THE EVOLUTION OF

Water Management

IN THE MUSKOKA RIVER WATERSHED

Muskoka WATERSHED COUNCIL

By Chris Cragg

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Introduction

With 42 dams and 36 lakes connected by over 170 km of rivers, the Muskoka River Watershed is among the most complex in the Province. Management of the water in this watershed has evolved over 80 years to balance many competing needs, including, but not limited to, hydro electric power, transportation, tourism, environmental protection and shoreline landowners. Constrained by its backbone geology, management of water must adapt to a range of seasonal weather inputs plus an increasing frequency of extreme events driven by climate change. To fully understand the challenges of improving water management in this dynamic environment requires an appreciation of a broad range of information which is currently scattered in diverse sources. Without this appreciation there is a tendency to believe that changing the flow regime in the watershed is a simple matter.

This paper synthesizes watershed information from disparate sources for use by the "Water Quantity Task Force" recommended by the Muskoka Watershed Advisory Group (MWAG) in its Interim Report[1] and is also intended to enhance public understanding of the complexity of water management.

History of Water Management in Muskoka

*Dams and locks were originally constructed in the Muskoka River Watershed to enable transportation, industry and power production…but **not** to control water levels or stop flooding.*

Steamboat transport was largely responsible, along with land grants, for opening up Muskoka. Major adjustments were made to lake elevations and connections from 1869 to 1873 to facilitate navigation[2]. A cut was made at Port Sandfield to better link Lakes Rosseau and Joseph. This eliminated an 18-inch water elevation difference between these lakes. Locks were built at Port Carling establishing a 2 ft difference between Lakes Rosseau and Muskoka/Indian River where before there had only been 1 ft. Sandbars were dredged along the Indian River and at the mouth of the Muskoka River, and the falls at Bala were regulated by construction of the North control dam. Prior to this dam being built in 1873, there were water level fluctuations of several feet on Lake Muskoka[3]. The narrows around Bala Park Island were dredged of debris shortly afterward.

Lumbering was a major industry in Muskoka, so further dams and log chutes were built to facilitate the transport of logs to sawmills at Gravenhurst and other railheads[4]. The last major log drive was in 1930. Dams were built at Baysville (Lake of Bays) in 1873, Huntsville (Fairy Lake) in 1876, Port Sydney (Mary Lake) in 1881, and Hollow Lake (now named Kawagama Lake) in 1890. The Baysville Dam was replaced with a larger dam in 1918, which raised Lake of Bays 5 ft.

[1] Witzel. M. et al, 2020. "Interim Advice and Recommendations to Address Priority Environmental Issues in the Muskoka River Watershed", https://www.ontario.ca/page/advisory-group-report-protecting-muskoka-river-watershed, 76pp.
[2] Tatley,R. 1983. The Steamboat Era in the Muskokas, Volume 1, To The Golden Years, Boston Mills Press, 304pp.
[3] Tatley,R. 1983. The Steamboat Era in the Muskokas, Volume 1, To The Golden Years, Boston Mills Press, 304pp.
[4] Long, G. 1989. This River the Muskoka, Boston Mills Press, 184pp

Between these and several smaller dams near Algonquin Park, the Department of Public Works (DPW) took over control of all storage works in 1926[5].

Bracebridge started the move to town electric power by building Ontario's first municipal hydroelectric plant at Bracebridge Falls in 1894[6]. They added a second plant at Wilson Falls in 1910. The Hydro Electric Power Commission of Ontario (HEPC) then built several run-of-the river plants along the South Branch of the Muskoka River: South Falls (1904), Hanna Chute (1926) and Trethewey Falls (1929). Then they built larger plants on the Musquash River: Ragged Rapids (1938) and Big Eddy (1941). None of these "run-of-the-river" plants has a headpond but they do take advantage of the water storage in Lake of Bays and Kawagama Lake impounded by the Kawagama Dam and the Baysville Dam. HEPC was the original constructor and owner of the Kawagama Dam as well as a contributor to several other impoundment dams. The lack of headponds on the river-located hydroelectric plants means they cannot store significant volumes of water. The minor storage they do have, known as pondage, allows them to respond to short term (morning and evening) peak electricity demands. The upstream storage does allow seasonal response to the winter electricity demand. To make more efficient use of their investment would require altered management of the water stored by these dams. This realization led to cooperation between DPW and HEPC formalized in the 1940 Hackner-Holden Agreement. The 1940 Agreement established water levels for summer navigation and then optimized water usage for power generation at other times. By 1969, other interests needed to be accommodated so the agreement was revised to reduce lake fluctuations on cottage developed lakes, set timing of winter drawdown, limit spring drawdown on Lake trout lakes, and limit Lake Joseph drawdown to prevent freezing of water intake lines[7]. The redesign of the electricity market in Ontario in the late 1990's led to the introduction of Water Management Plans throughout the Province. Currently, there are about 70 such plans, 50 of which are rated as "simple" and 20 as "complex". The Muskoka River Water Management Plan (MRWMP) was completed in 2006 to replace the Hackner-Holden Agreement. A wider range of interests were input to the MRWMP, however, there was little change to the original navigation levels from 1940. The progressive plan changes did lessen the amount of storage, particularly on the South Branch of the Muskoka River, which has reduced the attenuation of peak flows in this part of the watershed and increased the risk of peak flows from the North and South Branches arriving simultaneously in the Lower Subwatershed.

The original 1940 water management agreement balanced navigation, industry and power production usages. Subsequent iterations accommodated other interests with little change to summer water levels but reduced storage in the south branch.

Watershed Description

The Muskoka River Watershed is a tertiary level watershed that extends from Algonquin Park to Georgian Bay, a distance of 120 km, covering an area of 5,100 km^2 and including some 2,000 lakes with a lake area of 780 km^2 (15% of the watershed). Within the watershed the Muskoka River traverses a length of 210 km and falls 345 m in elevation. Some 60% of this elevation drop

5 Hackner Holden Agreement, 1940. Muskoka River – Notes of Conferences and Agreements Re Lake Levels and River Flow.
6 Boyer, R.J. 1994. Power from Water, Muskoka Publications Press, 84pp.
7 Hackner Holden Agreement, 1969. Addendum No. 1 to Notes of Conferences and Agreements Re Lake Levels and River Flow.

occurs in the first 30% of the river's length[8]. The Muskoka River Watershed can be divided into three main basins, or sub-watersheds: the North Branch of the Muskoka River (1,655 km^2); the South Branch of the Muskoka River (1,755 km^2) and the Lower Muskoka Sub-watershed, containing Lakes Muskoka, Rosseau, Joseph and the outflow Moon and Musquash Rivers. Each basin comprises about a third of the total area (Figure 1).

Further divisions of the Muskoka River Watershed into quaternary watershed areas are shown in Figure 2 and Table 1 below.

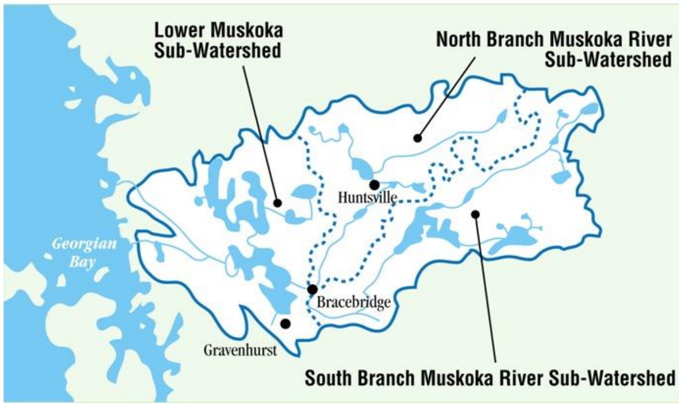

Figure 1. The three main basins of the Muskoka River Watershed as identified in the Muskoka River Water Management Plan[9].

