
Cumulative Impact Assessment of Withdrawals, Consumptive Uses and Diversions

2011-2015



Great Lakes-St Lawrence River
Water Resources Regional Body

Great Lakes-St. Lawrence River Basin
Water Resources Council

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Great Lakes - St. Lawrence River Water Resources Regional Body
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Executive Summary

In the Great Lakes-St. Lawrence River Basin Sustainable Water Resources Agreement (Agreement), the Great Lakes and St. Lawrence River States and Provinces (the Parties) commit to periodically assess the cumulative impacts of Withdrawals, Consumptive Uses and Diversions of Water from the Great Lakes—St. Lawrence River Basin (Basin). Similar commitments are included for the Great Lakes States in the companion Great Lakes-St. Lawrence River Basin Water Resources Compact (Compact). As required by the Agreement and Compact, the cumulative impact assessment will be conducted for each Lake and St. Lawrence River watershed and for the entire Basin. The assessment fulfills the requirement of the Compact and Agreement. The assessment will be used for a review of decision making standards and their application, and for other purposes.

The Basin water budget is an accounting of water flows into and out of the Basin. Some of these flows are natural and some are constructed or affected by humans. Withdrawals, Consumptive Uses, and Diversions are part of the water budget. These flows vary from year to year, either due to variability in climate or due to human activities. The timeframe for this assessment is 2011-2015. For comparative purposes, longer data sets for flows are presented to provide a historical context for 2011-2015 data. The longer data sets are 1948-2015.

Inflows include precipitation on the surface of the Lake(s), surface water runoff to the Lake(s) or River, Diversions into some Lakes, and connecting channel flows into each of the Lakes or River, except for Lake Superior which does not have an inflowing connecting channel. Outflows include evaporation from the surface of the Lake(s), Diversions from some Lakes, connecting channel flows out of each of the Lakes, and Consumptive Uses. The St. Lawrence River is the outflow for Lake Ontario and the entire Basin. Although Withdrawals are a component of water budgets, this assessment considers only the hydrologic effect of Consumptive Uses and Diversions. Consumptive Use is the portion of water withdrawn but not returned due to evaporation, incorporation into products, and other processes.

The cumulative hydrologic effect of Consumptive Uses and Diversions are small relative to inflows. Further, while inflows fluctuate from 2011-2015, the cumulative hydrologic effect of Consumptive Uses and Diversions is fairly constant for these annual averages. The net effect of Consumptive Uses and Diversions is positive for the Basin's water budget. In other words, more water is diverted into the Basin than the total combined amount of water diverted out of the Basin or withdrawn and not returned.

The specific contribution made by Diversions and Consumptive uses at any given point in time or space, separate and apart from natural variability, is uncertain given the complex hydrologic, geographic, and temporal variability of uses, and other factors. Since Diversions and Consumptive Uses are small compared to natural flows, their cumulative hydrologic effect on water levels is likewise small. A small hydrologic effect, however, does not necessarily mean that there are no cumulative impacts. On the contrary, a small hydrologic effect may still lead to significant impacts on ecosystems or other water uses depending on the scale or type of impacts being evaluated. Future assessments may reflect advancements in science, data, information, and assessment methods, and will investigate this distinction further.

Introduction

In the Great Lakes-St. Lawrence River Basin Sustainable Water Resources Agreement (Agreement), the Great Lakes and St. Lawrence River States and Provinces (the Parties) commit to periodically assess the cumulative impacts of Withdrawals, Consumptive Uses and Diversions of Water from the Great Lakes—St. Lawrence River Basin (Basin). Similar commitments are included for the Great Lakes States in the companion Great Lakes-St. Lawrence River Basin Water Resources Compact (Compact). As required by the Agreement and Compact, the cumulative impact assessments will be conducted for each Lake and St. Lawrence River watershed and for the entire Basin. The assessment fulfills the requirement of the Compact and Agreement. The assessment will be used for a review of decision making standards and their application, and for other purposes.

Purpose

Pursuant to Article 209 of the Agreement and Section 4.15 of the Compact the Parties¹ “...shall collectively conduct within the Basin, on a Great Lake and St. Lawrence River Basin basis, a periodic assessment of the Cumulative Impacts of Withdrawals, Diversions and Consumptive Uses from the Waters of the Basin. The assessment of the Cumulative Impacts shall be done upon the earlier of:

- a. Every 5 years;
- b. Each time the incremental losses to the Basin reach 50,000,000 gallons (190,000,000 litres) per day average in any 90-day period in excess of the quantity at the time of the last assessment; or,²
- c. At the request of one or more of the Parties.

The assessment of Cumulative Impacts shall form a basis for the review of the Standard and the Exception Standard and their application. This assessment shall:

- a. Utilize the most current and appropriate guidelines for such a review, which may include but not be limited to Council on Environmental Quality and Environment Canada guidelines;
- b. Give substantive consideration to climate change or other significant threats to Basin Waters and take into account the current state of scientific knowledge, or uncertainty, and appropriate Measures to exercise caution in cases of uncertainty, if serious damage may result;
- c. Consider Adaptive Management principles and approaches recognizing, considering and providing adjustments for the uncertainties in, and evolution of, science concerning the Basin’s water resources, watersheds and ecosystems including potential changes to Basin-wide processes, such as lake level cycles and climate; and,
- d. [The Regional Body shall] [i]nclude the evaluation of Article 201 [of the Agreement] concerning Exceptions. Based on the results of this assessment, the provisions in that Article may be maintained, made more restrictive or withdrawn....”

Furthermore, the review and potential revisions to Basin-wide water conservation and efficiency goals and objectives pursuant to Article 304 paragraph 3 of the Agreement and Section 4.2.3 of

¹ Quoted text taken from Article 209 of the Agreement. Section 4.15 of the Compact includes similar language.

² As of 2013, the Great Lakes Commission, at the request of the Regional Body and Compact Council, includes an interim cumulative impact assessment as an appendix to annual water use reports. This scaled-down assessment compares a given year’s water use data against Lake and River water budget data as included in the most recent 5-year assessment.

the Compact must be in part based on the cumulative impact assessment.

Definitions

The standard definitions set forth in Article 103 of the Agreement and Section 1.2 of the Compact shall apply to the cumulative impact assessment, including the following terms:

“Basin or Great Lakes—St. Lawrence River Basin” means the watershed of the Great Lakes and the St. Lawrence River upstream from Trois-Rivières, Québec within the jurisdiction of the Parties.

“Consumptive Use” means that portion of Water Withdrawn or withheld from the Basin that is lost or otherwise not returned to the Basin due to evaporation, incorporation into Products, or other processes.

“Cumulative impacts” mean the impact on the Great Lakes—St. Lawrence River Basin Ecosystem that results from incremental effects of all aspects of a Withdrawal, Diversion or Consumptive Use in addition to other past, present, and reasonably foreseeable future Withdrawals, Diversions and Consumptive Uses regardless of who undertakes the other Withdrawals, Diversions and Consumptive Uses. Cumulative impacts can result from individually minor but collectively significant Withdrawals, Diversions and Consumptive Uses taking place over a period of time.

“Diversions” means a transfer of Water from the Basin into another watershed, or from the watershed of one of the Great Lakes into that of another by any means of transfer, including but not limited to a pipeline, canal, tunnel, aqueduct, channel, modification of the direction of a watercourse, a tanker ship, tanker truck or rail tanker but does not apply to Water that is used in the Basin or Great Lakes watershed to manufacture or produce a Product that is then transferred out of the Basin or watershed.

“Source Watershed” means the watershed from which a Withdrawal originates. If Water is Withdrawn directly from a Great Lake or from the St. Lawrence River, then the Source Watershed shall be considered to be the watershed of that Great Lake or the watershed of the St. Lawrence River, respectively. If Water is Withdrawn from the watershed of a stream that is a direct tributary to a Great Lake or a direct tributary to the St. Lawrence River, then the Source Watershed shall be considered to be the watershed of that Great Lake or the watershed of the St. Lawrence River, respectively, with a preference to the direct tributary stream watershed from which it was Withdrawn.

“Withdrawal” means the taking of Water from surface Water or groundwater. **“Withdraw”** has a corresponding meaning.

Approach to Assessing Cumulative Impacts

The approach to assessing cumulative impacts for the period 2011-2015 is identical to that used in the first 5-year assessment for 2006-2010. The assessment focuses on the hydrologic effects of Withdrawals, Consumptive Uses and Diversions on water supply and flow at Watershed and Basin scales. These hydrologic effects are presented in the context of Watershed and Basin water budgets: that is, the flows into and out of each Watershed and the Basin. This assessment presents water budgets for the entire Basin and for each of the individual Watersheds. These include the

watersheds for Lake Superior, Lakes Michigan-Huron, Lake Erie, Lake Ontario (collectively, Lakes) and the St. Lawrence River (River). In the future, information may be developed through research and monitoring that would enable consideration of impacts other than hydrologic, such as economic and environmental, for the Basin, Lake, and River Watersheds.

The timeframe for this assessment is 2011-2015. For comparative purposes, longer data sets for flows are presented to provide a historical context for 2011-2015 data. The longer data sets for natural flows and Diversions are 1948-2015. For consumptive use, data for 2011-2015 are compared to those from the previous five-year report. Future assessments may take a different approach as data and information improve. To that end, in 2011 the Parties adopted new water use reporting protocols that improved the timeliness, consistency and comparability of water use data. In 2013, the Parties developed new metadata protocols that track differences in reported values from one year to another. This metadata has greatly improved the quality of water use data reported by the Parties. The Parties further reviewed and revised these protocols in 2016.

The Basin water budget is an accounting of water flows into and out of the Basin. Some of these flows are natural and some are constructed or affected by humans. Withdrawals, Consumptive Uses and Diversions are part of the water budget. Each of these flows vary from year to year, either due to climate variability or due to human activities.

Inflows include precipitation on the surface of the Lake(s), surface water runoff to the Lake(s) or River, Diversions into some Lakes, and connecting channel flows into each of the Lakes or River, except for Lake Superior which does not have an inflowing connecting channel. Outflows include evaporation from the surface of the Lake(s), Diversions from some Lakes, and connecting channels flows out of each of the Lakes and Consumptive Uses. The St. Lawrence River at Trois Rivieres, Quebec is the outflow for the entire Basin. Although Withdrawals are a component of water budgets, this assessment considers only the hydrologic effect of Withdrawals, which is Consumptive Use.

Some Great Lakes have *interbasin* Diversions, which are Diversions into or out of the Basin. Some Great Lakes have *intrabasin* Diversions, which are Diversions within the Basin from one Watershed to another Watershed. Only the intrabasin Diversion at the Welland Canal from Lake Erie to Lake Ontario is considered in this report. The Parties report Consumptive Uses and Diversions (interbasin and intrabasin) by Watershed on an annual basis.

Separately, groundwater seeps into and out of each Lake and the River through the Lake and River bottoms. In this assessment, however, groundwater seepage into the Lakes and the River is not included, for three reasons. First, there are limited data and computer models regarding seepage. The only computer model for an entire Lake is for Lake Michigan. Therefore, estimates of seepage into the Lake(s) and the River are not available. Second, the available data and computer models indicate that groundwater seepage is a relatively small component of the Lake(s) water budget and scientists agree the amount is less than the uncertainty associated with the major inflows and outflows of the Lake(s). Third, scientists generally ignore groundwater seepage in water budget calculations for the Lake(s), so historical and current data are not available. As data and information improve, this approach can be reconsidered.

The water budgets presented in the assessment are focused on inflows and outflows. Clearly, if a Lake has an inflow greater than outflow, water levels in the Lake will rise, and vice versa. The

effects of one particular inflow or outflow cannot be used to determine effects on water levels of a given Lake in a given year. Rather, the sum of all inflows and all outflows determines Lake levels. Historical water-level data for the Lake(s) is available for the time period covered in this assessment, 1948-2010. It is difficult, however, to directly relate annual water level changes on the Lake(s) to specific amounts of annual water flow change. The specific contribution made by Diversions and Consumptive Uses to water level changes, apart from natural variability, is uncertain given the complex hydrology, geographic and temporal variability of uses, and other factors.

Lake Superior and Lake Ontario connecting channel outflows--the St. Marys River and St. Lawrence River--are regulated by control structures at Sault St. Marie and Cornwall, respectively. Decisions about operation of these control structures affect historical and current water budgets for the affected Lake(s) and connecting channels and must be considered in any budget calculations. Additional information about these operations may be accessed through the International Joint Commission, <http://www.ijc.org/>.

Consistent datasets for all inflows and outflows, except Consumptive Uses, are available from 1948-2010. Although data for some flows date back to the late 19th century, this assessment requires data on all flows and the most consistent data for the Basin begins in 1948. This data consists of monthly computations of each of the inflows and outflows for the Great Lakes and the St. Lawrence River, not including Consumptive Uses and smaller Diversions. Information in this assessment on Consumptive Use and all Diversions is reported for 2011-2015. This information is reported by the Parties. For historical context, however, the reported data on Diversions is compared against historical data gathered by the U.S. Army Corps of Engineers. For the Basin and each Lake Watershed, individual Diversions are aggregated and presented as a single value by the Parties. Data for some Diversions in the States is collected separately by federal agencies and available from the U.S. Army Corps of Engineers. Consumptive Uses are reported by the Parties by Watershed to the Great Lakes Water Use Database Repository on an annual basis.

Flows are complex and can be difficult to relate to water supply. Therefore, the information is presented in text, graphic and tabular forms. Following standard scientific procedures, inflows are presented as positive numbers and outflows are presented as negative numbers. This convention is used to help relate different flows to one another and to supply. It is not intended to communicate a value judgment on whether these flows are good or bad for the Basin. All flows are given in cubic feet per second (cfs). Sources of all data are included in Appendix A, rather than being cited in the text, figures and tables of this report.

Hydrologic Effects of Consumptive Uses and Diversions

The following sections discuss the hydrologic effects of Consumptive Uses and Diversions for the Basin, Lakes and River. In each section, water budgets for the reporting period, 2011-2015, are presented and compared to long-term water budgets for 1948-2015 to provide a relative hydrologic context for the reporting period. Consumptive Uses and Diversions are then compared to natural inflows (connecting channel, precipitation on the Lake(s), and runoff).

