The District Municipality of Muskoka
Bracebridge, Ontario

Floodplain Mapping Technical Report

For

Muskoka Floodplain Mapping Phase III

H372027-0000-2B0-230-0001
Rev. 0
February 15, 2024

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Final Report

Muskoka Floodplain Mapping Phase III - Technical Report

H372027-0000-2B0-230-0001



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				Discipline Lead	**Functional Manager**	**Project Manager**

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Appendix A FHIMP Document

Appendix B Glossary

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1. Introduction

In August 2023, the District Municipality of Muskoka (District) initiated a floodplain mapping study for select river reaches and lakes within its boundaries and bordering Muskoka River watershed. Hatch Ltd. (Hatch) was retained to undertake the study, which represents an update and extension of previous floodplain mapping efforts in the region.

The study (identified as Phase III) builds upon two previous phases of floodplain mapping, which were completed by the District and Hatch in 2020 and 2023, respectively. Included in the scope of this Phase III study is the collection and extension of baseline topographic mapping, hydrologic analyses, hydraulic modeling, and production of updated and new floodplain maps for the selected areas.

Flooding is a significant issue in Muskoka River watershed, including within the District's boundaries, which underlines the importance of producing updated information about particularly vulnerable portions of Muskoka's floodplains. This information will assist in development of future communication and mitigation strategies for areas most affected by lake and riverine flood events. Floodplain mapping also allows municipalities and individuals to identify hazardous lands that are at risk of adverse effects and flood damage.

1.1 The Muskoka River Watershed

The Muskoka River watershed is located in central Ontario's lake country, with the main population centers being Huntsville, Bracebridge, and Gravenhurst. The Muskoka River watershed belongs to the southern Lake Huron/Georgian Bay drainage basin. The watershed originates on the western slopes of Algonquin Provincial Park and extends southwesterly for some 210 km to Georgian Bay, and is 62 km at its widest point.

The watershed encompasses an area of approximately 5,100 km^2 and includes 780 km^2 of lakes (15% of the watershed). The watershed, with its numerous lakes and wetland areas, all interconnected by river reaches, is typical of the many rivers of central Ontario on the Precambrian Shield. The watershed is divided into three subwatersheds: the North and South branches of the Muskoka River, and the Lower Muskoka.

The Muskoka River supports a range of aquatic and wildlife ecosystems and human uses, among them power generation, swimming, canoeing, boating, angling, hunting and trapping, and tourism operations. There are 42 dams on the river system of which 29 are owned/operated by the Ministry of Natural Resources and Forestry (MNRF), and 12 are owned/operated by the waterpower industry. The remaining structure is privately owned/operated.

Most of the waterbodies of interest for this study are located within the Muskoka River watershed. Further descriptions of the Muskoka River watershed are provided in the Phase II floodplain mapping report (Hatch Ltd., 2023a).

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1.2 The Severn River Watershed

The Severn River watershed is located downstream of the Trent River watershed. The Trent River watershed has a drainage area of 18,690 km^2, and includes the 386-km long inland navigation route (Trent-Severn Waterway) (AECOM, 2011a). Both the Severn River watershed and the Trent River watershed are located adjacent to the Muskoka River watershed.

The Severn watershed encompasses an area of approximately 6,160 km^2, which includes several large lakes (most notably Lake Simcoe). In total, 18 lakes over 8 hectares in size are identified throughout the watershed (Muskoka Watershed Council, 2010). The Severn River watershed extends from Balsam Lake to Port Severn (Georgian Bay).

The Severn River watershed is divided into three subwatersheds: Lake Simcoe and Lake Couchiching, Black River, and Severn River. Most of the watershed is crown land (56%), with the remaining land allocated for residential development, transportation corridors, and protected areas (Muskoka Watershed Council, 2010).

Several waterbodies of interest for this study are in the Severn River watershed.

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2. Study Area and Objectives

2.1 Study Area

The study area for this project includes numerous lakes and rivers throughout the District's boundaries, areas within both the Muskoka River watershed and Severn River watershed. Several of these lakes are hydrologically connected, while others are isolated within the watershed.

Phase III study waterbodies are listed in Table 2-1 and shown in Figure 2-1.

Table 2-1: List of Study Areas

Map ID	Study Areas	Watershed
RR	Buck River – Buck Lake to Fox Lake	Muskoka River
SS	Buck River – Fox Lake to Lake Vernon	Muskoka River
TT	Gibson River – Gibson Lake to Musquash River	Muskoka River
UU	Kahshe River – Kahshe Lake to Sparrow Lake	Muskoka River
VV	Bass Lake	Severn River
WW	Bella Lake	Muskoka River
XX	Black Lake	Muskoka River
YY	Brandy Lake	Muskoka River
ZZ	Buck Lake	Muskoka River
A3	Butterfly Lake	Muskoka River
B3	Camel Lake	Muskoka River
C3	Clear Lake	Muskoka River
D3	Clearwater Lake	Severn River
E3	Doe Lake	Severn River
F3	Echo Lake	Muskoka River
G3	Fawn Lake	Muskoka River
H3	Foote Lake	Muskoka River
I3	Fox Lake	Muskoka River
J3	Gibson Lake	Muskoka River
K3	Grandview Lake	Muskoka River
L3	Gull Lake	Muskoka River
M3	Harp Lake	Muskoka River
N3	Heney Lake	Muskoka River
O3	Leonard Lake	Muskoka River
P3	Long Lake	Muskoka River
Q3	Longline Lake	Muskoka River
R3	Longs Lake	Muskoka River
S3	Loon Lake	Severn River

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Map ID	Study Areas	Watershed
T3	Menominee Lake	Muskoka River
U3	Moot Lake	Muskoka River
V3	Morrison Lake	Severn River
W3	Muldrew Lakes (South/Middle/North)	Severn River
X3	Nine Mile Lake	Muskoka River
Y3	Otter Lake	Muskoka River
Z3	Oudaze Lake	Muskoka River
A4	Oxbow Lake	Muskoka River
B4	Oxtongue Lake	Muskoka River
C4	Paint Lake	Muskoka River
D4	Palette Lake	Muskoka River
E4	Pine Lake	Muskoka River
F4	Raven Lake	Severn River
G4	Rebecca Lake	Muskoka River
H4	Ril Lake	Muskoka River
I4	Riley Lake	Severn River
J4	Ripple Lake	Muskoka River
K4	Ryde Lake	Severn River
L4	Silver Lake (Gravenhurst)	Muskoka River
M4	Silver Lake (Muskoka Lakes)	Muskoka River
N4	Sparrow Lake	Severn River
O4	Sunny Lake	Severn River
P4	Thinn Lake	Muskoka River
Q4	Tooke Lake	Muskoka River
R4	Turtle Lake	Severn River
S4	Walker Lake	Muskoka River
T4	Waseosa Lake	Muskoka River

A list of areas where floodplain maps have already been produced, as part of Phases I and II, is provided in Table 2-2. These waterbodies, along with those included as part of the current study (Phase III), are shown in Figure 2-2.

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Table 2-2: List of Previous Study Areas

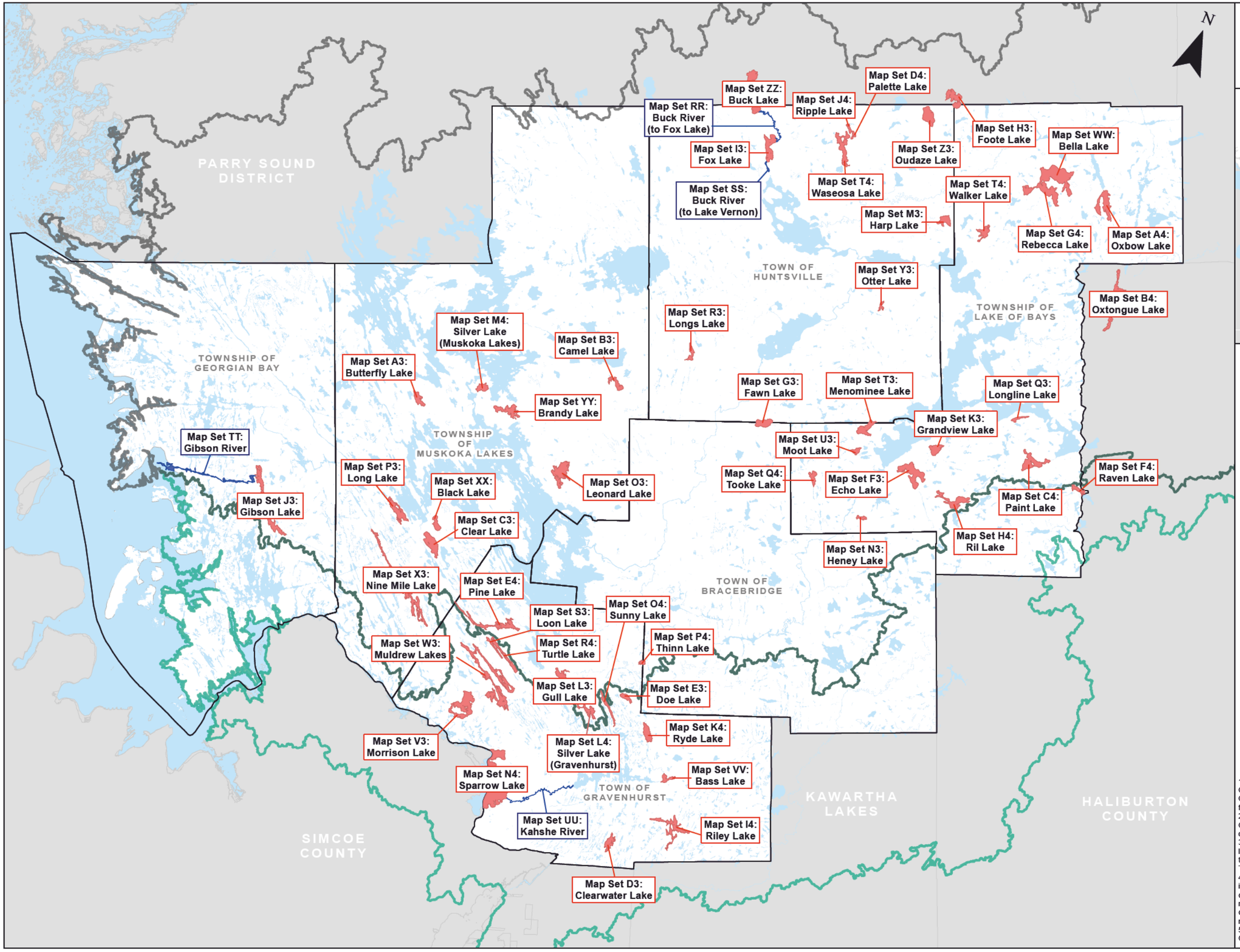
Mapping Completion Year	Map ID	Study Areas
2020[1]	A	Lake Vernon
2020	B	Peninsula Lake
2020	C	Fairy Lake
2020	D	Mary Lake
2020	E	Lake Joseph
2020	F	Lake Rosseau
2020	G	Lake Muskoka
2020	H	Bala Bay
2020	I	Port Severn
2020	J	Spence Lake
2020	K	Big East River
2020	L	Huntsville Narrows
2020	M	South Branch of the Muskoka River at Baysville
2020	N	South Branch of the Muskoka River at Purbrook
2020	O	North Branch of the Muskoka River at Springdale
2020	P	Muskoka River at Bracebridge
2020	Q	Indian River at Port Carling
2020	R	Bala Reach of the Muskoka River
2023[2]	S	North Branch Muskoka River - Bracebridge
2023	T	North Branch Muskoka River - Mary Lake
2023	U	North Branch Muskoka River - Port Sydney
2023	V	South Branch Muskoka River - Fraserburg
2023	W	South Branch Muskoka River - Matthias
2023	X	Moon River
2023	Y	Musquash River
2023	Z	Bent River
2023	AA	Black River
2023	BB	Lake of Bays
2023	CC	Georgian Bay
2023	DD	Twelve Mile Bay
2023	EE	Stewart Lake
2023	FF	Three Mile Lake
2023	GG	Skeleton Lake
2023	HH	Kahshe Lake
2023	II	Gloucester Pool
2023	JJ	Six Mile Lake

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Mapping Completion Year	Map ID	Study Areas
2023	KK	Go Home Lake
2023	LL	Leech Lake
2023	MM	Pine Lake
2023	NN	Prospect Lake
2023	OO	Wood Lake
2023	PP	Healey Lake
2023	QQ	McKay Lake
2023[3]	RR	Hollow River
2023[3]	SS	Kawagama Lake
2023[3]	TT	Trading Bay

Notes:
1. For the mapping completed in year 2020, see technical report (Hatch Ltd., 2020).
2. For the mapping completed in year 2023, see technical report (Hatch Ltd., 2023a).
3. For mapping of Hollow River, Kawagama Lake and Trading Bay, see Phase II addendum report (Hatch Ltd., 2023b).

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THE DISTRICT MUNICIPALITY OF MUSKOKA



Figure 2-1:
Study Areas and Mapped Flood Lines Within the District of Muskoka and Bordering Muskoka River Watershed and Severn River Watershed - Phase III

Legend

- District of Muskoka
- Muskoka River Watershed
- Severn River Watershed
- 2023 Lake Mapping
- 2023 River Mapping
- Waterbody

0 3.75 7.5 15
Kilometres

NOTES:

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2. Contains information used under the Open Government Licence - Ontario. The waterbody boundaries are an approximation of the location of waterbodies in the District of Muskoka derived from open source data.
3. The flood inundation limits shown on this map represents estimated limits associated with modelling of flows and water levels as found in the Hatch report titled Muskoka River Floodplain Mapping Study Technical Report, Document Number H372027-0000-2B0-230-0001.
4. This map is for illustrative purposes only. Information contained herein is not a substitute for professional review or site survey and is subject to change without notice. The District of Muskoka and Hatch Ltd take no responsibility for, nor guarantee, the accuracy of the information contained on this map. Any interpretation or conclusions drawn from this map are the sole responsibility of the user.
5. Spatial reference NAD83 UTM Zone 17, VerticalDatum CGVD28, Geoid Model HT2.0.

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THE DISTRICT MUNICIPALITY OF MUSKOKA



Figure 2-2:
Study Areas and Mapped Flood Lines Within the District of Muskoka and Bordering Muskoka River Watershed and Severn River Watershed - Phase I through Phase III

Legend

- District of Muskoka
- Muskoka River Watershed
- Severn River Watershed
- Phase I Mapping
- Phase II Mapping
- Phase III Mapping

0 5 10 20
Kilometres

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3. The flood inundation limits shown on this map represents estimated limits associated with modelling of flows and water levels as found in the Hatch report titled Muskoka River Floodplain Mapping Study Technical Report, Document Number H372027-0000-2B0-230-0001.
4. This map is for illustrative purposes only. Information contained herein is not a substitute for professional review or site survey and is subject to change without notice. The District of Muskoka and Hatch Ltd take no responsibility for, nor guarantee, the accuracy of the information contained on this map. Any interpretation or conclusions drawn from this map are the sole responsibility of the user.
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2.2 Previous Studies and Current Situation

In the 1980s and 1990s under the FDR Program, several communities in the Province of Ontario with a known history of flooding were mapped and the 1:100-yr return period flood risk zones were designated. Since their creation, these flood risk zone maps have been incorporated into a wide range of land-use policies by provincial and municipal governments, including transportation, land-use development, regulations, and municipal plans. Since the 1990s, little has been done to update the flood mapping for the growing communities.

From 2003 to 2005, the Ontario MNRF conducted studies of water operations and management of water in the Muskoka River watershed to assess the dam operating rules of the time (Hackner-Holden Agreement), and proposed improvements to the operating rules for the environment. Those studies culminated in the Muskoka River Water Management Plan (MRWMP), which was implemented in 2006 (Acres International, 2006, updated 2019). The goal of water management planning is to contribute to the environmental, social and economic well-being of the people of Ontario through the sustainable development of waterpower resources, and to manage these resources in an ecologically sustainable way for the benefit of present and future generations. The study used the historical average range of flows that occurred in the basin to study and develop a new set of water management rules for average hydrologic conditions. The management of floods and flooding is not explicitly a goal of water management planning, and water management plans are not designed to manage floods.

During the spring of 2013, the District of Muskoka encountered flooding across the Muskoka River watershed causing damage to municipal infrastructure and to personal property. In 2016, Muskoka again experienced high water levels along the major rivers and lakes.

Then in the spring of 2019, the Muskoka area experienced a significant freshet where the combination of a melting snowpack and significant April rain combined to cause flood flows of record throughout most of the basin. As people across Muskoka continue to recover from significant rain events and floods, mapping key portions of Muskoka's vulnerable floodplains is essential to ensure appropriate management of the District's shared natural environment and water system and, in turn, the continued sustainability and prosperity of this area in the face of increasing flood events.

Hatch conducted a floodplain mapping study of selected areas within the Muskoka River basin and Port Severn in 2020 (Phase I). The Phase I study area captured the most pressing flooding issues and high-population areas, including sections of river in Huntsville, Bracebridge, Bala Bay and Port Severn, and the largest waterbodies in the District of Muskoka. With the completion of Phase II in 2023, additional sections of the Muskoka River North Branch, Muskoka River South Branch, and the lower lakes area of the Muskoka River watershed were mapped. The Phase II study area also included smaller tributaries and lakes within both the Muskoka River watershed and Severn River watershed. The current study is a continuation of Phase I and Phase II.

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Both the Government of Canada and the Province of Ontario recognize that climate change is having significant impacts and cost implications for Canadians as significant weather events devastate communities; damage homes and businesses; and affect municipal infrastructure not able to manage wide variations in weather. The frequency of high flows in the Muskoka River since 2012 appears to indicate that climate conditions are changing and that an update to hydrologic and hydraulic studies presented in the Flood Damage Reduction report "FDR 43 - Hydrology Study for Major Lakes in the Muskoka River Watershed" (Marshall Macklin Monaghan, 1988) and other FDR reports is warranted, especially because the additional 30 years of flow records allow a better assessment of historical flood frequencies and potential trends throughout the Muskoka basin.

2.3 Study Objectives

The objectives of this study are as follows:

- receive and process baseline topographic and bathymetric data sets collected for use in hydrologic/hydraulic analyses and floodplain mapping
- conduct a hydrologic study of Phase III waterbodies, including a hydrology-focused site visit, and routing of flood hydrographs through lakes
- complete a hydraulic study for Phase III waterbodies, including hydraulic model development and application for river sites; and,
- produce floodplain maps for areas listed in Table 2-1 and shown in Figure 2-1.

The following is a description of the contents in each of the major sections of the report:

- **Section 3 – Background Information Collection/Review:** The background information collection/review section includes descriptions of key reports, hydrometric data sets, climatic data sets, models, and other information used as part of study analyses and mapping.
- **Section 4 – Hydrology Study:** The hydrologic study included review of annual peak flows and water levels recorded at Water Survey of Canada (WSC) gauges, as well as water levels from the Sparrow Lake gauge operated by Parks Canada. Hydrologic analyses also included development of lake-specific numerical models to quantify the response of lakes to snow- and rain-driven runoff events from their respective watershed areas. These models incorporate lake routing capabilities to simulate lake outflows and peak levels during a runoff event. Runoff hydrographs were also generated for use in hydraulic modeling as part of the river hydraulics study. Lastly, the hydrologic study incorporated effects of climate change on peak flow and water level conditions.
- **Section 5 – River Hydraulics Study:** The river hydraulic study included analyses of river hydraulics, through production of floodway and flood-line extents for study rivers. For Phase III, the river hydraulic study consisted of development of numerical models for

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three rivers: *Buck River*, *Kahshe River*, and *Gibson River*. Hydrologic conditions in these models were sourced from the hydrologic analyses.

- **Section 6 – Floodplain Maps:** This study includes production of floodplain mapping for selected flood-prone, high-risk areas. Floodplain maps (for lakes and rivers) allow both area municipalities and individuals to further identify hazardous lands that are at risk of adverse effects and flood damage.

The main deliverables for this study include:

- this technical report on hydrologic and hydraulic analyses, climate change sensitivity, and floodplain mapping
- HEC-HMS hydrologic models for select rivers and lakes
- HEC-RAS river hydraulic models for select rivers
- new and updated floodplain mapping at 1:2500 scale for 25 km of river reaches providing approximately 22 km^2 of floodplain mapping for rivers in a GIS database
- new floodplain mapping at 1:2500 scale for 598 km of lake shorelines providing approximately 222 km^2 of floodplain mapping for lakes in a GIS database.

Note that this study utilizes LiDAR data acquired as part of floodplain mapping Phase I and Phase II. Detail on this LiDAR collection is provided in Section 5.2, and in previous reports (Hatch Ltd., 2020), (Hatch Ltd., 2023a), and (Hatch Ltd., 2023b).

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3. Background Information Collection/Review

3.1 Reports Reviewed

The following documents/reports have been reviewed with an emphasis on any relevant hydrologic and hydraulic information contained therein:

- FDR 43 – Hydrology Study for Major Lakes in the Muskoka River Watershed (Marshall Macklin Monaghan, 1988)
- FDR 44 – Hydrology Study for Major Lakes in the Muskoka River Watershed; Supplementary Wave Runup/Offset Analysis (Marshall Macklin Monaghan, 1989a)
- FDR 45 – Water Management Improvement Study of the Muskoka River System; Technical Report, Volume II; Phase II – Operation of the System; Phase III – Improvement Measures (MacLaren Plansearch Inc., 1985)
- FDR 128 – Hydrology Study for Major Lakes in the Muskoka River Watershed; Supplementary Wave Runup/Offset Analysis (Marshall Macklin Monaghan, 1989b)
- FDR 140 – Proposal for Muskoka River Floodline Mapping, Town of Bracebridge (Paragon Engineering Ltd., 1986)
- FDR 141 – Muskoka River Floodline Mapping – Phase I, Town of Bracebridge – Technical Report (Hydraulics) (Paragon Engineering Ltd., 1988a)
- FDR 142 – Muskoka River Floodline Mapping – Phase I, Town of Bracebridge – General Report (Paragon Engineering Ltd., 1988b)
- FDR 143 – Flood Risk Mapping Muskoka River – Phase II, Town of Bracebridge – Executive Summary and Technical Report (Paragon Engineering Ltd., 1991)
- Floodplain Mapping Technical Report (Phase II) (Hatch Ltd., 2023a)
- Floodplain Mapping Phase II Addendum Report (Hatch Ltd., 2023b)
- Muskoka River Flood Plain Mapping Study (Hatch Ltd., 2020)
- Muskoka River Water Management Plan (Acres International, 2006, updated 2019)
- Severn River Watershed Hydro-Technical Study – Flood Flows Estimation Study Report (AECOM, 2012)
- Technical Guide – River and Stream Systems: Flooding Hazard Limit (MNRF, 2002)
- Trent Severn Waterway: Water Management Study – Water Management Manual (AECOM, 2011b)
- Trent Severn Waterway: Water Management Study – Data Collection and Management Guide (AECOM, 2011a)

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- Trent Severn Waterway: Water Management Study – Review of Water Management Systems and Models (AECOM, 2011c)
- Trent Severn Waterway: Water Management Study – Evaluation of the Current Approach to Water Management (AECOM, 2011d).

3.2 Data and Models

3.2.1 Climate Data

Daily precipitation and temperature data was obtained for three stations in the Muskoka River watershed region. Data from these stations (listed in Table 3-1) was used to characterize climate conditions during 2013 and 2019 flood-of-record events as part of the hydrology study.

Table 3-1: Environment Canada Climate Stations Used in Hydrologic Models

Name	Station ID	Latitude	Longitude	Elevation (m)	Parameters
Algonquin Park East Gate	6080192	45°32’00”	-78°16’00”	397.0	Precipitation, Temperature
Beatrice	6110605	45°08’25”	-79°24’10”	297.2	Precipitation, Temperature
Sprucedale	6117981	45°25’30”	-79°29’15”	337.1	Precipitation

An intensity-duration-frequency (IDF) curve was obtained to quantify rainfall amounts associated with 50-yr, 100-yr, and 200-yr return periods. This IDF curve, obtained for Muskoka A (Environment Climate Change Canada, 2022), was considered reflective of conditions throughout the entire study area.

The 12-hr storm hyetograph for the Timmins storm, along with areal adjustment factors, was obtained from the “Technical Guide – River and Stream Systems: Flooding Hazard Limit” report (MNRF, 2002). Areal adjustment factors for 50-yr, 100-yr, and 200-yr storms were also obtained from this 2002 report by the MNRF.

3.2.2 Hydrology Data

Streamflow/water level and climate records for the study were collected from various sources. WSC data was obtained for select gauges in the Muskoka River watershed and Severn River watershed. These gauges are listed in Table 3-2.

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Table 3-2: Select WSC Gauges in the Muskoka River Watershed and Severn River Watershed

Gauge Number	Gauge Name	Regulation	Type of Flow Data	Drainage Area (km^2)	Data Availability (*Total No. of Years*)
02EB013[1]	Big East River Near Huntsville	Regulated	Instantaneous and Daily	610	1973-2023 (*49 years*)
02EB004[1]	North Branch Muskoka River at Port Sydney	Regulated	Daily	1,410	1915-2023 (*105 years*)
02EB008[1]	South Branch Muskoka River at Baysville	Regulated	Daily	1,400	1941-2022 (*73 years*)
02EB011[1]	Moon River at Highway 400	Regulated	Instantaneous and Daily	4,790	1965-2021 (*56 years*)
02EB012[1]	Musquash River at Highway 400	Regulated	Instantaneous and Daily	N/A	1965-2022 (*56 years*)
02EB014[1]	Oxtongue River Near Dwight	Natural	Instantaneous and Daily	605	1981-2021 (*42 years*)
02EC019[2]	Black River Near Vankoughnet	Natural	Instantaneous and Daily	354	2005-2021 (*16 years*)
02EB003[1]	South Branch Muskoka River at Mathias	Regulated	Daily	1,710	1929-1949 (*19 years*)
02EB002[1]	South Branch Muskoka River at Black Ridge	Regulated	Daily	1,730	1914-1929 (*15 years*)
02EC003[2]	Severn River at Swift Rapids	Regulated	Daily	5,850	1953-2021 (*66 years*)
02EC014[2]	Severn River Above Wasdell Falls	Regulated	Daily	5,310	1978-2022 (*11 years*)
02EC016[2]	Trent Canal Lock 42 Near Washago	Regulated	Daily	N/A	1963-2004 (*38 years*)
02EC918[2]	Severn River Above Sparrow Lake	Natural	Daily	N/A	1993-2004 (*8 years*)
02EC002[2]	Black River Near Washago	Natural	Instantaneous and Daily	1,510	1915-2021 (*107 years*)
02EC022[2]	Head River Near Sebright	Not Listed	Instantaneous and Daily	233	2014-2021 (*7 years*)

Notes:
N/A = not applicable
1. WSC gauge belongs to the Muskoka watershed.
2. WSC gauge belongs to the Severn watershed.

To assist with verification of model results for Timmins storm modeling (see Section 4.3.1), data from additional WSC gauges in the Timmins region of Ontario were obtained. These gauges (Table 3-3) were selected specifically because they showed a peak flow in early

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September 1961, meaning these peak flows could be definitively characterized as a response to the Timmins storm.

Table 3-3: Select WSC Gauges in the Timmins Region

Gauge Number	Gauge Name	Regulation	Type of Flow Data	Drainage Area (km^2)	Data Availability (*Total No. of Years*)
04LB001	Mattagami River at Smooth Rock Falls	Regulated	Daily	10,000	1920-1997 (*76 years*)
04LD001	Groundhog River at Fauquier	Regulated	Daily	12,400	1920-2021 (*87 years*)
04LF001	Kapuskasing River at Kapuskasing	Regulated	Daily	6,760	1918-2021 (*89 years*)
04LG001	Mattagami River at Smoky Falls	Regulated	Daily	34,700	1926-1963 (*37 years*)
04MD002	Frederick House River at Frederick House Lake Dam	Regulated	Daily	2,870	1938-1994 (*54 years*)

Daily water level data for Sparrow Lake (total drainage area of 5,701 km^2; according to a delineation using the Ontario Watershed Information Tool (OWIT)) was obtained through direct request to Parks Canada. This data is available from 1988 to present (2023), which provided the basis for deriving static flood levels for floodplain mapping through flood frequency analysis.

Drainage areas for each study water body are provided in Section 4.

3.2.3 Models

Model files for the Muskoka River watershed from both HYMO (Acres International, 2006, updated 2019) and HEC-HMS (Hatch Ltd., 2023a) models of the Muskoka River watershed were reviewed to inform parameter selection.

SWAT model files and associated report (GHD, 2022) were referenced to acquire scaling factors for regional peak flow estimates (where needed).

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4. Hydrology Study

Similar to hydrologic analyses completed for Phase I (Hatch Ltd., 2020) and Phase II (Hatch Ltd., 2023a) of floodplain mapping by the District, the focus of the hydrologic analysis for Phase III is to derive flow and water level estimates for the regulatory flood. The regulatory flood is a large flood that is considered reasonably characteristic of what could be expected to occur within a particular water body.

All study lakes and rivers for Phase III are located within Zone 3 of the MNRF flood hazard criteria zones, meaning that the regulatory flood is the greater of the following:

- a flood resulting from the Timmins storm
- 100-yr flood
- flood of record.

In this study, the Timmins storm, 100-yr rainfall, and flood-of-record events (both 2013 and 2019) were evaluated for each study water body. In each case, the approach that yielded the highest water level or flow (as appropriate) was the regulatory event.

Two additional flood events were also assessed: 50-yr return period flood and the climate change proxy. The approach to derive all flood events (regulatory flood, 50-yr flood, and climate change proxy) are described in the following sections.

4.1 Hydrological Modeling Methodology

A common methodology was applied to the greatest extent possible to derive peak flow and water level estimates amongst study waterbodies. However, site specific considerations (e.g., characteristics of lake outlets) were accounted for as part of these analyses.

For cases where historical monitoring data was available, flood frequency analysis on historical data was applied (where possible). For waterbodies without historical monitoring data, site-specific hydrologic models were developed. As part of other studies, hydrological models have been developed for all, or parts of, the Muskoka River basin as follows:

- HYMO model of the complete basin (Marshall Macklin Monaghan, 1988)
- modified version of the MMM HYMO (Acres International, 2006, updated 2019) [Note that this model includes both winter and summer runoff settings.]
- HEC-HMS model of the Muskoka River basin to Huntsville Dam (KGS Group, 2021) [Note that this model was based on the Acres HYMO model, with some small changes to suit the HEC-HMS architecture.]
- HEC-HMS model of the Muskoka River basin to Mary Lake Dam (D.M. Wills Associates Ltd., 2021) [Note that this HEC-HMS model was the same as that developed by KGS.]

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- HEC-HMS model of the Muskoka River basin to Moon River and Musquash River (Hatch Ltd., 2023a). [Note this model is based on the 2001 Acres model structure.]

With some exceptions, these hydrologic models lack the detail required to assess the small waterbodies identified for this study. For instance, the most recent model (Hatch Ltd., 2023a) includes explicit representation of only three study waterbodies (or their drainage areas): *Walker Lake, Oxtongue Lake*, *Buck River*, *Buck Lake*, and *Fox Lake*. For these waterbodies, the 2023 HEC-HMS model (Hatch Ltd., 2023a) was adapted to derive flow and water level estimates for these lakes.

The following sections describe development of site-specific models and scenario design to derive flows and levels for the regulatory flood, 50-yr, and climate change proxy events. [Note: Development of these models utilized calibrated parameter values and other information from both the Acres (2001) and Hatch (2023) models. Additional calibration was applied to Oxtongue Lake basin, as described in Section 4.2.2.35.]

4.1.1 Hydrologic Model – HEC-HMS

Hydrologic modeling for this study made use of the U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) software (Version 4.11). HEC-HMS is a standard tool for hydrologic modeling, and has been widely used for lake and river sites throughout Canada. This precipitation-runoff model can represent snow accumulation and melt, infiltration, and runoff processes, as well as river and reservoir routing through a variety of user-selected model processes.

4.1.2 Study Lakes

A list of the lakes included in the Phase III study scope, along with their key basin characteristics is presented in Table 4-1. This table is referred to in more detail throughout Section 4.1.

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Table 4-1: Study Waterbodies

Model ID	Waterbodies (Listed Downstream to Upstream for Each Model ID)	Total Upstream Drainage Area of Water Body (km^2)	Incremental Drainage Area of Water Body (km^2)	Historical Water Level/Flow Availability	Dam Regulation	Summer Curve Number (CN)[1,2]	Winter Curve Number (CN)[1,3]	Sub-Basin Time of Concentration (hrs)	Sub-Basin Mean Slope (%)	Sub-Basin Longest Flow Path Length (km)
HYDRO-1	Gibson River	192.4	23.1	NO[4]	NO[4]	70	85	3.9	19.0	16.4
	Gibson Lake	169.3	131.8	NO	NO	70	85	11.1	4.9	30.7
	Nine Mile Lake	37.5	37.5	NO	NO	70	85	13.8	1.8	21.6
HYDRO-2	Kahshe River	245.7	26.9	NO	NO	63	79	6.8	5.8	18.6
	Kahshe Lake	218.8	218.8	NO	YES	63	79	17.4	5.2	55.8
HYDRO-3	Clear Lake	2.4	2.4	NO	NO	75	88	1.9	3.4	2.8
HYDRO-4	Black Lake	10.6	10.6	NO	NO	75	88	4.3	3.4	7.6
HYDRO-5	Pine Lake	23.9	23.9	NO	NO	62	75	6.8	4.6	10.3
HYDRO-6	Morrison Lake	72.3	17.3	NO	NO	62	79	5.1	5.0	7.5
	South Muldrew Lake	55.0	43.4	NO	YES	62	79	9.0	5.2	15.8
	Middle Muldrew Lake			NO	YES	62	79			
	North Muldrew Lake			NO	YES	62	79			
	Turtle Lake	11.6	1.4	NO	NO	62	79	3.0	6.4	4.6
	Loon Lake	10.2	10.2	NO	NO	62	79	6.0	6.6	11.0
HYDRO-7	Clearwater Lake	1.9	1.9	NO	NO	63	80	2.6	2.5	2.3
HYDRO-8	Riley Lake	42.4	42.4	NO	NO	63	80	7.6	4.9	12.6
HYDRO-9	Bass Lake	171.9	89.7	NO	NO	63	79	13.0	5.1	25.6
	Ryde Lake	82.2	71.2	NO	NO	63	79	9.8	4.6	16.9
	Doe Lake	11.0	11.0	NO	NO	63	79	6.6	4.7	10.3
HYDRO-10	Sunny Lake	2.1	2.1	NO	NO	63	80	2.4	7.7	4.0
HYDRO-11	Gull Lake	13.4	13.4	NO	YES	63	80	3.8	11.5	9.1
	Silver Lake (Gravenhurst)			NO	YES	63	80			
HYDRO-12	Thinn Lake	1.9	1.9	NO	NO	63	80	1.9	6.3	2.6
HYDRO-13	Leonard Lake	2.0	2.0	NO	NO	75	88	1.2	10.1	2.9
HYDRO-14	Brandy Lake	39.9	39.9	NO	NO	75	88	3.7	11.7	13.5
HYDRO-15	Silver Lake (Muskoka Lakes)	1.2	1.2	NO	NO	72	86	0.6	12.1	1.4
HYDRO-16	Butterfly Lake	4.2	4.2	NO	NO	75	88	1.3	10.4	3.2
HYDRO-17	Camel Lake	3.1	3.1	NO	YES	72	86	2.3	5.1	4.0
HYDRO-18	Longs Lake	11.6	11.6	NO	NO	72	86	3.3	7.0	7.5
HYDRO-19	Fawn Lake	17.2	17.2	NO	NO	66	82	4.2	8.9	7.4
HYDRO-20	Moot Lake	6.5	6.5	NO	NO	69	84	2.4	4.9	3.7
HYDRO-21	Tooke Lake	1.7	1.7	NO	NO	69	84	1.3	6.7	2.2
HYDRO-22	Heney Lake	1.1	1.1	NO	NO	63	80	1.3	5.9	1.6

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Model ID	Waterbodies (Listed Downstream to Upstream for Each Model ID)	Total Upstream Drainage Area of Water Body (km^2)	Incremental Drainage Area of Water Body (km^2)	Historical Water Level/Flow Availability	Dam Regulation	Summer Curve Number (CN)[1,2]	Winter Curve Number (CN)[1,3]	Sub-Basin Time of Concentration (hrs)	Sub-Basin Mean Slope (%)	Sub-Basin Longest Flow Path Length (km)
HYDRO-23	Echo Lake	27.0	23.7	NO	NO	63	80	7.9	11.8	23.4
	Grandview Lake	3.3	3.3	NO	NO	63	80	0.8	11.8	1.4
HYDRO-24	Ril Lake	17.1	17.1	NO	NO	63	80	12.6	4.1	21.5
HYDRO-25	Paint Lake	19.5	19.5	NO	NO	63	80	5.5	17.3	18.6
HYDRO-26	Raven Lake	68.1	68.1	NO	YES	63	80	16.0	14.3	62.9
HYDRO-27	Longline Lake	2.0	2.0	NO	NO	69	84	1.0	16.3	2.4
HYDRO-28	Oxtongue Lake	594.1	561.4	NO	NO	63	80	8.7	15.4	78.2
	Oxbow Lake	32.8	32.8	NO	NO	66	82	3.6	13.4	10.3
HYDRO-29	Rebecca Lake	31.7	31.7	NO	NO	64	81	6.1	12.4	17.8
	Bella Lake			NO	NO	64	81			
HYDRO-30	Walker Lake	3.1	3.1	NO	YES	72	86	1.3	13.8	3.5
HYDRO-31	Harp Lake	5.5	5.5	NO	NO	72	86	1.9	16.3	6.5
HYDRO-32	Oudaze Lake	13.9	13.9	NO	NO	72	86	3.2	10.5	75.2
HYDRO-33	Foote Lake	11.1	11.1	NO	NO	72	86	2.8	11.9	8.7
HYDRO-34	Ripple Lake	16.3[5]	0.49	NO	NO	64	81	0.6	12.3	1.0
	Waseosa Lake	14.9	14.9	NO	NO	64	81	2.9	10.5	6.2
HYDRO-35	Palette Lake	0.9	0.9	NO	NO	64	81	0.9	9.4	1.5
HYDRO-36	Fox Lake (including Buck River)	210.9	66.8	NO	YES	64	81	10.2	11.2	31.9
	Buck Lake	144.1	144.1	NO	YES	64	81	14.0	8.8	40.8
HYDRO-37	Otter Lake	0.9	0.9	NO	NO	72	86	1.2	6.0	1.9
HYDRO-38	Long Lake	3.8	3.8	NO	NO	70	85	2.0	4.1	4.5
HYDRO-39	Menominee Lake	11.2	11.2	NO	NO	69	84	2.7	9.3	6.4
N/A[6]	Sparrow Lake	5,701	5,701	YES (Parks Canada)	NO	N/A	N/A	N/A	N/A	N/A

Notes:
1. CN values sourced from regional watershed in the HYMO model (Acres International, 2006, updated 2019) that intersects or is closest to the water body.
2. Summer CN values applied for rainfall only simulations (50 years, 100 years, and Timmins storm).
3. Winter CN values applied for snow and rainfall simulations (i.e., 2013 and 2019 floods of record).
4. Gibson River receives inflows from Go Home Lake Dam, which regulates Go Home Lake. WSC data for Go Home Lake levels obtained from station 02EB023.
5. The upstream drainage area of Ripple Lake includes Palette Lake though Palette Lake was modeled separately.
6. N/A = not applicable (Sparrow Lake hydrology determined using historical water levels).

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4.1.3 Model Setup

4.1.3.1 Watershed Characteristics

As a first step to set up the hydrologic models, characteristics of a particular water body's drainage basin were defined. Key basin characteristics include drainage area, general topography and landcover trends, and presence or absence of flow regulation.

Basin boundaries for waterbodies listed in Table 4-1 were derived using a combination of ArcGIS Pro version 3.0.4 software and OWIT (MNRF, 2023). The outlet of each water body (which is effectively the outlet of its respective basin) was identified by thorough review of the following: (1) OWIT stream mapping, (2) historical lake bathymetry mapping from OMNR, and (3) aerial imagery. The outlet for select waterbodies was also verified as part of a field visit conducted by Hatch in fall 2023 (Hatch Ltd., 2024).

To delineate watersheds via ArcGIS Pro, a digital elevation model (DEM) was required to determine the flow paths that comprise the basin's drainage area, with a higher resolution DEM generally providing the most accurate estimate of drainage area boundaries. High-resolution LiDAR (see Section 5.2) was applied for each study lake (where available), and was combined with publicly-available DEM data to fill any gaps in coverage for a particular water body's basin.

ArcGIS Pro has built-in tools that calculate the sinks and sources of water within the DEM, the flow direction and accumulation, and finally the watershed area. All calculations are performed based on the elevation of the terrain. For waterbodies located in areas where the DEM resolution was lower, the drainage area was cross-checked with OWIT watershed area estimates, as well as field visit and satellite imagery. A summary of the drainage areas for each lake is provided in Table 4-1.