Figure 2. Map of the quaternary watersheds within the Muskoka River Watershed.

[8] Hatch Engineering Report, February 12, 2020. Technical Report for Muskoka River Floodplain Mapping Study, The District Municipality of Muskoka, H356689-00000-200-0002, Rev.0, Ver.04.03, 131pp.
[9] Muskoka River Water Management Plan, 2006. Final Plan Report.

Table 1. Characteristics of the quaternary watersheds in the Muskoka River Watershed.[10]

Quaternary Watershed	Area	Wetlands		Interior Forest		Lakes		
	km²	%	km²	km²	%	#>8ha	km²	%
North Branch								
Big East River	647	5	34	373	58	47	54	8
Little East River	96	7	8	47	49	13	8	9
Mary Lake	663	11	73	328	49	45	66	10
North Muskoka River	249	9	22	115	46	21	11	4
	1655	**8**	**137**	**863**	**52**	**126**	**139**	**8**
South Branch								
Oxtongue	607	5	30	319	53	38	76	13
Hollow	408	4	16	211	52	43	66	16
Lake of Bays	385	6	23	173	45	25	85	22
South Muskoka River	355	12	42	192	54	27	27	8
	1755	**6**	**111**	**895**	**51**	**133**	**253**	**14**
Lower Muskoka TO Bala								
Rosseau River	129	15	19	78	60	7	5	3
Skeleton River	92	6	5	36	39	11	24	26
Dee River	148	11	16	64	43	7	12	8
Lake Rosseau	426	5	21	117	27	52	135	32
Lake Muskoka	430	8	34	120	28	30	140	33
	1225	**8**	**95**	**415**	**34**	**107**	**316**	**26**
Lower Muskoka BELOW Bala								
Moon River	715	11	47	298	42	37	76	11
Gibson River	186	17	32	84	45	10	16	9
	901	**9**	**79**	**382**	**42**	**47**	**92**	**10**

This detail shows the North Branch has the least amount of lake area to contain surface water and attenuate flood flows[11]. As a result, the North Branch contributes half the flow to Lake Muskoka and delivers it faster than the South Branch. Flow from the upper lakes is usually under 17% of the total inflow. Forests cover over 50% of the North Branch and South Branch Sub-watersheds, while development has reduced the coverage to under one third of the Lower Muskoka Sub-watershed.

The Muskoka River Watershed sits atop the Canadian Shield with prominent Precambrian bedrock outcroppings covered by thin soils (<3 m). The exception to this is a band of deep sand deposits, frequently over 25 m thick, following along the Highway 11 corridor which is the former beach ridge/shoreline of glacial Lake Algonquin. Figure 3 shows the general geology of the Muskoka River Watershed.

[10] Muskoka Watershed Council, 2018. Watershed Report Card.
[11] Muskoka Watershed Council, 2018. Watershed Report Card.

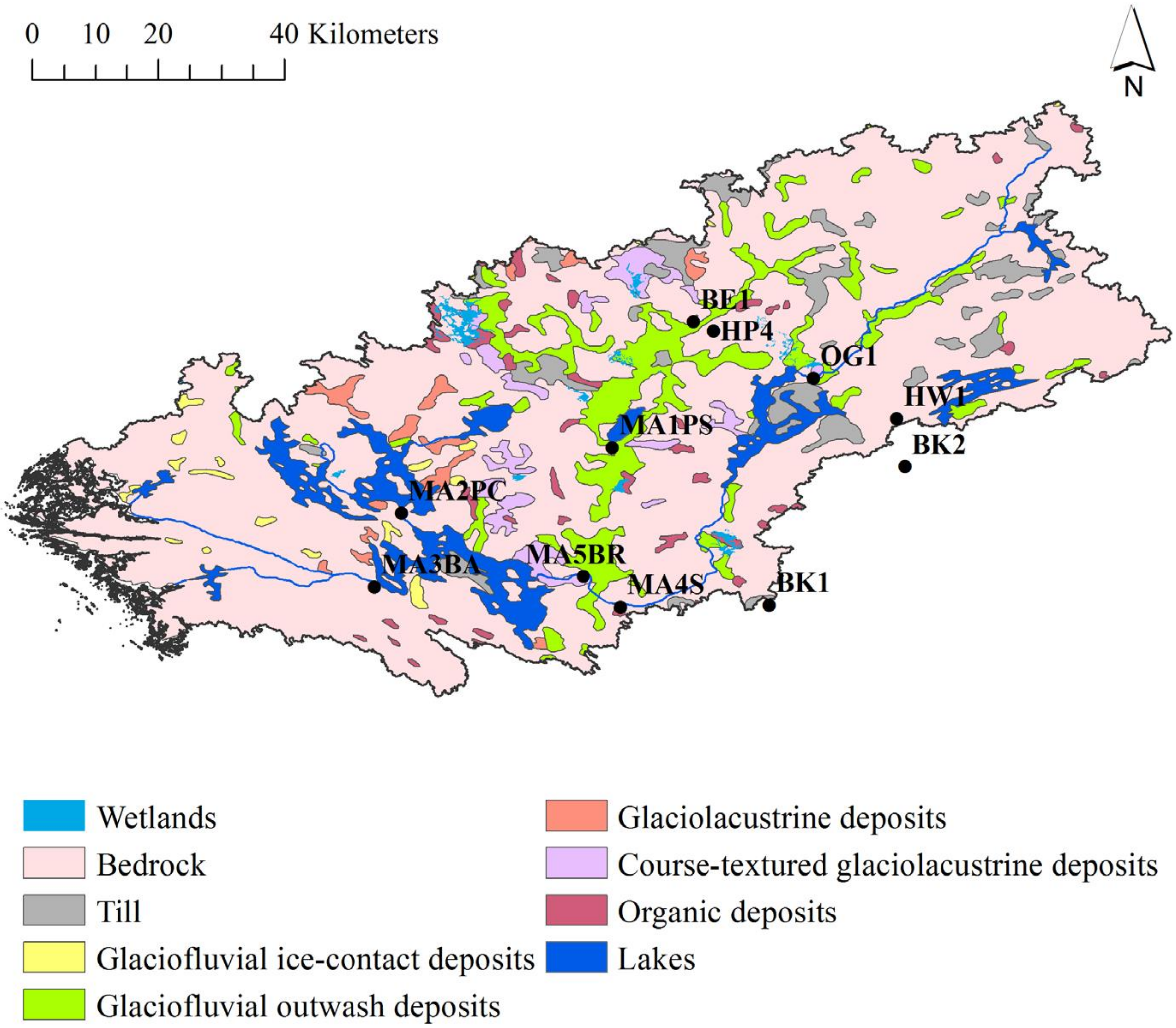

Figure 3. Quaternary geology of the Muskoka River Watershed[12].

The combination of steep topography, few lakes and large areas of exposed bedrock make the upper reaches of the watershed, particularly the Big East River, prone to rapid runoff and flash flooding.

Enhancing storage in the North Branch or South Branch Sub-watersheds and making use of wetlands, maintaining forests and, where possible, restoring forests in the Lower Muskoka Sub-watershed offer potential options to mitigating flooding in the watershed.

[12] James, A.L., et al, 2020, "The Isotope Hydrology of the Muskoka River Watershed, Ontario, Canada", Hydrological Processes, 34, 914-926.

Technical Considerations

Let's start with a basic water balance (Figure 4). When precipitation falls on the land in Muskoka, approximately 50% of it returns to the air via evaporation or, courtesy of the vegetation, evapotranspiration, seasonally. There is no significant evapotranspiration in winter[13]. The remainder either flows overland to the lakes and rivers or seeps into the ground and becomes groundwater. In winter, due to frozen, saturated soil plus snow and ice cover, a high percentage potentially runs off. In summer, dry ground absorbs more precipitation and much less runs off. Typical runoff values for hard surfaces, such as roads or ice crusted snow, may be up to 80%. Summer values for forested areas range from 5-20%.

