Great Lakes Forecast from Oct 2019 – Dec 2020

Figure 1: Seneca Ave - Algonquin Island 2019

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This report looks at the historical Great Lakes data and is used to formulate a forecast of the Great Lakes levels from October 2019 through to December 2020.

Lake level data for all of the Great Lakes is based on the Fisheries and Oceans Canada (FOC) recorded data going back to 1918. I have received similar data from the International Joint Commission (IJC) and the US Army Corp of Engineers as well as the Great Lakes Environmental Research Laboratory (GERL). The data since 2017 come directly from the FOC and IJC websites. The lake level data is taken from specific individual gauges on the lakes, so there may be a small error compared to lake-wide averaging of levels.

The data at the bottom of each chart in the appendix lists the monthly mean levels, min and max levels, the range, the standard deviation (sigma) and the +/- 3 sigma values. The +/- 3 sigma values are the statistical limits that capture 99.7% of all lake levels based on the sample data.

All of the Great Lakes in 2019 are well above their 100 yr average levels, especially MI-Huron and Erie. I have included Lake St. Clair with the Great Lakes because it is a key inter-connecting channel between MI-Huron and Erie.

LAKE LEVELS ABOVE THEIR 100 YR MEAN (measurements are in meters)										
2019	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
SUPERIOR	0.28	0.29	0.31	0.33	0.41	0.39	0.33	0.31	0.30	0.32
MI-HURON	0.57	0.60	0.60	0.61	0.72	0.81	0.84	0.82	0.80	0.88
ST. CLAIR	0.56	0.61	0.64	0.64	0.75	0.80	0.83	0.79	0.75	0.79
ERIE	0.65	0.64	0.51	0.55	0.69	0.76	0.78	0.73	0.67	0.68
ONTARIO	0.27	0.38	0.29	0.29	0.70	0.87	0.80	0.66	0.53	0.48

The question is why are the lakes so high?

Let's start by looking at Lake Superior, the largest of the Great Lakes covering 82,100 km^2 and the lake with the highest elevation. Lake Superior does not have any inflowing interconnecting channels. It has one outflowing interconnecting channel at Sault St. Marie through a set of locks and compensating works into the St. Mary's River. It also has two interbasin diversions into the lake know as Ogoki and Long Lac. There is not a lot of diversion data readily available from Ontario Power Generation (OPG) after 2016, but the average flow prior to 2016 is only 143 m^3/s.

The factors affecting the fluctuating lake levels, also known as the "change in supply", are inflows and outflows from/to interconnecting channels, precipitation, and run-off from the surrounding drainage basin, evaporation and diversions (D). The combined group of precipitation (P), run-off (R) and evaporation (E) are referred to as Component Net Basin Supply (CNBS). The relationship is as follows:

CNBS = P + R – E

The problem with using CNBS is that they are estimates only. It is difficult to use them in water balance equations due to inaccuracies of the estimates.

I prefer to use a modified Residual Net Basin Supply (RNBS) calculation, where:

RNBS = P + R – E +/- D

Using this relationship, we can balance the water equation.
The change in lake supply (△S) equals the change in lake level over the surface area of the lake.

△S = RNBS + I – O

Where I = inflow from interconnecting channels
O = outflow to interconnecting channels

Using the modified RNBS values, we can balance the equations with known values of lake levels and flows. Collectively, the RNBS values mainly represent the influence of climate on the lakes.

Since Lake Superior does not have any inflow from interconnecting channels, the only two factors affecting the lake's supply are RNBS and Outflow. Over the last five years, the average annual RNBS has been about 10% higher than the historic average, and in Lake Ontario flood years 2017 and 2019 it was close to 20%-30% higher. The IJC have increased the outflows from Lake Superior to help offset the higher RNBS, so looking at the ratio of RNBS/Outflow is a useful analytical tool.

