Michigan's Relative Risk Task Force Report on Hydrology

Prepared By

Surface and Ground Water Hydrology Alteration Task Force
Norman Grannemann, Chair

April 1998

DEQ Michigan Department of Environmental Quality
Office of Special Environmental Projects
http://www.deq.state.mi.us

John Engler, Governor
Russell J. Harding, Director

Blank

Michigan's Relative Risk Task Force Report on Hydrology

Prepared By

Surface and Ground Water Hydrology Alteration Task Force
Norman Grannemann, Chair
April 1998

Michigan Department of Environmental Quality
Office of Special Environmental Projects
http://www.deq.state.mi.us

John Engler, Governor
Russell J. Harding, Director

Michigan's Relative Risk Task Force Report on Hydrology, April 1998

Prepared by the
Surface and Ground Water Hydrology Alteration Task Force

Office of Special Environmental Projects' Administrative and Technical Staff to the Task Force

Keith G. Harrison, M.A., R.S., Cert. Ecol. .... Director
Jesse F. Harrold, Jr., M.S. .... Environmental Officer
Patricia Hiner .... Executive Secretary

Copies of this report may be obtained free of charge by writing to

Office of Special Environmental Projects
Michigan Department of Environmental Quality
Knapps Centre, Suite 340
P.O. Box 30680
Lansing, Michigan 48909-8180

or by downloading from

http://www.deq.state.mi.us/osep/errp.htm

Printed by Authority of Executive Order 1995-16
Total Number of Copies Printed: 60
Cost per Copy: $1.25
Total Cost: $75.00

Table of Contents

Table of Contents (Continued)

Tables

Figure

Michigan’s Relative Risk Task Force Report on Hydrology

EXECUTIVE SUMMARY

The Governor's Relative Risk Program was initiated in September 1991, with the creation of three multi-disciplined committees composed of scientists, citizens, and representatives of governmental agencies, respectively. The purpose of each committee was to identify and evaluate known and suspected environmental problems, decide which problems were of particular concern, and assign a relative rank to each by comparing the risks it posed to the environment and quality of life. The resulting report, entitled, *Michigan's Environment and Relative Risk* was presented to the Governor in July 1992.

The report identified 24 risk issues and ranked each in terms of concern as "high-high", "high", "medium-high", or "medium." The issue of “Alteration of Surface and Ground Water Hydrology” was ranked as a high risk. "White papers" were written to support the rankings for each issue.

The Surface and Ground Water Hydrology Alteration Task Force report addresses the data, analyses and interpretations needed to reduce the environmental risk that can be associated with human-derived and naturally changing hydrologic processes. The report discusses six areas of concern, waters management, Great Lakes water levels, ground water, wetlands, irrigation and dams and reservoirs, and provides a series of recommendations to help reduce the level of environmental risk. The recommendations contained in this report are purposefully not prioritized since it was felt by the Task Force that state and local government would be able to determine better which initiatives could be implemented given current fiscal limitations.

Recommendations:

1. Water Management

    a. Implementation of a holistic approach to water management with integrated decision-making,

    b. Inventory of all county and intercounty drains to minimize potential conflicts over their management,

    c. Expansion of Michigan’s stream gauging network to reduce risks associated with water-related development, and

    d. Identification of current water utilization with the water use registration program including mandated agricultural water use reporting.

2. Great Lakes Water Levels

    a. Until the skill of state-of-the-art water level forecasts significantly improves (and this depends on improved long-range weather forecasts), probabilistic water level forecasts should be used by state resource managers for anticipation of and preparation for crisis conditions, and for quantifying risks associated with mitigative actions. In addition, Michigan should develop reliable estimates of damages due to fluctuating lake levels for use with the probabilistic forecasts in assessing risks. This type of forecast should be requested as a special product from the U.S. Army Corps of Engineers, who now have the primary authority for issuing lake level forecasts,

    b. Michigan should ensure that all Great Lakes shoreline flood hazard areas are identified, adequately mapped (new or revised), and policies implemented for their management and development,

c. Michigan should continue its involvement with and its support of the binational project to assess and prevent encroachment upon the St. Clair and Detroit River channels, and assist in implementing findings and recommendations,

d. Michigan should try to ensure that adequate funding of the Water Use Information System be provided in order to obtain accurate accounting of Michigan water withdrawals and consumptive use of Great Lakes water, including projections of future uses,

e. Michigan should review the recommendations of the International Joint Commission's Levels Reference Study Board 1993 report and act upon them as appropriate, and

f. Michigan should evaluate the available scientific information (both pro and con) regarding climate change and its potential impacts, and formulate policies for adaptation, mitigation and further research as appropriate. Michigan should review the approach adopted by Illinois as a model for the development of a more focused program to address the concerns of possible climate change.