Great Lakes-St. Lawrence River Basin

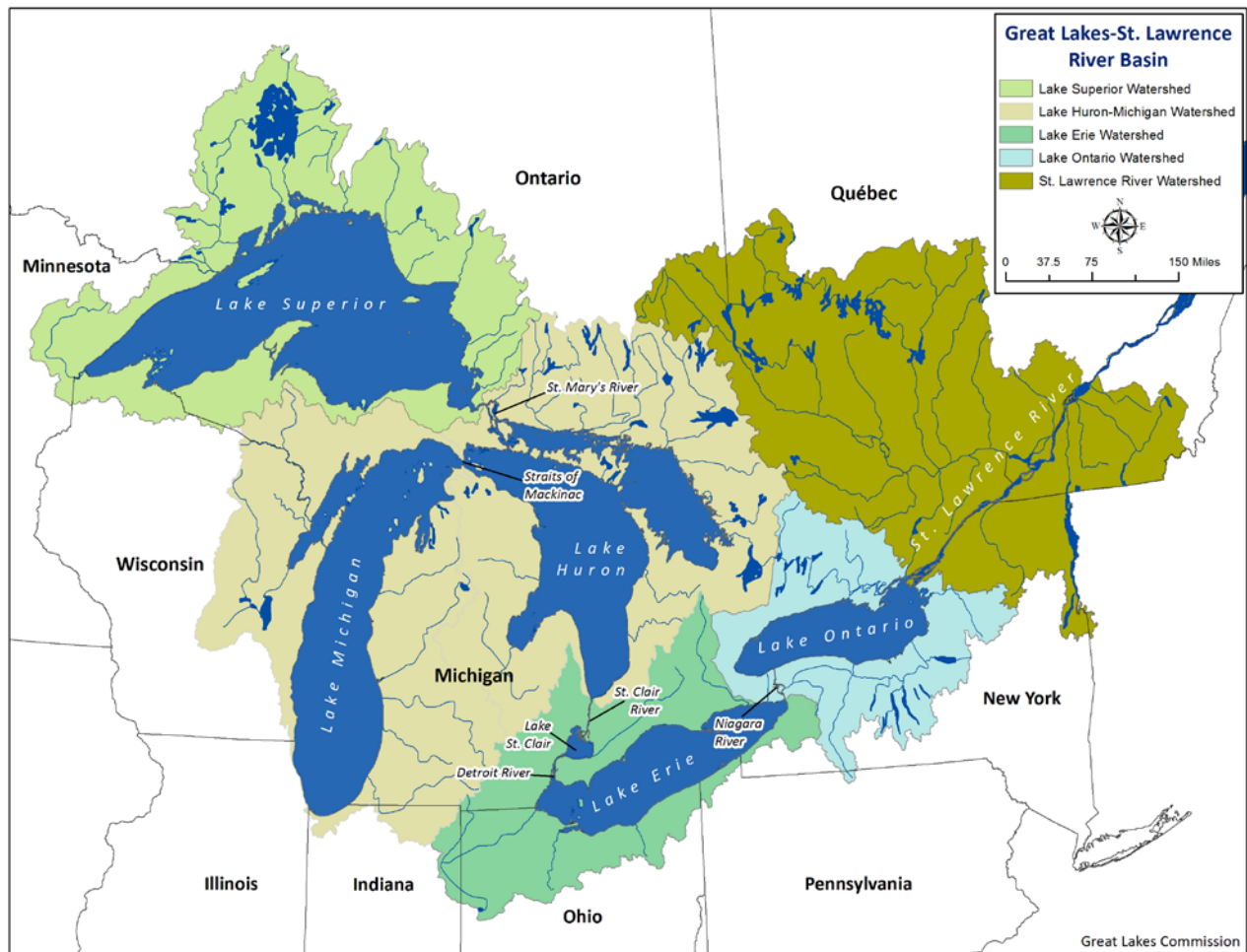


Figure 1. Great Lakes-St. Lawrence River Basin

Figure 1 shows the Basin and the Watersheds as defined by the Compact and Agreement. Upstream connecting channels are included in each Lake Watershed. Figure 2 and Table A present a comparison of five-year reporting period averages and 67-year historical period averages in water budget data for the Basin. As illustrated in Figure 2 and Table A, the largest outflow for the Basin is the St. Lawrence River and the smallest is Consumptive Use. The average Basin water flow components are variable when comparing components during these time periods. Precipitation on the Lakes and evaporation from the Lakes are greater during the five-year period compared to the 67-year period, whereas runoff is less. Figure 2 and Table A show that the natural inflows and outflows dominate the water budget. Figure 2 and Table A also illustrate that inflows do not always equal outflows, which is attributable to the imprecisions inherent in the techniques used to estimate average flows and to changes in storage over time. Many of these flows are imprecisely estimated and therefore have significant uncertainties associated with them. However, this is the best available data.

Great Lakes-St. Lawrence River Basin Water Budget

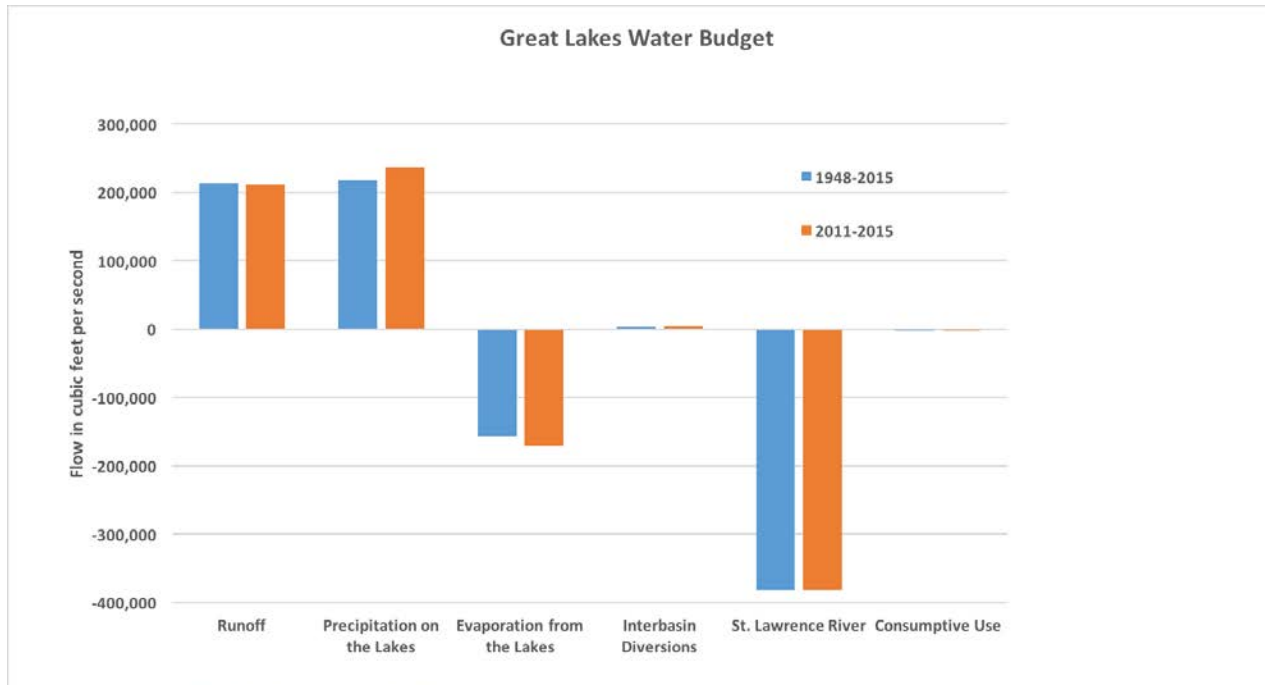


Figure 2. Great Lakes-St. Lawrence River Basin water budget using average annual flows, comparing a five-year period (2011-2015) to a historical 67-year period (1948-2015).

The cumulative hydrologic effect of Consumptive Uses and Diversions as compared to natural inflow for 2011-2015 is shown for the Basin in Figure 3. Table B includes the flow values used to construct Figure 3 and shows the amount of Consumptive Uses and Diversions compared to runoff and precipitation.

Water Budget Component	5-year Flow (cfs)	67-year Flow (cfs)
Runoff	210,457	212,511
Precipitation	236,298	217,851
Evaporation	-171,915	-156,944
St. Lawrence River	-381,782	-381,526
Interbasin Diversions	4,557	2,458
Consumptive Uses	-3,065	-2,899*

Table A. Water budget average flow values for the Great Lakes-St. Lawrence River Basin, comparing 5-year period (2011-2015) to a historical 67-year period (1948-2015). * Average consumptive use for 2006-2010.

As illustrated in Table B, the cumulative hydrologic effect of Consumptive Uses and Diversions (annual averages) for the Basin are small relative to inflows (runoff plus precipitation). Further, while inflows fluctuate from 2011-2015, the cumulative hydrologic effect of Consumptive Uses and Diversions is fairly constant for these annual averages. The net effect of Consumptive Uses and Diversions is positive for the Basin. In other words, more water is diverted into the Basin

than the total combined amount of water diverted out of the Basin or withdrawn and not returned.

Cumulative Hydrologic Effects on Flows for the Great Lakes-St. Lawrence River Basin

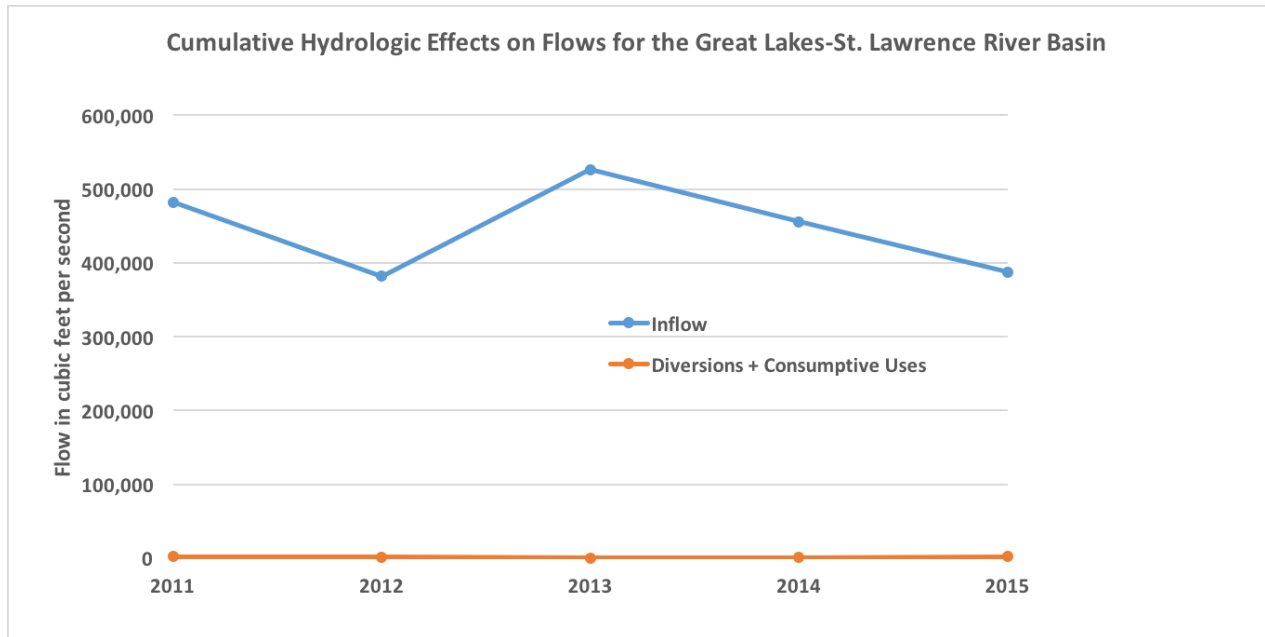


Figure 3. Cumulative hydrologic effects on flows for the Great Lakes-St. Lawrence River Basin, 2011-2015.

Year	Runoff + Precipitation (cfs)	Consumptive Uses + Diversions (cfs)
2011	482,269	2,364
2012	381,951	1,616
2013	526,537	61
2014	455,399	961
2015	387,617	2,457

Table B. Water budget values in cubic feet per second for the Great Lakes-St. Lawrence River Basin, 2011-2015.

The significance of changes to Basin flow or Lake water levels may differ depending on the temporal and geographic scales used or issues of concern related to a particular water use or water user. Assessments conducted at the Basin or Lake Watershed scale by design do not focus on potential impacts at smaller scales, nor on a particular water use or user. For example, higher water levels or river flow may generally improve boating opportunities or shipping carrying capacities, but also may increase flooding and erosion potential in particular areas. Similarly, certain plants and animals thrive at high water levels or flows, while others thrive at low water levels or flows. The International Upper Great Lakes Study concludes fluctuating water levels – which provide for optimal conditions for different species in different years – support the most diverse and resilient aquatic ecosystems.

For the Basin, the Lake and River Watersheds have unique varieties of Consumptive Uses and Diversions that are described in each of the sections below. For example, the cumulative hydrologic effect of Consumptive Uses and Diversions on the Lake Superior watershed (as for the entire Basin) is an increase in flow. Diversions into the Lake Superior watershed exceed Consumptive Uses, resulting in an increase in connecting channel outflow as compared to the natural baseline.

Lake Superior Watershed

Inflows to Lake Superior include runoff, precipitation on the surface of Lake Superior, and Diversions. Outflows include evaporation from the surface of Lake Superior, outflow from the St. Marys River, and Consumptive Uses throughout the Watershed. Figure 4 shows the watershed.

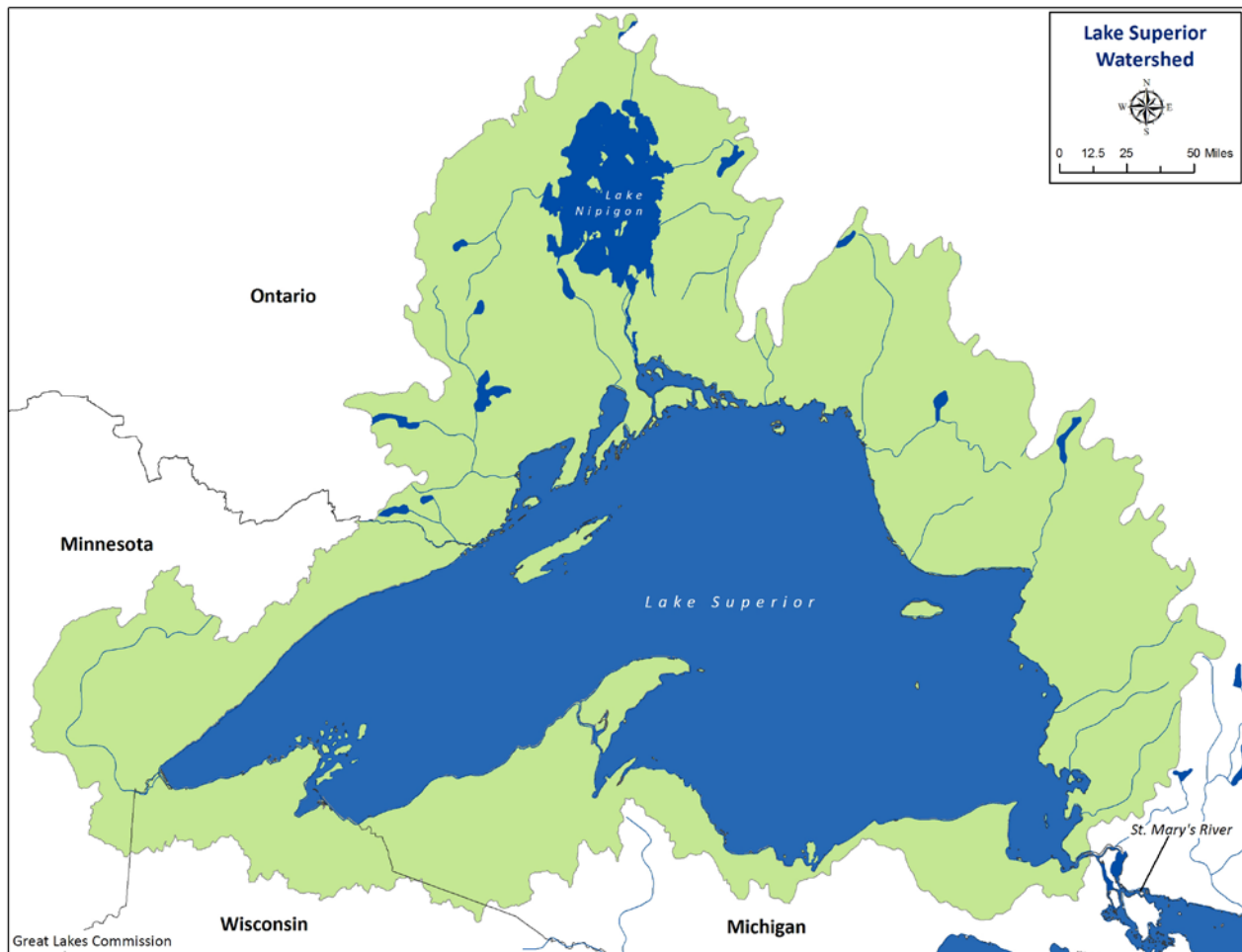


Figure 4. Lake Superior Watershed

Figure 5 and Table C present a comparison of the 5-year period and 67-year period averages in water budget data for Lake Superior. As illustrated in Figure 5 and Table C, the largest outflow for the Lake Superior Watershed is the St. Marys River and the smallest is Consumptive Use. Runoff, precipitation on the Lake, and evaporation from the Lake are greater for the 5-year reporting period, whereas flow of the St. Marys River is lower. Specifically, inflows of runoff and precipitation for the 5-year period were 9,114 cfs more than the historical average. Outflows of evaporation from the surface of Lake Superior and the St. Marys River for the 5-year period were 4,243 cfs greater than the historical average.