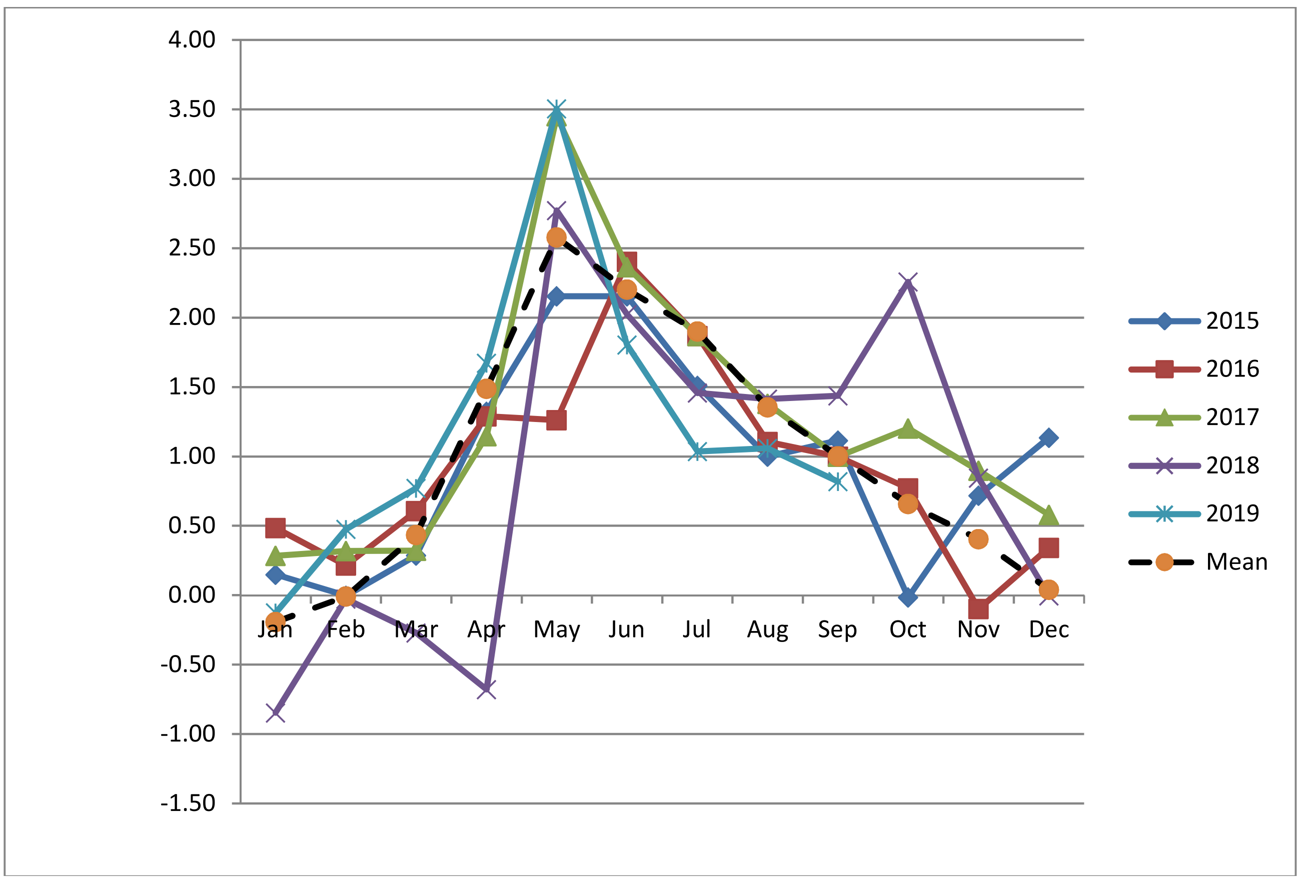

Figure 2: Lake Superior RNBS/OUTFLOW Ratio

From the graph above, any ratio >1 will increase the lake level. During the last five years, the Apr-Oct periods are predominantly lake level increasing periods, which doesn't give the lake enough time to drain back down before the next increasing cycle begins. This cycle has resulted in Lake Superior's annual average level to increase every year since 2011.

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So far in 2019, the Lake Superior average outflow is about 25% higher than the historic average outflow. Lake Superior's Plan 2012 uses a benchmark lake level of 183.9m to set maximum outflows and the lake is approaching that threshold limit, so it is likely that the IJC will increase the outflows from Lake Superior to try to reduce the lake levels. This will create even larger problems for the downstream lakes which are already over-stressed by extremely high lake levels. It will be absolutely devastating for Lake Ontario which has restrictions on outflow as determined by Plan 2014.

