Climate Change and the Water Levels of the Great Lakes

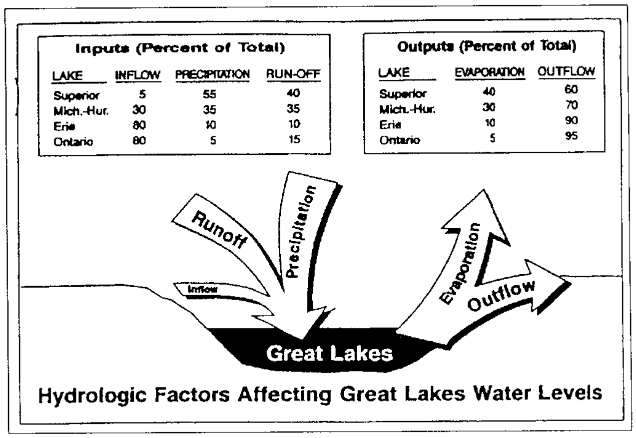
By
Stanley A. Changnon
Illinois State Water Survey
2204 Griffith Drive, Champaign, IL 61820-7495

What controls lake levels? The Great Lakes have an enormous capacity to store water, with the lakes serving as reservoirs for the largest supply of freshwater in the world. The large surface area of the lakes (32% of the basin) acts as a natural regulator of their water levels. Figure 1 shows the natural factors controlling lake levels and the relative magnitude of each factor on each lake. Climate conditions are the major factors affecting levels, and the values illustrate the enormous influence of precipitation and evaporation. The levels typically lag behind the precipitation fluctuations by 6 to 24 months. Human factors also affect levels, including diversions into Lake Superior and the diversion out at Chicago, with the net effect being an increase of 1% in outflow from the Great Lakes. Consumptive water use decreases basin outflow by 1 to 2 percent, and regulatory works at the outlets of Superior and Ontario affect the levels of these two lakes. In today's climate, the input to the basin is slightly greater than the output, and the water balance is:

INPUT (Precipitation + runoff + input diversions) =
OUTPUT (ET + natural and controlled outflow
+ diversion out + consumptive use)

We know that there have been major highs and lows in lake levels in past centuries. The formation of the Great Lakes is a result of climate fluctuations during the Pleistocene. For example, Lake Michigan, during the Cary Substage of the Wisconsin Stage, was much higher and named Lake Chicago which was confined by a moraine and shoreline that is 20 to 100 km outwards from today's lake shore. Ensuing climate fluctuations created Lake Algonquin which covered the entire area of today's Lakes Superior, Michigan, and Huron. The key point is that the climate has dictated what happened to lake levels, then and now.

Ironically, development of good measures of the components of the hydrologic cycle of the Great Lakes did not develop until 1920s, and the lack of their definition was a central problem in the early controversies over the effects on lake levels due to the diversion at Chicago. Figure 2 illustrates the problems and controversies that evolved from not understanding Lake Michigan's falling level from 1900 to 1940, a result of decreasing precipitation, the increases in the diversion, and the changes made in control works and drainage channels. All were affecting the level but their relative contributions were ill defined. The great influence of precipitation and evapotranspi-



Inputs (Percent of Total)			
LAKE	INFLOW	PRECIPITATION	RUN-OFF
Superior	5	55	40
Mich.-Hur.	30	35	35
Erie	80	10	10
Ontario	80	5	15

Outputs (Percent of Total)		
LAKE	EVAPORATION	OUTFLOW
Superior	40	60
Mich.-Hur.	30	70
Erie	10	90
Ontario	5	95

Figure 1. The Hydrologic components of the Great Lakes and relative magnitudes of each on the major lakes.

