The response of Great Lakes water levels to future climate scenarios with an emphasis on Lake Michigan-Huron

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A B S T R A C T

Future climate change and its impact on Lake Michigan is an important issue for water supply planning in Illinois. To estimate possible future levels of the Great Lakes due to climate change, the output of 565 model runs from 23 Global Climate Models were applied to a lake-level model developed by the Great Lakes Environmental Research Laboratory (GLERL). In this study, three future emission scenarios were considered: the B1, A1B, and A2 emission scenarios representing relatively low, moderate, and high emissions, respectively. The results showed that the A2 emission scenario yielded the largest changes in lake levels of the three emission scenarios. Of the three periods examined, lake levels in 2080–2094 exhibited the largest changes. The response of Lake Superior was the smallest of the Great Lakes, while lakes Michigan-Huron, Erie, and Ontario were similar in their response over time and between emission scenarios. For Lake Michigan-Huron, the median changes in lake levels at 2080–2094 were −0.25, −0.28, and −0.41 m for the B1, A1B, and A2 emission scenarios, respectively. However, the range in lake levels was considerable. The wide range of results is due to the differences in emission scenarios and the uncertainty in the model simulations. Selecting model simulations based on their historical performance does little to reduce the uncertainty. The wide range of lake-level changes found here make it difficult to envision the level of impacts that change in future lake levels would cause.

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Introduction

Future climate change and its impact on the Great Lakes is a critical issue for water supply planning in Illinois. Future water levels not only could affect water supply and quality for those Illinois residents that live within the Lake Michigan basin but also have significant repercussions regarding the diversion of Lake Michigan water down the Chicago River.

Lake Michigan supplies approximately 6800 ML/day (80 m³/s) to communities in northeastern Illinois that reside within the Lake Michigan basin (Injerd, 1998). That water is used for industry, agriculture, domestic consumption, commerce, and energy production. The demand for water will likely grow with the population and economy. Although water demands can be reduced through conservation and reuse, it is anticipated that 20% to 50% more water will be required in the decades ahead to meet the needs of Illinois’ residents and economy (Dziegielewski, 2008).

Hartmann (1990) identified possible impacts from declining water levels in the Great Lakes. The impacts range from environmental (e.g., loss of wetlands, changes in the shoreline) to socioeconomic (e.g., loss of hydropower, increased navigation challenges, loss of shipping, reduced marina access). Injerd (1998) outlined several concerns of lower Lake Michigan levels that are specific to Illinois. Three federally maintained commercial harbors in Illinois (Calumet, Chicago, and Waukegan Harbors) would require continual dredging with substantial costs to the point that it might not be affordable for two of the three to be maintained for deep draft navigation. Illinois has some 27 water supply intakes in Lake Michigan located between 900 and 1500 m offshore for water quality purposes and protection from ice. It is expected that these water supply intakes should have no major problem in adjusting to lower lake levels, even though it would increase energy costs to pump the water to the plants.

One major impact of lowering water levels in Lake Michigan would be in the operation of the Chicago River diversion management system. The history of the Chicago River diversion goes back to 1900 when the City of Chicago began diverting water from Lake Michigan to move its sewage down the Chicago River. This resulted in a long series of legal battles that ultimately led to a Supreme Court decision to allow a diversion of 90.6 m³/s (3200 ft³/s) from Lake Michigan.

