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SCENARIOS FOR CLIMATE CHANGE IMPACTS ASSESSMENTS IN THE GREAT LAKES REGION

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1. INTRODUCTION

The purpose of this study was to assess the effect of changed climate conditions similar to those predicted by some GCMs on the temporal behavior of various components of the hydrologic cycle of the Great Lakes basin, as measured over a series of seasons, years, and decades. We further sought a sensitivity-type investigation of the effects of temporal fluctuations associated with rather extreme climate conditions such as ones much warmer and drier, or much warmer and wetter, than the basin's current climate and with larger changes than predicted by GCMs. To this end, we developed a series of four climate scenarios each covering a 42-year period of time. These were used to study the primary water management problem in the Great Lakes with its many competing demands for water which is the interannual fluctuations in net basin supplies and lake levels.

The calculation of the hydrologic system effects including those to the net basin supply and lake levels, was done using a state-of-the-art Great Lakes hydrologic model (Croley, 1994). Operation of this complex model requires the input of temporally-detailed meteorological data for as many stations as possible distributed across the 800,000 km^2 basin. To meet the model's operational demands, and those imposed by this study's requirement to have 40-year tests of effects, long-term (40-year) measures of the hydrologically-relevant atmospheric conditions(i.e., daily values of temperatures, precipitation, cloud cover, humidity, and winds) and from a dense network of stations (or grid points) had to exist over the entire basin. To further achieve the desired test of different and more extreme climate conditions, several long-term sets of detailed meteorological data embracing areas the size of the Great lakes basin had to be found, or developed, for widely different climatic zones, or climate scenarios.

2. REQUIREMENTS FOR CLIMATE SCENARIOS

The climate scenarios needed to achieve the objectives of the study had to possess the following characteristics:

- Daily precipitation and daily maximum and minimum temperature data were required at a high spatial density of approximately 1 station per 1,000 km^2 over the Great Lakes region of 800,000 km^2.
- Hourly observations of wind, humidity, cloud cover, and temperature were required at a spatial density of approximately 1 station per 10,000 km^2.
- The hourly and daily data time series needed to be of considerable length in order to study variability. At least 30 years of data, and ideally 40 years or more, were considered essential.
- The data must possess spatial and temporal coherence that is realistic and

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consistent with the physical laws governing atmospheric behavior.

- At least four widely different climate scenarios were required. These must bracket the range of values estimated under doubled CO_2 conditions derived from widely used GCMs.

It was not considered scientifically valid to attempt to create 40 years of synthetic hourly and daily meteorological data for 1,000 locations and across four different climatic zones the size of the Great Lakes Basin. Another approach, using direct output of current GCMs, was also rejected because a single grid box represents an area of 20,000 km^2 or more which is far too crude spacing for input to the hydrology model. A third possibility is the use of regional climate models that are embedded in GCMs. However, the massive computer requirements of this approach and their development have thus far limited the length of time series to 1 to 2 years in length (Bates et al. 1994). Other approaches were needed.

3. CLIMATE SCENARIO SELECTION: SPATIAL TRANSFERS

The technique selected to define the weather conditions required for this study was "spatial transfers" or "climate transposition." We re-located the Great Lakes basin to four other climatic zones in the central and southern United States to sample the desired climatic differences in fluctuations over time. Robinson and Finkelstein (1989) assessed means of developing climate scenarios for impact studies like this, and they suggested, as one useful empirical method for developing climate scenarios, climate analogues. Climate analogues use historical data to represent a changed and often extreme climate condition perceived to exist at some future time. One form of climate analogue is labeled as "spatial transfers" (Changnon 1991). The underlying rationale for this approach is the expectation that future changes in basin climate conditions may approximate latitudinal and/or longitudinal shifts.

The major advantage of this approach is that the transposed data represent an actual climate time series (Robinson and Finkelstein 1989). They exist and thus conceivably could happen again somewhere else in the future. All key features of the climate are realistic, including the temporal variability and the frequency and magnitude of extremes. Further, the spatial relationships are obviously realistic. One can question whether the exact climate conditions currently existing in the southwestern United States could ever exist in the Great Lakes region, but for the sake of achieving the desired sensitivity analysis from drastically different climates, we have assumed this possibility exists.

This technique takes advantage of the existing detailed climatic data record in the United States and Canada. In this study we used data for the period 1949-1990. Data in digital form for both hourly and daily weather elements were readily available. By using the existing long-term observations, we were able to create a wide range of surface climate conditions. Also, by carefully choosing our latitudinal and longitudinal shifts, we were able to realize climates that approximate temperature and precipitation outcomes predicted by GCMs or that are more extreme. Finally, our past experience with those attempting to assess the impact of the climate change has revealed that use of "actual" historical data led to improved credence in understanding and accepting outcomes.