The first practical implication of the water balance is that any improvement in evapotranspiration or decrease in the runoff coefficient reduces the amount of surface water flowing though the watershed and, consequently, reduces flooding. Maintaining and improving forest health is important to regulating the water cycle[14] and has the potential to increase annual evapotranspiration by some 20%[15]. Similarly, reducing hard surfaces on a property and diverting surface runoff through collection ponds encourages infiltration into the ground and slows impacts on lake levels. Allowing precipitation to infiltrate into the ground also keeps surface contaminants from being washed into the lake, thus improving water quality.

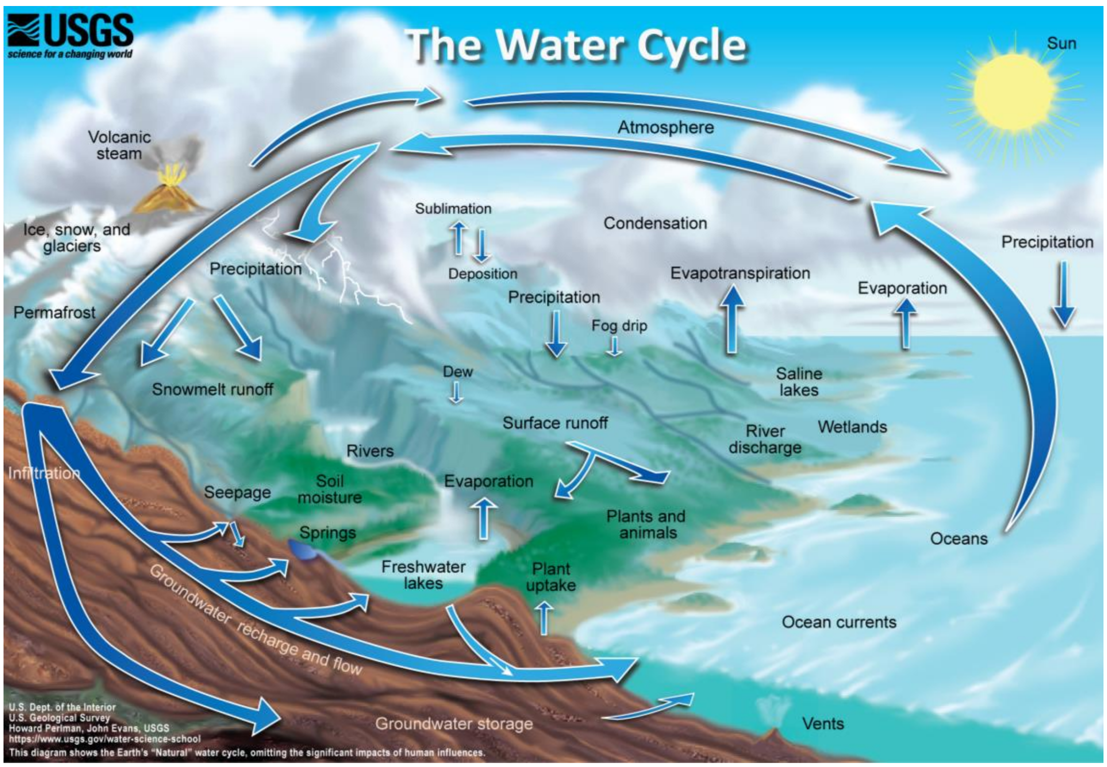

Figure 4. A diagram showing the Earth's "Natural" water cycle, omitting the significant impacts of human influences. Credit: Howard Perlman and John Evans, US Geological Survey.

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[13] Sinnige, J. 2020. Personnal communication re: monthly evapotranspiration in Ontario.
[14] Kozii, N. et al, 2020. Partitioning growing season water balance within a forested boreal catchment using sap flux, eddy covariance and a process-based model. Hydrol. Earth Syst. Sci., 24, 2999-3014.
[15] Green, M.B. et al, 2013. Decreased water flowing from a forest amended with calcium silicate. PNAS, Vol 110, No 15, pp5999-6003.

Lake Muskoka is the farthest downstream major lake in the watershed and acts as a tailwater lake. Over 90% of the watershed flows through Lake Muskoka en route to Georgian Bay via the Moon and Musquash Rivers. Due to such physical factors as distance, slope and surface roughness, rainfall in Algonquin Park takes some eight to ten days to peak in Lake Muskoka. By contrast, Lakes Rosseau and Joseph are essentially headwater lakes. They are predominantly filled by rain on their surface and surrounding lands and can produce peak water levels in a couple of days. Figure 5 shows generically how lake levels rise after a storm due to overland surface runoff, then recede when excess water drains from the local watershed.

In springtime the rainfall impact in Figure 5 is superimposed on snowmelt. The water contribution from the snow is released by melting temperatures with daytime temperatures above 10°C and/or nighttime temperatures above 0°C causing accelerated melting. Melting can contribute to runoff in the range of 1 to 5 mm/hr/°C.

Due to the complexities of selecting the factors for runoff, historical measurements of streamflow in response to weather impacts on a watershed are generally used for watershed hydraulic analyses.

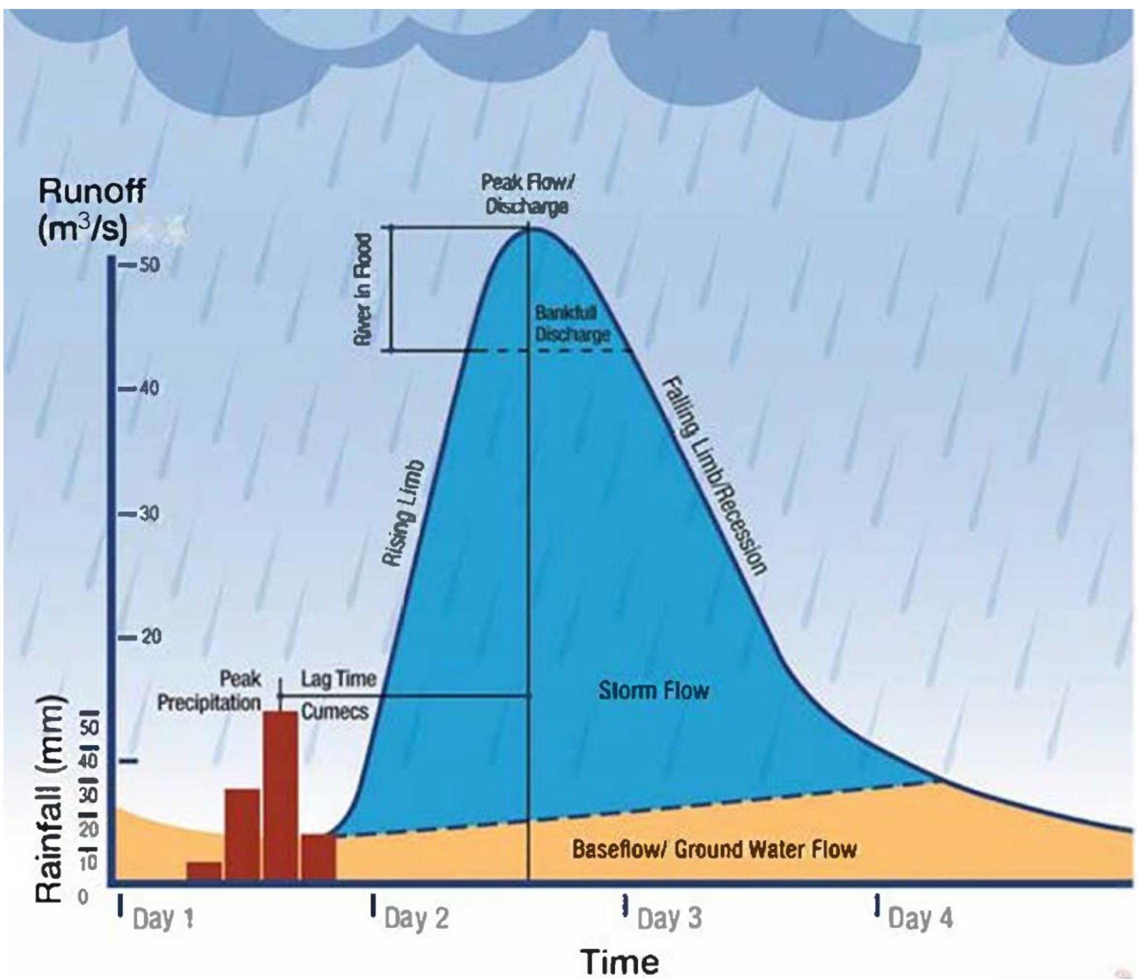
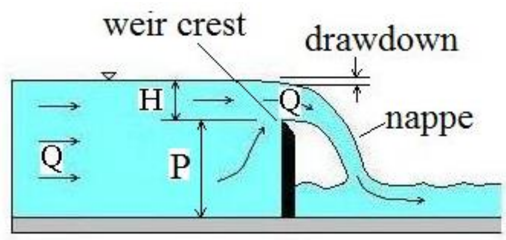