Lakes MI-Huron are the next largest Great Lakes. They share the same elevation and are separated by the Strait of Mackinac, which is only 6.5km wide. Their combined size exceeds that of Lake Superior and covers 117,600km^2. Lakes MI-Huron has one inflowing interconnecting channel coming from Lake Superior via the St. Mary's River. It has one outflowing interconnecting channel through the St. Clair River and one interbasin diversion out of the system to the Illinois River at Chicago. The average diversion outflow is only 91 m^3/s.

Since MI-Huron has inflow, RNBS and outflow influencing lake levels, a more useful analytical tool is the following: (Inflow + RNBS)/Outflow.

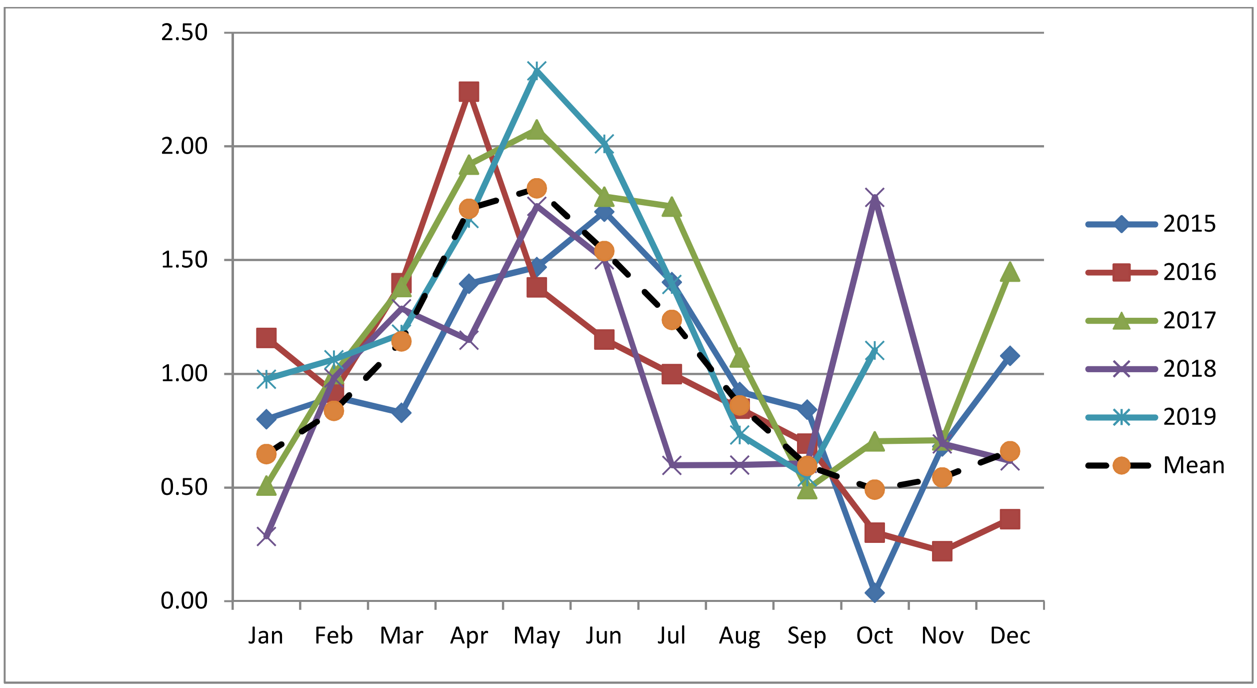

Figure 3: Lakes MI-Huron (INFLOW+RNBS)/OUTFLOW Ratio

During the last five years, the Mar-Jul periods are predominantly lake level increasing periods, with Feb generally being a slightly balanced system, while the rest of the year the levels generally drop, however since 2013, the drops have not matched the increases and the result is that there have been annual increases in the average lake levels since then. The lakes are at near record level this year and the October Lakes MI-Huron levels are on track for another increase.

It is important to look at the two factors, inflow and RNBS. Historically, the average ratio of Inflow/RNBS = 0.66, but the 2019 ratio = 0.44. In 2019, the RNBS has influenced the lake level much more than the regulated inflow from Lake Superior. The RNBS of MI-Huron is 86% higher than the historic average and this unusually high RNBS is impacting all of the downstream lakes.

