Spring Hydrological Analysis of Lakes in Climatically Changing Environment of the Mississippi River Watershed

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Abstract

The main objective of this study was to determine if sufficient seasonal rainfall is available after the spring freshet to fill the seven major lakes in the Mississippi River Watershed, from the winter drawdown levels to the summer target levels. At the MVCA, the spring freshet occurs between mid-March and the end of April. The freshet triggers a rush of dam operations spanning the entire watershed to store this inflow while mitigating spring flooding. With an earlier occurrence of the spring freshet, there is a greater risk of reaching target levels too early, potentially exposing the watershed to flooding after the freshet due to reduced storage capacity. The daily levels of each lake, the rainfall from the closest climate station, the flows from the nearest streamflow station, and the storage capacity and runoff associated with each lake were analyzed to determine if the lakes could be filled annually after the freshet. Based on the inputted parameters, the analysis returned probabilities for filling the seven major lakes. The results suggest that the lakes can be partially filled during the freshet while maintaining storage capacity and achieving summer target levels in late spring. Future analysis will develop watershed operational guidelines for reflecting recent hydroclimatic trends.

Introduction

- The MVCA conducts dam operations to keep lake levels consistent and mitigate flooding
- The aim is to fill the lakes by Victoria Day (May 20th) and keep constant levels until Labour Day (Sep 2nd) for recreational lake users
- Lake levels are controlled by the manual addition or removal of stoplogs in the dams at the outlet of each lake, which is a time-consuming operation

Figure 1: Location of the Mississippi Valley Conservation Authority within Conservation Ontario

- Goal: Reduce the risk of spring flooding by optimizing the MVCA's dam operations
- Analyze if it is possible to reduce the amount of dam operations performed by letting some of the spring freshet pass before filling up the lakes for the summer
- The study covers seven major lakes: Big Gull, Crotch, Kashwakamak, Mazinaw, Mississagagon, Shabomeka and Widow Lake (Figure 2a)
- Results present Mazinaw Lake in greater detail (Figure 2b)

Figure 2: (a) Location of the seven major lakes of study and (b) Mazinaw Lake drainage area

Methodology

In the analysis, the following two scenarios are considered.

Scenario I:
Can the lake be filled from its Winter Target Level (WTL) to its Summer Target Level (STL) with the precipitation from the Peak Flow Date to the Target Date? This simulates a situation where most of the freshet water passes through the lake.

Scenario II:
Can the lake be filled from its level on the Spring Peak Flow Date to its Summer Target Level with the precipitation from the Peak Flow Date to the Target Date? This simulates holding most of the freshet water in the lake.

Gather data on:

- Dam operations records, to find target levels and Target Dates (TD)
- Flows, to find Peak Flow Dates (PFD)
- Precipitation, to find the total amount between the PFD and TD
- Levels, to find the levels on the PFD
- Lake area, drainage areas, and runoff estimates to calculate lake storage volumes and runoff

Assumptions:

- Peak Flow Dates are representative of the timing of the freshet
- The lake's storage volume is the area times the change in level
- Precipitation is received uniformly over the drainage area
- The runoff is the amount of precipitation times the runoff coefficient and the area of the land
- Precipitation over the lake is not subject to any loss

Steps:

1. Compile all necessary data for the analysis.
2. Assuming reasonable runoff coefficients, calculate the total volume of water ending up in the lake.

$$V_{tot\ in} = V_{land\ precip} \cdot C + V_{lake\ precip}$$

3. Compare the volume of water received with the storage volume of the lake

Results

Data for Mazinaw Lake:

- The Summer Target Level is 267.8 m.a.s.l., the Winter Target Level is 266.7 m.a.s.l. and the TD is May 18th
- The PFD, the total precipitation from the PFD to May 18th and the level on the PDF are listed in Table 1
- The area of the lake is 16.3 km^2 and the drainage area is 339 km^2
- Chosen runoff coefficients include C = 0.1 and C = 0.5, to represent a range of possibilities
- The storage volume of the lake is 1793 ha*m

