Muskoka River Watershed Hydrological Model

Additional Scenarios

District Municipality of Muskoka

29 September 2023

The Power of Commitment

Executive Summary

This report is subject to, and must be read in conjunction with, the limitations set out in section 1 and the assumptions and qualifications contained throughout the Report.

The Province of Ontario has provided funding to the District Municipality of Muskoka (District) to help reduce the impact of flooding and improve the watershed's health while considering implications of social, environmental, and economic factors in the decision-making process. GHD was contracted to perform one of the first five technical projects, which was to develop a hydrologic model of the Muskoka River watershed that incorporates its ecological structure and dynamics and characterizes its functions. The project was completed in 2022 (GHD, 2022).

As part of the model build project, GHD ran thirty-three scenarios encompassing climate change, population growth, changes to wetlands, deforestation, and extreme events such as 100-year storms and wildfires. These scenarios are referred to as Phase I. The results of the Phase I analyses indicated that climate change will have the largest impact on the watershed with changes to the hydrologic cycle. The District contracted GHD to perform additional scenario analysis (Phase II scenarios) to gain further understanding into the watershed processes including additional climate change scenarios, inline manmade wetlands/ponds, and structural changes suggested by Hatch (2022). Phase II also includes an ecological flow assessment to evaluate the impact of the various scenarios on channel forming flow and subsistence (low) flows. The ecological flow assessment was performed for select scenarios from Phase I and Phase II. In total eighteen Phase II peak flow scenarios were run, and an ecological flow assessment performed on thirty-three scenarios.

Model results indicate that climate change continues to have a significant impact on peak and average flows in the watershed in both the mid-range (2050) and medium impact (SSP2-4.5) climate scenarios. The resulting trends in peak and average flows and timing agreed with the Phase I results, with climate change shifting freshet earlier and decreasing snowpack as temperatures in the watershed increase. However, cool temperatures combined with increased precipitation due to climate change may still cause an increase in flood risk. The North Branch Muskoka River was found to be highly sensitive to rain-on-snow events, with a quick response time. Moving downstream through the watershed, the river is less sensitive to rapid changes in peak flow (slower response time as the additional flow moves through the system), however the impact of the event may cause flows to remain elevated above baseline for up to one month. Downstream of Bala Dams, rain-on-snow events occurring near the upper reaches of the watershed (on the north or south branches) increase the peak flows by approximately 5%. The timing of the rain-on-snow event is significant downstream of reservoirs and large lakes. Multiple events in a row, or an event occurring when the lake or reservoir is full will likely lead to increased risk of flooding.

The impact of online reservoirs was assessed. It was found that in order to have a significant effect on reducing peak flows in the main river system, the reservoir would need to be unrealistically large, or many reservoirs would need to be constructed on the tributaries and upper reaches of the river system. However, reservoirs can have a significant impact on reducing flood risk locally.

Modelled results also indicated that the Muskoka River is more sensitive to changes in peak flows in the North Branch compared to the South Branch. When flows were artificially increased in the North Branch, peak flows increased in the Muskoka River disproportionately compared to the average flows. Conversely, when flows were artificially increased in the South Branch, the peak and average flow increases in the Muskoka River were proportional to the flow increase in the South Branch. This demonstrates the ability of Lake of Bays to attenuate peak flows due to its large storage capacity.

The ecological flow assessment results indicated that the subsistence flows in the watershed are sensitive to climate change in basins 1, 4, and 5. Channel forming flows were likewise sensitive to climate change, particularly with timing and duration. An increase in channel forming flows, and a shift to earlier occurrences is seen in the majority of the climate scenarios modelled.

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1. Introduction

1.1 Background

The District Municipality of Muskoka (District) to working to help reduce the impact of flooding and improve the Muskoka River watershed's health while considering implications of social, environmental, and economic factors in the decision-making process. GHD developed a hydrologic model of the Muskoka River watershed that incorporates its ecological structure and dynamics and characterizes its functions. The project was completed in 2022 (GHD, 2022).

The hydrologic model was built in SWAT+ (**SWAT | Soil & Water Assessment Tool (tamu.edu)**). SWAT+ is a small watershed to river basin scale numerical model used to simulate the quality and quantity of surface and groundwater and predict the environmental impact of land use, land management practices, and climate change. SWAT+ is used in assessing soil erosion prevention and control, non-point source pollution control and regional management in watersheds.

The focus of the hydrologic model was to develop an understanding of the existing conditions in the watershed. The model was then used in several scenarios to identify the impact of changes to the watershed. The list of scenarios was developed by the District and Water Quantity Task Force with the aim of addressing four key issues raised by the Muskoka Public in the Interim Advice and Recommendations to Address Priority Environmental Issues in the Muskoka River Watershed report (MWAG, 2020). Thirty-three scenarios were run which encompassed climate change, population growth, changes to wetlands, deforestation, and extreme events such as 100-year storms and wildfires. Analyses were also carried out to evaluate current and potential flood mitigation measures and potential future impacts to watershed operations and management. The objective of the scenario analysis was to identify the impact of the changes on the flow regime in the watershed. In this report, the scenarios analyzed as part of the original study are referred to as the Phase I scenarios.

The District contracted GHD to perform additional scenario analysis and low flow analysis, which is the focus of this report. The additional scenarios described in this report are referred to as the Phase II scenarios. They include: additional climate change scenarios, inline manmade wetlands/ponds, and structural changes suggested by Hatch (2022). This report also performed low flow analysis, which included recalibration of the model specific to low flows, and reanalysis of both the Phase I and Phase II scenarios.

1.2 Description of Muskoka River Watershed

The Muskoka River watershed consists of three subbasins: North Branch Muskoka River (Huntsville and Bracebridge), South Branch Muskoka River (Gravenhurst), and Lower Muskoka River (Port Carling and Bala). The watershed is located on the Canadian Shield, is mainly forested (outside of the urban areas) and is approximately 5,100 square kilometres in area. There are 38 provincially significant wetlands and over 2,000 lakes in the watershed. There are 650 lakes that are over eight hectares in size. There are 23 major water control structures. The Muskoka River includes 65 water control structures (dams) that control water levels in the lakes and rivers. None of the dams were built for flood control purposes - many were built to facilitate log transport and commercial navigation, but have evolved over time to support recreation, fisheries enhancement, and flood control.

The Muskoka River watershed has experienced several recent significant flooding events in 2019, 2016, 2013, and 2008. Significant flooding areas were: Big East River north of Huntsville, North Branch of Muskoka River between Huntsville and Bracebridge, Lake Rosseau and Lake Joseph, and Lake Muskoka. Road washouts have occurred throughout the District. There was significant damage to both public and private property and infrastructure.

GHD performed a preliminary flooding factors analysis for the watershed. The recent major flooding events (in 2019, 2016, 2013, and 2008) were primarily driven by snowmelt and multi-day rainfall events. A second factor was the high-water level in Lake Muskoka, which is controlled by a dam operated by the Ministry of Natural Resources and Forestry (MNRF).

In addition to flooding concerns, there are also concerns relating to water level fluctuations and water level drawdown (MNRF, 2019). The Muskoka River watershed is home to various fish and wildlife species (such as Lake Trout (*Salvelinus namaycush*), Brook Trout (*Salvelinus fontinalis*), Walleye (*Sander vitreus*), and the Common Loon (*Gavia immer*)), many of which require consistent lake water levels and sufficient river flows. The watershed contains a thriving tourist industry with interest in many water-based recreational activities, all of which require a consistent water level, especially during the summer months when recreation is at its peak. The existing control structures within the watershed help to maintain consistent water levels throughout the year, however there may be competing interests in how the dams are controlled (i.e., maintaining lake levels upstream of a dam for recreational purposes, but inadvertently reducing flows in the downstream reaches and limiting the amount of fish refuge habitat). There are various other concerns relating to water level fluctuations and low water levels which include the following: navigation, property damage, access to property, ability to draw water, dry wells, wetlands, scenery, and smelly stagnant water.

1.3 Phase I Scenario Analysis

The scenario analysis was performed to simulate potential changes in the watershed (e.g., increased development, climate change, an increase/decrease in wetlands) and evaluate their impacts on the flow regime. No model parameters related to hydrologic processes were adjusted during the scenario analysis, only the watershed characteristics (such as land use and weather station inputs).

The baseline (Existing Conditions) scenario was run as a continuous simulation using observed daily air temperature and precipitation data, for the period 1974 – 2005. The model warm-up period was 1974 – 1975, resulting in a 30-year analysis period (1976 – 2005). The Existing Conditions scenario was used as the baseline to define the existing hydrological regime for the watershed, against which the other scenarios were compared.

Thirty-three scenarios were run encompassing watershed changes due to climate change, development, extreme events, wetland increases, and deforestation. **Table 1** contains the list of scenarios which was developed by the District and the Water Quantity Task Force with input from GHD.

Table 1 Phase I Scenarios

ID	Name of Scenario	Scenario Description
S01	Existing Conditions	Existing conditions (used as baseline for comparison for all of the other scenarios)
S02	Climate change 1	2080 Wet climate (90^{th} percentile precipitation, median temperature)
S02B	Climate change 2	Wet climate, no temperature change (90^{th} percentile precipitation, historic temperature)
S03	Climate change 3	2080 Dry climate (10^{th} percentile precipitation, median temperature)
S04	Climate change 4	2080 Median climate (median precipitation, median temperature)
S05	Climate change 5	Coincident spring melt
S06	Development 1	Complete urban and shoreline development
S07	Development 2	Complete urban development only
S08	Development 3	Complete shoreline development only
S09	Development 4	2080 Wet climate, urban, and shoreline development (S2 & S6)
S10	Development 5	2080 Dry climate, urban, and shoreline development (S3 & S6)
S11A	Extreme events 1	Baseline Historic for S11B1 – S11E2, 1979 existing conditions
S11B1 – S11E2	Extreme events 2 - 5	Historic 100-year storm in Huntsville or Bracebridge (applied in each season)
S11F	Extreme events 6	Baseline Median Climate Change (S4) for S11G1 – S11J2, 1979

ID	Name of Scenario	Scenario Description
S11G1 – S11J2	Extreme events 7 - 10	100-year CC storm in Huntsville or Bracebridge (applied in each season)
S12	Extreme events 11	Forest fire of 500 km^2 applied in upper watershed
S13	Land use 1	Wetland increase (30% increase in entire watershed)
S14-S18	Land use 2-6	Wetland increase (30% increase in five different sub-basins)
S19	Land use 7	Deforestation (30% loss in entire watershed)
S20-S24	Land use 8-12	Deforestation (30% loss in five different sub-basins)

1.4 Purpose of this report

The purpose of this report is to provide the results of Phase II of the project. The remainder of this report is organized as follows:

– Section 2 provides the details of the additional scenarios, and the results of each scenario
– Section 3 describes the ecological flow analysis, including the low flow calibration and the ecological flow results of both the Phase I and Phase II scenarios
– Section 4 provides the conclusions
– Section 5 describes the next steps

1.5 Scope and limitations

This report: has been prepared by GHD for District Municipality of Muskoka and may only be used and relied on by District Municipality of Muskoka for the purpose agreed between GHD and District Municipality of Muskoka as set out in section 1.4 of this report.

GHD otherwise disclaims responsibility to any person other than District Municipality of Muskoka arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer section(s) 1,2,3 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

Accessibility of documents

If this report is required to be accessible in any other format, this can be provided by GHD upon request and at an additional cost if necessary.

2. Phase II Scenario Analysis

After the completion of Phase I of the project as described in Section 1, the District requested additional scenarios be modelled to further explore potential impacts to the watershed based on findings and comments from Phase I. The additional scenarios encompass mid-century and alternative climate change horizons, more detailed rain-on-snow analyses, inline potential flood attenuating wetland and reservoir options, further understanding of flow contributions from the North and South branches to downstream flows, and the integration of several flood mitigation options proposed by Hatch (2022). The list of scenarios modelled in Phase II is provided in **Table 2**.

Some scenarios require more effort than other scenarios. The scenarios have been classed as either “simple” or “complex” depending on the level of effort required to model the scenario. Simple scenarios do not require that the model be re-built. Scenarios that involve changes to the meteorological forcing data (precipitation and temperature) would fall under this category. Examples include: additional climate change scenarios, and additional extreme precipitation scenarios. For complex scenarios, there are changes to the watershed data which require a model re-build. One example is land use changes; the model must be re-built to re-define the HRUs based on the new land use raster file(s). Another example is a change to the built infrastructure. Such a change could result in changes to the reservoir area/depth relationship, and/or require the new operating rules for the dam to be added to the model.

Each additional scenario was entered into the model, and the 30-year time series was simulated with the model. The output was then analyzed to produce a comparison of peak and average flows to baseline conditions, including magnitude and timing.

Since completion of the Phase I modelling, the District has received updated land-use and topography data from the Natural Capital Inventory project. The District requested the base model be updated and validated using the new information. The details of the base model update and validation are provided in Section 2.1. This updated base model was used as the baseline for comparison for all additional scenarios in Phase II.

Table 2 Phase II Scenarios

ID	Type	Name of Scenario	Scenario Description
S26	Simple	Climate change 6	SSP5-8.5[1] 2050 Wet climate (90th percentile precipitation, median temperature)
S27		Climate change 7	SSP5-8.5 2050 Wet & Cold climate (90th percentile precipitation, 10th percentile temperature)
S28		Climate change 8	SSP2-4.5[2] 2080 Wet climate (90th percentile precipitation, median temperature)
S29		Climate change 9	SSP2-4.5 2080 Wet & Cold climate (90th percentile precipitation, 10th percentile temperature)
S30		Climate change 10	SSP5-8.5 2050 Dry climate (10th percentile precipitation, median temperature)
S31		Climate change 11	SSP2-4.5 2050 Dry climate (10th percentile precipitation, median temperature)
S32		Rain-on-snow 1	2-year rain event applied to high snowpack upstream of Bracebridge and Lake Muskoka (downstream of Port Sydney)
S33		Rain-on-snow 2	2-year rain event applied to high snowpack at northern end of watershed (upstream end of North and South Branches)
S34		Rain-on-snow 3	2-year rain event applied to high snowpack in Huntsville
S35		Rain-on-snow 4	2-year rain event applied to high snowpack in Bracebridge
S36	Complex	Update existing conditions	Base model updated with new data from Natural Capital Inventory project.
S37		Flood attenuating wetland 1	Located on the Oxtongue River upstream of Dwight and Lake of Bays
S38		Flood attenuating wetland 2	Located on a tributary of the South Branch Muskoka River upstream of Purbrook
S39		Hatch mitigation option 1	Reinstating the Distress Dam
S40		Hatch mitigation option 2	Removing bedrock shelf upstream of the South Bala Dam
S41		Branch impact to flooding 1	Simulate “dry” conditions on the North branch and “wet” conditions on the South branch during freshet and vice versa for comparison
S42[3]		Additional reservoir 1	Quarry located north of Bracebridge on the North Branch Muskoka River

ID	Type	Name of Scenario	Scenario Description
S43[3]		Additional reservoir 2	Reservoir storage location 1, South Branch near Purbrook
S44[3]		Additional reservoir 3	Reservoir storage location 3, Big East River near Highway 11
S45[3]		Additional reservoir 4	Reservoir storage location 5, Lake Vernon at outlet of Big East River

1. Shared Socio-economic Pathway (SSP) 5-8.5 assumes fossil fueled development and high (8.5W/m^2) radiative forcing in 2080
2. SSP2-4.5 assumes "middle of the road" adaptation and medium (4.5W/m^2) radiative forcing in 2080.
3. Assessed outside of the SWAT+ model as an in-line flood attenuating wetland

2.1 Updated Baseline Model – Peak Flow

2.1.1 Baseline (peak flow) model updates

The existing conditions baseline model developed in Phase I was updated with new land cover data from the Natural Capital Inventory (NCI) project and updated LiDAR topographical data. The land cover data included updated and refined cover types for broad land classes, plus wetland, aquatic, and terrestrial features (Dougan & Associates, 2022). The updated LiDAR data was produced as part of the District's Floodplain Mapping Study (Hatch, 2023). To update the model, the HRUs were re-built (following the methods described in the Phase I report) using the updated land-cover data. The sub-basin and channel slopes were also updated to reflect the new topography data. No other changes were made to the baseline model.

The most significant land cover change with the update was an increase in wetland cover overall in the watershed from 24% (Phase I) to 35% (Phase II), the urban and forest land cover classification decreased from original to updated model. The updated model land cover classification as a portion of the watershed is shown on **Figure 1**.

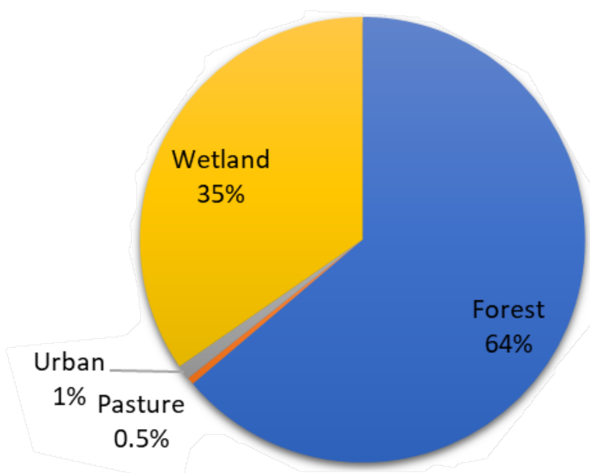


Figure 1 Land cover distribution in updated baseline model

A comparison was run between the Phase I baseline model results and Phase II updated baseline model results. Results of the analysis indicated that both models performed similarly for calibration targets, and that the updated baseline model matched well with the original model with some minor variations. For all basins, the calibration parameters achieved the same classification target ("good", "very good", "fair", etc.…) (refer to Phase I report, GHD 2022) except for Basin 5 percent bias (PBIAS) parameter which improved from "good" to "very good" in the updated model. The average monthly and peak flows showed similar magnitudes and timing of spring peaks, with slightly lower fall peaks and average flows. These results are consistent with the increase in wetlands across the basin. Based on these results, it was agreed with the District that re-calibration of the updated baseline model was not required and that the updated baseline model is considered valid for the purposes of this analysis.

2.2 Climate Change Scenarios

2.2.1 Climate Change Scenarios Setup

The purpose of the climate change scenarios was to analyse the impact of potential changes in precipitation and temperature on the Muskoka River Watershed flow regime. Phase I considered four climate scenarios focused on the long-range (2080) Shared Socio-economic Pathway (SSP) 5-8.5 which assumes fossil fueled development and high radiative forcing. To analyse the range in potential future climates, Phase II additional climate change scenarios include the SSP2-4.5 which assumes "middle of the road" adaptation and medium radiative forcing as well as mid-range (2050) projections.

Table 3 lists the six additional climate change scenarios and their related datasets. The scenarios included 2050 SSP5-8.5 Wet and Wet & Cold, 2080 SSP2-4.5 Wet and Wet & Cold, 2050 SSP5-8.5 Dry, and 2050 SSP2-4.5 Dry. No changes were made to the update baseline (Existing Conditions) model, except for the weather station data. The scenarios were each run for a 30-year period, with two additional years as model warm-up. The corresponding historic years are 1974-1975 (warm-up) and 1976-2005 (analysis).

Table 3 Climate Change Scenario Setup

ID	Scenario Name	Description	Weather Station Input Data
S26	Climate change 6	2050 SSP5-8.5 Wet	SSP5-8.5[1] 2050 Wet climate (90th percentile precipitation, median temperature)
S27	Climate change 7	2050 SSP5-8.5 Wet and Cold	SSP5-8.5 2050 Wet & Cold climate (90th percentile precipitation, 10th percentile temperature)
S28	Climate change 8	2080 SSP2-4.5 Wet	SSP2-4.5[2] 2080 Wet climate (90th percentile precipitation, median temperature)
S29	Climate change 9	2080 SSP2-4.5 Wet and Cold	SSP2-4.5 2080 Wet & Cold climate (90th percentile precipitation, 10th percentile temperature)
S30	Climate change 10	2050 SSP5-8.5 Dry	SSP5-8.5 2050 Dry climate (10th percentile precipitation, median temperature)
S31	Climate change 11	2050 SSP2-4.5 Dry	SSP2-4.5 2050 Dry climate (10th percentile precipitation, median temperature)

1. Shared Socio-economic Pathway (SSP) 5-8.5 assumes fossil fueled development and high (8.5W/m^2) radiative forcing in 2080
2. SSP2-4.5 assumes "middle of the road" adaptation and medium (4.5W/m^2) radiative forcing in 2080.

2.2.1.1 Climate change dataset derivation

The climate change time series datasets for precipitation and temperature were derived following the procedure detailed in the Phase I report Section 2.8 (GHD, 2022). At the time of this additional analysis, the Coupled Model Intercomparison Project Phase 6 (CMIP6) ensemble data were available to download from ClimateData.ca (2023). To develop the climate change time series for daily precipitation, the monthly precipitation deltas (change from historic period) for the 2080s (2071 – 2100) and 2050s (2031 – 2060), SSP2-4.5 and SSP5-8.5, CMIP6, were applied to the historic time series at each of the selected climate stations. Four future precipitation time-series were created, utilizing two sets of deltas – wet (90th percentile) and dry (10th percentile), the 2050 SSP5-8.5 dataset, and the 2080s and 2050s SSP2-4.5 datasets, for each climate station location.

To develop the climate change time series for daily minimum and maximum temperature, the CMIP6 monthly minimum and maximum temperature deltas (for the same scenarios and time periods as the precipitation datasets) were downloaded from ClimateData.ca and applied to the historic data. Four future temperature time-series were created, utilizing two sets of deltas – median (50th percentile) and cold (10th percentile), the 2050 SSP5-8.5 dataset, and the 2080s and 2050s SSP2-4.5 datasets. As noted in Phase I, temperature change is projected to be consistent across the watershed, therefore one set of temperature monthly deltas were derived and applied to the historic observed data at each climate station. The set of climate change deltas for the three different climate change horizons (SSP5-8.5 2050s, SSP2-4.5 2080s, and SSP2-4.5 2050s) are provided in **Table 4** through **Table 6**.

As described in Phase I, the SSP5-8.5 2080s (2071- 2100) climate is projected to have an increase in precipitation of 14% annually in the Muskoka River Watershed. The changes in precipitation are not evenly distributed across the year, with 31% increases seen in November through April, and a decrease of up to 3% seen in July through September. The median temperature likewise is projected to increase by 7°C, with larger increases occurring in the winter, particularly the minimum daily temperature. Together, the changes in precipitation and temperature will have a noticeable impact on the hydrologic cycle, including reducing the total snowfall, shifting snowmelt to occur more frequently in the winter and earlier in the spring, reducing the snowpack, increasing the ET, and increasing the annual precipitation.

Similar trends relating to precipitation and temperature changes are seen in the additional climate scenarios, to a lesser degree. However, notably, there are no decreases in monthly precipitation projected in the additional climate scenarios. In the 2050s, for both SSP5-8.5 and SSP2-4.5, the precipitation is projected to increase 11% and 9% annually, respectively. The increases are similarly larger in the winter months (up to 21%) and smaller in the summer months (3 to 5%). No decreases in precipitation are projected. In the SSP2-4.5 2080s, a larger increase is projected annually (12%), with winter increases up to 25% and summer increases from 1 to 3%. There are no decreases in monthly precipitation projected for this scenario.

Figure 2 shows the median monthly precipitation for the four different climate horizons considered in Phase I (RCP 8.5) and Phase II (SSP5-8.5 and SSP2-4.5).