Figure 5. Flood hydrograph showing the typical flow of water during a precipitation event.

Impact of Water Retaining Structures



Flow Over a Sharp Crested Weir

There is a widespread belief that lowering lake levels ahead of a spring freshet will directly prevent flooding. This assumes that lakes have vertical sides, like swimming pools, which is not the case. Lake shores may be as steep as 1:1 (Horizontal to Vertical) in rocky areas but could be as flat as 20:1 where sandy shorelines exist. Also, the lake bottom is not flat but dotted by many shoals that become exposed as the water is lowered. Just ask anyone who has unexpectedly dinged a propeller during low water in fall season. Collectively less storage is gained as lake levels are drawn down. This means that extra drawdown has progressively less benefit for storage. Second, there is a negative consequence to lowering any lake upstream of a control dam, as lowering water level reduces the flow quantity that can pass the dam due to the weir equation (left). In this equation, flow over the dam sluice is proportional to the height of water above the sill (bottom) of the sluice. The higher the water level (H), the faster the flow (Q). And, conversely, the lower the water level above the sill, the slower the flow.

As an example, during the 2019 flood, inflow to Lake Muskoka peaked at 500 m^3/s while outflow at Bala did not build to 400 m^3/s until several days later (Figure 6). By this time inflow had decreased to match the 400 m^3/s outflow. During the time inflow exceeded outflow, lake levels rose rapidly. Contrary to popular belief, modestly lower drawdown levels do not make an appreciable improvement in peak water levels as the build rate (rate of water level rise with inflow) eliminates the drawdown gain in a few hours to a day.

Three choke points restrict flow entering Bala Bay to the extent that, during floods, Bala Bay water levels are 0.3 to 0.5 m lower than the general level of Lake Muskoka. This means that the flow capacity of the North and South control dams (over 400 m^3/s last year) exceeds the inflow capacity of the choke points.

Early in 2020 the flow capacity at Bala was augmented by the addition of the North Bala Generating Station (92 m^3/s). The plant intake is at a lower elevation than the dam sills which has the potential to enhance outflow capability for Bala Bay.

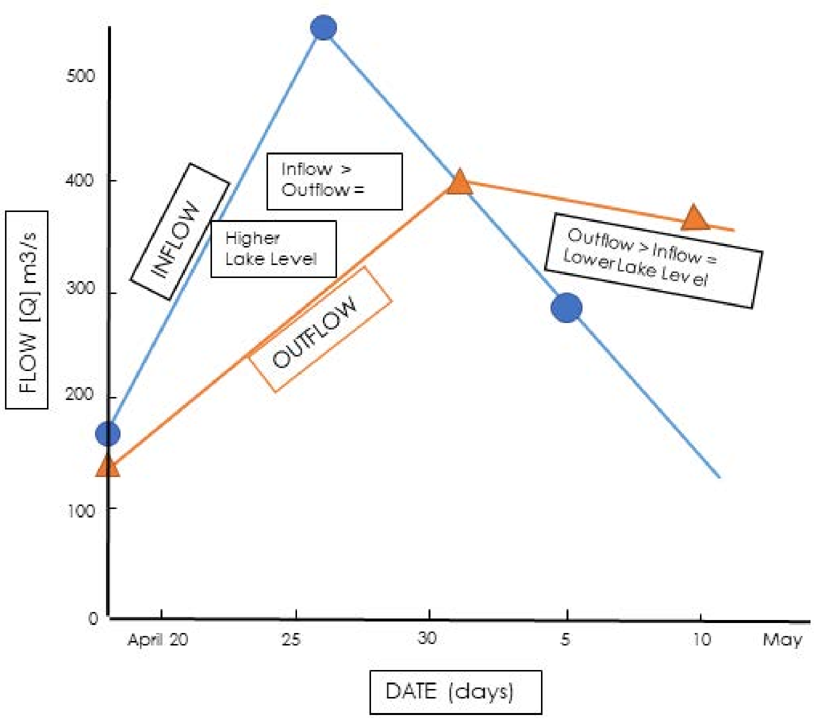


Figure 6. Chart of inflows vs outflows at Bala Bay in the spring of 2019.

The Current Water Management Plan

The 2006 Muskoka River Water Management Plan[16] (MRWMP) incorporates the experience the Ministry of Natural Resources and Forestry (MNRF) has accumulated since 1965 in Snow Water Equivalent (SWE) measurement across the watershed and operating experience back to 1940. With 42 dams/generating stations, the MRWMP has the most structures of the 20 complex Water Management Plans in the Province. The water levels in the plan are based on a custom hydrological model of the Muskoka River Watershed and employed weather data for the period from 1970 to 2000 in its modelling. Rule curves, representing average conditions, are defined for each structure/waterbody. Operational flexibility is given within a Normal Operating Zone (NOZ) with deviation permitted in response to defined snow, rain and thawing temperature triggers. Specifically, lower winter drawdowns are triggered if SWE is more than 25% of mean snowfall on the North Branch or more than 50% above mean snowfall on the South Branch. Even deeper drawdown is triggered by 100% exceedance of mean SWE. These deeper drawdowns may be implemented in advance based on snow cores. Drawdowns to the bottom of NOZ may also be triggered by rain events exceeding 25 mm (1 in) on frozen ground or by temperatures exceeding 10^{o}C for two days or by nighttime temperature above 0^{O}C for more than 2 days. However, these latter drawdowns cannot be done in advance but, rather, wait until actual weather occurs. There is no reliance placed on weather forecasts, even short-term forecasts, being accurate. Currently the best accuracy for weather is only 48 hours in advance and temperature predictions are better than precipitation forecasts. It is well known that combination weather events (rain + snow + melt) pose the greatest risks for flooding. The MRWMP does not provide guidance on drawdowns for combination weather events.

In terms of storage capacity, the 2006 MRWMP is little changed from the 1969 version. The main difference is less winter drawdown in Kawagama Lake to reduce spawning impacts on Lake trout. Another small change (8 ha) was the decommissioning of the Findlayson Pond dam on the Big East River[17].