Upon delineation of each watershed, additional basin information, such as the presence of flow regulation control structures and proximity to other study Phase III waterbodies, was gathered to aid in the next steps of model development. Waterbodies within the same watershed were modeled together since the upstream waterbodies will influence the hydrologic response of downstream waterbodies. Instances of these groupings are indicated by multiple lakes listed under the same model ID in Table 4-1.

Of the Phase III waterbodies, the following are influenced by dams and other flow control structures:

- Buck Lake, Fox Lake, South/Middle/North Muldrew lakes, Gull Lake, Camel Lake, and Raven Lake outlet flows are controlled by dams
- Gibson River receives adjacent flows from Go Home Lake Dam
- Gibson Lake is separated from Six Mile Lake by Hungry Bay Dam
- Kahshe River inlet flows are from Kahshe Lake dams.

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4.1.3.2 *Rainfall Processes*

In HEC-HMS, rainfall is incorporated into model simulations through use of a rainfall hyetograph, which is time-series of rainfall intensity. Design and application of these rainfall hyetographs is discussed in more detail in Section 4.1.4.

4.1.3.3 *Snowmelt Processes*

In addition to rainfall processes, snowmelt processes are an important aspect of modeling both 2013 and 2019 flood-of-record events (see Section 4.1.4.1).

In HEC-HMS, snowmelt processes are modeled via a temperature index method, which uses parameters such as the temperature lapse rate, melt rate function, and cold rate function. The temperature index method simplifies heat transfer calculations to estimate how much snow would accumulate or melt based on the air temperature and land surface temperature. The temperature index method requires air temperature data and calibrated parameters to yield a satisfactory model performance.

For Phase III models, calibrated temperature index parameters were obtained from the Phase II HEC-HMS model of the Muskoka River watershed (Hatch Ltd., 2023a). Average elevations for each basin were updated based on analysis of topographic data in ArcGIS Pro. The purpose of this basin elevation is to provide a reference elevation for comparison with the elevation of the temperature monitoring gauge site. When these elevations are compared, an adjustment to temperature records can be made based on a defined lapse rate (i.e., rate at which temperature changes with elevation).

4.1.3.4 *Runoff Processes*

The hydrologic models developed for this study employed the Soil Conservation Service (SCS) unit hydrograph method to simulate runoff processes within each watershed basin. The SCS unit hydrograph method employs a dimensionless, curvilinear unit hydrograph that is based on measured rainfall and runoff data for small agricultural watersheds throughout the United States, under a range of landcover conditions.

Despite its development in agricultural regions, the SCS unit hydrograph method has been successfully adapted for studies sites globally, including the Muskoka River watershed (Acres, 2001), (Hatch Ltd., 2023a).

To convert a rainfall hyetograph to a runoff hydrograph, the SCS unit hydrograph method requires two main parameters: (1) unit hydrograph type, and (2) watershed lag time. The unit hydrograph type for this study was selected as the standard PRF 484 unit hydrograph, and the watershed's lag time was calculated using the following equation:

$$Lag = \frac{227}{10^5}\left(\frac{l^{0.8}\left(\frac{1000}{CN} - 9\right)^{0.7}}{Y^{1/2}}\right)$$

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where,

Lag = the lag time (hrs)
l = the longest flow path length (m)
Y = the average watershed land slope (%)
CN = the SCS curve number (CN) that is based on the predominant landcover and hydrologic soil group classification of the basin.

The CN applied to each study basin was obtained from the corresponding regional basin in the Acres HYMO model (2001) that the study basin is located. If a study basin fell outside the modeling domain of the Acres HYMO model, CNs were obtained from the closest regional basin in the HYMO model.

Two sets of calibrated CN values were available in the Acres HYMO model: (1) winter CN, and (2) summer CN. Winter CN values were applied to simulate flood-of-record events (which included snowmelt; see Section 4.1.4.1), while all other events (i.e., 50 years through 200 years, Timmins storm) were simulated using summer CN values.

4.1.3.5 Lake Routing

For river sites, the runoff hydrograph generated by each study basin served as input to the hydraulic model as part of the river hydraulics study (see Section 5).

For lake sites, the runoff hydrograph was routed in HEC-HMS using a combination of stage-storage and stage-discharge relationships. When combining a runoff hydrograph with these relationships, HEC-HMS performs routing calculations to yield time-series of lake water surface elevation and outflow. Derivation of stage-storage and stage-discharge relationships are described in the following sections.

4.1.3.5.1 Stage-Storage Relationships

If a water body is regulated by a dam, stage-storage relationships were obtained primarily from operations, maintenance, and systems (OMS) manuals for that dam. If the water body is not regulated by a dam, or information reported in OMS manuals requires supplemental detail, the following approach was followed to derive a stage-storage curve:

- Using the water level in the LiDAR as a reference elevation, a stage-storage relationship for water body both above and below this elevation was derived.
  - For storage below the reference elevation, assume the surface area of the water body remains constant. This approach yields a linear relationship between lake storage and water level.
  - For storage above the reference elevation, employ the *Stage-Storage* tool in ArcGIS Pro to derive a stage-storage curve. The *Stage-Storage* tool was developed in the Model Builder application in ArcGIS Pro, and determines the surface area and volume of the terrain at user-specified terrain elevations. For each of the sub-basins, the terrain elevations were specified to start at the lake surface elevation and end at

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an arbitrary maximum elevation, taken as the highest terrain elevation within the watershed basin. Unlike the first section of the curve, this section will be non-linear due to the shape of the floodplain around the lake.

An illustration of the stage-storage curve (both sections) is shown in Figure 4-1.

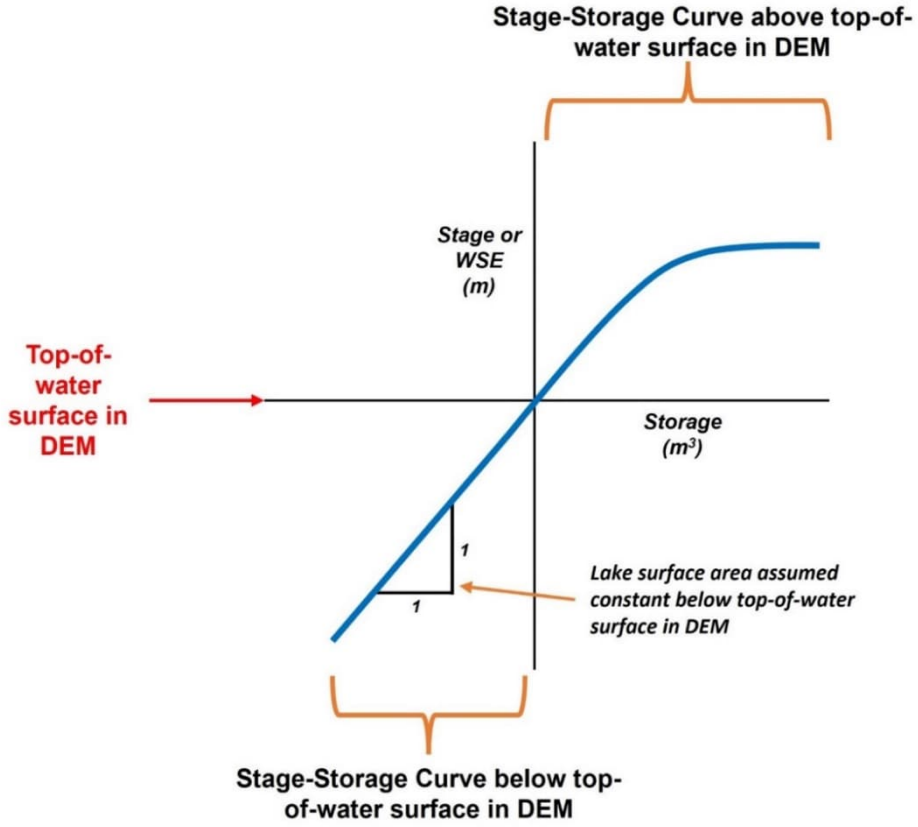


Figure 4-1: Stage-Storage Curve Derivation for Waterbodies, Both Above and Below Top-of-Water Surface in DEM

4.1.3.5.2 Stage-Discharge

If a water body is regulated by a dam, stage-discharge relationships were obtained primarily from OMS manuals for that dam. For regulated waterbodies, the stage-discharge curves were determined for both summer and winter season, based on the different operating rules outlined in the OMS.

If the water body is not regulated by a dam, the following approach was followed to derive a stage-storage curve:

1) For unregulated waterbodies, the relationship between lake level and lake outflow ($Q_{outflow}$) was estimated using a broad-crested weir equation:

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$$Q_{outflow} = CLH^{\frac{3}{2}}$$

where,

L = the width of the channel at the outlet of the water body (m)
H = the water depth above the reference elevation (m) (i.e., the water level in the LiDAR)
C = the weir coefficient (1.6 for a broad-crested weir).

The width of the outlet channel from the water body was estimated using aerial imagery as well as any accompanying notes from the site visit (if available) (Hatch Ltd., 2024).

If site visit observations (Hatch Ltd., 2024) indicated that lake levels were controlled by a feature that is not best described by a broad-crested weir equation (e.g., a culvert), a suitable stage-discharge relationship was derived. These site-specific considerations are described in Section 4.2.

4.1.4 Scenario Assessment

The hydrologic models developed for this study were utilized in both continuous mode and event mode:

- A continuous-mode model makes no predefined assumptions about the condition of the basin at the start of the flood event, and instead simulates the response of the basin based on actual precipitation and temperature data from local climate stations over a longer timeframe before and after the flood event of interest. Both 2013 and 2019 flood-of-record events were simulated using continuous mode.
- An event-mode model focuses on conditions related to a specific design storm event. All rainfall driven events (i.e., 50 years, 100 years, and Timmins storm) were simulated using event mode.

4.1.4.1 Flood-of-Record (2013 and 2019) Events

The 2013 and 2019 floods of record are both characterized as spring events and observed heavy rainfall on melting snowpacks. The 2013 event had a heavier rainfall and smaller snowpack compared to 2019. As a result, the 2013 event produced higher flood peaks in the upper Muskoka River watershed compared to the 2019 event, which produced higher flood peaks in the lower Muskoka River watershed due to its higher regulating storage.

The 2013 and 2019 flood-of-record events were modeled as continuous models. The simulation periods started on October 15, coinciding with the date most stop logs switch from summer to winter settings, and ended on June 30 to capture the entire receding wave of the flood. Available climate data used for the 2013 and 2019 events are summarized in Table 3-1. For each water body, one climate station from Table 3-1 was assigned to its basin to provide temperature and precipitation inputs during both 2013 and 2019 simulations.

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Model parameters for 2013 and 2019 simulations were sourced from the watershed-scale Muskoka River watershed HEC-HMS model (Hatch Ltd., 2023a), except for those that are specific to a water body (e.g., drainage area). These parameters are considered reflective of the Muskoka River watershed, as this watershed-scale model was calibrated to historical data. Further details on the watershed-scale model and its calibration are provided in the Phase II report (Hatch Ltd., 2023a).

4.1.4.2 50-Yr, 100-Yr and 200-Yr Events

The 50-yr, 100-yr and 200-yr events refer to a flood of a particular magnitude that has a statistical probability of 2%, 1% and 0.5%, respectively, of occurring within any particular year. Flows and water levels associated with these events are determined in this study either using frequency analysis on observed data, or by simulating a 50-yr, 100-yr or 200-yr rainstorm using a hydrologic model. The latter approach is predicated on the assumption that a certain return period rainstorm will result in a flood of the same return period.

The 50-yr, 100-yr and 200-yr flows and water levels for each water body were derived using a rainfall hyetograph. The total rainfall depth for this event was estimated based on IDF curves for Muskoka A (Environment Climate Change Canada, 2022). The IDF curves provide the total rainfall over different storm durations at different flood return periods and are shown in Figure 4-2 and summarized in Table 4-2. These IDF curves did not initially include the 200-yr return period, and the 200-yr return period rainfall values were estimated by extrapolating the IDF curves for each storm duration.

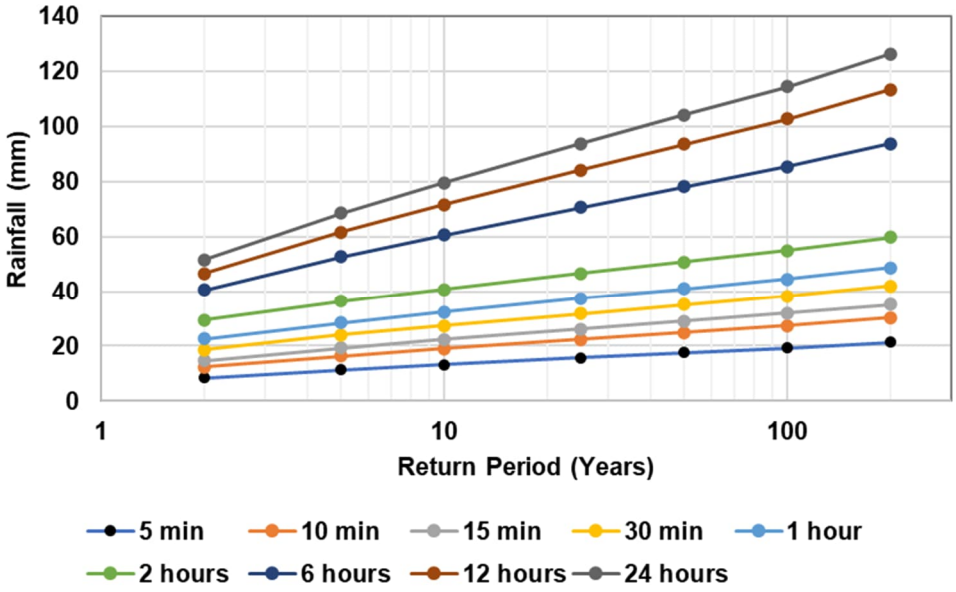


Figure 4-2: IDF Curves for Muskoka River Basin for Various Storm Durations

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Table 4-2: IDF Curve Data

Storm Duration	Return Period (years)						
	2	5	10	25	50	100	200
5 minutes	8.4	11.3	13.2	15.7	17.5	19.2	21.3
10 minutes	12.4	16.4	19.1	22.4	24.9	27.4	30.2
15 minutes	14.7	19.3	22.3	26.2	29.1	31.9	35.2
30 minutes	18.7	24.0	27.4	31.8	35.0	38.3	42.0
1 hour	22.6	28.4	32.3	37.3	40.9	44.5	48.6
2 hours	29.5	36.3	40.8	46.5	50.7	54.9	59.7
6 hours	40.6	52.6	60.5	70.6	78.0	85.4	93.8
12 hours	46.6	61.6	71.6	84.1	93.5	102.7	113.3
24 hours	51.6	68.5	79.6	93.7	104.2	114.5	126.4

Event duration (5 minutes through 24 hours; see Figure 4-2) were selected based on the time of concentration (T_c) of the basin. T_c, which represents the time required for runoff to travel from the hydraulically most distance point of the watershed, was estimated as a function of lag time (Natural Resources Conservation Service, 2010):

$$T_c = \frac{Lag}{0.6}$$

An areal adjustment to the rainfall amount was applied to each sub-basin, to scale the storms according to the different basin drainage areas (MNRF, 2002).

Once the total rainfall depth is established (based on event return period and T_c), a synthetic rainfall hyetograph is developed using the SCS Type II storm distribution (US Department of Agriculture (USDA), 1986). The SCS Type II storm distribution has been widely applied throughout both Ontario and Canada, in settings like the Muskoka River watershed.

4.1.4.3 Timmins Storm Events

The Timmins storm was a short duration, intense rainfall event that occurred near Timmins in September 1961, when basin conditions were dry. The Timmins storm is generally dominant for small to medium size watersheds.

The rainfall pattern of the Timmins storm was obtained from the “Technical Guide – River and Stream Systems: Flooding Hazard Limit” (MNRF, 2002). Table 4-3 and Table 4-4 are reproductions of Table D-4 and Table D-5 (MNRF, 2002), which reflect the Timmins storm and areal adjustment factors, respectively.

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Table 4-3: Timmins Storm Point Rainfall

Hour	Point Rainfall (mm)
1	15
2	20
3	10
4	3
5	5
6	20
7	43
8	20
9	23
10	13
11	13
12	8
Total	**193**

Table 4-4: Timmins Storm Rainfall Areal Adjustment Factors

Drainage Area (km^2)		Percent of Point Rainfall (%)
From	To	
0	25	100
26	50	97
51	75	94
76	100	90
101	150	87
151	200	84
201	250	82
251	375	79
376	500	76
501	750	74
751	1,000	70
1,001	1,250	68
1,251	1,500	66
1,501	1,800	65
1,801	2,100	64
2,101	2,300	63
2,301	2,600	62
2,601	2,900	58

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Drainage Area (km²)		Percent of Point Rainfall (%)
From	To	
2,901	5,200	56
5,201	6,500	53
6,501	8,000	50

For Timmins storm simulations, summer CN values were applied for each basin (see Table 4-1). Further, no snowmelt was included for these simulations. For waterbodies regulated by dams, stage-discharge curves were set to reflect summer operating conditions.

4.1.4.4 Climate Change Uncertainty

Climate change is expected to have a wide variety of impacts on the water resources of the Muskoka region. Included among these is potential increases to the magnitude and frequency of floods.

To account for climate change uncertainty related to flood magnitude, this study incorporates guidance from the Flood Hazard Identification and Mapping Program (FHIMP) (see Appendix A). The applied approach to account for climate change uncertainty depends on which event governs as the regulatory flood:

- **If the regulatory flood is the 100-yr event** – select a climate change proxy event equal to the 200-yr flood. The 200-yr flood is estimated either based on analysis of historical flow/level records, or by simulating the 200-yr rainfall hyetograph using the method described in Section 4.1.4.2. To implement the methodology in Section 4.1.4.2, IDF curves were extrapolated beyond their 100-yr rainfall value to yield an estimate for the 200-yr return period (see Figure 4-2 and Table 4-2 for rainfall estimates).
- **If the regulatory flood is the Timmins storm** – select a climate change proxy flood resulting from a scaled Timmins storm hyetograph. In this case, the Timmins storm is scaled by a factor derived from the methodology outlined in Appendix A. The RCP4.5 scenario data for the time horizon of 2050 was collected from climatedata.ca for Muskoka A (i.e., the location corresponding with the historical IDF curve). This scenario corresponded to a mean annual temperature change of 2.9°C which was input into the equation below to determine the climate change factor for rainfall intensity.

$$\frac{R_P}{R_C} = 1.07^{\Delta T}$$

where,

R_P = the future rainfall intensity
R_C = the historic rainfall intensity
ΔT = the long-term annual mean temperature change.

A climate change factor of 1.22 was derived. The scaled Timmins storm is derived by multiplying all rainfall values by 1.22.

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- **If the regulatory flood is the flood of record** – select a climate change proxy flood resulting from scaling precipitation and temperature records. To account for the cumulative effects of changing precipitation and temperature records simultaneously, two scenarios are considered, and the one resulting in the largest flood governs as the climate change proxy:
  - *Scenario 1*: Scale air temperature and precipitation throughout the entire winter (either 2012-2013 or 2018-2019 in the case of the Muskoka River watershed) using guidance from the FHIMP guidance document (Appendix A). Evaluate peak spring flows at the location of interest.
  - *Scenario 2*: Leave air temperature records unchanged, and only scale precipitation records for the immediate time-period (i.e., days or weeks) leading up to the peak flood-of-record flows in the spring. Evaluate peak spring flows at the location of interest.

The resulting flood from this analysis is referred to as the 'climate change proxy'.

4.2 Hydrologic Study Results

The following is a description of the water levels and flows for study waterbodies. Site-specific considerations (e.g., stage-discharge curve design) are also included.

While all three regulatory flood candidate events (100 years, Timmins storm, flood of record) were evaluated for each water body, only results for the regulatory flood are presented in this section.

4.2.1 Rivers

4.2.1.1 Gibson River

Gibson River has a total upstream drainage area of 192 km^2 (excluding the drainage area of Go Home Lake Dam), which includes Gibson Lake and Nine Mile Lake. Gibson River receives inflows from three locations: (1) outflow from Gibson Lake, (2) local runoff from lands surrounding Gibson River, and (3) outflow from Go Home Lake Dam.

For inflow locations (1) and (2), flow estimates were obtained from the Gibson River hydrologic model (HYDRO-1; see Table 4-1). The stage-discharge relationship in the hydrologic model for Gibson Lake was generated using steady-state simulations over a range of flows by using the Gibson River hydraulic model (described in Section 5).

For inflow location (3), flows from Go Home Lake Dam were estimated as follows:

- For the 50-yr flood, apply a 10-yr return period water level for Go Home Lake.
- For the regulatory event, apply a 25-yr return period water level for Go Home Lake.
- For the climate change proxy, apply a 50-yr return period water level for Go Home Lake.

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Log settings at Go Home Lake Dam were assumed to be those reflective of a historical high level event (i.e., September 8, 1981) as indicated in the Go Home Lake Dam operating manual (MNRF, 2007). This configuration of water level and log settings at Go Home Lake Dam yields a total estimated outflow ranging from 49.5 m^3/s to 56.4 m^3/s.

All inflow estimates for Gibson River are provided in Table 4-5, Table 4-6, and Table 4-7 for the 50-yr, regulatory flood (Timmins storm), and climate change proxy events, respectively.

Table 4-5: 50-Yr Peak Flows (Gibson River)

Location	Distance From Upstream (km)	Flow (m^3/s)	Incremental Inflow (m^3/s)	Inflow Mode
Outlet at Gibson Lake	0.0	21.9	-	Point Inflow
Gibson River Flow Upstream of Go Home Lake Dam	7.3	40.0	18.1	Distributed Inflow
Gibson River Flow Downstream of Go Home Lake Dam	7.4	89.5	49.5	Point Inflow

Table 4-6: Regulatory Flood (Timmins Storm) Peak Flows (Gibson River)

Location	Distance From Upstream (km)	Flow (m^3/s)	Incremental Inflow (m^3/s)	Inflow Mode
Outlet at Gibson Lake	0.0	61.3	-	Point Inflow
Gibson River Flow Upstream of Go Home Lake Dam	7.3	115.5	54.2	Distributed Inflow
Gibson River Flow Downstream of Go Home Lake Dam	7.4	168.2	52.7	Point Inflow

Table 4-7: Climate Change Proxy Peak Flows (Gibson River)

Location	Distance From Upstream (km)	Flow (m^3/s)	Incremental Inflow (m^3/s)	Inflow Mode
Outlet at Gibson Lake	0.0	87.3	-	
Gibson River Flow Upstream of Go Home Lake Dam	7.3	149.7	62.5	Distributed Inflow
Gibson River Flow Downstream of Go Home Lake Dam	7.4	206.1	56.4	Point Inflow

These peak flood estimates serve as inputs to the Gibson River hydraulic model (Section 5).

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4.2.1.2 *Kahshe River*

Kahshe River has a total upstream drainage area of 245 km^2, and receives inflows from two locations: (1) Kahshe Lake outflows, and (2) local runoff from lands surrounding Kahshe River. These flow estimates were obtained from the Kahshe River hydrologic model (HYDRO-2; see Table 4-1).

The stage-discharge curve for Kahshe Lake was obtained from the Kahshe Lake Dam OMS manual (MNRF, 2018a).

Outflows from Kahshe Lake and the lands surrounding Kahshe River were combined into a single flood hydrograph. These flood hydrographs (shown in Figure 4-3) were applied as the upstream boundary condition to the Kahshe River hydraulic model (see Section 5).

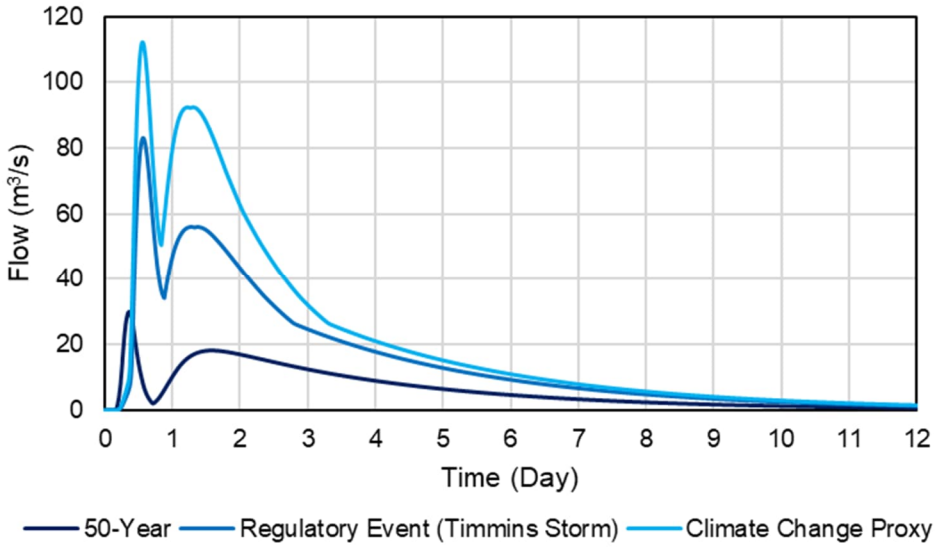


Figure 4-3: Flood Hydrographs at Kahshe River

These flow hydrographs serve as inputs to the Kahshe River hydraulic model (Section 5).

4.2.1.3 *Buck River*

Buck River receives inflows from two locations: (1) Buck Lake outflows, and (2) local runoff from lands surrounding both Buck River and downstream Buck Lake. These flow estimates were obtained from the Buck River hydrologic model (HYDRO-36; see Table 4-1). For these simulations, the stage-discharge curve for Buck River Dam was obtained from the Buck River Dam OMS manual (MNRF).

Hydrographs for the 50-yr flood, regulatory event, and climate change proxy are shown in Figure 4-4, Figure 4-5, and Figure 4-6, respectively.

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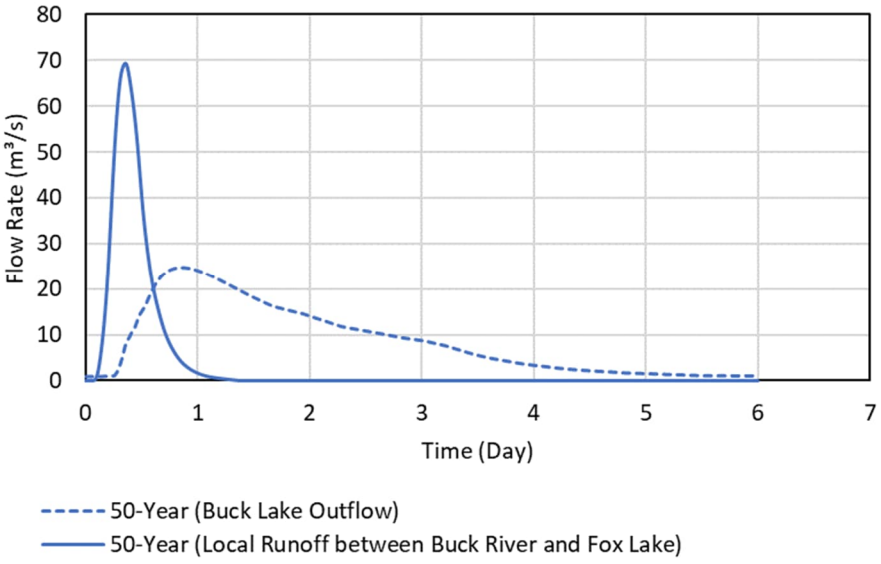


Figure 4-4: 50-Yr Flood Hydrographs at Buck River

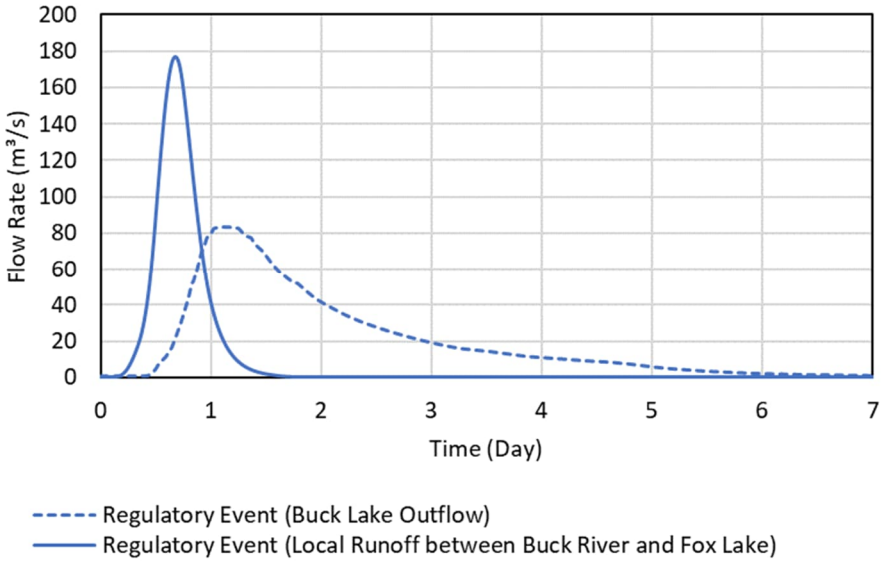


Figure 4-5: Regulatory Event Flood Hydrographs at Buck River

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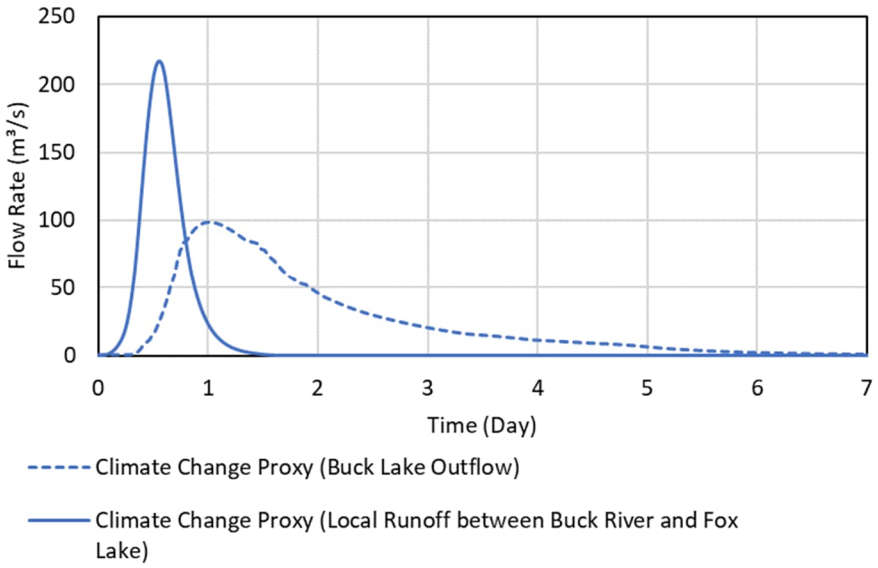


Figure 4-6: Climate Change Proxy Hydrographs at Buck River

These flow hydrographs serve as inputs to the Buck River hydraulic model (Section 5). Note that while *Buck Lake Outflow* is applied directly to the upstream boundary of the hydraulic model, *Local Inflows – Buck River and Fox Lake* hydrographs are introduced uniformly along Buck River and Fox Lake. This is because the local inflow hydrograph represents the culmination of runoff from the drainage area between Buck Lake Dam and Fox Lake Dam, and thus should be distributed throughout the Buck River and Fox Lake reach in the hydraulic model.

4.2.2 Lakes

4.2.2.1 Gibson Lake

Gibson Lake has a total upstream drainage area of 169.3 km^2, which includes Nine Mile Lake and its respective drainage area (37.5 km^2).

The hydrology of Gibson Lake was estimated as part of the Gibson River hydrologic model (HYDRO-1; see Table 4-1). However, instead of obtaining peak water levels for Gibson Lake from the hydrologic models, peak levels were obtained from the Gibson River hydraulic model (Section 5). These water levels (summarized in Table 4-8), which were obtained from the most upstream cross-section of the model, are more accurate than those estimated through lake routing in the hydrologic model.

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Table 4-8: Peak Event Statistics for Gibson Lake

Event	Peak Inflow[1] (m^3/s)	Peak Outflow[1] (m^3/s)	Peak Water Level[2] (m)
50-Year	138.3	22.0	185.39
Regulatory Flood (Timmins Storm)	350.5	61.3	187.12
Climate Change Proxy	461.9	87.3	187.79

Notes:
1. Flow statistics were obtained from the Gibson Lake hydrologic model (HYDRO-1).
2. Water level statistics were obtained from the hydraulic model results.

4.2.2.2 *Nine Mile Lake*

Nine Mile Lake has a drainage area of 37.5 km^2. The Nine Mile Lake outflow is uncontrolled, such that the discharge was calculated using the weir equation at the outlet channel and the storage was determined using ArcGIS tools, as described in Section 4.1.3.5. The outlet channel of Nine Mile Lake is 14.2 m wide, and the lake has a maximum depth of 60 ft (18.3 m). The initial water level of the lake was assumed to be 225.0 m. Under these assumptions, the corresponding stage-discharge-storage curve is summarized in Table 4-9.

Table 4-9: Stage-Storage-Discharge Curves for Nine Mile Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
225.00[1]	0.0	249
226.00	22.7	3,188
227.00	64.2	6,718
228.00	117.9	10,792
229.00	181.5	15,769
230.00	253.7	22,061

Note:
1. 225.0 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Nine Mile Lake are summarized in Table 4-10. The climate change proxy level calculated for Nine Mile Lake is 226.17 m.

Table 4-10: Peak Event Statistics for Nine Mile Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	30.2	7.1	225.31
Regulatory Flood (Timmins Storm)	85.5	20.9	225.92
Climate Change Proxy	112.5	29.7	226.17

A summary of lake level, lake inflow, and lake outflow hydrographs for Nine Mile Lake are provided in Figure 4-7.

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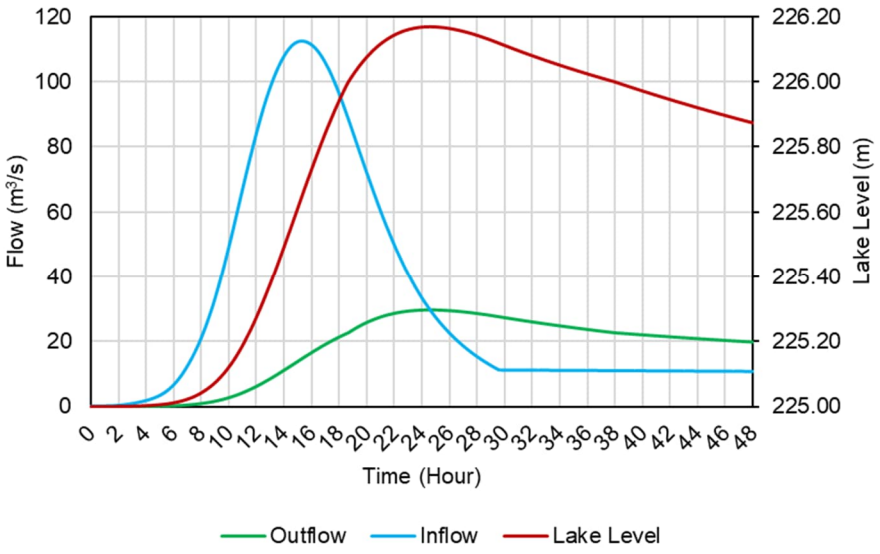


Figure 4-7: Climate Change Proxy Hydrographs for Nine Mile Lake

4.2.2.3 *Brandy Lake*

Brandy Lake has a drainage area of 39.9 km^2. The lake discharges into a natural channel at the south end of the lake, after flowing under Road 118 West through a box culvert. The stage-discharge relationship of the box culvert was developed using CulvertMaster (Bentley, 2023). During the regulatory event, it is likely that the roadway is overtopped by the rising water levels, which would result in an increase in outflow at higher stages. The stage-discharge relationship of the road deck was developed under the assumption that the road behaved as a weir, with four different weir widths for four different invert elevations, i.e., the elevation of the road deck at the lake's outlet. The stage-discharge relationship of Brandy Lake was developed by combining the two rating curves from the box culvert and the roadway. Under these assumptions, the corresponding stage-discharge-storage curve is summarized in Table 4-11.

Table 4-11: Stage-Storage-Discharge Curves for Brandy Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
226.26[1]	0.0	8,406
227.00	6.3	8,821
228.00	22.7	9,388
229.00	44.9	9,971
230.00	67.9	10,576
231.00	156.0	11,626
232.00	397.4	12,286

Note:
1. 226.26 m corresponds with water level elevation in LiDAR data (Airborne Imaging, 2018).

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Peak levels for Brandy Lake are summarized in Table 4-12, with the climate change proxy peak level estimated to be 231.11 m.

Table 4-12: Peak Event Statistics for Brandy Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	78.2	9.3	227.18
Regulatory Flood (Timmins Storm)	205.5	124.8	230.77
Climate Change Proxy	265.2	201.4	231.19

A summary of lake level, lake inflow, and lake outflow hydrographs for Brandy Lake are provided in Figure 4-8.

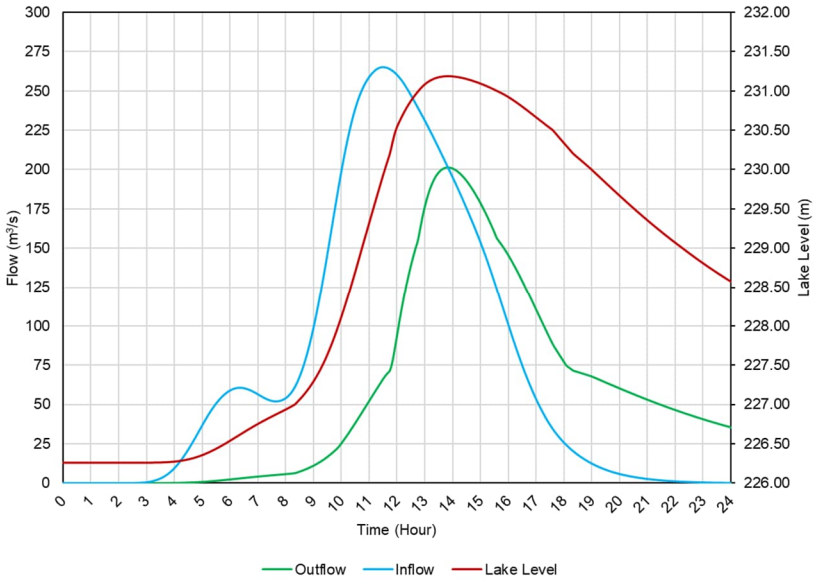


Figure 4-8: Climate Change Proxy Hydrographs for Brandy Lake

4.2.2.4 Leonard Lake

Leonard Lake has a drainage area of 2.0 km^2. The Leonard Lake outflow is controlled by an 11.4-m concrete weir at the west end of the lake. Downstream of the weir, the channel flows into a triple-barreled culvert beneath the access road, Leonard Lake 2 Road, before moving further downstream within the system. However, field observations indicate that the 11.4-m concrete weir controls water levels on the lake. The initial water level of the lake was assumed to be 264.12 m. Under these assumptions, the corresponding stage-discharge-storage curve is summarized in Table 4-13.

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Table 4-13: Stage-Storage-Discharge Curves for Leonard Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
264.12[1]	0.0	29,874
265.00	13.8	31,681
266.00	43.2	34,094
267.00	81.9	36,874
268.00	128.0	39,908
269.00	180.6	43,187

Note:
1. 264.12 m corresponds with water level elevation in LiDAR data (Airborne Imaging, 2018).

Peak levels for Leonard Lake are summarized in Table 4-14. The climate change proxy peak level calculated for Leonard Lake is 264.27 m.

Table 4-14: Peak Event Statistics for Leonard Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	7.9	0.3	264.14
Regulatory Flood (Timmins Storm)	17.0	1.9	264.24
Climate Change Proxy	21.5	2.4	264.27

A summary of lake level, lake inflow, and lake outflow hydrographs for Leonard Lake are provided in Figure 4-9.

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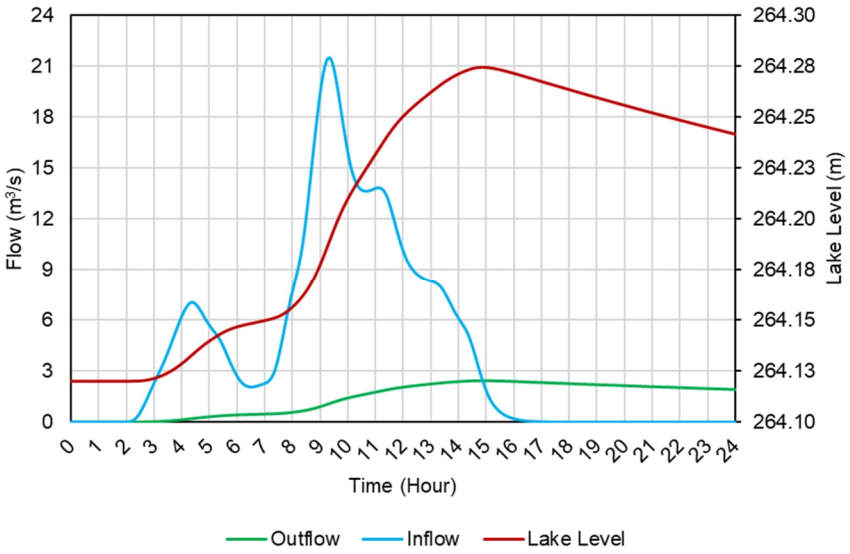


Figure 4-9: Climate Change Proxy Hydrographs for Leonard Lake

4.2.2.5 *Long Lake*

Long Lake has a drainage area of 3.8 km^2. The Long Lake outflow is controlled by a 1.25-m diameter culvert at the northeast end of the lake. The culvert is 33.1 m long and flows under an access road, Muskoka Road 169, before flowing into Bala Bay. A rating curve for this culvert was developed using CulvertMaster (Bentley, 2023). The initial water level of the lake was assumed to be 227.28 m. Under these assumptions, the corresponding stage-discharge-storage curve is summarized in Table 4-15.