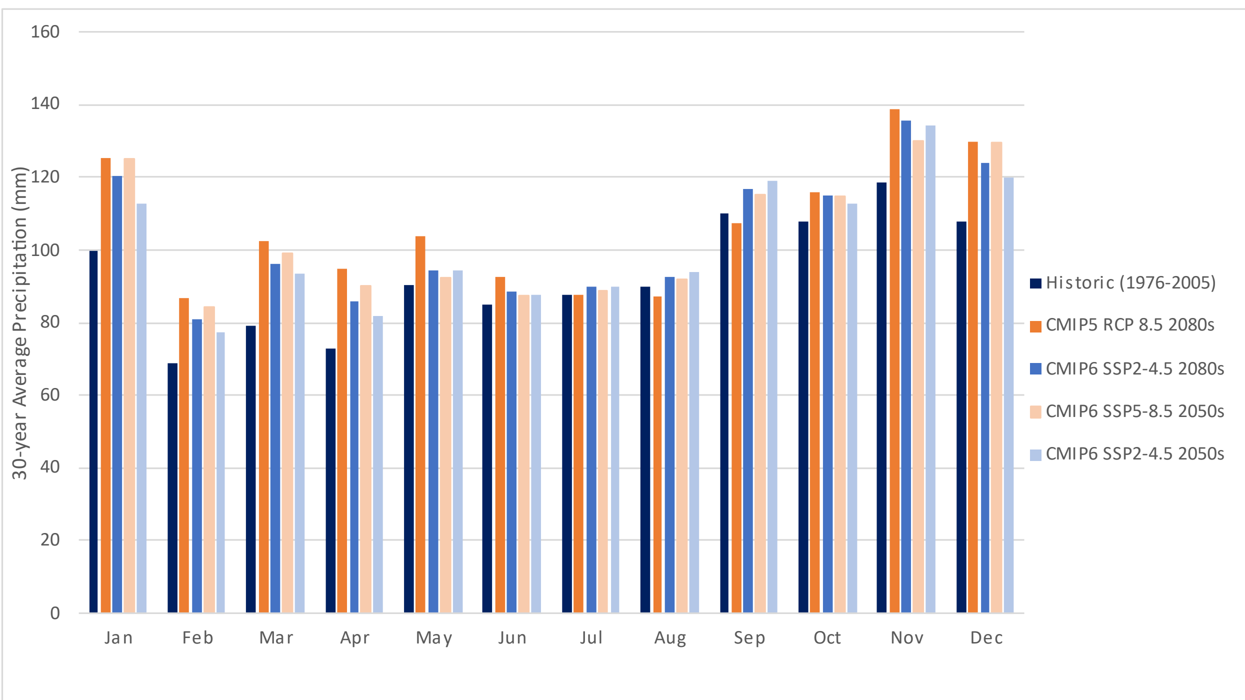


Figure 2 ***Average monthly precipitation for Muskoka Watershed (historic and median CMIP6), as used in the SWAT+ model scenario analysis***

The annual maximum and minimum temperatures are projected to increase in all additional modelled future median scenarios by 3°C to 4°C. The largest increases are seen in the minimum temperatures during the winter months, with increases up to 7°C (January, SSP2-4.5 2080s). The projected temperature changes for the modelled median climate scenarios are shown on **Figure 3** and **Figure 4.**

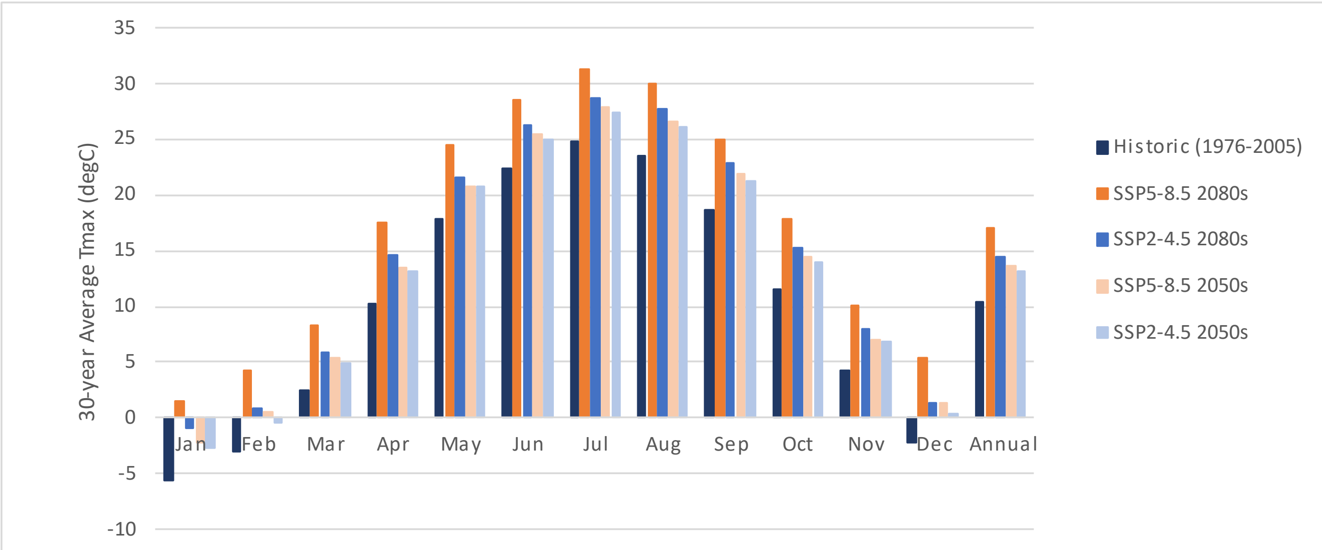


Figure 3 ***Average maximum monthly temperature for Muskoka Watershed (historic and Median CMIP6), as used in the SWAT model scenario analysis***

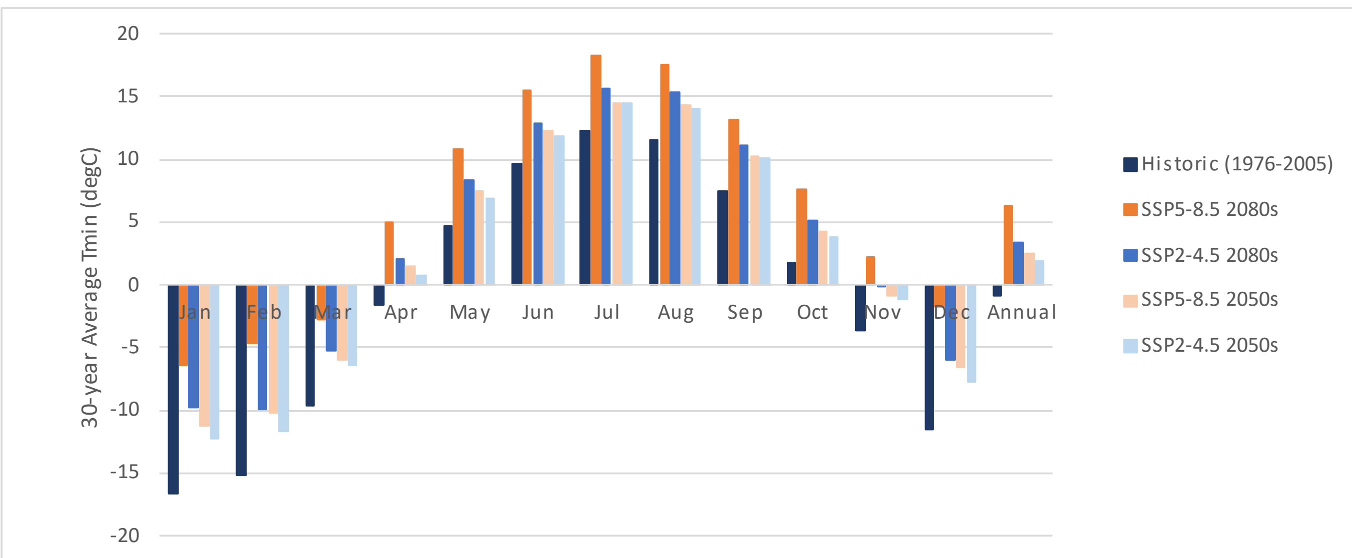


Figure 4 ***Average minimum monthly temperature for Muskoka Watershed (historic and Median CMIP6), as used in the SWAT model scenario analysis***

Table 4 Precipitation and temperature deltas used in climate change analysis SSP5-8.5 2050s from CMIP6

Station	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Precipitation (% change from historic)														
Dwight	Dry[1]	11%	7%	9%	-7%	-6%	-15%	-20%	-20%	-15%	-7%	-1%	6%	-5%
Dwight	Median	20%	16%	20%	18%	6%	2%	5%	2%	6%	7%	14%	15%	11%
Dwight	Wet[2]	32%	31%	39%	32%	19%	17%	22%	19%	19%	18%	24%	30%	25%
HWPCP	Dry	10%	7%	8%	-9%	-6%	-14%	-21%	-19%	-16%	-8%	-1%	6%	-5%
HWPCP	Median	21%	16%	21%	17%	5%	3%	1%	2%	5%	7%	14%	15%	11%
HWPCP	Wet	32%	31%	41%	32%	20%	17%	22%	18%	20%	18%	23%	31%	25%
DMOE	Dry	11%	7%	10%	-8%	-5%	-14%	-24%	-22%	-17%	-8%	-1%	6%	-6%
DMOE	Median	25%	20%	23%	18%	5%	5%	4%	3%	8%	7%	16%	17%	13%
DMOE	Wet	38%	35%	42%	32%	20%	18%	22%	19%	20%	21%	27%	34%	27%
Beatrice2	Dry	9%	7%	8%	-10%	-6%	-16%	-24%	-21%	-16%	-7%	-1%	6%	-6%
Beatrice2	Median	20%	17%	22%	18%	4%	5%	1%	4%	6%	6%	15%	15%	11%
Beatrice2	Wet	32%	32%	41%	31%	20%	18%	21%	20%	19%	16%	24%	30%	25%
MuskokaA	Dry	9%	6%	8%	-10%	-6%	-18%	-24%	-23%	-16%	-8%	-1%	5%	-6%
MuskokaA	Median	19%	18%	21%	18%	2%	8%	1%	4%	5%	5%	13%	14%	11%
MuskokaA	Wet	32%	32%	42%	31%	19%	21%	20%	21%	20%	18%	25%	29%	26%
Temperature, median (°C change from historic)														
All	Min T	5.3	5.0	3.6	3.0	2.8	2.7	2.2	2.8	2.7	2.5	2.8	5.0	3.4
All	Max T	3.5	3.6	2.9	3.2	2.9	3.1	3.1	3.1	3.2	3.0	2.8	3.6	3.2
Temperature, cold[1] (°C change from historic)														
All	Min T	3.6	2.4	2.5	2.0	1.9	2.0	1.8	2.3	2.3	1.9	2.1	3.0	2.3
All	Max T	2.6	2.0	1.8	2.2	1.7	1.8	1.9	2.1	2.1	2.1	2.3	2.3	2.1

1. 10^{th} percentile of multi-model ensemble
2. 90^{th} percentile of multi-model ensemble

Table 5 Precipitation and temperature deltas used in climate change analysis SSP2-4.5 2080s from CMIP6

Station	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Precipitation (% change from historic)														
Dwight	Dry[1]	13%	6%	5%	7%	-10%	-18%	-18%	-15%	-19%	-10%	0%	4%	-5%
Dwight	Median	25%	19%	25%	24%	4%	4%	1%	2%	5%	6%	10%	19%	12%
Dwight	Wet[2]	41%	31%	43%	31%	20%	16%	23%	22%	25%	21%	33%	30%	28%
HWPCP	Dry	12%	6%	5%	7%	-9%	-19%	-19%	-15%	-17%	-9%	1%	4%	-4%
HWPCP	Median	24%	16%	25%	25%	3%	3%	1%	1%	4%	7%	10%	20%	12%
HWPCP	Wet	41%	31%	44%	32%	23%	16%	23%	23%	26%	22%	33%	31%	29%
DMOE	Dry	15%	7%	7%	7%	-11%	-16%	-21%	-17%	-18%	-11%	0%	4%	-5%
DMOE	Median	29%	26%	26%	24%	2%	2%	3%	3%	5%	7%	11%	22%	13%
DMOE	Wet	49%	36%	47%	31%	21%	16%	26%	24%	26%	24%	37%	34%	31%
Beatrice2	Dry	13%	6%	5%	7%	-11%	-16%	-20%	-15%	-15%	-9%	0%	4%	-4%
Beatrice2	Median	24%	24%	25%	24%	1%	4%	0%	1%	4%	6%	8%	19%	12%
Beatrice2	Wet	42%	32%	46%	31%	22%	16%	25%	25%	24%	21%	31%	30%	29%
MuskokaA	Dry	12%	6%	6%	7%	-12%	-17%	-21%	-4%	-15%	-9%	0%	3%	-4%
MuskokaA	Median	25%	24%	24%	24%	1%	3%	0%	3%	4%	5%	8%	20%	12%
MuskokaA	Wet	42%	32%	45%	31%	24%	17%	24%	25%	23%	22%	30%	30%	29%
Temperature, median (°C change from historic)														
All	Min T	6.9	5.3	4.4	3.6	3.6	3.3	3.4	3.7	3.6	3.3	3.5	5.5	4.2
All	Max T	4.8	3.9	3.4	4.3	3.6	3.9	3.9	4.3	4.1	3.7	3.7	3.7	4.0
Temperature, cold[1] (°C change from historic)														
All	Min T	5.1	3.7	3.2	2.8	2.0	2.5	2.5	2.7	2.8	2.1	2.6	3.7	2.9
All	Max T	3.5	2.5	2.3	2.9	2.1	2.5	2.5	2.6	2.8	2.3	2.6	2.9	2.6

1. 10th percentile of multi-model ensemble
2. 90th percentile of multi-model ensemble

Table 6 Precipitation and temperature deltas used in climate change analysis SSP2-4.5 2050s from CMIP6

Station	Scenario	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Precipitation (% change from historic)														
Dwight	Dry[1]	5%	4%	2%	0%	-9%	-15%	-17%	-21%	-15%	-14%	1%	1%	-6%
Dwight	Median	13%	12%	17%	13%	6%	2%	4%	4%	8%	5%	13%	11%	9%
Dwight	Wet[2]	25%	22%	37%	24%	20%	21%	26%	14%	25%	22%	25%	27%	24%
HWPCP	Dry	6%	4%	2%	4%	-10%	-16%	-18%	-21%	-15%	-15%	0%	1%	-6%
HWPCP	Median	12%	12%	17%	14%	5%	3%	3%	5%	8%	4%	12%	11%	9%
HWPCP	Wet	26%	22%	38%	29%	19%	21%	26%	15%	24%	22%	25%	28%	24%
DMOE	Dry	7%	5%	2%	0%	-10%	-14%	-19%	-23%	-14%	-16%	1%	0%	-7%
DMOE	Median	15%	13%	18%	11%	5%	4%	3%	4%	8%	5%	15%	13%	9%
DMOE	Wet	29%	23%	41%	24%	18%	22%	30%	14%	26%	24%	28%	31%	26%
Beatrice2	Dry	6%	5%	2%	-1%	-10%	-18%	-17%	-20%	-11%	-14%	1%	0%	-6%
Beatrice2	Median	14%	12%	19%	10%	1%	5%	0%	7%	7%	4%	13%	12%	9%
Beatrice2	Wet	24%	21%	39%	24%	21%	24%	29%	16%	23%	20%	25%	27%	24%
MuskokaA	Dry	6%	5%	2%	-1%	-10%	-18%	-17%	-20%	-11%	-14%	1%	0%	-6%
MuskokaA	Median	14%	12%	19%	10%	1%	5%	0%	7%	7%	4%	13%	12%	9%
MuskokaA	Wet	24%	21%	39%	24%	21%	24%	29%	16%	23%	20%	25%	27%	24%
Temperature, median (°C change from historic)														
All	Min T	4.3	3.5	3.2	2.3	2.2	2.2	2.2	2.5	2.5	2.1	2.4	3.8	2.8
All	Max T	3.0	2.6	2.5	2.9	2.8	2.6	2.6	2.6	2.5	2.5	2.6	2.7	2.7

1. 10^{th} percentile of multi-model ensemble
2. 90^{th} percentile of multi-model ensemble

2.2.2 Climate Change Scenarios Results

The analysis showed that there is a slight shift in flow regime for all scenarios, with spring freshet flows occurring in March and April instead of April and May in the Baseline scenario. Due to the projected increases in temperature, the analysis showed a reduction in snowfall and snowpack resulting in increased flows in the winter months (up to a maximum of a 160% increase in February flows for SSP2-4.5 2080 Wet Scenario) and a slight shift in timing of the freshet to March/April, as shown on **Figure 5** and **Figure 6** for Muskoka River at Bala Dams. For both 2050 SSP5-8.5 Dry and 2050 SSP2-4.5 Dry, summer flows (June to October) are reduced compared to Baseline.

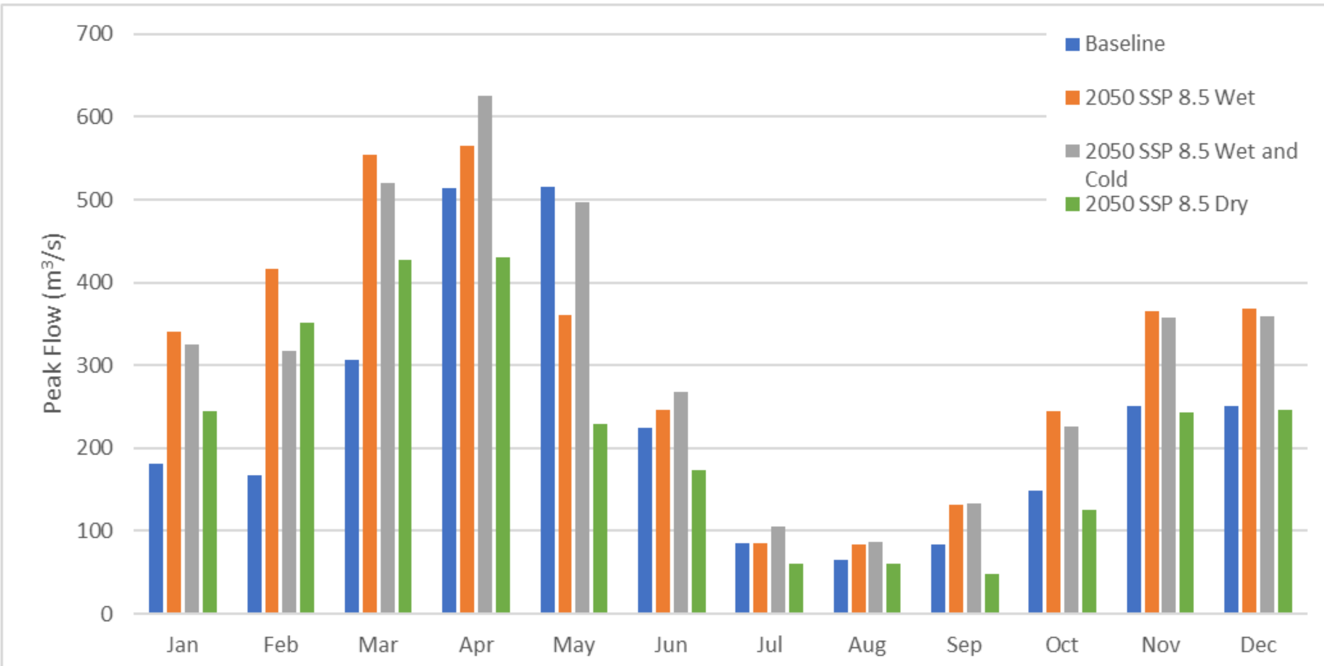


Figure 5 Monthly Peak Flows in Muskoka River at Bala Dams under Baseline and SSP5-8.5 Climate Change Scenarios

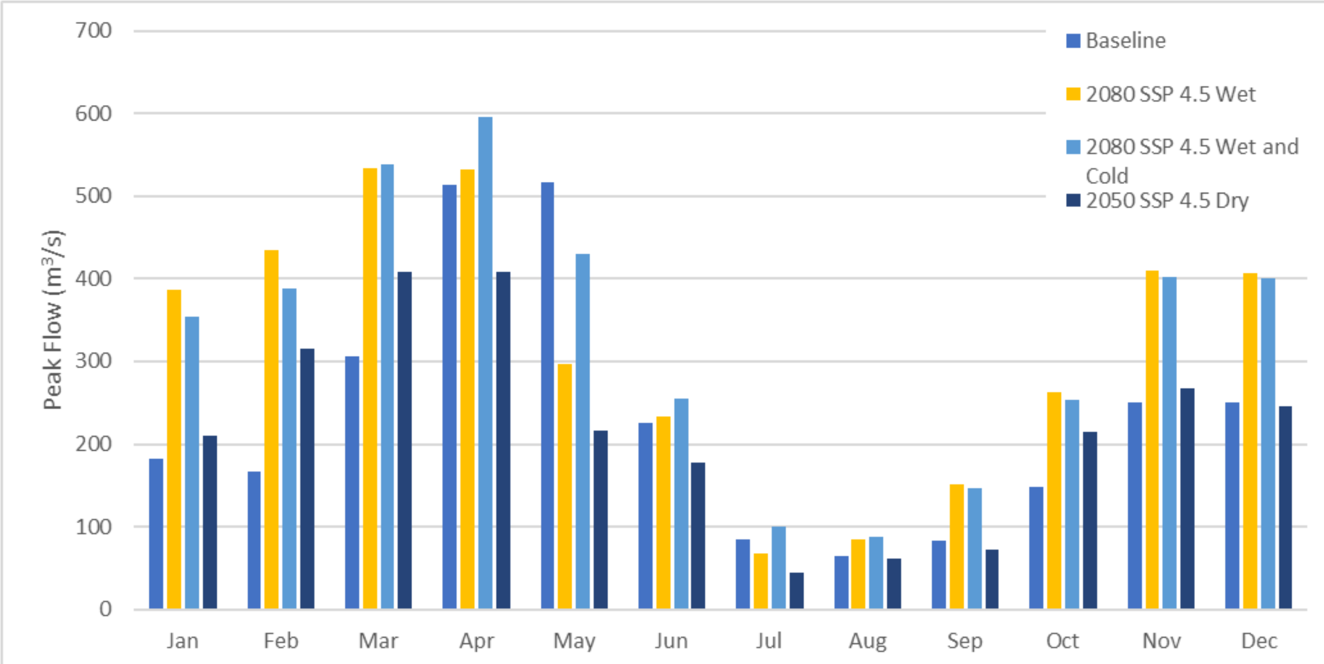


Figure 6 ***Monthly Peak Flows in Muskoka River at Bala Dams under Baseline and SSP2-4.5 Climate Change Conditions***

Total average annual flows across the watershed are projected to increase in all scenarios except for the 2050 SSP5-8.5 Dry and 2050 SSP2-4.5 Dry scenarios (**Table 7**) which show minor decreases. The 2050 SSP5-8.5 and 2080 SSP2-4.5 results are very similar to each other across the watershed for all scenarios (wet, wet and cold, dry). This indicates that the mid-range, high emission scenario is projected to have similar impacts to the watershed as the long-range medium emission scenario. Slightly larger increases in average annual flow are seen in the long-range climate scenario (2080 SSP2-4.5). The SSP2-4.5 2080 Wet and Cold scenario has very similar results to the Phase I 2080 Wet scenario (which represents SSP5-8.5).

In the 2050 SSP5-8.5 Wet Scenario, average flows are projected to increase from July through March (Big East River and North Branch), August through April (South Branch and Muskoka River at Bala), and June through March (Port Carling). As previously mentioned, the increase in temperature resulted in a reduction in snowfall and snowpack and so the largest changes in flows occurred in February at a maximum of 428% increase at Big East River. In the 2050 SSP2-4.5 Dry Scenario, average flows are projected to increase from July through March (Big East River), September through March (South Branch), October through March (North Branch and Muskoka River at Bala), and December through March (Port Carling). The largest increase in flows occurred in October at Big East River, and the largest decrease in flows occurred in April at Big East River. The two dry scenarios showed an earlier freshet (March and April opposed to April and May in Baseline) and reduced flows from the freshet and through the summer months. Despite the drier conditions, the winter flows are increased due to higher winter temperatures causing increased snowmelt and rain events as compared to Baseline.

Table 7 ***Average Annual Daily Flow Percent Change from Baseline (Climate Change Scenarios), over 30-year simulation***

Location	Associated WSC Station ID	Average Annual Flow % Change from Existing Conditions					
		2050 SSP5-8.5 Wet	2050 SSP5-8.5 Wet and Cold	2080 SSP2-4.5 Wet	2080 SSP2-4.5 Wet and Cold	2050 SSP5-8.5 Dry	2050 SSP2-4.5 Dry
Big East River near Huntsville	02EB013	40%	41%	43%	45%	-5%	-3%

Location	Associated WSC Station ID	Average Annual Flow % Change from Existing Conditions					
		2050 SSP5-8.5 Wet	2050 SSP5-8.5 Wet and Cold	2080 SSP2-4.5 Wet	2080 SSP2-4.5 Wet and Cold	2050 SSP5-8.5 Dry	2050 SSP2-4.5 Dry
North Branch Muskoka River at Port Sydney	02EB004	45%	45%	51%	52%	-6%	-9%
South Branch Muskoka River at Baysville	02EB008	47%	48%	51%	53%	-5%	-3%
Indian River (Port Carling)	02EB020	56%	60%	60%	66%	3%	0%
Muskoka River below Bala	02EB006	50%	52%	55%	58%	-3%	-4%
Orange cells indicate an increase, while blue cells indicate a decrease from baseline conditions. A darker shade indicates a greater change.							