Year	PFD	Precip (mm)	Reaches STL?		Level on PFD	Reaches STL?	
			C = 0.1	C = 0.5		C = 0.1	C = 0.5
2001	Apr 16	16	N	N	267.74	N	Y
2002	Apr 20	95	N	N	267.76	Y	Y
2003	Apr 05	68	N	N	267.24	N	Y
2004	Apr 08	69	N	N	267.43	N	Y
2005	Apr 13	36	N	N	267.72	Y	Y
2006	Apr 07	124	N	Y	267.74	Y	Y
2008	Apr 22	50	N	N	267.98	Full	Full
2009	Apr 07	100	N	N	267.92	Full	Full
2010	Mar 21	131	N	Y	267.37	N	Y
2012	Mar 22	113	N	Y	267.56	Y	Y
2013	Apr 22	54	N	N	267.78	Y	Y
2014	Apr 18	120	N	Y	268.18	Full	Full
2015	Apr 24	17	N	N	267.67	N	Y
2016	Apr 06	90	N	N	267.93	Full	Full
2017	Apr 14	202	N	Y	268.03	Full	Full
2018	Apr 30	23	N	N	268.14	Full	Full
2019	Apr 23	126	N	Y	268.57	Full	Full
2020	Apr 08	157	N	Y	267.85	Full	Full
2021	Apr 01	95	N	N	267.52	Y	Y
2022	Apr 11	117	N	Y	267.65	Y	Y
2023	Apr 15	172	N	Y	267.85	Full	Full
			0%	**43%**		**76%**	**100%**

Table 1: Theoretical percentages of Mazinaw Lake's Summer Target Level achievement based on historical data

What is the occurrence of filling the lake under Scenario I?
Mazinaw Lake will not reach its Summer Target Level at a runoff coefficient (C) of 0.1. With a C = 0.5 it will reach its target 43% of the time based on the past 21 years of available data. (Table 1)

How about under Scenario II?
The occurrence of filling the lake become far more likely in Scenario II. With a coefficient of 0.1, the occurrence is at 76%, and with a coefficient of 0.5, the data shows that the lake would fill every time in the 21 years of available data. (Table 1)

Results

What is a typical year like?
A typical year under Scenario I shows the lake reaching 28% of its storage volume for C = 0.1 and 103% (slightly over capacity) for C = 0.5 (Table 2).

What were the years representing minimum and maximum precipitation conditions like?
The lake does not reach capacity in the minimum year (16 mm received in 2001), and, in the maximum year (202 mm received in 2017), the lake reaches half capacity with a conservative C and doubles capacity with a high C under Scenario I (Table 2).

Precipitation (mm)	Scenario I % full from the WTL		Scenario II % full from the PFDL		Change in level (m)	
	C = 0.1	C = 0.5	C = 0.1	C = 0.5	C = 0.1	C = 0.5
16 (Min 2001)	4%	16%	76%	277%	0.05	0.17
104 (Average)	28%	103%	6324%	23132%	0.31	1.14
202 (Max 2017)	55%	200%	Full	Full	0.60	2.20

Table 2: Storage capacity conditions of Mazinaw Lake in a typical year, in the minimum year (2001) and in the maximum year (2017)

Is the Peak Flow Date happening earlier?
This fact is not reflected in the data in Figure 3a, but climate change points to an earlier occurrence of the spring freshet.

Is the watershed receiving more precipitation in the spring?
Yes, there has been an increase in precipitation in recent years; conditions might also be more variable (Figure 3b).

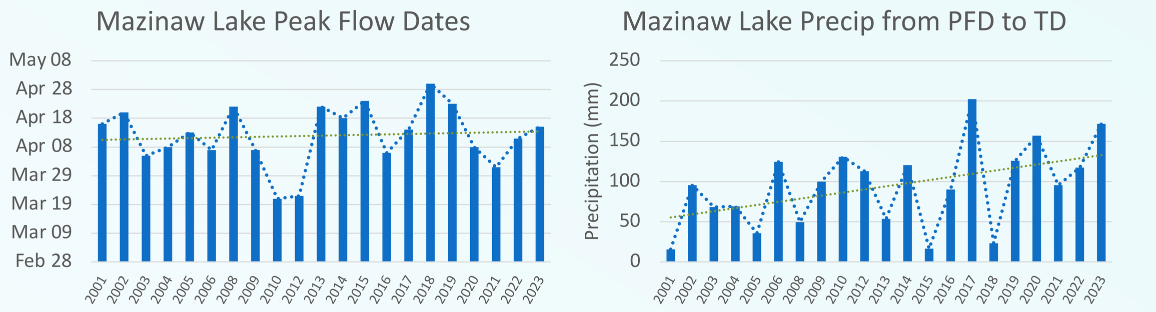

Figure 3: Mazinaw Lake (a) Peak Flow Dates and (b) Precipitation from the PFD to TD

Conclusion

- A portion of the freshet water may pass through the system before raising lake levels
- This operation remains a delicate balance due to the variable nature of climate
- Next steps include research to develop numerical flood forecasting models to assist with operations
- This study offers crucial insights for optimizing dam operations and mitigating spring flooding in a changing climate