Data in Table C and used in Figure 5 indicate that inflows do not equal outflows. In some years outflows may exceed inflows while in other years inflows may exceed outflows. This is due in part to changes in storage in Lake Superior and in part to a lack of accuracy or uncertainties in

measurements or estimates of the flows. This inequality of inflow and outflow is true for each of the Lakes and the River. Issues of uncertainty are discussed in the next main section.

Lake Superior Water Budget

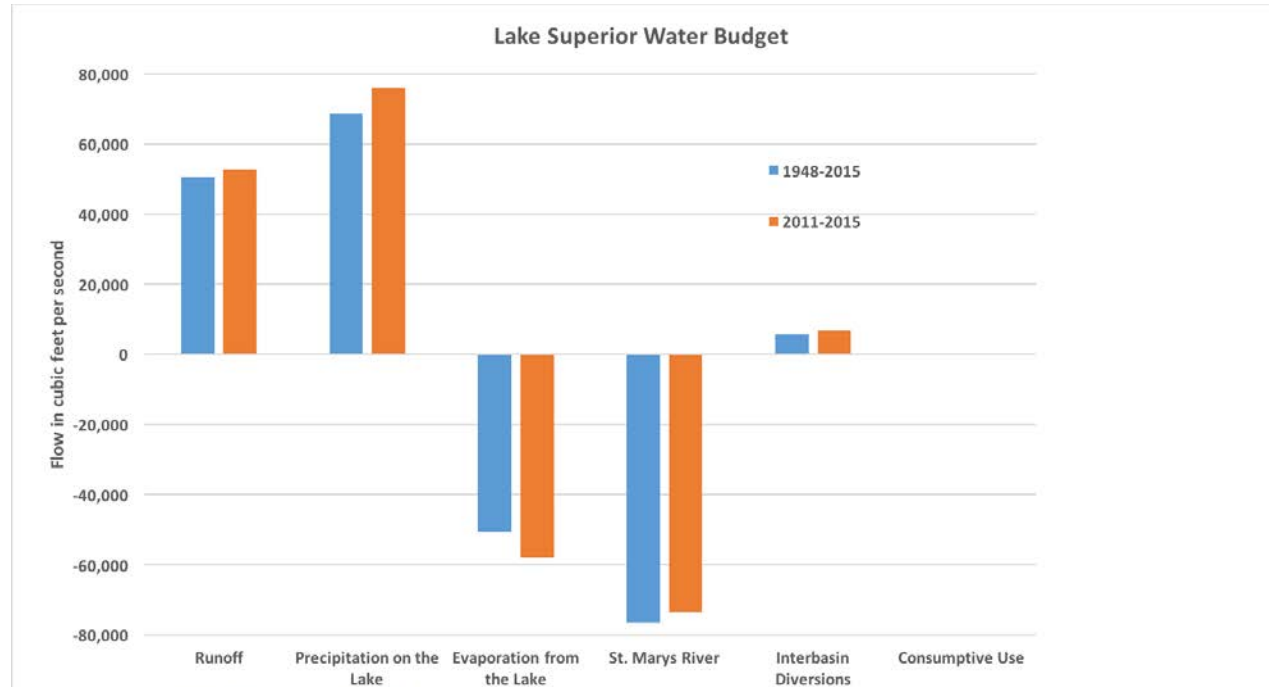


Figure 5. Water budget average flow values for Lake Superior using average annual flows, comparing a 5-year period (2011-2015) to a historical 67-year period (1948-2015).

Water Budget Component	5-year Flow (cfs)	67-year Flow (cfs)
Runoff	52,741	50,634
Precipitation	75,981	68,794
Evaporation	-57,907	-50,661
St. Marys River	-73,465	-76,468
Diversions	6,773	5,559
Consumptive Uses	-76	-110*

Table C. Water budget average flows for Lake Superior, comparing a 5-year period (2011-2015) to a historical 67-year period (1948-2015). *Average consumptive use for 2006-2010.

The hydrologic effect of Consumptive Uses and Diversions as compared to natural inflows for 2011-2015 is shown for the Lake Superior Watershed in Figure 6 and Table D. As described previously, this assessment defines a hydrologic effect as the Consumptive Uses plus Diversions compared to the inflows (connecting channel flow plus precipitation and runoff). Note that the net effect of Consumptive Uses and Diversions for Lake Superior is an increased average flow of 6,697 cfs during the 5-year reporting period. As with similar information described previously in this assessment, each data point has significant uncertainty associated with it, and is based on

averages on a 5-year timescale. Future assessments may take a different approach as data and information improve.

As illustrated in Table D, for the Lake Superior Watershed the hydrologic effect of Consumptive Uses and Diversions (annual averages) are small relative to inflows. Further, while inflows fluctuate from 2011-2015, the cumulative hydrologic effect of Consumptive Uses and Diversions is fairly constant for these annual averages. The net effect of Consumptive Uses and Diversions is positive for the Lake Superior Watershed.

Cumulative Hydrologic Effects on Flows for Lake Superior

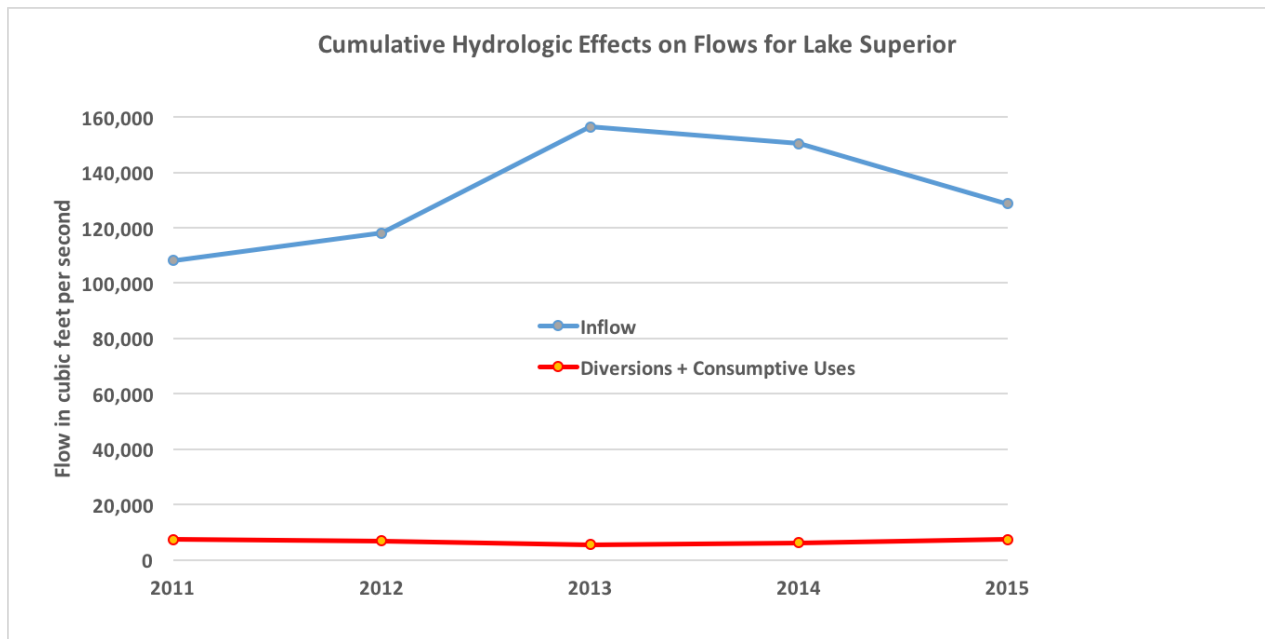


Figure 6. Cumulative hydrologic effects on flows for Lake Superior, 2011-2015.

Year	Total Inflow	Estimated net volume of consumptive uses and diversions	Consumptive uses and diversions as a percentage of total inflow
2011	104,425	7,340	7.03%
2012	114,878	6,948	6.05%
2013	152,672	5,493	3.60%
2014	146,605	6,176	4.21%
2015	125,030	7,444	5.95%

Table D. Water budget values in cubic feet per second for Lake Superior, 2011-2015.

While the water budgets presented in this assessment focus on flow, water supply can either be described in volumetric terms (e.g. quadrillion of gallons) or in terms of water levels for the individual Lakes. Water level data is available both on an historical and current basis. When compared to this baseline data, water levels can help characterize how flow changes affect supply.

Accordingly, below are graphic presentations for Lake Superior levels, both historically and for the period of 2011-2015. The historical water levels in Figure 7 show natural cyclical variability. As illustrated in figure 8, water levels during 2011-2015 also show this variability with an overall range of about .8 feet. Both figures present average data. The specific contribution made by Diversions and Consumptive Uses at any given point in time or space, separate and apart from natural variability, is uncertain given the complex hydrologic, geographic and temporal variability of uses, and other factors. Since Diversions and Consumptive Uses are small compared to natural flows, their cumulative hydrologic effect on water levels is likewise small.

Water Level of Lake Superior, 1860-2015

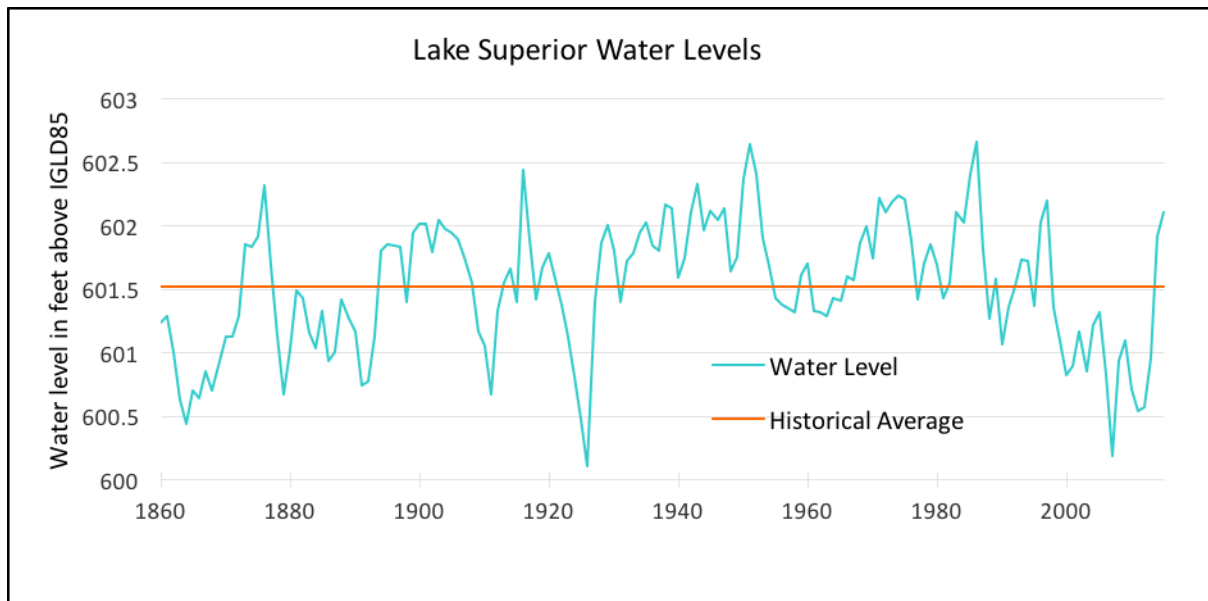


Figure 7. Historical water levels for Lake Superior, 1860-2015³

³ Water levels presented throughout this assessment are compared against International Great Lakes Datum (IGLD) 1985. IGLD is the reference system by which Great Lakes-St. Lawrence River Basin water levels are measured. It consists of benchmarks at various locations on the Lakes and St. Lawrence River that roughly coincide with sea level. All water levels are measured in feet or meters above this point. Movements in the earth's crust necessitate updating this datum every 25-30 years. The first IGLD was based upon measurements and bench marks that centered on the year 1955. The most recently updated datum uses calculations that center on 1985.

Water Level of Lake Superior, 2011-2015

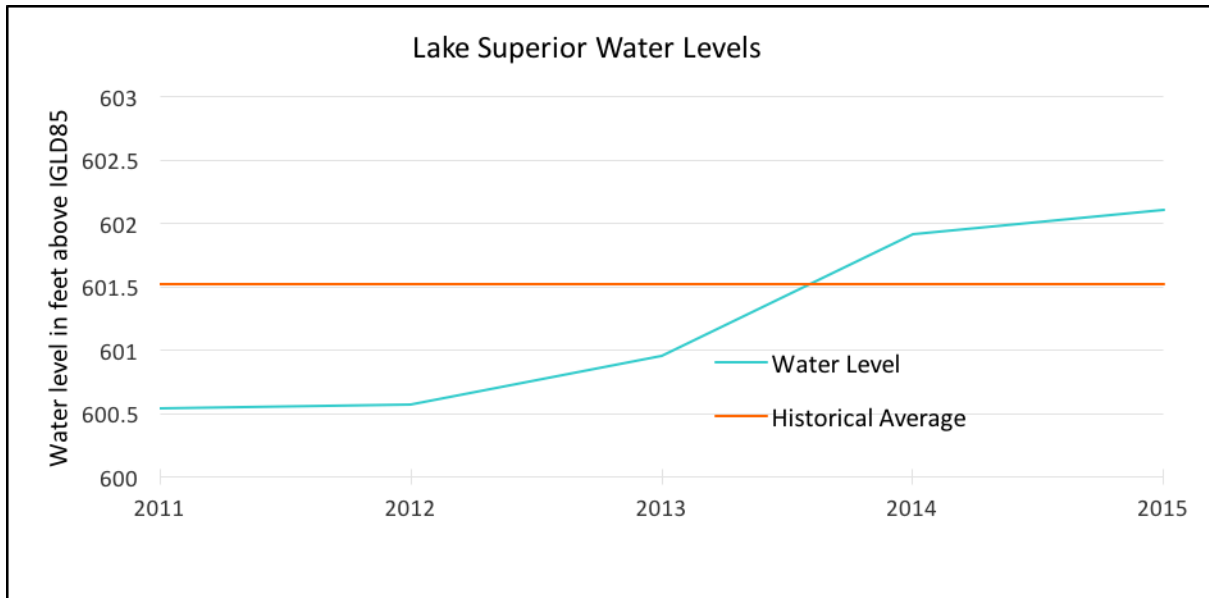


Figure 8. Water levels for Lake Superior, 2011-2015.