Impacts of low lake levels could be considerable for the diversion. Injerd (1998) noted that if Lake Michigan water levels dropped below 1.5 m, the modern-day diversion would end, as lake levels would be lower than in the canal system. The only alternative would be to lower the canal system by 1.5 m, requiring 48 km of dredging including 24 to 27 km of rock excavation, all at an enormous cost (Injerd, 1998).
Several studies have addressed this issue of future water levels in the Great Lakes as it relates to greenhouse gas-induced climate change. These studies rely on various Global Climate Models (GCM) and scenarios of future emissions, most often a doubling in CO₂ levels. Cohen (1986) used the results of two GCMs for a doubling in CO₂ to estimate future changes in water supply and found large reductions in the net basin supply (the sum of precipitation over the lakes and runoff into the lakes minus evaporation from the lake surfaces) in several instances. However, one scenario yielded a slight increase in the net basin supply. Croley (1990) applied the results of three GCM simulations to a hydrologic model, finding a 23% to 51% reduction in net basin supplies. Hartmann (1990) applied the net basin supply results of Croley (1990) to system models that took into account regulation plans and net basin supply to determine water levels. Under three steady-state and one transient climate change scenarios, the Great Lakes water levels declined by 0.13 to 2.5 m, depending on the lake and the scenario. Lofgren et al. (2002) examined changes in Great Lakes water levels using scenarios from two GCMs and a hydrologic model. One GCM yielded sharp drops in lake levels, up to 1.4 m on Lake Michigan by 2090 due to a considerable increase in temperature more than offsetting an increase in precipitation. The second GCM yielded moderate increases in lake levels, up to 0.35 m in Lake Michigan by 2090 due to a considerable increase in precipitation more than offsetting an a moderate increase in temperature. Croley and Lewis (2006) examined a different but related climate change problem—the circumstances required to make the Great Lakes terminal (in this case water levels dropping below the outlet sills) as happened about 7900 ¹⁴C years BP. Using a version of the hydrologic model used here, they identified the contribution of rising temperatures and declining precipitation that would make this happen.

Two other studies used the direct output of the hydrologic component of GCMs to characterize the outflow of the St. Lawrence River in so-called quadrupled CO₂ experiments. Milly et al. (2002) found a 20% increase in the annual mean simulated outflow while Manabe et al. (2004) found a 12% increase. The results of both studies suggest an overall increase in the net basin supply of water in Great Lakes and presumably would result in higher lake levels, at least in Lake Ontario.

The common themes of previous studies on changing water levels were the limited number of climate scenarios used and the wide range of results. In this paper, a large number of climate scenarios for the Great Lakes region from multiple GCMs using three emission scenarios were employed to estimate possible future levels of Lake Michigan using the lake-level model developed by the Great Lakes Environmental Research Laboratory (GLERL).

**Methodology**

Potential future changes in climate over the Great Lakes region were derived from the latest set of global climate model simulations produced for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) (IPCC, 2007a). The study area used here is shown in Fig. 1. Model data were obtained and information for the Great Lakes region extracted for the 20th and 21st centuries. In this study, simulations for three emission scenarios (Nakicenovic et al., 2000) were selected (Fig. 2): a moderately high emission scenario.
The emission scenarios are as follows: A2 = moderately high, A1B = intermediate, and B1 = low.

Between 18 and 23 GCMs were used in this project—the number varied depending on their availability for each particular emission scenario. A complete list of the 23 GCMs and selected model features can be found in Table 8.1 on page 597 of Chapter 8 of Working Group 1 of AR4 (IPCC, 2007b). In many cases, multiple runs were made for each model with slight adjustments in their initial conditions. A total of 160 model runs were used for the A2 emission scenario, 211 for the A1B emission scenario, and 194 for the B1 emission scenario. Because there is no universally accepted methodology for evaluating the relative quality of GCMs with regard to their skill in predicting the future (CCSP, 2008), the model simulations are considered in this study as having an equal, but unknown, probability of occurrence.

The GLERL Advanced Hydrologic Prediction System (AHPS) was used here to determine final lake levels. AHPS is a system of integrated models to estimate lake levels, lake heat storage, and water and energy balances. Separate components model rainfall–runoff, evapotranspiration, and basin soil moisture, over-the-lake precipitation, one-dimensional heat storage, and net lake supplies. These models have been calibrated to available observed conditions within each of the 121 watersheds within the Great Lakes. The models agree well with weekly and monthly observations (Croley, 2002, 2003). Additional models are employed for channel routing (Hartmann, 1988), lake regulation (International St. Lawrence River Board of Control, 1963), diversions, and water consumption (International Great Lakes Diversions and Consumptive Uses Study Board, 1981). Croley (2005) describes AHPS in greater detail. AHPS has been used to make probabilistic hydrologic outlooks of the Great Lakes based on long-range outlooks of temperature and precipitation (GLERL, 2008) as well as several studies of climate change impacts (e.g., Lofgren et al., 2002; Croley and Lewis, 2006).

