The Current State of Great Lakes Water Levels

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ELPC
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Outline

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3. May 2022 water level status
4. Future water levels
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Environment Studies
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2021 retrospective
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Montreal Flooding Displaces Thousands

By CRAIG S. SMITH  MAY 11, 2012
Groundwater running out in northeastern Illinois

FEB 25, 2021
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regional climate models (RCMs) driven by GCMs from CMIP5 indicate a 10%–20% increase in precipitation (specifically for Lake Erie) by mid-21st century.

Interestingly, between 1998 and 2013, when water levels on Lakes Superior, Michigan, and Huron were very low (Figure 2), land evapotranspiration and lake evaporation dominated the water balance (Figures 3b and 3e). Only when lake evaporation shifted abruptly from above-to below-average conditions in the winter of 2013–2014 (Figure 3e) did abundant precipitation across the region propagate into a record-setting rate of water level rise (Gronewold et al., 2016) and the recent series of record-high monthly and annual average levels (Figure 2).

It is informative to note that the rapid decline in overlake evaporation in early 2014 coincided with an extreme Arctic polar vortex deformation (Clites et al., 2014; Zhang et al., 2016) that resulted in an outburst of very cold air over central North America, and a decrease in Great Lakes surface water temperatures (Gronewold et al., 2015). While there appears to be a strong association between the cold air outburst and the decrease in evaporation, the nature of connections between global climate change and the frequency, intensity, and orientation of Arctic polar vortex deformations is less clear (Lee & Butler, 2020; Zhang et al., 2016). It is also worth noting that evapotranspiration on the land surface of the Great Lakes basin, which had been increasing over the period of record (Figure 3b), also abruptly declined in 2014 but, unlike lake evaporation, has since returned to high levels. Improving understanding of the mechanisms that initiated and continue to maintain low levels of evaporation after 2014, and whether those mechanisms might continue to be linked to Arctic polar vortex deformations, is an area for future research.

We have found evidence of an increase in the variability of competing forces on the water balance across a large portion of central and eastern North America, suggesting a continental-scale hydrological tug-of-war. We also note that runoff into the lakes, despite the rise in regional precipitation, has been relatively stable.
Geophysical Research Letters

Research Letter

A tug-of-war within the hydrologic cycle of a continental freshwater basin

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Introduction

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Changes in Large Lake Water Level Dynamics in Response to Climate Change

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Understanding impacts of climate change on water level fluctuations across Earth's large lakes has critical implications for commercial and recreational boating and navigation, coastal planning, and ecological function and management. A common approach to advancing this understanding is the propagation of climate change scenarios (often from global circulation models) through regional hydrological models. We find, however, that this approach does not always fully capture water supply spatiotemporal features evolving from complex relationships between hydrologic variables. Here, we present a statistical approach for projecting plausible climate-related regional water supply scenarios into localized net basin supply sequences utilizing a parametric vine copula. This approach preserves spatial and temporal correlations between hydrologic components and allows for explicit representation and manipulation of component marginal and conditional probability distributions. We demonstrate the capabilities of our new modeling framework on the Laurentian Great Lakes by coupling our copula-derived net basin supply simulations with a newly-formulated monthly lake-to-lake routing model. This coupled system projects monthly average water levels on Lake Superior, Michigan-Huron, and Erie (we omit Lake Ontario from our study due to complications associated with simulating strict regulatory controls on its outflow). We find that our new method faithfully replicates marginal and conditional probability distributions, as well as serial autocorrelation, within and among historical net basin supply sequences. We find that our new method also reproduces seasonal and interannual water level dynamics. Using readily-available climate change simulations for the Great Lakes region, we then identified two plausible, transient, water supply scenarios and propagated them through our model to understand potential impacts on future water levels. Both scenarios result in an average water level increase of <10 cm on Lake Superior and Erie, with slightly larger increases on Michigan-Huron, as well as elevated variability of monthly water levels and a shift in seasonal water level modality. Our study contributes new insights into plausible impacts of future climate change on Great Lakes water levels, and supports the application and advancement of statistical modeling tools to forecast water supplies and water levels on not just the Great Lakes, but on other large lakes around the world as well.