Lakes Michigan-Huron Watershed

Inflows to Lakes Michigan-Huron include the St. Marys River, runoff, precipitation on the surface of the Lakes, and Diversions. Outflows for the Watershed include the St. Clair River, evaporation from the surface of the Lakes, Diversions and Consumptive Uses throughout the Watershed. Figure 9 shows the watershed.



Figure 9. Lakes Michigan-Huron Watershed

Figure 10 and Table E present a comparison of the 5-year period and 67-year period averages in water budget data for Lakes Michigan-Huron. As illustrated in Figure 10 and Table E, the largest outflow for the Lakes Michigan-Huron Watershed is the St. Clair River and the smallest is Consumptive Use. Precipitation on the Lakes, and evaporation from the Lakes are higher for the 5-year reporting period, whereas connecting channel flows and runoff are lower. Specifically, inflows of runoff, precipitation, and St. Marys River were 4723 cfs greater for the 5-year period than the historical average. Outflows of evaporation from the surface of Lakes Michigan-Huron and the St. Clair River were 7,774 cfs less during the 5-year period. As noted previously, groundwater seepage into the Lakes and the River is not included in water budgets because data is lacking. For Lake Michigan, however, the U.S. Geological Survey has developed a groundwater

flow model that calculates groundwater seepage of 337 cfs. Lake Michigan is the only Great Lake for which such an estimate is available.

Data in Table E and used in Figure 10 indicate that inflows do not equal outflows. In some years outflows may exceed inflows while in other years inflows may exceed outflows. This is due in part to changes in storage in Lakes Michigan-Huron and in part to a lack of accuracy or uncertainties in measurements or estimates of the flows. This inequality of inflow and outflow is true for all of the Lake(s) and the River. Issues of uncertainty are discussed in the next main section.

Lakes Michigan-Huron Water Budget

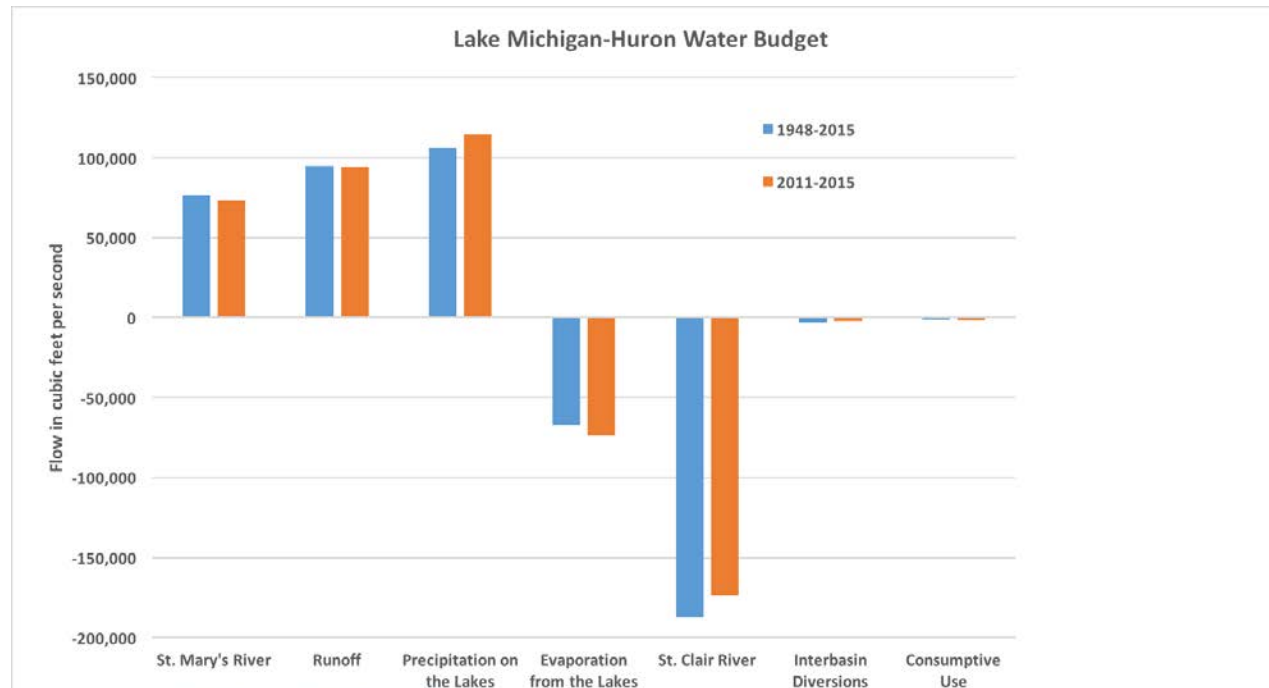


Figure 10. Water budget average flow values for Lakes Michigan-Huron using average annual flows, comparing a 5-year period (2011-2015) to a historical 67-year period (1948-2015).

Water Budget Component	5-year Flow (cfs)	67-year Flow (cfs)
St. Marys River	73,465	76,468
Runoff	94,408	94,750
Precipitation	114,282	106,214
Evaporation	-73,571	-67,247
St. Clair River	-173,423	-187,521
Diversions	-2,216	-3,101
Consumptive Uses	-1,668	-1,117*

Table E. Water budget average flows for Lakes Michigan-Huron, comparing a 5-year period (2011-2015) to a historical 67-year period (1948-2015). *Average consumptive use for 2006-2010.

The hydrologic effect of Consumptive Uses and Diversions as compared to natural inflows for 2011-2015 is shown for the Lakes Michigan-Huron Watershed in Figure 11. As previously described, this assessment defines a hydrologic effect as the Consumptive Uses plus Diversions compared to the inflows (connecting channel flow plus precipitation and runoff). Table F includes the flow values used to construct Figure 11 and shows the volume of Consumptive Uses and Diversions compared to runoff and precipitation. As with similar information previously described in this assessment, each data point has significant uncertainty associated with it, and is based on averages on a 5-year timescale. Future assessments may take a different approach as data and information improve.

As illustrated in Table F, for the Lakes Michigan-Huron Watershed the hydrologic effect of Consumptive Uses and Diversions (annual averages) are small relative to inflows. The net effect of Diversions and Consumptive Uses is an increased outflow of 3,884 cfs for the 5-year reporting period. Further, while inflows fluctuate from 2011-2015, the hydrologic effect of Consumptive Uses and Diversions is fairly constant for these annual averages.

Cumulative Hydrologic Effects on Flows for Lakes Michigan-Huron

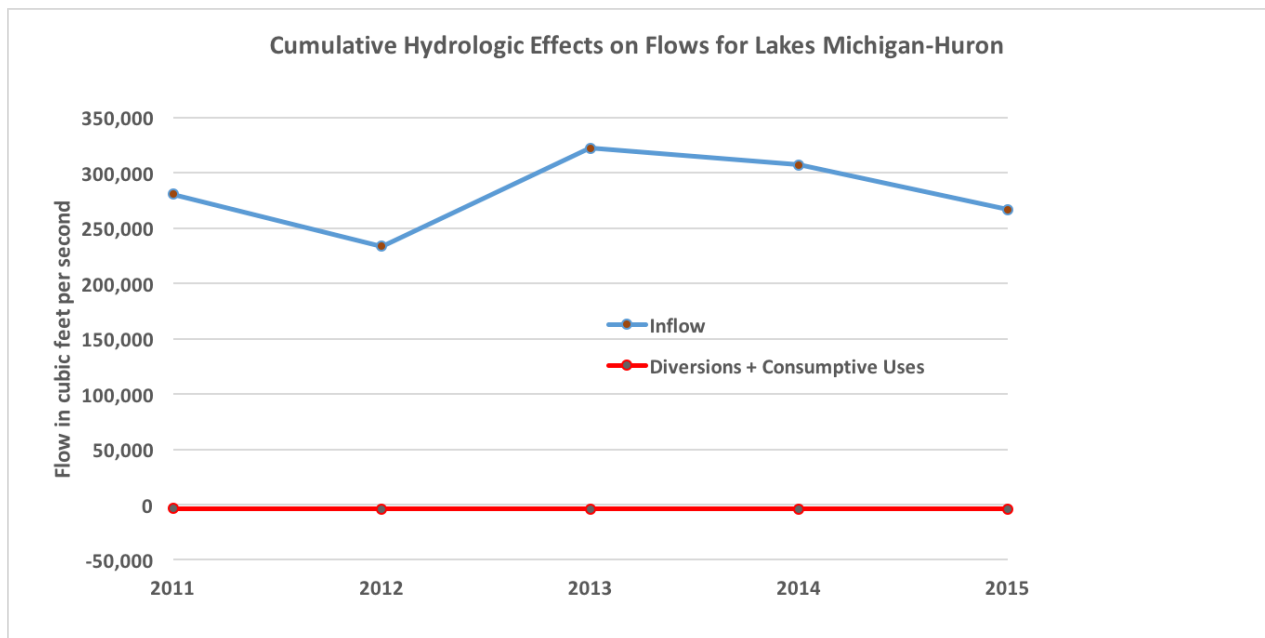


Figure 11. Cumulative hydrologic effects on flows for Lakes Michigan-Huron, 2011-2015.

Year	Total Inflow	Estimated net volume of consumptive uses and diversions	Consumptive uses and diversions as a percentage of total inflow
2011	280,818	-3,412	1.22%
2012	233,678	-4,043	1.73%
2013	322,440	-4,187	1.30%
2014	307,227	-3,990	1.30%
2015	266,610	-3,788	1.42%

Table F. Water budget values in cubic feet per second for Lakes Michigan-Huron, 2011-2015.

While the water budgets presented in this assessment focus on flow, water supply can either be described in volumetric terms (e.g. quadrillion of gallons) or in terms of water levels for the individual Lakes. Water level data is available both on an historical and current basis. When compared to this baseline data, water levels can help characterize how flow changes affected supply. Accordingly, below are graphic presentations for Lakes Michigan-Huron water levels, both historically and for the period of 2011-2015. The historical water levels in Figure 12 show natural cyclical variability. As illustrated in Figure 13, water levels during 2011-2015 also show this variability with an overall range of 2.3 feet. Both figures present average data. The specific contribution made by Diversions and Consumptive Uses at any given point in time or space, separate and apart from natural variability, is uncertain given the complex hydrologic, geographic and temporal variability of uses, and other factors. Since Diversions and Consumptive Uses are small compared to natural flows, their hydrologic effect on water levels is likewise small.

Water Level of Lakes Michigan-Huron, 1900-2015

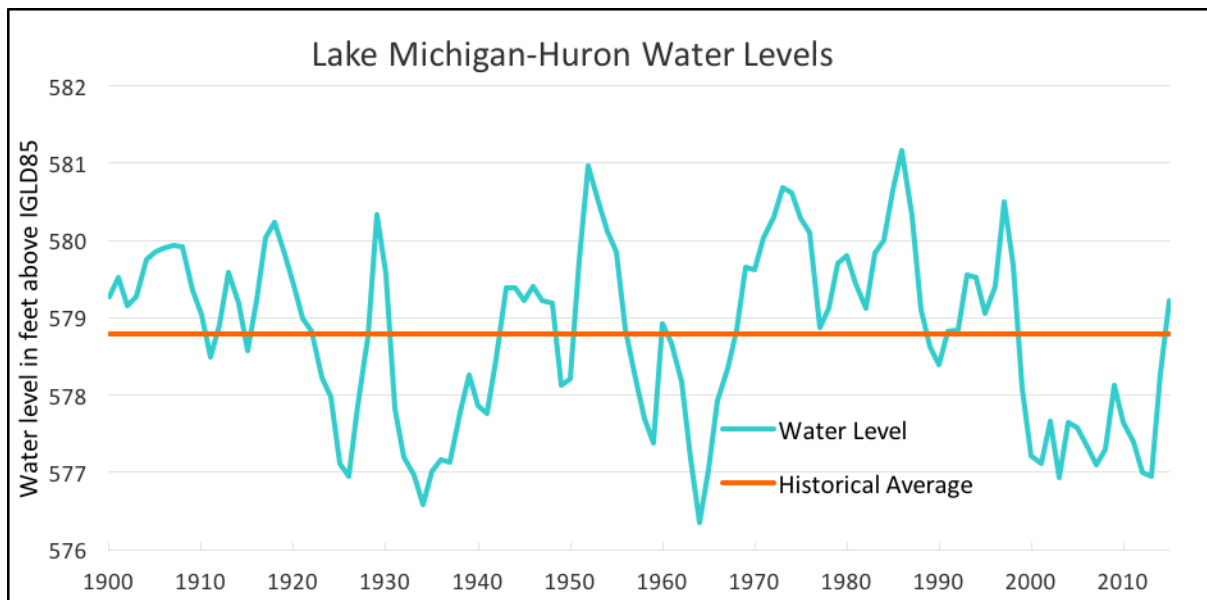


Figure 12. Historical water levels for Lakes Michigan-Huron, 1900-2015.

Water Level of Lakes Michigan-Huron, 2011-2015

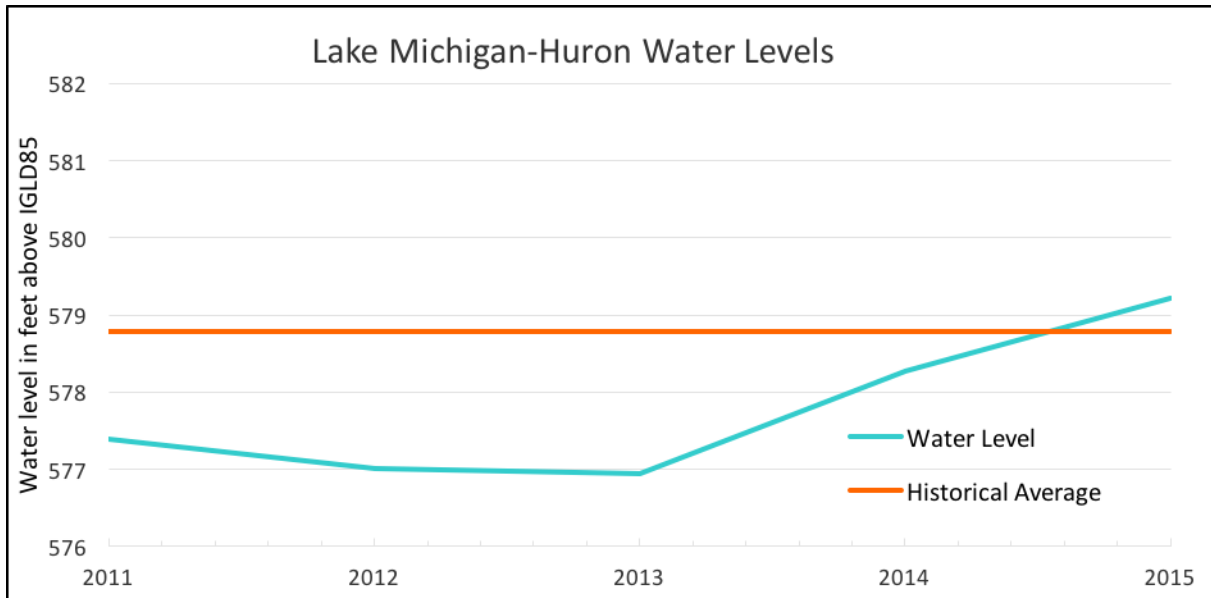


Figure 13. Water levels for Lakes Michigan-Huron, 2011-2015.