Table 4-15: Stage-Storage-Discharge Curves for Long Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
227.28[1]	0.00	0
228.28	1.16	942
229.28	3.09	2,405
230.28	4.41	4,068
231.28	5.48	5,913
232.28	6.39	7,901

Note:
1. 227.28 m corresponds with water level elevation in LiDAR data (Airborne Imaging, 2018).

Peak levels for Long Lake are summarized in Table 4-16. The climate change proxy lake level calculated for Long Lake is 227.82 m.

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Table 4-16: Peak Event Statistics for Long Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	0.1	6.4	227.34
Regulatory Flood (Timmins Storm)	0.5	18.9	227.69
Climate Change Proxy	0.6	25.0	227.82

A summary of lake level, lake inflow, and lake outflow hydrographs for Long Lake are provided in Figure 4-10.

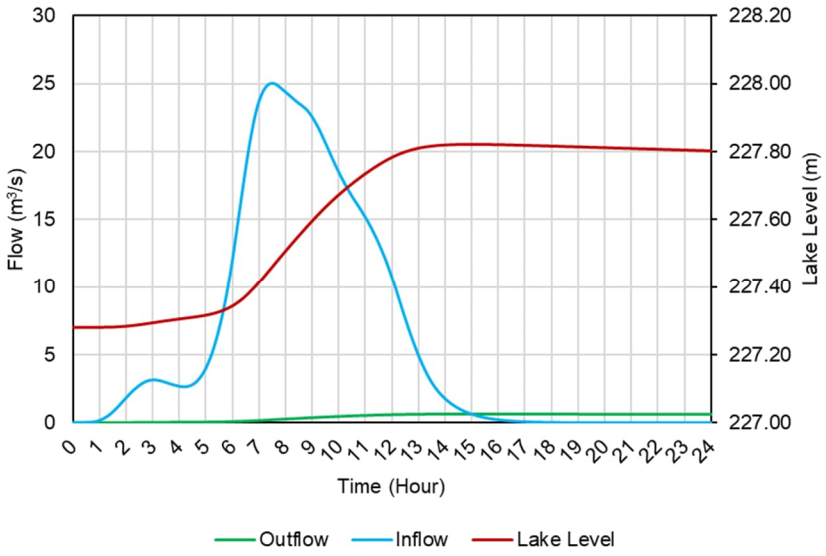


Figure 4-10: Climate Change Proxy Hydrographs for Long Lake

4.2.2.6 Butterfly Lake

Butterfly Lake has a drainage area of 4.2 km^2. Butterfly Lake outflow is controlled by a metal culvert located at the northwest end of the lake, underneath Highway 118 West. The culvert has a diameter of approximately 1.84 m and a length of 41.3 m. There is a trashrack at the culvert inlet. A rating curve for this culvert was developed using CulvertMaster (Bentley, 2023). The completed outlet rating curve is presented below in Table 4-17. Based on LiDAR data, the initial water level of the lake was assumed to be 227.34 m.

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Table 4-17: Stage-Storage-Discharge Curves for Butterfly Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
227.34[1]	0.00	3,211
228.00	0.75	3,673
229.00	3.98	4,556
230.00	7.05	5,956
231.00	9.78	7,632

Note:
1. 227.34 m corresponds with water level elevation in LiDAR data (Airborne Imaging, 2018).

Peak levels for Butterfly Lake are summarized in Table 4-18. The climate change peak lake level calculated for Butterfly Lake is 228.29 m.

Table 4-18: Peak Event Statistics for Butterfly Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	12.8	0.1	227.44
Regulatory Flood (Timmins Storm)	34.1	1.1	228.12
Climate Change Proxy	43.7	1.7	228.29

A summary of lake level, lake inflow, and lake outflow hydrographs are provided in Figure 4-11 for Butterfly Lake.

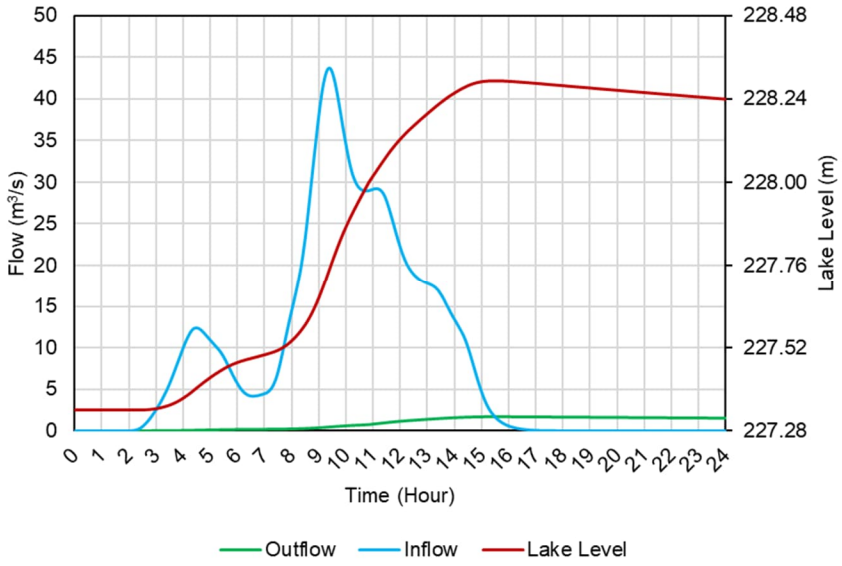


Figure 4-11: Climate Change Proxy Hydrographs for Butterfly Lake

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4.2.2.7 *Longline Lake*

Longline Lake has a drainage area of 2.0 km^2. Longline Lake outflow is controlled by a metal triple-barreled culvert located at the northeast end of the lake, approximately 300 m from Road 117. This triple-barreled culvert includes two culverts with a diameter of 0.60 m and one culvert with a diameter of 0.80 m. The culvert length is 11.2 m, and the rating curve for this culvert was developed using CulvertMaster (Bentley, 2023). The completed outlet rating curve is presented below in Table 4-19. Based on LiDAR data, the initial water level of the lake was assumed to be 334.36 m.

Table 4-19: Stage-Storage-Discharge Curves for Longline Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
334.36[1]	0.0	4,135
335.00	1.0	4,231
336.00	2.5	4,534
337.00	3.6	4,853
338.00	4.2	5,188
339.00	4.7	5,543
340.00	5.3	5,918

Note:
1. 334.36 m corresponds with water level elevation in LiDAR data (Airborne Imaging, 2018).

Peak levels for Longline Lake are summarized in Table 4-20. The climate change proxy lake level calculated for Longline Lake is 335.63 m.

Table 4-20: Peak Event Statistics for Longline Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	5.6	0.2	334.52
Regulatory Flood (Timmins Storm)	15.9	1.6	335.40
Climate Change Proxy	20.7	2.0	335.63

A summary of lake level, lake inflow, and lake outflow hydrographs for Longline Lake are provided in Figure 4-12.

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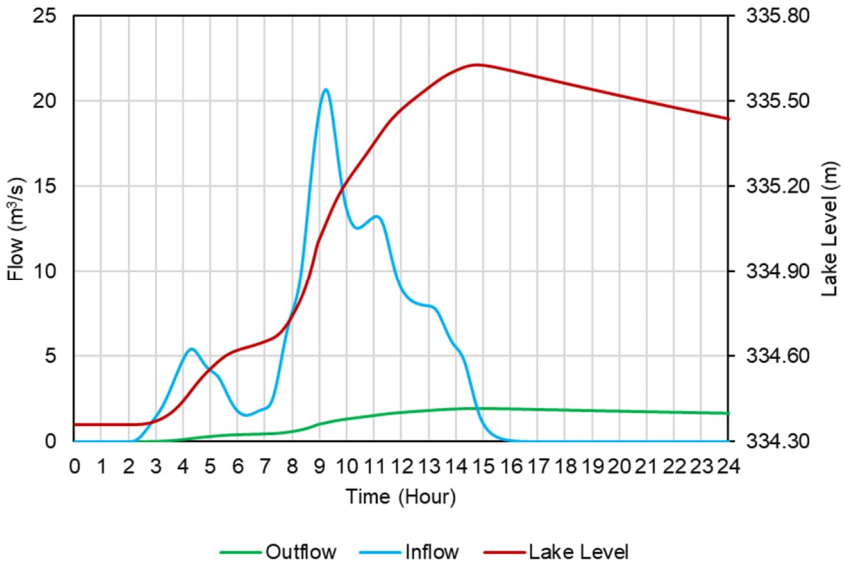


Figure 4-12: Climate Change Proxy Hydrographs for Longline Lake

4.2.2.8 Gull Lake and Silver Lake (Gravenhurst)

Gull Lake and Silver Lake (Gravenhurst) are hydrologically connected though wide lake channels, meaning flood levels derived for this site are applicable to both lake areas. The cumulative drainage area for these lakes is 13.4 km^2. Gull Lake discharges out of the north end of the lake, over a 10.71 m long dam, into a natural channel. The stage-discharge relationship of Gull Lake was provided in the Gull Lake Dam operating manual (MNRF). The outlet rating curve is presented below in Table 4-21. The initial water level of the lake was assumed to be 247.20 m.

Table 4-21: Stage-Storage-Discharge Curves for Gull Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
247.20[1]	0.0	8,163
248.00	12.3	9,145
249.00	41.3	10,879
250.00	80.2	13,744
251.00	126.8	17,180
252.00	180.0	21,128

Note:
1. 247.20 m corresponds with water level elevation in LiDAR data (Airborne Imaging, 2018).

Peak levels for Gull Lake and Silver Lake (Gravenhurst) are summarized in Table 4-22. The climate change proxy peak level calculated for these lakes is 248.30 m.

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Table 4-22: Peak Event Statistics for Gull Lake and Silver Lake (Gravenhurst)

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	22.2	2.8	247.39
Regulatory Flood (Timmins Storm)	60.9	15.2	248.10
Climate Change Proxy	79.9	21.0	248.30

A summary of lake level, lake inflow, and lake outflow hydrographs for these lakes are provided in Figure 4-13.

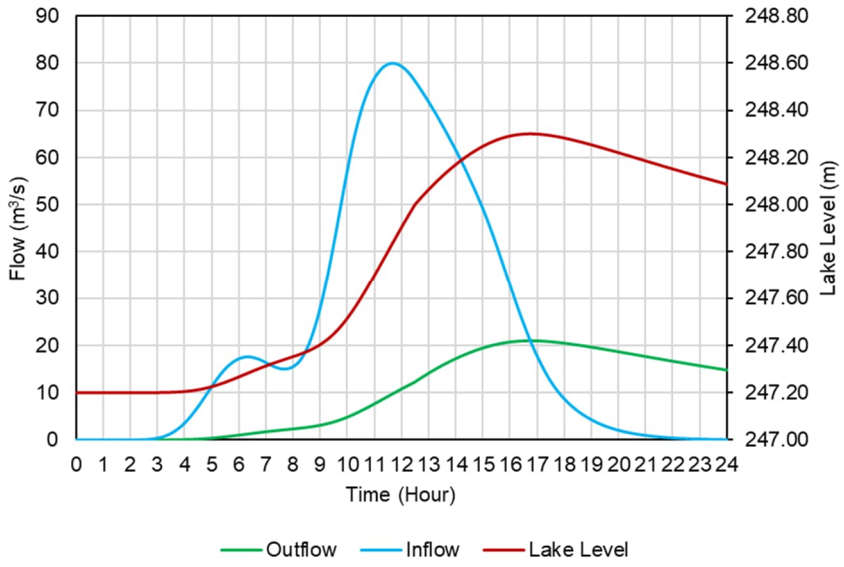


Figure 4-13: Climate Change Proxy Hydrographs for Gull Lake and Silver Lake (Gravenhurst)

4.2.2.9 Silver Lake (Muskoka Lakes)

Silver Lake (Muskoka Lakes) has a drainage area of 1.2 km^2. Silver Lake (Muskoka Lakes) is located east of the town of Port Carling, and drains out the south end of the lake through a natural channel. The stage-discharge relationship of Silver Lake (Muskoka Lakes) was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-23. The initial water level of the lake was assumed to be 225.75 m.

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Table 4-23: Stage-Storage-Discharge Curves for Silver Lake (Muskoka Lakes)

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
225.75[1]	0.0	7,840
226.00	1.6	7,980
227.00	17.9	8,541
228.00	43.2	9,108
229.00	75.0	9,691
230.00	112.1	10,296

Note:
1. 225.75 m corresponds with water level elevation in LiDAR data (Airborne Imaging, 2018).

Peak levels for Silver Lake (Muskoka Lakes) are summarized in Table 4-24. The climate change proxy lake level calculated for Silver Lake (Muskoka Lakes) is 226.06 m.

Table 4-24: Peak Event Statistics for Silver Lake (Muskoka Lakes)

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	4.5	0.2	225.78
Regulatory Flood (Timmins Storm)	12.0	1.9	226.02
Climate Change Proxy	14.7	2.5	226.06

A summary of lake level, lake inflow, and lake outflow hydrographs for Silver Lake (Muskoka Lakes) are provided in Figure 4-14.

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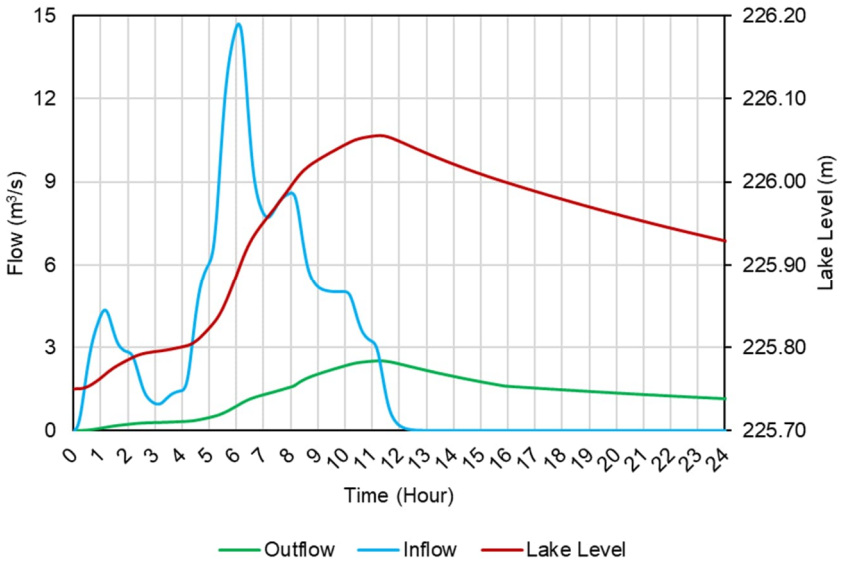


Figure 4-14: Climate Change Proxy Hydrographs for Silver Lake (Muskoka Lakes)

4.2.2.10 Clear Lake

Clear Lake has a drainage area of 2.4 km^2. Clear Lake is located southeast of Bala Bay, and drains out the northeast end of the lake into Brandy Creek through a natural channel. The stage-discharge relationship of Clear Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-25. The initial water level of the lake was assumed to be 232.07 m.

Table 4-25: Stage-Storage-Discharge Curves for Clear Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
232.07[1]	0.00	23,971
233.00	5.74	25,288
234.00	17.16	26,882
235.00	32.10	28,542
236.00	49.86	30,270
237.00	70.06	32,087

Note:
1. 232.07 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Clear Lake are summarized in Table 4-26. The climate change proxy level calculated for Clear Lake is 232.34 m.

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Table 4-26: Peak Event Statistics for Clear Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	6.2	0.2	232.10
Regulatory Flood (Timmins Storm)	16.4	1.3	232.28
Climate Change Proxy	21.0	1.7	232.34

A summary of lake level, lake inflow, and lake outflow hydrographs for Clear Lake are provided in Figure 4-15.

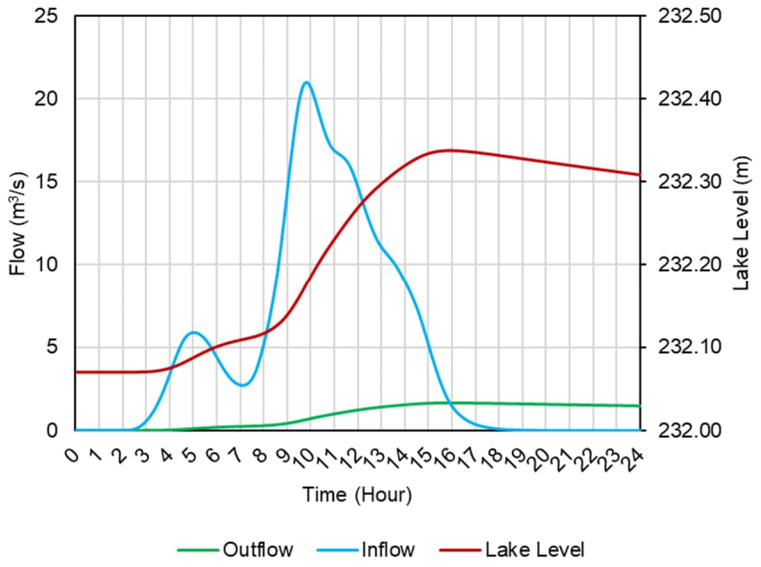


Figure 4-15: Climate Change Proxy Hydrographs for Clear Lake

4.2.2.11 Black Lake

Black Lake has a drainage area of 10.6 km^2. Black Lake is located northeast of the town of Torrance, and drains out the west end of the lake through a double-barreled culvert into Brandy Creek. Approximately 500 m downstream of the double-barreled culvert, the channel flows through a single culvert, which would act as the control point for the lake's water levels. Therefore, the downstream location was selected as the lake's outlet location. The single culvert is 24.8 m long and 1.80 m in diameter, and is accessed from the Frank Miller Memorial Route. A rating curve for this culvert was developed using CulvertMaster (Bentley, 2023). During the regulatory event, it is likely that the roadway is overtopped by the rising water levels, which would result in an increase in outflow at higher stages. The stage-discharge relationship of the road deck was developed under the assumption that the road behaved as a weir, with an invert elevation of 233.10 m, i.e., the elevation of the road deck at the lake's outlet on the Frank Miller Memorial Route. The stage-discharge relationship of Black Lake was developed by combining the two rating curves from the culvert and the

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roadway. The completed outlet rating curve is presented below in Table 4-27. The initial water level of the lake was assumed to be 231.81 m.

Table 4-27: Stage-Storage-Discharge Curves for Black Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
231.81[1]	0.0	2,754
232.00	0.1	2,774
233.00	2.2	3,434
234.00	211.0	4,921
235.00	637.6	7,043
236.00	1,196.3	9,405

Note:
1. 231.81 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Black Lake are summarized in Table 4-28. The climate change proxy lake level calculated for Black Lake is 233.23 m.

Table 4-28: Peak Event Statistics for Black Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	24.1	1.0	232.44
Regulatory Flood (Timmins Storm)	56.1	35.3	233.16
Climate Change Proxy	71.6	50.4	233.23

A summary of lake level, lake inflow, and lake outflow hydrographs for Black Lake are provided in Figure 4-16.

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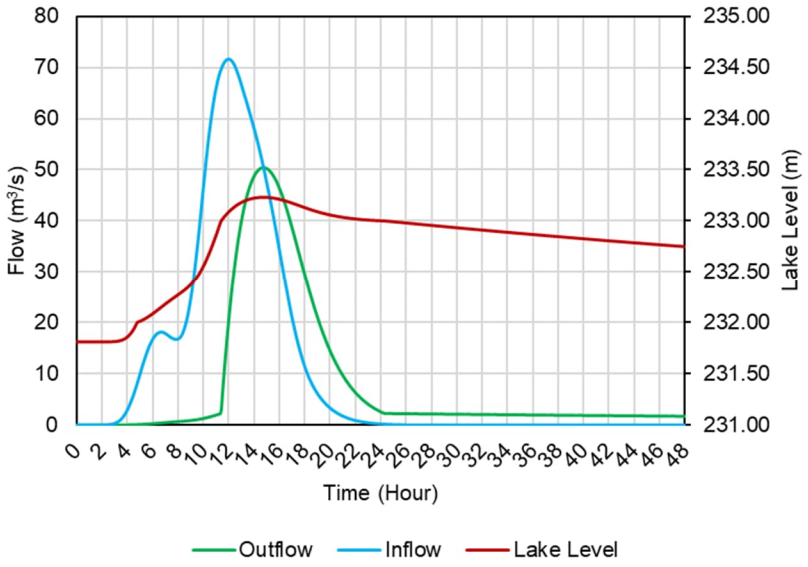


Figure 4-16: Climate Change Proxy Hydrographs for Black Lake

4.2.2.12 *Pine Lake*

Pine Lake has a drainage area of 23.9 km^2. Pine Lake is located northwest of the town of Gravenhurst, and drains out the northeast end through a natural channel. The channel passes under a bridge located on Muskoka Road 169 and eventually flows into Muskoka Bay. The stage-discharge relationship of Pine Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-29. The initial water level of the lake was assumed to be 231.14 m.

Table 4-29: Stage-Storage-Discharge Curves for Pine Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
231.14[1]	0.0	25,153
232.00	12.1	26,465
233.00	38.6	28,682
234.00	73.5	31,260
235.00	115.3	34,475
236.00	162.8	38,862

Note:
1. 231.14 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Pine Lake are summarized in Table 4-30. The climate change proxy lake level calculated for Pine Lake is 232.62 m.

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Table 4-30: Peak Event Statistics for Pine Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	5.6	34.0	231.53
Regulatory Flood (Timmins Storm)	21.2	89.2	232.34
Climate Change Proxy	28.6	116.5	232.62

A summary of lake level, lake inflow, and lake outflow hydrographs for Pine Lake are provided in Figure 4-17.

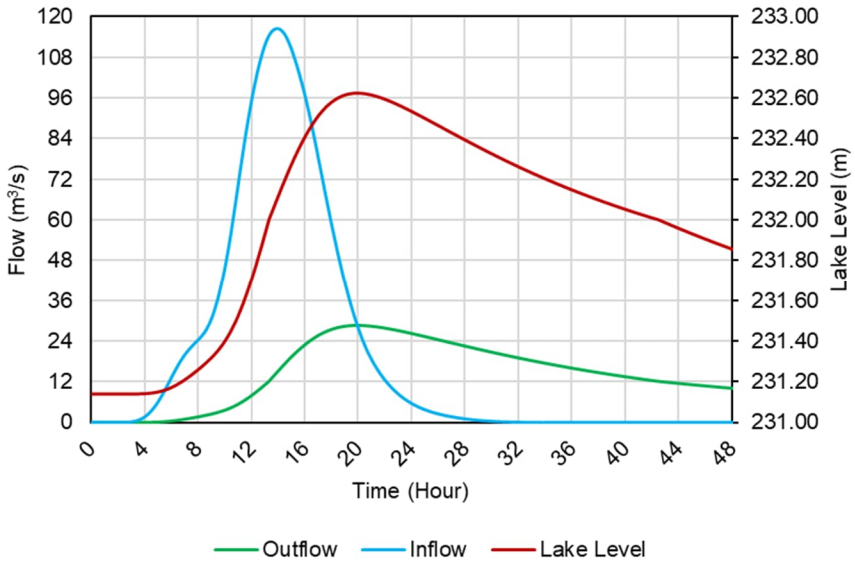


Figure 4-17: Climate Change Proxy Hydrographs for Pine Lake

4.2.2.13 Morrison Lake

Morrison Lake has an incremental drainage area of 17.3 km^2, from the Morrison Lake outlet to the Muldrew Lake Dam, and a total drainage area of 72.3 km^2. Morrison Lake is located southwest of the town of Gravenhurst, and drains out the south end of the lake through a natural channel. The outlet channel, Morrison Creek, flows into the Severn River. The stage-discharge relationship of Morrison Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-31. The initial water level of the lake was assumed to be 216.22 m.

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Table 4-31: Stage-Storage-Discharge Curves for Morrison Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
216.22[1]	0.0	32,908
217.00	13.2	34,587
218.00	45.6	37,910
219.00	89.0	41,658
220.00	141.1	45,728
221.00	200.7	50,248

Note:
1. 216.22 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Morrison Lake are summarized in Table 4-32. The climate change lake level calculated for Morrison Lake is 217.12 m.

Table 4-32: Peak Event Statistics for Morrison Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	29.6	3.2	216.41
Regulatory Flood (Timmins Storm)	68.9	12.2	216.94
Climate Change Proxy	90.6	17.2	217.12

A summary of lake level, lake inflow, and lake outflow hydrographs for Morrison Lake are provided in Figure 4-18.

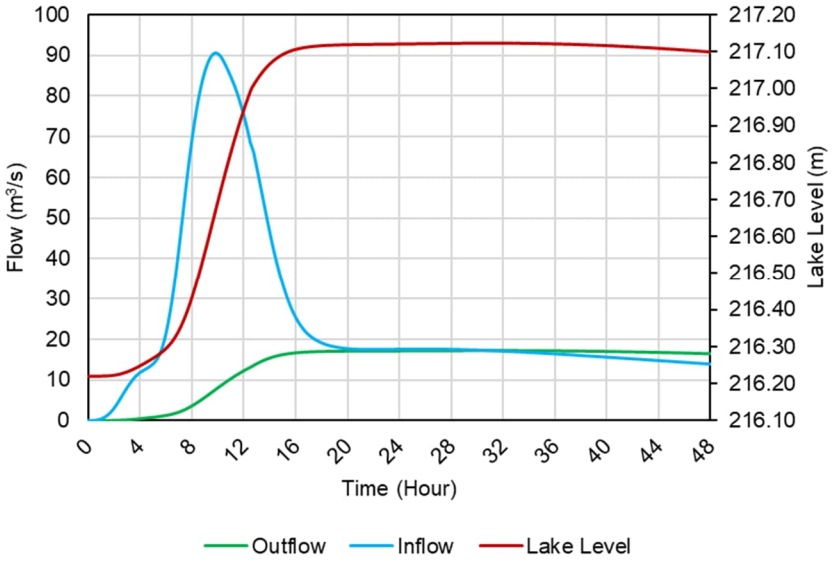


Figure 4-18: Climate Change Proxy Hydrographs for Morrison Lake

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4.2.2.14 *South, Middle and North Muldrew Lakes*

The Muldrew lakes have an incremental drainage area of 43.4 km^2, from the Muldrew Lake Dam to the Turtle Lake outlet, and a total drainage area of 55.0 km^2. The Muldrew lakes are located upstream of Morrison Lake, and drain out the south end into Morrison Lake through the Muldrew Lake Dam.

The stage-discharge relationship of the Muldrew lakes was developed using the data provided in the Muldrew Lake Dam OMS Manual (Genivar Inc., 2012). Two stage-discharge relationships were defined: a summer relationship with all logs in, and a winter or spring relationship with zero logs in. The completed outlet rating curves are presented below in Table 4-33. The initial water level of the lake was assumed to be 221.92 m, which was also assumed to be the crest elevation when all logs are in place.

Table 4-33: Stage-Storage-Discharge Curves for the Muldrew Lakes

Stage (m)	Summer Discharge (m^3/s)	Winter Discharge (m^3/s)	Storage (1,000 m^3)
221.17[1]	0.0	0.0	77,708
221.77	0.0	1.1	80,251
221.92[2]	0.0	2.1	80,302
222.54	3.7	8.2	82,942
222.66	6.3	9.5	83,531
222.75	7.2	10.6	83,972
223.00	10.0	13.6	85,155
224.00	23.1	27.4	91,465

Notes:
1. 221.17 m was assumed to be the sill elevation.
2. 221.92 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b). This was assumed to be the crest elevation when all logs are in place.

Peak levels for the Muldrew lakes are summarized in Table 4-34. The climate change proxy lake level calculated for the Muldrew lakes is 223.16 m.

Table 4-34: Peak Event Statistics for the Muldrew Lakes

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	54.8	2.2	222.30
Regulatory Flood (Timmins Storm)	136.0	11.1	222.94
Climate Change Proxy	178.9	17.6	223.16

A summary of lake level, lake inflow, and lake outflow hydrographs for the Muldrew lakes are provided in Figure 4-19.

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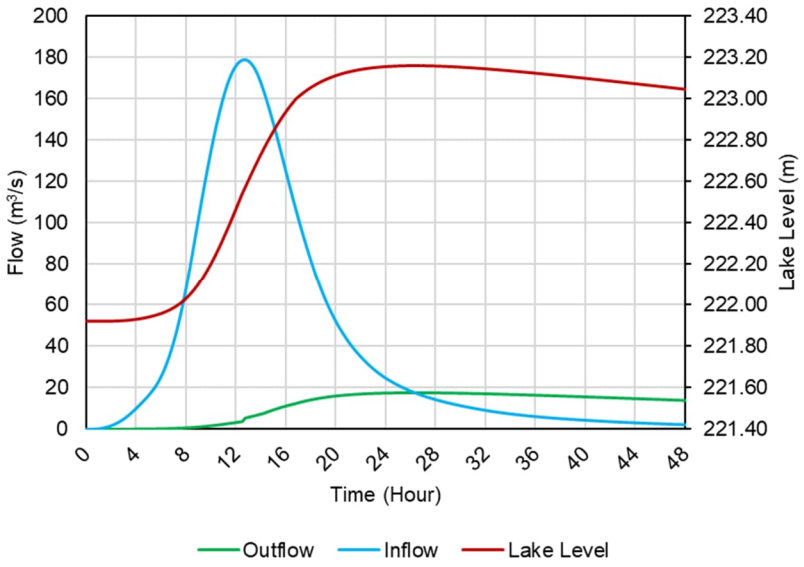


Figure 4-19: Climate Change Proxy Hydrographs for the Muldrew Lakes

4.2.2.15 *Turtle Lake*

Turtle Lake has an incremental drainage area of 1.4 km^2, from the Loon Lake outlet to the Turtle Lake outlet, and a total drainage area of 11.6 km^2. Turtle Lake is located directly upstream of the Muldrew lakes, and drains out the west end through a natural channel into the North Muldrew Lake.

The stage-discharge relationship of Turtle Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-35. The initial water level of the lake was assumed to be 229.17 m.

Table 4-35: Stage-Storage-Discharge Curves for Turtle Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
229.17[1]	0.0	4,582
230.00	14.5	4,812
231.00	47.5	5,238
232.00	91.4	5,750
233.00	143.9	6,318
234.00	203.8	6,953

Note:
1. 229.17 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Turtle Lake are summarized in Table 4-36. The climate change proxy lake level calculated for Turtle Lake is 230.14 m.

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Table 4-36: Peak Event Statistics for Turtle Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	4.2	3.6	229.38
Regulatory Flood (Timmins Storm)	15.9	13.6	229.95
Climate Change Proxy	22.4	19.2	230.14

A summary of lake level, lake inflow, and lake outflow hydrographs for Turtle Lake are provided in Figure 4-20.

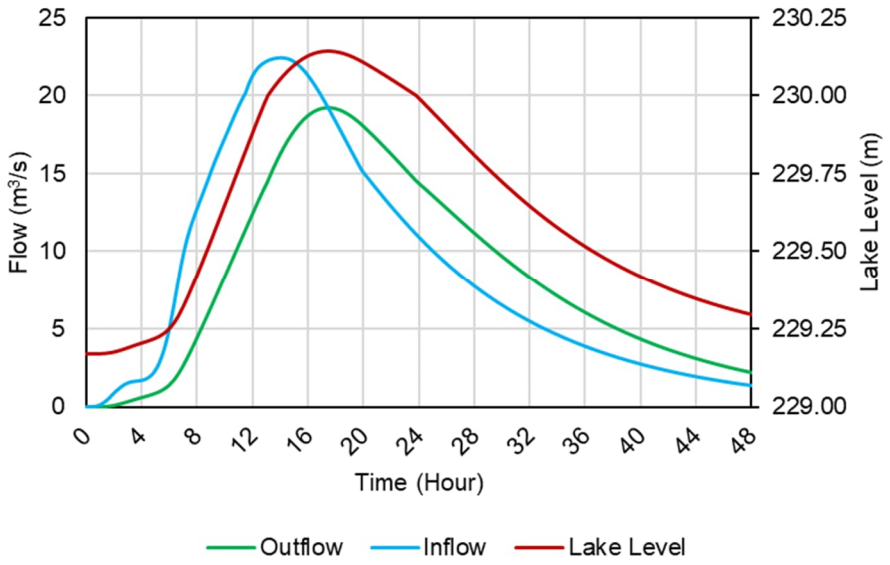


Figure 4-20: Climate Change Proxy Hydrographs for Turtle Lake

4.2.2.16 Loon Lake

Loon Lake has a drainage area of 10.2 km^2. Loon Lake is located directly upstream of Turtle Lake, and drains out the southwest end of the lake through a natural channel into Turtle Lake. The stage-discharge relationship of Loon Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-37. The initial water level of the lake was assumed to be 229.14 m.

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Table 4-37: Stage-Storage-Discharge Curves for Loon Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
229.14[1]	0.0	12,419
230.00	15.2	13,051
231.00	48.3	14,008
232.00	92.1	15,103
233.00	144.4	16,394
234.00	204.0	17,900

Note:
1. 229.14 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Loon Lake are summarized in Table 4-38. The climate change proxy lake level calculated for Loon Lake is 230.20 m.

Table 4-38: Peak Event Statistics for Loon Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	12.3	4.2	229.38
Regulatory Flood (Timmins Storm)	37.6	15.4	230.01
Climate Change Proxy	49.4	21.8	230.20

A summary of lake level, lake inflow, and lake outflow hydrographs for Loon Lake are provided in Figure 4-21.

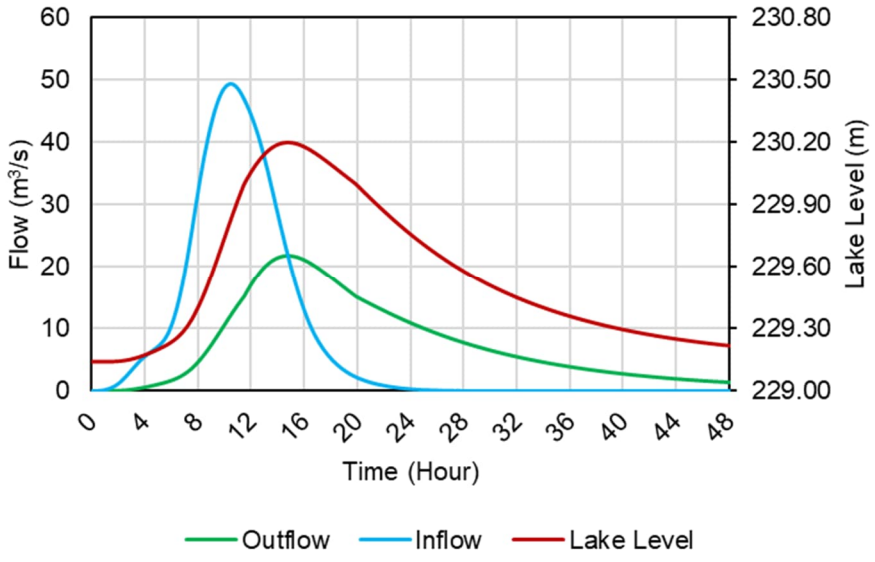


Figure 4-21: Climate Change Proxy Hydrographs for Loon Lake

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4.2.2.17 Clearwater Lake

Clearwater Lake has a drainage area of 1.9 km^2. Clearwater Lake is located within the Kahshe Lake Barrens Conservation Reserve, and drains out the south end of the lake through a circular culvert under Clear Road. The stage-discharge relationship of the culvert was developed using CulvertMaster (Bentley, 2023). The completed outlet rating curve is presented below in Table 4-39. The initial water level of the lake was assumed to be 251.35 m.

Table 4-39: Stage-Storage-Discharge Curves for Clearwater Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
251.35[1]	0.0	21,323
252.00	0.5	21,636
253.00	1.9	22,508
254.00	2.7	23,646
255.00	3.4	25,011
256.00	3.9	26,544

Note:
1. 251.35 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Clearwater Lake are summarized in Table 4-40. The climate change proxy lake level calculated for Clearwater Lake is 251.93 m.

Table 4-40: Peak Event Statistics for Clearwater Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	3.7	0.2	251.41
Regulatory Flood (Timmins Storm)	9.9	0.4	251.78
Climate Change Proxy	13.0	0.5	251.93

A summary of lake level, lake inflow, and lake outflow hydrographs for Clearwater Lake are provided in Figure 4-22.

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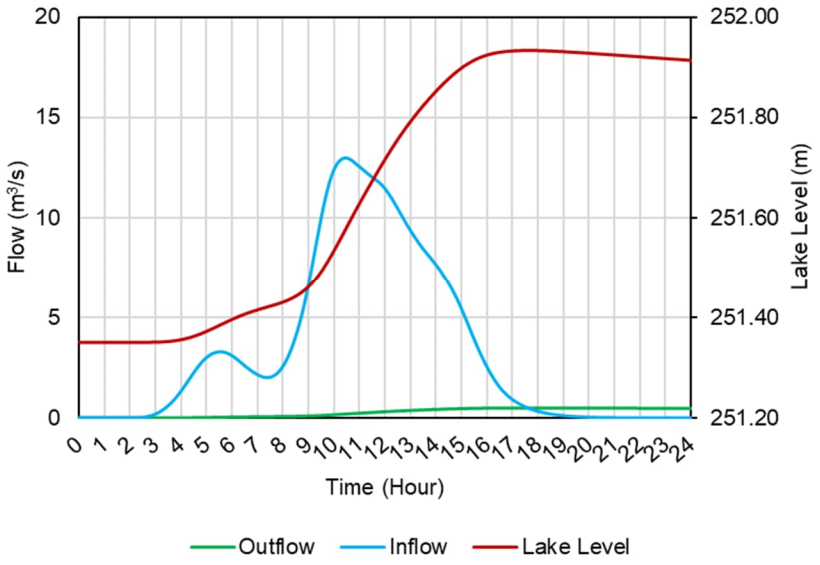


Figure 4-22: Climate Change Proxy Hydrographs for Clearwater Lake

4.2.2.18 Riley Lake

Riley Lake has a drainage area of 42.4 km^2. Riley Lake is located southeast of the town of Gravenhurst and northeast of Clearwater Lake. Riley Lake drains out the south end of the lake through a natural channel.

The stage-discharge relationship of Riley Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-41. The initial water level of the lake was assumed to be 246.14 m.

Table 4-41: Stage-Storage-Discharge Curves for Riley Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
246.14[1]	0.0	25,065
247.00	20.3	26,162
248.00	64.5	27,860
249.00	123.1	29,782
250.00	192.9	31,933
251.00	272.6	34,344

Note:
1. 246.14 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Riley Lake are summarized in Table 4-42. The climate change proxy lake level calculated for Riley Lake is 248.70 m.

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Table 4-42: Peak Event Statistics for Riley Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	58.1	17.4	246.88
Regulatory Flood (Timmins Storm)	146.3	64.4	248.00
Climate Change Proxy	191.0	88.3	248.41

A summary of lake level, lake inflow, and lake outflow hydrographs for Riley Lake are provided in Figure 4-23.

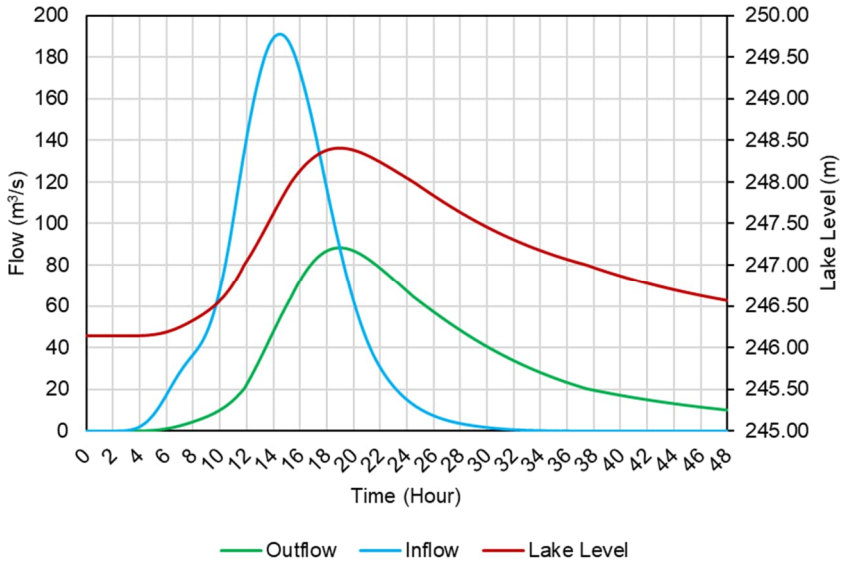


Figure 4-23: Climate Change Proxy Hydrographs for Riley Lake

4.2.2.19 Bass Lake

Bass Lake has an incremental drainage area of 89.7 km^2, from the Bass Lake outlet to the outlet of Ryde Lake, and a total drainage area of 171.9 km^2. Bass Lake is located directly upstream of Kahshe Lake, and drains out the southwest end of the lake through a natural channel. The channel flows across the Housey's Rapids Road under a bridge into Kahshe Lake.

