The College at Brockport: State University of New York
Digital Commons @Brockport

FODL Library Research Awards

Friends of Drake Library

2017

Great Lakes Water Levels Trends

Joshua Marchner
jmarc7@u.brockport.edu

GREAT LAKES WATER LEVEL TRENDS

By Joshua Marchner

NOVEMBER 16, 2017

DEPARTMENT OF ENVIRONMENTAL SCIENCE AND ECOLOGY
THE COLLEGE AT BROCKPORT, BROCKPORT, NY 14420

Introduction:

The Great Lakes water system is the largest freshwater reservoir in the world. Water from the Great lakes could cover North America, South America and Africa in 1 foot of water (Neff and Nicholas, 2005). Fluctuations in these water levels has been documented and retroactively inferred to occur on cyclical patterns. These trends occur naturally and can have a positive or negative impact on the environment and human populations. This review will analyze the methods for determining historical, and future trends of lake levels with regards to natural and human effects on water levels and look at one plan for regulating water levels. To review the trends of Great Lakes levels it is important to understand the geological history that has created them.

Laurentian Ice Sheet:

Fifteen Thousand years ago a glacier known as the Laurentian Ice Sheet covered the Great Lakes basin. This ice sheet advanced and retreated multiple times over ten thousand years. Figure 1 (Larson and Schaetzl, 2001) shows the position of the ice sheet at different geological times. Each advance and retreat of the glacier effected the landscape below in three major ways. Firstly, the abrasive ice scoured the land and down cut into the crust causing variations in topography. Secondly, topography was further disrupted by sedimentation. Eskers and moraines from the glacier were formed from deposited sediment which was carried by water flowing under the ice to new locations. Lastly, the entirety of the Great Lakes basin was depressed under the weight of the Laurentian Ice Sheet. An ice sheet estimated to have been between 750 and 2,500 m in height which is based on glaciological theory estimates (Hughes et al. 1981, Boulton et al. 1985). Deformable and impermeable sediments which underlie parts of the glacier account for the range in estimated thickness lower values (Boulton et al. 1985).

Isostatic Rebound:

Once the Laurentian Ice Sheet was removed the ground could decompress in a process known as isostatic rebound or adjustment. The rates of rebound in relation to Port Huron outlet are depicted in figure 2. Rates of isostatic rebound are not uniform; generally, rates of rebound around Lakes Superior and Ontario are greater than those around Lakes Michigan-Huron and Erie (Neff and Nicholas, 2005). This is due to the thickest glacial ice having been located north of the Great Lakes Basin, pictured in figure 3. Lack of uniformity causes segments of coastline rebounding more rapidly than the lake's outlet to experience a long-term lake-level fall, whereas coastlines rebounding more slowly than the outlet experience a long-term lake-level rise (Wilcox et al. 2007). Isostatic adjustment accounts for long term adjustment of the Lake levels that have been happening since the final glacial retreat, but to assess fluctuations on a smaller time frame, balances of inflow and outflow must be analyzed.

Inflow:

Neff and Nicholas (2005) described inflow as over-lake precipitation, runoff, ground-water seepage into the Great Lakes, diversion of water into the Great Lakes, and flow from the connecting channels. Contribution levels of inflow for each lake differ because lakes farther down on the hydrologic cycle receive much of their inflow from the previous lakes as shown in figure 4. Over-lake precipitation is often negligible in the hydrologic cycle. However, due to the large surface area of the Great Lakes, approximately 94,250 mi^2 or about one-third of the total area of the Great Lakes Basin (Coordinating Committee, 1977); over-water precipitation accounts for more inflow than runoff (Croley et al. 2001). Runoff is a measure of all the water that flows into the lakes from the 200,000 mi^2 area of land within the Great Lakes basin. Groundwater discharge is sourced by precipitation that falls on land and soaks into the ground. Most of this water flows into tributaries which eventually connect with the lakes as runoff inflow, however a portion of groundwater enters the lakes directly though the ground accounting for groundwater discharge (Neff and Nicholas, 2005). Two rather large diversions, the Ogoki and Long Lac, redirect water into the Lake Superior basin at a rate of 5580 ft^3/s (Neff and Nicholas, 2005). These two diversions alone contribute 60% more inflow to the Great Lakes basin than all outflow diversions (International Joint Commission, 1999).