The 2050 SSP5-8.5 Wet peak flows are lower than the Baseline peak flows by up to 12% at each assessment point except for Port Carling and Muskoka River at Bala (**Table 8**). Here, the modelled peak flows increase by up to 22% (occurring in April versus historic May). The South Branch had the largest peak flow reductions at 12%, while the North Branch and Big East River peak flows were reduced by 6% and 4%, respectively. These results indicate that the projected increase in temperature will have a significant impact on the timing and magnitude of the freshet and may reduce the peak flows overall due to a smaller snowpack, particularly in the upper reaches of the watershed. Peak flows in the 2050 SSP2-4.5 Dry scenario were reduced by 14% (Port Carling) to 30% (North Branch). The reduced peaks are due to lower precipitation and higher temperature compared to historic conditions.

Table 8 Daily Peak Flow Percent Change from Baseline (Climate Change Scenarios), over 30-year simulation

Location	Associated WSC Station ID	Peak Flow Flow % Change from Existing Conditions					
		2050 SSP5-8.5 Wet	2050 SSP5-8.5 Wet and Cold	2080 SSP2-4.5 Wet	2080 SSP2-4.5 Wet and Cold	2050 SSP5-8.5 Dry	2050 SSP2-4.5 Dry
Big East River near Huntsville	02EB013	-4%	11%	-1%	-4%	-15%	-18%
North Branch Muskoka River at Port Sydney	02EB004	-6%	10%	-14%	2%	-27%	-30%
South Branch Muskoka River at Baysville	02EB008	-12%	-1%	-13%	-5%	-32%	-29%
Indian River (Port Carling)	02EB020	22%	31%	10%	30%	-15%	-14%
Muskoka River below Bala	02EB006	9%	21%	3%	15%	-16%	-21%
Orange cells indicate an increase, while blue cells indicate a decrease from baseline conditions. A darker shade indicates a greater change.							

Due to the large increase in temperature (particularly in the winter), the overall flood risk may be reduced under climate change conditions. However, the increases in peak flows in the summer, fall, and winter compared to Existing Conditions indicates that the watershed may become more sensitive to rainfall events throughout the year (including during the winter). Additionally, wider ranges in extreme temperature and precipitation due to climate change means it is possible to experience a cold year combined with higher precipitation which would increase the risk of winter and spring flooding, with peak flows up to 31% higher (**Table 8**, Wet and Cold scenarios) than existing peak flow conditions.

Changes in freshet timing and magnitude may impact dam operation strategies and necessitate altering operation protocols. Significant changes to average and peak flows will likely require changes to dam management procedures to achieve minimum flow levels in the summer months and maintain desired water levels in the lakes (refer to Section 3 for further discussion on low flow analysis). Spring flooding may become less frequent as temperature increases in the next century, however there is the potential for high precipitation years occurring together with cooler temperatures causing significant increases in winter and spring peak flows.

2.3 Rain-on-Snow Scenarios

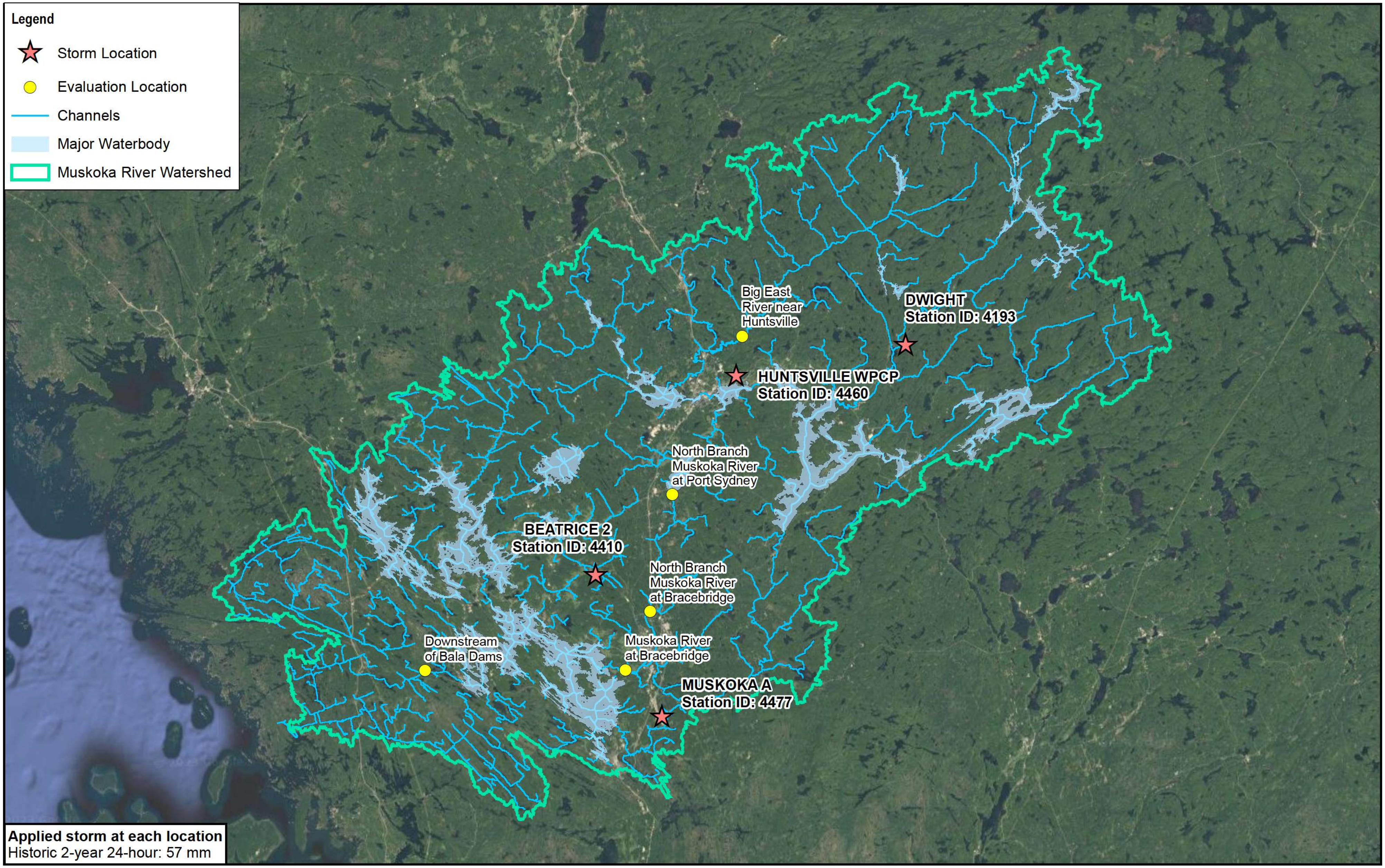
2.3.1 Rain-on-snow Scenarios Setup

The purpose of the rain-on-snow scenarios was to analyze the impact of rain events on different areas of the watershed when there is snowpack present. **Table 9** lists the scenarios and their related datasets that were developed for this analysis. The historical data and results from the updated baseline model (S36) were reviewed to select a short period with snowpack and a rain event for further analysis. A rain event occurred on March 28, 1989 which was recorded at each of the modelled climate stations ranging from 20 to 31 mm across the watershed. The mean daily temperature across the watershed on March 28 was 9°C. The modelled basin snowpack depth for March 1989 was 304 mm.

To evaluate the sensitivity of various basins in the watershed to rain-on-snow events, a baseline comparison scenario with no precipitation was compared against four scenarios with rain applied at varying climate stations. The models were run from 1986 – 1989 (using modified historic data), with the first two years as model warm-up. The baseline scenario was created by removing all observed precipitation from March 24 to 31, 1989 at each climate station to simulate flow generated only from baseflow and snowpack melt. Next, the four scenarios were developed by applying the 2-year 24-hour storm event (as derived by the Ministry of Transportation Ontario Intensity Duration Frequency (MTO IDF) tool) of 57 mm at Beatrice2, Dwight, Huntsville WPCP, and Muskoka A climate station locations, respectively. For each scenario, the storm was applied at one climate station on March 28, and the modified historic baseline data (zero precipitation during March 24 – 31) applied at the remaining stations. The selected climate stations are located as shown on **Figure 7**.

Table 9 Rain-on-snow model setup

ID	Scenario Name	Description	Weather Station Input Data	Weather Station with Applied Storm
n/a	Rain-on-snow Baseline	Baseline run for comparison	Historic precipitation (1986 – 1989) modified to remove any precipitation from March 24 – 31, 1989 at all stations Historic temperature (1986 – 1989)	n/a
S32	Rain-on-snow 1	2-year rain event applied to snowpack upstream of Bracebridge and Lake Muskoka (downstream of Port Sydney)	Historic precipitation (1986 – 1989) modified to have 57mm rain on March 28,1989 at selected climate station and no precipitation at the remaining climate stations from March 24 – 31, 1989 Historic temperature data (1986 – 1989)	Beatrice2
S33	Rain-on-snow 2	2-year rain event applied to snowpack at northern end of watershed (upstream end of North and South Branches)		Dwight
S34	Rain-on-snow 3	2-year rain event applied to snowpack in Huntsville		Huntsville WPCP
S35	Rain-on-snow 4	2-year rain event applied to snowpack in Bracebridge		MuskokaA



Paper Size ANSI A

0 6.5 13 19.5

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 UTM Zone 17N

N

GHD

DISTRICT MUNICIPALITY OF MUSKOKA
MUSKOKA RIVER WATERSHED HYDROLOGICAL MODEL
ADDITIONAL SCENARIOS

Project No. **12561902**
Revision No. **-**
Date **Sep 28, 2023**

RAIN-ON-SNOW EVENT SCENARIOS

FIGURE 7

Q:\GIS\PROJECTS\12561000s\12561902\Layouts\202309_AdditionalScenarios\12561902_001_RainOnSnow.mxd
Print date: 28 Sep 2023 - 11:36

Data source: Google Earth Satellite Imagery Accessed 2023-09-28. . MNRF NRVIS, 2018. Produced by GHD under licence from Ontario Ministry of Natural Resources and Forestry, © Queen's Printer 2023

2.3.2 Rain-on-snow Scenarios Results

To evaluate the impact of rain-on-snow events in the watershed, flows at five locations were investigated: Big East River upstream of Huntsville, North Branch Muskoka River at Port Sydney, the North Branch Muskoka River at Bracebridge, Muskoka River after confluence near Bracebridge, and the outlet of Lake Muskoka downstream of Bala Dams (refer to **Figure 7**). The sections below describe the reaction of the flows at each listed location in the watershed to rain-on-snow events occurring locally, or upstream of, each location.

Big East River at Huntsville

Modelling results show that a 2-year 24-hour rain event occurring on snowpack within the contributing basin of the Big East River, upstream of Huntsville, increases the daily peak flow by more than two times (117% increase) relative to flow occurring with no recent precipitation. Increased flows compared to baseline continued for approximately two weeks. The shape of the hydrographs for both baseline and modified scenarios shows a steep incline at the time of snowmelt (and rain) which indicates the location has a quick response to increasing temperature and precipitation. These results suggest that the Big East River is very sensitive to rain-on-snow events. There are not many large lakes or reservoirs upstream of this point to attenuate the additional run-off caused by these events.

North Branch Muskoka River at Port Sydney

Downstream of Mary Lake in Port Sydney, the flow in the North Branch Muskoka River gradually increases during freshet due to the controls at Port Sydney dam. The peak flow occurs nearly two weeks after the initial melt event. This behaviour occurs in both the baseline and rain-on-snow scenarios. When rain is applied to the contributing area, the flows increase by up to 164% relative to baseline, with the largest increase occurring the day after the rain event. Elevated flows (compared to baseline) occur for approximately 4 weeks after the event. These results indicate that the North Branch Muskoka River at Port Sydney is sensitive to rain-on-snow events, with the impact being seen over several weeks as the additional flow is routed through the upstream lakes. This also suggests that multiple rain-on-snow events in a row could have a significant impact downstream if the reservoir storage is full.

North Branch Muskoka River at Bracebridge

Further downstream on the North Branch, at Bracebridge, the attenuating effect of the Huntsville Lakes is lessened, and a quicker response peak flow is seen during the rain-on-snow event. Depending on the rain coverage over the contributing basin, the flows on the day of the event increase from 11% (rain applied at Dwight, on the south branch) up to 112% (rain applied at Huntsville). However, after 10 days, there is little difference between peak flows generated from a rain-on-snow event on the South Branch, and an event on the North Branch. By day 10, the flows have increased overall (with freshet), and the rain-on-snow scenario peak flow is approximately 12% increased over baseline, for both Huntsville and Dwight rain events. The rain-on-snow peak flows remain elevated at this location for approximately 3 weeks.

Confluence Muskoka River at Bracebridge

At the confluence of the North and South Branch Muskoka Rivers, rain-on-snow events occurring in Bracebridge have the largest impact on flows on the day of the event (up to 69% increase for daily flow). However, the peak freshet flows at this location occur later in the season. These peak flows are the most impacted by rain-on-snow occurring upstream on the North or South Branch, increasing flows by up to 15% at the confluence. At this point (10 days after the applied rain event), there is no longer an impact on flows from a local rain-on-snow event. These results indicate that a similar sized rain-on-snow event occurring further upstream (on either branch) may have longer term impacts on peak flows downstream of Bracebridge, than a local event.

Muskoka River at Bala

Downstream of the Bala Dams at Lake Muskoka, the baseline hydrograph shows a gradual increase during freshet with peak flows occurring near the end of April. The hydrograph is generally smooth and does not show rapid responses to precipitation, due to the dam control upstream. Inducing a rain-on-snow event locally (either at

Muskoka A or Beatrice2) at the beginning of freshet (while snowpack is still high and before flows have peaked) has a large impact on flows on the day of the event, with increases of 17 – 36%, respectively. However, during peak freshet flow (occurring 25 days after the rain-on-snow events were applied in the model), the largest increase is seen from rain events occurring on the upstream branches of the North and South Muskoka Rivers (Dwight). At this point, nearly one month after the event, an increase of 5% is modelled. The hydrograph showing the impact of the rain-on-snow events applied on March 28th, at four different locations in the watershed, on the flows downstream of Bala Dams are shown on **Figure 8**.

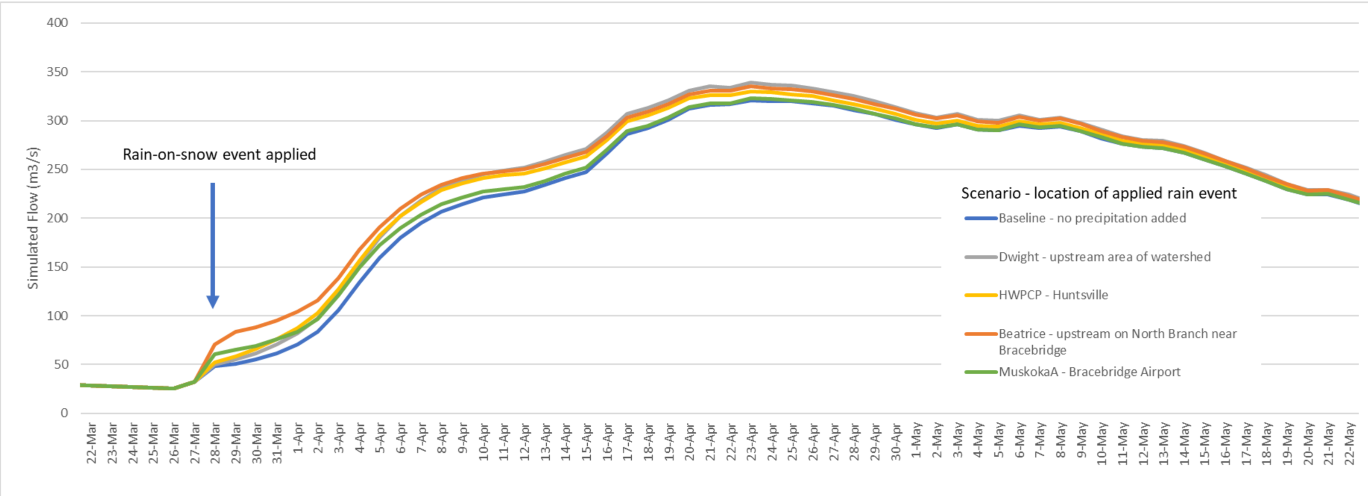


Figure 8 Rain-on-snow effects on Muskoka River at Bala

2.4 Reservoir Storage Scenarios

The scenarios presented in this section include the addition of reservoir storage through the watershed. The first part of this section describes the selection and model setup of new reservoir storage areas (i.e., flood-attenuating wetlands and a quarry lake) online to the river system. The second part describes the model setup for two potential flood mitigation options identified by Hatch. These flood mitigation options involve the retrofit of existing water management infrastructure. Then, the results for the selected reservoir storage scenarios are assessed for their ability to reduce peak flow rates in the river system.

2.4.1 Reservoir Storage – Scenarios Setup

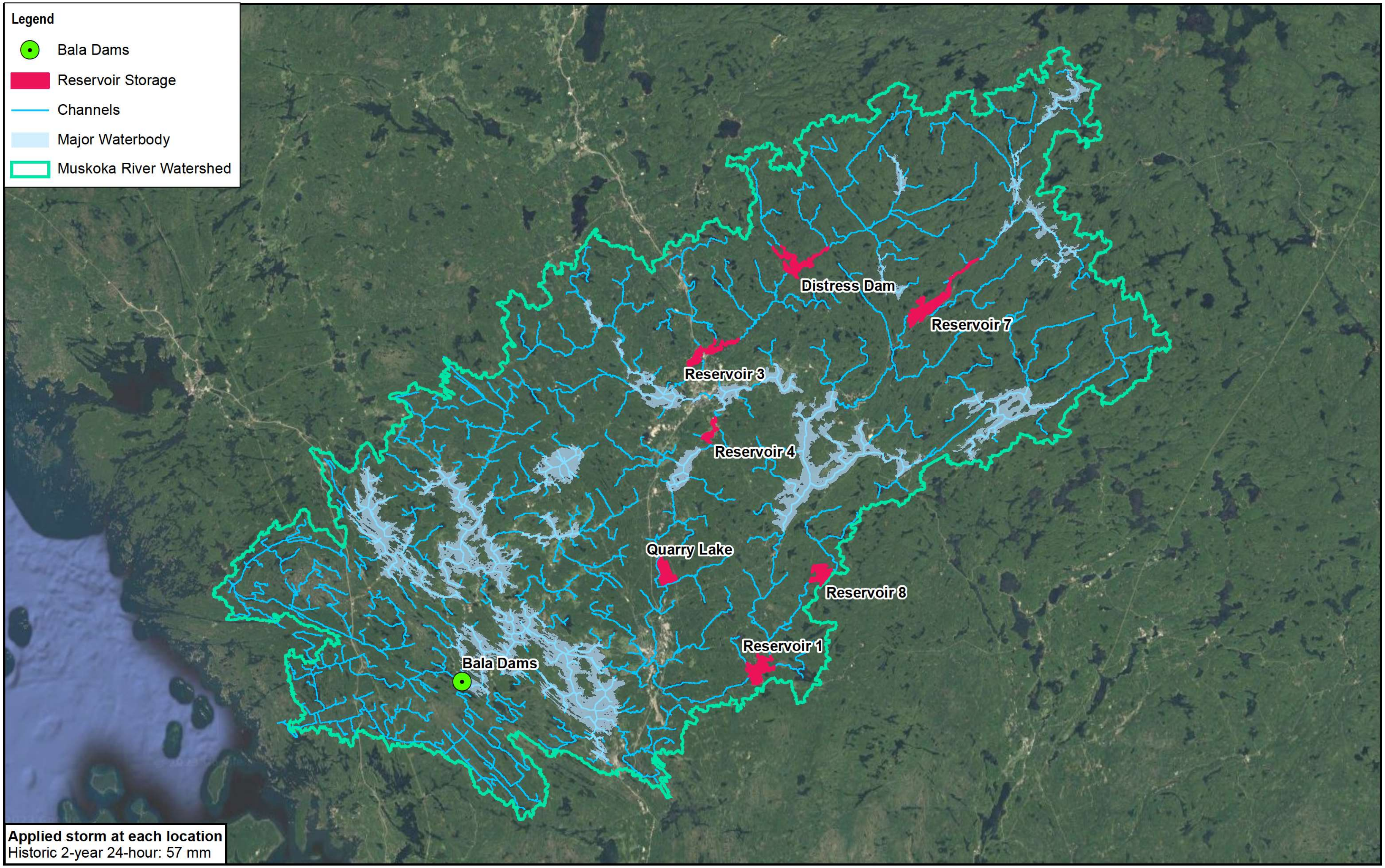
The District provided GHD with a list of five flood-attenuating wetlands to include in the scenario analysis in priority order, including:

- Reservoir 1: South Branch Muskoka near Purbrook
- Reservoir 2: South Branch Muskoka River/Spence Lake just upstream of Muskoka Falls
- Reservoir 3: Big East River near Highway 11
- Reservoir 4: North Branch Muskoka River between Fairy Lake and Mary Lake
- Reservoir 5: Lake Vernon at outlet of Big East River

The reservoirs are mapped on **Figure 9**. Reservoirs 1, 3, and 4 were considered for inclusion in the scenario analysis. Reservoirs 2 and 5 were not included. Reservoir 2 is located at the downstream end of the South Branch Muskoka River and is currently controlled by a dam at the Hanna Chute Generating Station. Reservoir 5 is an extension of Lake Vernon and is already incorporated into the SWAT+ model. The flows have already been attenuated at these locations by the dam or lake. A sixth reservoir was added to the analysis, which is an active quarry located adjacent to the North Branch Muskoka River between Port Sydney and Springdale Park. Theoretically, the quarry pit would be converted to a lake and used as storage for the North Branch Muskoka River upon closure. The storage volume of the quarry lake was calculated with the intention of providing as much capacity as possible given the property boundary shapefile, and the topographic and built infrastructure constraints.

Before incorporating these reservoirs into a SWAT+ model and including them in the scenario analysis, their ability to reduce the design peak flow rate used in the Flood Modifications Review Project (Hatch, 2022) was assessed. The Hatch (2022) study applied two design flood events to assess flood impacts on the Muskoka River, which represent two of the largest flood events on record depending on the location within the watershed. The 2013 flood event was applied to assess flood impacts and mitigation measures on the Big East River and Oxtongue River, and the 2019 flood event was applied on the north and south branches of the Muskoka River. The 2013 and 2019 floods were classified as rain-on-snow events, which produced peak flow rates in April and May of these years. The design flood events were obtained from the nearest WSC hydrometric station and prorated to the reservoir locations.

The PCSWMM hydrologic and hydraulic modelling software was used to assess the ability of the reservoirs to reduce the design flood peak flow rate. The PCSWMM software was used for this assessment for its fast, user-friendly GIS-based interface, which allowed multiple reservoir locations to be tested quickly to identify the best options to include in the SWAT+ model for the scenario analysis. First a spatial analysis of the LiDAR was completed upstream of the reservoir outlets to determine the depth, area, and volume relationship from the lowest elevation to a maximum elevation at 1 m intervals. The maximum elevations of the reservoirs were selected either as the containing elevation within the contour data, or a contour elevation that balances maximizing storage capacity while minimizing impacts to built infrastructure to give these potential scenarios the best chance of showing a reduction in peak flow rates. This information was used to characterize the available storage in the reservoirs. Then the design flood was routed through the reservoir storage nodes and a weir outlet control was sized by varying the width of the crest to determine the maximum design flood peak flow reduction that can be achieved with the reservoir storage available. **Figure 10** shows the inflow and outflow hydrographs at the Quarry Lake. **Table 10** summarizes the reservoirs available storage and ability to reduce the design flood peak flow rates.