The stage-discharge relationship of Bass Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-43. The initial water level of the lake was assumed to be 242.38 m.

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Table 4-43: Stage-Storage-Discharge Curves for Bass Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
242.38[1]	0.0	2,022
243.00	35.2	2,044
244.00	148.5	2,167
245.00	305.3	2,821
246.00	495.9	3,727
247.00	715.0	4,752

Note:
1. 242.38 m corresponds with water level elevation in LiDAR data (Tulloch, 2023a).

Peak levels for Bass Lake are summarized in Table 4-44. The climate change proxy lake level calculated for Bass Lake is 245.62 m.

Table 4-44: Peak Event Statistics for Bass Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	139.5	139.1	243.92
Regulatory Flood (Timmins Storm)	327.8	316.7	245.06
Climate Change Proxy	441.3	424.3	245.62

A summary of lake level, lake inflow, and lake outflow hydrographs for Bass Lake are provided in Figure 4-24.

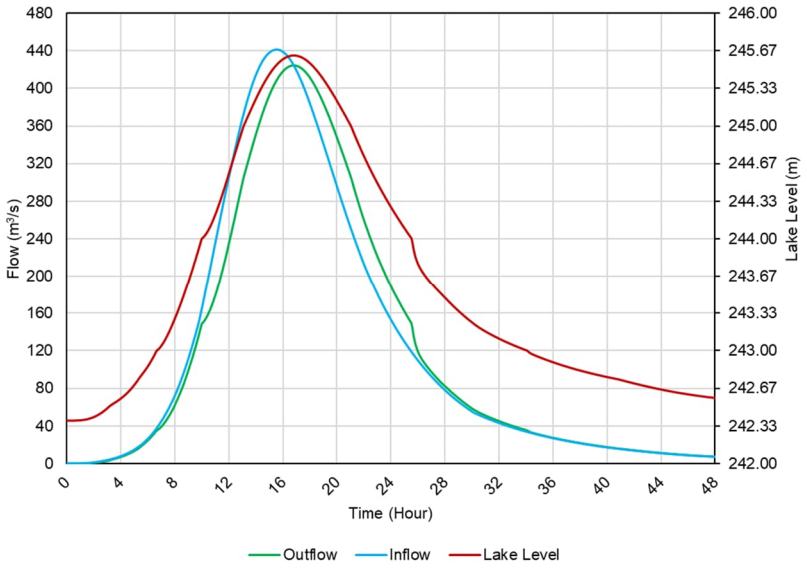


Figure 4-24: Climate Change Proxy Hydrographs for Bass Lake

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4.2.2.20 Ryde Lake

Ryde Lake has an incremental drainage area of 71.2 km^2, from the Ryde Lake outlet to the outlet of Doe Lake, and a total drainage area of 82.2 km^2. Ryde Lake is located upstream of Bass Lake, and drains out the south end of the lake through a natural channel. The stage-discharge relationship of Ryde Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-45. The initial water level of the lake was assumed to be 252.88 m.

Table 4-45: Stage-Storage-Discharge Curves for Ryde Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
252.88[1]	0.0	10,754
253.00	0.5	10,767
254.00	37.4	11,958
255.00	120.0	13,426
256.00	229.9	15,088
257.00	361.3	16,895

Note:
1. 252.88 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Ryde Lake are summarized in Table 4-46. The climate change proxy lake level calculated for Ryde Lake is 255.74 m.

Table 4-46: Peak Event Statistics for Ryde Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	91.7	48.4	254.13
Regulatory Flood (Timmins Storm)	215.4	146.8	255.24
Climate Change Proxy	286.8	201.6	255.74

A summary of lake level, lake inflow, and lake outflow hydrographs for Ryde Lake are provided in Figure 4-25.

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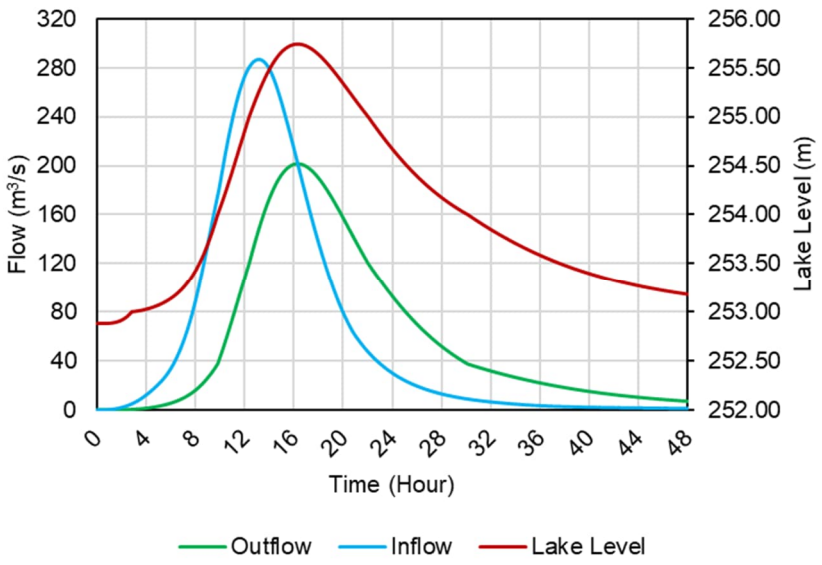


Figure 4-25: Climate Change Proxy Hydrographs for Ryde Lake

4.2.2.21 Doe Lake

Doe Lake has a drainage area of 11.0 km^2. Doe Lake is located upstream of Ryde Lake, and drains out the east end of the lake through a single metal culvert and into a natural channel. The single metal culvert is 3.3 m long and accessed via Boyes Bridge Lane. A rating curve for the culvert was developed using CulvertMaster (Bentley, 2023). During the regulatory event, it is likely that the roadway is overtopped by rising water levels due to the low topography, which would result in an increase in outflow at higher stages. The stage-discharge relationship of the road deck was developed under the assumption that the road behaved as a weir, with an invert elevation of 257.70 m, i.e., the elevation of the road deck at the lake's outlet on Boyes Bridge Lane. The stage-discharge relationship of Doe Lake was developed by combining the two rating curves from the culvert and the roadway. The completed outlet rating curve is presented below in Table 4-47. The initial water level of the lake was assumed to be 256.83 m.

Table 4-47: Stage-Storage-Discharge Curves for Doe Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
256.83[1]	0.0	1,922
257.00	0.1	1,933
258.00	9.3	2,353
259.00	73.8	2,935
260.00	170.8	4,279
261.00	291.7	5,874

Note:
1. 256.83 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

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Peak levels for Doe Lake are summarized in Table 4-48. The climate change proxy lake level calculated for Doe Lake is 258.44 m.

Table 4-48: Peak Event Statistics for Doe Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	16.1	4.9	257.53
Regulatory Flood (Timmins Storm)	39.6	26.3	258.26
Climate Change Proxy	51.9	37.6	258.44

A summary of lake level, lake inflow, and lake outflow hydrographs for Doe Lake are provided in Figure 4-26.

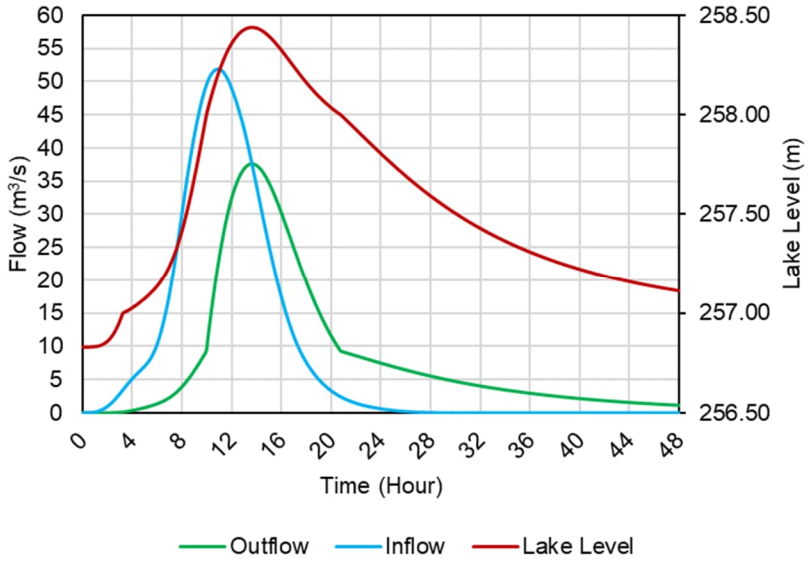


Figure 4-26: Climate Change Proxy Hydrographs for Doe Lake

4.2.2.22 Sunny Lake

Sunny Lake has a drainage area of 2.1 km^2. Sunny Lake is located east of the town of Gravenhurst, and drains out the southeast end of the lake through a natural channel. The stage-discharge relationship of Sunny Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-49. The initial water level of the lake was assumed to be 254.91 m.

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Table 4-49: Stage-Storage-Discharge Curves for Sunny Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
254.91[1]	0.0	6,092
255.00	0.1	6,096
256.00	3.6	6,611
257.00	9.7	7,153
258.00	17.4	7,761
259.00	26.5	8,442

Note:
1. 254.91 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Sunny Lake are summarized in Table 4-50. The climate change proxy lake level calculated for Sunny Lake is 255.52 m.

Table 4-50: Peak Event Statistics for Sunny Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	4.1	0.3	255.05
Regulatory Flood (Timmins Storm)	11.0	1.5	255.39
Climate Change Proxy	14.4	1.9	255.52

A summary of lake level, lake inflow, and lake outflow hydrographs for Sunny Lake are provided in Figure 4-27.

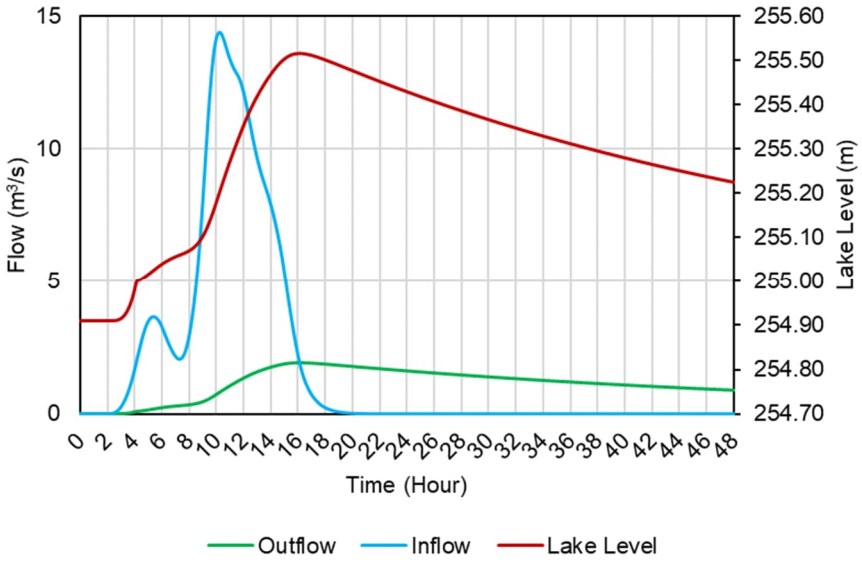


Figure 4-27: Climate Change Proxy Hydrographs for Sunny Lake

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4.2.2.23 *Thinn Lake (Reay Lake)*

Thinn Lake, also called Reay Lake, has a drainage area of 1.9 km^2. Thinn Lake is located southeast of Kilty Switch, and drains out the west end of the lake through a horizontal ellipse-shaped culvert under Reay Road. The stage-discharge relationship of the culvert was developed using CulvertMaster (Bentley, 2023). During the regulatory event, it is likely that the roadway is overtopped by the rising water levels, which would result in an increase in outflow at higher stages. The stage-discharge relationship of the road deck was developed under the assumption that the road behaved as a weir, with an invert elevation of 262.50 m, i.e., the elevation of the road surface at the lake's outlet. The stage-discharge relationship of Thinn Lake was developed by combining the two rating curves from box culvert and the roadway overtopping. The completed outlet rating curve is presented below in Table 4-51. The initial water level of the lake was assumed to be 261.97 m.

Table 4-51: Stage-Storage-Discharge Curves for Thinn Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
261.97[1]	0.0	2,361
262.00	0.0	2,362
262.50	0.8	2,454
263.00	17.5	2,547
264.00	85.3	2,770
265.00	180.9	3,060
266.00	297.8	3,405

Note:
1. 261.97 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Thinn Lake are summarized in Table 4-52. The climate change proxy lake level calculated for Thinn Lake is 262.76 m.

Table 4-52: Peak Event Statistics for Thinn Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	3.9	0.2	262.14
Regulatory Flood (Timmins Storm)	11.0	6.5	262.67
Climate Change Proxy	14.4	9.4	262.76

A summary of lake level, lake inflow, and lake outflow hydrographs for Thinn Lake are provided in Figure 4-28.

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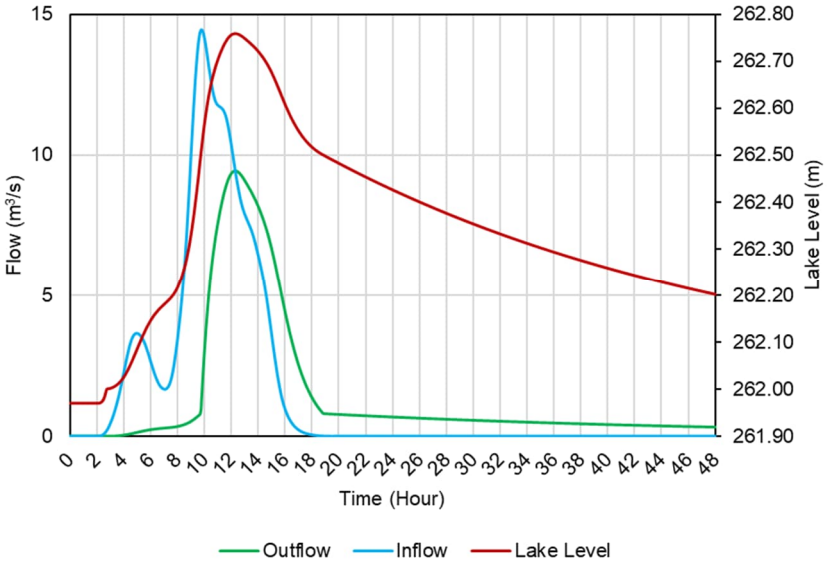


Figure 4-28: Climate Change Proxy Hydrographs for Thinn Lake

4.2.2.24 Camel Lake

Camel Lake has a drainage area of 3.1 km^2. Camel Lake is located southwest of the town of Port Sydney, and drains out the west end of the lake through a dam into Three Mile Lake. The Camel Lake Dam is a 12-m rock weir and is not operated (MNRF).

The stage-discharge relationship of Camel Lake was, therefore, developed under the assumption the outflow channel behaved as a weir with the same dimensions of the Camel Lake Dam. The completed outlet rating curve is presented below in Table 4-53. The initial water level of the lake was assumed to be 290.53 m.

Table 4-53: Stage-Storage-Discharge Curves for Camel Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
290.53[1]	0.0	8,807
291.00	6.2	8,942
292.00	34.2	9,620
293.00	74.5	10,372
294.00	124.1	11,203
295.00	181.5	12,112

Note:
1. 290.53 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Camel Lake are summarized in Table 4-54. The climate change proxy lake level calculated for Camel Lake is 291.20 m.

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Table 4-54: Peak Event Statistics for Camel Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	7.54	2.04	290.68
Regulatory Flood (Timmins Storm)	19.40	9.32	291.11
Climate Change Proxy	25.05	11.87	291.20

A summary of lake level, lake inflow, and lake outflow hydrographs for Camel Lake are provided in Figure 4-29.

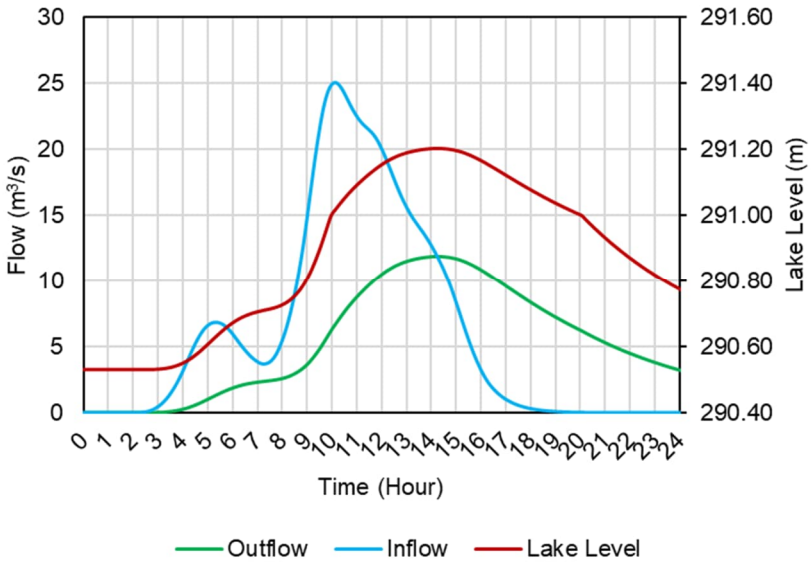


Figure 4-29: Climate Change Proxy Hydrographs for Camel Lake

4.2.2.25 Longs Lake

Longs Lake has a drainage area of 11.6 km^2. Longs Lake is located southwest of the town of Utterson, and drains out the southwest end of the lake through a metal culvert and into a natural channel. The single metal culvert is 15.37 m long with a 2.78-m diameter, and is accessed from Longs Lake Road. A rating curve for the culvert was developed using CulvertMaster (Bentley, 2023). During the regulatory event, it is likely that the roadway is overtopped by the rising water levels, which would result in an increase in outflow at higher stages. The stage-discharge relationship of the road deck was developed under the assumption that the road behaved as a weir, with an invert elevation of 297.50 m, i.e., the elevation of the road deck at the lake's outlet. The stage-discharge relationship of Longs Lake was developed by combining the two rating curves from the culvert and the roadway. The completed outlet rating curve is presented below in Table 4-55. The initial water level of the lake was assumed to be 295.26 m.

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Table 4-55: Stage-Storage-Discharge Curves for Longs Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
295.26[1]	0.0	6,613
296.00	1.2	6,860
297.00	5.9	7,358
298.00	27.0	7,915
299.00	93.9	8,538
300.00	183.2	9,259

Note:
1. 295.26 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Longs Lake are summarized in Table 4-56. The climate change proxy lake level calculated for Longs Lake is 298.14 m.

Table 4-56: Peak Event Statistics for Longs Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	25.8	1.3	296.03
Regulatory Flood (Timmins Storm)	64.0	21.6	297.74
Climate Change Proxy	82.5	36.5	298.14

A summary of lake level, lake inflow, and lake outflow hydrographs for Longs Lake are provided in Figure 4-30.

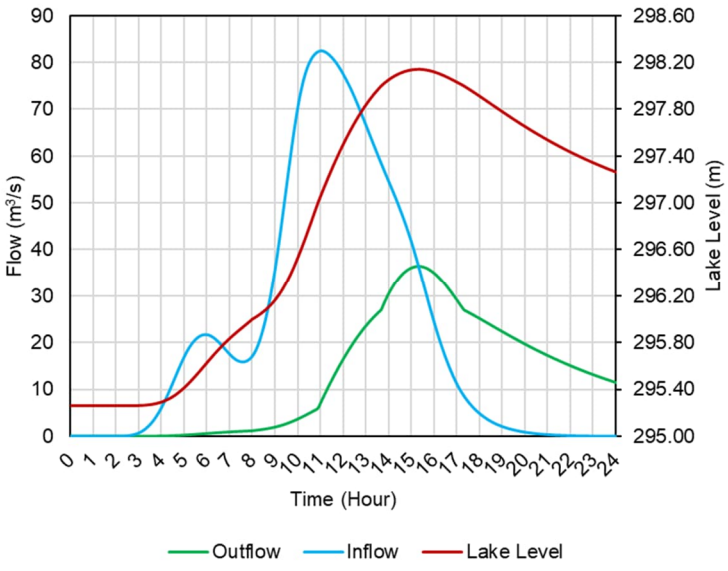


Figure 4-30: Climate Change Proxy Hydrographs for Longs Lake

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4.2.2.26 Fawn Lake

Fawn Lake has a drainage area of 17.2 km^2. Fawn Lake is located southeast of the town of Port Sydney, and drains out the northwest end of the lake through a double-barreled culvert into a natural channel. Each culvert barrel has a diameter of 0.90 m and are approximately 12 m long, and are accessed from North Deer Lake Road. A rating curve for the culvert was developed using CulvertMaster (Bentley, 2023). The completed outlet rating curve is presented below in Table 4-57. The initial water level of the lake was assumed to be 288.08 m.

Table 4-57: Stage-Storage-Discharge Curves for Fawn Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
288.08[1]	0.0	12,815
289.00	1.6	13,700
290.00	3.6	14,942
291.00	4.8	16,974
292.00	5.7	19,335
293.00	6.5	22,142

Note:
1. 288.08 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Fawn Lake are summarized in Table 4-58. The climate change proxy lake level calculated for Fawn Lake is 290.26 m.

Table 4-58: Peak Event Statistics for Fawn Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	32.5	0.9	288.55
Regulatory Flood (Timmins Storm)	81.2	3.5	289.93
Climate Change Proxy	105.5	3.9	290.26

A summary of lake level, lake inflow, and lake outflow hydrographs for Fawn Lake are provided in Figure 4-31.

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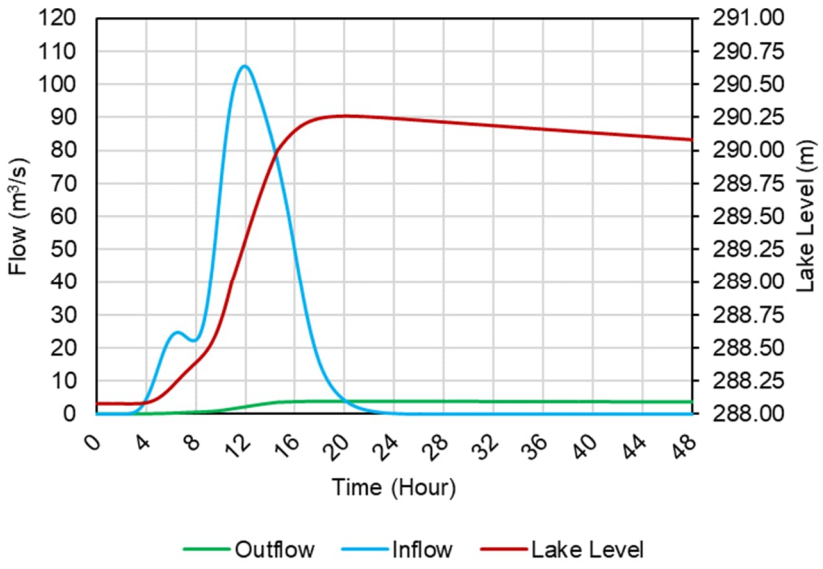


Figure 4-31: Climate Change Proxy Hydrographs for Fawn Lake

4.2.2.27 Moot Lake

Moot Lake has a drainage area of 6.5 km^2. Moot Lake is located west of the town of Baysville, and drains out the southeast end of the lake through a natural channel and eventually into the South Muskoka River. The stage-discharge relationship of Moot Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-59. The initial water level of the lake was assumed to be 333.17 m.

Table 4-59: Stage-Storage-Discharge Curves for Moot Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
333.17[1]	0.0	3,458
334.00	1.2	3,809
335.00	4.0	4,436
336.00	7.6	5,264
337.00	12.0	6,369
338.00	17.0	7,667

Note:
1. 333.17 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Moot Lake are summarized in Table 4-60. The climate change proxy lake level calculated for Moot Lake is 335.00 m.

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Table 4-60: Peak Event Statistics for Moot Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	14.42	0.42	333.46
Regulatory Flood (Timmins Storm)	37.74	2.99	334.65
Climate Change Proxy	49.05	3.96	335.00

A summary of lake level, lake inflow, and lake outflow hydrographs for Moot Lake are provided in Figure 4-32.

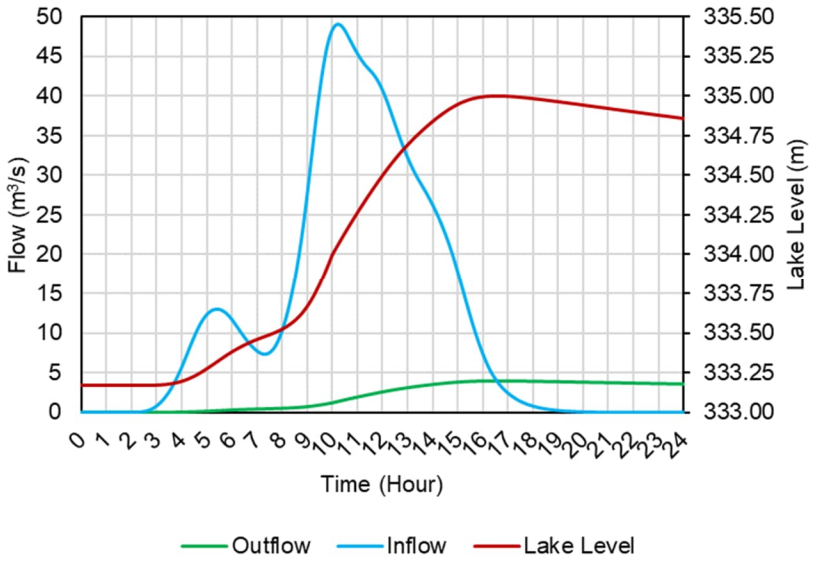


Figure 4-32: Climate Change Proxy Hydrographs for Moot Lake

4.2.2.28 Tooke Lake

Tooke Lake has a drainage area of 1.7 km^2. Tooke Lake is located northwest of the town of Baysville, and drains out the west end of the lake through a natural channel. The Lower Schufelt Lake flows into Tooke Lake via a small culvert, and while Lower Schufelt Lake does not explicitly drain towards Tooke Lake, the presence of this drainage culvert suggests that the Lower Schufelt Lake drainage area should be included in the total delineated watershed area of Tooke Lake. The stage-discharge relationship of Tooke Lake was developed under the assumption the natural outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-61. The initial water level of the lake was assumed to be 344.65 m.

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Table 4-61: Stage-Storage-Discharge Curves for Tooke Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
344.65[1]	0.0	4,823
345.00	2.0	4,862
346.00	15.1	5,324
347.00	34.6	5,998
348.00	58.9	6,734
349.00	87.1	7,536

Note:
1. 344.65 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Tooke Lake are summarized in Table 4-62. The climate change proxy lake level calculated for Tooke Lake is 345.27 m.

Table 4-62: Peak Event Statistics for Tooke Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	4.4	0.9	344.81
Regulatory Flood (Timmins Storm)	12.6	4.4	245.18
Climate Change Proxy	16.4	5.5	345.27

A summary of lake level, lake inflow, and lake outflow hydrographs for Tooke Lake are provided in Figure 4-33.

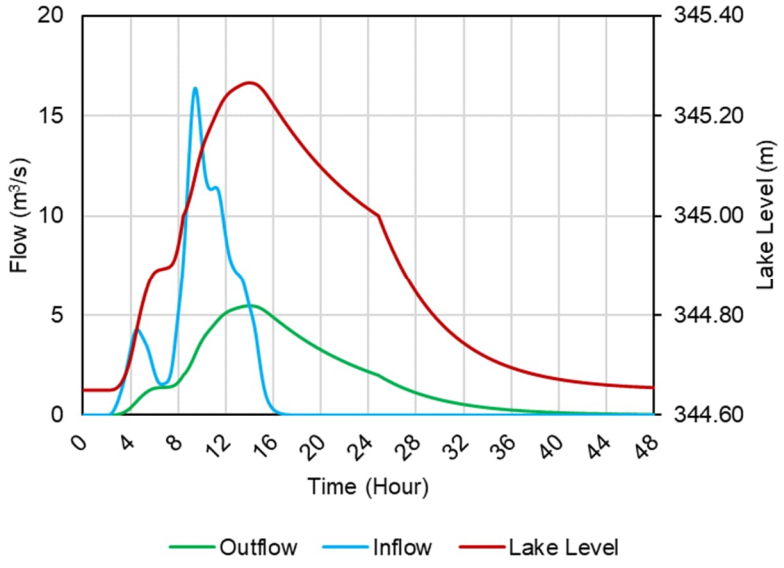


Figure 4-33: Climate Change Proxy Hydrographs for Tooke Lake

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4.2.2.29 Heney Lake

Heney Lake has a drainage area of 1.1 km^2. Heney Lake is located southeast of the town of Baysville, and drains out the east end of the lake through a plastic culvert into Heney Creek. The culvert is accessed from Heney Lake Road, is 10.3 m long, and has a diameter of 0.47 m. A rating curve for the culvert was developed using CulvertMaster (Bentley, 2023). The completed outlet rating curve is presented below in Table 4-63. The initial water level of the lake was assumed to be 344.00 m.

Table 4-63: Stage-Storage-Discharge Curves for Heney Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
344.00[1]	0.0	3,421
345.00	0.3	3,652
346.00	0.4	3,941
347.00	0.6	4,265
348.00	0.7	4,631
349.00	0.8	5,307

Note:
1. 344.00 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Heney Lake are summarized in Table 4-64. The climate change proxy lake level calculated for Heney Lake is 344.68 m.

Table 4-64: Peak Event Statistics for Heney Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	2.4	0.1	344.06
Regulatory Flood (Timmins Storm)	6.9	0.2	344.52
Climate Change Proxy	9.1	0.2	344.68

A summary of lake level, lake inflow, and lake outflow hydrographs for Heney Lake are provided in Figure 4-34.

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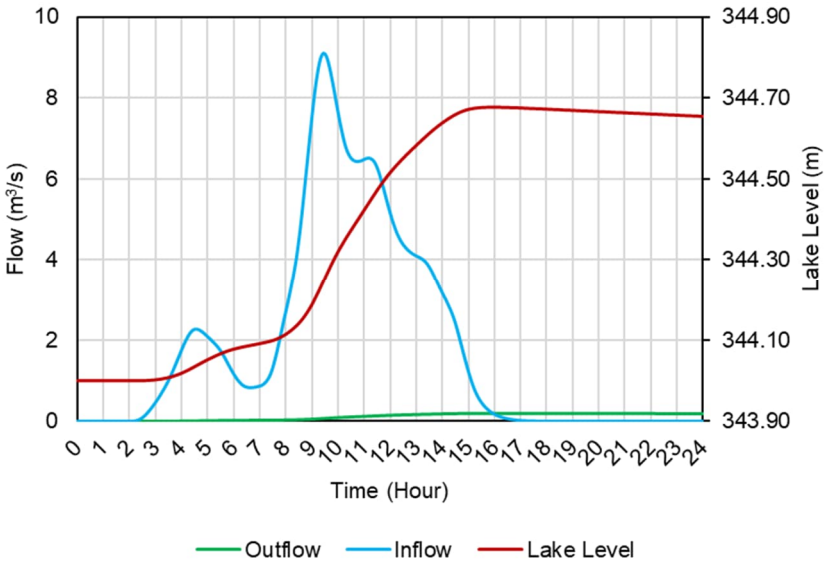


Figure 4-34: Climate Change Proxy Hydrographs for Heney Lake

4.2.2.30 Echo Lake

Echo Lake has an incremental drainage area of 23.7 km^2, and a total drainage area of 27.0 km^2. Echo Lake is located northeast of the town of Baysville, and drains out the southeast end of the lake through a bridge into Martin Creek. The bridge has a span of 3.7 m and height of 1.42 m. A rating curve for the bridge was developed using CulvertMaster (Bentley, 2023), under the assumption that the hydraulic conditions through the bridge would be similar to an equivalent sized box culvert. During the regulatory event, it is likely that the roadway is overtopped by rising water levels due to the low topography, which would result in an increase in outflow at higher stages. The stage-discharge relationship of the road deck was developed under the assumption that the road behaved as a weir, with an invert elevation of 334.0 m, i.e., the elevation of the road deck at the lake's outlet on Echo Lake Road. The stage-discharge relationship of Echo Lake was developed by combining the two rating curves from the culvert and the roadway. The completed outlet rating curve is presented below in Table 4-65. The initial water level of the lake was assumed to be 332.92 m.

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Table 4-65: Stage-Storage-Discharge Curves for Echo Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
332.92[1]	0.00	20,552
333.00	0.13	20,564
334.00	6.35	22,695
335.00	27.07	25,610
336.00	55.20	28,834
337.00	87.44	32,322

Note:
1. 332.92 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Echo Lake are summarized in Table 4-66. The climate change proxy lake level calculated for Echo Lake is 334.35 m.

Table 4-66: Peak Event Statistics for Echo Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	35.45	2.26	333.34
Regulatory Flood (Timmins Storm)	84.29	8.68	334.11
Climate Change Proxy	109.67	13.62	334.35

A summary of lake level, lake inflow, and lake outflow hydrographs for Echo Lake are provided in Figure 4-35.

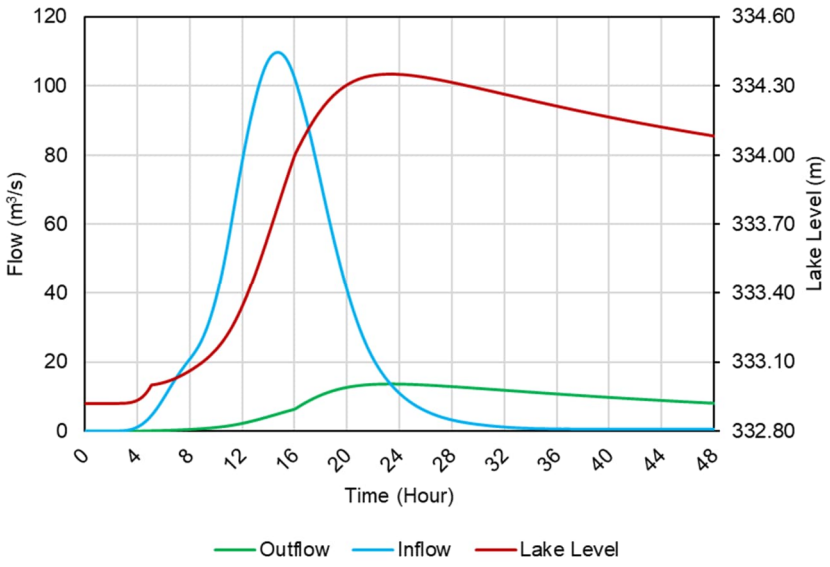


Figure 4-35: Climate Change Proxy Hydrographs for Echo Lake

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4.2.2.31 Grandview Lake

Grandview Lake has a drainage area of 3.3 km^2. Grandview Lake is located upstream of Echo Lake, and drains out the southwest end of the lake through a double-barreled culvert. The diameter of the right barrel is 0.45 m and the diameter of the left barrel is 0.35 m, and both barrels are 12.7 m long. The culverts are accessed from Grandview Lake Road. A rating curve for the culvert was developed using CulvertMaster (Bentley, 2023). The completed outlet rating curve is presented below in Table 4-67. The initial water level of the lake was assumed to be 339.53 m.

Table 4-67: Stage-Storage-Discharge Curves for Grandview Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
339.53[1]	0.00	12,426
340.00	0.50	12,696
341.00	0.97	13,667
342.00	1.29	14,710
343.00	1.60	15,844
344.00	1.79	17,119

Note:
1. 339.53 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Grandview Lake are summarized in Table 4-68. The climate change proxy lake level calculated for Grandview Lake is 340.26 m.

Table 4-68: Peak Event Statistics for Grandview Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	11.3	0.1	339.61
Regulatory Flood (Timmins Storm)	26.0	0.6	340.14
Climate Change Proxy	33.9	0.6	340.26

A summary of lake level, lake inflow, and lake outflow hydrographs for Grandview Lake are provided in Figure 4-36.

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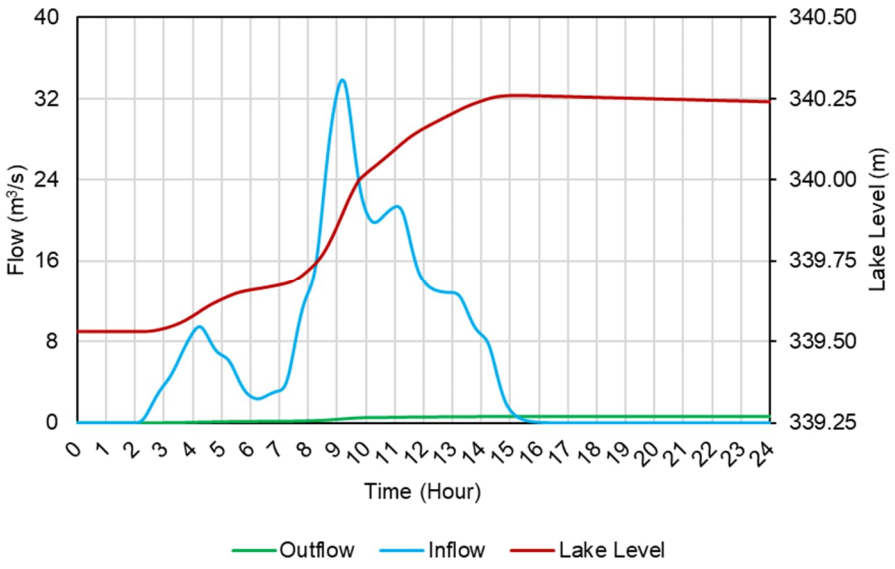


Figure 4-36: Climate Change Proxy Hydrographs for Grandview Lake

4.2.2.32 Ril Lake

Ril Lake has a drainage area of 17.1 km^2. Ril Lake is located east of Echo Lake, and drains out the southwest end of the lake through a 12.7-m long culvert into Martin Creek. The diameter of the culvert is estimated to be 0.90 m, and the culvert is accessed from South Ril Lake Road. A rating curve for the culvert was developed using CulvertMaster (Bentley, 2023). During the regulatory event, it is likely that the roadway is overtopped by the rising water levels, which would result in an increase in outflow at higher stages. The stage-discharge relationship of the road deck was developed under the assumption that the road behaved as a weir, with an invert elevation of 342.30 m, i.e., the elevation of the road deck at the lake's outlet. The stage-discharge relationship of Ril Lake was developed by combining the two rating curves from the culvert and the roadway. The completed outlet rating curve is presented below in Table 4-69. The initial water level of the lake was assumed to be 341.32 m.

Table 4-69: Stage-Storage-Discharge Curves for Ril Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
341.32[1]	0.00	9,031
342.00	0.72	9,663
343.00	26.2	11,382
344.00	92.8	13,438
345.00	182.7	16,044
346.00	290.8	19,228

Note:
1. 341.32 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

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Peak levels for Ril Lake are summarized in Table 4-70. The climate change proxy lake level calculated for Ril Lake is 342.67 m.

Table 4-70: Peak Event Statistics for Ril Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	17.8	0.7	341.97
Regulatory Flood (Timmins Storm)	43.9	12.2	342.45
Climate Change Proxy	57.6	17.7	342.67

A summary of lake level, lake inflow, and lake outflow hydrographs for Ril Lake are provided in Figure 4-37.

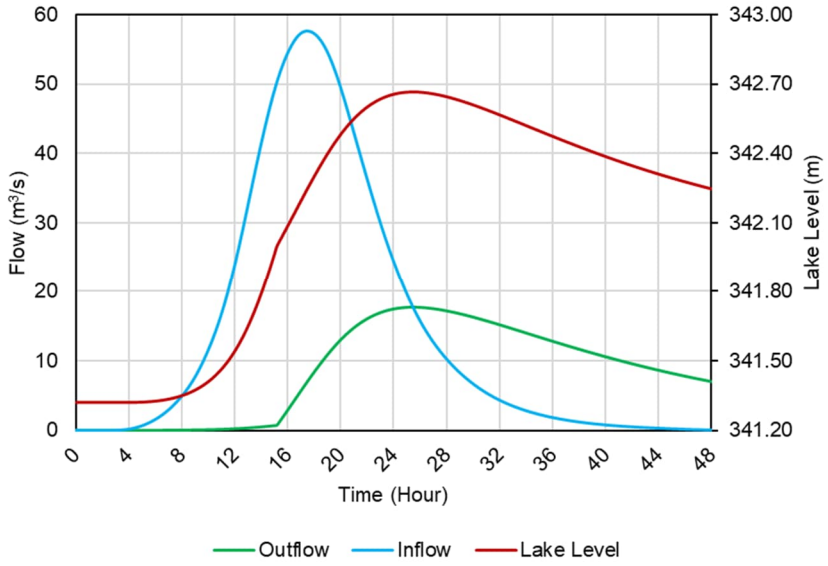


Figure 4-37: Climate Change Proxy Hydrographs for Ril Lake

4.2.2.33 Paint Lake

Paint Lake has a drainage area of 19.5 km^2. Paint Lake is located northeast of the town of Baysville, and drains out of the north end of the lake into the Lake of Bays through a natural channel. The stage-discharge relationship of Paint Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-71. The initial water level of the lake was assumed to be 315.06 m.