Outflow:

Outflow, according to Neff and Nicholas (2005), is a measure of water exiting the lakes by evaporation, flow through connecting channels, diversion of water away from the Great Lakes, and consumptive use. Evaporation is water lost to the atmosphere through vapor, data presented by Croley et al. (2001) show evaporation exceeding the total amount of runoff entering the Great Lakes basin (figure 4). Levels of evaporation are highest in the fall and winter, and conversely lowest in the spring and summer. This is due to cold dry air moving over the lakes during the two former seasons. Heat from the water increases the temperature of the air moving above, allowing it to hold more moisture and leach water from the lake (Neff and Nicholas, 2005). Ice covering the lakes reduces the amount of moisture lost due to evaporation (Eichenlaub, 1979) and amounts lost are conditional to both the surface area and depth of the lake. Flow through connecting channels accounts for the greatest loss of water from the Great Lakes system. Each subsequent lake loses an increasing amount of water as shown in figure 4. Diversions of water account for a portion of water lost, particularly at the Chicago canal system which ultimately flows into the upper Mississippi river basin (Neff and Nicholas, 2005). According to the International Joint Commission (1985) the Chicago diversion has lowered the water level of Lakes Michigan-Huron by 6.35cm and of Lake Erie by 4.32 cm. The two other major diversions, New York State Barge

Canal and the Welland Canal, divert large amount of water out of Lake Erie but it is eventually returned to the system at Lake Ontario. Consumptive use, as described by Neff and Nicholas (2005), refers to any water that is withdrawn from the system and either lost to evapotranspiration or incorporated into products that does not return to the water system. Consumptive use is a negligible loss compared to evaporation, connecting channels and diversions. Inflow and outflow are the major contributors to seasonal trends in water levels but these trends may be changing due to anthropogenic causes.

Seasonal Trends:

Seasonal water level trends are governed by inflow outflow factors associated with the Great Lakes. Low lake levels generally occur during winter, when precipitation is both lower and tied up on the land as snow. Lake levels are then highest in July, after the addition of summer precipitation, and spring snowmelt (Larson and Schaetzl, 2001). Quinn (2002) looks at the changing trends of seasonal lake fluctuations over the past 140 years and concludes that all the Great Lakes as well as Lake St. Clair have experienced changes. These changes are often due to anthropogenic factors which cause a decrease in the robustness of seasonal changes. Factors include diversion of water from the basin, consumptive use of water by municipalities, construction of control structures, and land use alteration (Larson and Schaetzl, 2001).

Quinn (2002) stresses the importance of ice accumulation during winter months. Ice often jams the flow of connecting tributaries and retards the flow of water to lower lakes in the hydrologic cycle. During spring months, the ice melts, increasing flow rates. Melting ice paired with higher levels of precipitation in spring and summer causes lake levels to increase. However, current trends show ice retardation in Lake Michigan-Huron have decreased. This causes a lower summer maximum for subsequent lakes as the flow of water is spread over a longer time frame at a more constant rate. A possible cause of decreased ice retardation at channels is by human terraforming of channels. Dredging and widening of channels allows for increased levels of transportation for vessels, but also effects the natural water flow. Documented water levels for the past 150 years show exact fluctuations, but to analyze Great Lakes water level trends on a large temporal scale, historical water levels must be derived.

Reconstructing Historical Water Levels:

Lake level data has been documented since 1860, but trends from before that can be inferred using several techniques. Shoreline features including wave-cut terraces, mainland attached beaches, barrier beaches, spits, dunes, deltas, and riverine, palustrine, and lacustrine sediments are formed from specific interactions. Depending on the elevation at which they occur, a water level and date of creation may be determined (Wilcox et al. 2007). Additionally, Beach ridges from previous shorelines were assessed to determine lake levels at different time periods. Swash zones, or beach faces, deposit a specific grain size of particles that is much coarser than underlying or overlying sediments. Studying the coarse sediment in the soil sample can determine the elevation of the lake when each beach ridge was originally formed. An age of the formation can be determined by dating sand grains in the ridges using a technique known as optically stimulated luminescence or, by radiocarbon-dating the base of the wetlands deposits between the ridges (Thompson and Baedke, 1997; Argyilan et al. 2005). Juxtaposing age and elevation data creates a hydrograph for the historical elevations of a certain lake; generally, the more beach ridges present, the more accurate the hydrograph (Wilcox et al. 2007). With historical documentation of water fluctuations, patterns can be derived and thus prediction models utilized.