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Lakes MI-Huron are not regulated, meaning that the flow into the St. Clair River is open channel flow. This implies that the outflow is related to the lake level. There are many factors that affect the actual flow in rivers, but in general, as the lake level increases the flow will increase too. Therefore, it is very concerning that as Lake Superior approaches its 183.9m level and the IJC decides to implement higher outflows, that it will further stress the downstream lakes. Higher Lake Superior outflows will ripple through the middle Great Lakes and eventually reach Lake Ontario.

The graph below plots MI-Huron outflow vs lake level. There is a strong correlation between the two.

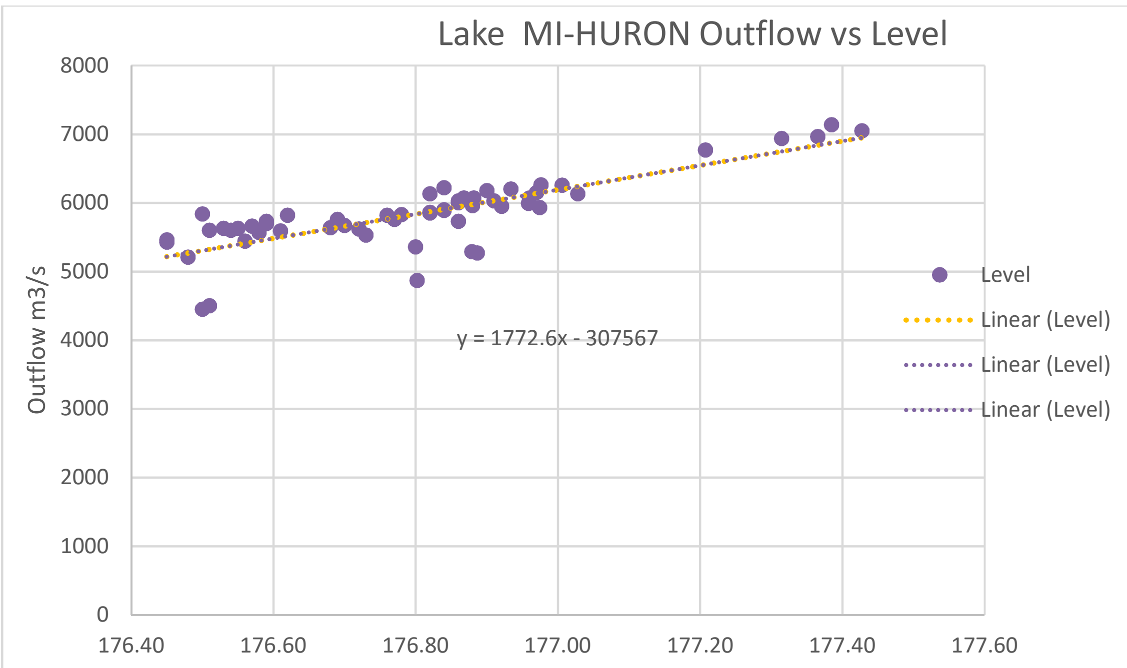

Figure 4: MI-Huron Outflow vs. Lake Level (data from 2015-present)

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Lake St. Clair lies between Lakes MI-Huron and Lake Erie, covering 1,170km^2, with flow into the lake from the St. Clair River and out via the Detroit River. The lake acts as a small buffer between the Great Lakes, but in general will follow their patterns. Like MI-Huron, Lake St. Clair has risen annually since 2013 and is at near record levels.

Both the St. Clair River and the Detroit River are unregulated, open channel flow systems. They have undergone many dredging operations over the years to help balance the flow through the system. Looking at the relationship of MI-Huron outflow vs. Lake St. Clair outflow you can see that it is fairly well balanced.