As input into the GLERL AHPS model, change functions were calculated for each of the 565 GCM simulations for all grid points near the basin. The resolution of the change functions reflected the resolution of each GCM. The change function represented the change in a climate variable between a future period and the base period of 1970–1999 for each month of the year and expressed as either ratios or differences depending on the variable. Change functions were computed for maximum, minimum, and mean temperature, precipitation, humidity, wind speed, and solar radiation for each of three future periods (2005–2034, 2035–2064, and 2065–2094). A more complete discussion of the methodology can be found in Lofgren et al. (2002).

These change functions were introduced into the GLERL model to compute the expected water levels for each of the future periods. The first 15 years of the 30-year period were used as a spin-up period for the GLERL model to adjust to the new climate state. Then averages were taken of the second 15 years. Lake-level departures were calculated between the historical run of the GLERL model (1970–1999) and each future period. Here the results are referenced by the first year of the averaging period (e.g., 2020 represents the period 2020–2034). Lakes Michigan and Huron, as well as Georgian Bay, are all linked hydraulically as one unit and treated as such here.

In nature, climate conditions are varying on a range of time scales and the Great Lakes are rarely in balance with the climate. This is certainly the case with a response to any future climate change, during which climate conditions are will vary by season, year, and decade. Nevertheless, these lake-level model results indicate the potential for lake-level changes due to climate change.

Box-and-whisker plots are used here to illustrate the range of possible outcomes in lake levels, given the climate projections of many GCM/GLERL simulations. The top and bottom of the box represent the 25th and 75th percentile values while the whiskers represent a range 1.5 times the interquartile range. Values outside the whiskers are labeled with plus symbols.

Results and discussion

The GLERL model is formulated such that temperature and precipitation are the primary drivers (Croley, 2006) in determining
water levels in the Great Lakes. Fig. 3 presents the range of change values for annual temperature over the Great Lakes from the GCM simulations for all three emission scenarios. For the B1 low emission scenario, both the 95th and 5th percentiles show steadily increasing temperatures over the basin. By the end of the 21st century, the annual temperatures range from 1.5 to 4 °C above the 1970–1999 average. The change values for the A1B emission scenario are slightly larger, ranging from 2 to 5 °C by the end of the 21st century. For the A2 high emission scenario, the change values are larger still, ranging from 3.5 to 7 °C by the end of the 21st century. Clearly annual temperature over the Great Lakes in these GCM simulations is quite sensitive to the level of emissions, becoming warmer with a slightly wider range of changes as emissions increased.

In Fig. 4, annual precipitation change values from the GCM simulations for all three scenarios are summarized. In general, the precipitation changes were similar for all three scenarios. In some cases, the model simulations showed drying over the basin while a majority of cases showed wetter conditions. By the end of the 21st century, the A2 emission scenario did yield a slightly larger range in precipitation changes, from a 5 cm drop to a 20 cm increase in annual precipitation.

With precipitation remaining constant, increasing temperature should lead to decreases in future lake levels (Croley and Lewis, 2006); any future decreases in annual precipitation are likely to lead to substantial declines in lake levels. In the case of increasing precipitation, there will be a counterbalance to the effects of rising temperatures, leading to smaller declines in lake levels or perhaps even small increases in lake levels.

Fig. 5 summarizes the GCM/GLERL simulations of lake-level changes for all four lake groups (Superior, Michigan-Huron, Ontario, and Erie) for the A2 high emission scenario and the three future periods. The A2 emission scenario generated the largest changes in lake levels of the three emission scenarios. Fig. 5 shows the response of the four lake groups during 2020–2034. Lake Superior had the narrowest range of lake-level changes. For Lakes Michigan-Huron, Erie, and Ontario, the range was wider. For all four lake groups, about 75% of the model simulations yielded steady to declining lake levels. However, the median drop in lake levels is modest in all four cases, 0.1 m or less. This was expected since the level of CO2 forcing and simulated climate changes is still relatively small during this period (see Figs. 2, 3, and 4). At least 25% of the model simulations showed a decrease of 0.12 m or more for Lake Superior and 0.26 to 0.33 m or more for the other lakes.