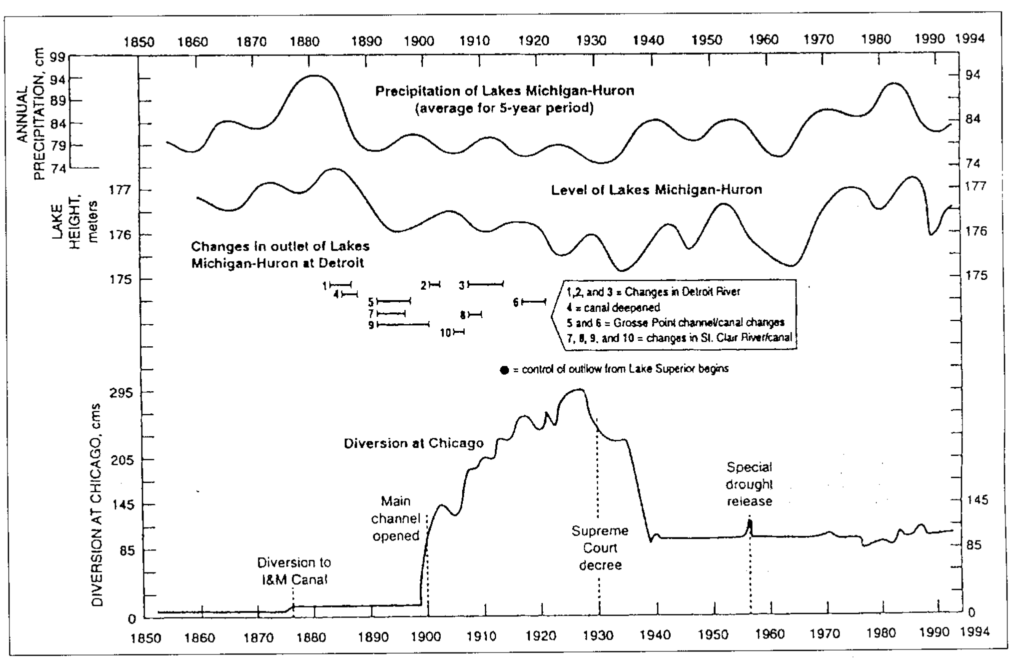


Figure 2. Temporal shifts from 1850 to 1994 in Lake Michigan's levels and precipitation, changes in channels and controlling works, and diversion amounts at Chicago.

ration (ET) on lake levels was not clearly defined until Horton's definitive hydrologic studies of the late 1920s, revealing the quantitative extent of each hydrologic component and proving how small the effects of Chicago's diversion and channel drainage changes were on lake levels (Changnon and Glantz, 1996). Most important was the continuing decline in precipitation from the 1890s to 1940, the basin's longest dry period in the last 200 years (Fig. 2). Definitive statistical studies in the 1940s and 1950s determined the time lag between precipitation and lake levels. By the 1970s, complex computer-based hydrologic models had been developed (Croley, 1990), and these allowed analyses of the effects of altering components in the hydrologic cycle on net basin supply (NBS) and on lake levels.

Recent fluctuations in basin's climate with wetter conditions in the 1970s and again in the 1980s brought the highest lake levels and outflow since records began in 1861 (Fig. 3). These record highs brought a host of problems to shorelines and other lake-related activities (Changnon, 1987). Then, a major drought in 1987-1988 lowered lake levels faster than ever before in recorded history, and new problems arose when several states wanted to increase the diversion at Chicago to enhance the low flows on the Mississippi River system (Changnon, 1989). Varied interests in the Great Lakes have conflicting desires for lake levels — some want higher levels and some desire lower levels. The extensive studies of the IJC on how to manage the lakes to control lake levels have shown that existing and potential controls could only affect about 10 to 20% of the fluctuations in lake levels under today's climate regime. The point is, climate shifts will continue to control lake levels and thus materially affect what can be done on and around the lakes.

GLOBAL CLIMATE CHANGE

Past climate conditions reveal extremes greater than anything the basin has experienced in the past 200 years. Thus, we should not be surprised that future climate conditions will be different than today's. The possibility that human activities are capable of affecting the global climate was a concept that emerged in the 1960s with early fears of impending global cooling. However, the evolution of sophisticated computer-driven global climate models (GCMs) allowed atmospheric scientists to assess more relistically future climatic conditions, and a series of studies indicated the liklihood of a global warming of climate. This was because a continuing rise in the emissions of CO_2 and other trace gases (NO_2, methanes, and CFCs) were enhancing the atmosphere's greenhouse layer which modulates the global climate and makes the earth inhabitable-solar energy comes in but less is being radiated out due to more gases. These ever increasing gases, when simulated in the GCMs, indicated a global warming varying from 1 to 3.5° C by the middle of the 21st century, an outcome expected from an enhanced greenhouse (IPCC, 1996).

POTENTIAL EFFECTS ON LAKE LEVELS

During the 1980s, GCMs, which had been developed independently by scientists at several institutions, were used to estimate future climates under a doubling of CO_2. Their climate outcomes varied, but they all a climate for the Great Lakes basin that was much warmer and drier due to much greater ET than is shown in Figure 1.