Analyzing Spectral Patterns:

A historical view of Great Lakes water fluctuations allows for mathematical analysis of spectral patterns in the data. Cohn and Robinson (1976) extrapolated cyclical patterns from 115 years of water level trends. The results showed patterns of 1, 11, 22, and 36 year periods of highs and lows in the form of sine waves. When multiple peaks or troughs coincide with one another, lake levels were at an irregular high or an irregular low. Cohn and Robinson (1976) hoped to use this data to predict future water levels to prepare for extreme conditions. Similarly, Walton (1989) used historical models of annual lake level fluctuations to predict future erosional patterns. This study looks at monthly changes and attempts to separate out white noise from lake patterns. Walton (1989) claims that human influence on lake levels is minor in comparison to natural cycles. Sine waves are derived through mathematical equations of known data and projected on additional time frames. In both Cohn and Robinson (1976) and Walton (1989) models could accurately predict patterns for other documented years. However, while their models matched well with documented data, Findings from Wilcox et al. (2007) disagree with the pattern times and their models failed to consider changing climatology. It is unlikely that fluctuating lake patterns can be extrapolated from 150 years of data, especially with current climate change trends. When historical data is overlaid with climatological records patterns with both appear to coincide giving a more encompassing picture of lake level fluctuations.

Climatology:

Tree rings, dune soils, and the sediments of small lakes and wetlands are used as proxy records of past climate variability (Wilcox et al. 2007). Peatlands, or bogs, are a valuable source of data on changes in water balance; the sediments of peatlands receive moisture almost exclusively from precipitation and therefore contain particularly sensitive records of moisture variability. Testate amoebae are a moisture sensitive protozoa that live on the surface of peatlands. These amoebae produce decay resistant shells and are one of the proxies used to infer bog surface moisture conditions (Wilcox et al. 2007). A clear link between Great Lakes water level fluctuation and climate variability is suggested by the moisture content studies of peatlands (figure 5; Booth and Jackson, 2003). Because past trends of climate variability align with lake level fluctuations, predictions of future climate change can be used to infer lake level changes.

Prediction Methods with Climatology:

Angel and Kunkel (2009) composed three predictive models of carbon dioxide emissions concentrations out to year 2100. The models ranged from moderately high, intermediate, and low predictions (figure 6). Increases in greenhouse gasses cause the atmosphere to hold in greater amounts of radiation from the sun. The models consider that this will likely increase average temperatures and change levels of precipitation, though the latter could increase or decrease. With precipitation remaining constant, increasing temperature should lead to decreases in future lake levels (Croley and Lewis, 2006). As such, decreases in precipitation would then lead to substantial decline in lake levels; whereas, increases in precipitation would counteract rising temperatures and lead to smaller declines, or possibly increase, lake levels (Angel and Kunkel, 2009). Figure 7 represents lake level deviation from the 1970-1990 averages for all lakes using the highest emission models. Lake Superior showed the least amount of variation likely due to its extreme depth in relation to surface area. Less surface area to depth ratio means there is less evaporation from the water body. In totality, Angel and Kunkel (2009) used 565 model simulations from 23 global climate models (GCM) and three emission scenarios (figure 6) as input into the advanced hydrologic prediction system Great Lakes hydrology model developed by Great Lakes environmental research laboratory (GLERL). The GLERL model is formulated such that temperature and precipitation are the primary drivers (Croley, 2006) in determining water levels. However, due to the broad range of input factors, results from the study were extremely diverse and because the relative certainty of each GCM is unknown, each result is equally as likely as any other. Table 1 depicts simulated changes of Lake Michigan-Huron out to 2080 with the three emission concentrations predicted. Most model results predicted reductions in lake levels due to increases in greenhouse gases. This should be of direct concern to populations living on the lakes as it will affect their lives in numerous ways.

Human Impact:

The Great Lakes are a major part of the North American ecosystem and changes in the lake levels will affect everything around them. Humans rely on the Lakes for transportation of goods. If water levels decrease dramatically, ships will be unable to navigate through the shallower waters and water budget of major industrial and agricultural locations will be adversely effected (Cohn and Robinson, 1976). Dredging can be implemented to deepen waterways but this causes degradation of adjacent shorelines by removing sediment that would be used to replenish the shore. The use of the Great Lakes and addition of locks and hydroelectric power plants have increased the desire to have the lakes at a consistent water level. While regulations on water levels appears to have beneficial effects, it disrupts natural systems and increases rates of erosion.

Erosion:

Regulations on water levels have changed both erosion and aggradation levels at various shorelines in the Great Lakes, particularly on Superior and Ontario. Increasing levels of erosion are detrimental to coastal populations as they cause expensive property damage (Cohn and Robinson, 1976). Sandy shorelines are effected most prominently when large storms sweep sediment out into deeper water (Larson and Schaetzl, 2001). In addition to storms, human intervention has further reduced the supply of sand to the shore zone. Jetties and other engineering structures at river mouths prevent aggradation of sediment to shoreline zones and instead allow for sediment to directly move to deeper areas of the lakes. Dams located on tributaries to the Great Lakes reduce water flow rates causing deposition of sediment at dam sites prior to entering the main water body (Larson and Schaetzl, 2001).

