Rising Water Levels Across the Great Lakes

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Hydrologic Science and Uncertainty Assessment

Lab at the University of Michigan School for Environment and Sustainability

Research

Our research focuses on developing and communicating answers to important societal questions about historical and future variability in regional water quantity and quality over multiple time scales. We pursue projects that directly support sustainable environmental and human-health management and policy decisions. Planning for and adapting to fluctuating water supplies, for example, requires differentiating and effectively communicating relative impacts of climate change, consumptive use, and engineered water management solutions. Similarly, ensuring water supplies are of a high enough quality to meet their intended use requires identifying and mitigating detrimental impacts of point and non-point source pollution and understanding complex coastal physical processes. Our research group develops creative and high impact solutions to these types of real-world hydrologic science problems through novel modeling and statistical analysis techniques, direct engagement with stakeholders, and integration of expertise and resources across scientific disciplines and institutions.

Understanding Great Lakes water level variability

The Laurentian Great Lakes represent the largest system of lakes on Earth and contain roughly 20% of all the fresh surface water of the nation. Our team’s work research aimed at understanding short- and long-term changes in Great Lakes water level variability, including pathways through which climate change impacts the major components of the Great Lakes water balance. This research extends into other Great Lakes regional projects, including model and dataset development for water quantity and quality management.

Seasonal coastal ice cover forecasting

Coastal ice cover has been changing at a rapid pace throughout the globe. In the Laurentian Great Lakes, coastal regions have had to adapt management protocols to an increase in ice cover variability over the past 20 years. Our research on this topic has focused on developing statistical models that forecast seasonal ice cover onset, with the ultimate goal of supporting regional management decisions.

Modelling the water balance of large African Lakes

Building on our extensive research on the Laurentian Great Lakes, our group has launched a collaboration with the Malian Department of Fisheries to understand drivers of water level changes in Mali’s largest lakes. Our approach is based on customising statistical water balance models to two large and iconic lakes in East Africa to understand and forecast seasonal water level dynamics.

Improving flow simulations in the Niagara River

The Niagara River transports a continent-scale flow of over 6000 cubic meters per second (an annual average basis) and spans the two most downstream lakes of the Laurentian Great Lakes (Erie and Ontario). Our work on this project has focused on employing legacy and novel streamwise bathymetry data to extend the dataset of an existing model to improve water management planning capability for this region, which includes two prominent hydroelectric facilities located along Niagara Falls.

Developing interactive dashboards and management tools to support water management planning

Hydrologic model datasets are an important asset for understanding hydrologic variability. To improve the effectiveness of these data resources, our team develops on-line, interactive tools that transform data into useful information for practitioners in decision making processes, and to help scientists and citizen to understand drivers of changes in large lake water resources over time.

Coastal and inland flood modelling and infrastructure planning

Our group works on several projects related to simulating and forecasting projected water levels along coastal and inland environments. The goal of this work is to project future climate changes, as well as sea level and coastal flood changes, in regional hydrologic response order to guide prudent infrastructure planning decisions.

Projects

People

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abundant, clean water. In contrast, extremely high water levels often lead to extensive shoreline damage, erosion, and loss of both beaches and shorefront property (Rasid et al., 1992). At the same time, high water levels can be a benefit to the shipping industry.

Figure 2: Annual (black dots) and monthly (light blue dots) historical average lake-wide water levels on each of the Great Lakes. Horizontal red lines represent the mean water level for each of the Great Lakes over the period of record.