Keywords: climate change, statistical model, Great Lakes, water supplies, copula
Climate change is underway and the impacts are being felt. Assessments of climate change impacts, adaptation, and vulnerability (collectively termed “climate assessments”) are being undertaken to inform decision making in this environment of uncertainty (Carter et al. 2007). The urgent need for climate information for management and adaptation decisions has led to an increase in the number of climate assessments being performed across the United States (National Assessment Synthesis Team 2001; New England Regional Assessment Group 2001; Frumhoff et al. 2007; Titus et al. 2009; Jacobson et al. 2009; Moser et al. 2009; Karl et al. 2009; NYSERDA ClimAID Team 2010). Assessment methodologies have gradually evolved and increased in number (Carter et al. 2007), and this trend is likely to continue. In recent years, climate assessments have been progressively propelled from exclusively research-oriented summaries or activities toward analytical frameworks that are designed for practical decision making (Carter et al. 2007). The latest climate assessments (the “new generation”) are often required to formulate comprehensive adaptation alternatives or, at the very least, recommendations that will guide the choice of alternatives. This transition is occurring with mixed success, as the aims of research and decision analysis differ somewhat in their treatment of uncertainty (Dessai and Hulme 2004; Rayner et al. 2005). Research seeks to understand and minimize uncertainty, whereas decision analysis aims to manage uncertainty in order to prioritize and carry out actions (Carter et al. 2007).

Despite the increase in assessments that deal with adaptation alternatives, and the increasing recognition that climate impacts and adaptation are unique issues in each community (Miles et al. 2006; Lynch and Brunner 2007; Christoplos et al. 2009; Brunner and Lynch 2010a,b), there has continued to be a lack of practical advice for adaptation decision making at the local level (Arnell 2010). This is particularly true when considering smaller, less urbanized communities. There are a number of examples of larger well-resourced communities taking adaptation action (Lowe et al. 2009; NYC Climate Change Adaptation Task Force), but at smaller scales communities that are proactive with adaptation are a rarity. The attitude is captured by the quote used for the title of this essay from a water supply plant manager when asked about future planning efforts.

The focus of this essay is therefore ways in which assessments can make themselves more socially relevant (i.e., better link climate science to real-world problems being faced by communities) and successfully meet the new demands that are being asked of them. This essay draws on experiences from the 2010 Integrated Assessment for Effective Climate Change
Lake Michigan–Huron Monthly Mean Water Levels

Published 04 May 2021

Observed Monthly Mean
Long Term Average
Long Term Max/Min

Range of Possible Outcomes
Low Jan–Mar NBS
May Bulletin Forecast Range
Bulletin Forecast Most Probable

1987–88
2015–16
Lake Michigan–Huron Monthly Mean Water Levels

Published 04 May 2021

Observed Monthly Mean
Long Term Average
Long Term Max/Min

Range of Possible Outcomes
Low Jan–Mar NBS
May Bulletin Forecast Range
Bulletin Forecast Most Probable

1987–88
2015–16
Published 04 May 2021
Lake Michigan–Huron Monthly Mean Water Levels

Published 03 May 2022

- Observed Monthly Mean
- Long Term Average
- Long Term Max/Min
- Range of Possible Outcomes
- Ice Cover near 56%
- May Bulletin Forecast Range
- Bulletin Forecast Most Probable

Range of Possible Outcomes
- 2007–08
- 2008–09
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Drivers of water level change: hydrologic cycle

Great Lakes System Profile

- Lake Superior
  - St. Mary's River: Depth 1,333 ft.
  - Lake Huron: Depth 750 ft., Depth 925 ft.
- Lake Michigan: Depth 925 ft.
- Lake Erie: Depth 210 ft., Elevation 243 ft.
- Lake Ontario: Elevation 20 ft.
- St. Lawrence River: Elevation 0 ft.

- Soo Locks & Dams Sault Ste. Marie
- Detroit River
- St. Clair River
- Niagara River
- St. Lawrence River
- Iroquois Dam
- Beauharnois Power Dam

Total Distance Along Floor Path: 2,212 Miles

Surface elevations are Chart Datum values above MSL, and depths are maximum of each lake.

NOT TO SCALE. Vertical elevations are exaggerated.

Modified from Michigan Sea Grant
flow between lakes. The NBS for each lake is defined as the sum of the overlake precipitation and drainage basin runoff minus lake evaporation. Each lake’s drainage basin is larger than the lake’s surface area; therefore, if precipitation rates are equal over land and lake, then the water accumulated over land will add a greater mass of water to the lake. The impact of runoff on lake depth is computed by multiplying the runoff per area by the ratio of the corresponding basin area to lake area.