Paper Size ANSI A

0 6.5 13 19.5

Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 UTM Zone 17N

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GHD

DISTRICT MUNICIPALITY OF MUSKOKA
MUSKOKA RIVER WATERSHED HYDROLOGICAL MODEL
ADDITIONAL SCENARIOS

RESEVOIR STORAGE SCENARIOS

Project No. **12561902**
Revision No. **-**
Date **Sep 28, 2023**

FIGURE 9

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Print date: 28 Sep 2023 - 13:00

Data source: Google Earth Satellite Imagery Accessed 2023-09-28. . MNRF NRVIS, 2018. Produced by GHD under licence from Ontario Ministry of Natural Resources and Forestry, © Queen's Printer 2023

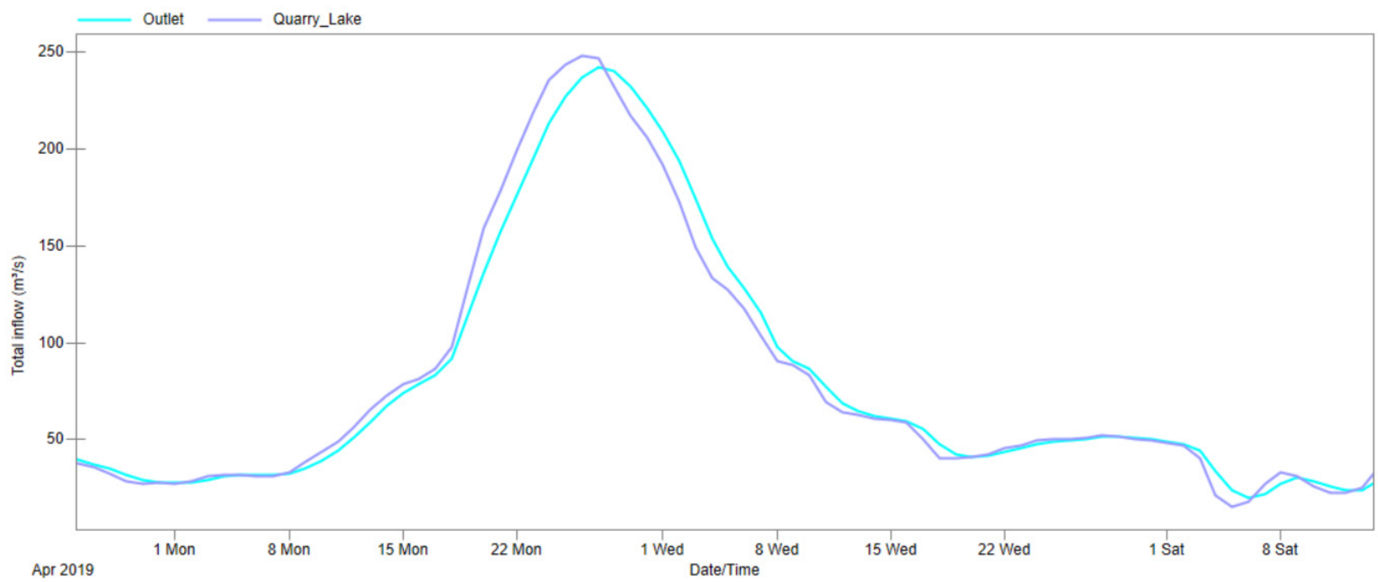


Figure 10 ***Quarry Lake Effective Design Flood Peak Flow Reduction***

Table 10 ***Reservoir Storage Volumes and Effective Design Flood Peak Flow Reduction***

Reservoir	Description	Design Flood Peak Flow Rate[1] (m^3/s)	Maximum Storage Volume Available (m^3)	Maximum Depth Available (m)	Maximum Design Flood Depth (m)	Effective Design Flood Peak Flow Reduction
Reservoir 1	Flood-attenuating wetland	192.8	14,827,618	4.0	3.93	Reduction in design flood peak flow rate less than 1 m^3/s
Reservoir 3	Flood-attenuating wetland	277.4	2,797,280	4.0	3.95	Reduction in design flood peak flow rate of less than 10 m^3/s
Reservoir 4	Flood-attenuating wetland	209.1	1,317,310	2.0	2.0	Reduction in design flood peak flow rate of less than 1 m^3/s
Reservoir 6	Quarry lake	247.9	22,787,142	6.0	5.92	Reduction in design flood peak flow rate of approximately 5 m^3/s

The results presented in **Table 10** demonstrate that the reservoirs have limited ability to reduce flood risk in the watershed. This may be attributed to the locations of the wetlands and quarry lake on the main branches of the river system, which have large contributing drainage areas and very high flood volumes relative to the peaks due to the attenuation of flows by the major lakes. The 2019 design flood hydrograph spans approximately 1 month as shown on **Figure 10**. The results show that any reservoir storage on the main river system, particularly downstream of the Huntsville Lakes and Lake of Bays on the North and South Branch Muskoka River, respectively, would have to be very large to effectively reduce peak flow rates though the system. As such, two additional reservoir locations were included for consideration in the scenario analysis: reservoir 7 located on the Oxtongue River upstream of the community of Dwight and Lake of Bays, and reservoir 8 located on a tributary of the South Branch Muskoka River upstream of Purbrook. Neither of these reservoirs are located on the main branches of the system as shown on **Figure 9**.

A spatial analysis was performed to determine the stage, area, and volume relationships for reservoirs 7 and 8, and they were incorporated into the PSCWMM model. The PCSWMM Pond Sizing Tool was used to estimate reasonable target release rates that the design flow rates could be controlled to based on the available storage within each reservoir. The design flood events were both obtained from the Oxtongue River near Dwight WSC hydrometric station and prorated to the respective reservoir locations. **Table 11** summarizes the reservoir storage characteristics, design flood peak flow rates, and target outflow rates. Control structures were sized to pass the target outflow rates during the design flood event. The conceptual control structure dimensions are also included in the table. The results of the PCSWMM modelling assessment show that reservoirs 7 and 8 can effectively reduce the peak flow rates on river reach where they are located.

Table 11 Reservoir 7 and 8 Geometries and Performance

Reservoir	Maximum Volume (m3)	Maximum Depth (m)	Control	Design Flood Peak Flow Rate (m^3/s)	Target Release Rate (m^3/s)	Volume Required to Control to Target Release Rate (m^3)
Reservoir 7	12,200,000	4	8 m long weir	107.1	78.8	11,000,000
Reservoir 8	11,900,000	8	0.5 m high x 1 m long orifice	15.1	3.4	6,400,000

Reservoirs 7 and 8 were incorporated into separate SWAT+ models (i.e., S37 and S38) and evaluated as part of the scenario analysis. They were modelled as “reservoirs” that are online to the channel network. For each scenario, a new polygon was added to the major lakes shapefile to represent the reservoir surface area. The channel shapefile was modified by breaking the channel lines at the inlet(s) and outlet of the new reservoir polygon, and the channel attributes, which provide information on connectivity (i.e., downstream channel ID, and whether it is an inlet to, outlet from, or located within a reservoir) were updated accordingly. Then the model geometry was rebuilt using the updated channel and lakes shapefiles, the hydrologic response units (HRUs) were re-generated, and the model input parameters were characterized to match the baseline model, apart from the new reservoir.

The principal and emergency spillway area/volume of the new reservoir were set equal to the area/volume of the lowest and highest elevation, respectively, calculated upstream of the reservoir outlet in the spatial analysis. Lastly, a reservoir release decision table was written for the new reservoir using the same method applied for the reservoirs in the baseline model. The rules of the reservoir release decision table are equivalent to a rating curve that relates reservoir volume, to water surface elevation, to discharge over the weir control structure.

2.4.2 Hatch Mitigation Option Scenarios Setup

Hatch was retained by the District to identify and evaluate potential flood mitigation options to reduce flood risk in the Muskoka River Watershed. They developed 10 options that are summarized in the Flood Modifications Review Project report (Hatch, 2022). GHD and the District selected two of the flood mitigation options for incorporation in the scenario analysis, including:

– Option 1: Retrofit of the Distress Dam
– Option 9: Retrofit of the Control Structure at Bala South Dam

Hatch Mitigation Option 1 – Retrofit of the Distress Dam

Option 1 involves reinstatement of the Distress Dam on the Big East River. The location of the dam is shown in **Figure 9**. The dam is currently not operable and functions as a weir control structure with limited capacity for flood mitigation. This option involves construction of a new dam sized to pass the probable maximum flood with a peak flow rate of 848 m^3/s and a design head of 11 m. The new dam control structure has two 8.3 m wide by 6.9 m high gates. Under normal conditions, the gates would be fully raised to pass the flow, and under flood conditions the gates would be lowered to control the flow through the spillway and into a stilling basin before continuing down the Big East River.

The design flood event was obtained from the Big East River near Huntsville WSC hydrometric station for the 2013 period. The design flood peak flow rate prorated to the Distress Dam location is 176.4 m^3/s (calculated by GHD). The orifice equation was used to determine the opening of the gates required to reduce the design flood peak flow rate by approximately 55 m^3/s to approximately match the Hatch (2022) results for the North Branch Muskoka River upstream of Lake Vernon. A gate opening of 1 m approximately provides this peak flow reduction.

To incorporate this scenario into the SWAT+ model, a new polygon was added to the major lakes shapefile to represent the surface area of the Distress Dam reservoir, and the channels shapefile was modified as described in the reservoir storage scenario setup section above. Then the model geometry was rebuilt using the updated channel and lakes shapefiles, the hydrologic response units (HRUs) were re-generated, and the model input parameters were characterized to match the baseline model, apart from the new reservoir.

The principal spillway area/volume were set equal to the area/volume corresponding to the spillway crest elevation, and the emergency spillway area/volume were set equal to the area/volume corresponding to the design head of 11 m over the spillway. Lastly, a new reservoir release decision table was written for the Distress Dam. The rules of the reservoir release decision table are equivalent to a rating curve that relates reservoir volume, to water surface elevation, to discharge through the gated control structure with a 1 m opening. Discharge through the 1 m gate opening was calculated using the orifice equation for a range of water levels at 1 m intervals.

Hatch Mitigation Option 9 – Retrofit of the Control Structure at the South Bala Dam

There is currently a bedrock shelf located immediately upstream of the South Bala Dam, which is 0.3 m above the sill of the dam and acts as the control when then gates are fully open (i.e., when all stop logs are out). Hatch Option 9 involves excavation of the bedrock shelf, which allows the South Dam to control water levels in Lake Muskoka in flood conditions.

This scenario was incorporated in the SWAT+ model by modifying the reservoir release decision table for the Bala Dams at Lake Muskoka. The modifications impact flows during the spring flood conditions when the stop logs are removed to increase storage in the lake and the capacity of the dam control structure. The invert of the control structure was lowered by 0.3 m, thereby increasing the capacity of the South Dam.

2.4.3 Reservoir Storage Scenarios Results

The impacts of the reservoir storage scenarios on peak flow rates are summarized in **Table 12**.

Table 12 Daily Peak Flow Percent Change from Baseline (Reservoir Storage Scenarios), over 30-year simulation

Location	Associated WSC Station ID	Peak Flow % Change from Existing Conditions			
		Reservoir 7	Reservoir 8	Retrofit Distress Dam	Retrofit South Bala Dam
Big East River near Huntsville	02EB013	0%	0%	-6%	0%
North Branch Muskoka River at Port Sydney	02EB004	0%	0%	-1%	0%
South Branch Muskoka River at Baysville	02EB008	0%	0%	0%	0%
Indian River (Port Carling)	02EB020	0%	0%	0%	0%
Muskoka River below Bala	02EB006	0%	0%	0%	-1%
Oxtongue River near Dwight	02EB014	-11%	0%	0%	0%
South Branch Muskoka River near Purbrook	n/a	0%	0%	0%	0%

Location	Associated WSC Station ID	Peak Flow % Change from Existing Conditions			
		Reservoir 7	Reservoir 8	Retrofit Distress Dam	Retrofit South Bala Dam
Big East River near Williamsport Road	n/a	0%	0%	-31%	0%

The results demonstrate that larger reservoirs can reduce peak flow rates locally; however, their ability to reduce peak flow rates is diminished further downstream in the system as the river receives runoff from larger contributing drainage areas and flows through the operated major lakes. This is most evident in the results for Reservoir 7 and the Distress Dam. Reservoir 7 provides an 11% reduction in peak flow rate on the Oxtongue River near Dwight, and no change on the South Branch Muskoka River at Baysville. The Distress Dam provides a 31% reduction in peak flow rate in the Big East River near Williamsport Road; however, as the river gains more runoff from the downstream contributing drainage areas, and meanders through wetlands and under roads toward Lake Vernon, the flow reduction is diminished to 6%, and 1% downstream of the Huntsville Lakes and Mary Lake at Port Sydney.

Reservoir 8 has the capacity to significantly attenuate the peak flow rate on the tributary where it is located as shown in **Table 11**; however, it provides negligible impact on the main branches of the Muskoka River system. Reservoirs 7 and 8 were selected as examples to demonstrate how online storage can be an effective way of reducing peak flow rates on the tributaries and upper reaches of the river system. It is important to note that there may be other locations within the watershed where online storage could effectively mitigate flooding at a local level. The potential reservoir locations should be selected in topographically flat, undeveloped areas. To mitigate flooding on the main branches of the Muskoka River, very large reservoirs would be required, or many relatively smaller reservoirs would need to be constructed on the tributaries and upper reaches of the river system to reduce the peak flow rates contributing to the main stems.

Lastly, the retrofit of the South Bala Dam results in a small reduction in peak flow rate of 1% on the Muskoka River downstream. This option will also reduce water levels in Lake Muskoka in flood conditions.

2.5 Branch Impact to Flooding

2.5.1 Branch Impact to Flooding Scenarios Setup

The purpose of the branch impact to flooding scenario was to assess the relative contribution of the north and south branches to flood potential in the watershed. Two scenario runs were performed for this analysis. First, the historical baseline model results were reviewed to select one seasonal time series (September to May) with relatively high snowpack, precipitation, and runoff and another with relatively low snowpack, precipitation, and runoff. These are termed the ‘wet’ year and ‘dry’ year, respectively. Next, an average precipitation period (September to May) was selected as basis for comparison. For the first comparison, the climate data for the ‘wet’ year were applied to the model HRUs contributing to the south branch, and the ‘dry’ year climate data were applied to the model HRUs contributing to the north branch. This scenario simulates higher flow in the south branch relative to the north branch. For the second comparison, the climate data were reversed to have relatively dry conditions in the south and relatively wet conditions in the north. This second scenario simulates higher flow in the north branch relative to the south branch. The comparison of both scenarios against the average precipitation year baseline and each other provides insight to the relative contributions of the branches to peak flows downstream. The results of this particular scenario are meant to provide a better understanding of the watershed connections and sensitivities, and do not necessarily translate to real-life climate scenarios. For example, similar snowpack conditions would be expected in the upper reaches of the north and south branches within the same season.

The analysis season was selected as September to May, to capture peak flow, including all snow events and freshet that may occur. Historically, the peak flows in the Muskoka River watershed are observed during freshet. For simplicity, this time period is referred as ‘winter’ of its starting (September) year. For example, the period covering September 1984 through May 1985 is referred to as winter 1984. **Figure 11** shows the total and average precipitation, snowpack, and surface flow watershed-wide for each winter season. Winter 1984 was selected for the above-average precipitation and flow ('wet') year, while Winter 1997 was selected for the below-average precipitation and flow ('dry') year. For comparison, the baseline scenario was selected as Winter 1989, which had average precipitation and flow.

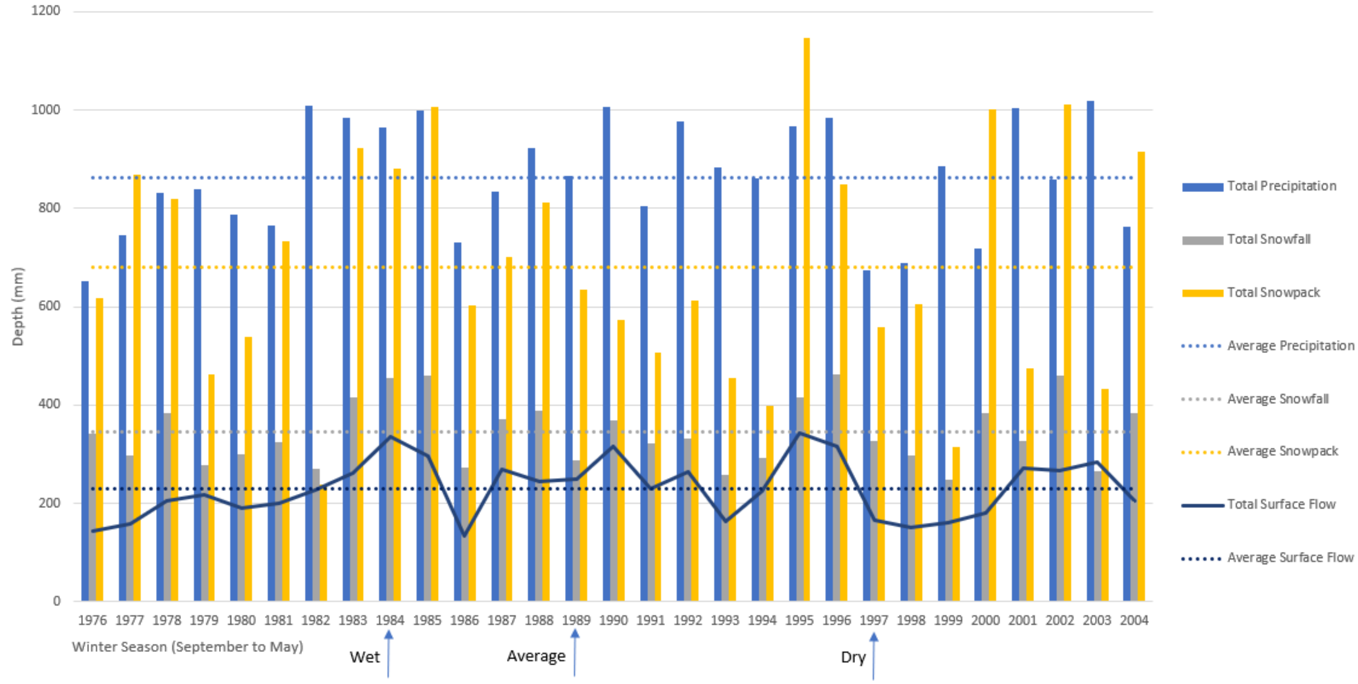


Figure 11 Historical seasonal precipitation and surface flow

2.5.2 Branch Impact to Flooding Scenarios Results

In the first scenario, the winter 1984 'wet' climate data are applied to the model HRU's contributing to the North Branch Muskoka River, and the winter 1997 'dry' climate data are applied to the model HRU's contributing to the South Branch Muskoka River. This scenario simulates a higher relative contribution of flow in the north branch than the south branch. In the second scenario, the climate data are switched, with the south branch HRU's having the wet climate data.

In the average year, the average flows in the North and South Branches during March, April, and May (freshet) are nearly equal. However, when the wet year climate data are applied to the North Branch contributing areas, the north branch average freshet flows are nearly double those in the south branch. In the opposite scenario, the south branch average flows are nearly 1.5 times those in the north branch. These flow results demonstrate that the method of applying wet and dry climate data by contributing basin, provides the desired model outcome of increasing the difference in relative flow magnitudes in the north and south branches for further analysis.

At the confluence, the high north flow scenario shows a significant increase in peak flow relative to average conditions, despite having similar average flow. The average flow in the high north flow scenario decreased by 8% relative to the average baseline conditions, while the peak flows increased by 13%. This suggests that higher flows in the north branch disproportionately impact the peak flows relative to the average flows. Therefore, the Muskoka River is sensitive to high flow increases in the North Branch.

Conversely, average freshet flows at the confluence decreased by 16% in the high south flow scenario with a corresponding decrease of 22% in the peak flows. This suggests that the average and peak flows at the confluence of the Muskoka River are proportional to the changes in flow in the South Branch. Therefore, the Muskoka River is likely not sensitive to high flow increases in the South Branch, relative to the North Branch. A potential reason for this behaviour is the large storage capacity of Lake of Bays which provides attenuation of peak flows for a large portion of the south branch contributing areas.

3. Ecological Flow Analysis

The results of the scenario analysis presented above show the impacts of climate change, population growth, deforestation, extreme events, and reservoir storage on mean annual and peak flow rates calculated at five assessment points across the river system. In this study, mean annual flows represent the average volume of water that passes through an assessment point, and peak flows are calculated as the highest daily flow rate in the 30-year simulation period. Mean annual flow impacts are used to assess the water balance, and peak flow impacts are used to assess flood potential and mitigation. To assess the affect of the scenarios on the ecological conditions of the river, multiple components of the flow regime must be evaluated.

The flow regime is the pattern of discharge in a watercourse that is characterized in terms of the magnitude, duration, frequency, timing, and rate of change of flows. **Figure 12** shows the components of the flow regime that are important to the ecological condition of the watercourse. In general, low flows (baseflows and subsistence flows) maintain longitudinal connectivity and are required to sustain form and function of aquatic habitat, and moderate to high flows (high pulse flows, channel forming flows, riparian flows) are needed to flush the system and provide lateral connectivity to oxbows and floodplains. These components of the flow regime are used as “indicators” to assess the impact of a flow alteration on the ecological condition of a watercourse. The indicator flows selected for the ecological flow assessment of the Muskoka River are presented in the sections below. First the model updates, and calibration and validation results are presented.

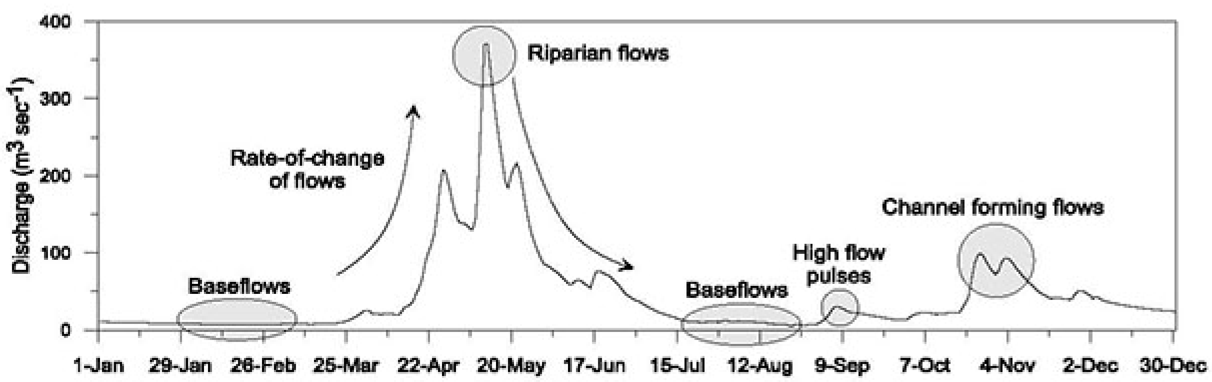


Figure 12 Ecologically Important Components of the Flow Regime (Metcalfe et. al, 2013)

3.1 Model Update

Prior to re-calibrating and validating the model in preparation for the ecological flow analysis, the model was updated to include more detailed reservoir release functions for the largest lakes, which have the greatest impact on the Muskoka River low flow regime, including the Huntsville Lakes (Vernon, Peninsula, Fairy), Mary Lake, Lake of Bays, and Lake Muskoka.

As documented in the Phase I study, the major lakes are modelled as reservoirs online to the channel network. The reservoirs are characterized by the surface area and volume required to fill them up to two elevations: the principal spillway and the emergency spillway. The volume at the principal spillway elevation is equal to the normal reservoir storage volume, and the volume at the emergency spillway elevation is equal to the maximum reservoir storage volume. These measurements define the stage-storage relationship for each reservoir, which is used to relate reservoir volume to water surface elevation and each timestep.

The volume of water to be released from the reservoirs is determined by a set of rules coded in decision tables. The rules change based on the water surface elevation relative to the principal spillway, and the time of year to simulate seasonal operations at the dam control structures. In the Phase I study, the decision tables were coded based on the MNRF’s most recent Water Level Operating Zone Limits data for each dam structure, which aimed to release water from the reservoir at a rate equal to the historical median weekly flow rate. During flood events, the release rate over the emergency spillway was calibrated. The release rates were defined in the decision tables as drawdown days for incremental water surface elevations.