By 2050–2064 (Fig. 5b), the lake-level response to the A2 scenario is larger with a wider range of changes than at 2020–2034. While the
response for Lake Superior is still relatively small, the remaining lakes show larger drops in lake levels. The median drop was 0.07 m for Lake Superior and about 0.2 m for the other lakes. At least 75% of the model simulations indicated steady to declining lake levels. At least 25% of the model simulations showed a decrease of 0.16 m or more for Lake Superior and 0.4 to 0.53 m or more for the other lakes.

By 2080–2094 (Fig. 5c), Lake Superior still shows the smallest response while the other lakes a much wider range of responses. The median decline is 0.12 m in Lake Superior, 0.41 m in Lake Michigan-Huron, 0.32 m in Lake Erie, and 0.39 m in Lake Ontario. At least 75% of the model simulations showed steady or declining levels in Lake Superior, and a decline of 0.13 m or more for the other lakes. At least 25% of the model simulations showed a decrease of at least 0.23 m for Lake Superior, 0.76 m for Lake Michigan-Huron, 0.57 m for Lake Erie, and 0.71 m for Lake Ontario. A large number of model simulations fall outside the whiskers. The full range is +0.35 m to −0.58 m for Lake Superior, +0.89 m to −1.77 m for Lake Michigan-Huron, +0.61 m to −1.31 m for Lake Erie, and +0.80 m to −1.65 m for Lake Ontario.

Since the focus of this special issue is on Chicago, a closer examination of the results for Lake Michigan-Huron is warranted. Table 1 and Figs. 6–8 present more detail on the GCM/GLERL model-simulated lake-level changes.

Table 1
Summary of the GCM/GLERL model simulated changes of Lake Michigan-Huron water levels (m) at selected percentiles (5th, 25th, 50th, 75th, and 95th).

<table>
<thead>
<tr>
<th>Year</th>
<th>5th</th>
<th>25th</th>
<th>50th</th>
<th>75th</th>
<th>95th</th>
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<tr>
<td>B1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>−0.60</td>
<td>−0.34</td>
<td>−0.18</td>
<td>0.02</td>
<td>0.28</td>
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<tr>
<td>2050</td>
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<td>−0.23</td>
<td>−0.06</td>
<td>0.15</td>
</tr>
<tr>
<td>2080</td>
<td>−0.87</td>
<td>−0.51</td>
<td>−0.25</td>
<td>0.01</td>
<td>0.31</td>
</tr>
<tr>
<td>A1B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>−0.55</td>
<td>−0.28</td>
<td>−0.07</td>
<td>0.16</td>
<td>0.46</td>
</tr>
<tr>
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<td>0.40</td>
</tr>
<tr>
<td>2080</td>
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<td>−0.62</td>
<td>−0.28</td>
<td>0.03</td>
<td>0.83</td>
</tr>
<tr>
<td>A2</td>
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<td></td>
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<td>2020</td>
<td>−0.63</td>
<td>−0.33</td>
<td>−0.18</td>
<td>0.01</td>
<td>0.20</td>
</tr>
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<td>−0.02</td>
<td>0.42</td>
</tr>
<tr>
<td>2080</td>
<td>−1.81</td>
<td>−0.76</td>
<td>−0.41</td>
<td>−0.13</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Fig. 6. Lake Michigan-Huron level departure (m) distributions based on the GCM/GLERL simulations for all three averaging periods for (a) B1, (b) A1B, and (c) A2 emission scenarios. The years represent the first year of a 15-year averaging period, e.g., 2020 represents the period 2020 through 2034. Lake-level departures are departures from the 1970–1999 average lake level.