Roughly one decade ago, Great Lakes water management authorities were compelled by information in the National Climate Assessment (NCA), among other publicly-available records and reports (Lofgren et al., 2002; Lofgren, 2004; Hayhoe et al., 2010; Angel and Kunkel, 2010), to plan around a future characterized by higher temperatures, increased evapotranspiration and, ultimately, water loss and drought. Indeed, water levels on the upper Great Lakes (i.e. Superior, Michigan, and Huron) had been below or near average
Drivers of water level change: hydrologic cycle


From NOAA-GLERL
Introduction

Historical water levels

Projections

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EXTRA SLIDES (AS NEEDED)
Fig. 5 Historical gauge-based basin-wide precipitation estimates (in mm) for the North American Laurentian Great Lakes and, for comparison, water level observations (for details, see Fig. 3). Green and orange bars represent annual basin-wide precipitation values (in mm) above and below (respectively) the average for the period of record (Woodworth 1999; Ekman 1999). This historical record, synthesized in Quinn (1981) and Croley and Hunter (1994), underscores important linkages between changes in Great Lakes regional climate, and how those changes propagate through changes in the Great Lakes water budget and, ultimately, into changes in Great Lakes water levels.

Historical variability in annual basin-wide precipitation, for example, coincides with annual water level fluctuations over much of the period of record (Fig. 5). Over the Lake Superior basin, annual precipitation follows a somewhat cyclical pattern, with an increasing trend from the early 1900s toward the 1950s and 1960s, followed by a slight decreasing trend over the past 30 years. Water levels on Lake Superior have followed a similar pattern. Precipitation over Michigan-Huron, Erie, and Ontario, however, has followed a different pattern, with annual averages since 1970 consistently above the long-term average. While water levels on each of these systems rose significantly during the late 1960s and early 1970s, the water levels on these systems also dropped significantly between 1997 and 2000 despite relatively stable annual precipitation (for further discussion, see Assel et al. 2004; Sellinger et al. 2007; Stowe et al. 2008).

The drops in annual average water levels during the late 1990s do, however, coincide with significant increases in Great Lakes surface water temperatures (not shown) and overlake evaporation rates (Fig. 6). In particular, the steady increase in
Fig. 6 Simulated annual overlake evaporation (in mm) based on Croley (1992) and Croley and Assel (1994) and historical annual lake-wide average water levels. Orange vertical bars represent annual evaporation rates greater than the average over the simulation period (1948–2010), while green vertical bars represent annual evaporation rates below the average.

Overlake evaporation over each of the lake systems for the past 50 years synthesizes long-term changes in multiple regional climate variables including, most notably, the difference between air and surface water temperature (for details, see Austin and Colman 2007) as well as the decreasing areal extent and thickness of lake ice (Wang et al. 2010, 2012). In light of these changes, and of the recently recorded (January 2013) all-time record low water levels on Lake Michigan-Huron, one of the more challenging research questions facing the Great Lakes region at present is, “will water levels rebound, or have we entered a new hydrologic regime?” Responses to this question depend, in part, on forecasts of regional climate variables, and appropriate interpretation of how those forecasts propagate into water level dynamics. Interpretation of these forecasts depends, in turn, on the context in which they are presented. Importantly, this context rarely includes a comparison between historical forecasts and data from the same period of record. This comparison is important, as we discuss further in Section 3, because it provides an indication of model forecasting skill (Gronewold et al. 2011).

2.1 Great Lakes basin precipitation and evaporation monitoring

Basin-wide annual precipitation totals (Fig. 5) are derived from a network of land-based gauges in the US and Canada (using a methodology described in Croley...
<table>
<thead>
<tr>
<th>Name</th>
<th>Country</th>
<th>Surface area (km²)</th>
<th>Volume (km³)</th>
<th>Surface area (mi²)</th>
<th>Volume (mi³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan–Huron</td>
<td>U.S. and Canada</td>
<td>117,702</td>
<td>8,458</td>
<td>45,445</td>
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<td>Superior</td>
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<td>12,100</td>
<td>31,820</td>
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<td>Multiple</td>
<td>69,485</td>
<td>2,750</td>
<td>26,828</td>
<td>660</td>
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<tr>
<td>Tanganyika</td>
<td>Multiple</td>
<td>32,893</td>
<td>18,900</td>
<td>12,700</td>
<td>4,500</td>
</tr>
<tr>
<td>Baikal</td>
<td>Russia</td>
<td>31,500</td>
<td>23,600</td>
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<td>30,044</td>
<td>8,400</td>
<td>11,600</td>
<td>2,000</td>
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<tr>
<td>Great Slave Lake</td>
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<td>489</td>
<td>9,930</td>
<td>117</td>
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<td>Winnipeg</td>
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<td>9,094</td>
<td>68</td>
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<td>Ontario</td>
<td>U.S. and Canada</td>
<td>19,477</td>
<td>1,639</td>
<td>7,520</td>
<td>393</td>
</tr>
</tbody>
</table>