In the Phase II study, the decision tables were expanded to include more coordinates of drawdown days based on water surface elevation, and different combinations of operational controls (i.e., stop logs in the gate openings) based on the time of year. In addition, a minimum release rate was added to the decision tables based on the operational rules for each dam to support fisheries and hydropower production. The reservoir release rate during flood events was not re-calibrated: these changes would affect the reservoir drawdown period and low flows.

3.2 Ecological Flow Calibration

The model calibration and validation performed in the Phase I study focused on the model's ability to capture the peak flow rates and volumes in the observed hydrographs, as well as the average monthly and annual streamflow volumes. The ecological flow assessment evaluates both low and high flow statistics; therefore, the model was re-calibrated and validated to assess the model's ability to represent both low and high flow conditions in the observed record using the same approach applied in the Phase I study.

3.2.1 Calibration and Validation Approach

Calibration is the process by which estimated parameters are adjusted to match modelled to observed flow data. Validation uses a set of model input data that is independent of the calibration process to measure the performance of the calibrated model without further adjustment to model parameters. The period from 1983 to1987 was selected for calibration as it contains the year with the highest precipitation (1983), highest snowfall (1985), and average precipitation (1984) from the 30-year (1974 – 2005) period of record. The validation period was selected to be 1988 to 1992, which contains a period of both high snowfall and low precipitation (1989), and average precipitation (1990).

In the Phase I study, a sensitivity analysis was performed to determine the parameters of the hydrological processes (i.e., snowmelt factors, infiltration parameters, baseflow parameters) that impact streamflow from which 11 were selected. Hydrological parameters that could be measured and assigned with a higher level of certainty were excluded from the calibration process. These parameters, including area, slope, length, Manning's n, Curve Number, soil depth, and other soil parameters (i.e., bulk density, hydraulic conductivity) were measured or selected from reference documents based on the topographic, land use, and soil data available for the watershed.

Of the 11 parameters chosen to calibrate the model in the Phase I study, five control snow accumulation and melt, four are related to infiltration and baseflow processes, and two are related to reservoir release. In the Phase II study, only the snowmelt, infiltration, and baseflow parameters were used to re-calibrate the model, because the reservoir release parameters were calculated with a higher level of certainty as described in the model update section of this report. **Table 13** lists the calibrated parameters with descriptions, value ranges, and references.

Table 13 Sensitive Parameters Selected for Calibration

Parameter	Description	Units	Initial or default value	Range	Source
fall_temp	Snowfall temperature	°C	0.7	-4 – 5.1	Analysis of DWIGHT climate station data
melt_temp	Snow melts base temperature	°C	0.3	-1.5 – 5.1	Analysis of DWIGHT climate station data
melt_max	June 21 melt rate for snow	mm/°C/day	2.74	1.6 – 6	USDA, 2004
melt_min	December 21 melt rate for snow	mm/°C/day	2.74	1.6 – 6	USDA, 2004
tmp_lag	Snowpack temperature lag factor	n/a	1	0 – 1	SWAT+
revap	Threshold depth of water in shallow aquifer required to allow revap to occur	mm	0.02	0.02 – 0.2	SWAT+
alpha_bf	Alpha factor for groundwater recession curve	1/days	0.048	0 – 1	SWAT+
flo_min	Water table depth for return flow to occur	m	3	0 – 10	SWAT+
awc	Available water capacity of soil layer	mm/mm	varies	0 – 1	Saxton and Rawls, 2006

The results of the calibration and validation procedures were evaluated using both graphical and statistical methods, including percent bias (PBIAS), Nash Sutcliffe Efficiency (NSE), and the Coefficient of Determination (R^2), which are defined in the Phase I report.

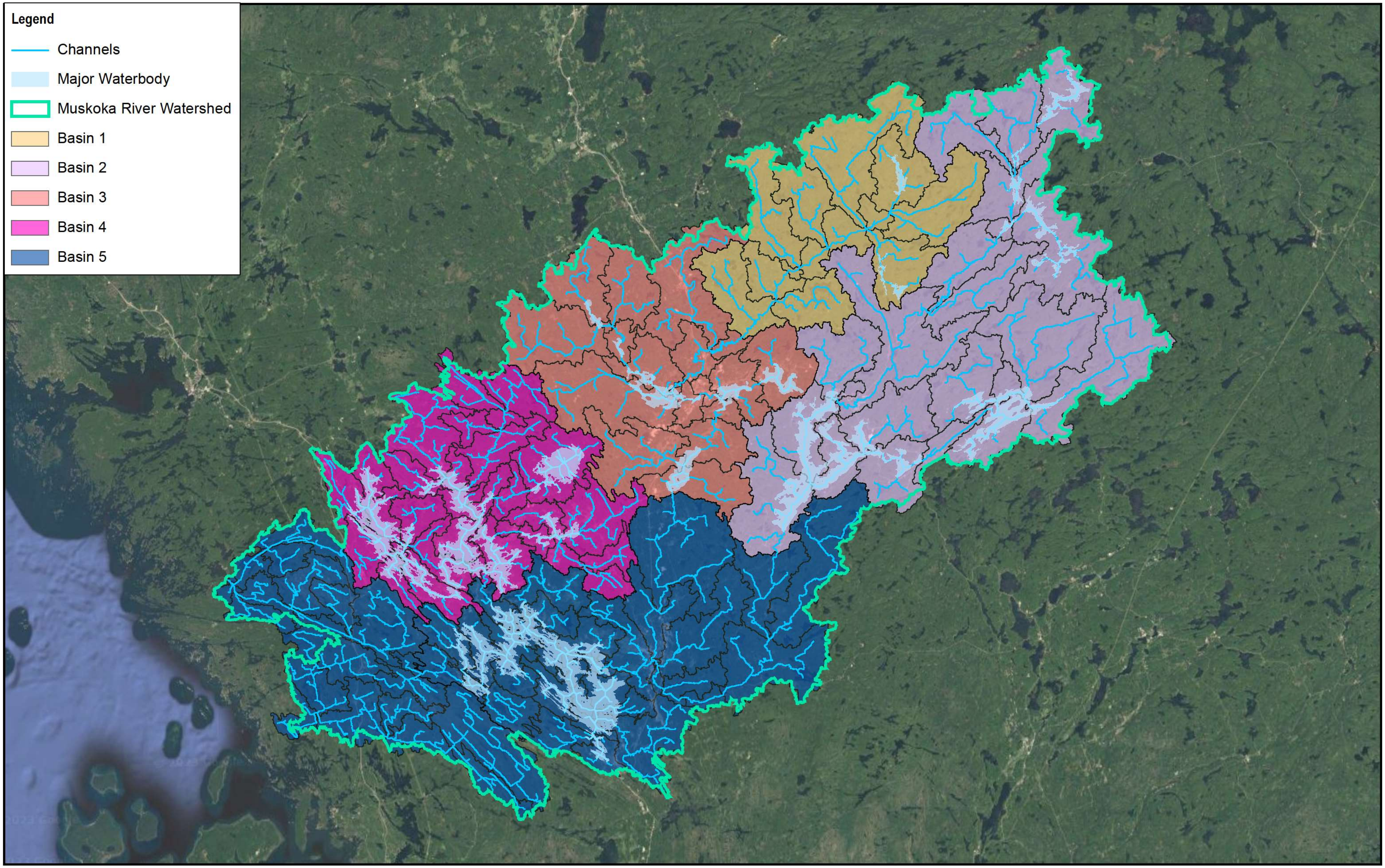
3.2.2 Calibration and Validation Results

The model was re-calibrated and validated at the basin 1, 2, 3, and 5 outlets shown on **Figure 13**, which coincide with Water Survey Canada (WSC) hydrometric stations with long-term flow records. Basin 4 was excluded from the re-calibration and validation process, because the WSC hydrometric station located at its outlet in Port Carling records water level only. The “observed” flow rates used for model calibration of basin 4 in the Phase I study were estimated from the measured water levels using a rating curve. Although this was the best available data, it is an approximation, with limited opportunity for improvement.

The graphical calibration and validation results are presented by basin below, and the statistical results are summarized in tables at the end of the section.

3.2.2.1 Basin 1 – Graphical Results

Basin 1 is located at the northeast upstream edge of the watershed and drains into basin 3 as shown on **Figure 13**. The basin outlet is on the Big East River at Williamsport Road. The WSC hydrometric station used for calibration is 02EB013. **Figure 14** and **Figure 15** show the calibrated and validated model results, respectively, which are each compared to the observed flow record from the WSC gauge.



Paper Size ANSI A

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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: North American 1983
Grid: NAD 1983 UTM Zone 17N

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DISTRICT MUNICIPALITY OF MUSKOKA
MUSKOKA RIVER WATERSHED HYDROLOGICAL MODEL
ADDITIONAL SCENARIOS

Project No. **12561902**
Revision No. **-**
Date **Sep 28, 2023**

MODEL BASINS

FIGURE 13

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Data source: Google Earth Satellite Imagery. . MNRF NRVIS, 2018. Produced by GHD under licence from Ontario Ministry of Natural Resources and Forestry, © Queen's Printer 2023

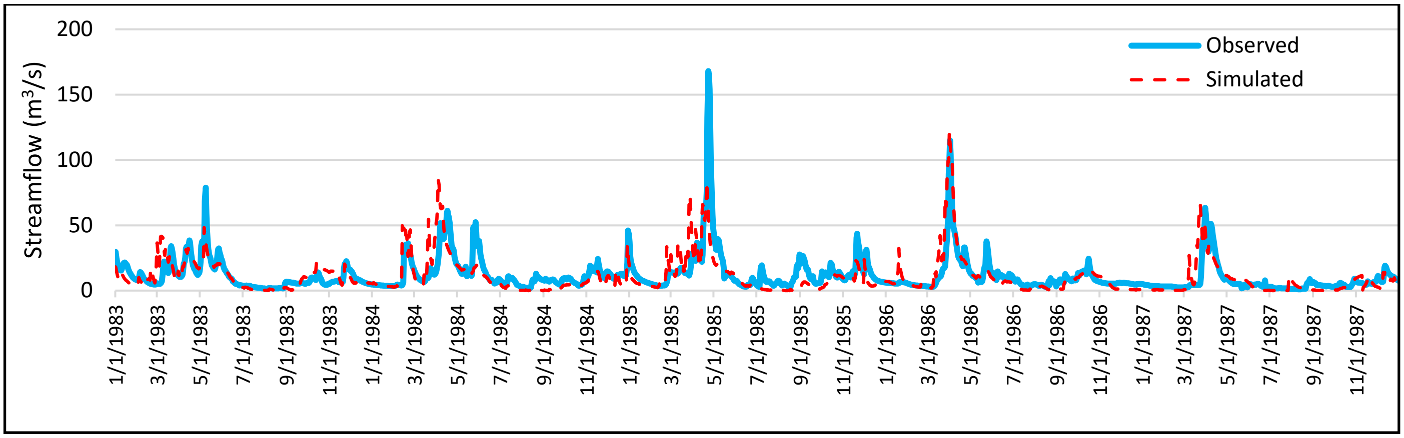

Figure 14 Basin 1 Observed and Modelled Streamflow During Calibration Period

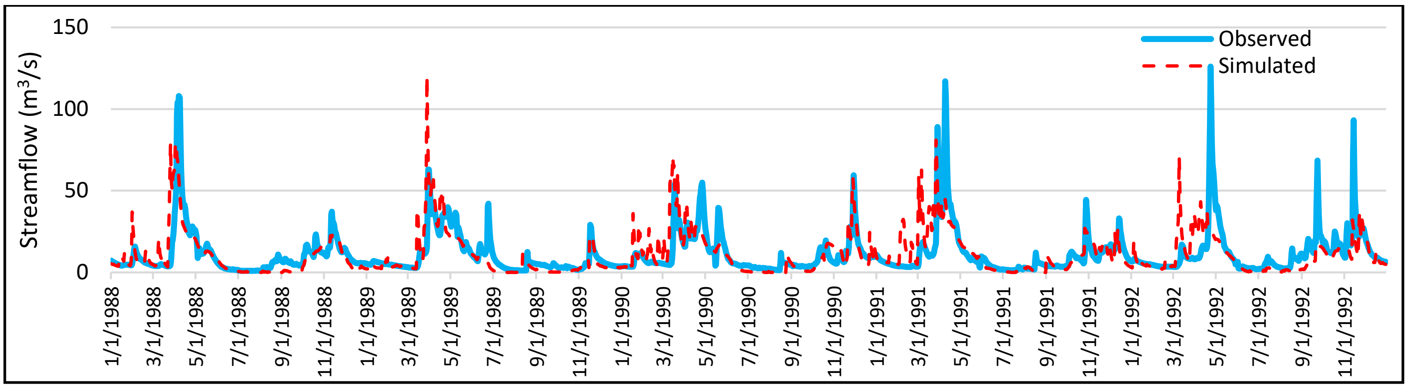

Figure 15 Basin 1 Observed and Modelled Streamflow During Validation Period

3.2.2.2 Basin 2 – Graphical Results

Basin 2 is located southeast of basin 1 and drains to the South Branch Muskoka River upstream of the Lake of Bays outlet at Baysville. The WSC gauge used for calibration is 02EB008, located near the basin 2 outlet. **Figure 16** and **Figure 17** show the calibrated and validated model output, respectively.

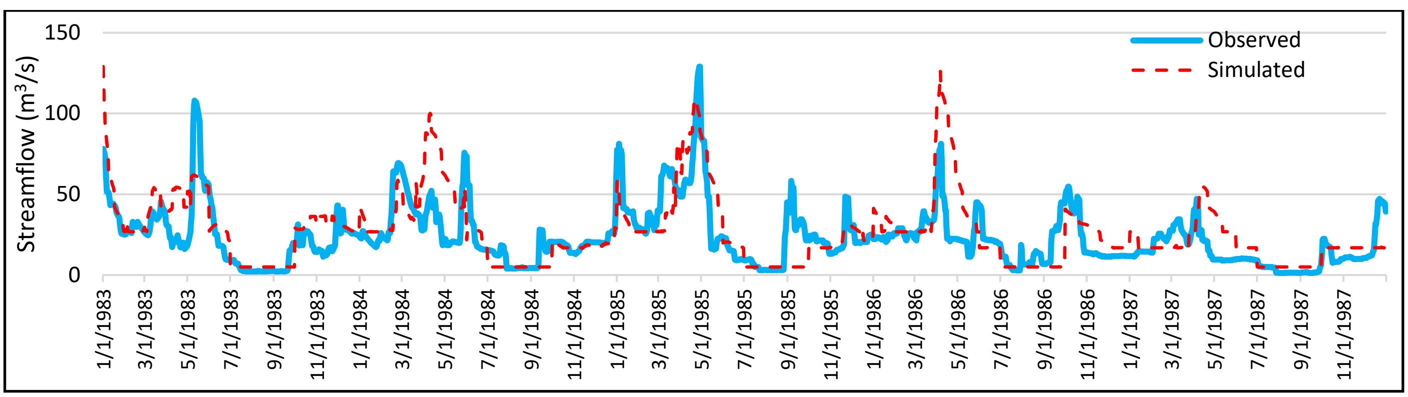

Figure 16 Basin 2 Observed and Modelled Streamflow During Calibration Period

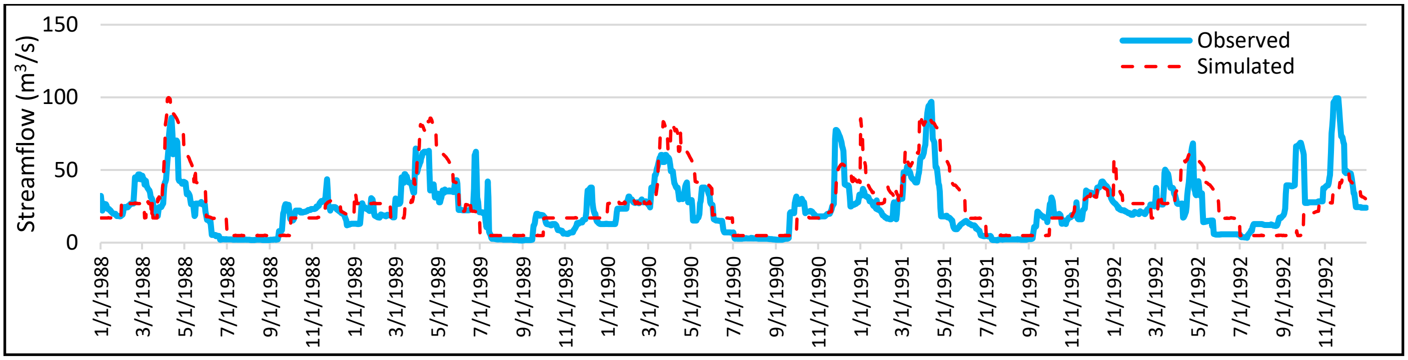

Figure 17 *Basin 2 Observed and Modelled Streamflow During Validation Period*

3.2.2.3 Basin 3 – Graphical Results

Basin 3 is located immediately downstream of basin 1, and northwest of basin 2. It receives inflow from basin 1 and drains into basin 5. The WSC gauge used for calibration is 02EB004, located at the basin 3 outlet immediately downstream of the Port Sydney Dam on the North Branch Muskoka River. **Figure 18** and **Figure 19** show the calibrated and validated model output, respectively.

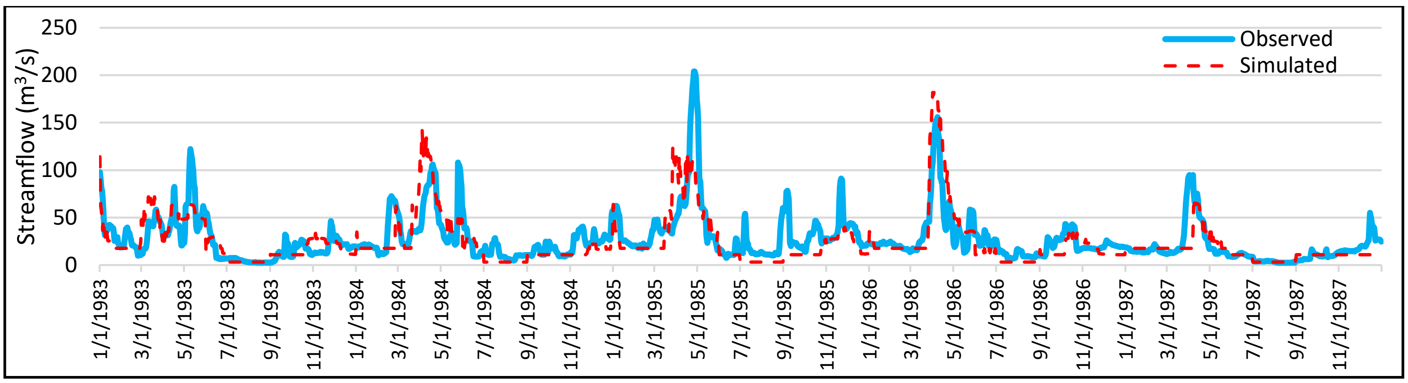

Figure 18 *Basin 3 Observed and Modelled Streamflow During Calibration Period*

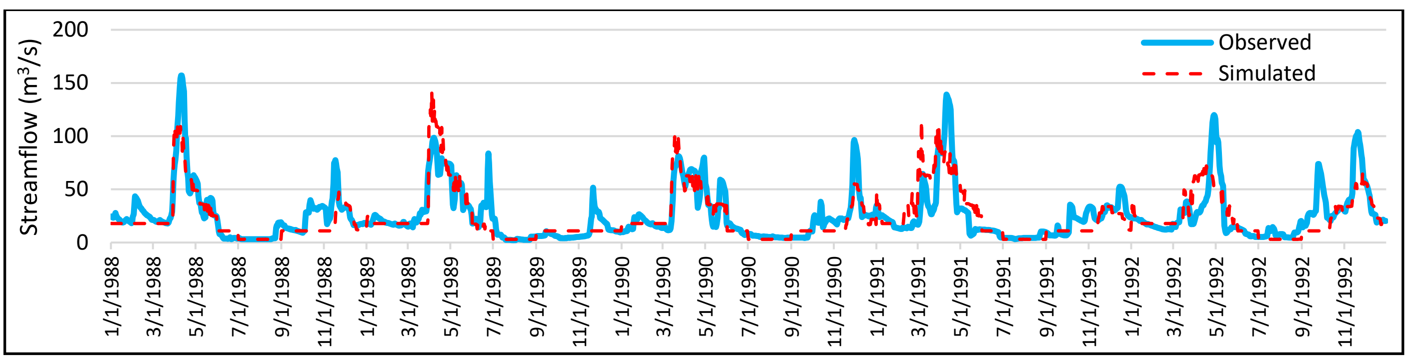

Figure 19 *Basin 3 Observed and Modelled Streamflow During Validation Period*

3.2.2.4 Basin 5 – Graphical Results

Basin 5 is located at the downstream, southwestern end of the watershed and receives inflow from basins 2, 3, and 4. The WSC gauge used for calibration is 02EB006, which is on the Muskoka River downstream of Lake Muskoka. The basin 5 outlet is controlled by the Bala Dams. Downstream of Bala dams the flow splits into the Musquash River and Moon River before continuing to Georgian Bay. **Figure 20** and **Figure 21** show the calibrated and validated model output, respectively.

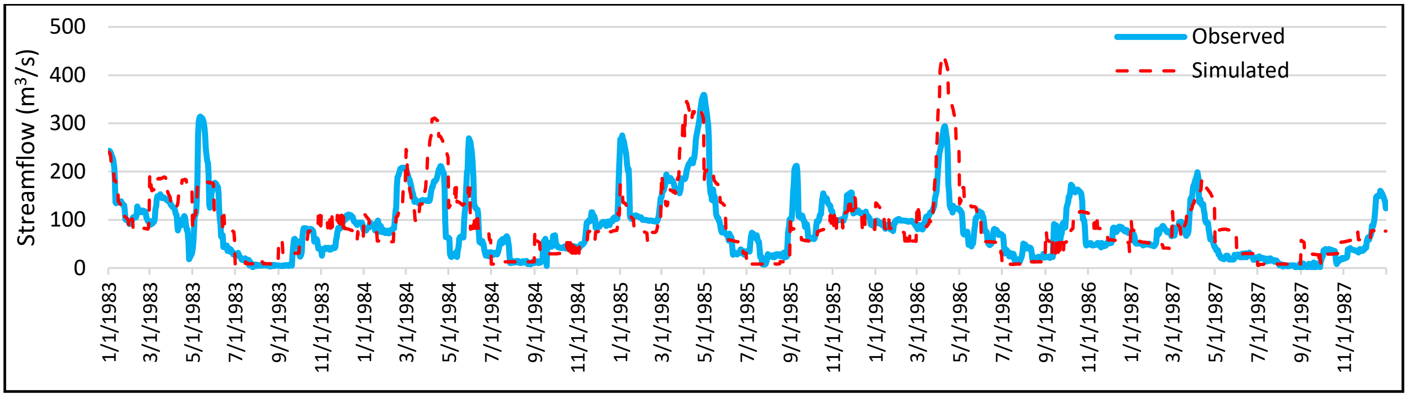

Figure 20 Basin 5 Observed and Modelled Streamflow During Calibration Period

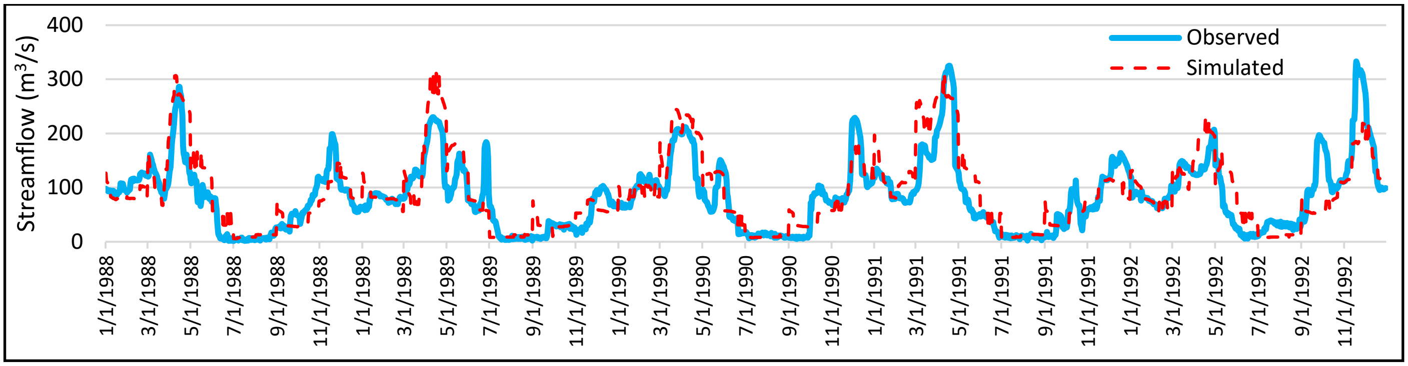

Figure 21 Basin 5 Observed and Modelled Streamflow During Validation Period

3.2.2.5 Statistical Results

The targets for re-calibration and validation are summarized in **Table 14**. The results of the statistical analysis used to measure the performance of the calibrated and validated models are summarized in **Table 15** and **Table 16**, respectively. The tables include two results for each metric and basin: the first result was calculated over the entire calibration (or validation) period, and the second was calculated from June to February of the following year and represents the low (non-flood) flow condition.