There are disadvantages to this approach. One is that the data do not maintain current major geographic controls on climate. A major example in this study is the effect of the Great Lakes on local snowfall, temperature, and other climatic elements. Data in the Great Plains (to take one possible shift) will not exhibit local gradients created by the lakes. Thus, some adjustments in the transposed data were required, negating some of the simplicity that makes this method attractive. Larger scale geographic features also play a role. For instance, the locations of the Rocky Mountains, the Gulf of Mexico, the Atlantic Ocean, and Hudson Bay have influences on the climate of North America. These influences in all likelihood will not shift in a changed climate in a straightforward fashion. For instance, it is highly improbable that the effect of the Rocky Mountains on the current climate of Kansas will be similar in a future climate of the southern Great Lakes. Thus, to the degree (unknown) that this effect is important, transposed data will be unrealistic.

4. ESTIMATION OF LAKE EFFECTS

Past Water Survey research based on the Lake Michigan basin used a climatological technique for defining the extent of the lake effect on upwind and downwind sides of the lake on monthly, seasonal, and annual precipitation, temperatures, and other weather conditions (Changnon, 1968). This technique was used to derive measures of lake effects around each lake for the four major seasons (winter, spring, summer, and fall), and for seven weather parameters including precipitation, maximum temperature, minimum temperature, average daily temperature, cloud cover, wind speed, and atmospheric water vapor pressure.

This empirical three-step technique involved first the deletion of existing stations within 80 km of the lee shores, assuming they are potentially lake influenced. Then, patterns of each weather condition were constructed based on the remaining data. Third, the interpolated values at each station were compared with the actual values to determine a percentage change due to lake effects. The use of atmospheric models to simulate the effects of the Great Lakes on regional climate conditions has begun but to date is limited to examining short discrete periods of time (Bates et al., 1994).

Maps for each element were developed to show the spatial pattern with and without lake effects, and for the lake-effect differences. The maps of lake effect differences were then interpreted and digitized on a 0.5° latitude-longitude grid. To obtain a measure of lake effects under more extreme weather conditions, the process for estimating lake effects was repeated for the five wettest and five driest years of each season. These represent natural changes that have occurred under more extreme conditions and which conceivably portray the magnitude of change that could be associated with future climate variations which could be wetter or drier.

For each meteorological element evaluated, two sets of maps were generated. The first included all observations. This map was used primarily to establish the spatial distribution pattern within the Great Lakes basin and the surrounding areas. The spatial pattern in the basin incorporates both lake-induced changes and those produced by the broad-scale climatic conditions of the region. A relatively large region surrounding the basin was used to provide an adequate measure of the spatial pattern characteristics well beyond the lake-effect regions.

A second map was then generated, after eliminating all stations in the 80-km lake effect band. The pattern existing in the no-effect region surrounding the basin was used as the primary guide in establishing the climatological pattern assumed to exist if no lake effect was present. The maps were overlaid and the lake effect in the basin was derived by determining differences between the two sets of values. These differences values were used to generate a digitized map of computed differences within the basin.

After lake-effect maps had been drawn for each condition, the analyzed data were digitized on grid squares for input to the hydrologic model.

5. CLIMATE SCENARIOS

We created four scenarios by moving the Great Lakes basin to the south and west of its current position. In all of these, the relative spatial relationships of the geography of the Great Lakes were preserved with the outline of the basin laid over the existing climate network. Table 1 gives basic information about these scenarios. Figures 1-4 shows the location of the Great Lakes basin for these scenarios.

Table 1. Basic information for climate transposition scenarios.

Number	Latitude Shift	Longitude Shift
1	6° South	10° West
2	6° South	0°
3	10° South	11° West
4	10° South	5° West

Croley et al. (1995) described the changes in climate for these scenarios and the associated changes in net basin supplies and lake levels. Scenarios 1 and 2 are associated with temperature changes of 5-7°C, the upper end of estimates from doubled-CO_2 GCM simulations (IPCC, 1992). Scenarios 3 and 4 represent more extreme conditions, with temperature changes of 8-11°C. With the exception of Lake Superior for scenarios 1 and 3, the scenarios are associated with substantial precipitation increases. However, accompanying increases in land evapotranspiration and lake evaporation negate these precipitation increases. Net basin supplies decrease substantially in scenarios 1 and 3, but are approximately equal to the present climate values in scenarios 2 and 4.

These scenarios are characterized by increased interannual variability in precipitation, overland evapotranspiration, and lake evaporation. As a result, net basin supplies exhibit substantial increases in interannual variability (Table 2). Even for scenarios 2 and 4 where mean values do not change substantially, the large increases in variability would create severe problems for lake water management.

Table 2. Standard Deviation (mm) of Annual Net Basin Supplies for Current Climate ("Base") and Percent Change for Climate Scenarios					
	Scenario				
Lake	Base	1	2	3	4
Superior	164	+21%	+32%	+39%	+78%
Michigan	203	+62%	+53%	+38%	+100%
Huron	165	+103%	+47%	+108%	+133%
Erie	268	+87%	+51%	+86%	+97%
Ontario	304	+102%	+57%	+141%	+74%

The adjustment of the climate data to include lake effects has mixed impacts on the results. In the case of scenario 1 (Table 3), lake effect adjustments decrease net basin supplies in Superior, Michigan, and Erie, with increases noted in Huron and Ontario. The changes in variability are also mixed with increases in Superior and Ontario, decreases in Michigan, and little change in Huron and Erie.