Fish Spawning Impacts

Fishing in Muskoka are lakes is a significant contributor to the tourism industry[18]. Water levels and flows in the MRWMP have features to protect the spawning of Lake trout and Pickerel (Walleye). There are approximately 32 lakes in Muskoka classified as "Lake trout lakes" by the MNRF. For these lakes, water is drawn down in the fall spawning season to encourage the trout to lay eggs on spawning shoals deep enough to avoid freezing of the fry hatchlings during spring drawdown. Spring drawdown of Kawagama Lake was limited to 0.2 m below Fall drawdown in the 2006 MRWMP based on a 2004 spawning study[19]. The revision of lake drawdown was aimed at reducing mortality from an unacceptable 30% to a projected 6%. A follow up study in 2007 found significantly reduced mortality but not as good as the 6% target[20].

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[16] Muskoka River Water Management Plan, 2006. Final Plan Report.
[17] Donnelly, C.R. et al, 2005. "Once removed – decommissioning Findlayson dam", Water Power magazine, 16 May 2005.
[18] Paterson, A. Sept 18, 2019. Water quality of aquatic ecosystems in Muskoka, Presentation to MWAG, 58pp.
[19] Acres International, May 2004. Kawagama Lake – Lake Trout Spawning Studies, Report for Ministry of Natural Resources, P15380.00, 66pp.
[20] Azimuth Environmental Consulting Inc. February 2007. Lake Trout Spawning and Egg Disposition Survey in Kawagama Lake, Report for Ontario Ministry of Natural Resources, AEC 06-213/214, 33pp.

The reduced storage capacity in Kawagama Lake reduces the ability of the South Branch of the Muskoka River to slow the passage of flood peaks and increases the risk of peak flows from the North and South Branches arriving simultaneously in the Lower Muskoka Sub-watershed.

Spawning beds for Walleye at the mouth of the Moon River entering Georgian Bay were enhanced in 2008 by the Moon River Walleye Rehabilitation Initiative. Fluctuations in Georgian Bay water levels are beyond the scope of this paper but are well treated elsewhere[21].

Hence the importance of adopting a watershed wide view afforded by Integrated Watershed Management (IWM), which allows the competing interests of flood mitigation and lake ecology to be reviewed to ensure that any single alteration is assessed for implications throughout the watershed.

Recent Water Quantity Experience

Since the implementation of the 2006 MRWMP, flood levels have been experienced in most major lakes across the watershed in three years: 2013, 2016 and 2019 (Table 2). These events appear to be strongly correlated with very heavy rain on frozen ground events [ie >51 mm or 2"] which were not anticipated in the MRWMP (Table 3). Table 4 shows that these events have occurred six times in the 20 years since 2000. By contrast, far fewer extreme rain events occurred during the 30-year period of record used for the MRWMP. But very heavy rainfall is not enough by itself to produce a spring freshet flood. It is the combination of events - extreme rain plus a secondary heavy rain plus snowmelt that produces the volumes of water that "overwhelms" both the storage and the flow capacity of the watershed to contain water within the desired confines of lake and river shorelines. When this occurs, nearshore floodplains are inundated, including any lakeside structures.

Recent work by Lammers[22] indicates that the 2019 flood produced one cubic kilometer of water that had to be routed through the watershed's lakes and rivers. This work calculated the available storage capacity of the lakes, when drawn down, to be 0.6 km^3. The remaining 0.4 km^3 water volume had to flow through the system in a few days. This flow is impeded in several places by channel restrictions, also known as choke points. Some of the better-known choke points are:

- The Moon Chutes – restrict outflow from Bala Reach to the Moon and Musquash Rivers [85 m^3/s*]
- Bala Park Island narrows [Wallis Cut, Jannack Narrows, Coulter Narrows] - restrict outflow from Lake Muskoka into Bala Bay
- The Muskoka River delta – increases flooding of residential and business properties along Muskoka River between Bracebridge and Lake Muskoka
- The Main Street Bridge in Huntsville – causes flow to flood downtown properties [50 m^3/s*]
- Port Carling small lock channel [30 m^3/s*]

  *Flow in cubic meters of water per second

The amount of lake level or river level rise behind each choke point depends on the quantity of inflow, the size of the "reservoir" behind the choke point and the individual flow characteristics

[21] Egan, D. 2017. The Death and Life of the Great Lakes, W.W.Norton & Company, 333pp.
[22] Sale,P. et al, 2020. The Case for Integrated Watershed Management in Muskoka, Muskoka Watershed Council, 25pp.

of the choke point. Examples of lake level rise versus inflow are shown in Figures 7 and 8 for Lake Muskoka and Bala Reach, respectively.

The flow volume calculation[23] can be repeated for other flood and 'near miss' years to establish a reference "flood volume" for watershed management purposes. Annual margin against flooding can then be assessed by subtracting the snow [SWE] and "normal" rainfall from the "flood volume". This process may form the basis for a risk-based approach to modifying the drawdown triggers in the MRWMP.

Table 2. Peak spring water levels (in metres) for major lakes in Muskoka from 2003 to 2019.

Gauge Location	Beaumaris Max (m)	Port Carling Max (m)	Baysville Max (m)	Port Sydney Max (m)	Fairy Lake Max (m)	Kawagama Max (m)
NOZ top level	**225.75**	**226.25**	**315.38**	**281.1**	**284.15**	**355.7**
Flood Level	**225.97**	**226.37**	**315.5**	**281.15**	**284.62**	**356.07**
2019	226.45	226.44	315.53	281.58	284.95	355.80
2018	225.60	226.18	315.40	280.89	283.98	355.76
2017	225.91	226.37	315.47	281.13	284.26	355.88
2016	226.04	226.47	315.54	281.09	284.25	355.72
2015	225.73	226.27	315.33	281.18	284.43	355.74
2014	225.84	226.34	315.37	281.01	284.11	355.67
2013	226.15	226.46	315.57	281.44	284.80	356.21
2012	225.59	226.20	315.32	280.93	284.18	355.61
2011	225.67	226.26	315.42	281.00	284.05	355.73
2010	225.54	226.18	315.29	280.88	283.98	355.63
2009	225.74	226.21	315.37	280.97	284.15	355.74
2008	225.93	226.35	315.41	281.05	284.26	355.72
2007	225.72	226.21	315.33	281.09	284.16	355.61
2006	225.65	226.17	315.37	280.95	284.00	355.69
2005	225.59	226.16	315.32	280.87	283.83	355.70
2004	225.66	226.22	315.36	280.96	284.01	355.74
2003	225.66	226.17	315.33	280.95	284.03	355.65

(red)	Record Flood Level
(orange)	Flood above MRWMP Flood level
(yellow)	Near Miss - Flood just below MRWMP Flood level

[23] Sale, P. et al, 2020. The Case for Integrated Watershed Management in Muskoka, Muskoka Watershed Council, 25pp.

Table 3. Flooding factors (orange shading indicates a flood on Lake Muskoka).

Year	Rain >51 mm [over 2 days]	2nd Rain >25 mm [Within 6 days]	SWE > Normal	Flooding [Lake Muskoka]
2019	**Yes** [58 mm]	Yes	**Yes** [187 mm]	Yes
2016	**Yes** [55 mm]	Yes	No [82 mm]	Yes
2013	**Yes** [76 mm]	Yes	**Yes** [134 mm]	Yes
2008	No [46 mm]	No	**Yes** [194 mm]	No
2007	**Yes** [57 mm]	No	No [87mm]	No
1998	**Yes** [57 mm]	No	No [125mm]	No
1985	**Yes** [59 mm]	Yes	**Yes** [202 mm]	Yes

Table 4. Frequency of spring rain storms.