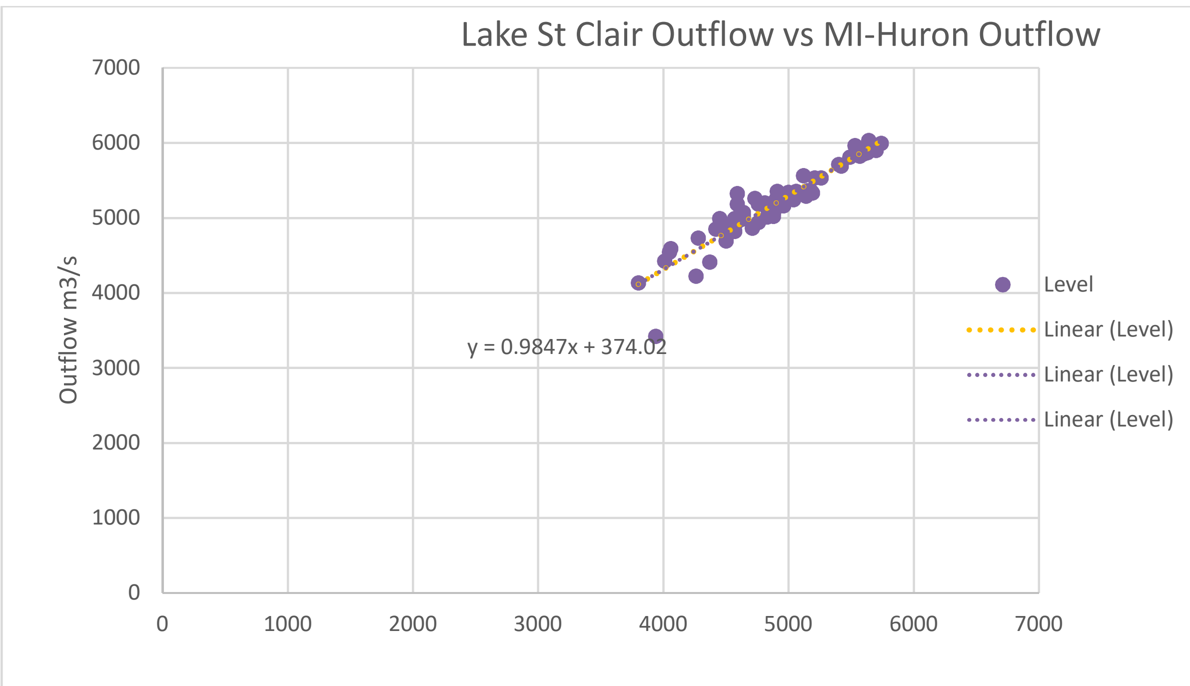

Figure 5: Lake St. Clair Outflow vs. MI-Huron Outflow (data 2015-present)

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Lake Erie is unregulated and covers 25,800km^2. It receives inflow from the Detroit River and outflows via the Niagara River into Lake Ontario. It has one interbasin diversion through the Welland Canal into Lake Ontario. The Welland Canal diversion averages 244 m^3/s.

Like Lakes MI-Huron, Lake Erie's annual lake level has been increasing steadily since 2013. The outflow is open channel flow out over Niagara Falls and generally increases with lake levels. The historic average outflow from Lake Erie is 6024 m^3/s, but in 2019 with near-record lake levels the average outflow so far this year is 7537 m^3/s, 25% above the historic average. You can see from the graph of 2019's outflow vs. lake level that the data correlates reasonably well.