To prevent erosion near populated areas, humans often implement defensive structures such as break walls, armoring shoreline, or groins. Break walls are thought to propel wave action back out to open waters, however, they often have detrimental effects that are not taken into consideration. Complicated flow patterns are developed through wave interaction and a greater level of erosion is concentrated on the lake floor below the structure parallel to the wall (Wilcox and Whillans, 1999). Groins are walls constructed perpendicular to coastlines that reach out approximately to the distance of breaking waves. The updrift side of the groin collects sediment and creates shoreline; this sediment is supposed to collect around the end of the groin and create more shoreline downdrift. However, rip tides often pull this sediment out into open water creating an erosional shadow zone (Silvester and Hsu, 1991). Beyond erosion, anthropogenic consistency of water levels can also be detrimental to shoreline wetland communities.

Wetlands:

Shoreline wetlands are a unique ecosystem that acts as a bond between terrestrial and aquatic life. Some unique species of plants and animals are specific to wetlands but a far greater amount use wetland as a refuge for portions of their life. The dense marriage of plant and water in a wetland offers for a great habitat for young macroinvertebrates, fish, and even birds and mammals. A diverse community supports the most diverse amounts of wildlife, but unfortunately human impact can reduce this diversity. When water levels are strictly maintained plant, communities become a monoculture. This happens when a strong competitor such as cattails or *phragmittes* outcompetes the other plant species. Normally, fluctuating water levels would cause conditions to dry out or flood more often, preventing the strong competitors from dominating the landscape. When intermediate disturbance is applied, the species which may be worse competitors but are stronger reproducers can maintain a balance. According to Wilcox and Whillans (1999) the best method for restoring diversity of shoreline plant communities and returning erosion to past levels is to let the Great Lakes maintain as close a trend as possible to that which natural conditions create.

Plan 2014:

Fortunately, the International Joint Commission (IJC) has adopted Plan 2014 which updates the control on water levels for Lake Ontario. The goals of which are multiple;

- Maintain more natural seasonal level and flow hydrographs on the lake and river.
- Provide stable lake releases.
- Maintain benefits to coastal interests as much as possible while enhancing environmental conditions.
- Maintain benefits to recreational boating as much as possible while enhancing environmental conditions.
- Obtain inter-annual highs and lows required for healthy vegetation habitats.
- Enhance diversity, productivity, and sustainability of species sensitive to water level fluctuations.
- Provide flood and low water protection to the lower St. Lawrence River comparable to Plan 1958- D with Deviations.
- Maintain benefits as much as possible for municipal water intakes, commercial navigation and hydropower interests while taking other interests into account. (International Joint Commission, 2016).

These goals aim to maximize the benefits for the environment while striking a balance with private residents and companies. Plant community should experience greater fluctuation of water levels and as such maintain a more extensive species diversity. This effect will be radiate to animal populations utilizing shoreline zones as habitat. Additionally, the plan should maintain recreational uses of the Lake and, given time, promote coastline that will be more resistant to erosion. Lastly, the plan intends to maximize water for municipal sources and hydropower. Unfortunately, the spring and summer following implementation of plan 2014 the Lake Ontario watershed experienced an excessive amount of precipitation. This lead to an unwarranted amount of criticism by lake shore property owners, who blamed their property damage on the new regulations. However, regardless of regulation changes, the amount of precipitation in early 2017 would have cause dangerous water levels. Though the initial response to Plan 2014 has been negative with time it will lead to healthier lake levels and benefit the environment as well as surrounding communities.

Conclusion:

To understand Great Lakes Water level trends, it is important to understand the formation of the Great Lakes basin. The Laurentian Ice Sheet advanced and retreated over thousands of years carving out the landscape and developing features through deposition. The terrain in the Great Lakes region is continually rising due to isostatic rebound after the removal of the heavy glacier. This causes water levels to rise where the land increases elevation at a slower rate and water levels decrease in places where the land rebounds faster. Inflow and outflow patterns are particularly important to assess short term trends and the impact of humans on the lake systems. Historical patterns of water levels can be derived through the study of sediment and shoreline features paired with carbon dating, and other dating techniques. Once historical models are developed, Mathematical calculations of wave patterns of the data can create forecast models of wave heights. These prediction models are moderately useful but, with changing climate their accuracy is not concrete. Historic climatology studies using bogs and the organisms that resided there can infer back dated moisture content. Climate data overlaid with lake levels shows correlations between data climatology and can then be used as a proxy for lake levels before documented data. Climate can be considered to develop more accurate models of future lake levels. These studies are important because lake levels directly affect populations residing on shoreline and industries that use the water or waterways to ship goods. In response, regulatory water procedures imposed by human changes dynamics of lake levels and decreases diversity while increasing erosional factors. Artificial methods to deal with erosion often only add to the problem and natural processes need to be restored to create a balanced stable environment.