Lake Erie Watershed

Inflows to Lake Erie include the Detroit River, runoff, precipitation on the surface of the Lake and Diversions. The Detroit River inflow incorporates runoff from the area between the Detroit River measurement site and the St. Clair River measurement site, as well as precipitation on and evaporation from Lake St. Clair. Outflows include the Niagara River, evaporation from the surface of the Lake, Diversions and Consumptive Uses throughout the Watershed.⁴ Figure 14 shows the watershed.

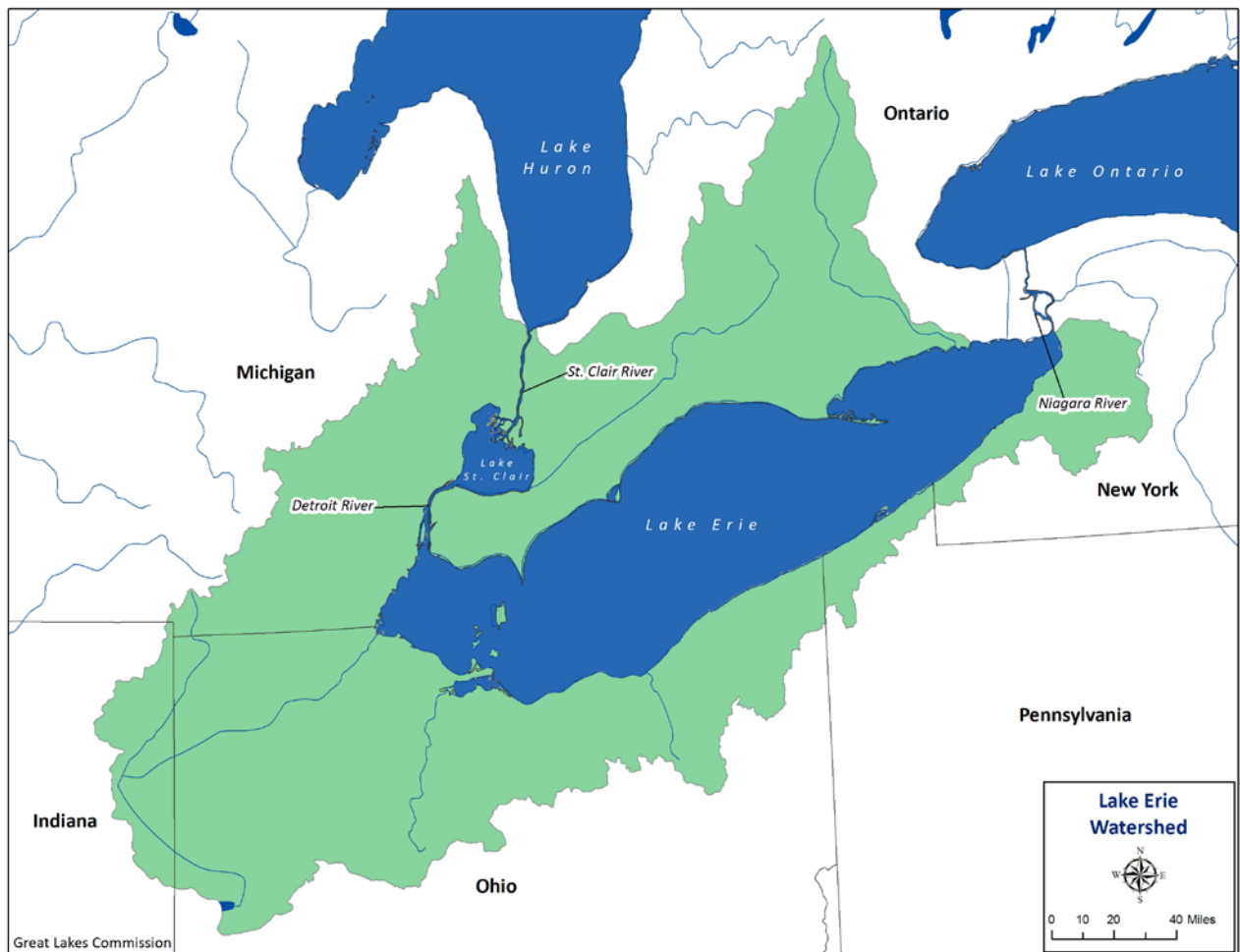


Figure 14. Lake Erie Watershed

Figure 15 and Table G present a comparison of the 5-year period and 67-year period averages in water budget data for Lake Erie. As illustrated in Figure 15 and Table G, the largest outflow for the Lake Erie Watershed is the Niagara River and the smallest is Consumptive Use. Most flows are similar between the two periods; connecting channel flows, however, are lower for the 5-year reporting period. Specifically, inflows of runoff, precipitation on the surface of Lake Erie, and the Detroit River were 5,924 cfs less during the 5-year period. Outflows of evaporation from the

⁴ Diversion data for the Lake Erie Watershed include an intrabasin diversion at Welland Canal.

surface of Lake Erie, the Niagara River, and intrabasin diversions were 4,138 cfs less during the 5-year period.

Data in Table G and used in Figure 15 indicate that inflows do not equal outflows. In some years outflows may exceed inflows while in other years inflows may exceed outflows. This is due in part to changes in storage in Lake Erie and in part to a lack of accuracy or uncertainties in measurements or estimates of the flows. This inequality of inflow and outflow is true for each of the Lake(s) and the River. Issues of uncertainty are discussed in the next main section.

Lake Erie Water Budget

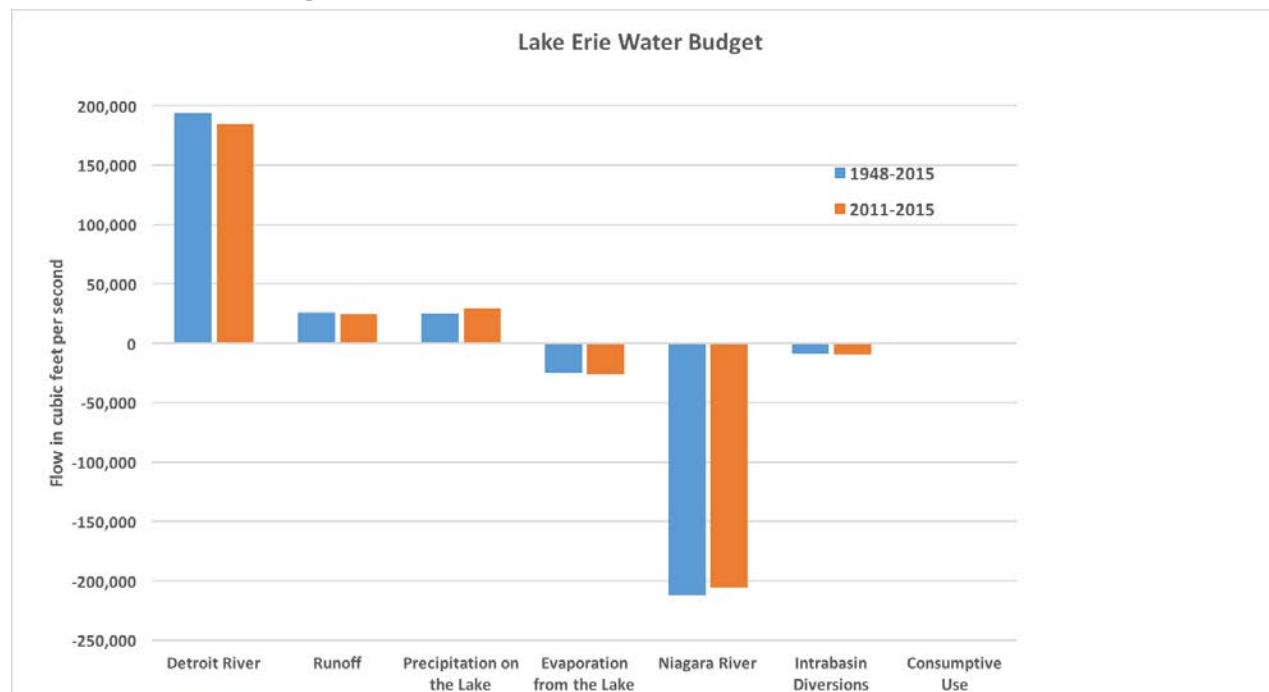


Figure 15. Water budget average flow values for Lake Erie using average annual flows, comparing a 5-year period (2011-2015) to a historical 67-year period (1948-2015).

Water Budget Component	5-year Flow (cfs)	67-year Flow (cfs)
Detroit River	184,719	193,796
Runoff	24,786	25,795
Precipitation	29,598	25,436
Evaporation	-25,992	-25,064
Niagara River	-205,976	-212,176
Diversions	-9,747	-8,613
Consumptive Uses	-704	-728*

Table G. Water budget average flows for Lake Erie, comparing a 5-year period (2011-2015) to a historical 67-year period (1948-2015). * Average consumptive use for 2006-2010.

The hydrologic effect of Consumptive Uses and Diversions as compared to natural inflows for 2011-2016 is shown for the Lake Erie Watershed in Figure 16. As previously described, this assessment defines a hydrologic effect as the Consumptive Uses plus Diversions compared to the inflows (connecting channel flow plus precipitation and runoff). Table H includes the flow values used to construct Figure 16 and shows the volume of Consumptive Uses and Diversions compared to runoff and precipitation. As with similar information described previously in this assessment, each data point has significant uncertainty associated with it, and is based on averages on a 5-year timescale. Future assessments may take a different approach as data and information improve.

As illustrated in Table H, for the Lake Erie Watershed the cumulative hydrologic effect of Consumptive Uses and Diversions (annual averages) are small relative to inflows. The net effect of Diversions and Consumptive Uses is an increased outflow of 10,451 cfs for the 5-year reporting period. Further, while inflows fluctuate from 2011-2015, the hydrologic effect of Consumptive Uses and Diversions is fairly constant for these annual averages.

Cumulative Hydrologic Effects on Flows for Lake Erie

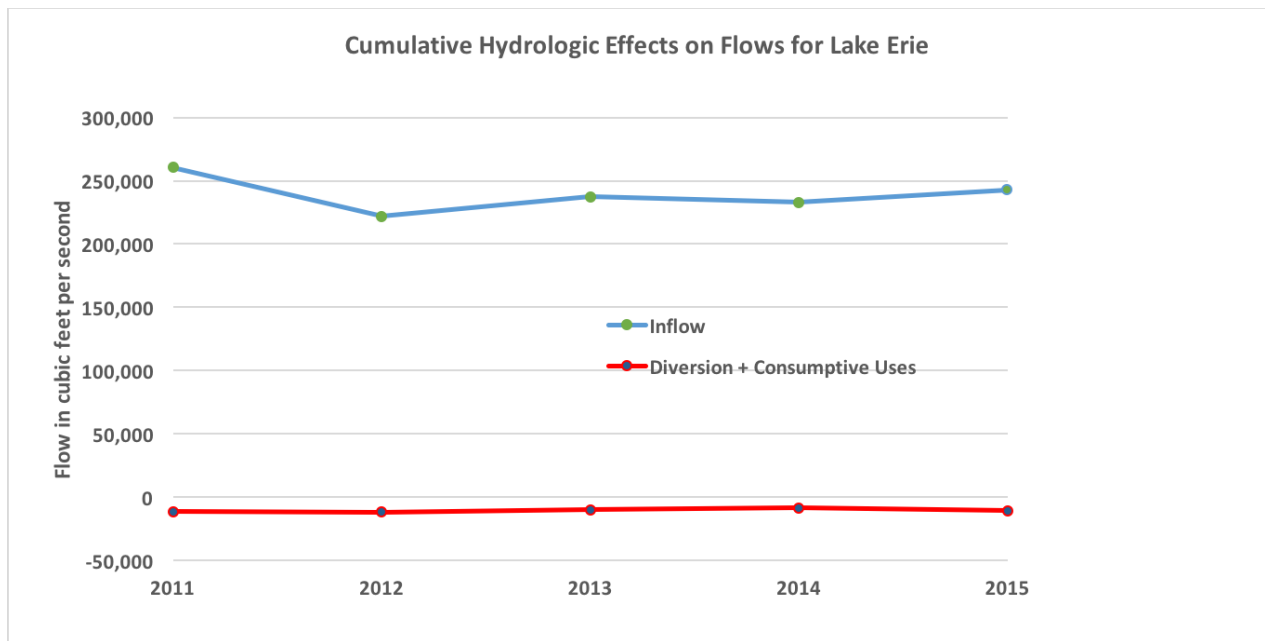


Figure 16. Cumulative hydrologic effects on flows for Lake Erie, 2011-2015.

Year	Total Inflow	Estimated net volume of consumptive uses and diversions	Consumptive uses and diversions as a percentage of total inflow
2011	260,582	-11,551	4.43%
2012	221,925	-11,675	5.26%
2013	237,459	-9,862	4.15%
2014	233,085	-8,446	3.62%
2015	242,461	-10,723	4.42%

Table H. Water budget values in cubic feet per second for Lake Erie, 2011-2015.

While the water budgets presented in this assessment focus on flow, water supply can either be described in volumetric terms (e.g. quadrillion of gallons) or in terms of water levels for the individual Lakes. Water level data is available both on an historical and current basis. When compared to this baseline data, water levels can help characterize how flow changes affect supply. Accordingly, below are graphic presentations for Lake Erie water levels, both historically and for the period of 2011-2015. The historical water levels in Figure 17 show natural cyclical variability. As illustrated in Figure 18, water levels during 2011-2015 also show this variability with an overall range of about .9 feet. Both figures present average data. The specific contribution made by Diversions and Consumptive uses at any given point in time or space, separate and apart from natural variability, is uncertain given the complex hydrologic, geographic and temporal variability of uses, and other factors. Since Diversions and Consumptive uses are small compared to natural flows, their cumulative hydrologic effect on water levels is likewise small.