Table 14 Calibration and Validation Goodness-of-Fit Targets

Metric	Very good	Good	Satisfactory
PBIAS	≤ ±10%	≤ ±15%	≤ ±25%
Daily NSE	≥ 0.75	≥ 0.6	≥ 0.36
Monthly NSE	≥ 0.75	≥ 0.65	≥ 0.5
R2	≥ 0.75	≥ 0.6	≥ 0.5
References: Moriasi et al. 2007, Mendoza et al. 2021			

Table 15 Calibration Goodness-of-Fit Results for Basins 1-5 Streamflow, 1983-1987

Calibration								
Statistic	Basin 1		Basin 2		Basin 3		Basin 5	
	Full	Low	Full	Low	Full	Low	Full	Low
PBIAS	11.48	30.39	-13.41	2.26	11.84	29.47	-4.24	14.03
Daily NSE	0.39	0.04	0.18	0.40	0.44	0.13	0.42	0.55
Monthly NSE	0.66	0.45	0.22	0.69	0.70	0.59	0.51	0.81
Monthly R2	0.73	0.61	0.58	0.72	0.81	0.73	0.72	0.84

Table 16 Validation Goodness-of-Fit Results for Basins 1-5 Streamflow, 1988-1992

Validation								
Statistic	Basin 1		Basin 2		Basin 3		Basin 5	
	Full	Low	Full	Low	Full	Low	Full	Low
PBIAS	5.27	19.27	-13.20	3.59	8.46	21.71	-6.15	8.64
Daily NSE	0.31	0.33	0.23	0.35	0.60	0.43	0.63	0.68
Monthly NSE	0.64	0.67	0.27	0.62	0.77	0.71	0.73	0.86
Monthly R2	0.68	0.71	0.58	0.63	0.80	0.78	0.80	0.87

3.2.2.6 Summary of Results

The graphical results show a good fit of both high and low modelled to observed flow rates for both calibration and validation periods.

The basin 1 model calibration achieves all targets for the full calibration record, while the calibration results for the non-flood record miss the targets for PBIAS, daily NSE, and monthly NSE by a marginal amount. The validation results for both the full and non-flood records meet all targets except for the daily NSE.

The basin 2 model calibration results achieve all targets for non-flood conditions. Streamflow recorded at the basin 2 outlet is heavily controlled by the operation of the Baysville Dam on Lake of Bays. The reservoir operations were coded in the model based on one set of rules applied in a typical year; however, the actual operations vary from year-to-year based on the flow conditions in the river system. As a result of this simplification, and the influence of the reservoirs on the flow regime, the daily NSE is a difficult target to optimize and PBIAS, which compares the modelled to observed flow volumes, is the most important metric to achieve. PBIAS is good or very good for both full and non-flood conditions.

The basin 3 model calibration and validation results achieved all targets except for PBIAS and daily NSE for non-flood conditions and the calibration period. The hydrographs plotted on **Figure 18** show the low flows matched well, but that small peaks were missed, particularly in the 1985 non-flood season.

The basin 5 calibration and validation results were overall satisfactory to very good, with all targets being met for flood and non-flood conditions and calibration and validation periods.

Based on a review of both the graphical and statistical results, the model appears to underpredict summer peak flows in basin 1 and 3, which leads to some of the calibration metrics not meeting their targets. Summer peak flows are not critical to the peak flow or ecological flow assessments. Overall, the peak flow period is still acceptable and the low flow regime is improved from the Phase I study.

3.3 Ecological Flow Analysis Methodology

The ecological flow analysis was completed for the climate change scenarios S02 to S05 and S26 to S31, population growth scenarios S06 to S10, extreme events scenario S12 (forest fire of 500 km^2 applied in the upper watershed), land use scenarios S13 to S24, and reservoir storage scenarios S37 to S40. The extreme events scenarios related to high volumes of precipitation and snowmelt, including the rain-on-snow and branch impact to flooding scenarios (S41) were excluded from the ecological flow assessment, because they were used to assess flood potential in the watershed.

As described in Section 1.2, the Muskoka River includes 65 water control structures (dams) that control water levels in the lakes and rivers. Water level and flow fluctuations as well as drawdown are noted areas of concern in the Muskoka River Water Management Plan (MNRF, 2019) due to their effects on fish and wildlife. To address these concerns, target flow rates are applied to various control structures in the watershed. This means that fluctuations in flows upstream can be attenuated downstream through the many dams, which helps to maintain consistent flow rates even in low-flow conditions.

3.4 Ecological Indicators

The Ministry of Natural Resources and Forestry's (MNRF) Aquatic Ecosystem Assessment for Rivers (AEAR) was used to evaluate the baseline and potential alterations for two ecological flows: subsistence flow and channel forming flows (Metcalfe et. al, 2013). The AEAR is a science-based framework designed to provide technical information on a standardized approach for assessing baseline riverine ecosystems and identify potential changes from alteration of physical and biological processes. The framework was created for any in-stream development, climate change or factor that may alter water levels and flow within a river system. Subsistence flow and channel forming flows are both indicators of the "lower" hydrological regimes of a river as compared to peak and riparian flows (**Figure 10**), and they are directly tied to aquatic ecosystem function and biotic community. The AEAR provides quantitative assessment criteria to evaluate the degree of expected alteration for each assessment criteria and degree of alteration. The degree of alteration of each assessment criteria are ranked as low, medium, and high alteration (Metcalfe et. al, 2013).

3.4.1 Subsistence Flow

Subsistence flow (Q95) was selected as an indicator to evaluate potential impacts to the Muskoka River watershed fish habitat during extreme low flow conditions. It is the flow duration exceedance percentile, interpreted as the flow discharge which can be expected to be exceeded within a river 95% of the time. The Q95 subsistence flows are infrequently occurring, extreme low magnitude baseflows. These flows account for the water in a stream during prolonged dry weather/drought conditions. These flows maintain water tables for riparian vegetation, provide river connectivity, and habitat conditions that maintain natural diversity and ecosystems (Metcalfe, et al., 2013). In addition, they prevent direct mortality of aquatic species, ensuring the survival of populations capable of recolonization once normal flows return (Metcalfe et. al, 2013).

Subsistence flows maintain important ecological functions vital for the survival of fish and aquatic species and maintenance of fish habitat during natural extreme low flow conditions which may already be stressful to aquatic life. Low flows typically magnify the effects of naturally occurring stressors such as: water temperature, water pollution, winds, bank storage, spring seepage, available habitat and its quality and ultimately aquatic life. As such, assessments of flow alteration under low flow scenarios can be used to evaluate worst case impacts to fish and fish habitat.

The degree of alteration for subsistence flows includes the baseflow values associated with the 95 and 99 percent exceedance using a 30-year period-of-record from the reference condition streamflow time series (Metcalfe et. al, 2013).

The degree of alteration was evaluated as follows:

- **Low alteration:** A subsistence flow (m^3/s) indicator > the 95 percent exceedance flow of the flow duration curve for the period-of-record from the reference condition streamflow time series.
- **Medium alteration:** A subsistence flow (m^3/s) indicator > 99 percent exceedance of the flow duration curve for the period-of-record from the reference condition streamflow time series.
- **High alteration:** A subsistence flow (m^3/s) indicator < 99 percent exceedance of the period-of-record flow duration curve from the reference condition streamflow time series.

3.4.2 Channel Forming Flow

Channel forming flow was selected as an indicator to evaluate potential impacts to the Muskoka River watershed's sustained fish and aquatic habitat. Channel forming flows are measured using: magnitude (m^3/s), duration (days) and timing (month) of flows that occur every 1.5 years. Channel forming flows are flows that surpass the threshold of sediment erosion and movement and they typically occur at bankfull where water just begins to overflow onto the floodplain. They are important to fish habitat because they produce and maintain diverse natural channel structures such as bars, riffle-pool sequences, a diversity of width and depths, fish spawning and migration habitat and overall aquatic ecosystem function (Metcalfe et. al, 2013).

The degree of alteration for the channel forming flows indicator includes the streamflow magnitude (m^3/s) associated with a recurrence interval of 1.5 years (bankfull flow), duration indicators calculated as the median number of days that exceed the baseline bankfull flow in the simulated record (days) compared to the13^{th}, 38^{th}, 62^{nd}, and 87^{th} percentiles for number of days that exceed the baseline bankfull flow rate in the reference condition, and the distance from the modal month (measured in months) for all events equal to or greater than the baseline bankfull flow rate (Metcalfe et. al, 2013).

The degree of alteration was evaluated as follows:

- **Low alteration:** Magnitude indicators equal to or greater than the baseline bankfull flow magnitude, duration indicators that lie between the baseline 38^{th} and the 62^{nd} percentiles, and timing indicators within the same month of the reference condition.
- **Medium alteration:** Magnitude indicators within 80% of the baseline bankfull flow magnitude, duration indicators that lie between the baseline 13^{th} and 38^{th} or 62^{nd} and 87^{th} percentiles, and timing indicators within one month of the reference condition.
- **High alteration:** Magnitude less than 80% of the baseline bankfull flow magnitude, duration indicators that are less than the baseline 13^{th} or greater than the 87^{th} percentile, and timing indicators greater than two months of the reference condition.

3.5 Ecological Flow Analysis Results

The ecological flow results are summarized below by basin and are also provided in **Appendix B**. A predicted result of medium and/or high alteration were classified as *significant* and may have the potential to affect the natural flow regime, fish habitat and aquatic ecosystem function. A predicted low degree of alteration was classified as *not significant* and is unlikely to affect the natural flow regime, fish habitat and aquatic ecosystem function. The AEAR assessment framework classifies a low degree of alteration for subsistence flow and channel forming flow as no change from the baseline condition, while allowing for natural variability within each ecological flow indicator.

3.5.1 Basin 1

Subsistence Flows

Most of the scenarios in basin 1 were predicted to have a low degree of alteration for subsistence flow with 91% of scenarios classified as low within the climate change, population growth, land use and physical change (reservoir storage) scenarios. A medium degree of alteration was predicted in 9% of the results for the climate change scenarios (SL03, SL10, SL30) (**Appendix B**).

Channel Forming Flows

Overall, all channel forming flow metrics (magnitude, duration, timing) were predicted to result in a low degree of alteration in 74% of modelled scenarios. Most of these low alterations were observed in the population growth, land use change and physical change scenarios. A medium degree of alteration was predicted in 21% of the results for the land use and climate change scenarios and a high degree of alteration was predicted in 5% of the results for the climate change scenarios (**Appendix B**).

However, in four climate change scenarios (SL03, SL04, SL10 and SL31) medium to high predicted alterations for all three channel forming flow metrics (magnitude, duration, timing) were calculated, resulting in a higher risk of potential negative impacts to the natural flow regime and associated fish habitat. These climate change scenarios are associated with a drier projected climate compared to the reference condition.

The magnitude degree of alteration was predicted to be low, with five medium and three high occurrences observed in the climate change and population growth scenarios. For duration, the predicted alteration was also generally low, with ten medium and one high occurrence which were predicted within the climate change scenarios. In general, the median number of days in which the baseline bankfull flow is exceeded increases in wet climate change conditions and decreases in dry climate change conditions. For timing, the predicted alteration was generally low in most scenarios, except for six climate change scenarios predicted to have a medium degree of alteration. One high occurrence was observed in a climate change scenario, meaning the month in which the bankfull flow is exceeded most frequently is at least two months away (earlier) from the baseline condition (**Appendix B**).

3.5.2 Basin 2

Subsistence Flows

All subsistence flow calculations were predicted to have a low degree of alteration across all scenario types: climate change, population growth, land use and physical change modeled scenarios (**Appendix B**). No moderate or high alterations were predicted for subsistence flows in basin 2.

Channel Forming Flows

In general, all channel forming flow metrics (magnitude, duration, timing) were predicted to have a low degree of alteration in 72% of the modelled scenarios. The majority of these predictions were observed in the population growth, land use and physical change scenarios. A medium degree of alteration was predicted in 10% of the results for the land use and climate change scenarios. A high degree of alteration was predicted in 18% of the results for the climate change scenarios (**Appendix B**).

However, in three climate change scenarios (SL03, SL10 and SL31) medium to high alterations were predicted for all three channel forming flow metrics (magnitude, duration, timing), resulting in a higher risk of potential negative impacts to the natural flow regime and associated fish habitat.

The magnitude degree of alterations were predicted to be low, with two medium and two high occurrences observed in the climate change scenarios. For duration, the predicted alterations were mostly low; however, six medium and seven high occurrences were observed in the climate change and land use scenarios. For timing, the majority of predicted alterations were also low, with two medium and eight high occurrences within the climate change scenarios (**Appendix B**).

3.5.3 Basin 3

Subsistence Flows

Similar to Basin 2, all subsistence flow calculations were predicted to have a low degree of alteration across all scenario types: climate change, population growth, land use and physical change. No moderate or high alterations were predicted for subsistence flows in basin 3 (**Appendix B**).

Channel Forming Flows

In general, all channel forming flow metrics (magnitude, duration, timing) were predicted to have a low degree of alteration in 64% of the modelled scenarios. These occurrences were observed in the land use and population growth modeled scenarios. A medium degree of alteration was predicted in 24% of the results for the climate change scenarios. A high degree of alteration was predicted in 9% of the results for the climate change scenarios.

However, in four climate change scenarios (SL03, SL10, SL 30 and SL31) a medium to high alteration was predicted for all three channel forming flow metrics (magnitude, duration, timing), resulting in a higher risk of potential negative effects to the natural flow regime and associated fish habitat.

The magnitude of predicted alterations in the channel forming flows were in general low, with five medium and four high occurrences within the climate change and land use scenarios. For duration, the majority of predicted alterations were low with 11 medium and one high occurrence within the climate change and land use scenarios. For timing, the predicted alterations were overall low, with the exception of seven medium and four high occurrences in the climate change scenarios (**Appendix B**).

3.5.4 Basin 4

Subsistence Flows

Most of the scenarios in basin 4 were predicted to have a low degree of alteration to subsistence flow with 84% of occurrences observed in the climate change, population growth, land use and physical change modelled scenarios. A medium degree of alteration was predicted in 6% of the results for the climate change scenarios (SL04 and SL30) and 9% of the results were predicted to have a high degree of alteration in the climate change scenarios (S03, SL10 and SL31) (**Appendix B**).

Channel Forming Flows

In general, all channel forming flow metrics (magnitude, duration, timing) were predicted to have a low degree of alteration, 75% of the modelled results were low in the population growth, land use and physical change scenarios. A medium degree of alteration was predicted in 16% of the results for the climate change scenarios and a high degree of alteration was predicted in 9% of the results in the climate change scenarios (**Appendix B**).

However, in three climate change scenarios (SL03, SL10, and SL31) medium to high alterations were predicted for all three channel forming flow metrics (magnitude, duration, timing), resulting in a higher risk of potential negative effects to the natural flow regime and associated fish habitat.

The magnitude of predicted alterations in the channel forming flows were in generally low, with four medium occurrences observed in the climate change scenarios. For duration, the predicted alterations were primarily low. However, four medium and seven high occurrences were observed in the climate change scenarios. For timing, the predicted alterations were overall low, with seven medium and two high occurrences within the climate change scenarios (**Appendix B**).

3.5.5 Basin 5

Subsistence Flows

Most of the scenarios in basin 5 were predicted to have a low degree of alteration to subsistence flow with 88% of low occurrences observed within the climate change, population growth, land use and physical change scenarios. A medium degree of alteration was predicted in 13% of the results for the climate change scenarios (SL03, SL10, SL30, SL31) (**Appendix B**).

Channel Forming Flows

Overall, all channel forming flow metrics (magnitude, duration, timing) were predicted to result in a low degree of alteration in 74% of modelled scenarios. Most of these low alterations were observed in the population growth and land use scenarios. A medium degree of alteration was predicted in 17% of the results for the land use and climate change scenarios and a high degree of alteration was predicted in 9% of the results in the climate change scenarios (**Appendix B**).

However, in three climate change scenarios (SL03, SL10, and SL31) medium to high alterations were predicted for all three channel forming flow metrics (magnitude, duration, timing), resulting in a higher risk of potential negative effects to the natural flow regime and associated fish habitat.

The magnitude degree of alteration was predicted to be low, with five medium occurrences observed in the climate change scenarios. For duration, the predicted alterations were mostly low, however, three medium and seven high occurrences were observed in the climate change scenarios. For timing, the predicted alterations were primarily low, with eight medium and two high occurrences within the climate change scenario (**Appendix B**).

3.5.6 Summary of Results

Subsistence flows were mostly unaffected by climate change, population growth, land use change, and physical change scenarios, as most scenarios were predicted to have a low degree of alteration, with the exception of a few medium to high alterations predicted for the dry climate change scenarios in basins 1, 4, and 5. For channel forming, the results also mostly predicted low alterations for population growth, land use change, and physical change scenarios. Medium to high alterations were predicted for several climate change scenarios. For these scenarios, timing of the modal month in which the baseline bankfull flow rate occurs is generally shifted to earlier in the year. Overall, these findings are consistent with the peak flow analysis: population growth, land use change, and physical change scenarios have minor to no impact on the watershed; however, climate change does show an impact.

4. Conclusions

4.1 Phase II Peak Flow Scenarios

Following the results and next steps of Phase I, additional analysis was performed to better understand the impacts of various changes on watershed flood risk. The existing conditions model was updated using new land cover data from the Natural Capital Inventory (NCI) project and new LiDAR from the District’s Floodplain Mapping Study. An evaluation of the existing conditions results indicated that the updated model had similar or improved calibration targets compared to the Phase I existing conditions model, and that it is considered a valid representation of existing conditions for the purpose of this analysis.

An additional eighteen scenarios were run encompassing climate change, rain-on-snow, relative contributions of flow, flood attenuating wetlands, and structural changes (reservoirs, dams, etc.). The climate change scenarios expanded upon Phase I by adding mid-range (2031 – 2070) and medium greenhouse gas (GHG) emissions (SSP2-4.5) climate projections. The additional climate scenarios project increases to daily minimum and maximum temperatures, with larger increases occurring for minimum daily temperatures in the winter months. Precipitation is projected to increase in every month with minimal changes seen in the summer months, and large increases seen in the winter months. The impact of these projections to the hydrologic cycle and flows in the watershed reinforce the Phase I results under the long-range (2071-2100) high GHG emissions (RCP 8.5) scenarios. All scenarios show a shift in timing of the freshet by one to two months earlier, and higher peak and average flows are observed in the wet and wet and cold scenarios at Bala. A decrease in peak flows is observed in the wet scenarios (with median temperature change) at the upstream portions of the watershed due to a reduction in snowpack. The model results for both dry scenarios indicate that even with an overall reduction in annual average and peak flows, both show monthly increases in the winter and early spring. This is due to increased winter precipitation and temperature and the earlier shift of freshet. Overall, model results suggest that climate change will have a significant impact on the flow regime in the Muskoka River Watershed, in both mid-range and long-range time horizons, and in both medium and high GHG emissions scenarios.

Rain-on-snow events were modelled at various locations in the watershed. Model results indicate that the areas most sensitive to these events are those which do not have large lakes or reservoirs upstream to attenuate the flow. For example, the Big East River is very sensitive to local rain-on-snow events, while the North Branch Muskoka River at Port Sydney does not show the same fast response time due to the attenuating effects of the Huntsville Lakes upstream. The impact of rain-on-snow events occurs for a longer duration with progression downstream in the watershed. At Bala, peak flows are elevated nearly one month after a simulated rain-on-snow event occurring in the upper reaches of the South Branch Muskoka River near Dwight. The timing of the rain-on-snow event is also critical – if the event occurs at the beginning of freshet, there may be more storage available for attenuation in the lakes, which can mitigate the flood potential downstream. However, multiple events in a row (for areas downstream of a lake), or an event which coincides with peak freshet flows (particularly in the Big East River) is likely to increase the flood risk in the watershed.

Several reservoirs located on the main branches in the watershed were evaluated for their potential to reduce flood risk. It was found that the reservoirs did not have enough storage capacity to reduce peak flows downstream during the design flood events (2013 and 2019 floods). This can be attributed to the large contributing drainage areas and the large flood volumes attenuated by the major lakes located upstream. To further investigate the impacts of adding large reservoirs, additional model scenarios were run by adding two reservoirs online to smaller reaches of the river system. The results showed that the additional reservoirs effectively reduce peak flows in the area local to the reservoir (immediately downstream), but they did not have a significant impact on reducing flood risk downstream in the main system. To have a significant impact on reducing flood risk downstream on the main river system, a wetland or reservoir would have to be very large. Alternatively, construction of many smaller reservoirs would be required on the tributaries and upper reaches of the system to attenuate peak flows before reaching the main channels. The reservoir storage scenarios were selected and modelled for illustrative purposes. GHD is not advocating for the construction of a reservoir online to the Muskoka River system. There are many factors, including impacts to the natural environment, cultural environment, and built infrastructure that must be considered with the potential benefits of flood risk reduction.

The relative contribution of flows in the North and South Branches to downstream peak flows and flood risk was assessed. Model results indicate that peak flows in the Muskoka River are more sensitive to flow increases in the North Branch Muskoka River as compared to the South Branch Muskoka River. This may be due to Lake of Bays which has a large storage volume and associated attenuating effect on peak flows through the South Branch.

4.2 Ecological Flow Analysis

In basin 1, most modelled scenarios were predicted to have low alterations to subsistence flow with less than five medium predicted alteration occurrences and no high occurrences. For channel forming flows, basin 1 had a higher percentage of medium predicted alterations of 21% and the lowest percentage of high predicted alterations of 5% compared to all other basins. Four climate change scenarios (SL03, SL04, SL10 and SL31) had medium to high predicted alterations for all three channel forming flow metrics (magnitude, duration, timing), resulting in a higher risk of potential negative impacts to the natural flow regime and associated fish habitat.

In basin 2, no alterations were anticipated for subsistence flows under any modelled scenarios. For channel forming flows, basin 2 had the highest percentage of high predicted alterations of 18% compared to all other basins. Three climate change scenarios (SL03, SL10 and SL31) were predicted to have medium to high alterations for all three channel forming flow metrics, resulting in a higher risk of potential negative impacts to the natural flow regime and associated fish habitat.

In basin 3, no alterations were anticipated for subsistence flows under any modelled scenarios. For channel forming flows, basin 3 had the highest percent of moderate and high predicted alterations compared to all other basins. In basin 3, four climate change scenarios (SL03, SL10, SL 30 and SL31) had medium to high alterations predicted for all three channel forming flow metrics, resulting in a higher risk of potential negative impacts to the natural flow regime and associated fish habitat.

In basin 4, most modelled scenarios were predicted to have low alterations to subsistence flow. Basin 4 was the only basin with high predicted alterations (9%) observed in the climate change scenarios. For channel forming flows, basin 4 had the highest percentage of low predicted alterations of 75% compared to all the other basins. Three climate change scenarios (SL03, SL10, and SL31) had medium to high alterations for all three channel forming flow metrics, resulting in a higher risk of potential negative effects to the natural flow regime and associated fish habitat.

In basin 5, most modelled scenarios were predicted to have low alterations to subsistence flow. For channel forming flows, most modelled scenarios were predicted to have low alterations to the magnitude, duration, and timing indicators. Similar to basin 4, basin 5 had the second highest percentage of low predicted alterations of 74% compared to all other basins. Three climate change scenarios (SL03, SL10, and SL31) had medium to high alterations for all three channel forming flow metrics, resulting in a higher risk of potential negative effects to the natural flow regime and associated fish habitat.