Time Period	# Spring Storms > 51 mm	# Spring Storms > 25 mm
2000 – 2019 [20 years]	6	31
1970 – 1999 [30 years]	3	30

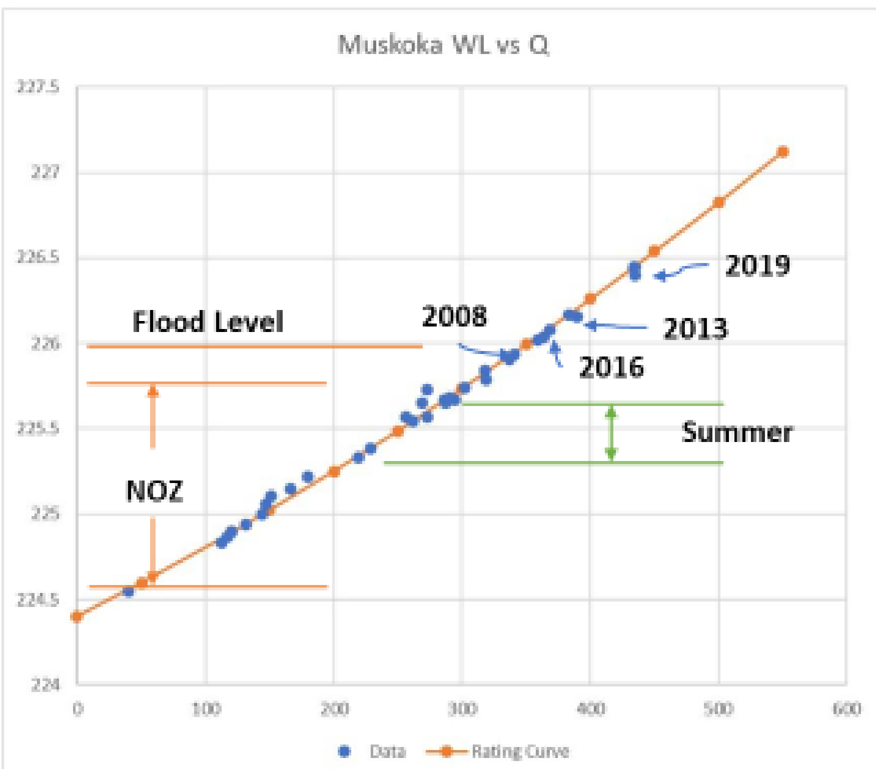


Figure 7. Lake elevation (metres) versus Inflow (Q in m3s) for Lake Muskoka[24].

[24] Hatch Engineering Report, February 12, 2020. Technical Report for Muskoka River Flood Plain Mapping Study, The District Municipality of Muskoka, H356689-00000-200-230-0002, Rev.0, Ver. 04.03, 131pp.

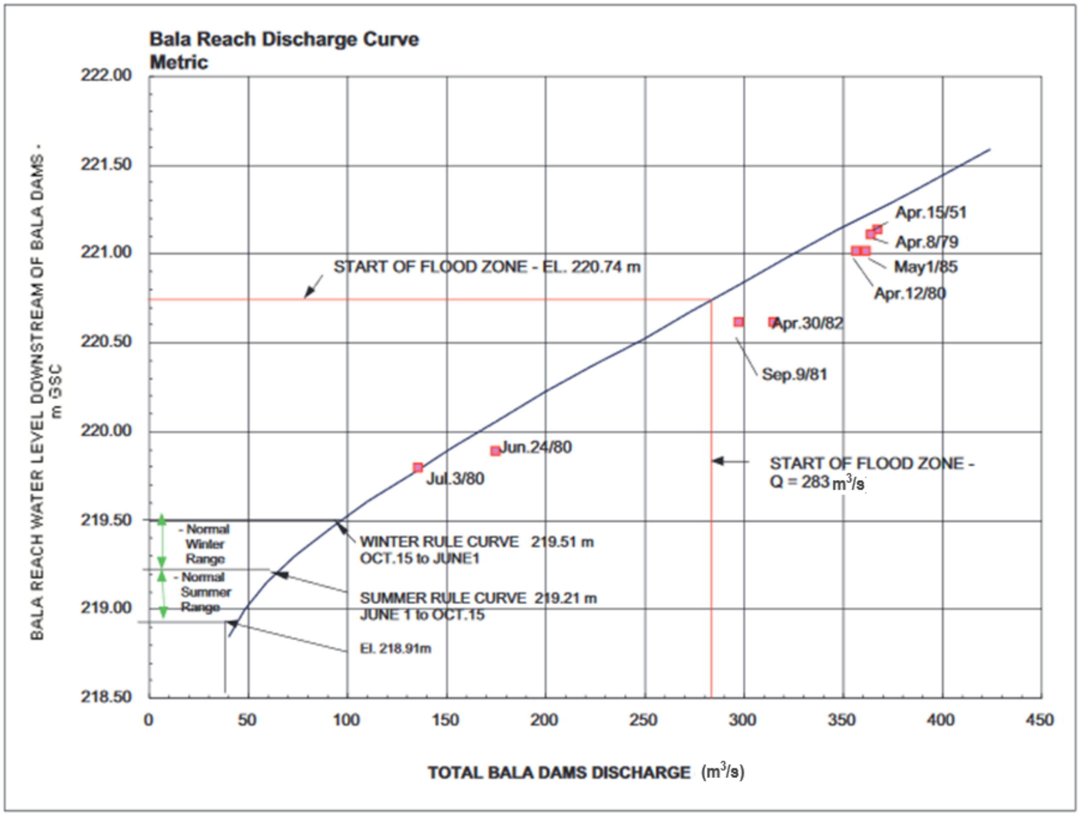


Figure 8. Elevation versus Inflow for Bala Reach[25].

Climate Change Implications

Recent climate change studies[26] forecast earlier and higher winter/spring flows and less summer flow (Figure 9). They also predict increased frequency of higher volume storms. Figure 10 shows that the current 1 in 50-year recurrence time storm may be a 1 in 10-year storm by year 2100. This means that the conditions that gave rise to the floods of 2013, 2016 and 2019 are predicted to occur more frequently in the future. This also means that when mitigation of floods is being considered, solutions need to be watershed based with preference given to increasing upstream storage over increasing flow past choke points, as upstream storage will also help mitigate lower summer flows/potential droughts.

It is recommended to assess all major upstream wetland areas as potential flood storage locations. These natural assets could be evaluated as the initial part of an integrated watershed management plan (IWM). IWM is an evidence-based approach to addressing land use decisions, environmental projects, infrastructure projects and broader public policy options on a watershed scale.

[25] Muskoka River Water Management Plan, 2006. Final Plan Report.
[26] Environment and Climate Change Canada, 2019. Canada's Changing Climate Report.