Fig. 7. Lake Michigan-Huron level departure (m) distributions based on the GCM/GLERL simulations for the three emission scenarios for (a) 2020–2034, (b) 2050–2064, and (c) 2080–2094.
0.18 m at 2020–2034 to 0.25 m at 2080. At least 75% of the model simulations show steady or declining lake levels, while 25% show rising lake levels. At least 25% of the model simulations show steadily larger declines of 0.34, 0.42, and 0.51 m or more for 2020–2034, 2050–2064, and 2080–2094, respectively.

The model simulations for the A1B scenario (Fig. 6b) with more CO2 forcing produce larger range of lake-level changes. The changes at 2020–2034 are relatively modest with a median of only a 0.07 m decline. By 2080–2094, the response is larger with a median decline of 0.28 m while 25% of the model simulations yielded a decline 0.62 m or more.

The model simulations for the A2 emission scenario (Fig. 6c) produce an even greater range of lake-level changes. Already by 2020–2034, the median change is a decline in lake levels of 0.18 m. By 2050–2064, the median decline is 0.23 m. By this point, the distribution of the model simulations is wider and shifted to larger declines. By 2080–2094, the median lake level shows a 0.41 m decline while 25% of the model simulations produce a decline of 0.76 m or more.

Fig. 7 provides a side-by-side comparison of the Lake Michigan-Huron level changes across the three emission scenarios for the 2020, 2050, and 2080 future periods, respectively. Fig. 7a shows that by 2020–2034, the response to all three emission scenarios is similar. Interestingly, the A1B emission scenario yielded a distribution with slightly more positive changes than the other two scenarios. This may be due to the slightly wetter GCM simulations in 2035–2064 for the A1B emission scenario, particularly compared to the B1 emission scenario as seen in the 5th percentile results (Fig. 4). The median response is −0.18, −0.07, and −0.18 m for the A2, A1B, and B1 emission scenarios, respectively.

For 2050–2064 (Fig. 7b), the distribution of lake-level changes is slightly larger and shifted to more negative values than for 2020–2034. The median response is 0.23, 0.24, and 0.23 m for the A2, A1B, and B1 emission scenarios, respectively. The distribution is slightly larger for the A2 and A1B emission scenarios.

For 2080–2094 (Fig. 7c), the distribution of lake-level changes is considerably larger for the A2 emission scenario. Because the A2 high emission scenario (Fig. 2) produces the largest range of temperature changes, it exhibits the largest range lake levels. The full range of model simulations is from almost a 1.5 m rise to a 3 m decline in lake levels.

While a majority of the model runs results in reductions in lake levels, these results point to a high degree of uncertainty in possible future lake levels. One major source of uncertainty is the path of future emissions. In this study, large differences were noted in the median and range of lake levels in response to the three selected emission scenarios.

Another source of the uncertainty in future lake levels is in the differences between the GCMs used in this study. In addition, many of these GCMs produced multiple runs with varying initial conditions. Fig. 8 shows the results of one model, the National Center for Atmospheric Research (NCAR) Community Climate System Model (CCSM) version 3.0, with varying sets of initial conditions at 2080–2094 for all three emission scenarios for Lake Michigan-Huron. This model produced 64 runs for the B1 emission scenario, 56 runs for the A1B emission scenario, and 32 runs for the A2 emission scenario. The response of this one model to differing initial conditions resulted in a wide range of responses in lake levels in all three emission scenarios. The 5th and 95th percentile lake levels for Michigan-Huron were +0.16 to −0.60 m for the B1 emission scenario, +0.07 to −0.96 m for the A1B emission scenario, and −0.34 to −0.99 m for the A2 emission scenario. Even if a subset of models was selected based on criteria such as their historical performance over the region, the large uncertainty of each model is an important consideration when evaluating overall uncertainty.