A treaty between the United States and Canada regulates the channel flow between Lakes Superior and Huron and out of Lake Ontario. The Lake Superior regulation and routing module determines the human-controlled flow out of Lake Superior and includes the Ogoki and Long Lac diversions into the lake, as well as total Superior outflow and the permitted minima and maxima in side channel outflow. This model is combined with a coordinated hydrologic response model for the middle Great Lakes, the

Fig. 2. Projected changes in 2-m air temperature (°C) and precipitation (mm day⁻¹), both (a) annually and (b)–(e) by season, across the Great Lakes region (40°–50°N, 95°–70°W; land only), computed as the difference between either 2040–59 or 2080–99 and 1980–99. Each dot represents one of 33 CMIP5 GCMs for mid-twenty-first- (orange) or late twenty-first- (red) century projections. Model-mean projections are shown for the mid- and late twenty-first century with brown and blue crosses, respectively. Projections from GCM-CNRM (large dot) and GCM-MIROCS (sideways triangle) are identified with green and blue symbols for the mid-twenty-first and late twenty-first century, respectively.
Surface Water Temperature (degrees C), since 1995

data source: http://coastwatch.glerl.noaa.gov
A review of cyclone track shifts over the Great Lakes of North America: implications for storm surges

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Abstract
Cyclone tracks over the Great Lakes of North America shift, both East–West as well as North–South. The reasons for the shifts are various small-scale as well as large-scale processes associated with the general circulation of the atmosphere. The East–West shift has an approximate periodicity of 10 years, while the North–South shift occurs roughly with a periodicity of 20 years. The East–West shift is more important than the North–South shift. The amount of shift could be as much as a few hundred kilometers. The implication of these shifts for storm surges in the Great Lakes is considered.

Keywords Storm surges · Cyclone tracks shift · Great Lakes of North America

1 Introduction
Figure 1 shows a map of the five Great Lakes of North America.
This paper considers tracks of extra-tropical cyclones (ETC) travelling generally from the west, as well as tropical cyclones (TC) from the Atlantic Ocean and the Gulf of Mexico, that get somewhat modified when they reach the Great Lakes.
NAV Canada (2017) identified the following lows (low-pressure systems) that influence the Great Lakes in winter (Fig. 2): Mackenzie, Alberta, Colorado, Gulf, Hatteras, Great Lakes.
A careful examination of their diagram reveals the deduction given in Table 1.

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3 Computation of storm surges

Linear storm surge prediction equations (Murty 1984) are given below:

\[
\frac{\partial M}{\partial t} - fN = -gD \frac{\partial h}{\partial x} - \frac{D}{\rho_o} \frac{\partial P_a}{\partial x} + \frac{1}{\rho_o} \left( \tau_{S_x} - \tau_{B_x} \right) \tag{1}
\]

\[
\frac{\partial N}{\partial t} + fM = -gD \frac{\partial h}{\partial y} - \frac{D}{\rho_o} \frac{\partial P_a}{\partial y} + \frac{1}{\rho_o} \left( \tau_{S_y} - \tau_{B_y} \right) \tag{2}
\]

\[
\frac{\partial h}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0. \tag{3}
\]

For convenience, hereafter, the subscript on the density field will be omitted.

In these linear storm surge prediction equations, the dependent variables are the transport components \( M \) and \( N \) and the water level \( h \). The forcing functions are the atmospheric pressure gradients given by \( \frac{\partial P_a}{\partial x} \) and \( \frac{\partial P_a}{\partial y} \) and the wind stress components \( \tau_{S_x} \) and \( \tau_{S_y} \). The retarding force is the bottom stress. At this stage, there are more unknowns

\[\text{Table 1} \quad \text{Names of the lakes affected by lows in winter}\]

<table>
<thead>
<tr>
<th>Name of low</th>
<th>Names of lakes affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mackenzie</td>
<td>Superior</td>
</tr>
<tr>
<td>Colorado</td>
<td>Erie, Ontario</td>
</tr>
<tr>
<td>Alberta Low</td>
<td>Michigan, Huron</td>
</tr>
</tbody>
</table>

\[\text{Fig. 2} \quad \text{Cyclone tracks during winter in North America. (Reproduced with permission from NAV Canada 2017)}\]