Water Level of Lake Erie, 1900-2015

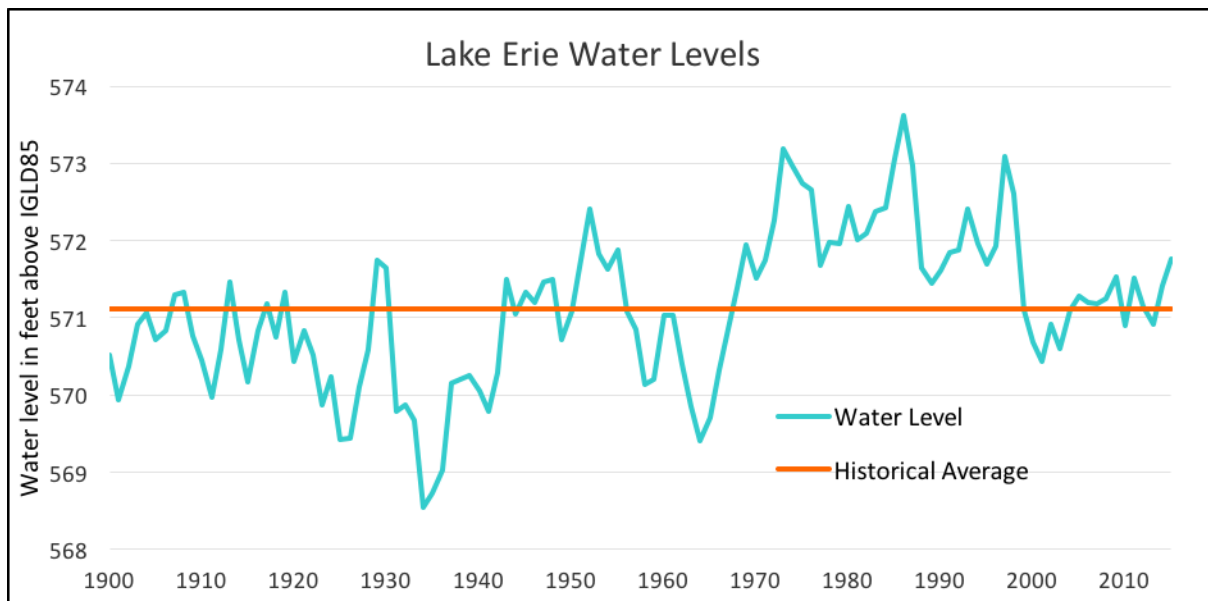


Figure 17. Historical water levels for Lake Erie, 1900-2015.

Water Level of Lake Erie, 2011-2015

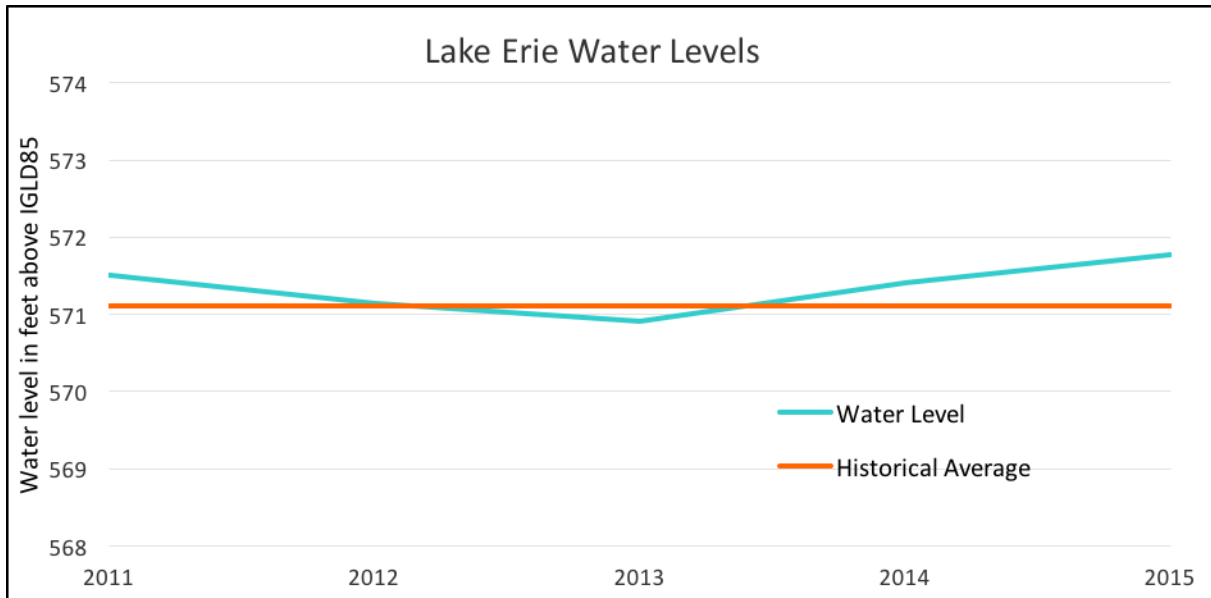


Figure 18. Water levels for Lake Erie, 2011-2015.

Lake Ontario Watershed

Inflows to Lake Ontario include the Niagara River, runoff, precipitation on the surface of the Lake and Diversions. Outflows for the Watershed include the St. Lawrence River, evaporation from the surface of the Lake, Diversions, and Consumptive Uses throughout the Watershed. Figure 19 shows the watershed. The measuring location for the St. Lawrence River is downstream from the Watershed as shown in figure 19. Thus, some of the St. Lawrence River outflow reported in this section is not from the Lake Ontario Watershed but from the St. Lawrence River Watershed.

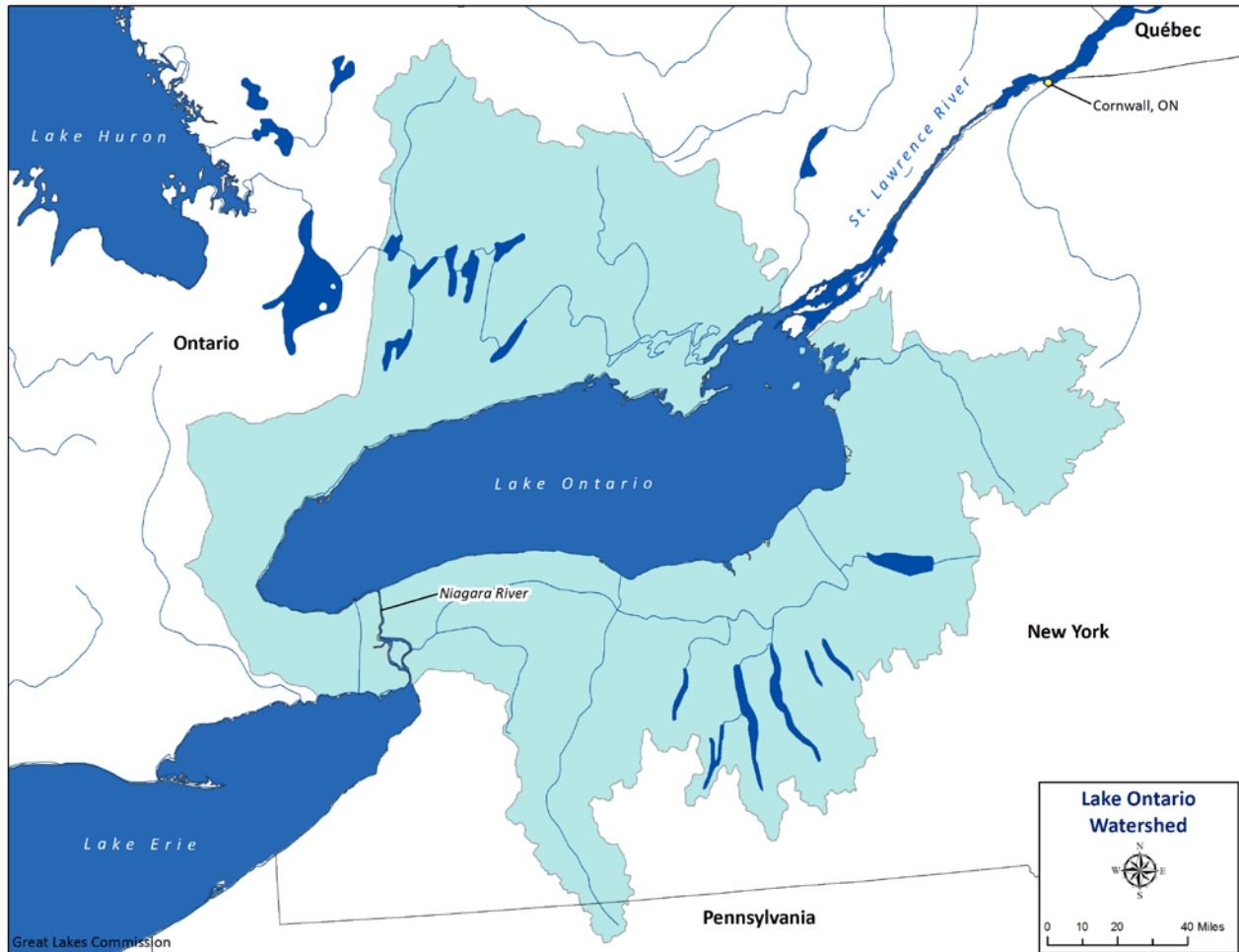


Figure 19. Lake Ontario Watershed.

Figure 20 and Table I present a comparison of the 5-year period and 67-year period averages in water budget data for Lake Ontario. As illustrated in Figure 20 and Table I, the largest outflow for the Lake Ontario Watershed is the St. Lawrence River and the smallest is Consumptive Use. Flows for the two time periods are fairly similar. Specifically, inflows of runoff, precipitation on the surface of Lake Ontario, intrabasin diversion, and Niagara River were 8,455 cfs less during the 5-year period. Outflows of evaporation from the Lake and St. Lawrence were 3,766 cfs less during the 5-year period.

Data in Table I and used in Figure 20 indicate that inflows do not equal outflows. In some years outflows may exceed inflows while in other years inflows may exceed outflows. This is due in part to changes in storage in Lake Ontario, as well as regulation of outflows by the International Joint Commission to meet International Boundary Waters Treaty of 1909 obligations, and in part to a lack of accuracy or uncertainties in measurements or estimates of the flows. This inequality of inflow and outflow is true for all of the Lake(s) and the River. Issues of uncertainty are discussed in the next main section.

Lake Ontario Water Budget

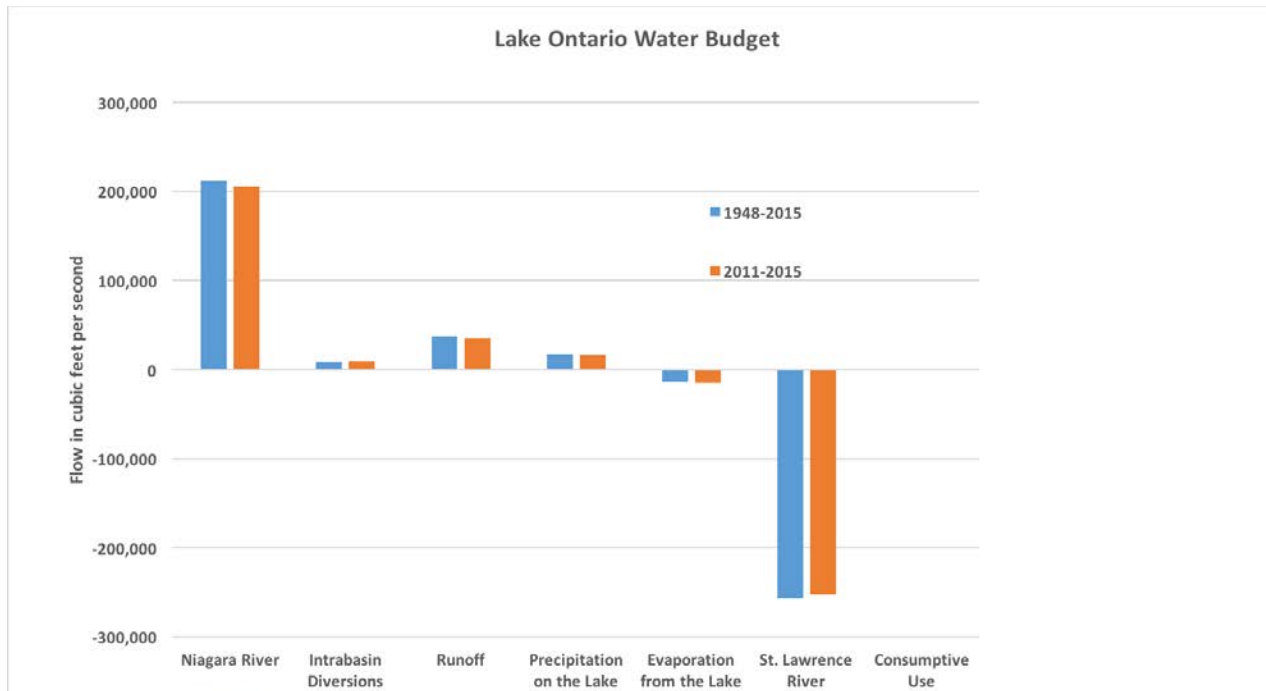


Figure 20. Water budget average flow values for Lake Ontario using average annual flows, comparing a 5-year period (2011-2015) to a historical 67-year period (1948-2015).

Water Budget Component	5-year Flow (cfs)	67-year Flow (cfs)
Niagara River	205,976	212,176
Runoff	34,929	37,348
Precipitation	16,438	17,408
Evaporation	-14,446	-13,973
St. Lawrence River	-252,221	-256,460
Diversions	9,747	8,613
Consumptive Uses	-617	-564*

Table I. Water budget average flows for Lake Ontario, comparing a 5-year period (2011-2016) to a historical 67-year period (1948-2015). * Average consumptive use for 2006-2010.

The hydrologic effect of Consumptive Uses and Diversions as compared to natural inflows for 2011-2015 is shown for the Lake Ontario Watershed in Figure 21. The net effect is an increased inflow of 9,130 cfs for the 5-year reporting period. As previously described, this assessment defines a hydrologic effect as the Consumptive Uses plus Diversions compared to the inflows (connecting channel flow plus precipitation and runoff). Table J includes the flow values used to construct Figure 21 and shows the volume of Consumptive Uses and Diversions compared to runoff and precipitation. As with similar information described previously in this assessment, each data point has significant uncertainty associated with it, and is based on averages on a 5-year timescale. Future assessments may take a different approach as data and information improve. As illustrated in Table J, for the Lake Ontario Watershed the cumulative hydrologic effect of Consumptive Uses and Diversions (annual averages) are small relative to inflows. Further, while inflows fluctuate from 2011-2015, the cumulative hydrologic effect of Consumptive Uses and Diversions is fairly constant for these annual averages.