The most significant predicted alterations were observed in channel forming flows in the climate change scenarios. Specifically, climate change scenarios SL03, SL10, and SL31 were predicted to have medium to high alterations for all three channel forming flow metrics (magnitude, duration, timing) across all basins. These scenarios show the highest risk of potential negative effects to the natural flow regime and associated fish habitat of all modelled scenarios, because they reduce the magnitude and frequency of the baseline bankfull flow, which are important because they produce and maintain diverse natural channel structures such as bars, riffle-pool sequences, a diversity of width and depths, fish spawning and migration habitat and overall aquatic ecosystem function. In addition, the month in which bankfull flow most frequency occurs is shifted to earlier in the year, which impacts important fish life histories.

5. Next Steps

Due to the project results showing a significant impact on the flow regime in the watershed due to climate change, climate change mitigation planning is recommended. Watershed planning to address projected changes in the flow regime is recommended.

The subsistence flow and channel forming flow analysis results provide an indicator of the potential degree of alteration to the existing flow regime and ultimately the aquatic ecosystem form and function. To understand potential impacts to fish and fish habitat from a predicted hydrological flow alteration, additional studies that integrate baseline fish and fish habitat data are required. Baseline fisheries data is required to assess how proposed changes to the hydraulic regime (timing, frequency, and duration) may affect fish species key life history processes, fish community compositions and populations on a watershed scale. In addition, the scope of future hydrological models/analysis should be developed based on indicator fish species most sensitive life history process such as spawning, rearing and migration and include both timing and location of these processes.

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Appendices

Appendix A

Peak Flow Model Results

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Peak Flows

Table 1 Baseline Scenario – Average Monthly Flow at Select Channels

Channel	Branch	WSC Station ID and Name	Average Flow (m3/s) from 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	3.0	3.1	18.9	48.0	16.8	5.0	1.5	1.5	2.4	6.4	10.7	5.8	10.2
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	10.5	7.1	27.9	102.3	48.0	15.9	5.2	4.1	6.1	11.3	22.7	18.3	23.3
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	19.2	14.7	25.8	83.3	68.0	30.1	11.0	5.6	7.0	15.3	26.2	27.8	27.8
cha0647	Central North	02EB020 - Indian River (Port Carling)	11.9	9.7	16.2	46.4	32.4	14.3	6.9	4.2	4.4	8.5	15.5	15.8	15.5
cha0905	Central	02EB006 - Muskoka River below Bala	60.2	44.5	83.1	281.3	209.1	88.8	30.5	16.8	21.3	44.2	83.8	88.4	87.6

Table 2 Baseline Scenario – Peak Monthly Flow at Select Channels

Channel	Branch	WSC Station ID and Name	Peak (Max Daily) Flows (m3/s) from 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	39.9	49.3	148.0	201.0	108.0	21.3	11.4	12.0	19.9	32.1	73.6	57.7	201.0
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	44.1	61.7	171.0	291.0	191.0	57.3	20.2	19.6	34.4	55.8	72.6	74.0	291.0
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	66.6	44.0	88.8	160.0	167.0	78.8	39.1	31.8	31.1	46.7	76.5	76.1	167.0
cha0647	Central North	02EB020 - Indian River (Port Carling)	33.7	29.5	62.3	101.0	89.9	34.1	15.4	12.2	20.8	27.3	47.7	48.2	101.0
cha0905	Central	02EB006 - Muskoka River below Bala	182.0	167.0	306.0	514.0	516.0	225.0	84.8	65.1	83.1	148.0	251.0	251.0	516.0

Table 3 S26 – Average Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Average Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	327%	428%	96%	-37%	-23%	-32%	13%	32%	114%	101%	84%	205%	40%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	235%	422%	168%	-22%	-24%	-25%	5%	6%	53%	110%	77%	150%	45%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	167%	207%	157%	6%	-20%	-19%	-11%	29%	61%	82%	79%	111%	47%
cha0647	Central North	02EB020 - Indian River (Port Carling)	180%	226%	148%	-1%	-9%	5%	3%	0%	29%	77%	81%	119%	56%
cha0905	Central	02EB006 - Muskoka River below Bala	180%	244%	170%	0%	-17%	-14%	-4%	16%	50%	89%	78%	115%	50%

Table 4 S26 – Peak Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Peak (Max Daily) Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	111%	160%	30%	-25%	-29%	0%	0%	54%	166%	122%	45%	39%	-4%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	145%	221%	58%	-6%	-50%	11%	22%	38%	115%	59%	53%	47%	-6%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	68%	157%	66%	-10%	-22%	-14%	-24%	27%	62%	84%	58%	60%	-12%
cha0647	Central North	02EB020 - Indian River (Port Carling)	112%	148%	96%	22%	-36%	34%	24%	19%	17%	66%	72%	54%	22%
cha0905	Central	02EB006 - Muskoka River below Bala	87%	150%	81%	10%	-30%	10%	0%	30%	59%	66%	45%	47%	9%

Table 5 S27 – Average Monthly Flow Precent Change from Baseline

Channel	Branch	WSC Station ID and Name	Average Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	214%	243%	95%	-10%	-10%	-16%	21%	19%	87%	92%	82%	138%	41%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	157%	245%	143%	4%	-8%	-6%	17%	18%	50%	98%	76%	113%	45%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	125%	142%	124%	25%	-1%	-1%	9%	40%	58%	69%	75%	94%	48%
cha0647	Central North	02EB020 - Indian River (Port Carling)	146%	161%	126%	26%	12%	28%	26%	17%	32%	70%	79%	105%	60%
cha0905	Central	02EB006 - Muskoka River below Bala	136%	165%	136%	22%	2%	8%	19%	32%	49%	78%	76%	98%	52%

Table 6 S27 – Peak Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Peak (Max Daily) Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	103%	107%	30%	11%	-22%	20%	18%	59%	143%	134%	52%	41%	11%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	145%	154%	63%	10%	-34%	25%	43%	53%	97%	48%	65%	46%	10%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	68%	92%	53%	3%	-1%	-3%	-5%	30%	60%	61%	53%	55%	-1%
cha0647	Central North	02EB020 - Indian River (Port Carling)	98%	87%	72%	31%	0%	40%	34%	13%	39%	54%	63%	48%	31%
cha0905	Central	02EB006 - Muskoka River below Bala	79%	90%	70%	22%	-4%	19%	24%	34%	61%	53%	42%	43%	21%

Table 7 S28 – Average Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Average Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	461%	455%	97%	-45%	-31%	-47%	18%	42%	152%	113%	105%	231%	43%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	319%	482%	176%	-30%	-30%	-36%	0%	13%	75%	139%	99%	178%	51%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	204%	251%	172%	-1%	-28%	-30%	-19%	35%	80%	94%	91%	128%	51%
cha0647	Central North	02EB020 - Indian River (Port Carling)	218%	267%	158%	-10%	-18%	-8%	-3%	1%	43%	97%	96%	134%	60%
cha0905	Central	02EB006 - Muskoka River below Bala	222%	293%	182%	-7%	-24%	-25%	-14%	19%	70%	110%	93%	134%	55%

Table 8 S28 – Peak Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Peak (Max Daily) Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	158%	154%	34%	-34%	-36%	-11%	0%	63%	220%	140%	52%	43%	-1%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	217%	234%	46%	-18%	-50%	12%	-2%	40%	141%	85%	68%	57%	-14%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	77%	159%	61%	-9%	-38%	-24%	-21%	26%	89%	100%	75%	77%	-13%
cha0647	Central North	02EB020 - Indian River (Port Carling)	147%	193%	78%	7%	-42%	34%	16%	17%	31%	73%	89%	63%	10%
cha0905	Central	02EB006 - Muskoka River below Bala	113%	160%	74%	4%	-42%	4%	-20%	30%	83%	78%	63%	62%	3%

Table 9 S29 – Average Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Average Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	343%	336%	101%	-25%	-20%	-25%	19%	25%	121%	107%	99%	192%	45%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	242%	368%	161%	-9%	-17%	-15%	14%	21%	60%	127%	95%	154%	52%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	171%	198%	146%	17%	-13%	-13%	-2%	39%	75%	87%	90%	118%	53%
cha0647	Central North	02EB020 - Indian River (Port Carling)	184%	216%	143%	15%	2%	20%	19%	10%	41%	92%	97%	124%	66%
cha0905	Central	02EB006 - Muskoka River below Bala	183%	233%	158%	13%	-8%	-3%	8%	30%	62%	101%	92%	122%	58%

Table 10 S29 – Peak Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Peak (Max Daily) Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	142%	131%	30%	-7%	-28%	2%	5%	64%	192%	128%	62%	51%	-4%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	172%	176%	56%	2%	-45%	21%	30%	52%	133%	79%	74%	58%	2%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	74%	132%	67%	-1%	-10%	-10%	-18%	30%	82%	75%	67%	68%	-5%
cha0647	Central North	02EB020 - Indian River (Port Carling)	120%	133%	88%	30%	-18%	40%	32%	16%	34%	63%	81%	59%	30%
cha0905	Central	02EB006 - Muskoka River below Bala	95%	132%	76%	16%	-17%	13%	18%	35%	76%	72%	60%	59%	15%

Table 11 S30 – Average Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Average Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	203%	302%	52%	-53%	-46%	-64%	4%	-16%	-38%	-12%	12%	105%	-5%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	123%	263%	99%	-43%	-49%	-56%	-29%	-47%	-32%	-29%	-8%	55%	-6%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	72%	106%	91%	-24%	-45%	-51%	-61%	-33%	-25%	-2%	-6%	25%	-5%
cha0647	Central North	02EB020 - Indian River (Port Carling)	82%	135%	90%	-28%	-36%	-35%	-40%	-36%	-29%	-14%	2%	32%	3%
cha0905	Central	02EB006 - Muskoka River below Bala	83%	138%	100%	-27%	-43%	-50%	-55%	-44%	-29%	-14%	-4%	30%	-3%

Table 12 S30 – Peak Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Peak (Max Daily) Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	73%	127%	15%	-40%	-64%	-19%	0%	-5%	-43%	-21%	-4%	0%	-15%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	89%	185%	23%	-30%	-69%	-17%	-21%	-19%	-37%	-30%	-6%	-2%	-27%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	20%	104%	27%	-32%	-50%	-39%	-62%	-53%	-35%	-8%	5%	8%	-32%
cha0647	Central North	02EB020 - Indian River (Port Carling)	50%	125%	38%	-16%	-57%	-3%	-32%	-42%	-44%	-8%	1%	-1%	-15%
cha0905	Central	02EB006 - Muskoka River below Bala	35%	111%	40%	-16%	-55%	-23%	-29%	-7%	-41%	-15%	-3%	-2%	-16%

Table 13 S31 – Average Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Average Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	101%	176%	36%	-64%	-56%	-42%	23%	28%	67%	215%	38%	48%	-3%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	74%	163%	85%	-47%	-54%	-55%	-23%	-29%	-16%	67%	23%	33%	-9%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	44%	57%	60%	-39%	-60%	-54%	-37%	-14%	15%	120%	89%	36%	-3%
cha0647	Central North	02EB020 - Indian River (Port Carling)	61%	99%	83%	-24%	-32%	-36%	-39%	-35%	-30%	-20%	-2%	24%	0%
cha0905	Central	02EB006 - Muskoka River below Bala	58%	89%	81%	-31%	-49%	-54%	-49%	-34%	-16%	32%	40%	32%	-4%

Table 14 S31 - Peak Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Peak (Max Daily) Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	36%	109%	11%	-45%	-57%	28%	0%	23%	124%	370%	-26%	-39%	-18%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	57%	150%	19%	-36%	-67%	-2%	-21%	-18%	11%	72%	11%	-18%	-30%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	-3%	83%	9%	-45%	-60%	-30%	-41%	-23%	23%	153%	56%	8%	-29%
cha0647	Central North	02EB020 - Indian River (Port Carling)	40%	93%	39%	-15%	-52%	-5%	-35%	-43%	-43%	-21%	1%	-9%	-14%
cha0905	Central	02EB006 - Muskoka River below Bala	15%	89%	34%	-20%	-58%	-21%	-47%	-7%	-13%	45%	6%	-2%	-21%

Table 15 S37 – Average Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Average Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	0%	0%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0647	Central North	02EB020 - Indian River (Port Carling)	-1%	-1%	0%	0%	-1%	0%	-1%	-4%	-2%	-1%	-1%	-1%	-1%
cha0905	Central	02EB006 - Muskoka River below Bala	0%	0%	0%	0%	0%	0%	0%	-1%	-1%	0%	0%	0%	0%

Table 16 S37 – Peak Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Peak (Max Daily) Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	0%	1%	1%	0%	-1%	0%	0%	0%	0%	0%	0%	0%	0%
cha0647	Central North	02EB020 - Indian River (Port Carling)	0%	0%	0%	0%	0%	-1%	-3%	-1%	-2%	-1%	0%	0%	0%
cha0905	Central	02EB006 - Muskoka River below Bala	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 17 S38 – Average Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Average Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	0.0%	-0.1%	-0.1%	-0.1%	-0.2%	0.0%	-0.1%	0.0%	-0.1%	-0.1%	-0.4%	-0.1%	-0.1%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
cha0647	Central North	02EB020 - Indian River (Port Carling)	-0.7%	-0.5%	-0.5%	-0.4%	-0.5%	-0.2%	-0.7%	-4.2%	-2.0%	-1.0%	-0.9%	-0.9%	-0.7%
cha0905	Central	02EB006 - Muskoka River below Bala	-0.1%	-0.3%	-0.3%	-0.2%	-0.3%	-0.3%	-0.3%	-1.5%	-0.5%	-0.6%	-0.5%	-0.5%	-0.3%

Table 18 S38 – Peak Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Peak (Max Daily) Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	0.0%	-0.1%	0.0%	0.0%	-0.1%	0.2%	0.0%	0.0%	-0.3%	0.1%	-0.1%	0.7%	0.0%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
cha0647	Central North	02EB020 - Indian River (Port Carling)	-0.3%	0.0%	-0.2%	-0.3%	-0.2%	-0.6%	-2.0%	-1.4%	-1.3%	-1.4%	-0.4%	-0.2%	-0.3%
cha0905	Central	02EB006 - Muskoka River below Bala	0.0%	0.0%	0.0%	0.0%	-0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.0%

Table 19 S39 – Average Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Average Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	0%	0%	0%	0%	0%	3%	10%	-1%	-7%	0%	0%	0%	0%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	-1%	0%	0%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0647	Central North	02EB020 - Indian River (Port Carling)	-1%	-1%	0%	0%	0%	0%	-1%	-4%	-2%	-1%	-1%	-1%	-1%
cha0905	Central	02EB006 - Muskoka River below Bala	0%	0%	0%	0%	0%	0%	0%	-1%	0%	-1%	-1%	0%	0%

Table 20 S39 – Peak Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Peak (Max Daily) Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	-1%	0%	-16%	-6%	-2%	0%	0%	-1%	0%	0%	-16%	-1%	-6%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	0%	0%	1%	0%	10%	0%	-1%	0%	0%	0%	0%	1%	0%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0647	Central North	02EB020 - Indian River (Port Carling)	0%	0%	0%	0%	0%	-1%	-2%	-1%	-1%	-1%	0%	0%	0%
cha0905	Central	02EB006 - Muskoka River below Bala	0%	0%	0%	0%	0%	-1%	0%	0%	0%	0%	0%	0%	0%

Table 21 S40 – Average Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Average Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0647	Central North	02EB020 - Indian River (Port Carling)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0905	Central	02EB006 - Muskoka River below Bala	-1%	0%	3%	0%	-2%	1%	4%	0%	-1%	1%	-1%	0%	0%

Table 22 S40 – Peak Monthly Flow Percent Change from Baseline

Channel	Branch	WSC Station ID and Name	Peak (Max Daily) Flow % Change from Baseline (S1) over 30-Year Record (1976-2005)												
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
cha0075	North	02EB013 - Big East River near Huntsville	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0647	Central North	02EB020 - Indian River (Port Carling)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
cha0905	Central	02EB006 - Muskoka River below Bala	4%	-9%	-10%	-1%	-5%	5%	-18%	5%	6%	2%	0%	0%	-1%

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Ecological Flow Model Results

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Subsistence Flows

Table 1 *Baseline Exceedance Flows*

Channel	Branch	WSC Station ID and Name	Exceedance Flow (m^3/s) from 30-Year Record (1976-2005)			
			Baseline Scenario - SL01		Baseline Scenario - SL36	
			95 Percent (Q95)	99 Percent (Q99)	95 Percent (Q95)	99 Percent (Q99)
cha0075	North	02EB013 - Big East River near Huntsville	0.1	0.0	0.1	0.0
cha0167	North	02EB004 - North Branch Muskoka River at Port Sydney	3.0	3.0	3.0	3.0
cha0363	South	02EB008 - South Branch Muskoka River at Baysville	5.0	5.0	4.9	4.9
cha0647	Central North	02EB020 - Indian River (Port Carling)	2.6	1.0	2.2	0.8
cha0905	Central	02EB006 - Muskoka River below Bala	8	6	8	6

Table 2 *Subsistence Flows Summary*

Scenario ID	Description	Baseline Scenario for Comparison	cha0075		cha0167		cha0363		cha0647		cha0905	
			Subsistence Flow (m^3/s) Indicator (Q95)	Evaluating alteration	Subsistence Flow (m^3/s) Indicator (Q95	Evaluating alteration	Subsistence Flow (m^3/s) Indicator (Q95	Evaluating alteration	Subsistence Flow (m^3/s) Indicator (Q95	Evaluating alteration	Subsistence Flow (m^3/s) Indicator (Q95	Evaluating alteration
LOW FLOW - Phase 1 baseline model adjusted for low-flow (SL01)												
SL01	Baseline	SL01	BASELINE									
SL02	Climate Change	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.9	LOW	8	LOW
SL02B	Climate Change	SL01	0.4	LOW	3.0	LOW	5.0	LOW	4.3	LOW	14	LOW
SL03	Climate Change	SL01	0.0	MEDIUM	3.0	LOW	5.0	LOW	0.3	HIGH	6	MEDIUM
SL04	Climate Change	SL01	0.1	LOW	3.0	LOW	5.0	LOW	1.6	MEDIUM	8	LOW
SL05	Climate Change	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL06	Population Growth	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL07	Population Growth	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL08	Population Growth	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL09	Population Growth	SL01	0.1	LOW	3.0	LOW	5.0	LOW	3.0	LOW	8	LOW
SL10	Population Growth	SL01	0.0	MEDIUM	3.0	LOW	5.0	LOW	0.4	HIGH	6	MEDIUM
SL11	SKIP	SL01	SKIP									
SL12	Extreme Event	SL01	0.3	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL13	Land Use	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL14	Land Use	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL15	Land Use	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL16	Land Use	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL17	Land Use	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL18	Land Use	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL19	Land Use	SL01	0.2	LOW	3.0	LOW	5.0	LOW	2.9	LOW	9	LOW
SL20	Land Use	SL01	0.2	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL21	Land Use	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL22	Land Use	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL23	Land Use	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.9	LOW	8	LOW
SL24	Land Use	SL01	0.1	LOW	3.0	LOW	5.0	LOW	2.6	LOW	8	LOW
SL25	SKIP	SL01	SKIP									
LOW FLOW - Phase 2 baseline model calibrated for low flow (SL36)												
SL26	Climate Change	SL36	0.2	LOW	3.0	LOW	4.9	LOW	3.1	LOW	8	LOW
SL27	Climate Change	SL36	0.2	LOW	3.0	LOW	4.9	LOW	3.5	LOW	9	LOW
SL28	Climate Change	SL36	0.2	LOW	3.0	LOW	4.9	LOW	2.8	LOW	8	LOW
SL29	Climate Change	SL36	0.2	LOW	3.0	LOW	4.9	LOW	3.4	LOW	8	LOW
SL30	Climate Change	SL36	0.0	MEDIUM	3.0	LOW	4.9	LOW	0.8	MEDIUM	6	MEDIUM
SL31	Climate Change	SL36	0.1	LOW	3.0	LOW	4.9	LOW	0.6	HIGH	6	MEDIUM
SL32	SKIP	SL36	SKIP									
SL33	SKIP	SL36	SKIP									
SL34	SKIP	SL36	SKIP									
SL35	SKIP	SL36	SKIP									
SL36	Baseline	SL36	BASELINE									
SL37	Physical Change	SL36	0.1	LOW	3.0	LOW	4.9	LOW	2.2	LOW	8	LOW
SL38	Physical Change	SL36	0.1	LOW	3.0	LOW	4.9	LOW	2.2	LOW	8	LOW
SL39	Physical Change	SL36	0.1	LOW	3.0	LOW	4.9	LOW	2.2	LOW	8	LOW
SL40	Physical Change	SL36	0.1	LOW	3.0	LOW	4.9	LOW	2.2	LOW	9	LOW

Channel Forming Flows

Table 3 Channel Forming Flow Analysis Summary for Big East River (cha0075)

	Channel Forming Flow Analysis over 30-year Record (1976-2005) for cha0075				
Scenario ID	Description	Baseline Scenario for Comparison	cha0075		
			Magnitude	Duration	Timing
LOW FLOW - Phase 1 baseline model adjusted for low-flow (SL01)					
SL01	Baseline	SL01	BASELINE		
SL02	Climate Change	SL01	MEDIUM	LOW	MEDIUM
SL02B	Climate Change	SL01	LOW	HIGH	MEDIUM
SL03	Climate Change	SL01	HIGH	MEDIUM	MEDIUM
SL04	Climate Change	SL01	HIGH	MEDIUM	MEDIUM
SL05	Climate Change	SL01	LOW	LOW	LOW
SL06	Population Growth	SL01	LOW	LOW	LOW
SL07	Population Growth	SL01	LOW	LOW	LOW
SL08	Population Growth	SL01	MEDIUM	LOW	LOW
SL09	Population Growth	SL01	MEDIUM	LOW	MEDIUM
SL10	Population Growth	SL01	HIGH	MEDIUM	MEDIUM
SL11	SKIP	SL01	SKIP		
SL12	Extreme Event	SL01	LOW	MEDIUM	LOW
SL13	Land Use	SL01	LOW	LOW	LOW
SL14	Land Use	SL01	LOW	LOW	LOW
SL15	Land Use	SL01	LOW	LOW	LOW
SL16	Land Use	SL01	LOW	LOW	LOW
SL17	Land Use	SL01	LOW	LOW	LOW
SL18	Land Use	SL01	LOW	LOW	LOW
SL19	Land Use	SL01	LOW	LOW	LOW
SL20	Land Use	SL01	LOW	LOW	LOW
SL21	Land Use	SL01	LOW	LOW	LOW
SL22	Land Use	SL01	LOW	LOW	LOW
SL23	Land Use	SL01	LOW	LOW	LOW
SL24	Land Use	SL01	LOW	LOW	LOW
SL25	SKIP	SL01	SKIP		
LOW FLOW - Phase 2 baseline model calibrated for low flow (SL36)					
SL26	Climate Change	SL36	LOW	MEDIUM	LOW
SL27	Climate Change	SL36	LOW	MEDIUM	LOW
SL28	Climate Change	SL36	LOW	MEDIUM	LOW
SL29	Climate Change	SL36	LOW	MEDIUM	LOW
SL30	Climate Change	SL36	MEDIUM	MEDIUM	LOW
SL31	Climate Change	SL36	MEDIUM	MEDIUM	HIGH
SL32	SKIP	SL36	SKIP		
SL33	SKIP	SL36	SKIP		
SL34	SKIP	SL36	SKIP		
SL35	SKIP	SL36	SKIP		
SL36	Baseline	SL36	BASELINE		
SL37	Physical Change	SL36	LOW	LOW	LOW
SL38	Physical Change	SL36	LOW	LOW	LOW
SL39	Physical Change	SL36	LOW	LOW	LOW
SL40	Physical Change	SL36	LOW	LOW	LOW

Table 4 Channel Forming Flow Analysis Summary for North Branch (cha0363)