**Table:** Water volume and surface area of Earth’s largest (ranked by surface area) fresh surface waters.

From: NOAA National Ocean Service (CO-OPs) and NOAA-GLERL.
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Lake Ontario-St. Lawrence River flooding 2017: Extra water on both sides of the dam

During the first six months of 2017, more than twice the normal amount of water accumulated on Lake Ontario (1.3 meters, compared to the average of 0.6 meters), while the Ottawa River saw the highest flows (cumulatively) in more than 50 years, leading to widespread flooding across the Lake Ontario - St. Lawrence River system. The graphs below indicate where the additional water came from by comparing system inflows and outflows from 2017 (dark lines) to previous years (light lines).

Lake Ontario Jan - June water budget (m)

<table>
<thead>
<tr>
<th></th>
<th>average*</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>inflow from Lake Erie</td>
<td>5.2</td>
<td>5.7</td>
</tr>
<tr>
<td>runoff</td>
<td>1.2</td>
<td>1.7</td>
</tr>
<tr>
<td>precipitation</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>evaporation</td>
<td>-0.2</td>
<td>-0.2</td>
</tr>
<tr>
<td>outflow to St. Lawrence R.</td>
<td>-6.0</td>
<td>-6.5</td>
</tr>
<tr>
<td>total</td>
<td>0.6</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Ottawa River Flows

Excessively wet weather from April through June led to unusually high flows in the Ottawa River, contributing to high water levels in the St. Lawrence River.

Inflow from Upper Lakes

In early 2017, Lake Erie levels were the highest they'd been for that time of year in almost 20 years. Inflows to Lake Ontario from Lake Erie were above average from January through June.

Rain/snow on Lake Ontario Basin

Lake Ontario saw two of the wettest months ever recorded in April and May of 2017. Water levels were impacted by precipitation falling directly on the lake’s surface.

Outflow to St. Lawrence River

Variable ice conditions in the St. Lawrence River from January through March along with high Ottawa River flows (see above box) limited outflows from Lake Ontario, which are controlled through the Moses-Saunders Dam. Still, from January to June, outflows removed half a meter (1.6 feet) more water than average from Lake Ontario.
Figure 1 - International river basins of North America that intersect land surfaces of the US. The Great Lakes – St. Lawrence River Basin is outlined in red.
Figure 2 – Jurisdictional boundaries (solid colored regions) of NOAA’s NWS river forecasting centers (shown here as one of the federal agencies responsible for collecting and disseminating broad-scale hydrometeorological data). The boundary of the Great Lakes - St. Lawrence River basin is shown (red) for comparison.
Fig. 3  Historical monthly and annual average surface water elevations in the North American Great Lakes and at other gauges from around the world. Annual average water levels are represented by black dots, and monthly average water levels are represented by light blue dots. Average elevations for each period of record are represented by horizontal red lines. Surface water elevations are referenced to either the 1985 International Great Lakes Datum (for the Great Lakes) or mean sea water level and are plotted at the same vertical scale. Breaks in the y-axis values between Great Lakes data sets reflect elevation changes through the St. Marys River, Niagara Falls, and the St. Lawrence River, respectively.
Great Lakes Water Levels: The Critical Role of Evaporation