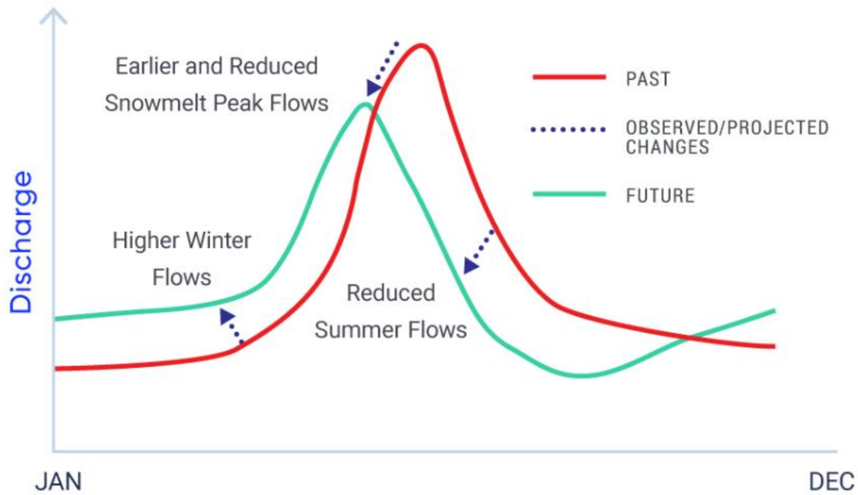
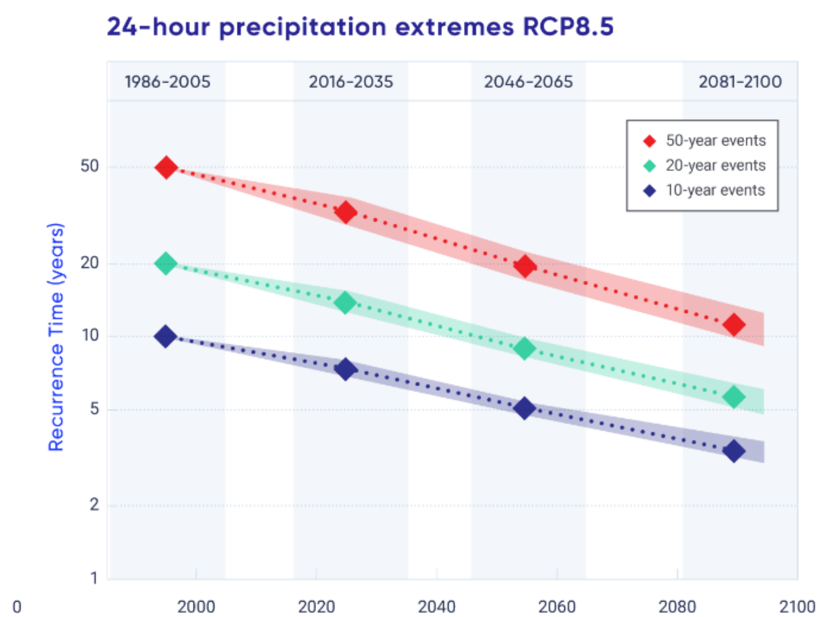


Figure 9. Projected change in stream flows with climate change.

Wetland areas could be enhanced by temporary storage dams, known as rubber dams[27] [28], which can be inflated to retain up to 3 m of water during freshet season. After freshet, dams could be deflated to restore recreational canoe/kayak use of these waterways[29]. As wetlands play a key role in the preservation of water quality as well as mitigating water quantity issues, preservation of these features needs official encouragement. Consideration of some form of tax incentive, such as is done for "managed forests" is recommended. The Conservation Land Tax Incentive Program may provide this service.

Figure 10. Increasing frequency of extreme storms over time due to climate change.



[27] Tam, W.M.P. 1998. Application of inflatable dam technology – problems and countermeasures, Can. J. Civ. Eng. Vol 25, pp 383-388.
[28] Kolte, D. March 2017. Rubber Dam, International Conference on Emerging Trends in Engineering, Science, Management, Hyderabad, India.
[29] Wilson, H. 2003. Canoeing and Hiking Wild Muskoka: an eco-adventure guide, Boston Mills Press, 144pp.

Droughts

The flip side of flooding is drought. MNRF has advised that there have been eight droughts since 1988. Most recent is the the drought of 2016, which followed a spring flood and broke the 123-year-old Provincial record for dryness (Figure 11). Dry or wet summers are now associated with stuck weather patterns where an omega wave pattern of the jet stream delivers long periods of a) cold wet air from the north, or b) hot dry air from the south. Severe dryness, besides lowering lake levels by evaporation, stresses the forests and raises forest fire risks. Treatment for floods needs to be considerate of raising forest fire risks in cottage country.

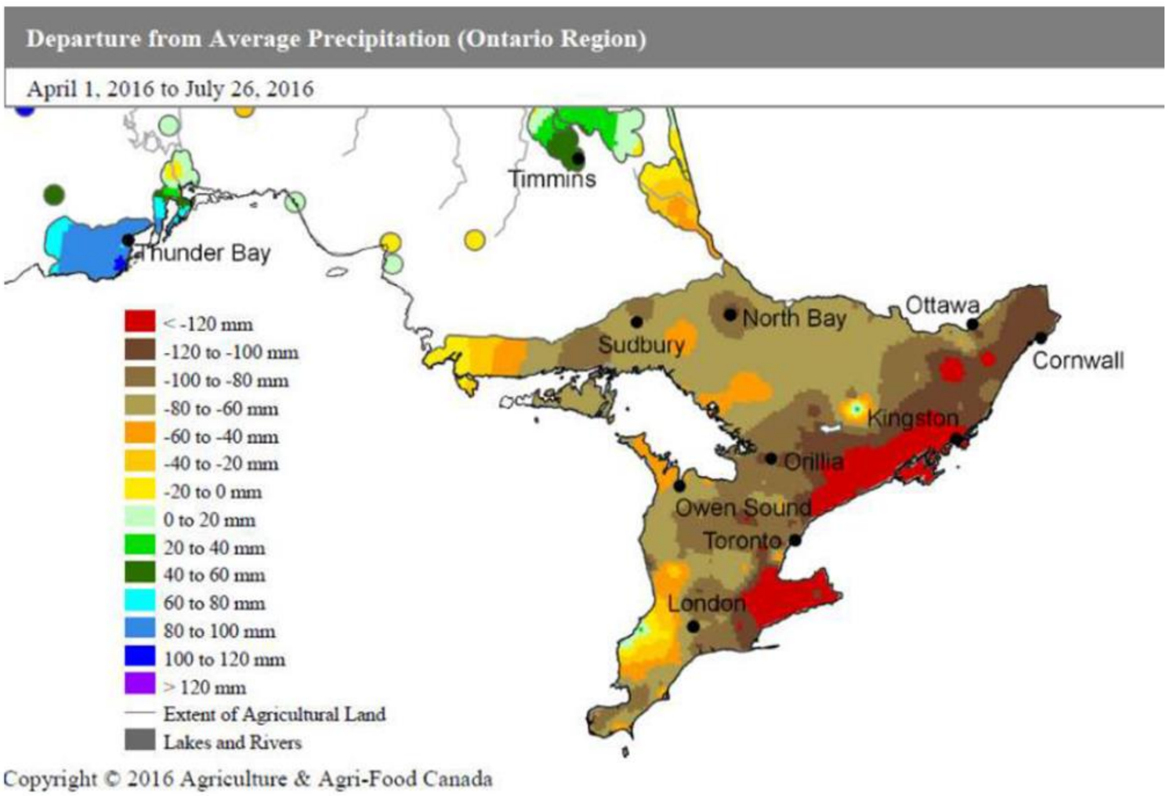


Figure 11. Rainfall deficit below the average, April 1 to July 26, 2016.

Development Implications

When the MRWMP was developed in 2006, it was acknowledged that a large quantity of high value property (i.e. docks and boathouses) is located within the Upper Operating Zone and even a small portion in the Normal Operating Zone[30]. Public input to the MRWMP via the Public Advisory Committee (PAC) listed many concerns about high spring water and ice damage that were documented but, while recognized, were not specifically addressed. Maps from 1899 indicate that many structures predate all water management initiatives in the watershed (see, for example, Figure 12 below). In a previous flood (1985), shoreline landowner concerns voiced by the Muskoka Lakes Association (MLA) resulted in a major, multi-volume study under the 1988

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[30] MRWMP, pg 12-102, 12-106.

Canada-Ontario Flood Damage Reduction program[31]. Despite having less capable analysis tools, this study produced a conservative 1:100 year water level forecast for Lake Muskoka that is remarkably similar to what was experienced in 2019 (Table 5). The District Municipality of Muskoka (DMM) was in the process of floodplain mapping the major development areas of the watershed when the 2019 flood occurred. So, this experience is now included in the mapping results[32]. Due to timing, the 2019 floodplain work does not form part of the recently updated District Official Plan. Updates to town and township Official Plans, based on the district Official Plan, are now in progress. The extent to which the recent floodplain work will be incorporated in these plans is an open question.

Table 5. Comparison between 1988 flood predictions and the 2019 actual flood.