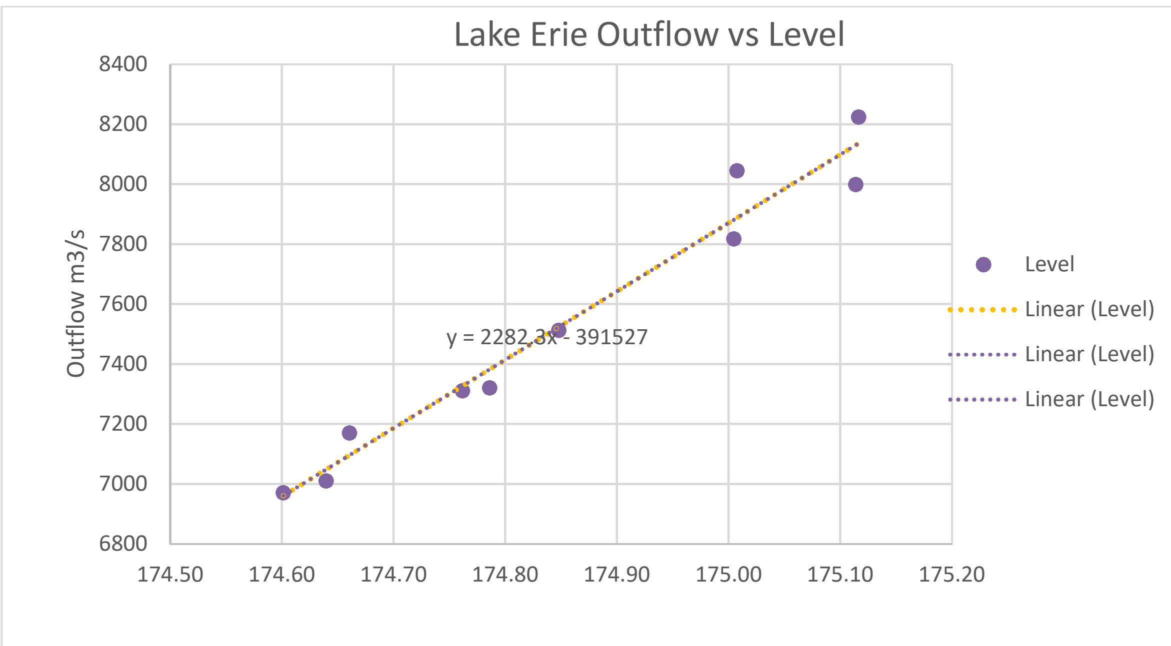

Figure 6: Lake Erie Outflow vs. Level (data 2019)

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Lake Erie is subject to inflow, outflow and RNBS, so looking at the ratio of (I+RNBS)/O shows a slightly different pattern than Lakes MI-Huron graph. It is a much flatter sinusoidal curve with Dec-Jul being predominantly lake level increasing periods. Again, the Aug-Nov period of decreasing lake level is not sufficient to offset the lake level increases from the rest of the year.

Looking at the relationship of RNBS and inflow we see that inflow has a far more significant impact on lake levels than RNBS. Historically, the ratio of Inflow/RNBS = 7.1, and in 2019 the ratio = 6.9, which isn't too different. But the 2019 inflow is 25% higher than the historic average, and the 2019 RNBS is 29% more than the historic average and their combined increases have resulted in increases in supply. To lower Lake Erie's levels, the inflow must be reduced.

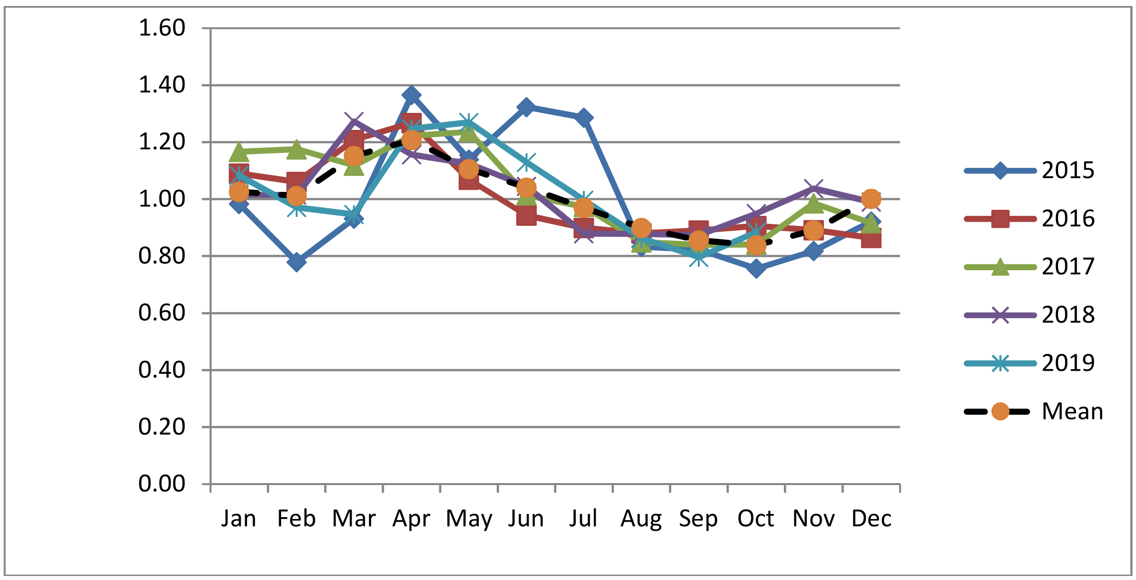

Figure 7: Lake Erie (Inflow+RNBS)/Outflow (data 2015-present)

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Lake Ontario is the last of the Great Lakes system and the lowest elevation of all the Great Lakes. It covers 19,000km^2 and has inflow from Lake Erie through the Niagara River, outflow to the St. Lawrence River through the Moses-Saunders Dam at Cornwall. It has one interbasin diversion from Lake Erie through the Welland Canal.