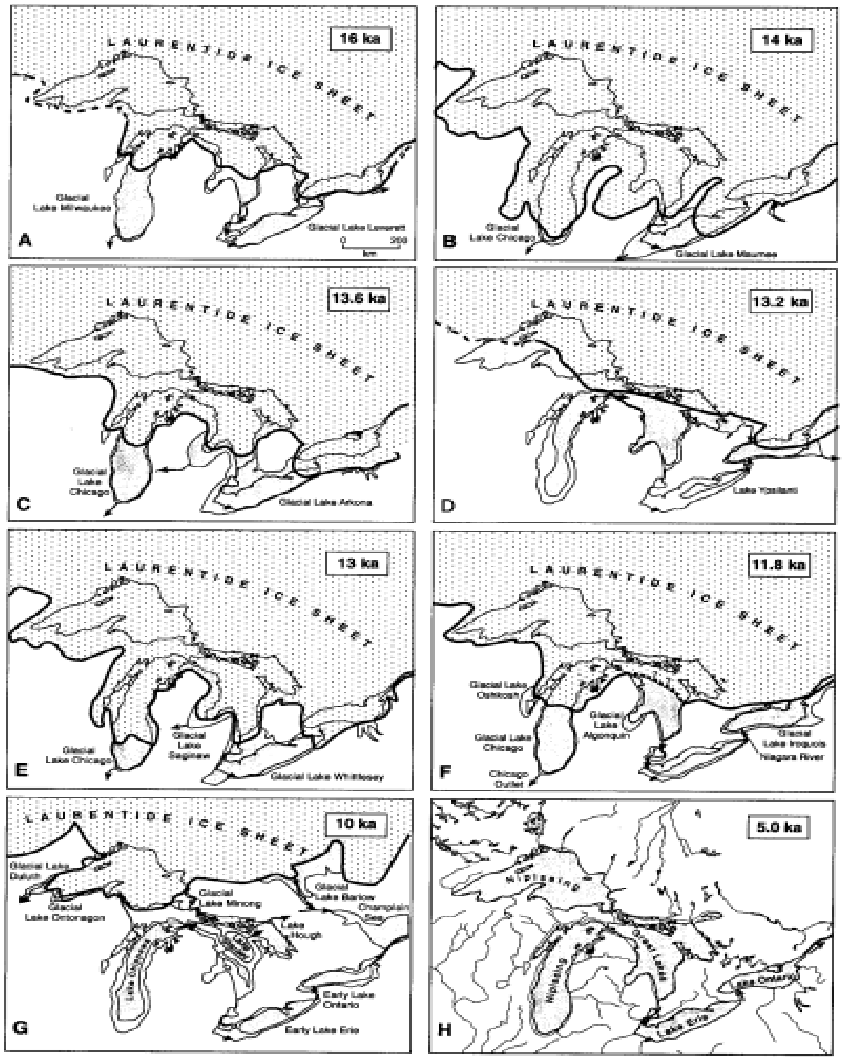

Figure 1. Larson and Schaetzl Locations and general extent of the major proglacial lakes associated