Cumulative Hydrologic Effects on Flows for Lake Ontario

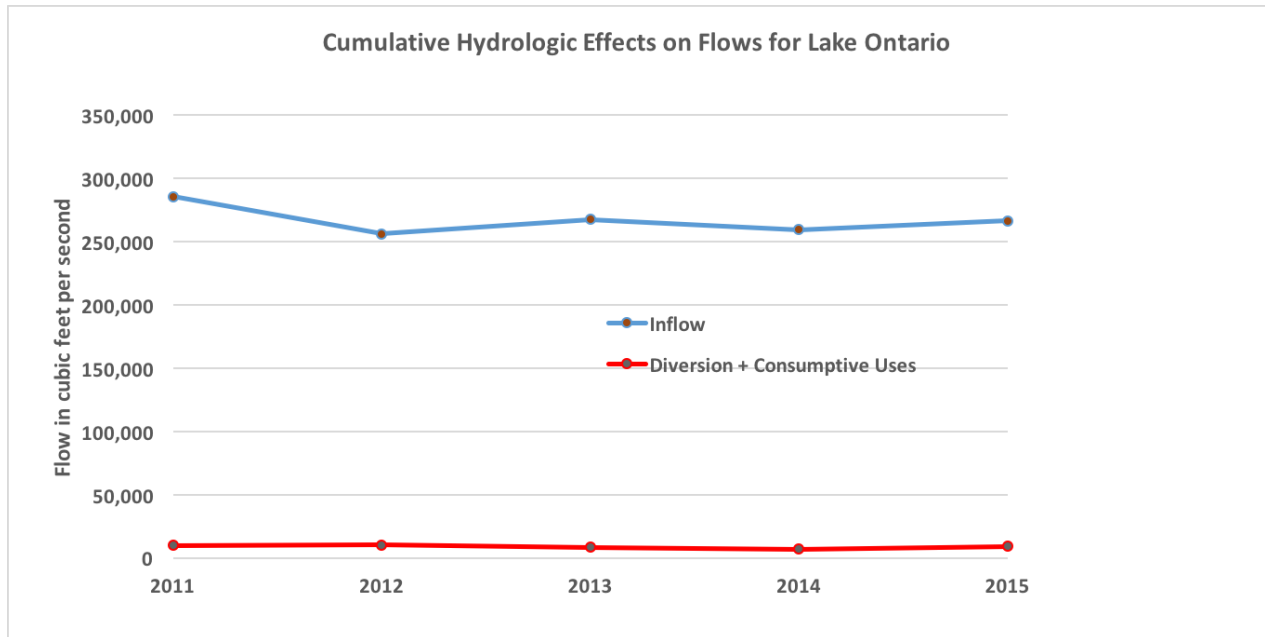


Figure 21. Cumulative hydrologic effects on flows for Lake Ontario, 2011-2015.

Year	Total Inflow	Estimated net volume of consumptive uses and diversions	Consumptive uses and diversions as a percentage of total inflow
2011	285,776	9,988	3.49%
2012	256,198	10,365	4.05%
2013	267,531	8,599	3.21%
2014	259,415	7,199	2.78%
2015	266,528	9,500	3.56%

Table J. Water budget values in cubic feet per second for Lake Ontario, 2011-2015.

While the water budgets presented in this assessment focus on flow, water supply can either be described in volumetric terms (e.g. quadrillion of gallons) or in terms of water levels for the individual Lakes. Water level data is available both on an historical and current basis. When compared to this baseline data, water levels can help characterize how flow changes affect supply. Accordingly, below are graphic presentations for Lake Ontario water levels, both historically and for the period of 2011-2015. The historical water levels in Figure 22 show natural cyclical variability. As illustrated in figure 23, water levels during 2011-2015 also show this variability with an overall range of about .4 feet. Both figures present average data. The specific contribution made by Diversions and Consumptive Uses at any given point in time or space, separate and apart from natural variability, is uncertain given the complex hydrologic, geographic and temporal variability of uses, and other factors. Since Diversions and Consumptive Uses are small compared to natural flows, their cumulative hydrologic effect on water levels is likewise small.

Water Level of Lake Ontario, 1900-2015

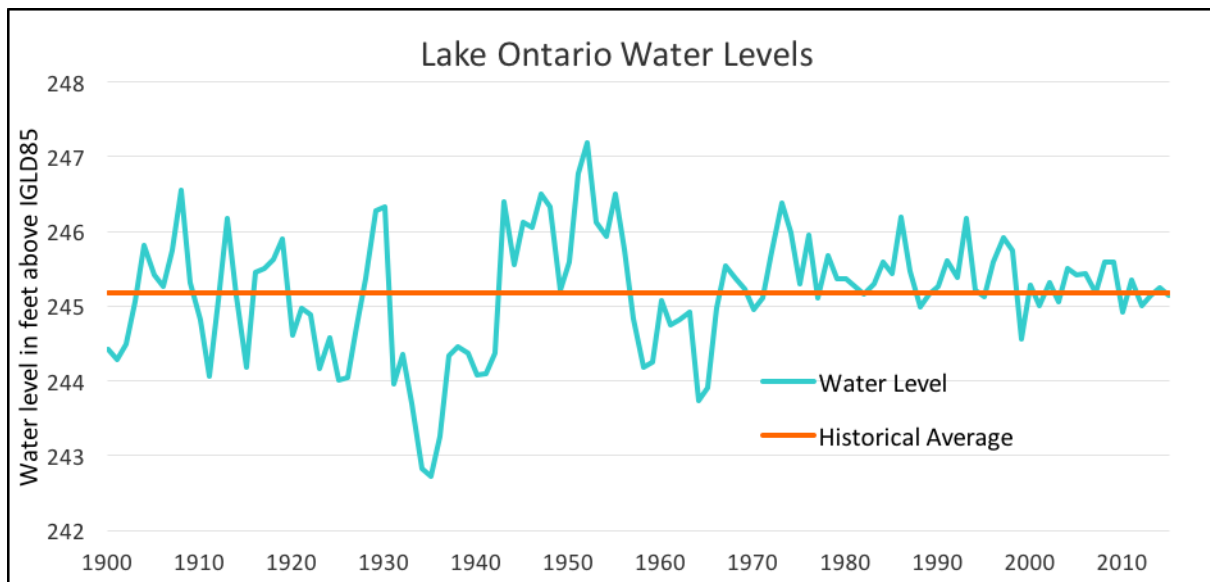


Figure 22. Historical water levels for Lake Ontario, 1900-2015.

Water Level of Lake Ontario, 2011-2015

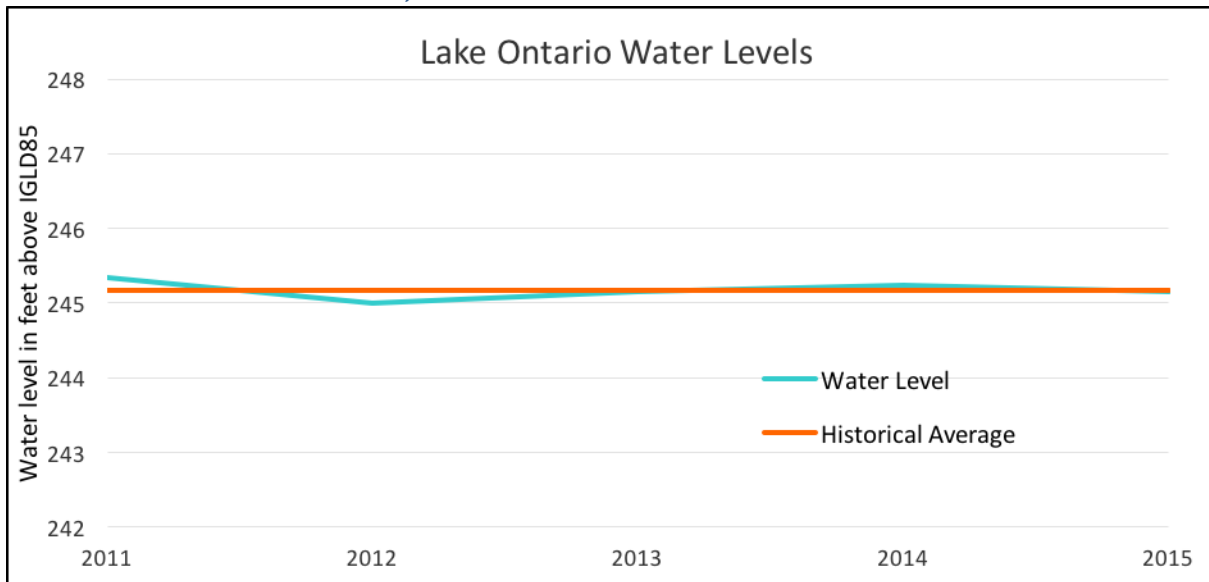


Figure 23. Water levels for Lake Ontario, 2011-2015.

St. Lawrence River Watershed

The St. Lawrence River Watershed in the Compact and Agreement is shown in Figure 24. The measuring location for the St. Lawrence River at Cornwall, Ontario is downstream from the western part of the watershed shown in figure 24. Thus, some of the St. Lawrence River inflow reported in this section is not only from the Lake Ontario Watershed, but from the western part of the St. Lawrence River Watershed.

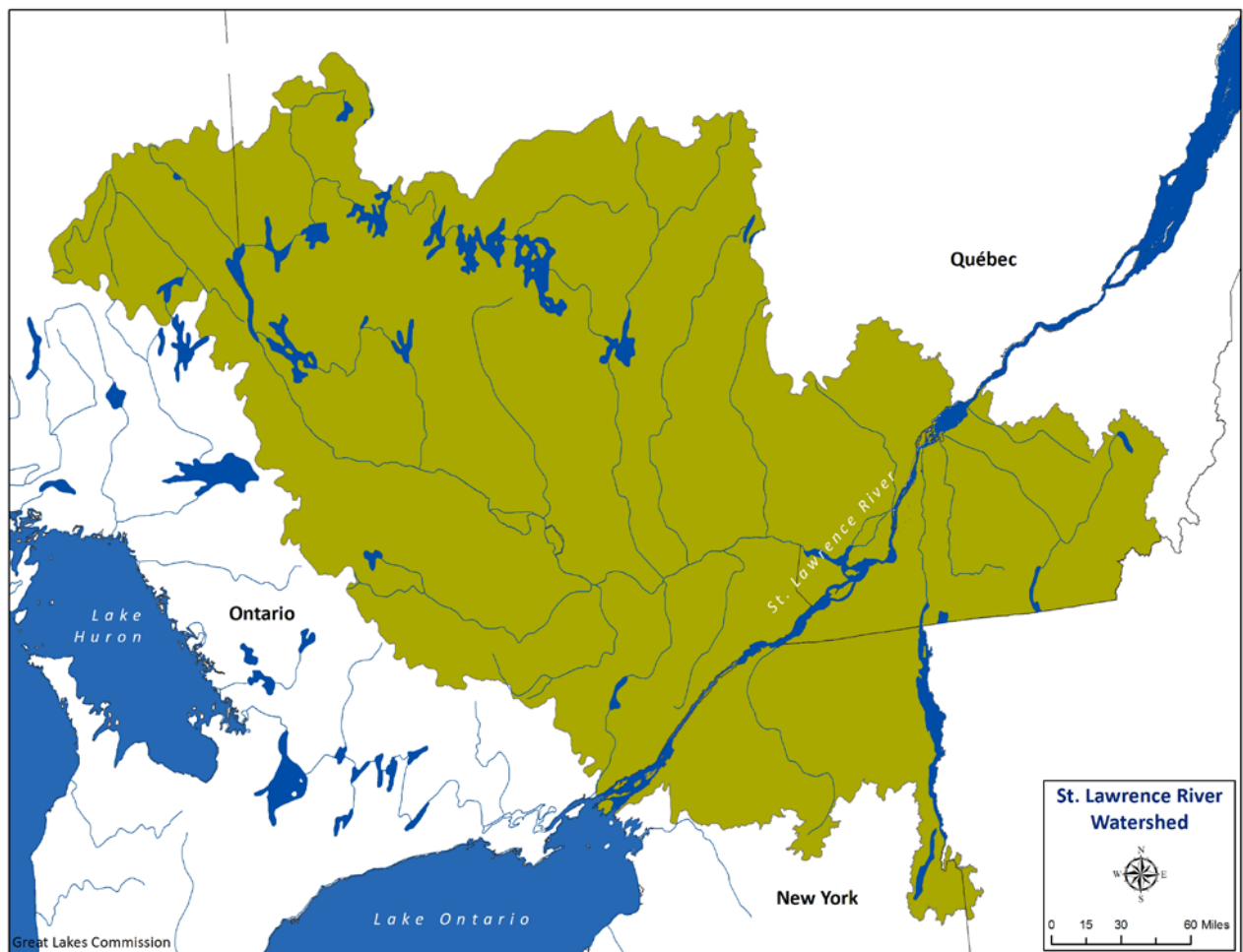


Figure 24. St. Lawrence River Watershed.

Precipitation on and evaporation from the River are not included in the water budget for the River because they contain a very small surface area compared to the Watershed and no data for these components are available. Runoff is also not reported since it is simply the difference between flow measurements for the River at Cornwall, Ontario and modeled estimates of flow at Trois Rivières, Québec. Additionally, no Diversions are reported by the Parties for the River Watershed prior to 2011.

Accordingly, the water budget for the St. Lawrence River Watershed is different than those for the Lakes. Inflow consists of the St. Lawrence River flow measured at Cornwall, Ontario.

Outflow consists of the River's flow modeled at Trois Rivieres, Québec and Consumptive Uses throughout the Watershed.

Figure 25 shows water budget data for 2011-2015. As illustrated in Table K, for the St. Lawrence River Watershed the hydrologic effect of Consumptive Use is small relative to inflows. Further, while inflows fluctuate from 2011-2015, the hydrologic effect of Consumptive Use is fairly constant for these annual averages.

St. Lawrence River Water Budget

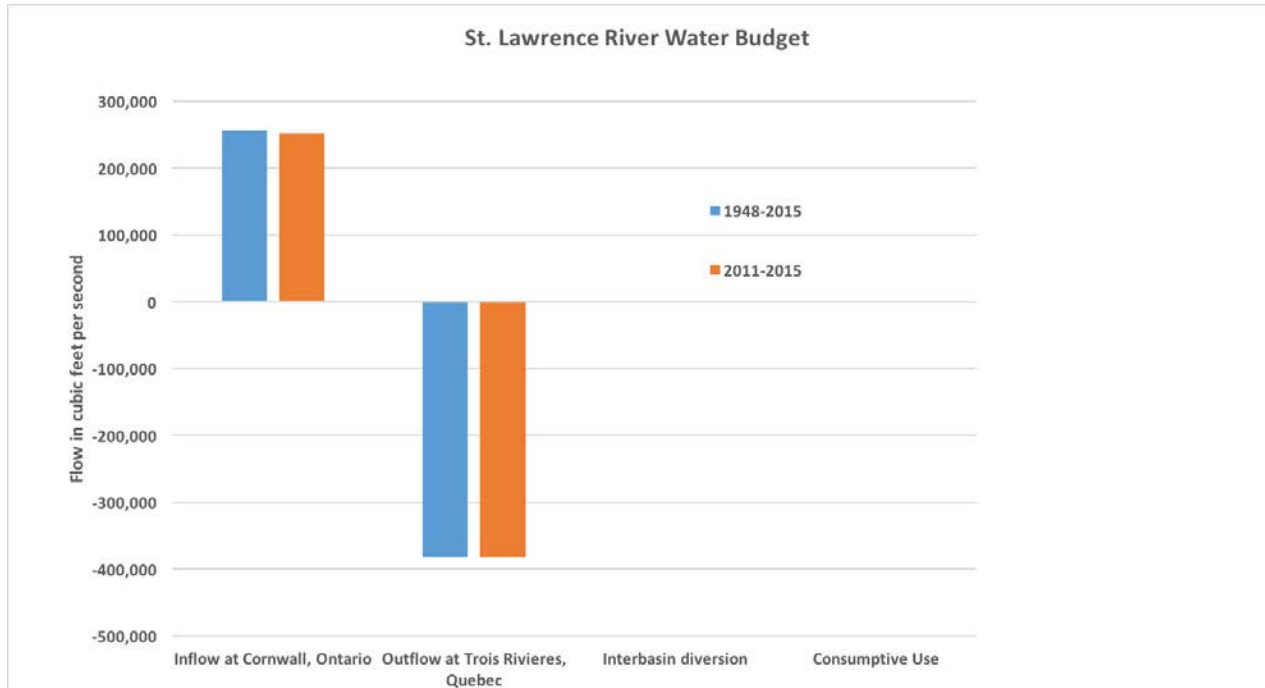


Figure 25. Water budget average flow values for the St. Lawrence River using average annual flows, comparing a 5-year period (2011-2015) to a historical 67-year period (1948-2015).