The question has been asked many times: “Who is draining all the water out of the Great Lakes?” As with many environmental issues—in this case low lake levels—people are interested in “the cause.” And with good reason: If the source of a problem is identified, the solution becomes more attainable. As with many problems, however, the issue of Great Lakes water levels is complex. Lake Superior, for example, loses almost three feet of water every year through the St. Marys River (Lenters, 2004). And roughly two feet of water is also lost every year just through evaporation (Figure 1). That is a total of five feet of water lost annually from the surface of Lake Superior due solely to natural processes. Relatively little water is gained or lost through direct human intervention (e.g., less than 1 inch per year flows into Lake Superior from the Long Lac diversion). So the next time the question arises about “who is draining all the water out of the Great Lakes,” the answer should be that it is mostly Mother Nature. This does not necessarily mean that nature is changing (e.g., due to human causes), but it does at least mean that one can stop looking for that secret water pipeline to the southwestern United States. As illustrated in Figure 1, the real “elephants in the room” are precipitation, evaporation, and runoff through rivers and connecting channels (Hunter et al., 2013). These are the processes that should be looked at most closely.

Evaporation is one of the most difficult water-loss processes to understand, and for a number of reasons. First of all, it is invisible. One cannot generally “see” a lake evaporating (an exception being the condensed water vapor or lake-effect clouds that sometimes hover above a lake’s surface in autumn and early winter). This is in contrast to rivers, for example, where water level and flow conditions are always visible. A second reason that evaporation can be difficult to understand is that it often varies in counterintuitive ways. For example, many people assume that the Great Lakes’ highest rates of evaporation are in the heat of summer (mid-July), since high temperatures are often equated with high rates of evaporation. It turns out, however, that this is simply not the case. The highest evaporation rates on the Great Lakes typically occur in late fall and early winter, when conditions are much colder (Figure 1). This is because evaporation is not directly driven by warm air temperatures, but instead by warm water temperatures (Lenters, 2004). More specifically, high evaporation requires three factors: 1) a large temperature difference between water and air (i.e., warm water and cold air), 2) low relative humidity, and 3) high wind speeds. If all three ingredients are present, as often occurs in the fall and winter, evaporation rates from the Great Lakes can get as high as 0.4-0.6 inches per day. To put this number in perspective, a 1-day loss of 0.5 inches of water from the total surface area of the Great Lakes (94,250 mi²) represents a volumetric flow rate of 820 billion gallons per day—nearly 20 times the flow rate of Niagara Falls.

A third problem with evaporation is that it is extremely difficult to measure—so it is rarely done. Unlike a rain gage, there is no simple “evaporation gage” that can be attached to a weather station to provide direct, accurate observations of water loss from soil, plant, or water surfaces. “Pan evaporation” gages are sometimes used, but they provide only indirect estimates of evaporation and are not suitable for measuring evaporation from large, deep lakes. Instead, meteorologists and hydrologists must use

![Figure 1. Four components of the monthly Lake Superior water balance, beginning with the month of June, which is the typical start of the “evaporation season.” Each component is shown as a flux of water in units of inches per month (left; spread out over the surface area of Lake Superior), as well as in equivalent “number of Niagara Falls” (right). Note, in particular, the strong seasonal variation in evaporation.](from Lenters et al. (2013): Assessing the impacts of climate variability and change on Great Lakes evaporation)
Great Lakes System Profile

Lake Superior
- Depth: 1,333 ft.

Lake Huron
- Depth: 750 ft.
- Depth: 925 ft.

Lake Michigan
- Depth: 802 ft.

Lake Erie
- Depth: 210 ft.

Lake Ontario
- Depth: 243 ft.
- Elevation: 20 ft.

St. Lawrence River
- Elevation: 0 ft.

St. Mary's River
- Elevation: 601 ft.

St. Clair River
- Elevation: 577 ft.

Detroit River
- Elevation: 566 ft.

Niagara River

Elevation: 0 ft.

Soo Locks & Dams
Sault Ste. Marie

Elevation: 0 ft.

Gulf of St. Lawrence

Atlantic Ocean

Total Distance Along Floor Path 2,212 Miles

NOT TO SCALE.
Vertical elevations are exaggerated. Surface elevations are Chart Datum values above MSL, and depths are maximum of each lake.

Modified from Michigan Sea Grant