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Table 4-71: Stage-Storage-Discharge Curves for Paint Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
315.06[1]	0.0	28,351
316.00	15.5	29,777
317.00	45.8	31,562
318.00	85.5	34,989
319.00	132.6	39,303
320.00	186.2	45,821

Note:
1. 315.06 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Paint Lake are summarized in Table 4-72. The climate change proxy lake level calculated for Paint Lake is 316.40 m.

Table 4-72: Peak Event Statistics for Paint Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	30.5	4.4	315.33
Regulatory Flood (Timmins Storm)	78.0	19.2	316.12
Climate Change Proxy	102.5	27.5	316.40

A summary of lake level, lake inflow, and lake outflow hydrographs for Paint Lake are provided in Figure 4-38.

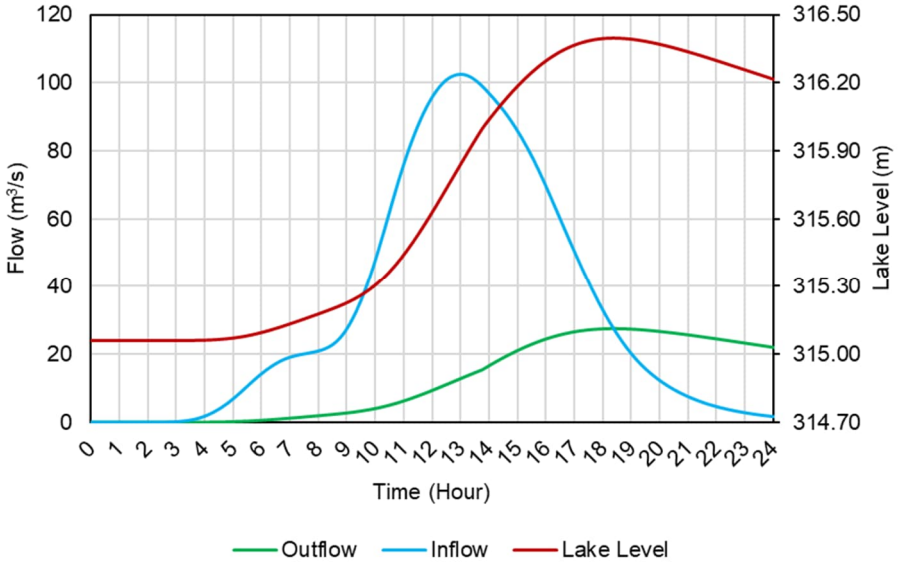


Figure 4-38: Climate Change Proxy Hydrographs for Paint Lake

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4.2.2.34 Raven Lake

Raven Lake has a drainage area of 68.1 km^2. Raven Lake is located southeast of the town of Dorset, and drains out the west end of the lake through a concrete dam. The stage-discharge relationship of Raven Lake was developed using the data provided in the Raven Lake Operation Maintenance, Surveillance & Safety Manual (MNRF, 2018b). Two stage-discharge relationships were defined: a summer relationship with six and a half logs in, and a winter relationship with six logs in. The completed outlet rating curves are presented below in Table 4-73. The initial water level of the lake was assumed to be 350.38 m, corresponding with the target level for spring and summer operations (Genivar Inc., 2012).

Table 4-73: Stage-Storage-Discharge Curves for Raven Lake

Stage (m)	Summer Discharge (m^3/s)	Winter Discharge (m^3/s)	Storage (1,000 m^3)
350.38[1]	0.4	1.1	84,291
351.00	22.1	23.5	84,764
352.00	99.2	101.0	91,136

Note:
1. 350.38 m corresponds with the target level for spring and summer operations (Genivar Inc., 2012).

Peak levels for Raven Lake are summarized in Table 4-74. The climate change proxy lake level calculated for Raven Lake is 351.66 m.

Table 4-74: Peak Event Statistics for Raven Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	51.7	27.3	351.07
Regulatory Flood (Timmins Storm)	134.7	57.4	351.46
Climate Change Proxy	177.7	73.3	351.66

A summary of lake level, lake inflow, and lake outflow hydrographs for Raven Lake are provided in Figure 4-39.

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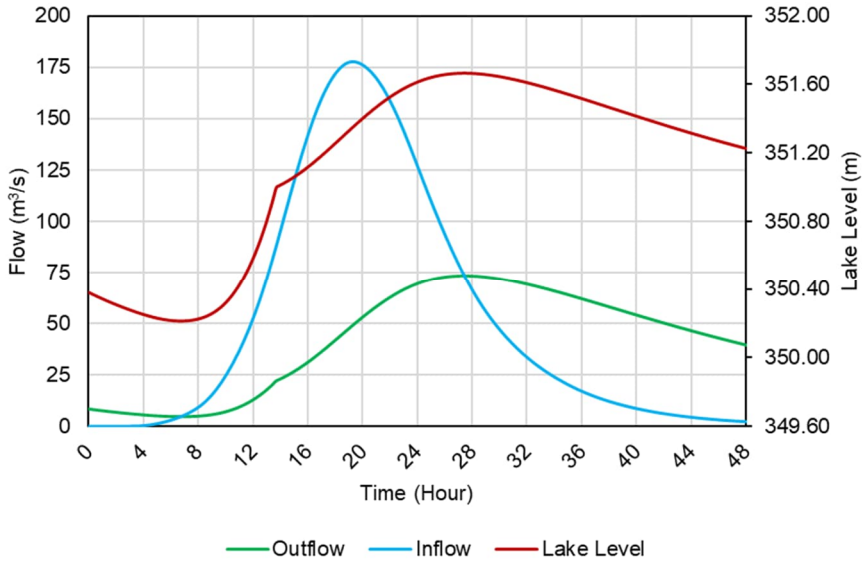


Figure 4-39: Climate Change Proxy Hydrographs for Raven Lake

4.2.2.35 Oxtongue Lake

Oxtongue Lake has an incremental drainage area of 215.01 km^2, and a total drainage area of 569.3 km^2. Oxtongue Lake is located immediately east of the town of Oxtongue Lake, and drains out the west end of the lake through a natural channel into Oxtongue River. The stage-discharge relationship of Oxtongue Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-75. The initial water level of the lake was assumed to be 363.83 m.

WSC station 02EB014 (Oxtongue River Near Dwight) is located downstream approximately 8 km downstream of the outlet of Oxtongue Lake. Using instantaneous peak flow data from this station and a Log-Pearson Type 3 (Method SAM), the 50-yr return period peak flow was estimated to be 120 m^3/s. To replicate this 50-yr estimate using the hydrologic model, it was necessary to increase the initial abstraction estimate for Oxtongue basin from 5 mm to 18 mm. This increase is justified by the high density of lakes (including Canoe Lake) in the headwater region of the Oxtongue basin.

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Table 4-75: Stage-Storage-Discharge Curves for Oxtongue Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
363.83[1]	0.0	48,239
364.00	3.8	48,309
365.00	116.0	51,101
366.00	412.2	54,526
367.00	938.0	58,572
368.00	1,732.5	63,124

Note:
1. 363.83 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Oxtongue Lake are summarized in Table 4-76. The climate change proxy lake level calculated for Oxtongue Lake is 366.23 m.

Table 4-76: Peak Event Statistics for Oxtongue Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	223.43	121.23	365.02
Regulatory Flood (Timmins Storm)	458.94	352.95	365.80
Climate Change Proxy	635.66	531.23	366.23

A summary of lake level, lake inflow, and lake outflow hydrographs for Oxtongue Lake are provided in Figure 4-40.

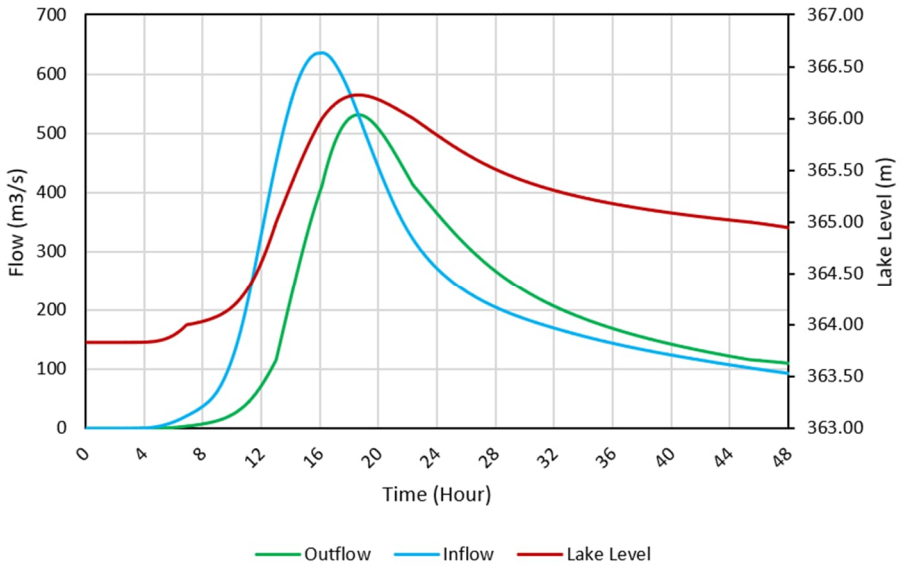


Figure 4-40: Climate Change Proxy Hydrographs for Oxtongue Lake

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4.2.2.36 Oxbow Lake

Oxbow Lake has a drainage area of 32.8 km^2. Oxbow Lake is located northeast of the town of Huntsville, and drains out the southeast end of the lake through a natural channel into Oxtongue Lake. The stage-discharge relationship of Oxbow Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-77. The initial water level of the lake was assumed to be 378.77 m.

Table 4-77: Stage-Storage-Discharge Curves for Oxbow Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
378.77[1]	0.00	59,773
379.00	3.44	59,865
380.00	42.56	63,101
381.00	103.90	66,973
382.00	181.12	71,620
383.00	271.43	76,696

Note:
1. 378.77 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Oxbow Lake are summarized in Table 4-78. The climate change proxy lake level calculated for Oxbow Lake is 379.66 m.

Table 4-78: Peak Event Statistics for Oxbow Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	76.24	10.93	379.19
Regulatory Flood (Timmins Storm)	91.55	21.64	379.47
Climate Change Proxy	125.24	29.10	379.66

A summary of lake level, lake inflow, and lake outflow hydrographs for Oxbow Lake are provided in Figure 4-41.

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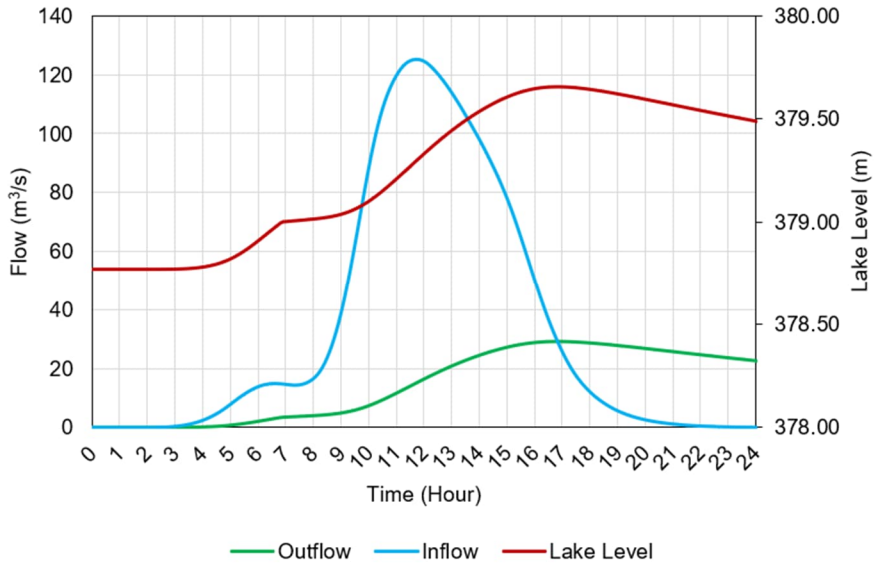


Figure 4-41: Climate Change Proxy Hydrographs for Oxbow Lake

4.2.2.37 Bella Lake and Rebecca Lake

Bella Lake and Rebecca Lake are hydraulically connected by a channel, meaning flood levels derived for this site are applicable to both lake areas. The cumulative drainage area for these lakes is 31.7 km^2. Rebecca Lake discharges out the west end of the lake through a natural channel that eventually flows into the Big East River. The stage-discharge relationship of the outlet was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-79. The initial water level of the lakes were assumed to be 355.88 m based on available LiDAR data. Note that through imagery, debris was visible at the outlet of Rebecca Lake, which may indicate beaver activity that can influence the water levels of the lake (see Figure 4-42).

Table 4-79: Stage-Storage-Discharge Curves for Bella Lake and Rebecca Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
355.88[1]	0.00	42,867
356.00	0.67	42,898
357.00	18.96	45,155
358.00	49.39	47,619
359.00	88.18	50,304
360.00	133.80	53,163

Note:
1. 355.88 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

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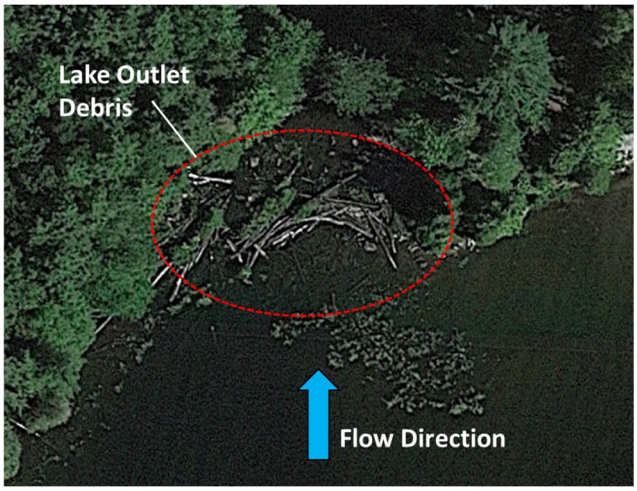


Figure 4-42: Presence of Debris at Rebecca Lake Outlet (Source: Google Earth™)

Peak levels for Bella Lake and Rebecca Lake are summarized in Table 4-80. The climate change proxy lake level calculated for Bella Lake and Rebecca Lake is 356.75 m.

Table 4-80: Peak Water Level for Bella Lake and Rebecca Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	62.5	4.0	356.18
Regulatory Flood (Timmins Storm)	129.9	11.1	356.57
Climate Change Proxy	168.5	14.3	356.75

A summary of lake level, lake inflow, and lake outflow hydrographs for Bella Lake and Rebecca Lake are provided in Figure 4-43.

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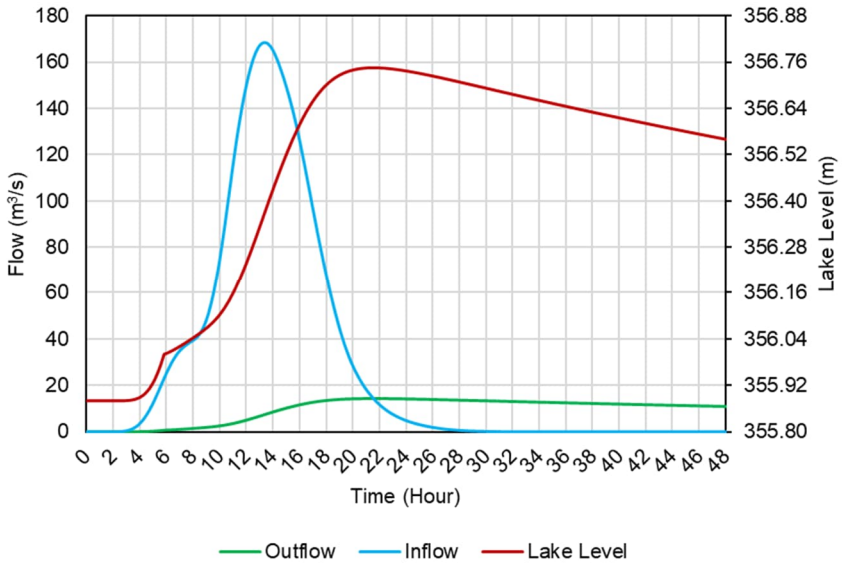


Figure 4-43: Climate Change Proxy Hydrographs for Bella Lake and Rebecca Lake

4.2.2.38 Walker Lake

Walker Lake has a drainage area of 3.07 km^2. Walker Lake is located northeast of the town of Huntsville, and drains out the south end of the lake through a double-barreled culvert. Both culvert barrels are 19.1 m long with a diameter of 0.55 m, and are accessed from Walker Lake Drive. A rating curve for the culvert was developed using CulvertMaster (Bentley, 2023). The completed outlet rating curve is presented below in Table 4-81. The initial water level of the lake was assumed to be 360.45 m.

Table 4-81: Stage-Storage-Discharge Curves for Walker Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
360.45[1]	0.00	10,613
361.00	0.22	10,839
362.00	0.59	11,626
363.00	0.83	12,482
364.00	1.03	13,399
365.00	1.16	14,373

Note:
1. 360.45 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Walker Lake are summarized in Table 4-82. The climate change proxy lake level calculated for Walker Lake is 361.39 m.

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Table 4-82: Peak Event Statistics for Walker Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	10.3	0.1	360.58
Regulatory Flood (Timmins Storm)	24.4	0.3	361.24
Climate Change Proxy	31.3	0.4	361.39

A summary of lake level, lake inflow, and lake outflow hydrographs for Walker Lake are provided in Figure 4-44.

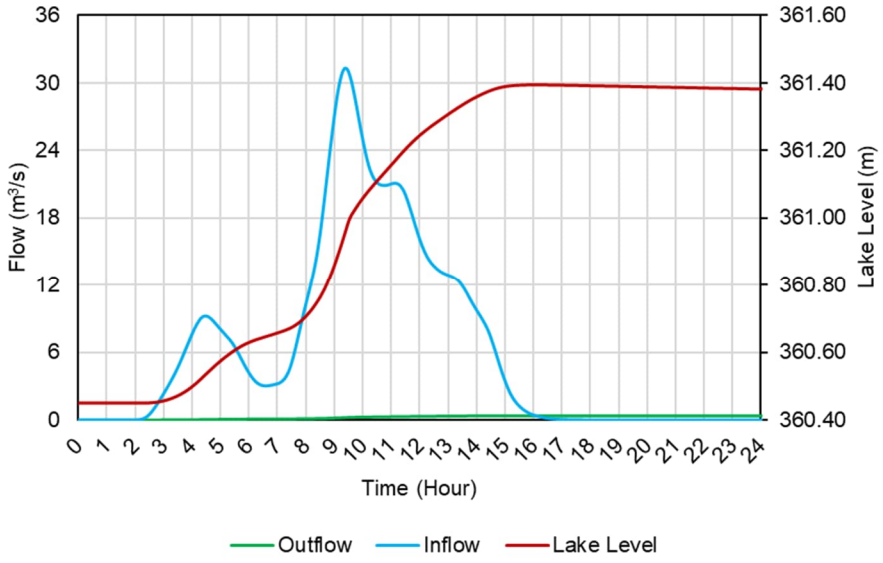


Figure 4-44: Climate Change Proxy Hydrographs for Walker Lake

4.2.2.39 Harp Lake

Harp Lake has a drainage area of 5.5 km^2. Harp Lake is located northeast of the town of Huntsville, and drains out the southeast end of the lake through a double-barreled culvert into a natural channel. Both culvert barrels are 4.9 m long with a diameter of 1.20 m, and are accessed from Harp Lake Road. A rating curve for the culvert was developed using CulvertMaster (Bentley, 2023). The completed outlet rating curve is presented below in Table 4-83. The initial water level of the lake was assumed to be 327.11 m.

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Table 4-83: Stage-Storage-Discharge Curves for Harp Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
327.11	0.00	19,184
328.00	5.79	20,146
329.00	17.92	20,935
330.00	33.88	21,806
331.00	52.91	22,722
332.00	74.57	23,680

Note:
1. 327.11 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Harp Lake are summarized in Table 4-84. The climate change proxy lake level calculated for Harp Lake is 328.30 m.

Table 4-84: Peak Event Statistics for Harp Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	13.9	0.5	327.26
Regulatory Flood (Timmins Storm)	36.5	3.7	328.10
Climate Change Proxy	47.3	5.3	328.30

A summary of lake level, lake inflow, and lake outflow hydrographs for Harp Lake are provided in Figure 4-45.

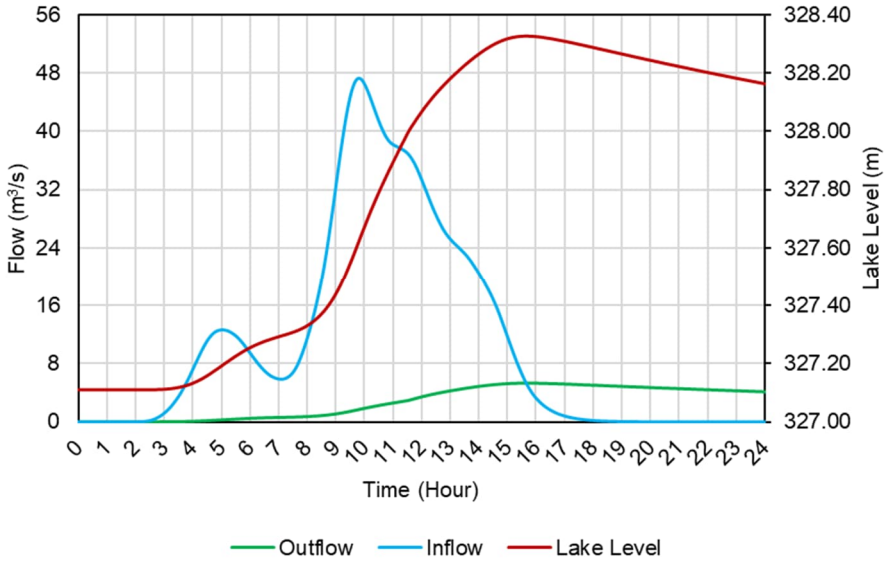


Figure 4-45: Climate Change Proxy Hydrographs for Harp Lake

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4.2.2.40 Oudaze Lake

Oudaze Lake has a drainage area of 13.9 km^2. Oudaze Lake is located northeast of the town of Novar, and drains out the southeast end of the lake through a natural channel. The stage-discharge relationship of Oudaze Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-85. The initial water level of the lake was assumed to be 332.58 m.

Table 4-85: Stage-Storage-Discharge Curves for Oudaze Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
332.58[1]	0	23,195
333.00	2	23,372
334.00	48	24,864
335.00	136	26,744
336.00	249	28,941
337.00	384	32,037

Note:
1. 332.58 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Oudaze Lake are summarized in Table 4-86. The climate change proxy lake level calculated for Oudaze Lake is 333.85 m.

Table 4-86: Peak Event Statistics for Oudaze Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	29.1	4.6	333.05
Regulatory Flood (Timmins Storm)	75.8	31.5	333.64
Climate Change Proxy	98.1	41.0	333.85

A summary of lake level, lake inflow, and lake outflow hydrographs for Oudaze Lake are provided in Figure 4-46.

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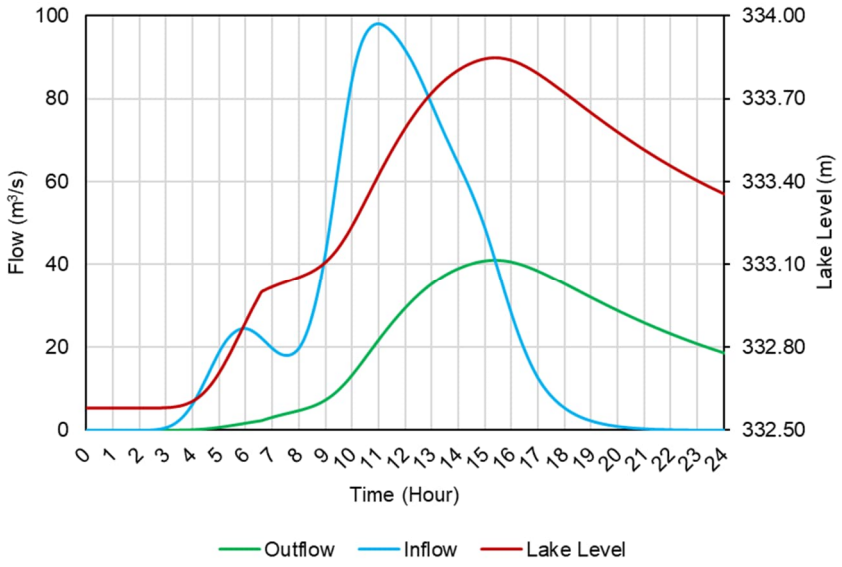


Figure 4-46: Climate Change Proxy Hydrographs for Oudaze Lake

4.2.2.41 *Foote Lake*

Foote Lake has a drainage area of 11.1 km^2. Foote Lake is located northeast of the town of Novar, and drains out the west end of the lake through a double-barreled culvert into a natural channel. The left culvert barrel has a diameter of 0.60 m, and the right culvert barrel has a diameter of 1.5 m, while both are 11.9 m long. The culverts are accessed from Sherwood Drive. A rating curve for the culverts was developed using CulvertMaster (Bentley, 2023). The completed outlet rating curve is presented below in Table 4-87. The initial water level of the lake was assumed to be 343.93 m.

Table 4-87: Stage-Storage-Discharge Curves for Foote Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
354.71[1]	0.00	12,522
355.00	3.12	13,073
356.00	29.30	14,480
357.00	69.31	16,262
358.00	119.35	18,517
359.00	177.71	21,117

Note:
1. 354.71 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Foote Lake are summarized in Table 4-88. The climate change proxy lake level calculated for Foote Lake is 335.85 m.

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Table 4-88: Peak Event Statistics for Foote Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	24.72	4.73	355.06
Regulatory Flood (Timmins Storm)	63.24	19.72	355.63
Climate Change Proxy	81.79	25.24	355.85

A summary of lake level, lake inflow, and lake outflow hydrographs for Foote Lake are provided in Figure 4-47.

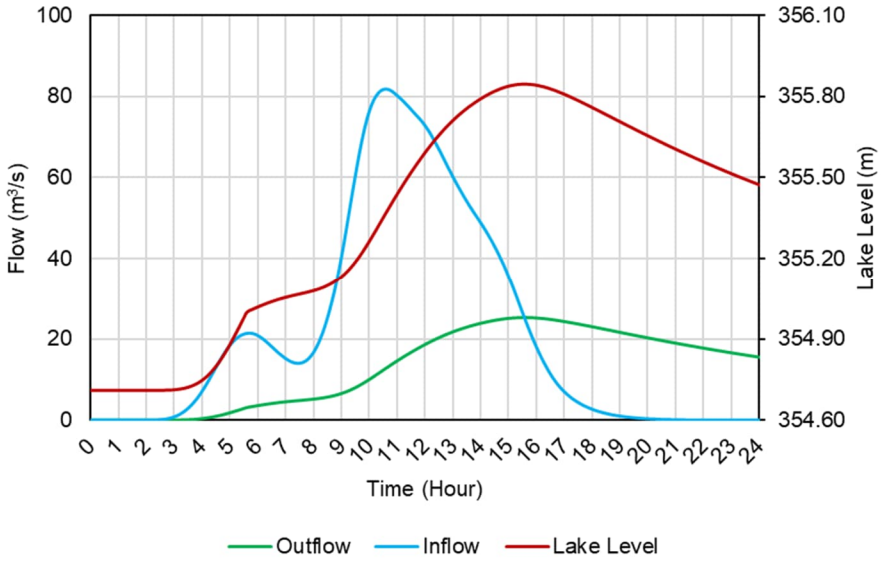


Figure 4-47: Climate Change Proxy Hydrographs for Foote Lake

4.2.2.42 Ripple Lake

Ripple Lake has an incremental drainage area of 0.5 km^2, and a total drainage area of 16.3 km^2. The upstream drainage area includes Palette Lake and Waseosa Lake. Ripple Lake is located southwest of the town of Novar, and drains out the north end of the lake. The stage-discharge relationship of Ripple Lake was developed under the assumption the outflow channel is routed through a culvert. The culvert diameter was assumed to be 2.5 m based on satellite imagery, and a rating curve for the culvert was developed using CulvertMaster (Bentley, 2023). The completed outlet rating curve is presented below in Table 4-89. The initial water level of the lake was assumed to be 329.96 m.

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Table 4-89: Stage-Storage-Discharge Curves for Ripple Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
329.96[1]	0.00	1,636
330.00	0.00	1,637
331.00	2.18	1,835
332.00	7.43	2,045
333.00	14.28	2,268
334.00	20.14	2,503

Note:
1. 329.96 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Ripple Lake are summarized in Table 4-90. The climate change proxy lake level calculated for Ripple Lake is 331.03 m.

Table 4-90: Peak Event Statistics for Ripple Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	2.7	0.3	330.12
Regulatory Flood (Timmins Storm)	5.1	1.7	330.79
Climate Change Proxy	6.5	2.3	331.03

A summary of lake level, lake inflow, and lake outflow hydrographs for Ripple Lake are provided in Figure 4-48.

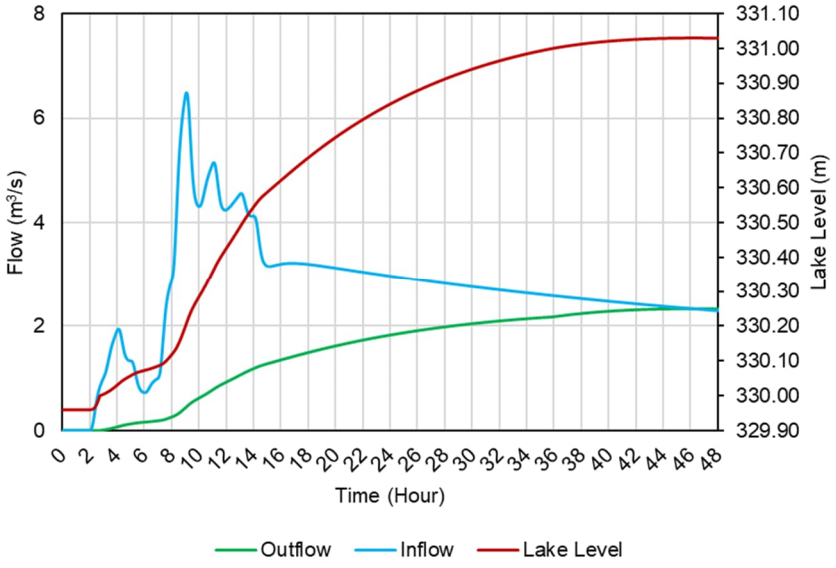


Figure 4-48: Climate Change Proxy Hydrographs for Ripple Lake

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4.2.2.43 Waseosa Lake

Waseosa Lake has a drainage area of 14.9 km^2. Waseosa Lake is located directly upstream of Ripple Lake, and drains out the north end of the lake through a culvert into Ripple Lake. The culvert diameter is 1.32 m and is accessed from North Waseosa Lake Road. A rating curve for the culverts was developed using CulvertMaster (Bentley, 2023). The completed outlet rating curve is presented below in Table 4-91. The initial water level of the lake was assumed to be 332.97 m.

Table 4-91: Stage-Storage-Discharge Curves for Waseosa Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
332.97[1]	0.00	23,399
333.00	0.00	23,401
334.00	1.73	25,262
335.00	4.53	27,712
336.00	6.59	30,931
337.00	8.27	34,765

Note:
1. 332.97 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Waseosa Lake are summarized in Table 4-92. The climate change proxy lake level calculated for Waseosa Lake is 334.14 m.

Table 4-92: Peak Event Statistics for Waseosa Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	27.1	0.2	333.10
Regulatory Flood (Timmins Storm)	74.4	1.6	333.90
Climate Change Proxy	97.9	2.1	334.14

A summary of lake level, lake inflow, and lake outflow hydrographs for Waseosa Lake are provided in Figure 4-49.

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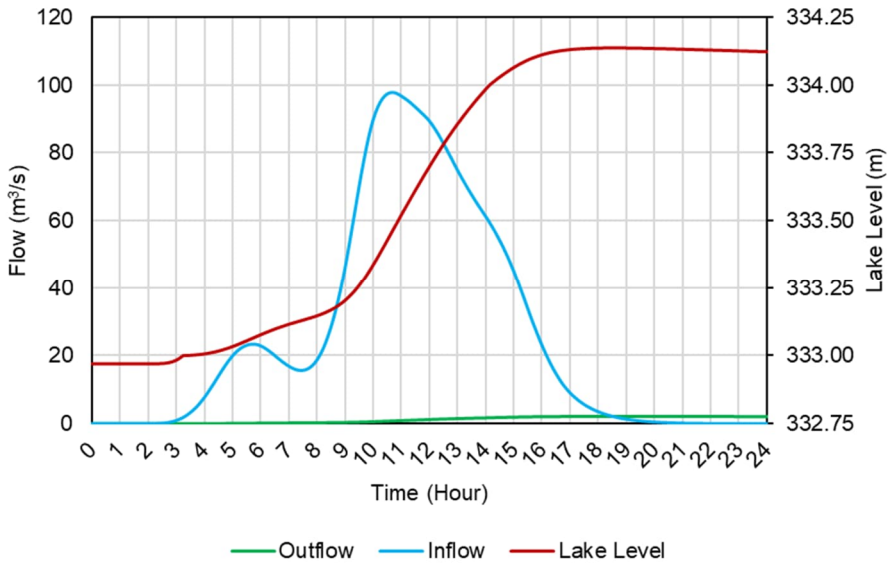


Figure 4-49: Climate Change Proxy Routing for Waseosa Lake

4.2.2.44 Palette Lake

Palette Lake has a drainage area of 0.9 km^2. Palette Lake is located southwest of the town of Novar, and drains out the west end of the lake through a culvert and into Ripple Lake. Note that Palette Lake was modeled in a separate HEC-HMS model due to initial uncertainty regarding the outlet structure and location, as well as the connection to Ripple Lake. The culvert diameter was assumed to be 1.0 m based on satellite imagery, and is accessed from Ripple & Palette Lake Road. A rating curve for the culvert was developed using CulvertMaster (Bentley, 2023). The completed outlet rating curve is presented below in Table 4-93. The initial water level of the lake was assumed to be 332.61 m.

Table 4-93: Stage-Storage-Discharge Curves for Palette Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
332.61[1]	0.00	6,522
333.00	0.20	6,547
334.00	1.78	6,724
335.00	2.83	6,923
336.00	3.52	7,149
337.00	4.10	7,413

Note:
1. 332.61 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Palette Lake are summarized in Table 4-94. The climate change proxy lake level calculated for Palette Lake is 333.63 m.

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Table 4-94: Peak Event Statistics for Palette Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	4.7	0.2	332.91
Regulatory Flood (Timmins Storm)	7.6	0.9	333.47
Climate Change Proxy	9.6	1.2	333.63

A summary of lake level, lake inflow, and lake outflow hydrographs for Palette Lake are provided in Figure 4-50.

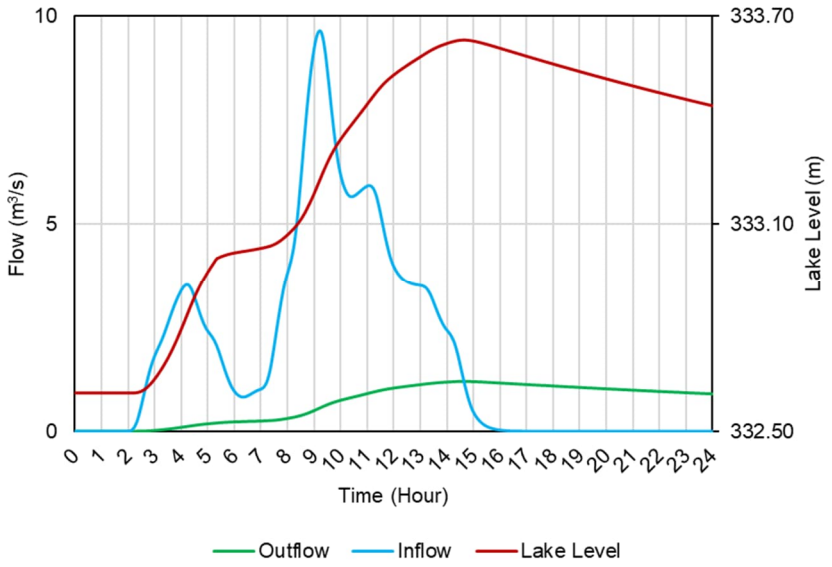


Figure 4-50: Climate Change Proxy Hydrographs for Palette Lake

4.2.2.45 Fox Lake

Fox Lake has a drainage area of 66.8 km^2. Fox Lake is located northwest of the town of Huntsville, directly upstream of Lake Vernon, and drains out the south end of the lake through a two-spillway concrete dam. The stage-discharge relationship of Fox Lake was developed using the data provided in the OMS Manual (MNRF). As both winter and summer scenarios are modeled, a rating curve was developed for each scenario. The completed outlet rating curves are presented below in Table 4-95. The initial water level of the lake was assumed to be 294.26 m.

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Table 4-95: Stage-Storage-Discharge Curves for Fox Lake

Stage (m)	Summer Discharge (m^3/s)	Winter Discharge (m^3/s)	Storage (1,000 m^3)
294.26[1]	0.00	6.76	17,391
295.32	15.73	30.48	18,877
296.31	53.30	58.32	20,742
297.00	97.06	79.37	22,133
298.00	173.31	112.48	24,295
299.00	261.04	147.57	26,587

Note:
1. 294.26 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Fox Lake are summarized in Table 4-96. The climate change proxy lake level calculated for Fox Lake is 297.44 m. The water level was estimated from the hydraulic model.

Table 4-96: Peak Event Statistics for Fox Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	77.5	24.2	295.62
Regulatory Flood (Timmins Storm)	201.2	110.3	297.12
Climate Change Proxy	244.5	136.3	297.44

4.2.2.46 Buck Lake

Buck Lake has a drainage area of 144.1 km^2. Buck Lake is located upstream of Fox Lake and drains out the south end of the lake through a natural channel. The outlet channel flows for approximately 1.3 km and is then attenuated by a two-spillway concrete dam, which releases water into Buck River. The stage-discharge relationship of Buck Lake was developed using the hydraulic model to account for the head drop through the outlet channel before it reaches the Buck Lake Dam. The Buck Lake Dam rating curve was developed using the data provided in the OMS Manual (MNRF). As both winter and summer scenarios are modeled, a rating curve was developed for each scenario. The completed outlet rating curves are presented below in Table 4-97. The initial water level of the lake was assumed to be 300.44 m.

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Table 4-97: Stage-Storage-Discharge Curves for Buck Lake

Stage (m)	Summer Discharge (m^3/s)	Winter Discharge (m^3/s)	Storage (1,000 m^3)
300.44[1]	0.92	11.98	57,114
301.00	8.28	21.74	58,017
302.00	31.22	69.99	61,256
303.00	78.04	119.47	65,053
304.00	123.49	173.40	69,733
305.00	170.72	240.47	75,553

Note:
1. 300.44 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Buck Lake are summarized in Table 4-98. The climate change proxy lake level calculated for Buck Lake is 303.49 m. The water level was estimated from the hydraulic model.

Table 4-98: Peak Event Statistics for Buck Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	115.9	24.7	301.79
Regulatory Flood (Timmins Storm)	273.8	83.7	303.35
Climate Change Proxy	333.3	98.4	303.49

4.2.2.47 Otter Lake

Otter Lake has a drainage area of 0.9 km^2. Otter Lake is located southwest of the town of Huntsville, and drains out the north end of the lake through a natural channel. The stage-discharge relationship of Otter Lake was developed under the assumption the outflow channel behaved as a weir. The completed outlet rating curve is presented below in Table 4-99. The initial water level of the lake was assumed to be 353.79 m.

Table 4-99: Stage-Storage-Discharge Curves for Otter Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
353.79	0.00	1,879
354.00	0.31	1,889
355.00	4.26	2,111
356.00	10.51	2,374
357.00	18.40	2,671
358.00	27.64	3,001

Note:
1. 353.79 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

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Peak levels for Otter Lake are summarized in Table 4-100. The climate change proxy lake level calculated for Otter Lake is 354.48 m.

Table 4-100: Peak Event Statistics for Otter Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	3.2	0.4	354.01
Regulatory Flood (Timmins Storm)	7.5	1.7	354.36
Climate Change Proxy	9.6	2.2	354.48

A summary of lake level, lake inflow, and lake outflow hydrographs for Otter Lake are provided in Figure 4-51.