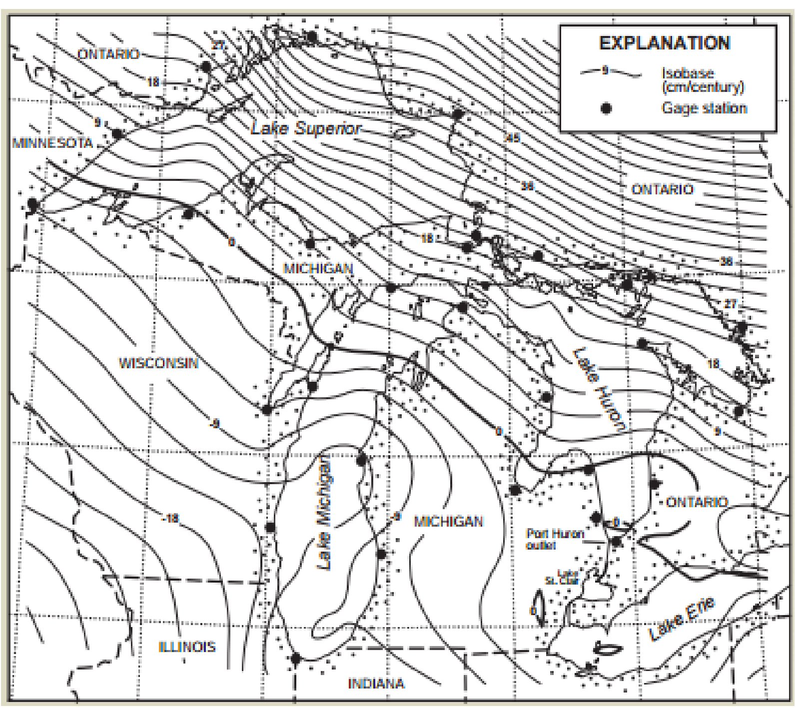

Figure 2. Map of the upper Great Lakes showing contoured rates of glacial isostatic adjustment in relation to the rates of Port Huron outlet. Scale is in centimeters per century (Wilcox et al. 2007).

Figure 1. Great Lakes watershed (Angel and Kunkel, 2009)

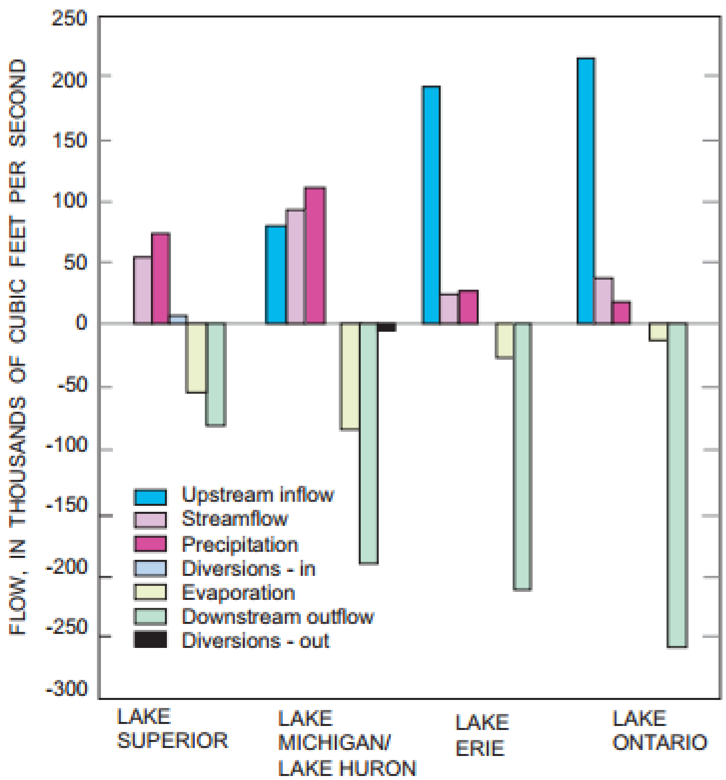

Figure 4. Inflow and outflow rates for each Great Lake, positive values denote an inflow, while negative values denote an outflow (Modified from Great Lakes Commission, 2003.)

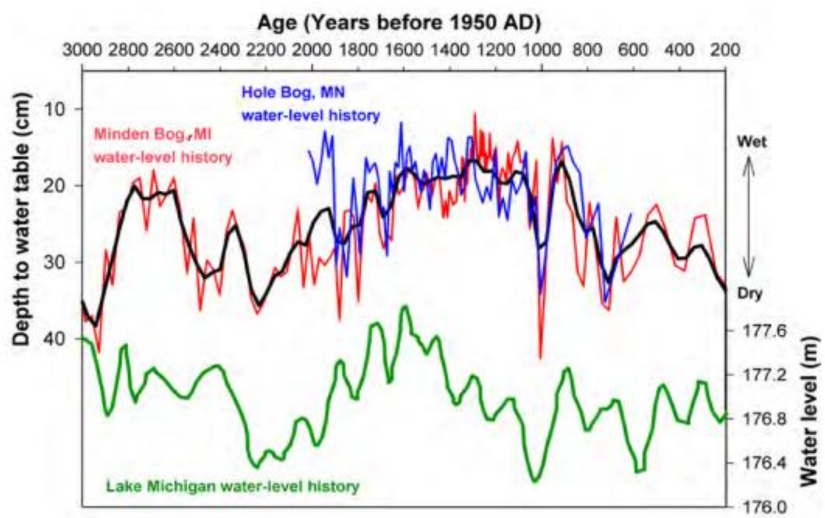

Figure 5. Late Holocene lake level interpreted from beach-ridge studies in relation to surface moisture interpreted from testate amoeba studies in peatlands (modified from Booth et al. 2006).

