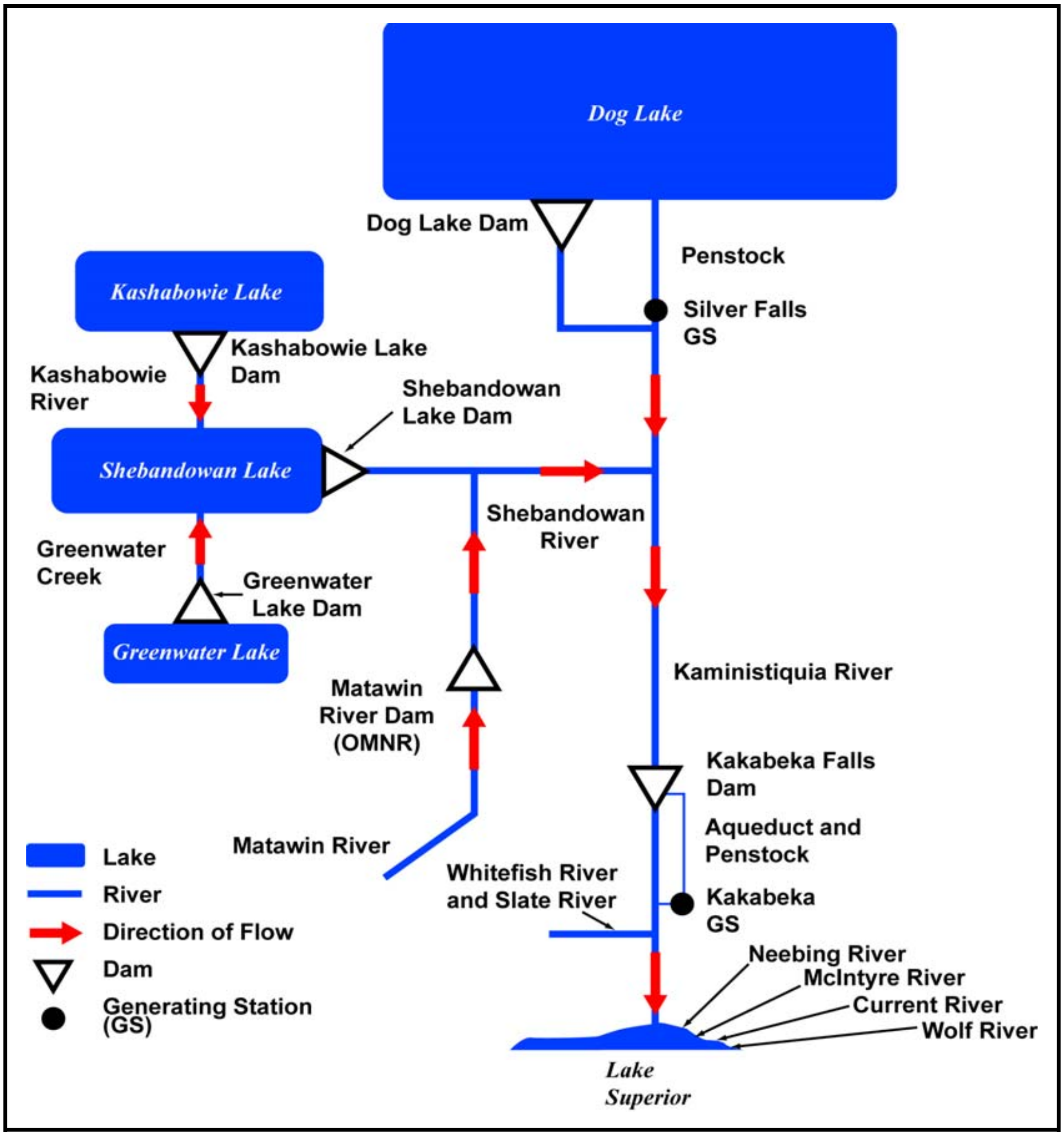
Table 1. Lakehead SPA Quaternary Watersheds and Drainage Areas

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 - Lomond Rivers	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 Lake - D'Arcy Creek - Pearl Lake – Big Pearl Lake - Welch Creek - Coldwater Creek	2AC07	381
	Portage Creek	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.*

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 Lakehead SPA. 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 (e.g., Kaministiquia and Slate River valleys) that are more fine grained (lacustrine silt and clay 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.



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

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

The major urban centre in the Lakehead SPA 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 February 2008. Thereafter, the Loch Lomond water supply may have alternate uses (It is undetermined at this time what the future use of this system will be). 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 Lakehead SPA, 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 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.

2. Objectives of Source Protection Planning of Lakehead SPA

The 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 subwatershed 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;

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.*

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 in the subsurface (as 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.

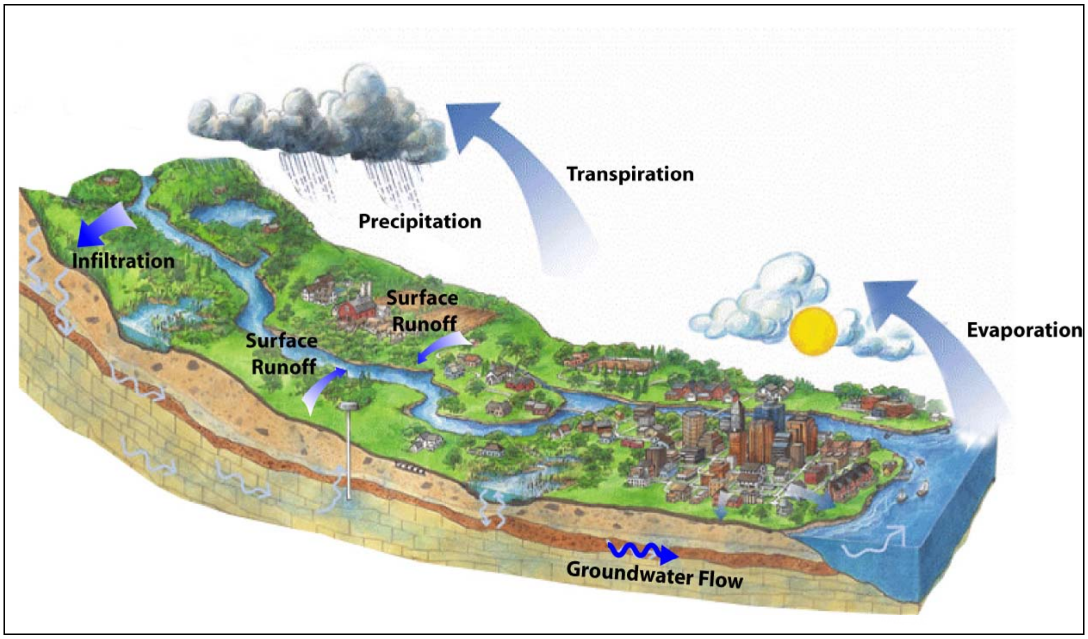


Figure 3. Conceptual Representation of the Hydrologic Cycle in a Watershed (Source: Conservation Ontario)

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 travel 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). During winter months (November through March), evapotranspiration does not appreciably occur in the Lakehead SPA (see the calculated Actual Evapotranspiration in Table A5 in Appendix A). This is due to the fact that during the winter months the seasonal vegetation and deciduous trees do not transpire, and the conifers trees are largely dormant.

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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 as the water moves through the plant body and subsequently is released to the air.