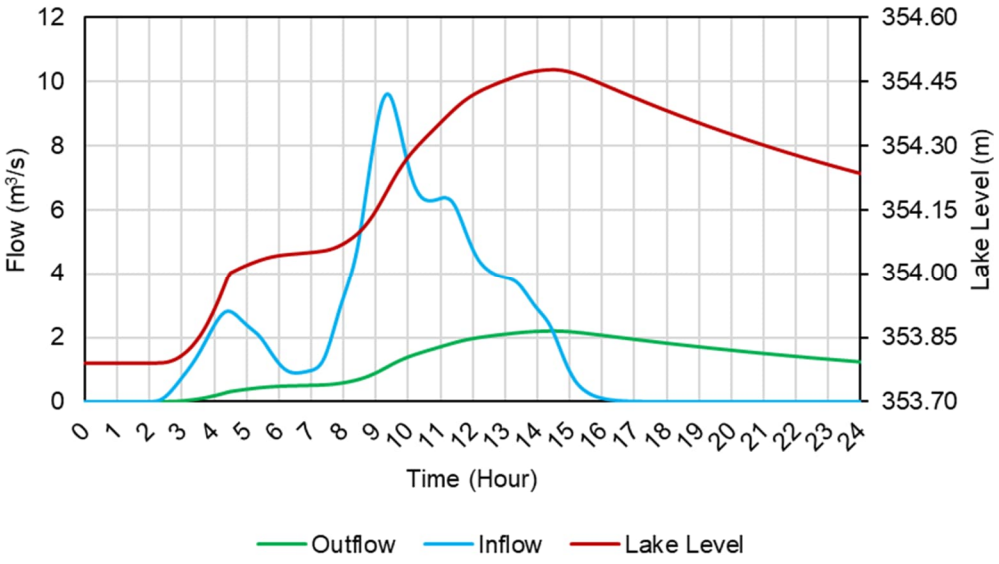


Figure 4-51: Climate Change Proxy Hydrographs for Otter Lake

4.2.2.48 Menominee Lake

Menominee Lake has a drainage area of 11.2 km^2. Menominee Lake is located southeast of the town of Huntsville, and drains out the northwest end of the lake through a box culvert and into the Lake of Bays. The box culvert has a span of 4.45 m and a rise of 2.0 m, and is accessed from Brunel Road. A rating curve for the culvert was developed using CulvertMaster (Bentley, 2023). The completed outlet rating curve is presented below in Table 4-101. The initial water level of the lake was assumed to be 338.02 m.

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Table 4-101: Stage-Storage-Discharge Curves for Menominee Lake

Stage (m)	Discharge (m^3/s)	Storage (1,000 m^3)
338.02	0.0	7,044
339.00	5.6	8,157
340.00	16.3	9,930
341.00	29.1	12,090
342.00	39.6	14,440
343.00	47.9	17,084

Note:
1. 338.02 m corresponds with water level elevation in LiDAR data (Tulloch, 2023b).

Peak levels for Menominee Lake are summarized in Table 4-102. The climate change proxy lake level calculated for Menominee Lake is 339.28 m.

Table 4-102: Peak Event Statistics for Menominee Lake

Event	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Water Level (m)
50-Year	40.1	2.3	338.42
Regulatory Flood (Timmins Storm)	61.4	6.3	339.07
Climate Change Proxy	80.2	8.6	339.28

A summary of lake level, lake inflow, and lake outflow hydrographs for Menominee Lake are provided in Figure 4-52.

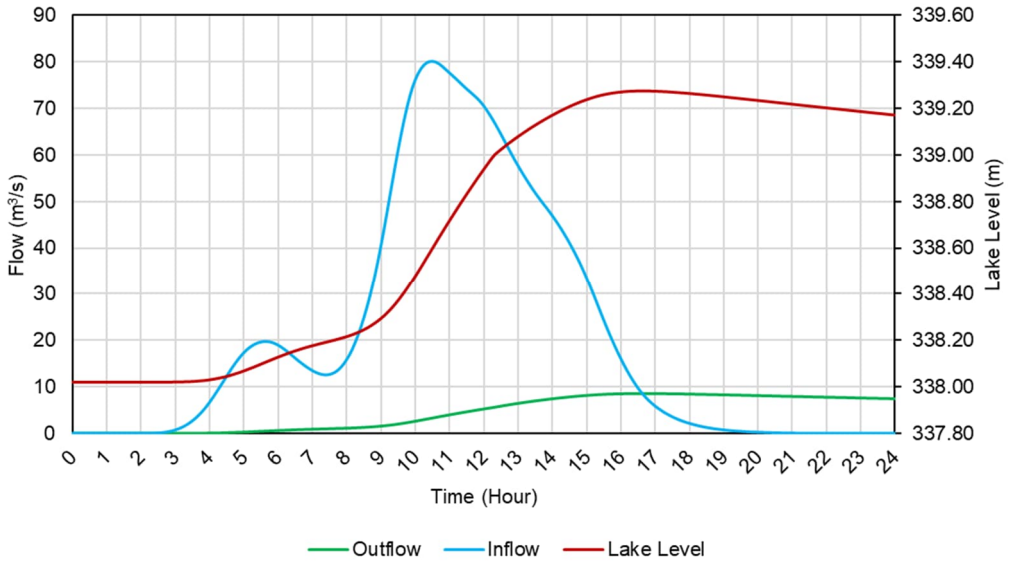


Figure 4-52: Climate Change Proxy Hydrographs for Menominee Lake

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4.3 Hydrologic Study Results

4.3.1 Timmins Storm Flows

Using flow data from the WSC stations in Table 3-2, the peak flows associated with the actual Timmins storm were identified. These peak flows are shown Figure 4-53, including the corresponding date of the flow observation in parentheses.

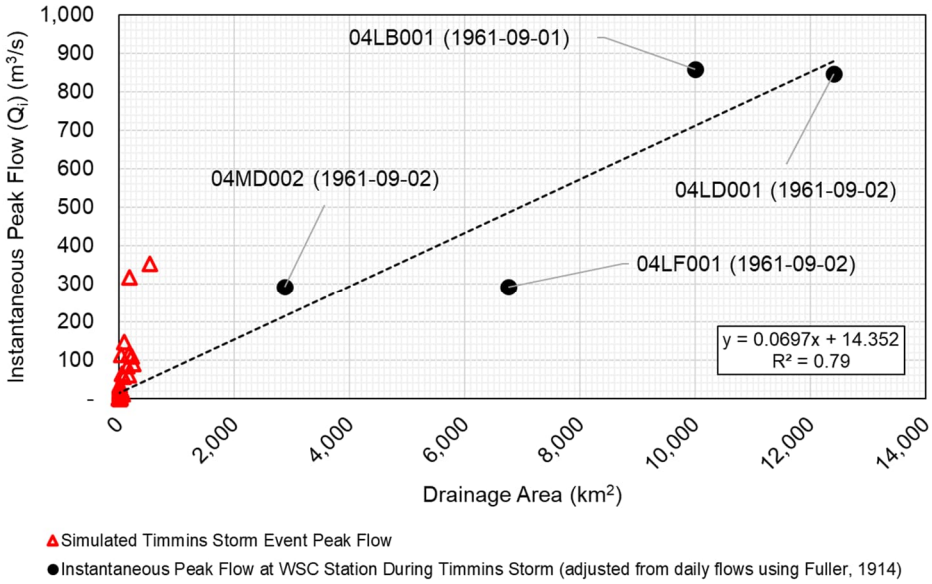


Figure 4-53: Timmins Event Simulation Comparison With Historical Observations

Daily peak flows (Q_{daily}) from WSC were converted to instantaneous peak flows (Q_i) (shown in Figure 4-53) by using the Fuller equation (Fuller, 1914) and WSC reported drainage area (A; km^2):

$$Q_i = Q_{daily}(1 + 2.66A^{-0.3})$$

From these flow estimates, a linear correlation was derived. This trendline can be compared, to some degree, to simulated peak flow observations from Timmins storm events for each water body (also plotted in Figure 4-53).

At first glance, the comparison in Figure 4-53 does indicate that simulated peak flows may be high compared to observed data from the Timmins storm. However, they are reasonable when compared to the uncertainty bounds of the observed data. Factors contributing uncertainty include: (1) limited sample size of observed Timmins storm peak flows, and (2) large drainage area size (over 1,000 km^2) for Timmins region WSC stations.

Regional differences in watershed land use, soil cover, and regulation between Timmins and Muskoka regions is also a consideration as part of this comparison.

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Overall, the comparison in Figure 4-53 provides some indication of model performance compared to regional data, but is not conclusive. The adequacy of site level flow estimates is supported by using calibrated model coefficients from historical modeling studies in the region.

4.3.2 50-Yr Flows

Using select WSC stations throughout the Muskoka River watershed and Severn River watershed, a flood frequency analysis was completed for WSC data to derive a trendline for the 50-yr flood event (Figure 4-54).

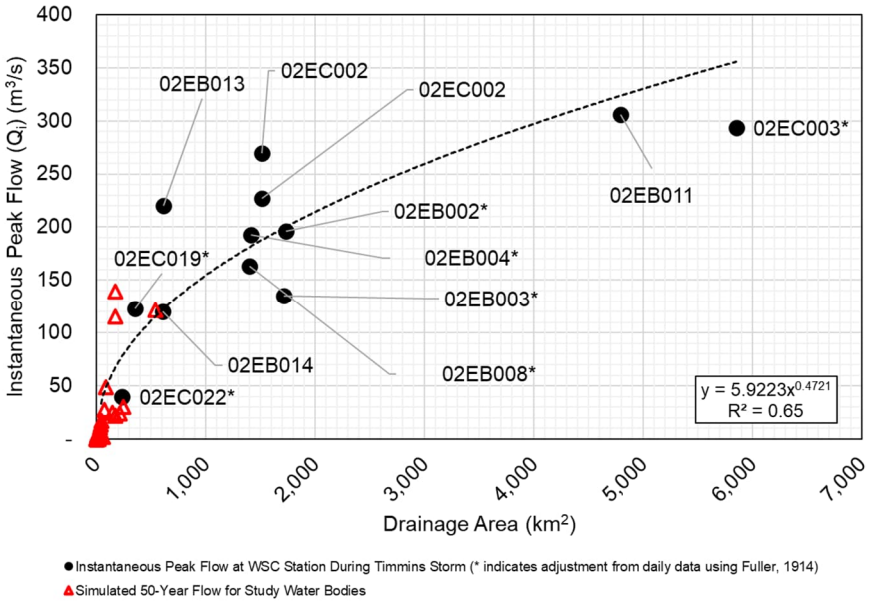


Figure 4-54: 50-Yr Event Simulation Comparison With Historical Observations

Where available, instantaneous data was applied to derive 50-yr flood estimates. The Fuller equation (described in Section 4.3.1) was applied where only daily data was available. The 50-yr flow estimates were derived using HYFRAN software, with a selected distribution of Log Pearson Type III.

A comparison of estimated and modeled 50-yr peak flows show reasonable agreement. As with the Timmins storm comparison in Section 4.3.1, the drainage areas of WSC stations exceeds the size of study watersheds in most cases, which limits the conclusiveness in this comparison.

Overall, the comparison in Figure 4-54 provides some indication of model performance compared to regional data, but is not conclusive based on the above-described limitations. The adequacy of site level flow estimates is supported by using calibrated model coefficients from historical modeling studies in the region.

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4.4 Flood Frequency Analysis (Water Levels)

4.4.1 Sparrow Lake

Using daily water level data from Parks Canada (1988 to 2023), a flood frequency analysis was completed to derive flood levels for Sparrow Lake. This approach is an alternative to hydrologic modeling, as the study basin was deemed large and complex, making it difficult to simulate numerically for the purposes of floodplain mapping.

A visual assessment of the Sparrow Lake maximum annual water level data set indicates that the data does not have any significant trend, and appears homogenous, making it suitable for flood frequency analysis (Figure 4-55).

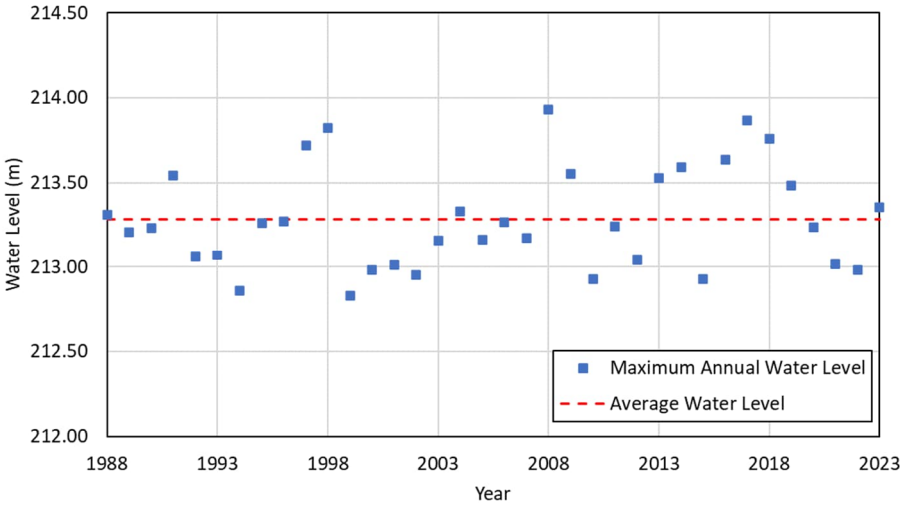


Figure 4-55: Sparrow Lake Maximum Annual Water Levels

The water level estimates were derived using HYFRAN software, with a selected distribution of Gumbel (Figure 4-56).

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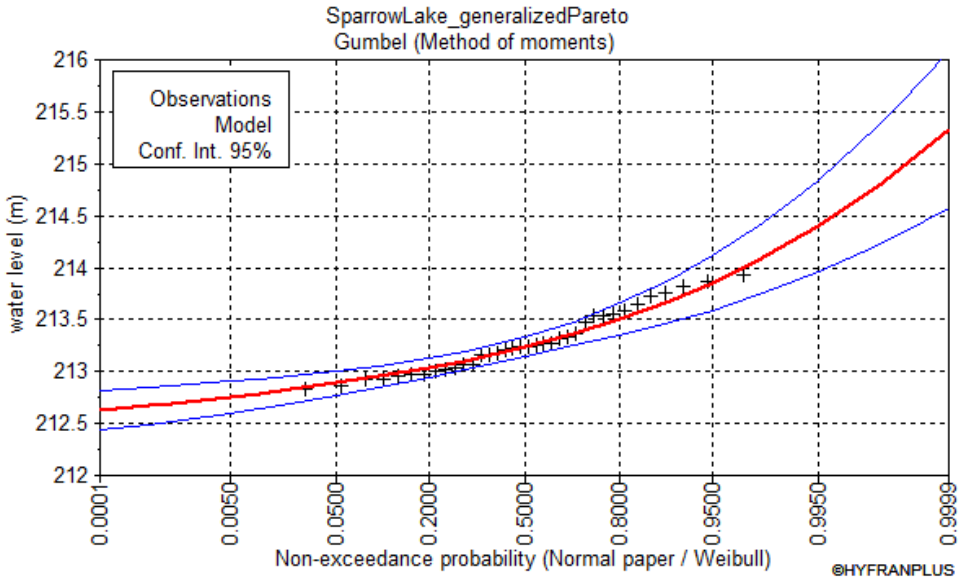


Figure 4-56: Flood Frequency Analysis of Sparrow Lake Water Levels (36-Yr Record)

The Gumbel distribution was selected as it yielded a good fit to the data and yielded reasonably conservative water level estimates relative to other statistical distributions tested. Other statistics describing the maximum annual water level data are provided in Table 4-103.

Table 4-103: Statistics Calculated From Maximum Annual Water Levels (1988-2023)

Statistic	Water Surface Elevation (m)
Mean (m)	213.29
Standard Deviation (m)	0.030326
Skewness Coefficient (-)	1.1395
Kurtosis Coefficient (-)	2.4000

The regulatory flood is governed by the 100-yr water level (214.24 m), which exceeds the flood of record or highest level on record (213.93 m). The Timmins storm would not govern in this case, as the large drainage area of Sparrow Lake (over 5,000 km^2) would correspond with a nearly 50% rainfall reduction factor applied to this event (see Section 4.1.4.3). The climate change proxy was then selected as the 200-yr water level (214.40 m). A summary of these values is provided in Table 4-104.

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Table 4-104: Analysis of Sparrow Lake Water Surface Elevation Data

Event	Water Surface Elevation (m)
50-Year	214.07
Regulatory Flood (100-Yr Level)	214.24
Climate Change Proxy (200-Yr Level)	214.40
Highest Water Level on Record (36-Yr Record)	213.93

4.5 Climate Change Proxy Scaling Factors

In previous floodplain mapping studies in the Muskoka River watershed, uniform scaling factors were applied to account for potential effects of climate change on floodplain mapping. These uniform scaling factors, which ranged from 5% to 20% (Hatch Ltd., 2023a), (Hatch Ltd., 2020), were applied to scale flows that served as the basis for flood map development.

As described in Section 4.1.4.4, flow scaling factors in this study were not explicitly defined, but were instead dictated by hydrologic model simulations by evaluating the impact of increasing rainfall time-series hyetographs by a factor of 1.22 (for Timmins storm as regulatory event).

As illustrated in Figure 4-57, this approach results in a more variability in the flow scaling factors estimated for each site. The average ratio between climate change proxy peak flow and regulatory event peak flow was found to range from 111% to 169%, with an average value of 135%. This variation reflect the differences in runoff responses between study waterbodies, which are the result of factors such as runoff lag time, drainage area, stage-storage-discharge relationships, and curve number.

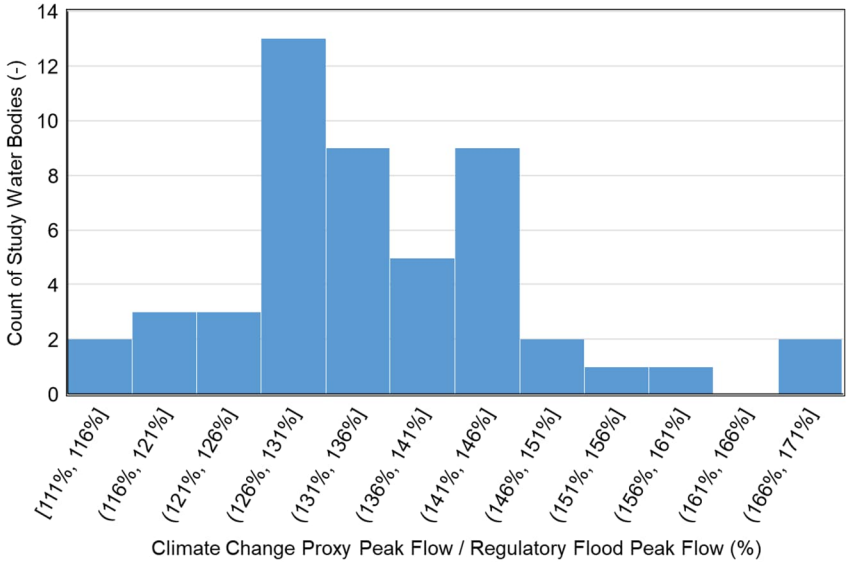


Figure 4-57: Histogram of Climate Change Scaling Factors (Calculated From Peak Outflows)

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4.6 Hydrology Conclusions

All study waterbodies have a regulatory flood corresponding with the Timmins storm, except for Sparrow Lake, which has a regulatory flood corresponding with a 100-yr return period.

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5. River Hydraulics Study

5.1 HEC-RAS Program

Models of each of the selected river reaches were created using HEC-RAS (Version 6.1, September 2021) developed by the US Army Corps of Engineers Hydrologic Engineering Center. HEC-RAS Version 6.1 is capable of modeling both one-dimensional (1-D) and two-dimensional (2-D) hydraulic conditions.

While the hydraulic layout of Gibson River can be adequately represented using a 1-D modeling approach, Kahshe River has flat marshy floodplains where major flow occurs in the floodplain with major changes in direction occurring when water levels exceed the banks of the river. Hydraulic modeling of this type of flow characteristics in the floodplain is best done in 2-D.

5.1.1 HEC-RAS 1-D

In 1-D modeling, the hydraulic characteristics of the river channel is defined by a series of user input cross-sections. These user input cross-sections were placed to reflect changes in river features (e.g., width and slope) for proper simulation of channel hydraulics. While LiDAR data was used for the topographical information, detailed cross-sections survey was carried out for the bathymetric information. There were 67 cross-sections drawn throughout the 8.4-km reach to model the Gibson River.

Channel roughness parameters and other minor loss coefficients are selected to account for the effects of channel boundary roughness, meanders, debris, and other obstructions. Roughness values can be varied spatially across a section, which allows the model to best simulate the effect that variations in infrastructure/vegetation might have on local hydraulic conditions. Proper characterization of hydraulic conditions is important both for in-channel and floodplain areas, as during flood events overland flow is typical. Based on a sensitivity analysis, Section 5.4.2, a Manning's roughness of 0.04 and 0.06 was chosen for the channel and floodplain, respectively.

Results from the HEC-RAS program are exported using the RAS Mapper application in a format which can be imported to the ESRI's ArcGIS program. This allows model flood-line results to be exported into a GIS database of the river and surrounding floodplain, where flood lines can be layered with other maps of the area denoting infrastructure and properties.

5.1.2 HEC-RAS 2-D

HEC-RAS 2-D models use an implicit finite volume solution algorithm, which employs a structured mesh. This allows for larger time steps compared to an explicit solution method. Using the finite volume method provides increased calculation stability in situations where the cell may start completely dry and then has a rush of water through it. The finite volume solution algorithm has the additional advantage of being able to handle supercritical, subcritical, and mixed flow regimes. In addition, every cell edge in the mesh represents an

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area-averaged representation of the underlying terrain which allows shorter computation times.

The model uses the 2D Full Momentum computational method (Shallow Water Equations), often referred to as the Saint Venant equations for shallow flow to account for turbulence and Coriolis effects, making it applicable to a wider range of hydraulic conditions. The HEC-RAS model also allows for combined 1-D and 2-D modeling.

5.1.3 GeoHEC-RAS

The hydraulic model geometries were assembled in a specialty software developed by CivilGEO Engineering Software named GeoHEC-RAS (Version 4.1.0.2847, August 2023). GeoHEC-RAS combined the functionality of 2-D and 3-D AutoCAD, MicroStation, and GIS environment to allow for quick and effective combination of multiple data inputs into the HEC-RAS model files.

5.2 Survey Data

The geometry of both the 1-D and 2-D models was created using a combination of LiDAR data and bathymetric data from the river reaches. LiDAR data was also utilized as part of the hydrologic study (Section 4).

5.2.1 LiDAR Collection

The LiDAR data cloud was collected by Airborne Imaging, processed by Tulloch, and provided to Hatch for hydraulic modeling and floodplain mapping. LiDAR was collected in several stages as part of a series of floodplain mapping projects completed by the District:

- A LiDAR survey covering more than 1,500 km^2 of the Muskoka region was completed between May 18 and 24, 2018. Two flight series were flown, one where the density of points acquired were a minimum of 2.5 pts/m^2 in the less populated areas of the region, and the other with 10 pts/m^2 in the most developed urban areas; a point density of 12.5 pts/m^2 occurred where there was overlap of the two-flight series (Hatch Ltd., 2020).
- A LiDAR survey covering approximately 910 km^2 of the Muskoka region was completed on November 9 and 10, 2021. The minimum point density required was 4 pts/m^2; however, on average, the point density was observed at approximately 7 pts/m^2 on the hard and flat surfaces in open areas (Hatch Ltd., 2023a).
- A LiDAR survey covering 1,859 km^2 of the Muskoka region and Haliburton county was completed on May 25 to 27, 2023. The minimum point density required was 8 pts/m^2; an average point density of 25 pts/m^2 was observed in the final data set acquired (Tulloch, 2023b).
- As described in the Phase II report (Hatch Ltd., 2023a), LiDAR for the Moon and Musquash river reaches was collected by Ontario Power Generation, and shared with the District Municipality of Muskoka through a data-sharing agreement. The LiDAR captured an area of the Musquash River and Moon River in the Muskoka region. The data was

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reviewed and compared in areas that overlapped with the data collection for the District. The data was found to be complete and of sufficient quality for floodplain mapping. The DEM surface used for this study was hydroflattened and used the vertical datum CGVD28.

The horizontal datum used is NAD83 CSRS (2010) and the vertical datums used is CGVD28, with Geoid Model HT2.0. The project resided in Zone 17 in the UTM coordinate system. The 95%, or 2δ, accuracy of the LiDAR data cloud acquired was 35 cm horizontally and 15/10 cm vertically.

Further information on LiDAR collection is found in previous reports (Hatch Ltd., 2020), (Hatch Ltd., 2023a), and (Hatch Ltd., 2023b).

5.2.2 LiDAR Processing

LiDAR data cloud was collected by Airborne Imaging and processed by Tulloch. The processing provided a full feature digital surface model (DSM) and removal of structures and vegetation for a “bare earth” DEM product.

Generally, as per the American Society for Photogrammetry and Remote Sensing (ASPRS) standard, islands smaller than 1,000 m^2 are not required to be classified for this type of study. However, there are several islands in the Muskoka region which are smaller than 1,000 m^2, and many of them have buildings. Therefore, based on discussion with the District, all islands greater than 100 m^2 have been included in the processed DSM/DEM. Islands smaller than 100 m^2 with structures on them, as identified by the District’s Buildings shapefile, have also been included in the processed DSM/DEM.

It is also noted that the water body and building shapefiles provided by the District were used in the floodplain maps, which are approximations and are derived from open source data. As a result, the following visual discrepancies can be noticed in some of the floodplain maps:

- Areas that may look like islands in imagery and/or the water body polygon; however, the LiDAR didn’t register them as islands. These are reviewed and confirmed as wetland areas covered with vegetation, and therefore are not shown as islands.
- The regulatory flood polygon extent in some areas is smaller than the water body polygon.
- The regulatory flood polygons for some islands and along the river/lake shorelines may look different than the existing shapes and/or locations.
- A few buildings may be found in the middle of the water body.

Further information on LiDAR processing is found in previous reports (Hatch Ltd., 2020), (Hatch Ltd., 2023a), and (Hatch Ltd., 2023b).

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5.2.3 *River Cross-Section Bathymetry Collection*

Since LiDAR does not return laser points for any ground below the water surface, it is necessary to supplement these areas with surveyed bathymetry data to create accurate river geometry for the HEC-RAS model. Bathymetric survey points at selected cross-section locations were taken in-channel by Tulloch Engineering using sonar data. Bathymetric data was collected during the periods of September to November 2021, May to June 2022, and September 2023, and is presented in Table 5-1 and summarized in the survey reports for Kahshe River (Tulloch, 2023c), Gibson River (Tulloch, 2023d) and Buck River (Tulloch, 2023e).

Table 5-1: Bathymetric Data Collection

River Name	Data Collection Dates
Kahshe River	May 24 to June 2, 2022
Gibson River	September 3, 2021 September 15, 2021 November 8 to November 10, 2021
Buck River	September 13 to September 21, 2023

5.2.4 *Hydraulic Structures Information*

During the site surveys listed in Table 5-1, elevation information was captured for the following bridges listed in Table 5-2. The elevation information contained top of road, top of opening, and pier location where applicable.

Table 5-2: Surveyed Bridges

River Name	Bridge
Kahshe River	Southwood Road Bridge King's Highway 11 South Bridge Sparrow Lake Route D Bridge
Gibson River	Northbound Highway 400 Southbound Highway 400
Buck River	Ravenscliffe Road Bridge Hoodstown Road Bridge

The survey information of these bridges were incorporated into the hydraulic models, with the exception of Hoodstown Road Bridge. Hoodstown Road Bridge was not represented in the hydraulic model as the bridge was not constricting the flow and would have resulted in additional computational effort and time; additional details are provided in Section 5.4.3.

Buck Lake Dam and Fox Lake Dam were modeled based on information in their respective dam operating manuals.

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5.3 Geometry Development

The HEC-RAS model geometry of both the 1-D and 2-D models was created using a combination of LiDAR data and bathymetric data from the river reaches.

5.3.1 Kahshe River

Combining the bathymetric data with the LiDAR data was performed using similar methods as in the 1-D models with a few additional steps. Representative riverbed cross-sections were developed from the bathymetric data. In HEC-RAS, multiple closely spaced cross-sections were interpolated between the bathymetric cross-sections then extruded to a surface. This created a fully developed channel which is bounded by the banks defined by the LiDAR surface.

The combination of the fully developed channel with the LiDAR 1-m hydroflattened bare earth product results in a complete surface elevation model in HEC-RAS with a representative channel based on collected bathymetric data (example in Figure 5-1).

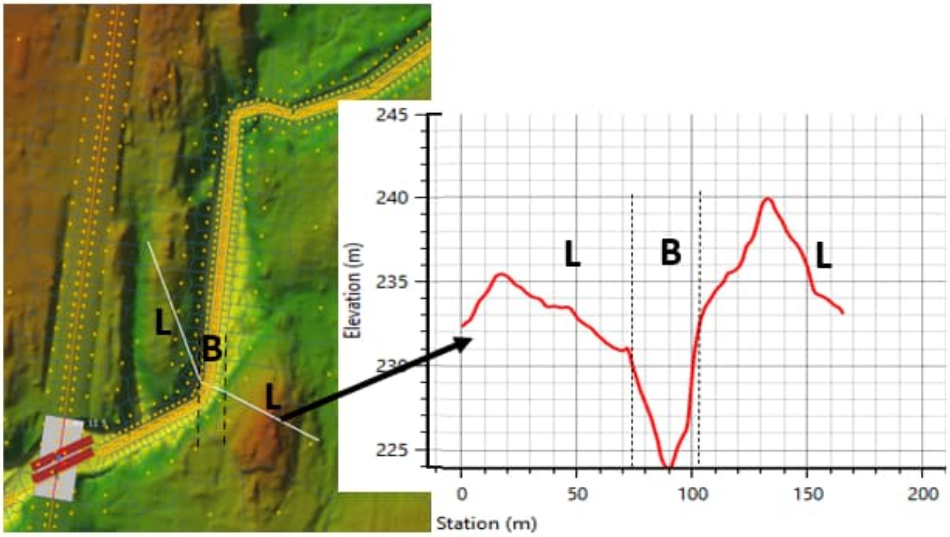


Figure 5-1: Terrain Example Section From Kahshe River Model (L=LiDAR; B=Bathymetry)

The 2-D modeling results are less sensitive to mesh size in HEC-RAS than other hydrodynamic 2-D software because HEC-RAS retains underlying terrain information of each cell face. Each cell has a storage elevation curve, and each cell face has a rating curve into the next cell.

For water to pass from one cell to the next, it must cross the cell face. In HEC-RAS 2-D, modeler-applied breaklines are often used to align cell faces along a high topographic ridge such as a road. The new cell face position forces the water surface to exceed the elevations of the cell faces along the breakline before water can cross into the adjacent cell.

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Figure 5-2 illustrates the effect of applying breaklines at the roads on the mesh in the Kahshe River HEC-RAS model. The Kahshe River was modeled in full 2-D from Kahshe Lake to Sparrow Lake (see Figure 5-3 for full extent of the model reach).

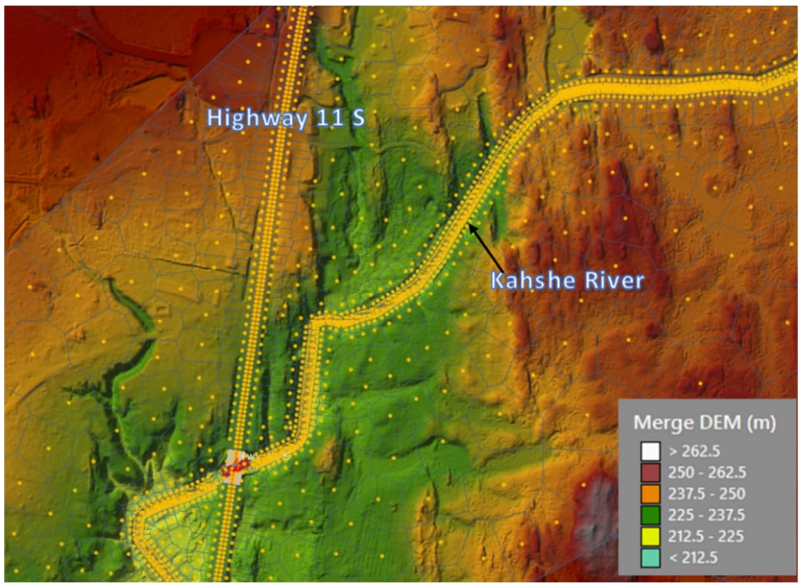


Figure 5-2: Breaklines in Mesh of Kahshe River Model

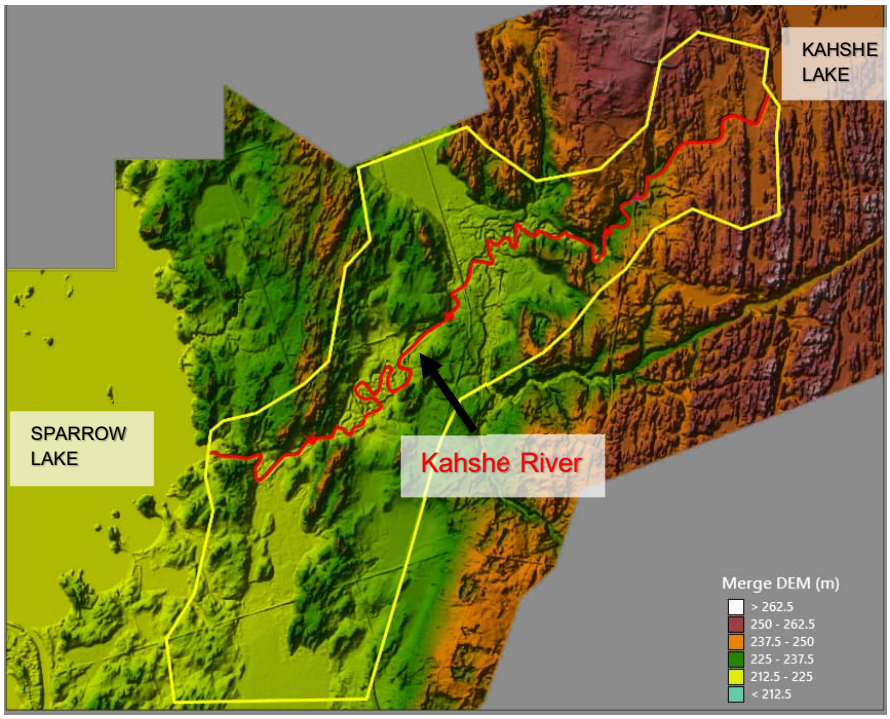


Figure 5-3: Kahshe River Model Arrangement (model extent is indicated by yellow border)

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5.3.2 Gibson River

The HEC-RAS model geometry was created using a combination of LiDAR data and bathymetric data from the river reach, Figure 5-4 and Figure 5-5. GeoHEC-RAS (Section 5.1.3) was used as a supplementary tool to combine the LiDAR and bathymetric data. The combined data was then used to create the 1-D HEC-RAS cross-sections used for hydraulic simulations in HEC-RAS (Figure 5-6). The resulting geometry files were exported to HEC-RAS for calibration and flood simulations.

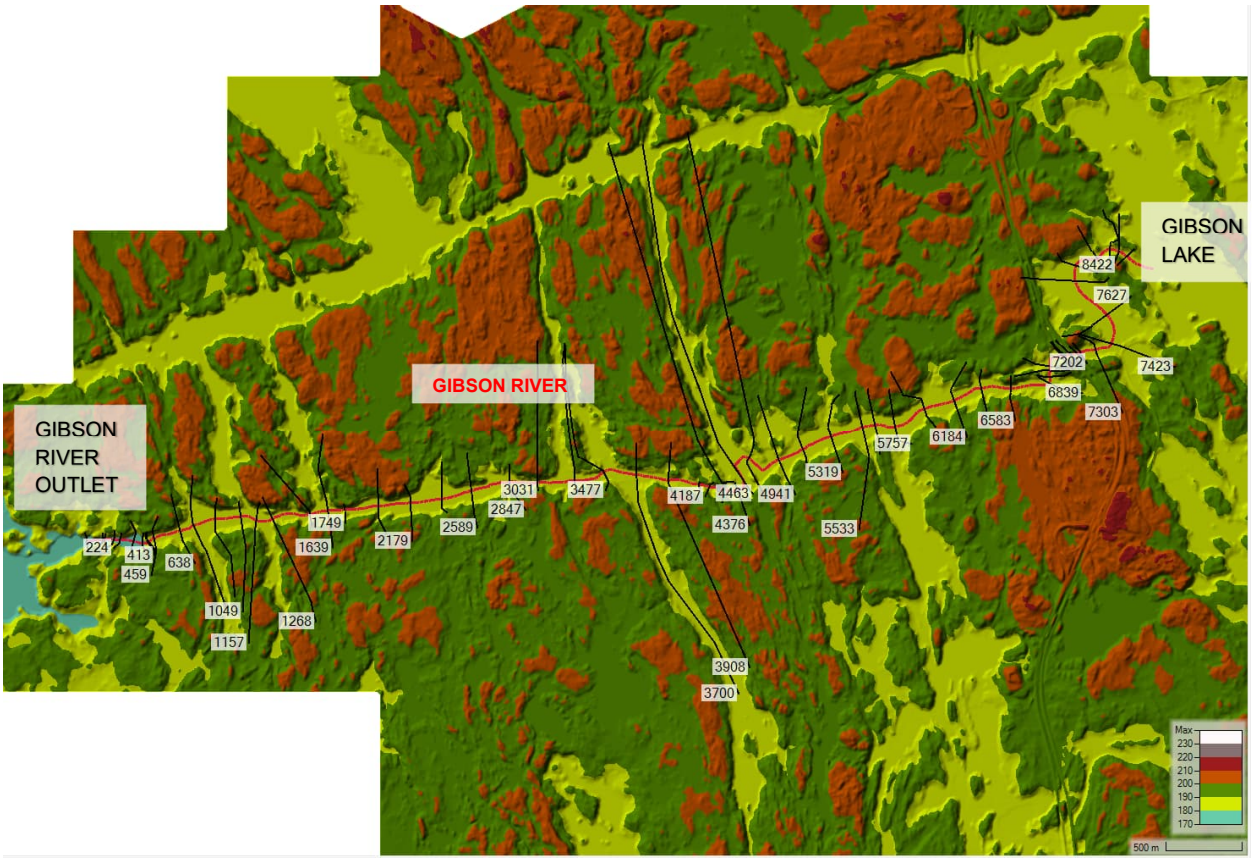


Figure 5-4: Gibson River Model Arrangement

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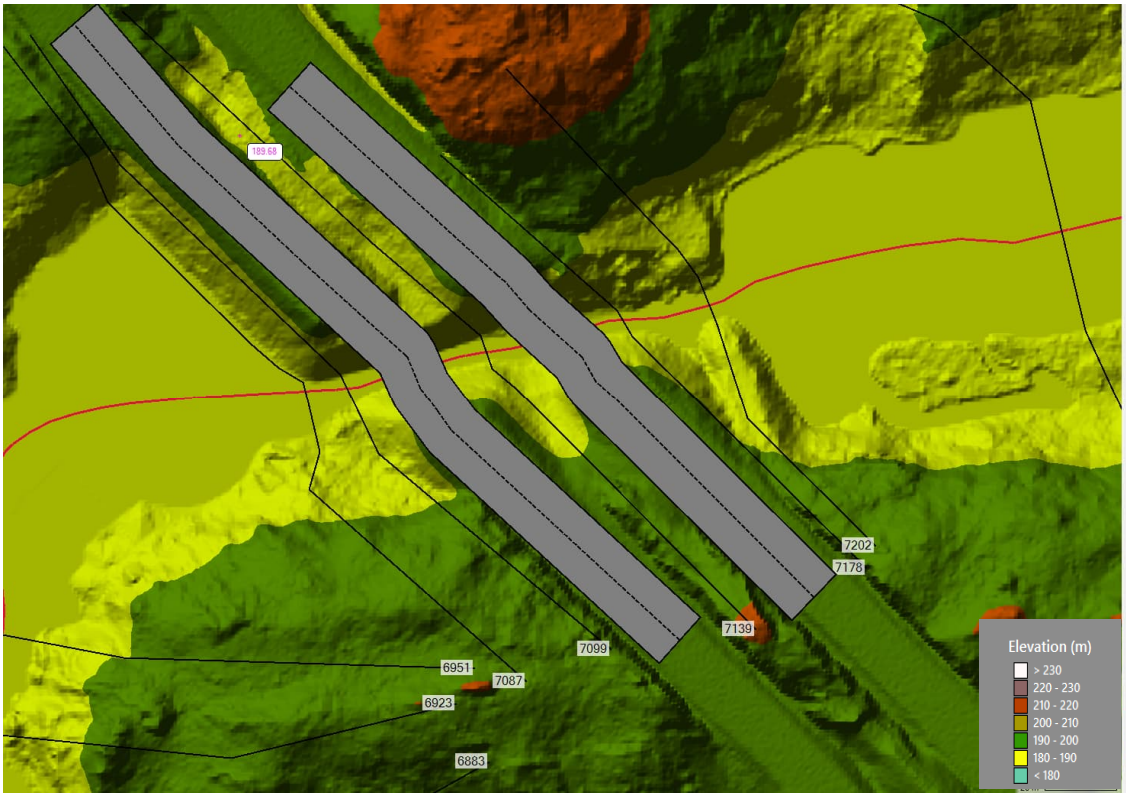


Figure 5-5: Gibson River Model Arrangement Near Highway 400 Bridge

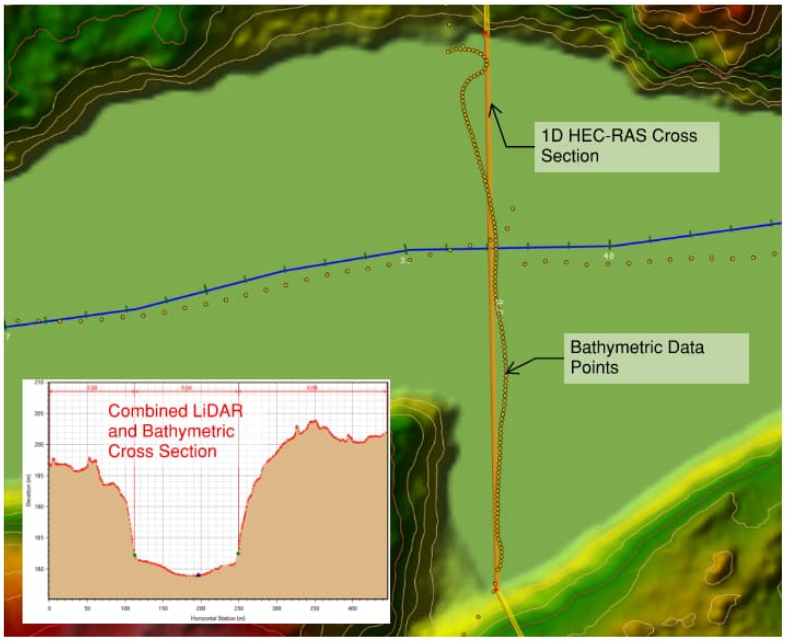


Figure 5-6: Cross-Section Cut From Combined Terrain and Bathymetric Data

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5.3.3 Buck River

The Buck River LiDAR and bathymetric data were combined using the same method as Kahshe River. Representative riverbed cross-sections were developed from the bathymetric data, interpolated and then extruded to a surface. This created a fully developed channel which is bounded by the banks defined by the LiDAR surface. Bathymetric data was not collected at Fox Lake. The Fox Lake bathymetry was generated based on contour layers, Figure 5-7, and stamped into the DEM.