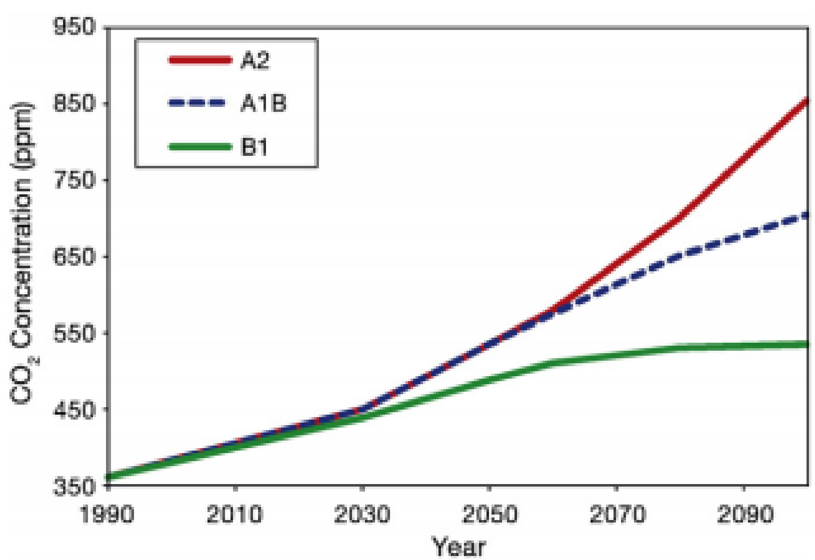

Figure 6. Time series of CO2 concentration for 1990–2100 for the three CO2 emission scenarios used in this study. The emission scenarios are as follows: A2=moderately high, A1B=intermediate, and B1=low. (Angel and Kunkel, 2009)

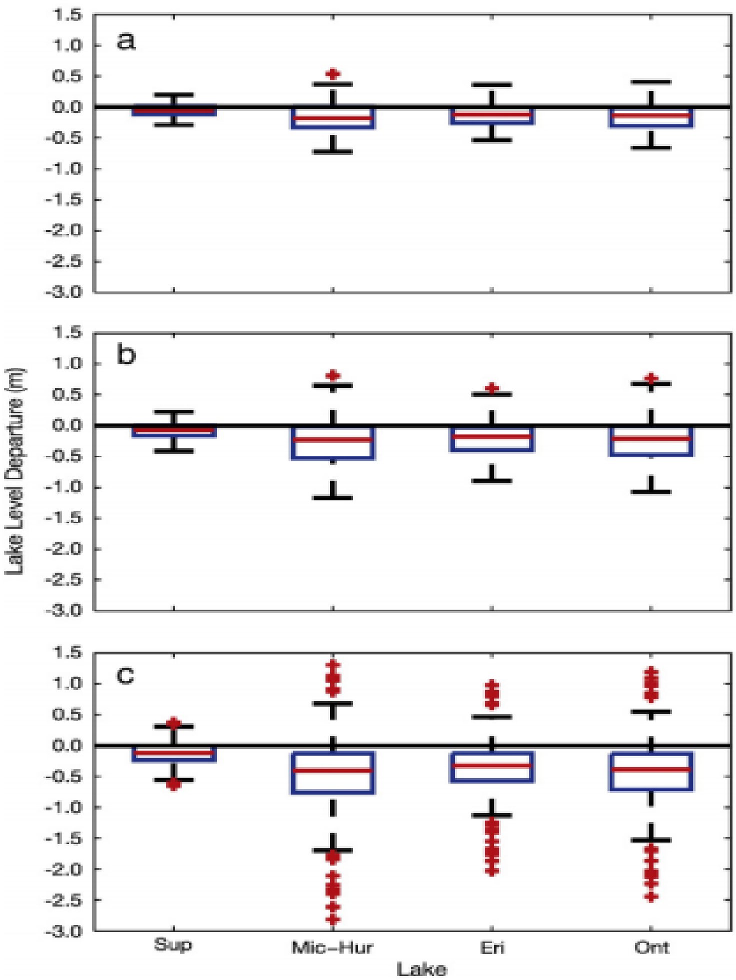

Figure 7. Lake-level departure (m) for the A2 high emissions scenario for (a) 2020–2034, (b) 2050– 2064, and (c) 2080–2094. The line in the box represents the median (50th percentile) of all cases. The top and bottom of each box represent the 25th and 75th percentile values. The plus signs represent outliers. Lake-level departures are departures from the 1970–1999 average lake level.

Table 1. Summary of the GCM/GLERL model simulated changes of Lake Michigan–Huron water levels in meters at 5th, 25th, 50th, 75th, and 95th percentiles (Angel and Kunkel, 2009).