In this study, all GCM simulations were assumed to have an equal but unknown probability of occurrence. As mentioned earlier, this assumption was made because there is no widespread agreement on judging the skill of GCMs in predicting the future (CCSP, 2008). Even the selection of particular models based on their ability to match the
The 20th-century climate of the region may not be a sufficient criterion. In fact, their skill in matching observations may have no bearing on results for the 21st century. To test this, the performances of 160 model simulations using the A2 emission scenario were compared for the 20th and 21st centuries for both temperature and precipitation (Figs. 9 and 10). First, the model performance in the 20th century was assessed by comparing the difference in the 1970–1999 average temperature and precipitation for the Lake Michigan-Huron for each model simulation versus the observed temperature and precipitation for that period. The 1970–1999 period was chosen over the more standard 1971–2000 period because of the 1970–1999 climatology used in the GLERL model. Next, the observed model bias was then compared to the 21st-century model-simulated changes in temperature and precipitation.

For temperature (Fig. 9), the scatter plot reveals that the historical model performance had little bearing on the results for the 21st century. Models that showed warm or cold biases in the 20th century yielded results that were uniformly warmer in the 21st century. For example, a cluster of model simulations that showed a 3 °C cold bias yielded a 3 °C increase in the 21st century while a model simulation with a 4 °C warm bias yielded a 3.5 °C increase.

For precipitation (Fig. 10), the results are similar—no strong relationship between model bias and 21st-century results. Models that showed wet and dry biases in the 20th century both yielded increases in precipitation in the 21st century. Paradoxically, the only consistent result is that model simulations with a dry bias did not yield dry results in the 21st century. Another feature in the figure is a cluster of model simulations from the Max Planck Institute model that showed a strong wet bias in the 20th century and significant increases in the 21st century, indicating a consistently poor performance by this model.

Besides the uncertainties in the analysis concerning future emissions and the response of the GCMs to those future emissions, there are uncertainties in calculating the resulting future lake levels using only one hydrology model (AHPS). While AHPS has been used successfully in previous studies (Lofgren et al., 2002) and in operational seasonal forecasts (Croley, 2005), it provides an additional source of uncertainty about future lake levels.

Summary

This study examined the potential future response of Great Lakes water levels using 565 model simulations from 23 GCMs used in the fourth IPCC report and three emission scenarios (A2, A1B, and B1) as input into the AHPS Great Lakes hydrology model developed by GLERL. While other studies of future Great Lakes levels had employed a limited number of GCM simulations, this study used a much broader range of models and emission scenarios. The lake-level results are sensitive to the emission scenario principally because there are sizeable differences in the magnitude of temperature increases with time among the three emission scenarios. There are also some differences in the range of precipitation changes, although this is a lesser effect. Furthermore, while the temperature scenarios show consistent warming, the precipitation scenarios show a wide range of both wetter and drier conditions. Thus, the range of resulting lake levels is large; varying from sizeable increases to large declines (a total range of −3 to +1.5 m). The A2 high emission scenario produced larger temperature increases and a slightly greater range of precipitation changes than either the A1B or the B1 emission scenarios.

As shown here, there is a large range of uncertainty regarding potential future lake levels, but a majority of the projections would indicate a decrease in lake levels with time. This is most evident for the A2 scenario where the range of lake levels is the largest of the three scenarios. Nevertheless, the B1 low emission and A1B intermediate emission scenarios still lead to substantial climate changes and lake-level responses.

There is no universally accepted methodology for evaluating the relative quality of GCMs with regard to their skill in predicting the future (CCSP, 2008). Thus, all of the GCM model simulations should be viewed as possible future outcomes. The examination one model with a large number of model simulations using differing initial conditions (NCAR CCSM 3.0) illustrates the wide range of responses that are possible from a single GCM. Furthermore, an examination of 20th-century model bias reveals no connection to the 21st-century temperature changes and very little for 21st-century precipitation changes.

The wide range of lake-level changes found here makes it difficult to envision the level of impacts that changes in future lake levels would cause. Clearly, the more severe declines found in some model simulations with up to 3 m departures with the A2 emission scenario would cause significant environmental and economic impacts. The challenge is to reduce the range of uncertainty in possible future changes in temperature and precipitation for decision makers.

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References