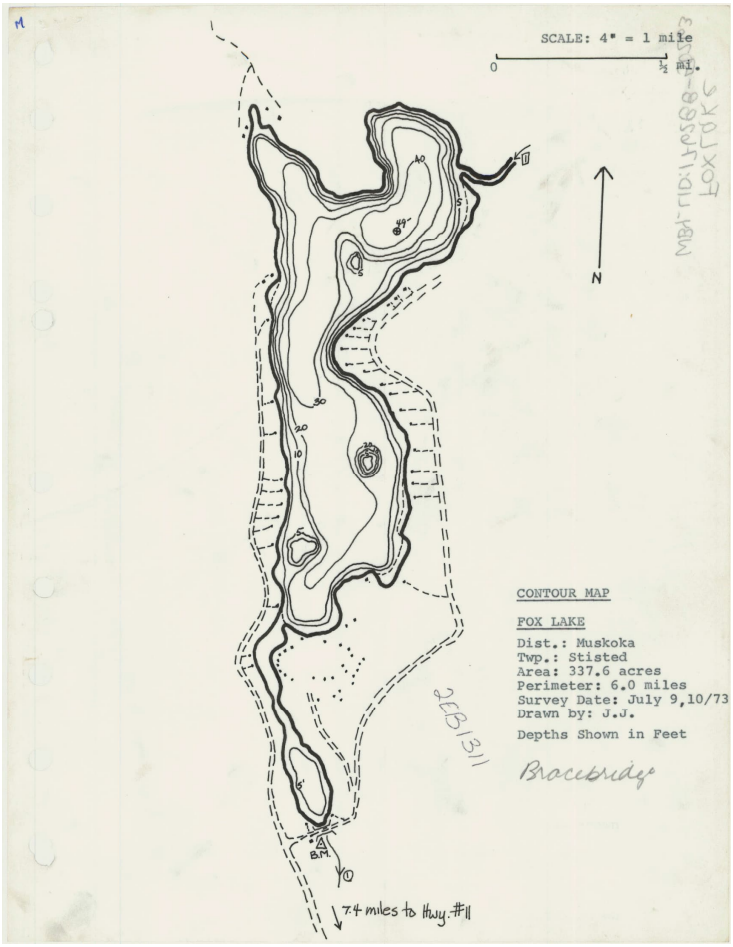


Figure 5-7: Fox Lake Contour Map

The combination of the fully developed channel with the LiDAR 1-m hydroflattened bare earth product results in a complete surface elevation model in HEC-RAS with a representative channel based on collected and recorded bathymetric data (example in Figure 5-8).

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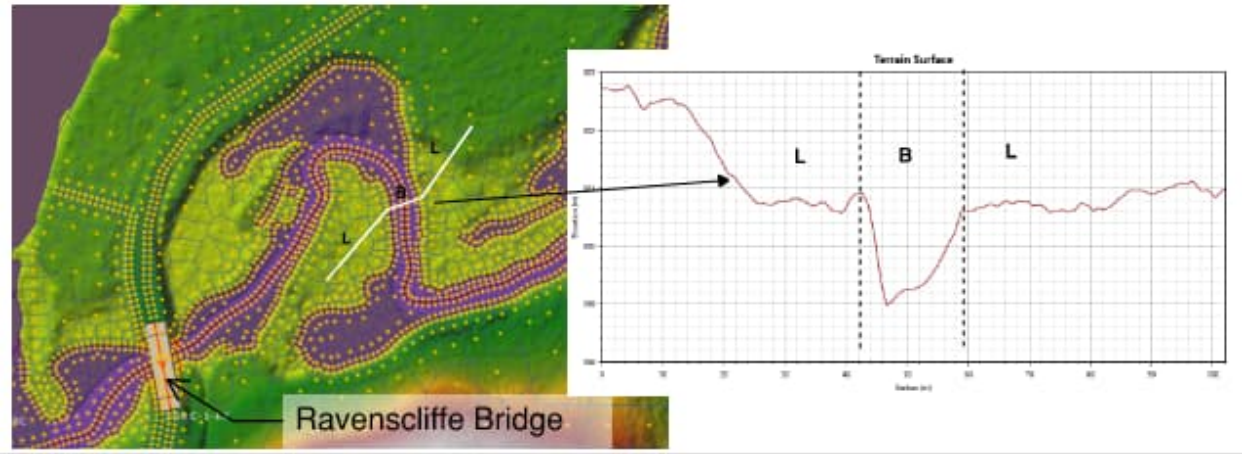


Figure 5-8: Terrain Example Section From Buck River Model (L=LiDAR; B=Bathymetry)

The 2-D modeling results are less sensitive to mesh size in HEC-RAS than other hydrodynamic 2-D software because HEC-RAS retains underlying terrain information of each cell face. Each cell has a storage elevation curve, and each cell face has a rating curve into the next cell.

For water to pass from one cell to the next, it must cross the cell face. In HEC-RAS 2-D, modeler-applied breaklines are often used to align cell faces along a high topographic ridge such as a road. The new cell face position forces the water surface to exceed the elevations of the cell faces along the breakline before water can cross into the adjacent cell.

Figure 5-9 illustrates the effect of applying breaklines at the roads on the mesh in the Buck River HEC-RAS model. The Buck River was modeled in full 2-D from Buck Lake to Vernon Lake (see Figure 5-10 for full extent of the model reach).

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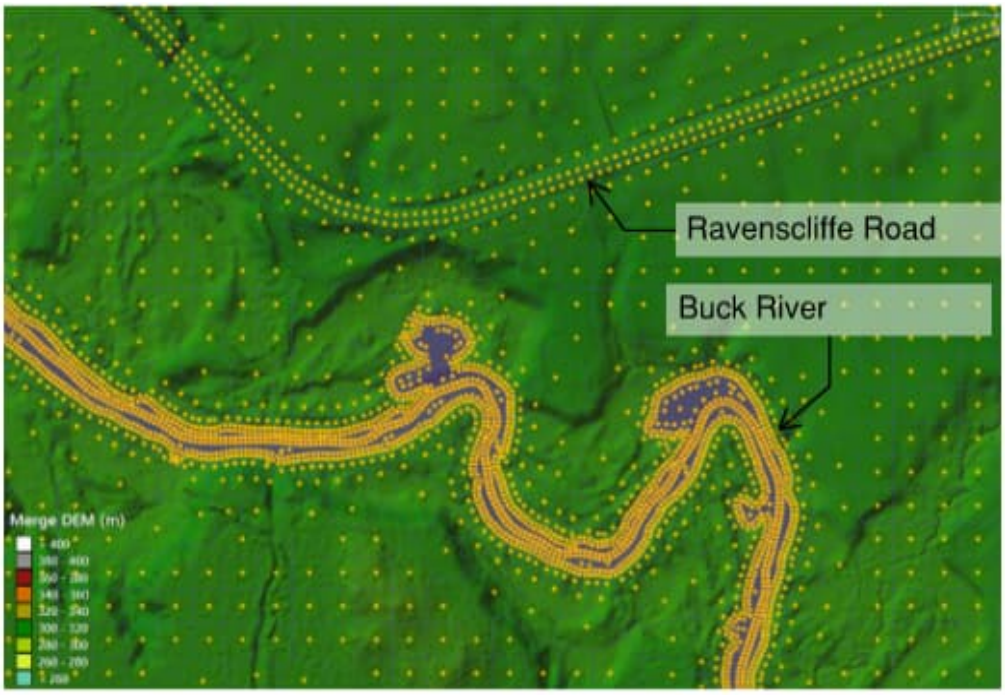


Figure 5-9: Breaklines in Mesh of Buck River Model

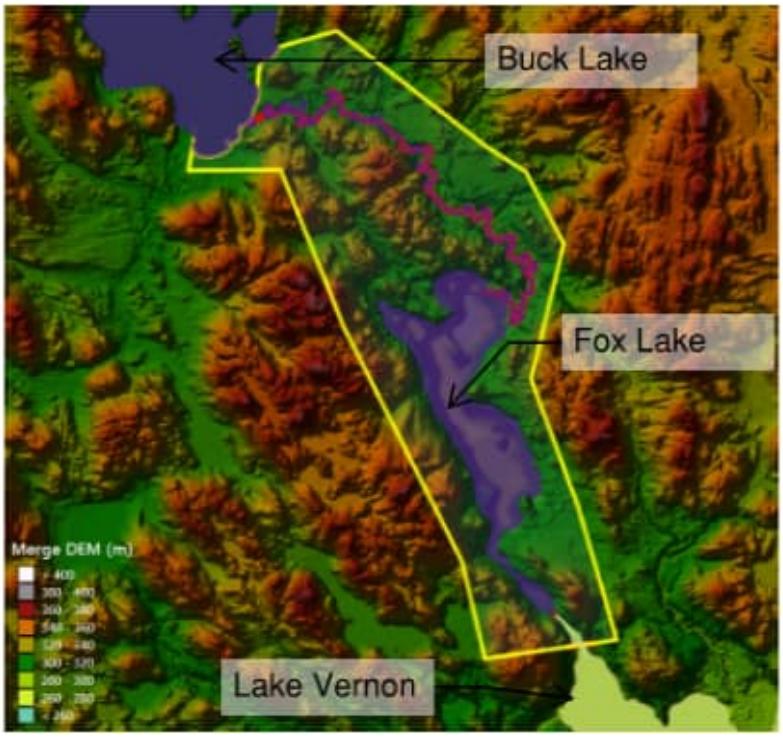


Figure 5-10: Buck River Model Arrangement (model extent is indicated by yellow border)

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5.4 Model Calibration

For each of the river reaches, different types of information were available for calibration, and as such the methods for calibration differed accordingly. The main method of calibration along the river reaches in the models is the adjustment of the hydraulic roughness (resistance to flow) by means of Manning's n to match observed water levels in the reach at a given flow.

5.4.1 Kahshe River

Kahshe River water levels are controlled primarily by outflow from Kahshe Lake and the tributary flow from South Kahshe River. The hydraulic model for Kahshe River was calibrated to match the water level data measured on the day of the bathymetric survey with a flow of 2 m^3/s, which was estimated by scaling flow records from WSC station 02ED024 for the dates of survey.

No data is available for calibration of Manning's n values in the overbank areas of the Kahshe River. In lieu of a calibration, a sensitivity analysis was conducted using the climate change proxy flood event. The sensitivity analysis was completed by adjusting the roughness coefficient of the overbank area by ±15% to observe the modeled water surface elevation change.

The results of the sensitivity analysis are summarized in Table 5-3. The selected value for the overbank Manning's n roughness (0.085 to 0.14) represents a resistance to flow associated with the varying land cover. The sensitivity analysis shows the water surface elevation change over the range of possible overbank roughness values. The model is moderately sensitive to overbank roughness for the regulatory flood with a maximum difference of +0.59 m and -0.33 m for the high Manning's n and low Manning's n condition, respectively.

Figure 5-11 presents a summary of the calibration results as they compare to the measured levels. The calibration was achieved by adjusting the critical cross-sections at meanders and the Manning's n values considering the physical characteristics of the river. A notable controlling feature in the channel is a bridge 500 m downstream from Highway 11S (Figure 5-2). The bridge consists of a weir and two concrete piers, and was represented in the model using LiDAR data and photos from the field survey.

Figure 5-12 presents points used in the calibration along the reach. The error consistently ranges between +40 cm to -40 cm, which is considered the normal range for a 2-D HEC-RAS model. The trend of the error is consistent across the reach, in that it does not trend either positively or negatively over the length of the reach.

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Table 5-3: Kahshe River Sensitivity Results (Climate Change Flow)

Location	Calibrated Model WSE (n_{cal} = 0.085-0.14) (m)	High Manning's Sensitivity (n_{high} = 0.098-0.161) [where n_{high} = 1.15n_{cal}]		Low Manning's Sensitivity (n_{low} = 0.072-0.119) [where n_{low} = 0.85n_{cal}]	
		Model WSE (m)	Difference (m)	Model WSE (m)	Difference (m)
Downstream of Kahshe Lake	243.00	243.02	0.02	242.93	-0.07
Upstream of Highway 11S Culvert	229.02	229.61	0.59	228.89	-0.13
Downstream of Highway 11S Culvert	226.80	227.35	0.55	226.69	-0.11
Upstream of Train Crossing	217.73	217.86	0.13	217.70	-0.03
Downstream of Train Crossing	217.61	217.85	0.24	217.60	-0.01
Upstream of Sparrow Lake Bridge	217.44	217.80	0.36	217.30	-0.14
Downstream of Sparrow Lake Bridge	216.94	217.52	0.58	216.85	-0.09
Upstream of Southwood Road Bridge	215.88	216.26	0.38	215.55	-0.33
Downstream of Southwood Road Bridge	215.65	215.85	0.20	215.59	-0.06
Upstream of Sparrow Lake	214.04	214.05	0.01	214.01	-0.03

Notes:
WSE = water surface elevation
1. n_{cal} = calibrated Manning's n.

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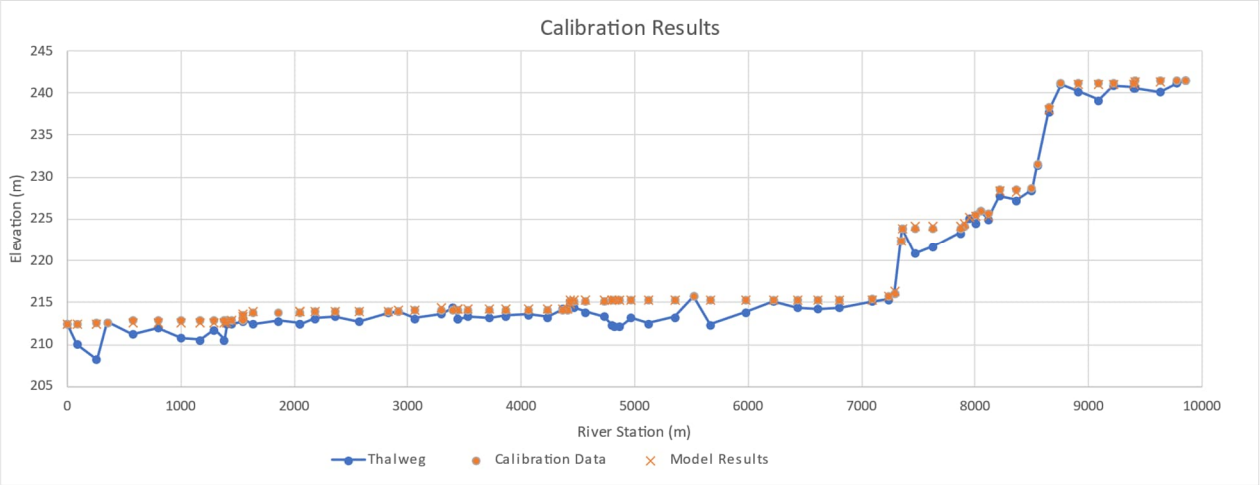


Figure 5-11: Kahshe River Model Calibration Results

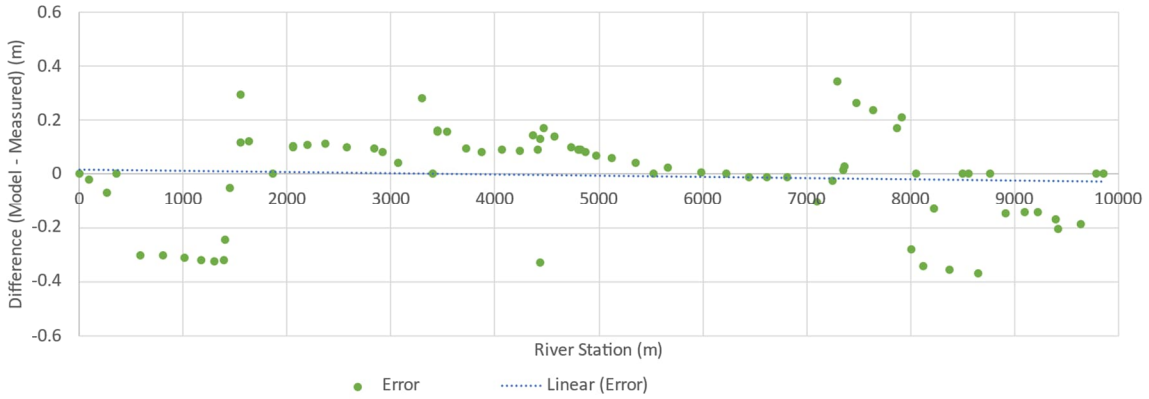


Figure 5-12: Kahshe River Model Calibration Error

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5.4.2 Gibson River

Water levels in the Gibson River flow west from Gibson Lake, below Highway 400 and outlets from the Three Rock Chute to Georgian Bay. The model was calibrated to match the water surface elevation during the November 2021 LiDAR and bathymetric surveys with a flow of 1.6 m^3/s. The flow was estimated by scaling flow records from WSC station 02ED024 for the dates of survey.

Gibson River contains a series of channelized flow, interspersed with areas of high elevation, creating areas that choke the flow. Most structures along Gibson River are at the upstream end of the river near Gibson Lake. One structure is visible further downstream on a peninsula, approximately 2.3 km downstream from the Highway 400 bridge.

The hydraulic model for the Gibson River was calibrated to match LiDAR data throughout the river and edge of water measurements downstream of the Highway 400 bridge. The edge of water measurements were collected between November 8 and 10, 2021, and the LiDAR was collected November 9 and 10, 2021. As the data was collected during the same November events the flow was calibrated to these two data sources, primarily the edge of water measurements and filling in with LiDAR data where necessary. Additional edge of water measurements were taken in September 2021, but it was determined that the flow during this event was too dissimilar to the November 2021 flows.

Limited data was available for calibration of Manning's n values in the overbank areas of the Gibson reach. In lieu of a calibration, a sensitivity analysis was conducted using the climate change scenario flood. The sensitivity analysis was completed by adjusting the roughness coefficient of the overbank area to observe its effect on modeled water surface elevation. The results of the sensitivity analysis are summarized in Table 5-4. The selected value for the overbank Manning's n roughness, 0.06, represents a resistance to flow associated with light to medium brush in winter.

The sensitivity analysis shows the water surface elevation change over the range of possible overbank roughness values. The reach is controlled by a series of hydraulic controls in the form of high elevation areas. The model was not sensitive to overbank roughness at the calibration flow (as flows were contained within the main channel). However, the model is moderately sensitive to overbank roughness at the climate change flow, with a maximum difference of +0.13 m and -0.12 m for the High Manning's and Low Manning's n, respectively.

Figure 5-13 presents a summary of the calibration results as it compares to the measured levels. The calibration was achieved by adjusting the critical cross-sections at the series of rapids along the reach, and the Manning's n values within the main channel, considering the physical characteristics of the river.

Figure 5-14 presents the error at each point used for calibration along the reach. The error consistently ranges between +10 cm to -10 cm, within the normal range for a 1-D HEC-RAS model. There is a slight trend of the error through the reach, with the upstream end of the

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reach tending to be lower than the calibration points and the downstream end of the reach tending to be greater than the calibration points. This was likely due to the use of LiDAR data for calibration which contained less variation in the data set than the edge of water point measurements. Upstream of and including station 6923, the model was calibrated to LiDAR data.

Locations of cross-sections are shown in Figure 5-4 and Figure 5-5. Downstream of station 6923, the model was calibrated to the edge of water points surveyed in November 2021. If edge of water points at the upstream end of the model had been collected at the same time as the LiDAR data, more variation would be expected in the data set and therefore less of a trend may be present.

Table 5-4: Gibson River Sensitivity Results (Climate Change Flow)

Location	Cross-Section	Calibrated Model WSE (n = 0.06) (m)	High Manning's Sensitivity (n = 0.08)		Low Manning's Sensitivity (n = 0.045)	
			WSE (m)	Difference (m)	WSE (m)	Difference (m)
Outlet of Gibson River	8422	187.79	187.89	0.10	187.69	-0.10
Upstream of Highway 400 Bridge	7178	187.62	187.69	0.07	187.55	-0.07
In Between Highway 400 Bridge	7139	187.54	187.64	0.10	187.45	-0.09
Downstream Highway 400 Bridge	7099	187.55	187.65	0.10	187.45	-0.10
At Peninsula	4701	187.56	187.66	0.10	187.46	-0.10
Upstream of Go Home Lake Dam	1157	184.03	184.16	0.13	183.92	-0.11
Downstream of Go Home Lake Dam	1049	184.02	184.15	0.13	183.90	-0.12

Note:
WSE = water surface elevation

The final selected Manning's n roughness values are 0.04 for the main channel and 0.06 for the overbank based on the site topography.

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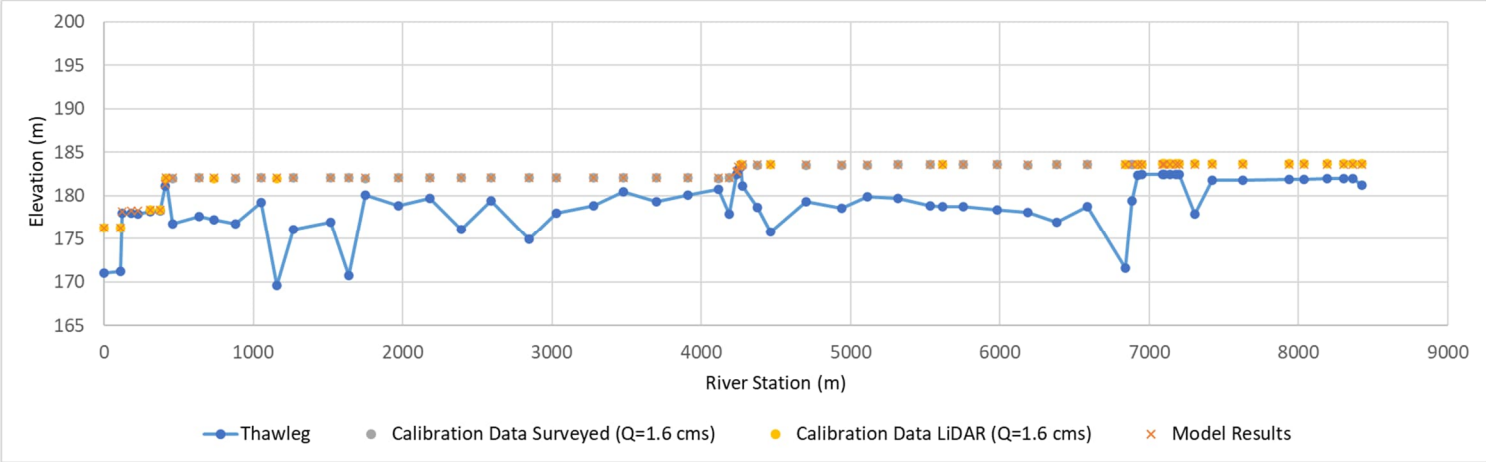


Figure 5-13: Gibson River Model Calibration Results

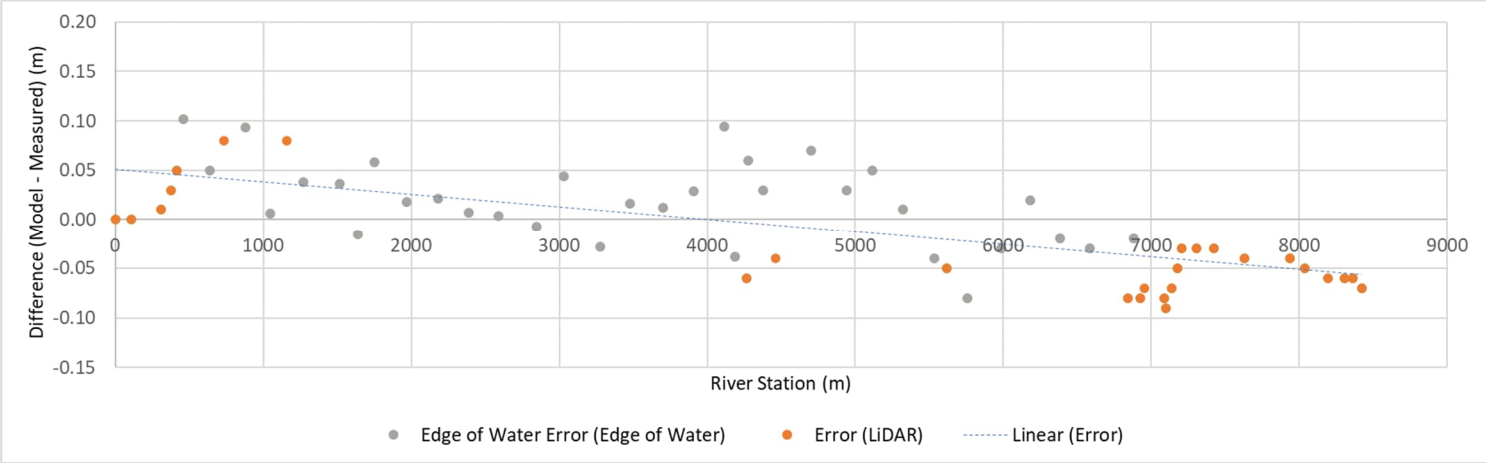


Figure 5-14: Gibson River Model Calibration Error

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5.4.3 Buck River

Buck River water levels are controlled by outflow from Buck Lake, Buck Lake Dam and Fox Lake Dam, and local inflows to Buck River and Fox Lake. The hydraulic model for Buck River was calibrated to match the water level data measured on the day of the bathymetric survey with a flow of 3 m^3/s, which was estimated by scaling flow records from WSC station 02EB013 for the dates of survey.

No data is available for calibration of Manning's n values in the overbank areas of the Buck River. In lieu of a calibration, a sensitivity analysis was conducted using the climate change scenario flood event. The sensitivity analysis was completed by adjusting the roughness coefficient of the overbank area by ±15% to observe the modeled water surface elevation change.

The results of the sensitivity analysis are summarized in Table 5-5. The selected value for the overbank Manning's n roughness (0.03 to 0.14) represents a resistance to flow associated with the varying land cover. The sensitivity analysis shows the water surface elevation change over the range of possible overbank roughness values. The model is moderately sensitive to overbank roughness for the climate change scenario with a maximum difference of +0.08 m and -0.09 m for the high Manning's n and low Manning's n condition, respectively. There is a high velocity area downstream of Fox Lake Dam, which resulted in the water surface elevation in the lower Manning's n scenario being 2 cm higher than the higher Manning's n scenario. The 2-cm error is within acceptable modeling error (+/-40 cm).

Figure 5-15 presents a summary of the calibration results as they compare to the measured levels. The calibration was achieved by adjusting the critical cross-sections at meanders and the Manning's n values considering the physical characteristics of the river. Notable controlling features are the Buck Lake and Fox Lake dams and a bridge at Ravenscliffe Road (no piers), Figure 5-8. There is an additional bridge at Hoodstown Road which was not represented in the hydraulic model as the bridge was greater than 2 m above the water surface elevation in the climate change proxy scenario, and would have resulted in additional computational effort and time.

Figure 5-16 presents points used in the calibration along the reach. The error consistently ranges between +40 cm to -40 cm, which is considered the normal range for a 2-D HEC-RAS model.

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Table 5-5: Buck River Sensitivity Results (Climate Change Flow)

Location	Calibrated Model WSE (n_{cal} = 0.03-0.14) (m)	High Manning's Sensitivity (n_{high} = 0.035-0.161) [where n_{high} = 1.15n_{cal}]		Low Manning's Sensitivity (n_{low} = 0.026-0.119) [where n_{low} = 0.85n_{cal}]	
		Model WSE (m)	Difference (m)	Model WSE (m)	Difference (m)
Upstream of Ravenscliffe Bridge	303.63	303.68	0.05	303.56	-0.08
Downstream of Ravenscliffe Bridge	303.16	303.24	0.08	303.07	-0.09
Upstream of Buck Lake Dam	302.45	302.48	0.03	302.43	-0.02
Downstream of Buck Lake Dam	301.28	301.34	0.06	301.24	-0.05
Fox Lake	297.44	297.45	0.01	297.44	-0.01
Upstream of Fox Lake Dam	295.71	295.71	0.00	295.71	0.00
Downstream of Fox Lake Dam	294.10	294.10	0.00	294.12	0.01

Notes:
WSE = water surface elevation
1. n_{cal} = calibrated Manning's n.

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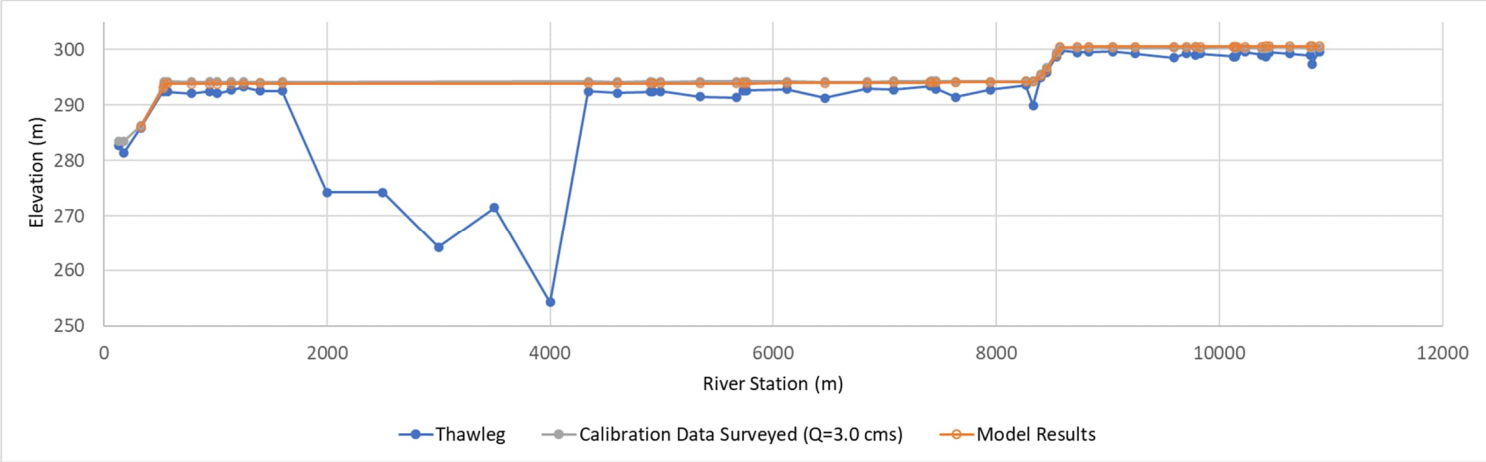


Figure 5-15: Buck River Model Calibration Results

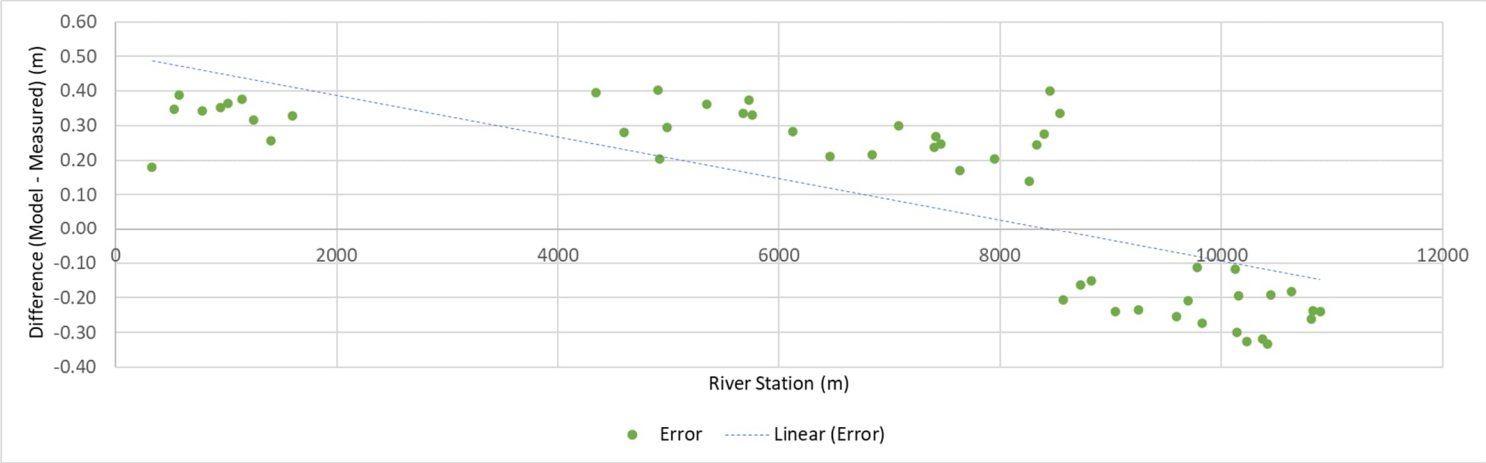


Figure 5-16: Buck River Model Calibration Error

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5.4.4 Summary of Manning's n

A summary of the calibrated Manning's n values used in the models is presented in Table 5-6.

Table 5-6: Summary of Manning's n Roughness Coefficients

Model	1-D or 2-D	Channel Manning's n	Overbank Manning's n
Kahshe River	2-D	0.035 to 0.039	0.085 to 0.14
Gibson River	1-D	0.040	0.060
Buck River	2-D	0.03 to 0.06	0.03 to 0.14

5.5 Hydraulic Parameters

The downstream boundary (i.e., water level) for Kahshe River was estimated using uniform flow calculation and the cross-section geometry at the most downstream section of the model. This uniform flow calculation (using FlowMaster software) provided a relationship between flow and water level for a given cross-section, under an assumed water surface slope (estimated from field measurements). This approach provided a different water level boundary condition for each flow event (Figure 5-17).

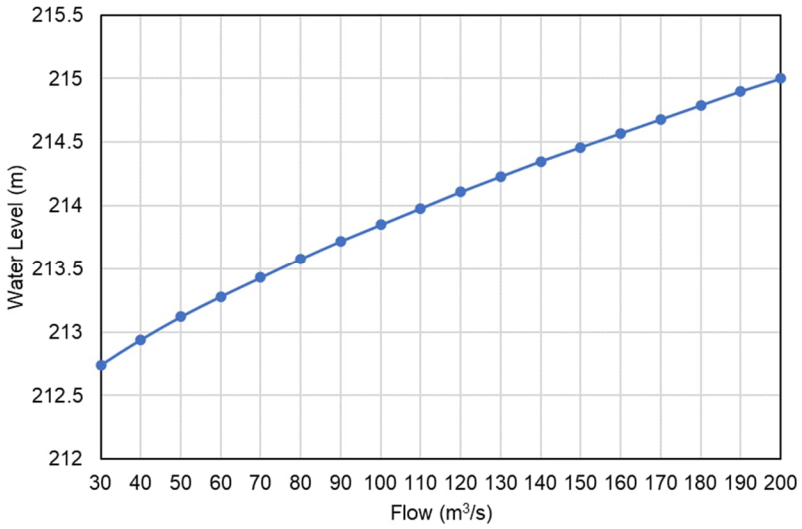


Figure 5-17: Kahshe Lake Downstream Boundary Rating Curve

The downstream water level boundary condition for Gibson River was specified using a more simplified approach, which was to apply a normal water level boundary with the constant water surface elevation collected during the LiDAR survey for all three flood events. The model was extended approximately 400 m downstream of Three Rock Chute. Three Rock Chute acts as a control that influences the water levels upstream. There is a significate drop in elevation of approximately 6 m from Three Rock Chute (station 413 of the HEC-RAS model) to the downstream boundary of the model. Therefore, this boundary condition does

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not influence water levels upstream of Three Rock Chute due to this large drop in elevation. For this reason, flood mapping will be limited to areas upstream of Three Rock Chute.

The downstream water level boundary condition for Buck River was also specified using a simplified approach, which was to apply the constant water surface elevation collected during the LiDAR survey of Vernon Lake for all three flood events. This was deemed acceptable since the reach downstream of Fox Lake Dam is very steep. Flood mapping was limited to an area upstream of the Map Set A - Lake Vernon.

The hydraulic parameters selected as the boundary conditions for floodplain mapping of each model are summarized below in Table 5-7 through Table 5-9.

Table 5-7: Summary of Hydraulic Conditions for 50-Yr Flood

Model	Type of Modeling	Inflow Location	Peak Inflow (m^3/s)	Downstream Boundary Condition (Water Level) (m)
Kahshe River	2-D	Kahshe Lake Dam (includes Kahshe River Local Inflows)	30.2	212.75
Gibson River	1-D	Gibson Lake Inflow	22.0	176.30
		Local Inflow	40.9	
		Go Home Dam	97.3	
Buck River	2-D	Buck Lake Inflow	24.7	285.20
		Local Inflow	69.3	

Table 5-8: Summary of Hydraulic Conditions for Regulatory Flood (Timmins Storm)

Model	Type of Modeling	Inflow Location	Peak Inflow (m^3/s)	Downstream Boundary Condition (Water Level) (m)
Kahshe River	2-D	Kahshe Lake Dam (includes Kahshe River Local Inflows)	83.1	213.62
Gibson River	1-D	Gibson Lake Inflow	61.3	176.30
		Local Inflow	115.5	
		Go Home Dam	171.9	
Buck River	2-D	Buck Lake Inflow	83.7	285.20
		Local Inflow	177.1	

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Table 5-9: Summary of Hydraulic Conditions for Flood Mapping Modeling (Climate Change Proxy)

Model	Type of Modeling	Inflow Location	Peak Inflow (m^3/s)	Downstream Boundary Condition (Water Level) (m)
Kahshe River	2-D	Kahshe Lake Dam (includes Kahshe River Local Inflows)	112.2	214.01
Gibson River	1-D	Gibson Lake Inflow	87.3	176.30
		Local Inflow	149.8	
		Go Home Dam	206.2	
Buck River	2-D	Buck Lake Inflow	98.4	285.20
		Local Inflow	216.8	

5.6 Flood Levels and Sensitivity to Climate Change

Due to the increase in flows during recent flooding events, it is prudent to evaluate how future increases in flows will affect the water levels in each of the study reaches. Each of the hydraulic models were run under three conditions, the first representing a flood equivalent to the 50 year flood, the second representing a flood equivalent to the regulatory flood, and the third representing a potential climate change scenario in the basin (i.e., climate change proxy).

The climate change proxy scenario includes an increase in flow based on the method described in Section 4.1.4.4. The discussion below details the effects of an increase in flow in each of the study rivers (assuming all other hydraulic parameters remain constant).