Lake Ontario is regulated by the IJC under Plan 2014. This regulation sets outflow limits based on specific conditions and time of year. The objective of the plan is to optimize flows to primarily serve the navigation and hydro-electric industries at the peril of riparians.

Lake Ontario reached historic levels in 2017 and those level were exceeded in 2019. Both years resulted in catastrophic flooding around the lake.

Analyzing the (Inflow + RNBS)/Outflow data, the historic pattern is for the lake levels to increase from Dec-Jun, then drop from Jul-Nov.

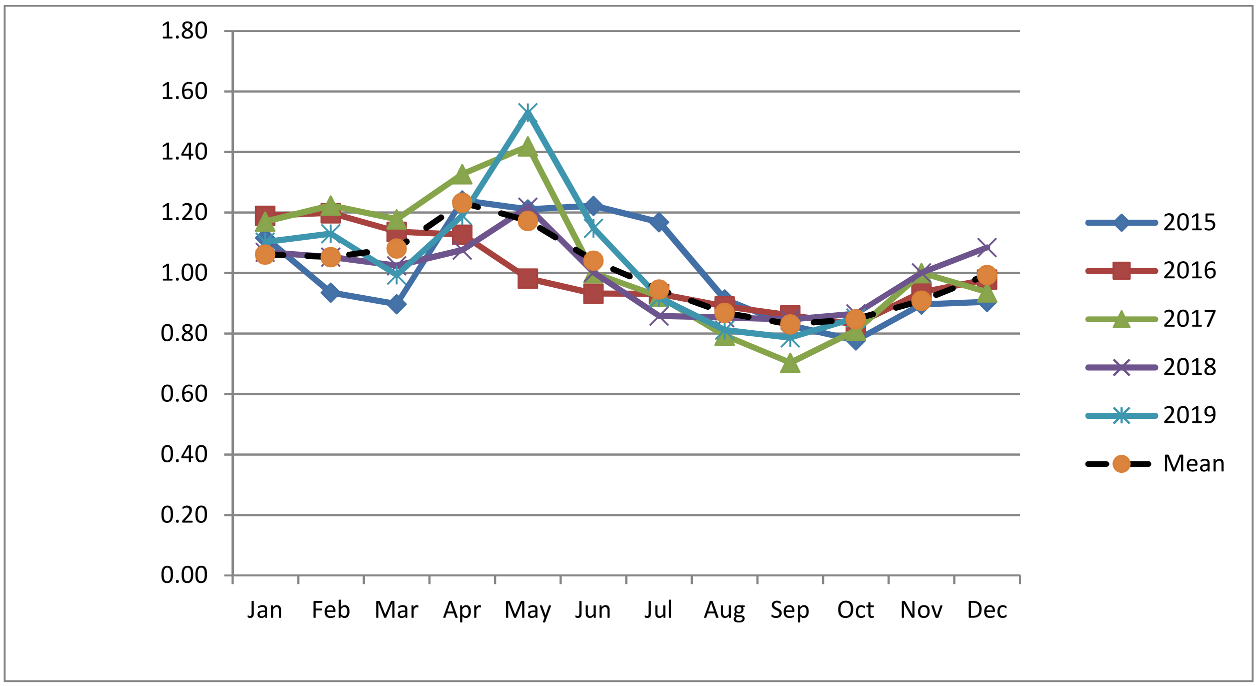

Figure 8: Lake Ontario (Inflow + RNBS)/Outflow (data 2015-present)

We know that the historic average Lake Erie outflow makes up 85% of Lake Ontario's net total supply (NTS). The average inflows coming from Lake Erie have increased each year since 2013. The average inflow, so far in 2019, is 25% higher than the historic average. This continuously high inflow is putting massive pressure on the lake, as the outflow is restricted.