Table 3. Comparison of simulation results for annual total net basin supplies (mm) with and without adjusting station data for estimated lake effects. These are results for scenario 1.				
	Annual Total		Standard Deviation of Annual Total	
Lake	Without Lake Effect	With Lake Effect	Without Lake Effect	With Lake Effect
Superior	-24	-220	198	231
Michigan	419	249	329	281
Huron	468	554	335	337
Erie	933	834	501	500
Ontario	1941	2163	616	734

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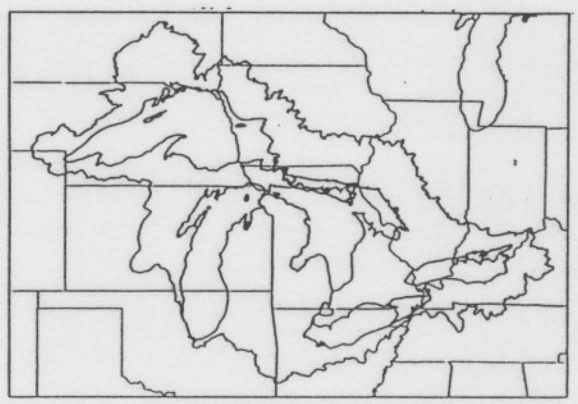

Figure 1. Location of Great Lakes basin for scenario 1.

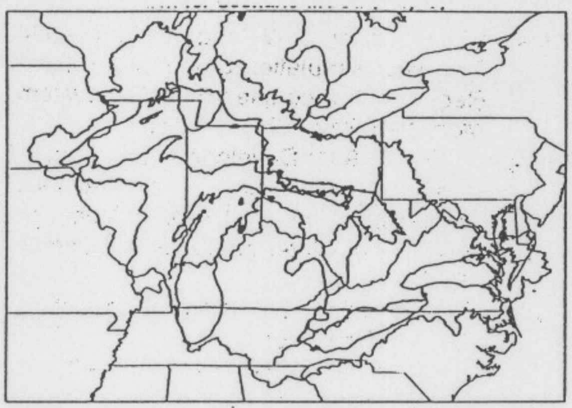

Figure 2. Location of Great Lakes basin for scenario 2.

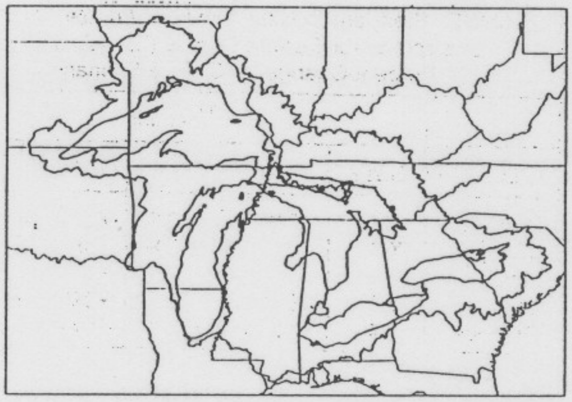

Figure 4. Location of Great Lakes basin for scenario 4.

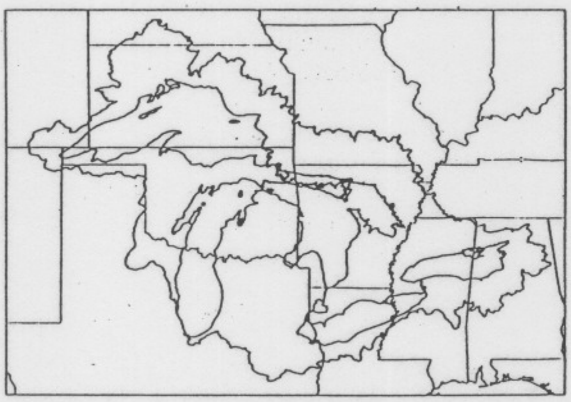

Figure 3. Location of Great Lakes basin for scenario 3.

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Front Cover: The two figures, prepared from Landsat MSS data, depict the expansion of urban land cover in the Dallas-Fort Worth, Texas region between 1974 and 1989. The urban-related land cover features are represented by light blue and grey, while the arable land is represented by brown, green, and red. The displacement of arable land by urban expansion is evident around and between the two cities. The increased urbanization around the Dallas-Fort Worth International Airport is clearly visible (slightly right of center of figures). During this time interval the population of the Dallas-Fort Worth Metropolitan area increased from 2,467,000 to greater than 3,766,000.

The influence of land use/land cover on climatological values of the diurnal temperature range is presented in paper 6.4 included in this preprint volume on page 163 by Kevin P. Gallo, NOAA/NESDIS, Washington, DC and T. C. Peterson and D. R. Easterling.

Cover figures courtesy of NOAA/NESDIS/National Climatic Data Center and USGS/EROS Data Center.

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