Year	5th	25th	50th	75th	95th
B1 emission scenario					
2020	−0.60	−0.34	−0.18	0.02	0.28
2050	−0.79	−0.42	−0.23	−0.06	0.15
2080	−0.87	−0.51	−0.25	0.01	0.31
A1B emission scenario					
2020	−0.55	−0.28	−0.07	0.16	0.46
2050	−0.91	−0.60	−0.24	0.03	0.40
2080	−1.41	−0.62	−0.28	0.03	0.83
A2 emission scenario					
2020	−0.63	−0.33	−0.18	0.01	0.20
2050	−0.94	−0.52	−0.23	−0.02	0.42
2080	−1.81	−0.76	−0.41	−0.13	0.88

References

Angel, J. and K. Kunkel. 2009. The response of Great Lakes water levels to future climate scenarios with an emphasis on Lake Michigan-Huron. Journal of Great Lakes Research. 36:51-58.

Argyilan, E.P., S.L. Forman, J.W. Johnston, and D.A. Wilcox. 2005. Optically stimulated luminescence dating of late Holocene raised strandplain sequences adjacent to Lakes Michigan and Superior, Upper Peninsula, Michigan, USA: Quaternary Research. 63: 122–135.

Booth, R.K., and S.T. Jackson. 2003. A high-resolution record of late-Holocene moisture variability from a Michigan raised bog. USA: Holocene. 13: 863–876.

Boulton, G.S., Smith, G.D., Jones, A.S., and Newsome, J. 1985. Glacial geology and glaciology of the last mid-latitude ice sheet. Journal of the Geological Society London 142:447–474

Cohn, B.P., and J.E. Robinson.1976. A Forecast Model for Great Lakes Water Levels. The Journal of Geology. 84:455–465.

Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. 1976. Lake Erie outflow 1860-1964 with addendum 1965-1975: Chicago, Ill., and Cornwall, Ont., 20 p.

Croley, T. E. 2006. Modified Great Lakes hydrology modeling system for considering simple extreme climates. NOAA Technical Memorandum GLERL-137. NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 27 pp.

Croley, T.E., C.F.M. Lewis. 2006. Warmer and drier climates that make terminal Great Lakes. Journal of Great Lakes Research. 32: 852–869.

Croley, T.E., T.S. Hunter, and S.K. Martin. 2001. Great Lakes monthly hydrologic data: NOAA Technical Report TM-083. 13 p.

Eichenlaub, V.L. 1979. Weather and climate of the Great Lakes region: Notre Dame, Ind., University of Notre Dame Press, 335 p.

Great Lakes Commission. 2003. Toward a water resources management decision support system for the Great Lakes-St. Lawrence River basin-status of data and information on water resources, water use, and related ecological impacts: Great Lakes Commission, Ann Arbor, Mich., 142 p.

Hughes, T., G.H. Denton, B.G. Anderson, D.H. Schilling, J.L. Fastook, and C.S. Lingle. 1981. The last great ice sheet: A global view. In the last great ice sheets, eds. G.H. Denton, and T.J. Hughes, New York: John Wiley and Sons. 263–317.

International Joint Commission. 2016. Regulation Plan 2014 for the Lake Ontario and the St. Lawrence River.

International Joint Commission. 1999. Protection of the waters of the Great Lakes: Ottawa, Ont., and Washington, D.C., 40 p.

Larson, G., and R. Schaetzl. 2001. Origin and Evolution of the Great Lakes. Journal of Great Lakes Research. 27: 518-546.

Neff, B.P., and J.R. Nicholas. 2005. Uncertainty in the Great Lakes Water Balance. U.S. Geological Survey Scientific Investigations Report 2004-5100. 42 p.

Quinn, F.R. 2002. Secular changes in Great Lakes water level seasonal cycles. Journal of Great Lakes Research. 28:451-165.

Silvester, R. and J. R C. Hsu. 1991. New and old ideas in coastal sedimentation. Reviews in Aquatic Sciences. 4:375-410.

xThompson, T.A., S.J. Baedke. 1997. Strandplain evidence for late Holocene lake-level variations in Lake Michigan: Geological Society of America Bulletin. 109: 666–682.

xWalton, T.L. Jr. 1989. Simulating Great Lakes Water Levels for Erosion Prediction. Journal of Coastal Research. 5:377-389.

xWilcox, D.A., T.A. Thompson, R.K. Booth, and J.R. Nicholas. 2007. Lake-level variability and water availability in the Great Lakes. U.S. Geological Survey Circular 1311, 25 p.

xWilcox, D.A., and T.H Whillans. 1999. Techniques for Restoration of Disturbed Coastal Wetlands of the Great Lakes. Wetlands 19:835-857.