Scenario ID	Description	Baseline Scenario for Comparison	Channel Forming Flow Analysis over 30-year Record (1976-2005) for cha0363		
			cha0363		
			Magnitude	Duration	Timing
LOW FLOW - Phase 1 baseline model adjusted for low-flow (SL01)					
SL01	Baseline	SL01	BASELINE		
SL02	Climate Change	SL01	LOW	HIGH	HIGH
SL02B	Climate Change	SL01	LOW	HIGH	LOW
SL03	Climate Change	SL01	HIGH	MEDIUM	HIGH
SL04	Climate Change	SL01	LOW	LOW	HIGH
SL05	Climate Change	SL01	MEDIUM	LOW	LOW
SL06	Population Growth	SL01	LOW	LOW	LOW
SL07	Population Growth	SL01	LOW	LOW	LOW
SL08	Population Growth	SL01	LOW	LOW	LOW
SL09	Population Growth	SL01	LOW	HIGH	HIGH
SL10	Population Growth	SL01	HIGH	MEDIUM	HIGH
SL11	SKIP	SL01	SKIP		
SL12	Extreme Event	SL01	LOW	LOW	LOW
SL13	Land Use	SL01	LOW	LOW	LOW
SL14	Land Use	SL01	LOW	LOW	LOW
SL15	Land Use	SL01	LOW	LOW	LOW
SL16	Land Use	SL01	LOW	LOW	LOW
SL17	Land Use	SL01	LOW	LOW	LOW
SL18	Land Use	SL01	LOW	LOW	LOW
SL19	Land Use	SL01	LOW	MEDIUM	LOW
SL20	Land Use	SL01	LOW	LOW	LOW
SL21	Land Use	SL01	LOW	MEDIUM	LOW
SL22	Land Use	SL01	LOW	LOW	LOW
SL23	Land Use	SL01	LOW	LOW	LOW
SL24	Land Use	SL01	LOW	LOW	LOW
SL25	SKIP	SL01	SKIP		
LOW FLOW - Phase 2 baseline model calibrated for low flow (SL36)					
SL26	Climate Change	SL36	LOW	HIGH	MEDIUM
SL27	Climate Change	SL36	LOW	HIGH	LOW
SL28	Climate Change	SL36	LOW	HIGH	HIGH
SL29	Climate Change	SL36	LOW	HIGH	HIGH
SL30	Climate Change	SL36	LOW	MEDIUM	MEDIUM
SL31	Climate Change	SL36	MEDIUM	MEDIUM	HIGH
SL32	SKIP	SL36	SKIP		
SL33	SKIP	SL36	SKIP		
SL34	SKIP	SL36	SKIP		
SL35	SKIP	SL36	SKIP		
SL36	Baseline	SL36	BASELINE		
SL37	Physical Change	SL36	LOW	LOW	LOW
SL38	Physical Change	SL36	LOW	LOW	LOW
SL39	Physical Change	SL36	LOW	LOW	LOW
SL40	Physical Change	SL36	LOW	LOW	LOW

Table 5 Channel Forming Flow Analysis Summary for South Branch (cha0167)

Scenario ID	Description	Baseline Scenario for Comparison	Channel Forming Flow Analysis over 30-year Record (1976-2005) for cha0167		
			cha0167		
			Magnitude	Duration	Timing
LOW FLOW - Phase 1 baseline model adjusted for low-flow (SL01)					
SL01	Baseline	SL01	BASELINE		
SL02	Climate Change	SL01	LOW	MEDIUM	HIGH
SL02B	Climate Change	SL01	LOW	HIGH	LOW
SL03	Climate Change	SL01	HIGH	MEDIUM	HIGH
SL04	Climate Change	SL01	MEDIUM	LOW	HIGH
SL05	Climate Change	SL01	MEDIUM	LOW	LOW
SL06	Population Growth	SL01	MEDIUM	LOW	LOW
SL07	Population Growth	SL01	LOW	LOW	LOW
SL08	Population Growth	SL01	LOW	LOW	LOW
SL09	Population Growth	SL01	LOW	MEDIUM	MEDIUM
SL10	Population Growth	SL01	HIGH	MEDIUM	HIGH
SL11	SKIP	SL01	SKIP		
SL12	Extreme Event	SL01	LOW	MEDIUM	LOW
SL13	Land Use	SL01	LOW	LOW	LOW
SL14	Land Use	SL01	MEDIUM	LOW	LOW
SL15	Land Use	SL01	LOW	LOW	LOW
SL16	Land Use	SL01	MEDIUM	LOW	LOW
SL17	Land Use	SL01	LOW	LOW	LOW
SL18	Land Use	SL01	LOW	LOW	LOW
SL19	Land Use	SL01	LOW	LOW	LOW
SL20	Land Use	SL01	LOW	LOW	LOW
SL21	Land Use	SL01	LOW	LOW	LOW
SL22	Land Use	SL01	LOW	LOW	LOW
SL23	Land Use	SL01	LOW	LOW	LOW
SL24	Land Use	SL01	LOW	LOW	LOW
SL25	SKIP	SL01	SKIP		
LOW FLOW - Phase 2 baseline model calibrated for low flow (SL36)					
SL26	Climate Change	SL36	LOW	MEDIUM	MEDIUM
SL27	Climate Change	SL36	LOW	MEDIUM	MEDIUM
SL28	Climate Change	SL36	LOW	MEDIUM	MEDIUM
SL29	Climate Change	SL36	LOW	MEDIUM	MEDIUM
SL30	Climate Change	SL36	HIGH	MEDIUM	MEDIUM
SL31	Climate Change	SL36	HIGH	MEDIUM	MEDIUM
SL32	SKIP	SL36	SKIP		
SL33	SKIP	SL36	SKIP		
SL34	SKIP	SL36	SKIP		
SL35	SKIP	SL36	SKIP		
SL36	Baseline	SL36	BASELINE		
SL37	Physical Change	SL36	LOW	LOW	LOW
SL38	Physical Change	SL36	LOW	LOW	LOW
SL39	Physical Change	SL36	LOW	LOW	LOW
SL40	Physical Change	SL36	LOW	LOW	LOW

Table 6 Channel Forming Flow Analysis Summary for Indian River at Port Carling (cha0647)

	Channel Forming Flow Analysis over 30-year Record (1976-2005) for cha0647				
Scenario ID	Description	Baseline Scenario for Comparison	cha0647		
			Magnitude	Duration	Timing
LOW FLOW - Phase 1 baseline model adjusted for low-flow (SL01)					
SL01	Baseline	SL01	BASELINE		
SL02	Climate Change	SL01	LOW	HIGH	HIGH
SL02B	Climate Change	SL01	LOW	HIGH	LOW
SL03	Climate Change	SL01	MEDIUM	MEDIUM	MEDIUM
SL04	Climate Change	SL01	LOW	MEDIUM	MEDIUM
SL05	Climate Change	SL01	LOW	LOW	LOW
SL06	Population Growth	SL01	LOW	LOW	LOW
SL07	Population Growth	SL01	LOW	LOW	LOW
SL08	Population Growth	SL01	LOW	LOW	LOW
SL09	Population Growth	SL01	LOW	HIGH	HIGH
SL10	Population Growth	SL01	MEDIUM	MEDIUM	MEDIUM
SL11	SKIP	SL01	SKIP		
SL12	Extreme Event	SL01	LOW	LOW	LOW
SL13	Land Use	SL01	LOW	LOW	LOW
SL14	Land Use	SL01	LOW	LOW	LOW
SL15	Land Use	SL01	LOW	LOW	LOW
SL16	Land Use	SL01	LOW	LOW	LOW
SL17	Land Use	SL01	LOW	LOW	LOW
SL18	Land Use	SL01	LOW	LOW	LOW
SL19	Land Use	SL01	LOW	LOW	LOW
SL20	Land Use	SL01	LOW	LOW	LOW
SL21	Land Use	SL01	LOW	LOW	LOW
SL22	Land Use	SL01	LOW	LOW	LOW
SL23	Land Use	SL01	LOW	LOW	LOW
SL24	Land Use	SL01	LOW	LOW	LOW
SL25	SKIP	SL01	SKIP		
LOW FLOW - Phase 2 baseline model calibrated for low flow (SL36)					
SL26	Climate Change	SL36	LOW	HIGH	MEDIUM
SL27	Climate Change	SL36	LOW	HIGH	LOW
SL28	Climate Change	SL36	LOW	HIGH	MEDIUM
SL29	Climate Change	SL36	LOW	HIGH	MEDIUM
SL30	Climate Change	SL36	MEDIUM	LOW	LOW
SL31	Climate Change	SL36	MEDIUM	MEDIUM	MEDIUM
SL32	SKIP	SL36	SKIP		
SL33	SKIP	SL36	SKIP		
SL34	SKIP	SL36	SKIP		
SL35	SKIP	SL36	SKIP		
SL36	Baseline	SL36	BASELINE		
SL37	Physical Change	SL36	LOW	LOW	LOW
SL38	Physical Change	SL36	LOW	LOW	LOW
SL39	Physical Change	SL36	LOW	LOW	LOW
SL40	Physical Change	SL36	LOW	LOW	LOW

Table 7 Channel Forming Flow Analysis Summary for Muskoka River at Bala (cha0905)

	Channel Forming Flow Analysis over 30-year Record (1976-2005) for cha0905				
Scenario ID	Description	Baseline Scenario for Comparison	cha0905		
			Magnitude	Duration	Timing
LOW FLOW - Phase 1 baseline model adjusted for low-flow (SL01)					
SL01	Baseline	SL01	BASELINE		
SL02	Climate Change	SL01	LOW	HIGH	HIGH
SL02B	Climate Change	SL01	LOW	HIGH	LOW
SL03	Climate Change	SL01	MEDIUM	MEDIUM	MEDIUM
SL04	Climate Change	SL01	LOW	LOW	MEDIUM
SL05	Climate Change	SL01	MEDIUM	LOW	LOW
SL06	Population Growth	SL01	LOW	LOW	LOW
SL07	Population Growth	SL01	LOW	LOW	LOW
SL08	Population Growth	SL01	LOW	LOW	LOW
SL09	Population Growth	SL01	LOW	HIGH	HIGH
SL10	Population Growth	SL01	MEDIUM	MEDIUM	MEDIUM
SL11	SKIP	SL01	SKIP		
SL12	Extreme Event	SL01	LOW	LOW	LOW
SL13	Land Use	SL01	LOW	LOW	LOW
SL14	Land Use	SL01	LOW	LOW	LOW
SL15	Land Use	SL01	LOW	LOW	LOW
SL16	Land Use	SL01	LOW	LOW	LOW
SL17	Land Use	SL01	LOW	LOW	LOW
SL18	Land Use	SL01	LOW	LOW	LOW
SL19	Land Use	SL01	LOW	LOW	LOW
SL20	Land Use	SL01	LOW	LOW	LOW
SL21	Land Use	SL01	LOW	LOW	LOW
SL22	Land Use	SL01	LOW	LOW	LOW
SL23	Land Use	SL01	LOW	LOW	LOW
SL24	Land Use	SL01	LOW	LOW	LOW
SL25	SKIP	SL01	SKIP		
LOW FLOW - Phase 2 baseline model calibrated for low flow (SL36)					
SL26	Climate Change	SL36	LOW	HIGH	MEDIUM
SL27	Climate Change	SL36	LOW	HIGH	LOW
SL28	Climate Change	SL36	LOW	HIGH	MEDIUM
SL29	Climate Change	SL36	LOW	HIGH	MEDIUM
SL30	Climate Change	SL36	MEDIUM	LOW	MEDIUM
SL31	Climate Change	SL36	MEDIUM	MEDIUM	MEDIUM
SL32	SKIP	SL36	SKIP		
SL33	SKIP	SL36	SKIP		
SL34	SKIP	SL36	SKIP		
SL35	SKIP	SL36	SKIP		
SL36	Baseline	SL36	BASELINE		
SL37	Physical Change	SL36	LOW	LOW	LOW
SL38	Physical Change	SL36	LOW	LOW	LOW
SL39	Physical Change	SL36	LOW	LOW	LOW
SL40	Physical Change	SL36	LOW	LOW	LOW

Table 8 SL02 Channel Forming Flow Criteria

SL02: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	79.3	112.0	133.5	58.2	351.0
Evaluation	MEDIUM	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	1	41	5	66	58
Evaluation	LOW	HIGH	MEDIUM	HIGH	HIGH
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Feb	Jan	Jan	Jan	Jan
Evaluation	MEDIUM	HIGH	HIGH	HIGH	HIGH

Table 9 SL02B Channel Forming Flow Criteria

SL02B: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	124.4	151.4	165.4	85.2	445.0
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	12	62	34	61	59
Evaluation	HIGH	HIGH	HIGH	HIGH	HIGH
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Apr	Apr	Apr	Apr	Apr
Evaluation	MEDIUM	LOW	LOW	LOW	LOW

Table 10 SL03 Channel Forming Flow Criteria

SL03: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	45.7	38.2	65.9	37.3	240.4
Evaluation	HIGH	HIGH	HIGH	MEDIUM	MEDIUM
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	0	0	0	0	1
Evaluation	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Jan	Jan	Jan	Feb	Mar
Evaluation	MEDIUM	HIGH	HIGH	MEDIUM	MEDIUM

Table 11 SL04 Channel Forming Flow Criteria

SL04: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	59.7	81.1	99.3	46.8	286.9
Evaluation	HIGH	LOW	MEDIUM	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	0	12	1	31	19
Evaluation	MEDIUM	LOW	LOW	MEDIUM	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Jan	Jan	Jan	Feb	Mar
Evaluation	MEDIUM	HIGH	HIGH	MEDIUM	MEDIUM

Table 12 SL05 Channel Forming Flow Criteria

SL05: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	88.2	63.3	92.3	44.7	236.0
Evaluation	LOW	MEDIUM	MEDIUM	LOW	MEDIUM
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	8	2	18	10
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 13 SL06 Channel Forming Flow Criteria

SL06: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	83.0	79.4	100.0	44.0	243.4
Evaluation	LOW	LOW	MEDIUM	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	17	1	15	10
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 14 SL07 Channel Forming Flow Criteria

SL07: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	83.3	79.4	103.8	44.0	242.9
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	17	1	15	10
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 15 SL08 Channel Forming Flow Criteria

SL08: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	82.0	103.2	243.4	44.0	243.4
Evaluation	MEDIUM	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	17	1	15	10
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 16 SL09 Channel Forming Flow Criteria

SL09: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	79.6	112.5	134.5	58.2	350.5
Evaluation	MEDIUM	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	1	41	6	65	58
Evaluation	LOW	HIGH	MEDIUM	HIGH	HIGH
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Feb	Jan	Feb	Jan	Jan
Evaluation	MEDIUM	HIGH	MEDIUM	HIGH	HIGH

Table 17   SL10 Channel Forming Flow Criteria

SL10: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	45.5	40.8	65.9	37.1	239.9
Evaluation	HIGH	HIGH	HIGH	MEDIUM	MEDIUM
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	0	0	0	0	1
Evaluation	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Jan	Jan	Jan	Feb	Mar
Evaluation	MEDIUM	HIGH	HIGH	MEDIUM	MEDIUM

Table 18   SL12 Channel Forming Flow Criteria

SL12: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	92.5	79.5	108.5	44.0	245.3
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	3	16	5	15	15
Evaluation	MEDIUM	LOW	MEDIUM	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 19   SL13 Channel Forming Flow Criteria

SL13: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	82.7	79.0	107.0	44.1	243.9
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	16	1	15	10
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 20 SL14 Channel Forming Flow Criteria

SL14: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	82.7	79.0	99.8	44.0	243.4
Evaluation	LOW	LOW	MEDIUM	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	16	1	15	10
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 21 SL15 Channel Forming Flow Criteria

SL15: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	83.1	79.0	103.3	44.0	242.9
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	16	2	15	10
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 22 SL16 Channel Forming Flow Criteria

SL16: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	83.3	79.0	99.8	44.0	243.9
Evaluation	LOW	LOW	MEDIUM	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	16	2	15	10
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 23 SL17 Channel Forming Flow Criteria

SL17: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	83.3	79.0	108.0	44.1	243.4
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	16	2	15	10
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 24 SL18 Channel Forming Flow Criteria

SL18: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	83.3	79.0	108.0	44.0	243.4
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	16	2	15	10
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 25 SL19 Channel Forming Flow Criteria

SL19: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	84.0	88.8	108.0	46.6	248.4
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	20	4	17	16
Evaluation	LOW	MEDIUM	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 26 SL20 Channel Forming Flow Criteria

SL20: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	84.0	79.0	108.0	44.0	244.9
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	16	3	15	12
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 27 SL21 Channel Forming Flow Criteria

SL21: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	83.3	88.8	108.0	44.0	244.8
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	20	2	15	12
Evaluation	LOW	MEDIUM	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 28 SL22 Channel Forming Flow Criteria

SL22: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	83.3	79.0	108.0	44.0	244.8
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	16	2	15	14
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 29 SL23 Channel Forming Flow Criteria

SL23: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	83.3	79.0	108.0	46.6	244.4
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	16	2	17	12
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 30 SL24 Channel Forming Flow Criteria

SL24: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	83.1	79.0	103.3	44.0	243.4
Baseline 80% Q1.5	66.5	63.2	82.6	35.2	194.7
Modelled Q1.5	83.3	79.0	108.0	44.0	243.9
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	16	2	15	9
13th Percentile	0	0	0	0	0
38th Percentile	1	6	1	10	4
62nd Percentile	2	20	4	25	21
87th Percentile	5	30	16	41	33
Modelled Median	2	16	2	15	12
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 31 SL26 Channel Forming Flow Criteria

SL26: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	71.2	58.9	99.1	42.2	237.0
Baseline 80% Q1.5	57.0	47.1	79.3	33.8	189.6
Modelled Q1.5	80.1	105.5	129.4	54.3	332.4
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	31	1	10	6
13th Percentile	0	0	0	0	0
38th Percentile	1	22	1	4	2
62nd Percentile	3	35	5	16	21
87th Percentile	5	52	15	39	33
Modelled Median	3	94	12	58	44
Evaluation	MEDIUM	HIGH	MEDIUM	HIGH	HIGH
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Mar	Mar	Mar	Mar
Evaluation	LOW	MEDIUM	MEDIUM	MEDIUM	MEDIUM

Table 32 SL27 Channel Forming Flow Criteria

SL27: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	71.2	58.9	99.1	42.2	237.0
Baseline 80% Q1.5	57.0	47.1	79.3	33.8	189.6
Modelled Q1.5	87.6	105.4	115.0	52.9	329.0
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	31	1	10	6
13th Percentile	0	0	0	0	0
38th Percentile	1	22	1	4	2
62nd Percentile	3	35	5	16	21
87th Percentile	5	52	15	39	33
Modelled Median	5	94	13	65	45
Evaluation	MEDIUM	HIGH	MEDIUM	HIGH	HIGH
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Mar	Apr	Apr
Evaluation	LOW	LOW	MEDIUM	LOW	LOW

Table 33 SL28 Channel Forming Flow Criteria

SL28: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	71.2	58.9	99.1	42.2	237.0
Baseline 80% Q1.5	57.0	47.1	79.3	33.8	189.6
Modelled Q1.5	83.3	118.6	127.0	56.5	333.9
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	31	1	10	6
13th Percentile	0	0	0	0	0
38th Percentile	1	22	1	4	2
62nd Percentile	3	35	5	16	21
87th Percentile	5	52	15	39	33
Modelled Median	3	100	14	68	60
Evaluation	MEDIUM	HIGH	MEDIUM	HIGH	HIGH
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Jan	Mar	Mar	Mar
Evaluation	LOW	HIGH	MEDIUM	MEDIUM	MEDIUM

Table 34 SL29 Channel Forming Flow Criteria

SL29: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	71.2	58.9	99.1	42.2	237.0
Baseline 80% Q1.5	57.0	47.1	79.3	33.8	189.6
Modelled Q1.5	90.6	109.5	133.5	55.2	334.4
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	31	1	10	6
13th Percentile	0	0	0	0	0
38th Percentile	1	22	1	4	2
62nd Percentile	3	35	5	16	21
87th Percentile	5	52	15	39	33
Modelled Median	4	103	15	72	55
Evaluation	MEDIUM	HIGH	MEDIUM	HIGH	HIGH
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Jan	Mar	Mar	Mar
Evaluation	LOW	HIGH	MEDIUM	MEDIUM	MEDIUM

Table 35 SL30 Channel Forming Flow Criteria

SL30: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	71.2	58.9	99.1	42.2	237.0
Baseline 80% Q1.5	57.0	47.1	79.3	33.8	189.6
Modelled Q1.5	60.9	60.6	78.1	38.1	233.5
Evaluation	MEDIUM	LOW	HIGH	MEDIUM	MEDIUM
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	31	1	10	6
13th Percentile	0	0	0	0	0
38th Percentile	1	22	1	4	2
62nd Percentile	3	35	5	16	21
87th Percentile	5	52	15	39	33
Modelled Median	0	16	0	4	5
Evaluation	MEDIUM	MEDIUM	MEDIUM	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Mar	Mar	Apr	Mar
Evaluation	LOW	MEDIUM	MEDIUM	LOW	MEDIUM

Table 36 SL31 Channel Forming Flow Criteria

SL31: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	71.2	58.9	99.1	42.2	237.0
Baseline 80% Q1.5	57.0	47.1	79.3	33.8	189.6
Modelled Q1.5	59.5	53.7	67.9	34.9	198.9
Evaluation	MEDIUM	MEDIUM	HIGH	MEDIUM	MEDIUM
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	31	1	10	6
13th Percentile	0	0	0	0	0
38th Percentile	1	22	1	4	2
62nd Percentile	3	35	5	16	21
87th Percentile	5	52	15	39	33
Modelled Median	0	8	0	0	0
Evaluation	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Oct	Nov	Mar	Mar	Mar
Evaluation	HIGH	HIGH	MEDIUM	MEDIUM	MEDIUM

Table 37 SL37 Channel Forming Flow Criteria

SL37: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	71.2	58.9	99.1	42.2	237.0
Baseline 80% Q1.5	57.0	47.1	79.3	33.8	189.6
Modelled Q1.5	71.1	60.0	98.6	42.0	237.5
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	31	1	10	6
13th Percentile	0	0	0	0	0
38th Percentile	1	22	1	4	2
62nd Percentile	3	35	5	16	21
87th Percentile	5	52	15	39	33
Modelled Median	2	31	1	10	5
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 38 SL38 Channel Forming Flow Criteria

SL38: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	71.2	58.9	99.1	42.2	237.0
Baseline 80% Q1.5	57.0	47.1	79.3	33.8	189.6
Modelled Q1.5	71.2	60.0	99.1	42.0	237.5
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	13	3	12	6
13th Percentile	0	0	0	0	0
38th Percentile	1	4	1	5	2
62nd Percentile	3	21	7	24	18
87th Percentile	5	30	18	38	29
Modelled Median	2	13	2	7	6
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 39 SL39 Channel Forming Flow Criteria

SL39: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	71.2	58.9	99.1	42.2	237.0
Baseline 80% Q1.5	57.0	47.1	79.3	33.8	189.6
Modelled Q1.5	70.9	58.9	98.6	42.0	237.0
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	31	1	10	6
13th Percentile	0	0	0	0	0
38th Percentile	1	22	1	4	2
62nd Percentile	3	35	5	16	21
87th Percentile	5	52	15	39	33
Modelled Median	2	31	1	10	5
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW

Table 40 SL40 Channel Forming Flow Criteria

SL40: Channel Forming Flow Analysis over 30-Year Record (1976-2005)					
Magnitude (peak flow rate in m³/s)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Q1.5	71.2	58.9	99.1	42.2	237.0
Baseline 80% Q1.5	57.0	47.1	79.3	33.8	189.6
Modelled Q1.5	71.2	58.9	99.1	42.2	246.4
Evaluation	LOW	LOW	LOW	LOW	LOW
Duration (number of days where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Median	2	31	1	10	6
13th Percentile	0	0	0	0	0
38th Percentile	1	22	1	4	2
62nd Percentile	3	35	5	16	21
87th Percentile	5	52	15	39	33
Modelled Median	2	31	1	10	6
Evaluation	LOW	LOW	LOW	LOW	LOW
Timing (modal month where flow exceeds Q1.5)					
Criteria	**cha0075**	**cha0363**	**cha0167**	**cha0647**	**cha0905**
Baseline Mode	Mar	Apr	Apr	Apr	Apr
Modelled Mode	Mar	Apr	Apr	Apr	Apr
Evaluation	LOW	LOW	LOW	LOW	LOW