5.6.1 Kahshe River

Table 5-10 summarizes the computed water surface profile for the regulatory flood and the climate change proxy scenarios. The climate change proxy was derived by increasing the regulatory storm by a factor of 1.22. The increase in water level modeled in the reach caused by the increased flow is not consistent along the reach and has a wide range of 0.23 to 0.60 m.

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Table 5-10: Kahshe River Computed Water Surface Profile

Location	Water Surface Elevation (m)			Change in Water Level Between Regulatory Flood and Climate Change Proxy (m)
	50-Yr Flood	Regulatory Flood	Climate Change Proxy	
Downstream of Kahshe Lake	241.53	242.77	243.00	0.23
Upstream of Highway 11S Culvert	226.77	228.42	229.02	0.60
Downstream of Highway 11S Culvert	225.81	226.36	226.80	0.44
Upstream of Train Crossing	216.22	217.14	217.73	0.59
Downstream of Train Crossing	216.17	217.10	217.61	0.51
Upstream of Sparrow Lake Bridge	216.04	216.95	217.44	0.49
Downstream of Sparrow Lake Bridge	215.98	216.53	216.94	0.41
Upstream of Southwood Road Bridge	214.09	215.28	215.88	0.60
Downstream of Southwood Road Bridge	213.83	215.10	215.65	0.55
Upstream of Sparrow Lake	212.79	213.61	214.04	0.43

5.6.2 Gibson River

Table 5-11 summarizes the computed water surface profile for the regulatory flood and the climate change flood scenarios. The climate change proxy was derived by scaling rainfall inputs during the regulatory flood (Timmins storm) by a factor of 1.22. This increase builds in a moderate safeguard for the uncertainty brought on by climate change.

Table 5-11 summarizes the increase in simulated water level due to climate change in the Gibson River. The increase in water level modeled in the reach caused by the increased flow is not consistent along the reach and has a wide range of 0.24 to 0.67 m.

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Table 5-11: Gibson River Computed Water Surface Profile

Location	Cross-Section Chainage (m)	Water Surface Elevation (m)			Change in Water Level Between Regulatory Flood and Climate Change Proxy (m)
		50-Yr Flood	Regulatory Flood	Climate Change Proxy	
Outlet of Gibson Lake	8422	185.39	187.12	187.79	0.67
Upstream of Highway 400 Bridge	7178	185.28	186.98	187.62	0.64
In Between Highway 400 Bridge	7139	185.23	186.91	187.54	0.63
Downstream Highway 400 Bridge	7099	185.20	186.92	187.55	0.63
At Peninsula	4701	185.21	186.92	187.56	0.64
Upstream of Go Home Lake Dam	1157	183.17	183.79	184.03	0.24
Downstream of Go Home Lake Dam	1049	183.16	183.78	184.02	0.24
Outlet of Gibson River	0	176.30	176.30	176.30	0.00

5.6.3 Buck River

Table 5-12 summarizes the computed water surface profile for the regulatory flood and the climate change proxy scenarios. The climate change proxy was derived by increasing the regulatory storm by a factor of 1.22. The increase in water level modeled in the reach caused by the increased flow is not consistent along the reach and has a wide range of 0.14 to 0.33 m.

Table 5-12: Buck River Computed Water Surface Profile

Location	Water Surface Elevation (m)			Change in Water Level Between Regulatory Flood and Climate Change Proxy (m)
	50-Yr Flood	Regulatory Flood	Climate Change Proxy	
Upstream of Ravenscliffe Bridge	301.81	303.46	303.63	0.17
Downstream of Ravenscliffe Bridge	301.74	303.02	303.16	0.14
Upstream of Buck Lake Dam	301.63	302.31	302.45	0.15
Downstream of Buck Lake Dam	299.93	301.09	301.28	0.19
Fox Lake	295.62	297.12	297.44	0.33
Upstream of Fox Lake Dam	294.42	295.52	295.71	0.19
Downstream of Fox Lake Dam	292.93	293.96	294.10	0.15

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5.7 Flood Fringe Determination

The only currently accepted method by MNRF for assessment of life safety hazard is evaluated according to the “2x2 rule” as defined in the “Technical Guide – River and Stream Systems: Flooding Hazard Limit” (MNRF, 2002). Permanent residents are assumed to be at risk if the product of the flood flow velocity and the flood water depth at that location exceeds 0.37 m^2/s (or 4 ft^2/s, i.e., nominally a velocity of 2 ft/s times a depth of 2 ft, from which the name of the rule is derived). Life safety risks are also assumed to occur if the water depth exceeds 0.8 m, or if its velocity exceeds 1.7 m/s, even if the product of the two would not exceed the 0.37-m^2/s limit. This accounts for the fact that people can drown once the water becomes deep enough, even at low velocities, and that they can be swept off their feet if the velocity is too high, even at relatively small depths.

Therefore, the floodway as it appears on the floodplain maps is the maximum extent of three lines produced by each of the following criteria: depth greater than 0.8 m, velocity greater than 1.7 m/s, and depth times velocity greater than 0.37 m^2/s. Nevertheless, some adjustments were made to the extent of the floodway along the outer edges of the floodplain areas that were deemed to be outside of the main flow path.

The flood fringe is the area between the floodway and the flood-line boundary. Although the flood fringe may contain small area with depths greater than 0.8 m, they are not considered to be part of the floodway because there is limited flow and the area could be filled with engineered soils to reduce the flood depth and provide safe access, provided these activities are approved within municipal planning provisional rules.

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6. Floodplain Maps

Floodplain maps can have a variety of uses including Emergency Preparedness and Response Plans (EPRPs), mitigation planning, emergency response, consequence assessment, and zoning of land development. The mapping of potentially inundated areas during a flood should help authorities in identifying critical infrastructure and population-at-risk sites that might require protective measures, warnings, and evacuation planning.

Floodplain maps can be used to facilitate communication during a flood event but can also convey relevant information regarding at-risk areas, which can be useful for effective long-term mitigation planning. Base map data provide the background from which flood inundation hazard information is overlain and interpreted. Clear, easy-to-interpret base maps are critical for the effective use of a floodplain map. Additional content is added to annotate key road names and key landmarks to help orient users, and aid interpretation of the maps. Planimetric base maps use vector features, such as annotated road lines, political boundaries, streamlines, landmarks, etc, against a typically white background that allow users to orient themselves and interpret the maps.

The key information on a floodplain map is provided by flood-line polygons that show the intersection of the peak water surface elevations from the river hydraulic models and static flood-line water levels on the lakes with the ground elevations from the terrain source.

Preliminary flood lines are first auto-generated in GIS based on the water levels. Flood lines are derived from the most recent LiDAR-derived hydroflattened DEM for the location being mapped. All locations included in this study have LiDAR-derived DEM tiles available from either the 2018 survey (Airborne Imaging, 2018), 2021 survey (Tulloch, 2023a), or 2023 survey (Tulloch, 2023b). Where coverage for a study area was available for more than one LiDAR survey date, the most recent LiDAR products were used. The final floodplain maps are based on professional judgment and reasonable care, and upon information available in the bare earth 1-m topographic data. These maps were reduced to an equivalent scale or 1:2500, when printed in 11x17 tabloid paper size, for inclusion in the map sets. This scale is adequate for presenting the flood-line mapping results.

Professional judgment is important for interpretation of the flood lines illustrated on the floodplain maps, and will require geomatic ground survey to verify actual flood limits from the water surface elevations provided in this study and the floodplain maps.

Furthermore, to ensure legibility of the floodplain maps at the 1:2500 scale, very minimal manual post-processing, using experienced engineering judgment, is required to prepare final maps from auto-generated flood polygons. However, no post-processing has been applied for the islands. This means that the dry area of a partially flooded island is depicted in the floodplain maps, regardless of how small the dry area is. The result is based on the LiDAR-derived DEM, and it is highly recommended to interpret these maps cautiously.

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6.1 Lakes

The lake floodplain maps were developed in ArcGIS by first identifying, through GIS processing, the contours on the bare earth 1-m topographic data associated with the static lake levels described in Section 4.2. These static lake levels include the 50-yr, regulatory flood, and climate change proxy events.

The flood lines were then reviewed and, where necessary, minor adjustments have been made to match the site conditions based on satellite imagery, contour information, and professional judgment. The static flood lines were combined with the additional GIS map content provided by the District to produce map sets.

A complete list of maps is provided in Table 2-1.

6.2 Rivers

Floodplain mapping was prepared using a combination of HEC-RAS RasMapper and ArcGIS software. Polygons were produced by HEC-RAS RasMapper to represent the flood-line and floodway extents, and directly imported into ArcGIS for further review and processing. Minor adjustments, where necessary, have been made to match the site conditions based on satellite imagery, contour information, and professional judgment. The flood line and floodway were combined with the additional GIS map content provided by the District to produce map sets. In addition to floodway and flood fringe boundaries for the regulatory flood, these maps also include:

- key water levels
- locations of model cross-sections (for 1-D models only)
- 50-yr flood line
- climate change proxy flood line.

A complete list of maps is provided in Table 2-1.

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7. Recommendations and Mitigation Options

Due to the many variables that can influence flood modeling and mapping, areas inundated during an actual flood event may differ from the areas shown on the maps. As a precaution, it is to be noted that the flood-line locations and limits shown on the map sets must be considered approximate only and are to be used only as a guideline to illustrate potentially impacted areas.

Professional judgment is important for interpretation of the flood lines provided by the floodplain maps. Geomatic ground surveys will be required to verify actual flood limits from the water surface elevations provided in this study and the floodplain maps.

7.1 Wave Uprush

Wave uprush is defined as the rush of water up onto a shoreline or structure following the breaking of a wave; the limit of wave uprush is the point of furthest landward rush of water onto the shoreline (Ontario, 2020). Development should be restricted in Hazardous Lands as defined in the MNRF technical guides for flooding hazards. Flooding hazards include the consideration for wind setup, wave run-up, and wave uprush along shorelines subject to wave action, where winds can drive water farther inland, beyond the limit of the static flood line. Horizontal and vertical allowances must be added to the area covered by the static flood line to protect the Hazardous Lands.

The “Technical Guide for Large Inland Lakes” (MNRF, 1996) provides the methods and requirements for determining the required allowances and delineating the Flooding Hazard Limit for inland lakes. The report “Hydrology Study for Major Lakes in the Muskoka River Watershed; Supplementary Wave Runup/Offset Analysis, FDR 128” (Marshall Macklin Monaghan, 1989b) has recommendations for horizontal and vertical allowances but these are based on average fetch length and shoreline characteristics. However, it was not within the current study scope to estimate site-specific, detailed wind/wave analysis.

7.2 Watershed Management and Education

Based on review of the water management studies and flood studies on the Muskoka River watershed, it is evident that the dams in the basin are of little benefit for flood control; the available water storage that can be controlled by the dams is too small compared to the volume of water that runs off the watershed during a significant flood event. Flood events such as the 2013 and 2019 events, or larger, could happen again sometime in the future.

It is recommended that more education and understanding of the nature of floods within the basin would help all levels of government and the public gain further knowledge on why flooding occurs and inform on what areas are at risk during flood events.

Hatch also recommends that due to the increasing frequency of widespread flooding in the District of Muskoka there is a need for more active flood monitoring. A larger network of climate and flow gauges would provide better information preceding and during a flood event,

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and the data collected would provide better information for future flood studies and mitigation measure studies. More gauges and area wide geomatic surveys of flood water levels and measurement of flows would provide excellent information for future studies of flooding in the Muskoka River basin.

7.3 Flood Forecasting and Tracking

Climate monitoring is the first and most important step in flood risk management. The addition of a more extensive network of climate stations and flow gauges combined with data available from weather forecasts and radar sensing is required to keep track of snow depths, rainfall, and water flows across the basin. These would then be used for setup and calibration of a flow prediction model and monitoring of water flow and levels in the watershed. Foreknowledge of the magnitude of flooding and tracking of a flood event can help communities take the appropriate action to reduce risks and damages caused by flooding.

A forecasting and real-time flood routing model of the watershed may help determine the timing and magnitude of future flood events when coupled with accurate climate forecasts. Many conservation authorities in Ontario depend on flood forecasting to warn communities and manage risks. A similar system for flood risk management in Muskoka is advised to be considered by existing and/or new watershed governance bodies such as MNRF, with particular consideration to be given for resources and expertise required to manage such a system.

7.4 Mitigation Options

There are several mitigation options for consideration by all levels of government and the public to reduce future damages due to flooding. All levels of government may use this data to consider their approaches to Official Plans and Zoning By-laws, building regulations, emergency planning, and sizing of new or renewed infrastructure impacted by floods, such as roads and bridges.

The main essential mitigation option is the restriction of future development of any vulnerable residential buildings, commercial buildings, or infrastructure on hazardous lands. Vulnerable developments within the hazardous lands are at risk of damage and the lives of the people on those lands are also at risk during flooding events. Development plans of properties within floodplains need to be restricted and need to include floodproofing measures using established standards and procedures. The “Technical Guide – River and Stream Systems: Flooding Hazard Limit,” Appendix 6 (MNRF, 2002) provides recommendations for floodproofing.

Existing areas with buildings, infrastructure and properties within the flood line on the floodplain maps are possibly at risk. There are very few options available for these existing areas other than flood protection and floodproofing using established standards and procedures, or removal of the vulnerable buildings and infrastructure.

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The report “An Independent Review of the 2019 Flood Events in Ontario” (McNeil, 2019) provides a very good review of the 2019 flood event within Ontario and the flooding that occurred in the Muskoka River watershed. The report provides a number of recommendations to improve technical knowledge of flooding hazards that apply directly to the Muskoka River basin. The report also provides recommendations for improvement of provincial and municipal policies to restrict development in hazardous lands. As well, the report implies that direction is necessary for incorporating floodproofing measures into the construction plans for structures built in the floodplain such as boathouses. The recommendations provided in the report should be implemented and would provide beneficial measures to mitigate future damages, specifically Recommendation #25 provided by McNeil, which states:

> “***Recommendation #25***
> *That the MNRF review and update the appropriate technical guides, with consideration of a new category permitting development in hazardous lands along large inland lakes, rivers and streams, and along the Great Lakes/St. Lawrence River, utilizing flood protection land forms and/or other forms of flood protection and floodproofing methods with very strict requirements and conditions. Further, consideration should be given to enshrining this concept in legislation or in a regulation along with other structural methods that are now permitted in non-hazard lands or Special Policy Areas*.”

Additionally, infrastructure such as culverts could be added or increased in size at lake outlets to potentially reduce the impacts of flooding due to large floods. These designs would need to take into account the upstream and downstream impacts of the changes to these structures and the flow capacity in the downstream reach to determine if the changes would be feasible and acceptable.

To minimize any additional lake flooding due to debris or beaver dams, consideration could be given to periodic inspection and maintenance of lake outlets including removal of debris, beaver dams, and tall grasses in ditches, culverts and lake outlets to maintain lake outlet flow capacity.

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Appendix A
FHIMP Document

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Incorporating Climate Change in Floodplain Mapping under the Flood Hazard Identification and Mapping Program (FHIMP) where the Regulatory Storm Event is Timmins or Hurricane Hazel

This technical description is produced for the purpose of addressing climate change considerations in flood hazard mapping, as required under NRCan's FHIMP. This guidance should not be interpreted as a method or approach otherwise endorsed by Ontario for integrating climate change considerations into flood hazard identification or mapping for regulatory or planning purposes.

This technical description covers requirements for projects receiving funding under FHIMP with study areas located in Zone 1 and Zone 3 of the Flood Hazard Criteria Zones of Ontario as delineated in Figure B-1 of the Technical Guide on River & Stream Systems: Flood Hazard Limit (See Appendix A). Where the study area is located in Zone 2 or in circumstances where the 100-year flood produces the greatest flood magnitude, flood magnitudes of a 200-year storm event should be used as a proxy for climate change. A qualified professional may suggest alternate methodologies if the resulting flood magnitudes exceed the regulatory storm method outlined here. When alternate methodologies are proposed, the rationale and methods must be fully documented.

Methodology

The suggested method for incorporating Climate Change for floodplain modelling under FHIMP is based on the one recommended by Environment and Climate Change Canada (ECCC) and found on the climatedata.ca portal. The method described by ECCC is outlined as follows:

1. For the location of interest, download historical IDF curve data from ClimateData.ca or develop based on guidance from ECCC and CSA PLUS 4013:2019. Use this data to determine historical estimated rainfall intensity (R_C) for the storm duration and return period of interest.
2. Determine an appropriate future timeframe and emissions scenario, and using ClimateData.ca, the Climate Atlas of Canada, or Climate Resilient Buildings and Core Public Infrastructure data, find the long-term (30-year mean) annual mean temperature change (ΔT) for the specified location, timeframe and emission scenario. Develop this information by using results from an ensemble of climate models.
3. Determine future estimated rainfall intensity value (R_P), according to the historic estimated rainfall intensity (R_C) and the long term (30-year mean) annual mean temperature change (ΔT) using equation (1):

$$R_p = R_c \, x \, 1.07^{\Delta T} \qquad (1)$$

Since the regulatory storms include historical storm events (Hurricane Hazel and Timmins Storm) that cannot obtained from the IDF curves, ***the method used under FHIMP will be the following***:

1. Obtain hyetograph for the regulatory storm to obtain the hourly rainfall intensity (Table 1, Table 2)
2. Obtain the mean annual temperature change (ΔT) for the specified location from the federal climate data portal. MNRF recommends obtaining this value for the 50th percentile of the mean annual temperature change for the RCP 4.5 scenario (using CMIP 5) for time horizon 2050 or 2080.
    - **RCP4.5** is a moderate emission scenario under which rainfall is forecast to increase. RCP4.5 has been used in a range of recent studies, including those focussed on Ontario. It characterises an intermediate stabilisation pathway in which radiative forcing is stabilised at approximately 4.5 W/m^2 and 6.0 W/m^2 after 2100 (the corresponding ECPs assuming constant concentrations after 2150). In Canada, RCP 4.5 would mean an average

temperature increase of 3.2°C by the end of the century compared to baseline period of 1986-2005 (Source:climatedata.ca).

3. Use equation (1) previously shown to find the new hourly rainfall intensity from the known hourly rainfall intensity (mm/hr)
4. Using the new hourly rainfall intensity model the climate adjusted flood
5. Map the future climate change flood hazard limit (i.e., flood line) for the calculated time period.

Table 1 – Hurricane Hazel, 36th through 48th Hour Rainfall Depths

Timing	Intensity (mm/hr)	% of the last 12 hours
First 36 hours	73 mm/36 hr	-
37th hour	6	3
38th hour	4	2
39th hour	6	3
40th hour	13	6
41st hour	17	8
42nd hour	13	6
43rd hour	23	11
44th hour	13	6
45th hour	13	6
46th hour	53	25
47th hour	38	18
48th hour	13	6
TOTAL	285	100

Table 2 - Timmins Storm – Hourly Rainfall Depths

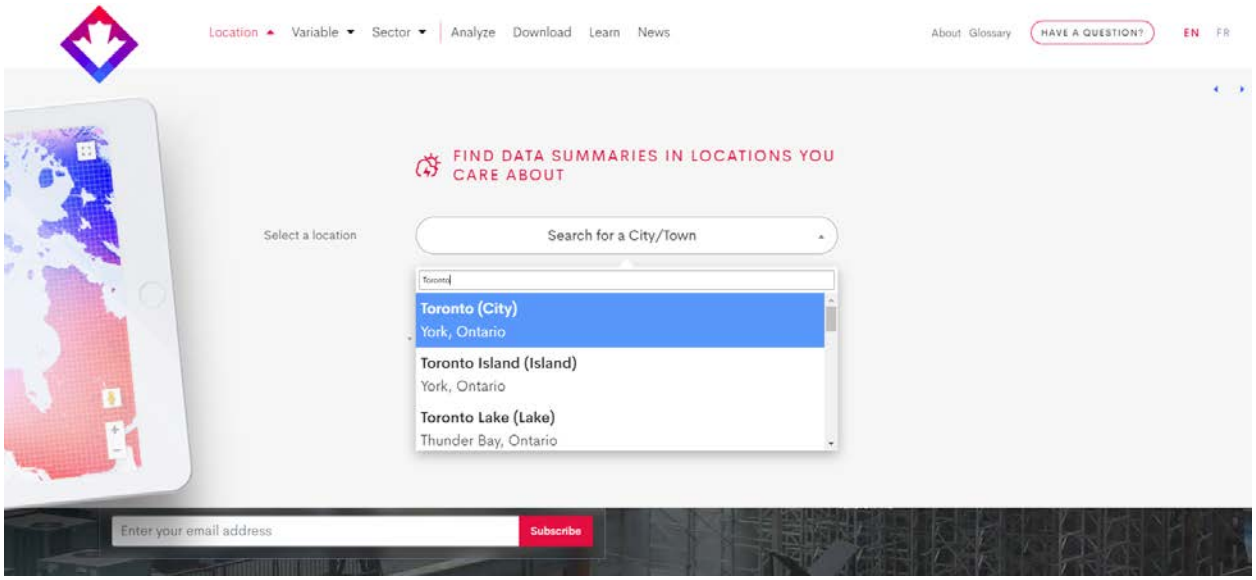
Hour	Intensity (mm/hr)	% of the last 12 hours
1st	15	8
2nd	20	10
3rd	10	6
4th	3	1
5th	5	3
6th	20	10
7th	43	23
8th	20	10
9th	23	12
10th	13	6
11th	13	7
12th	8	4
TOTAL	193	100

Data Sources:

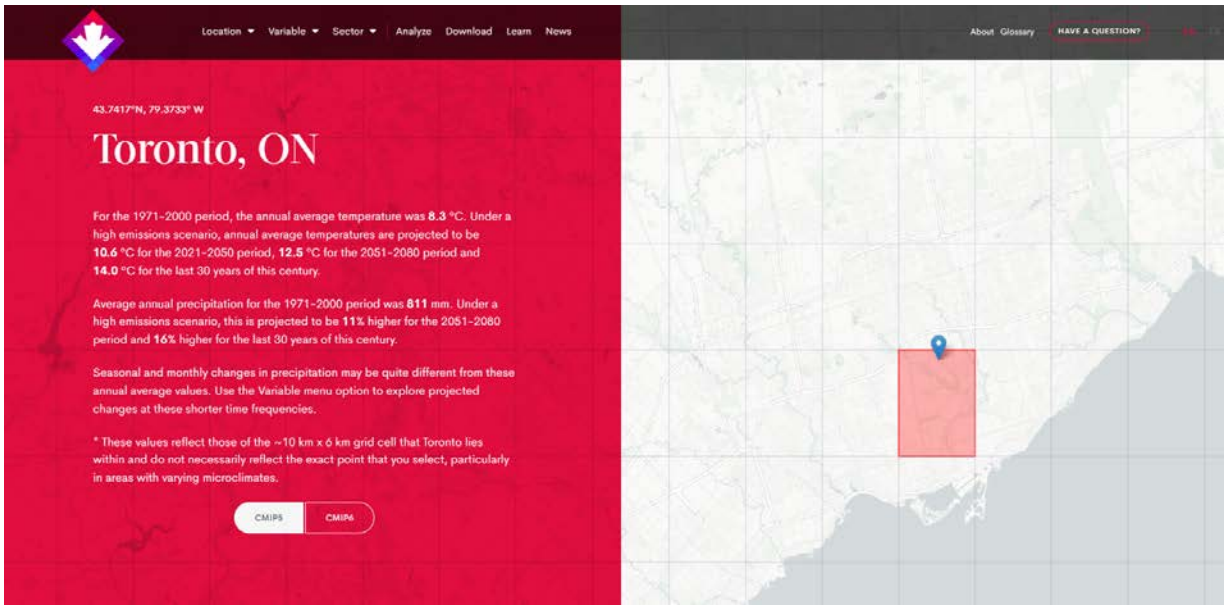
The primary data resource recommended by MNRF under FHIMP is the federal data resource found on climatedata.ca by ECCC – Canadian Centre for Climate Services (CCCS)). The data has a 10 km x 10 km resolution (Source - Training Materials) for data from the Coupled Model Intercomparison Project (CMIP) (Source – World Climate Research Programme). MNRF recommends downloading data for CMIP 5 for RCP 4.5 (50th percentile) for year 2050 or 2080.

Example steps to download for City of Toronto (located in Zone 1):

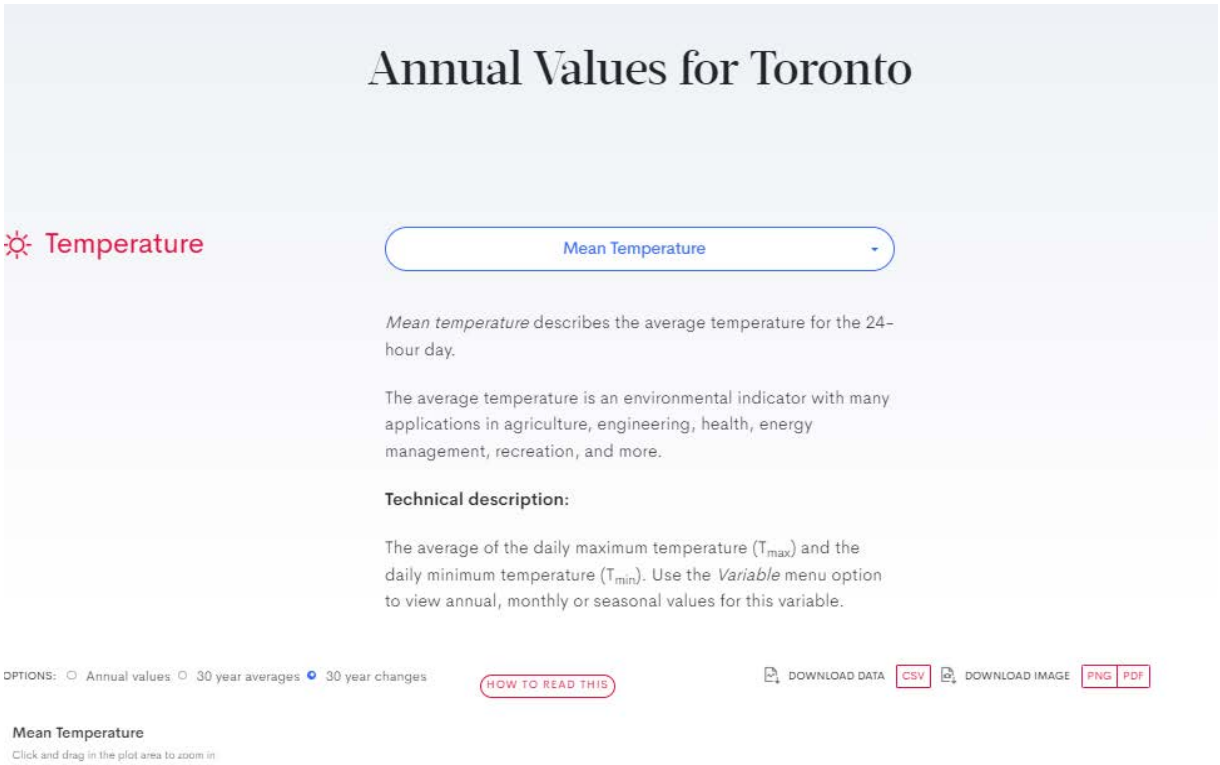
1. Obtain hyetograph for the regulatory storm in the zone where Toronto is located (Zone 1 – larger of 100-year flood and Hurricane Hazel), Table 1 – Hurricane Hazel
2. Obtain the mean annual temperature change (ΔT) for the specified location from the federal climate data portal. MNRF recommends obtaining this value for the 50th percentile of the mean annual temperature change for the RCP 4.5 scenario (using CMIP 5) for time horizon 2050 or 2080.
    a) Scroll to Location button in top ribbon and search for the desired located in the study area as shown below



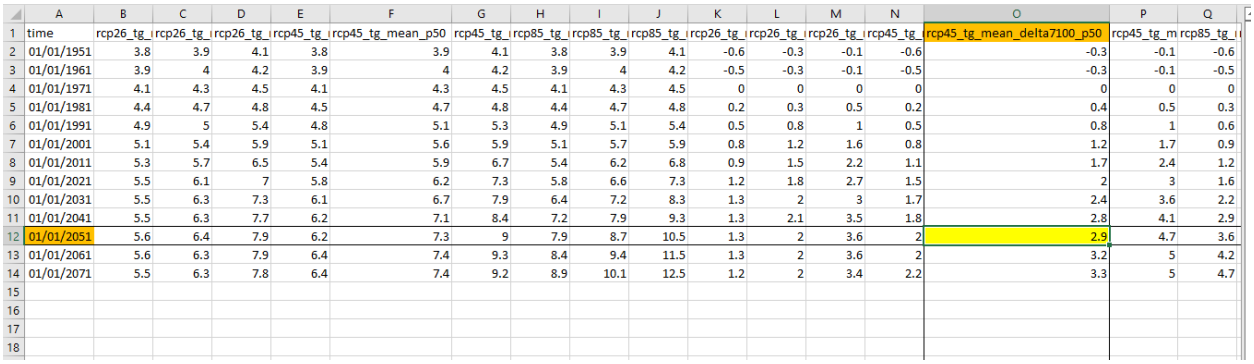
b) Choose CMIP 5 option as shown below



c) Choose “Mean Temperature” from the dropdown, and ‘30-year changes” options at the top of the time series figure as shown below. Then download data as CSV



d) Obtain the value for the mean annual temperature change (ΔT) for the cell of column “rcp45_tg_mean_delta7100_p50” and row “01/01/2051” as shown below.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	time	rcp26_tg_	rcp26_tg_	rcp26_tg_	rcp45_tg_	rcp45_tg_mean_p50	rcp45_tg_	rcp85_tg_	rcp85_tg_	rcp85_tg_	rcp26_tg_	rcp26_tg_	rcp26_tg_	rcp45_tg_	rcp45_tg_mean_delta7100_p50	rcp45_tg_m	rcp85_tg_
2	01/01/1951	3.8	3.9	4.1	3.8	3.9	4.1	3.8	3.9	4.1	-0.6	-0.3	-0.1	-0.6	-0.3	-0.1	-0.6
3	01/01/1961	3.9	4	4.2	3.9	4	4.2	3.9	4	4.2	-0.5	-0.3	-0.1	-0.5	-0.3	-0.1	-0.5
4	01/01/1971	4.1	4.3	4.5	4.1	4.3	4.5	4.1	4.3	4.5	0	0	0	0	0	0	0
5	01/01/1981	4.4	4.7	4.8	4.5	4.7	4.8	4.4	4.7	4.8	0.2	0.3	0.5	0.2	0.4	0.5	0.3
6	01/01/1991	4.9	5	5.4	4.8	5.1	5.3	4.9	5.1	5.4	0.5	0.8	1	0.5	0.8	1	0.6
7	01/01/2001	5.1	5.4	5.9	5.1	5.6	5.9	5.1	5.7	5.9	0.8	1.2	1.6	0.8	1.2	1.7	0.9
8	01/01/2011	5.3	5.7	6.5	5.4	5.9	6.7	5.4	6.2	6.8	0.9	1.5	2.2	1.1	1.7	2.4	1.2
9	01/01/2021	5.5	6.1	7	5.8	6.2	7.3	5.8	6.6	7.3	1.2	1.8	2.7	1.5	2	3	1.6
10	01/01/2031	5.5	6.3	7.3	6.1	6.7	7.9	6.4	7.2	8.3	1.3	2	3	1.7	2.4	3.6	2.2
11	01/01/2041	5.5	6.3	7.7	6.2	7.1	8.4	7.2	7.9	9.3	1.3	2.1	3.5	1.8	2.8	4.1	2.9
12	01/01/2051	5.6	6.4	7.9	6.2	7.3	9	7.9	8.7	10.5	1.3	2	3.6	2	2.9	4.7	3.6
13	01/01/2061	5.6	6.3	7.9	6.4	7.4	9.3	8.4	9.4	11.5	1.3	2	3.6	2	3.2	5	4.2
14	01/01/2071	5.5	6.3	7.8	6.4	7.4	9.2	8.9	10.1	12.5	1.2	2	3.4	2.2	3.3	5	4.7
15																	
16																	
17																	
18																	

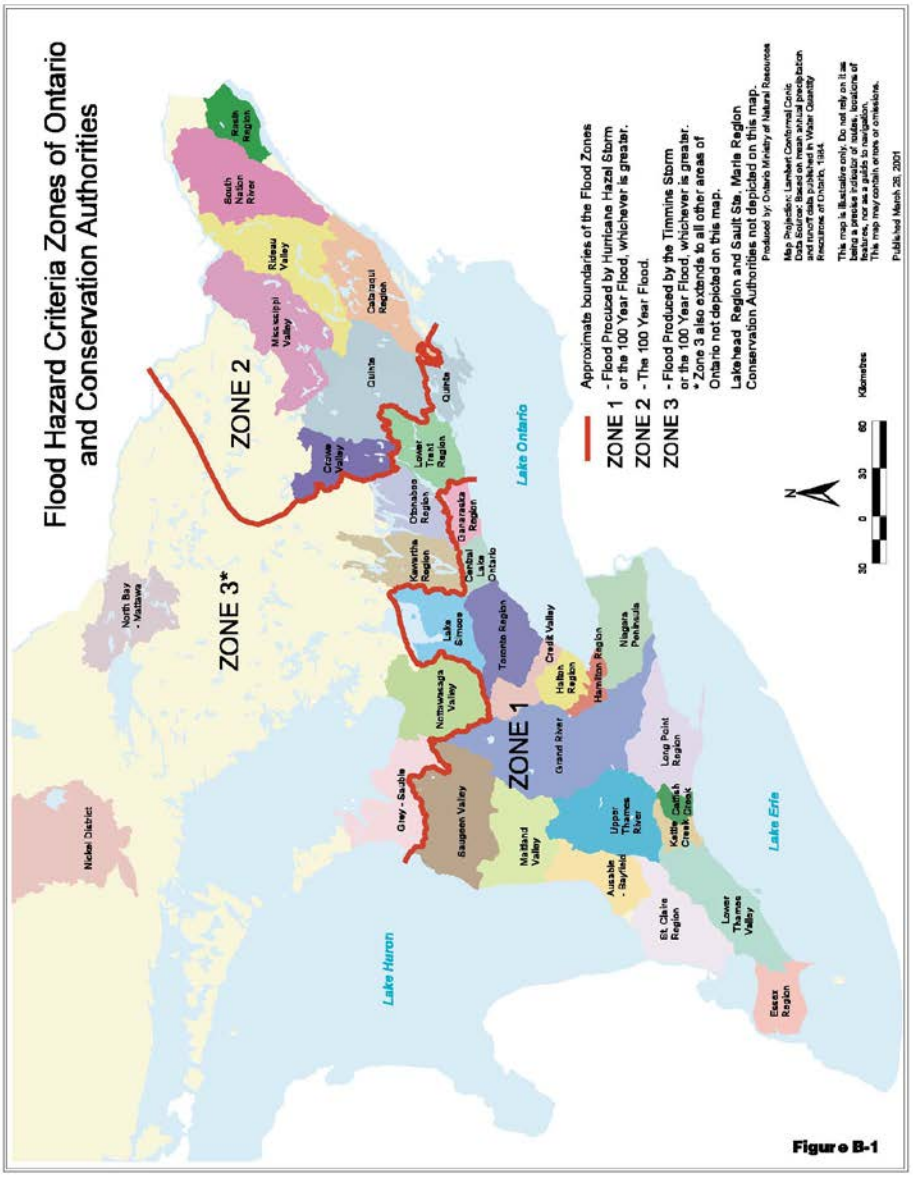
3. Use equation (1) previously shown to find the new hourly rainfall intensity from the known hourly rainfall intensity (mm/hr) as shown in the example Table 3 below.

Table 3 – Example calculation for future estimated rainfall for Hurricane Hazel for City of Toronto

Timing	Historic Estimated Intensity R_c (mm/hr)	% of the last 12 hours	Future Estimated Intensity $R_p = R_c \times 1.07^{\Delta T}$	% Increase in Intensity
First 36 hours	2	-	2.43	21.7%
37th hour	6	3	7.30	21.7%
38th hour	4	2	4.87	21.7%
39th hour	6	3	7.30	21.7%
40th hour	13	6	15.82	21.7%
41st hour	17	8	20.69	21.7%
42nd hour	13	6	15.82	21.7%
43rd hour	23	11	27.99	21.7%
44th hour	13	6	15.82	21.7%
45th hour	13	6	15.82	21.7%
46th hour	53	25	64.49	21.7%
47th hour	38	18	46.24	21.7%
48th hour	13	6	15.82	21.7%
TOTAL	**285**	**100**	**346.78**	**21.7%**

4. Using the new hourly rainfall intensity, model the climate adjusted flood.
5. Map the future climate change flood hazard limit (i.e., flood line) for the calculated time period.

Appendix A – Flood Hazard Criteria Zones of Ontario and Conservation Authorities



Appendix B
Glossary

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Appendix B: Glossary

Adverse Effects

As defined in the Environmental Protection Act, means one or more of

- impairment of the quality of the natural environment for any use that can be made of it
- injury or damage to property or plant and animal life
- harm or material discomfort to any person
- an adverse effect on the health of any person
- impairment of the safety of any person
- rendering any property or plant or animal life unfit for use by humans
- loss of enjoyment of normal use of property, and
- interference with normal conduct of business.

Design Flood

The flood which controls the design of a specific flood-related project, i.e., dam, diversion, bank protection, etc.

Development

Means the creation of a new lot, a change in land use, or the construction of buildings and structures, requiring approval under the Planning Act; but does not include activities that create or maintain infrastructure authorized under an environmental assessment process; or works subject to the Drainage Act.

Established Standards and Procedures

Means the following:

Floodproofing standard, which means the combination of measures incorporated into the basic design and/or construction of buildings, structures, or properties to reduce or eliminate flooding, wave uprush and other water-related hazards along the shorelines of the Great Lakes - St. Lawrence River System and large inland lakes, and flooding along river and stream systems. Recommendations for Floodproofing are provided in the “Technical Guide – River and Stream Systems: Flooding Hazard Limit,” Appendix 6 (MNRF, 2002).

Fetch

Length of water surface exposed to wind.

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Flood Fringe

Means the outer portion of the floodplain between the floodway and the flood-line limit. Depth and velocities of flooding are generally less severe in the flood fringe than those experienced in the floodway. The flood fringe is the area where development and site alteration may be permitted, subject to appropriate floodproofing to the flooding hazard elevation or another flooding hazard standard.

Floodplain

Floodplain of a river system means the area, usually low lands adjoining a watercourse, which has been or may be subject to flooding hazards.

Great Lakes - St. Lawrence River System

Means the major water system consisting of Lakes Superior, Huron, St. Clair, Erie and Ontario and their connecting channels, and the St. Lawrence River within the boundaries of the Province of Ontario.

Hazardous Lands

Means property or lands that could be unsafe for development due to naturally occurring processes. Along the shorelines of the Great Lakes - St. Lawrence River System, this means the land, including that covered by water, between the international boundary, where applicable, and the furthest landward limit of the flooding, erosion or dynamic beach hazard limits. Along the shorelines of large inland lakes, this means the land, including that covered by water, between a defined offshore distance or depth and the furthest landward limit of the flooding, erosion or dynamic beach hazard limits. Along river and stream systems, this means the land, including that covered by water, to the furthest landward limit of the flooding or erosion hazard limits.

Large Inland Lakes

Means those waterbodies having a surface area of equal to or greater than 100 square kilometres where there is not a measurable or predictable response to a single runoff event.

One Hundred Year Flood (100-Yr Flood) (for river and stream systems)

Means that flood, based on an analysis of precipitation, snowmelt, or a combination thereof, having a return period of 100 years on average, or having a 1% chance of occurring or being exceeded in any given year.

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One Hundred Year Flood (100-Yr Flood) Level

Means:

- For the shorelines of the Great Lakes, the peak instantaneous stillwater level, resulting from combinations of mean monthly lake levels and wind setups, which has a 1% chance of being equalled or exceeded in any given year.
- In the connecting channels (St. Mary's, St. Clair, Detroit, Niagara and St. Lawrence rivers), the peak instantaneous stillwater level which has a 1% chance of being equalled or exceeded in any given year.
- For large inland lakes, lake levels and wind setups that have a 1% chance of being equalled or exceeded in any given year, except that, where sufficient water level records do not exist, the 100-yr flood level is based on the highest known water level and wind setups.
- For rivers and streams, water levels caused by the 100-yr flood, resulting in a 1% chance of occurring or being exceeded in any year.

Regulatory Flood

Regulatory Flood (RF) is the flooding hazard limit used in Ontario for the purpose of regulating land development (LRIA, 2011). For Muskoka River Basin RF (Zone 3, MNRF Flood Hazard Criteria) must be the greater of the following:

- a flood resulting from the Timmins storm
- the 100-yr flood, and
- the flood of record.

River and Stream Systems

Means all watercourses, rivers, streams, and small inland lakes or waterbodies that have a measurable or predictable response to a single runoff event.

Thalweg

Line connecting the deepest points along a stream channel.

Valleylands

Means a natural area that occurs in a valley or other landform depression that has water flowing through or standing for some period of the year.

Wave Uprush

Means the rush of water up onto a shoreline or structure following the breaking of a wave; the limit of wave uprush is the point of furthest landward rush of water onto the shoreline.

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