Lake Muskoka	1988 FDRP 1:100-year Flood	2019 Actual Flood
Flood Elevation (m)	226.49	226.45
Drawdown Elevation (m)	224.70	224.76
Snow Water Equivalent (mm)	200	187
3 day rain (mm)	45	58*
Flow @ Port Sydney (m^3/s)	291	235
Flow @ Baysville (m^3/s)	226	160
Flow @ Bala (m^3/s)	514	430

*plus 36 mm 6 days later

Guidance on the location of shoreline structures, elevation of structures and floodproofing construction of structures would be an appropriate addition at this time. This is entirely supportive of the recommendations of the Special Flood Advisor[33] and consistent with recently released Provincial Flooding Policy. Remaining silent, as had been done previously, is no longer appropriate. In addition to treatment in Official Plans, a better public education initiative and possibly registration of water levels on deeds, as recommended by the Flood Advisor, should be considered.

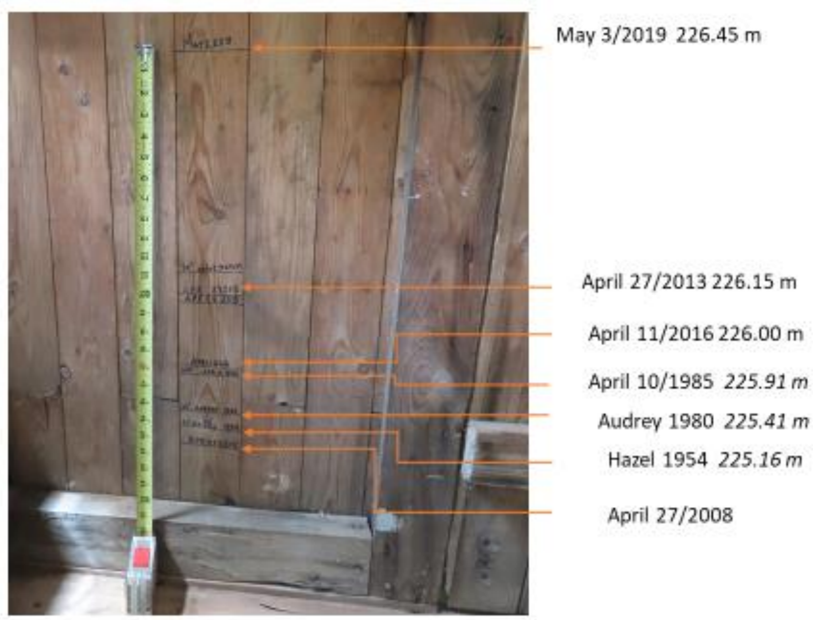

Figure 12. Flood record in the Anderson Boathouse (built 1922) near Beaumaris on Lake Muskoka.

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31 Marshall Macklin Monaghan, March 1988. Hydrology Study for the Major Lakes in the Muskoka Watershed, Report for the Ministry of Natural Resources and Environment Canada, FDR 43, 321pp.

32 Hatch Engineering Report, February 12, 2020. Technical Report for Muskoka River Flood Plain Mapping Study, The District Municipality of Muskoka, H356689-00000-200-230-0002, Rev.0, Ver. 04.03, 131pp.

33 Report of Ontario's Special Advisor on Flooding, 2019, p. 104.

In addition to water level information, building departments need to advise builders about loadings imposed by the expansion of lake ice[34] so that owners may take appropriate measures to protect their structures. As shown in Table 6, lake ice can exert forces on docks and boathouses in the range of 3,000 to 6,000 pounds per lineal foot of structure. These near irresistible forces are unleashed when temperature rises rapidly by 15 to 20°C during one day and there is little insulating snow over the ice. As little as 10 to 15 cm of ice thickness is needed. South facing structures, exposed to the sun, are most susceptible.

Table 6. Ice loads on dams[35].

Ice Loads Primarily Thermally Generated		Maximum Load	
Dam Name	Years of Record	kN/m	Kips/ft**
Paugan Dam, Hydro-Quebec	3	70	4.8
Outdoor Basin, National Research Council	1	47	3.2
Seven Sisters Dam, Manitoba Hydro	1	62	4.2
Pine Falls Dam, Manitoba Hydro	2	61	4.1
McArthur Falls Dam, Manitoba Hydro	2	85	5.8
Ice Loads Generated by Combination of Ice Temperature & Significant Water Level Change*			
Dam Name			
Arnprior Dam, Ontario Power Generation [OPG]	4	210	14.3
Otto Holden Dam, OPG – main reservoir	3	52	3.5
Otto Holden Dam, OPG – East Bay	2	65	4.4
Seven Sisters Dam, Manitoba Hydro	4	374	25.6
Churchill Falls Dam, Newfoundland Hydro	1	89	6.1

*Water level cycled 1 to 2 times per day; intermediate amplitude cycle 10 to 30 cm, large amplitude cycle 40 to 70 cm ** one Kip/ft = 1,000 pounds force per lineal foot of structure

Options for Action

There are two major types of options for decreasing the impacts of floods: mitigation (reducing the amount of flooding), and adaptation (protecting the property at risk from flood damage).

There is no real option to eliminate flooding as the volume of flood water produced by extreme combination weather events exceeds the storage capacity of the entire Muskoka River Watershed. The following are potential ways to lessen the amount of flooding:

1. Modest improvement may come from earlier and deeper lake drawdowns when heavy snow persists on the ground into Spring;

[34] Comfort, G. et al. 2006. Static Ice Loads on Dams, Can. J. Civ. Eng. Vol 30, No 1, pp 42-68.
[35] Comfort, G. et al, 2006. Static Ice Loads on Dams, Can. J. Civ. Eng. Vol 30, No 1, pp 42-68.

2. Structural improvement to watershed choke points can release water more quickly past impediments that are currently causing back ups;

3. Improving upstream storage could decrease the volume of water passed downstream (and potentially later mitigate downstream water shortage in "dry" years); and

4. Offsetting the timing of peak flows from the North and South Branches of the Muskoka River can reduce the coincident peak flow entering the Lower Muskoka Sub-watershed.

On a watershed scale, these options each have potential downside effects to consider. Earlier and deeper drawdowns potentially affect previous season Fall navigation, some water intake pipes and, for shallow properties, use of boathouses and boatlifts. There are also significant unknown effects on aquatic ecosystems and water quality. Removing choke points helps areas upstream while passing the extra volume on to areas downstream. Conversely, enhanced upstream storage may lessen impacts downstream while increasing impacts upstream.

In addition to the above mitigation options, each property owner faces choices in adaptation or flood proofing their own property. To make informed choices, everyone needs to be aware of the risks of and potential damage from high water. With results of the latest floodplain mapping on hand, municipalities should inform new builds and rebuilds on the waterfront about appropriate building levels/setbacks in Official Plan revisions. Broad public education is needed to promote a "build back better" mindset when the service life of structures expire and retrofits are being planned.

Summary

The Muskoka River Watershed is complex. As a result, there is no simple solution to flooding. Even predicting flooding is a difficult task as major floods are associated with the interaction of extreme weather events that are hard to predict.

While there are options to lessen flooding effects, implementing them without considering other elements of the watershed would inevitably come to an incomplete solution. The solution must include the watershed ecosystem, the interests of landowners and the local economy. All three pillars are needed to achieve the environmental quality that we depend on.

Overall, an integrated approach balancing flood management with the needs of all property owners, while preserving the environment that we all value, is needed. In other similar jurisdictions in Ontario, cottager associations have banded together to "share the pain" under the mantra of equitable water flow. In the Muskoka River Watershed, the solution to balance these interests is through Integrated Watershed Management. This will require that all levels of government and NGOs commit to collaborative investment in comprehensive studies to characterize the watershed, land and water resources, our changing climate, and social and economic interactions to ensure one fix doesn't break something else. In Muskoka, our environment is our economy.

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