Lake Ontario's RNBS is quite random but in both 2017 and 2019, the average RNBS is significantly higher than the historic average. In 2017 it was 62% higher than the historic average and so far in 2019 it is 49% higher. This observation supports the notion that if the lake levels are kept too high, there is insufficient buffer to handle variations in RNBS due to extreme climate events and flooding will occur.

The IJC outflow regulation restrictions puts Lake Ontario in a very vulnerable position when the upper Great Lakes are high, especially when it is combined with higher than normal RNBS. The concern now in the fall of 2019, is that Lake Ontario's level will not drop enough before the next cycle begins in Dec, and as a result, flooding in the spring of 2020 will be potentially worse than 2019.

Attached is a forecast with 5 different scenarios. The upper section of the table shows the key inputs for each lake since January 2015 and the actual lake levels that were recorded. This is to validate the forecasting equations. The 5 forecast scenarios below the actual data use these same equations to forecast the lake levels through to Dec 2020.

Forecast 1 simply uses the average values of inflow, outflow and RNBS calculated from 2015-present. I've chosen to use these averages instead of the historic averages because this data is more relevant to our current climate conditions.

The spring/summer period is highlighted and it is clear that the Lake Ontario will have major flooding with this scenario. Higher levels of precipitation will add to the problem.

Forecast 2 uses the same assumptions, except that the Lake Ontario outflow has been set at 9,000 m^3/s through until Dec1. As of Oct5, the IJC has dropped the outflow below this marker, but if 9,000 m^3/s could be maintained until Dec1, it would greatly reduce the flooding impact.

Forecast 3 uses the same assumptions, except that the Lake Ontario outflow has been set up to 10,000 m^3/s through until Dec1. This level of outflow would drop the lake level to a safe level and no flooding will occur in 2020.

Forecast 4 is similar to Forecast 1, except the inflows coming from Lake Erie have been increased from the average 2015-present values to a value determined by the best-fit outflow vs. level equation. It might sound confusing, but this equation produces higher outflows from Lake Erie that are consistent with the current 2019 outflows. This makes the 2020 flooding worse.

Forecast 5 is similar to Forecast 3, except the inflows coming from Lake Erie have been increased from the average 2015-present values to a value determined by the best-fit outflow vs. level equation. The Lake Ontario Outflow is bumped up to 10,000 m^3/s through until Dec1. This level of outflow would drop the lake levels and greatly reduce the flooding impact.

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Conclusion:

All of the Great Lakes are experiencing higher RNBS due to climate conditions. The combined RNBS contribution to supply in the upper Great Lakes will keep a continuous high inflow into Lake Ontario at least through 2020.

The IJC is following the Plan 2014 regulation for Lake Ontario and have started to reduce outflow through the Moses-Saunders Dam to match the prescribed L-limit flow, but this flow will not drop Lake Ontario enough to compensate for the spring change in supply. If the upper Great Lakes levels were close to their historic average and next spring's RNBS is somewhat average, then the system L-limits will work, but the current formula fails to take into consideration the flow potential of the upper Great Lakes.

From the Plan 2014 Compendium Document:
"The Board may also use the information acquired through the adaptive management strategy to propose to the Commission modifications to the plan should it learn over time that conditions (climatic, socio-economic or environmental) have changed enough such that the plan is no longer meeting its intended objectives or improvements to the plan could realize increased benefits."

This is a case where the Board must intervene and modify the flow limits to reduce the Lake Ontario levels down to ideally 74.5m before the next cycle begins, otherwise the lake will be faced with another catastrophic flood in spring 2020.

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Appendix:

1. Great Lakes Forecast
2. Lake Superior Levels
3. Lake Superior Outflows
4. Lake Superior RNBS
5. Lake MI-Huron Levels
6. Lake MI-Huron Outflows
7. Lake MI-Huron RNBS
8. Lake St Clair Levels
9. Lake St Clair Outflows
10. Lake St Clair RNBS
11. Lake Erie Levels
12. Lake Erie Outflows
13. Lake Erie RNBS
14. Lake Ontario Levels
15. Lake Ontario Levels Graph
16. Lake Ontario Outflows
17. Lake Ontario RNBS

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