Scientists then utilized sophisticated hydrologic models of the Great Lakes to calculate what would happen to the NBS and in turn to lake levels with the predicted climate conditions as derived from the GCMs (Croley, 1990; Hartmann, 1990). The effects of using these predicted climate conditions across the Great Lakes basin on water supply variables, as calculated from the hydrologic models, are shown in Table 1.

TABLE 1. Percentage change in water supply variables resulting from a doubling of CO_2 in four GCMs, and from using four transposed climates.

Model scenario	Basin runoff	Over-lake precipitation	Over-lake evaporation	Net basin supply
Climate change models				
GISS	-24	+4	+27	-37
GFDL	-23	0	+44	-51
OSU	-11	+6	+26	-23
CC	-32	0	+32	-46
Transposed Climates				
A scenario	-25	+3	+49	-48
B scenario	-1	+25	+33	-1
C scenario	+21	+13	+75	-54
D scenario	+2	+45	+69	-5

Another approach used to measure possible future lake-level changes, including changes in their annual fluctuations and extremes, has employed existing climate conditions in four different climatic zones of the United States. The 30 years of historical climate data from these zones have been transposed to the Great Lakes as input for hydrologic modeling (Croley et al, 1996). The climates tested, relative to that of Great Lakes, were labeled climate scenario A, which is drier and slightly warmer (from NE and KS east to IL); climate scenario B, which is slightly warmer but wetter (IL to VA); climate scenario C, which is much drier and much warmer (NM, OK, and TX to MS); and climate scenario D, which is much warmer and wetter (AR and MO to GA). The effects of these climates, when input in the Great Lakes hydrologic model, on basin water supply variables are also shown in Table 1. Most values in Table 1 show small precipitation increases, major increases in evaporation (+26% to +69%), decreased runoff, and sizable decreases in NBS. However, climates B and D, which are much wetter than today's basin conditions with precipitation changes of +25% and +45%, respectively, had only slightly lower NBS values.

TABLE 2. Changes in the average annual steady-state lake levels, as derived from GCMs and from transposed climates, expressed in meters.

	Models			Scenarios			
Lakes	GISS	GFDL	OSU	A	B	C	D
Superior	-0.5	a	-0.5	-2.1	-0.8	b	-1.0
Mich-Huron	-1.3	-2.5	-1.0	-3.3	-0.2	-3.5	-0.2
Erie	-1.2	-1.9	-0.8	-2.1	0	-2.3	-0.1
Ontario	c	c	c	-1.5	0	-1.5	0

a = Predicted level fell below regulation plan
b = Lake Superior becomes a terminal lake
c = Values not computed because of uncertainties related to regulation strategies

Table 2 shows the future mean lake levels as calculated for three GCMS with a doubling of CO_2, and for the four transposed climates. The departures under all these varying but warmer conditions vary from no change in levels to major decreases in excess of 3 meters. For Lakes Michigan-Huron the three GCMs lead to drops in levels ranging from 1 to 2.5 meters, and the four transposed climates show a range of decreases from 0.2 to 3.5 meters. Under two cases (GFDL model and climate scenario C) Lake Superior becomes a terminal lake without any outflow.

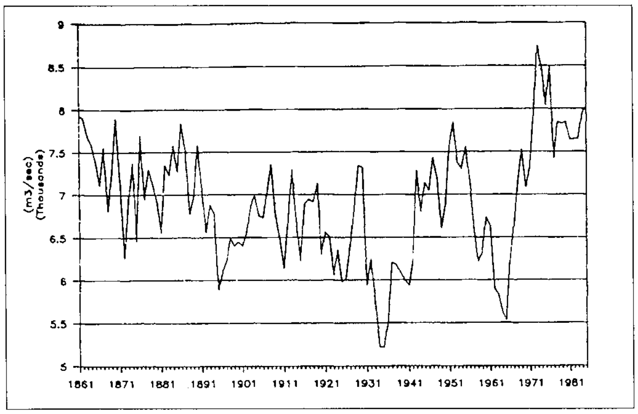


Figure 3. St. Lawrence discharge from 1861 to 1986. Note the dry period from 1900 to 1940, and the high values in recent years.

Research using the four transposed climates and their 30 years of data allowed assessment of the effect of a changed climate on the interannual variability of lake levels. The standard deviations around the mean lake levels for each climate scenario were compared with that of today's climate. The differences, expressed as a percent of today's values, appear in Table 3, and

TABLE 3. Standard deviation of the annual lake levels for four transposed climates expressed as a percent of the standard deviation under today's chain.