Cumulative Hydrologic Effects on Flows for the St. Lawrence River

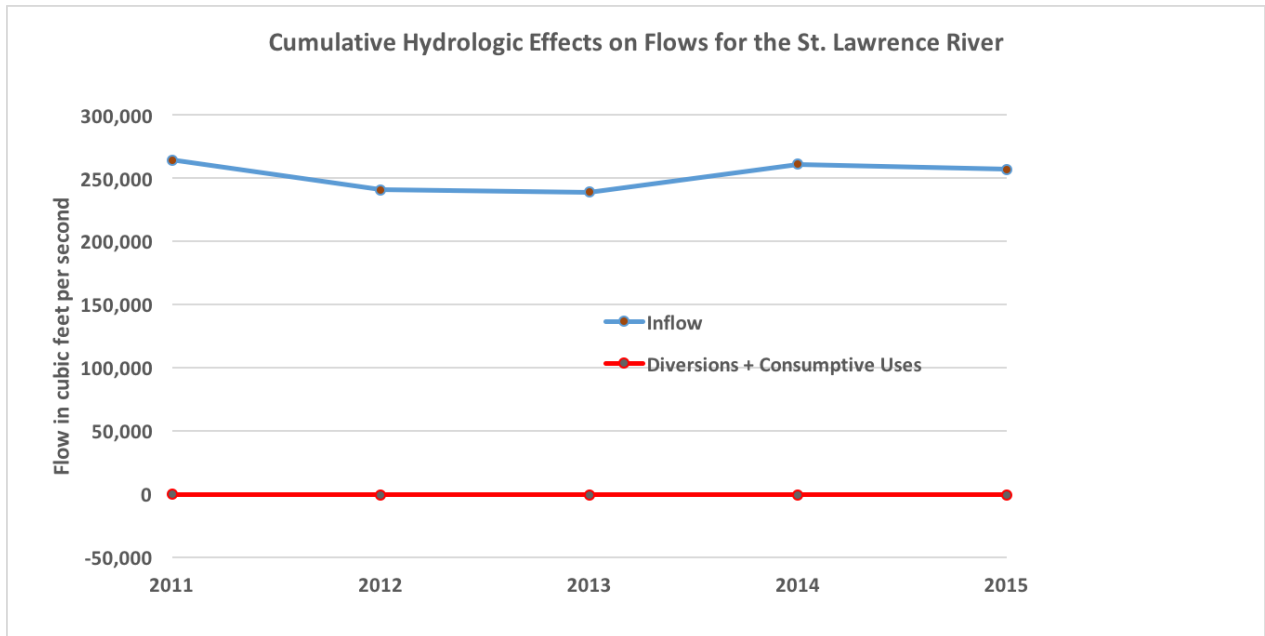


Figure 26. Cumulative hydrologic effects on flows for the St. Lawrence River, 2011-2015.

Year	Total Inflow	Estimated net volume of consumptive uses and diversions	Consumptive uses and diversions as a percentage of total inflow
2011	264,044	-302	0.11%
2012	240,481	-630	0.26%
2013	238,805	-753	0.32%
2014	260,929	-707	0.27%
2015	256,846	-641	0.25%

Table K. Water budget values in cubic feet per second for the St. Lawrence River, 2011-2015

Consideration of Uncertainty

All components of the Basin water budget have significant uncertainty. Runoff, evaporation from the Lake surfaces, and precipitation on the Lake surfaces are all calculated using models that compute watershed values from point data. No data exists, however, for many areas within the Basin and each Watershed. For instance, 34 percent of the Lake Huron watershed has no streamflow gauges, and runoff from this area is estimated from nearby gauges. Additionally, precipitation on the surfaces of the Lakes is calculated almost entirely from precipitation gauges that are near, but not on, the Lakes. The amount of uncertainty associated with various components of the water budget is difficult to quantify, but, as referenced in the appendix, scientists estimate it may range from 15-35 percent for runoff, 15-45 percent for precipitation on the Lake surfaces, and 10-35 percent for evaporation from the Lake surfaces. The International Upper Great Lakes Study (IUGLS) resulted in increased emphasis and research regarding uncertainty and the Great Lakes water budget. Appendix A includes references to recent technical publications associated with uncertainty in the Basin water budget.

Uncertainty in the Basin water budget has historically resulted in an inability for researchers to “close the water budget.” That is, if one computes the differences in inflow and outflows, one should be able to calculate the resulting water level change on a Lake; however, this has not been done until recently. Gronewold and others (2016, see Appendix A), used a statistical method that accounts for uncertainty in the water budget to calculate the historically large increase in water levels on Lake Superior and Lakes Michigan-Huron during 2013-2014, thus closing the water budget. This approach holds promise for the other Great Lakes as well.

Consumptive Use data also includes significant uncertainty. Consumptive Use is seldom measured directly. In most cases, Consumptive Use is calculated using a coefficient that represents a percentage of water consumed for a given category, such as domestic use, industrial use or irrigation. Each category has a wide range of reported values in the literature, and an average value for a category is generally used. Each of the Parties reports Consumptive Use by Watershed to the Great Lakes Commission annually for input to the water use database, and the Parties make independent decisions regarding the application of Consumptive Use coefficients. In 2011, under the Agreement, the Parties adopted new water use reporting protocols that have improved the timeliness, consistency and comparability of water use data. In 2016, the Parties reviewed and revised these reporting protocols. Appendix A includes information about the regional water use database and includes references to recent technical publications associated with Consumptive Use.

Uncertainty in the Basin water budget components is much larger than total Consumptive Uses. For example, total runoff to the Basin in 2015 was 163,197 cfs. Assuming a 15 percent uncertainty, the amount of calculated runoff may be off by over 24,000 cfs. In comparison, Consumptive Use in 2008 was only 2,965 cfs. Therefore, the hydrologic effects of Consumptive Uses on flows and water levels are masked by uncertainties in the natural inflows and outflows.

Consideration of Climate Change, Adaptive Management and Future Work

The effects of climate change on water levels in the Basin are difficult to model due to the uncertainty associated with future climate scenarios and the uncertainty in the calculation of Basin water budget components. Research conducted through the IUGLS, which ended in 2012, showed an increasing trend in evaporation from all of the Lakes since 1948. This was offset to some extent by increased precipitation, except for Lake Superior. Thus, this research suggested that the net effect on water levels is not as great as reported in previous studies. In fact, some models predicted an increase in water levels on Lakes Michigan-Huron, while others predicted a decrease. The study concluded: “In terms of the limits of the Study’s hydroclimatic analysis, perhaps most notable from the perspective of effective lake regulation is how little the lake dynamics on inter-annual and decadal timescales are understood. Despite best efforts, the lake levels remain almost entirely unpredictable more than a month ahead.”

More recent research, cited in Appendix A, aligns with that cited above. Although studies agree that air and lake temperature will increase in the future, models show different impacts of temperature increases, in terms of net basin supply and water levels. For instance, increases in lake evaporation may be greater than increases in precipitation, thus resulting in lower lake levels. Different scenarios of future climate change may indicate increasing or decreasing water levels, even if the same model is used for the scenarios.

As is stated in Article 209 of the Agreement and Section 4.15.1b of the Compact, this assessment shall “give substantive consideration to climate change...and take into account the current state of scientific knowledge, or uncertainty, and appropriate Measures to exercise caution in cases of uncertainty if serious damage may result.” Furthermore, other factors including isostatic rebound and dredging affect Lake water levels. More information on these factors is available from the International Joint Commission and the IUGLS.

Adaptive management has various definitions, but under the Agreement and Compact is defined as “a water resources management system that provides a systematic process for evaluation, monitoring and learning from the outcomes of operational programs and adjustment of policies, plans and programs based on experience and the evolution of scientific knowledge concerning water resources and water-dependent resources.” In other words, adaptive management essentially is a decision-making process that seeks, in the face of uncertainty, to improve resource management by learning from previously employed policies and practices. Adaptive management requires monitoring of the resource and benefits from modeling. As more is understood about the hydrologic effects of Diversions and Consumptive Uses, adaptive management will be an even more increasingly useful tool in addressing these effects. As noted in the Introduction, the review and potential revisions to Basin-wide water conservation and efficiency goals and objectives pursuant to Article 304 paragraph 3 of the Agreement and Section 4.2.3 of the Compact, and other future work, must be in part based on the cumulative impact assessment. Additionally, the Parties will promote an adaptive management approach to the conservation and management of Basin Water resources pursuant to Article 100 of the Agreement and Section 1.3.2h of the Compact.

Cumulative impact assessments require reliable data and information regarding the Basin water budget and Consumptive Uses. As noted throughout this report, much of this data and information has significant uncertainty associated with it. While work is needed in many areas to improve Basin water budget data and reduce uncertainty, several specific areas stand out for near-term action:

- Research is needed to improve estimates of Consumptive Use and to improve consistency in application of Consumptive Use coefficients by the Parties.
- Further work is needed to improve understanding of the impacts of new or increased withdrawals on flows, associated chemical and biological conditions, as well as on other water uses at scales from local to regional to Basin.
- Changes to methods to improve calculations of runoff, evaporation from the Lakes, and precipitation on the Lakes are ongoing at Provincial and federal agencies, and universities. This research is vital to understanding the natural variability of the Basin water balance and to assessing potential changes in the future.

As noted in the Introduction, future Cumulative Impacts shall be conducted upon the earlier of:

- a. Every 5 years;
- b. Each time the incremental losses to the Basin reach 50,000,000 gallons (190,000,000 litres) per day average in any 90-day period in excess of the quantity at the time of the last assessment; or,
- c. At the request of one or more of the Parties.

The new water use reporting protocols mentioned above will help to better determine when the incremental water losses to the Basin are such that an assessment is required. As noted throughout this assessment, however, further improvements to data and information are needed to track an incremental loss of 50,000,000 gallons per day with certainty.

Appendix

Sources of Data and Information

Numbers in this assessment, in text, graphs and tables, are all derived from the following sources.

Runoff

Monthly values from 1948-2015 are calculated by National Oceanic Atmospheric Administration's Great Lakes Environmental Laboratory (GLERL). The data are updated periodically and are in spreadsheets that can be downloaded from GLERL's web site. Values were converted from millimeters over the lake surface area to cubic feet per second using coordinated lake areas.

For Lake Superior, GLERL's runoff figure includes the Ogoki Diversion. In this assessment, the Ogoki Diversion was subtracted from GLERL's runoff using the Binational Coordinating Committee on Basic Hydrologic and Hydraulic Data (Coordinating Committee) Ogoki Diversion flow estimates, since Diversions are considered separately from runoff. Data for 2013-2015 for Ogoki Diversion are not available yet, so a value of 3,700 cfs was subtracted from runoff for those years.

Evaporation

Monthly values from 1948-2015 are calculated by GLERL. The data are updated periodically and are in spreadsheets that can be downloaded from GLERL's web site. Values were converted from millimeters over the lake surface area to cubic feet per second using coordinated lake areas.

Precipitation

Monthly values from 1948-2015 are calculated by GLERL. The data are updated periodically and are in spreadsheets that can be downloaded from GLERL's web site. Values were converted from millimeters over the lake surface area to cubic feet per second using coordinated lake areas.

Connecting Channel flows

Monthly values from 1948-2015 for the St. Marys, St. Clair, Detroit, Niagara, and St. Lawrence (at Cornwall, Ontario) Rivers were provided by the U.S. Army Corp of Engineers, Detroit District, on behalf of the Coordinating Committee. Flows through 2008 are coordinated, that is, the Coordinating Committee has agreed to these numbers. Other flows are considered provisional.

Annual flows from 1948-2015 for the St. Lawrence River at Trois Rivieres, Québec were provided by Environment Canada. These data are considered provisional.

Diversions and Consumptive Uses

Diversions and Consumptive Uses are reported annually by each Party by Watershed to the Great Lakes Commission. The Great Lakes Commission maintains the Great Lakes Water Use Database Repository on behalf of the Parties. This database includes data from 1998-2010. Earlier data is available only in paper or PDF format. In this assessment, only data from 2006-2015 are reported due to quality and consistency issues with earlier data. If these issues are resolved, earlier data can be included in future assessments of cumulative impacts.

For comparative purposes, this assessment uses Diversion data from 1948-2010 provided by the U.S. Army Corps of Engineers. While these data may differ from those included in the Great Lakes Water Use Database Repository, they provide a historical context for Diversions. For the Lakes Michigan-Huron Watershed, the five-year average data for Diversions do not include stormwater runoff, whereas the 1948-2015 data include stormwater runoff. Stormwater runoff is estimated to be in the range of 800 cfs on a long-term annual average basis.

Further information on individual diversions is reported by the Parties to the Great Lakes Water Use Database Repository. Information on some of these diversions in the States is separately collected by federal agencies, and is available from the U.S. Army Corps of Engineers.

Water levels

Lakes levels were downloaded from GLERL's web site. These are an average annual lake level for each lake in meters using the IGLD85 datum.

Other water budget assessments have estimated the effect of Diversions and Consumptive Uses on water levels. For further information on this effect, see for example the International Joint Commission's Great Lakes Study Water Use Report and Water Uses Reference Study.

Relevant publications

Information in the following publications assisted in the writing of this assessment.

DeMarchi, C., Dai, Q., Mello, M.E., Hunter, T.S., 2012, Estimation of Overlake Precipitation and Basin Runoff Uncertainty, IUGLS Technical Working Group report, 51 p. (available on IUGLS web site)

Feinstein, D.T., Hunt, R.J., and Reeves, H.W., 2010, Regional groundwater-flow model of the Lake Michigan Basin in support of Great Lakes Basin water availability and use studies: U.S. Geological Survey Scientific Investigations Report 2010-5109, 379 p.

Filatova, N.N., and Vyruchalkina, T.Y., 2017, Many-Year Level Variations in the Great Lakes of Eurasia and North America, *Water Resources*, Vol. 44 No. 5, pp 685-696.

Gronewold, A. D., J. Bruxer, D. Durnford, J. P. Smith, A. H. Clites, F. Seglenieks, S. S. Qian, T. S. Hunter, and V. Fortin , 2016, Hydrological drivers of record-setting water level rise on Earth's largest lake system, *Water Resour. Res.*, 52.

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