Lake	Climate A	Climate B	Climate C	Climate D
Superior	+136%	+100%	a	143%
Mich-Huron	+50%	-5%	+13%	47%
Erie	+45%	-7%	+28%	45%
Ontario	+433%	0	+411%	144%

a = Lake Superior becomes a terminal lake.

they reveal that all climates except scenario B on three lakes, would produce greater interannual fluctuations in lake levels than exist today. Lake Superior would experience more than a doubling of its interannual variability under all climate scenarios. Climate scenario A and D would also create new record high and low levels on Lakes Michigan-Huron and Superior. The regulation plan for Lake Ontario was modified in this analysis, but record high levels would occur under scenarios B and D, and extreme variability (changes greater than 400%) is found on Ontario for the two drier scenarios, A and C.

If the future changes in climate are similar to the those tested in recent modeling and climate transposition studies, the future outcomes for the Great Lakes' water levels will include:

- lower levels by 0.5 to 3.5 meters, varying between lakes.
- greater interannual variability in levels, up by 15% to 400%.
- greater extremes under certain climates and on certain lakes.

IMPLICATIONS

There have been several studies of the potential effects of a future climate change in the Great Lakes basin, and some have addressed the implications of changed water levels. One study assessed the effects on lake shipping and power generation showing numerous major problems (Sanderson, 1987). Another study assessed effects on water use and supplies and found major problem developing (Cohen, 1986). Changnon (1993) assessed the impacts of potential decreases in the levels of Lake Michigan on the 101-km Illinois shoreline activities. Sizable problems were detected including those related to harbors, beaches, outfalls and intakes, and the Chicago diversion works. Estimated costs to adjust to these changes ran from \$5 billion for a 1.3 meter drop, up to greater than \$30 billion for a 2.5 meter decrease in the lake's mean level.

Obviously, shorelines everywhere around the lakes would be changed, as new shores emerge as levels fall. Changnon and Glantz (1996) assessed the societal and institutional adjustments related to the Chicago diversion and the climate fluctuations of the past 100 years as an analogs for what may occur in the future under global climate change. They concluded that major controversies over water supplies, shorelines, and diversions would develop, severely challenging existing laws and institutions that deal with Great Lakes water issues.

Many who have assessed what to do about global climate change, either to mitigate by decreasing emissions, and/or to adapt to change, conclude that adaptation will be the most likely adjustment, at least during the next several decades. Essentially, society will have to learn how to cope with a changed climate, whatever its dimensions. This reality suggests that today's decisions about lake activities need to be designed or planned with as much future flexibility as possible (Changnon, 1996).

REFERENCES

1. Changnon, S.A. (1987) Climate fluctuations and record-high levels of Lake Michigan: *Bulletin Amer. Meteoro. Soc.*, 68, 1394-1402.
2. Changnon, S.A. (1989) The drought, barges and diversion: *Bulletin Amer. Meteoro. Soc.*, 70, 1092-1104.
3. Changnon, S.A. (1993) Changes in climate and levels of Lake Michigan: Shoreline impacts at Chicago: *Climatic Change*, 23, 213-230.
4. Changnon, S.A. (1995) Adaptation to climate change: The likely outcome: *Preparing for Global Change*: A Midwestern Perspective, Academic Pub., Amsterdam, 249-258.
5. Changnon, S.A. and M.H.Glantz (1996) The Great Lakes diversion at Chicago and its implications for climate change. *Climatic Change*, 32, 199-214.
6. Cohen, S. J., 1986: Impacts of CO_2-induced climatic change on water resources in the Great Lakes basin: *Climatic Change*, 8, 135-153.
7. Croley, T.E. (1990) Laurentian Great Lakes Double-CO_2 climate change hydrological impacts: *Climatic Change*, 17, 27-47.
8. Croley, T.E., Quinn, F., Kunkel, K.E., and S.A.Changnon (1996) *Climate transposition effects on the Great Lakes hydrological cycle*: NOAA Technical Memorandum ERL GLERL-89, Ann Arbor, 100pp.
9. Hartmann, H.C. (1990) Climate change impacts on Laurentian Great Lakes levels: *Climatic Change*, 17, 49-67.
10. Intergovernmental Panel on Climate Change (1996) *The Science of Climate Change 1995*: WMO, Geneva, 248pp.
11. Sanderson, M. (1987) Implications of climate change for navigation and power generation in the Great Lakes: *Climate Change Digest*, CCD 87-03, AES, Toronto.