3. Ground Water

a. *Water-level Data.* There is currently no coordinated network of observation wells to obtain data that will help answer questions about changes in ground water levels. The network should be constructed so as to address as many of the following general questions as possible:

   1. How much change in ground water levels is due to increases and decreases in the amount of precipitation?

   2. How much change in ground water levels is due to pumping or other human caused stress on the aquifers?

   3. How much water recharges aquifers in the state?

   4. How much water is available for use from the ground water system without causing reductions in stream flow, excessive drawdown, or environmental damage?

b. *Aquifer Mapping*. Little is known about the hydraulic and storage properties of many of the state's most productive aquifers. It is important to begin a long-term program to assess the thickness, extent, and hydraulic properties of the state's most used and most extensive aquifers. This program would consist of the following:

   1. Mapping aquifers in glacial deposits to determine the location and extent of aquifer material,

   2. Mapping aquifers in rapidly developing areas of Michigan, particularly the carbonate rock aquifers in northern Michigan,

   3. Determine hydraulic properties of mapped aquifers by conducting state-of-the-art hydraulic and geophysical tests,

   4 Determine long-term recharge rates to aquifers to help assess long-term yields and potential for contamination, and

5. Determine the degree of confinement of the aquifer to help assess vulnerability to contamination.

c. *Ground Water/Surface Water Interaction.* Many wells are located adjacent to streams. Pumping for public supply, industry, or irrigation may cause changes in the amount of water flowing to or from streams and wetlands to the ground water system. To more accurately assess these ground water/surface water interactions, a program is needed to more clearly define the relationships between ground water and surface water and illustrate the interconnected nature of surface and ground water systems.

4. Wetlands

a. State, county and local governments should commit to a program to ensure that agricultural, regulatory, fiscal and other policies support the conservation, re-establishment and wise use of wetland resources,

b. No governmental policy should contribute to a net loss of wetlands in the state,

c. State, county and local governments should commit to support projects that advance the causes of wetland conservation and sustainable utilization, and

d. The academic scientific communities should be encouraged by state government through grants (if possible), data sharing and in-kind contributions to further current and new wetlands research and existing wetlands management technology in order to meet the needs of the state.

5. Irrigation

The mandate for agricultural water-use reporting ended in 1995. This mandate should be extended in order to ensure the continued existence of a database from which the impacts of existing and new irrigation may be evaluated.

6. Dams and Reservoirs

In order to minimize the risks associated with dams, federal, state and local programs should be continued which ensure periodic dam inspection and proper maintenance, encourage operation of hydroelectric facilities as run-of-the-river, design discharge to minimize temperature and dissolved oxygen problems, and provide fish passage where appropriate.

BLANK

Michigan's Relative Risk Task Force Report on Hydrology

Blank

INTRODUCTION

In 1986, the U.S. Environmental Protection Agency (USEPA) initiated a program to examine environmental risks to U.S. citizens. Specifically, the federal agency identified critical risks and compared them with each other to develop a hierarchy for remediation and pollution prevention. This hierarchy, based on scientific knowledge, could then be used to design strategies that would yield the most positive results given the funds available. In late 1991, at the direction of Governor John Engler, Michigan became one of the first states to develop a similar relative risk program.

The Governor's Relative Risk Program was initiated in September 1991 with the creation of three multi-disciplined committees composed of scientists, citizens, and representatives of governmental agencies, respectively. The purpose of each committee was to identify and evaluate known and suspected environmental problems, decide which problems were of particular concern, and assign a relative rank to each by comparing the risks it posed to the environment and quality of life. The resulting report, entitled, *Michigan's Environment and Relative Risk* (Rustem *et. al.,* 1992a), was presented to the Governor in July 1992. In his July 17, 1992, issuance of the report to the citizens of Michigan, Governor Engler stated, "*I am convinced it is time to carefully review and evaluate our priorities and base those priorities on careful thought and scientific information. We must do this in order to efficiently apply our limited resources to addressing the most serious environmental risks that our state faces*."

The report identified 24 risk issues and ranked each in terms of concern as "high-high", "high", "medium-high", or "medium" (Table 1) The 24 risk issues were subsequently grouped into 19 task forces (Table 2). In the report, "risk" was considered to be any involuntary exposure to harmful substances or conditions outside the workplace. "Relative risks" were considered to be those residual risks remaining after consideration of current environmental control programs.

Table 1. Identified relative risks issues and rankings.[1]

High-High	High	Medium High	Medium
Absence of Land Use Planning	Point Source Dischargers	Contaminated Sites	Accidental Releases & Responses
Urban Environment Degradation	Air Toxics Deposition	Contaminated Sediments	Acid Deposition
Energy Production & Consumption	Biodiversity/Habitat Changes	Hazardous Waste	Critical Air Pollutants
Global Climate Change	Indoor Air Pollutants	Photochemical Smog	Electromagnetic Field
Lack of Environmental Awareness	Non-point Source Discharges	Solid Waste	
Ozone Depletion	Trace Metals in Ecosystem	High-Level Radioactive Waste	
	Alteration of Surface/ Ground Water Hydrology	Low-Level Radioactive Waste	

(1) From Rustem *et al.,* 1992a.

Alteration of surface and ground water hydrology, including the Great Lakes, was an issue that ranked as a high risk. "White papers" were written to support the rankings for each issue (Rustem *et al.,* 1992b). The "white paper" on alteration of hydrology describes the importance of water to Michigan's citizens as well as the natural and altered processes that impact the state's water resources.

Table 2. Relative risk task forces.[1]

Environmental Education	Integrated Land Use Planning	Trace Metals in Ecosystem
Urban Recreation	Non-point Source Dischargers	Biodiversity/Ecosystem Management.
Contaminated Sites	Air Issues	Alteration of Surface/Ground Water Hydrology
Low-Level Radioactive Wastes	Accidental Release & Response	Indoor Air
Surface Water Sediments	Point Source Dischargers	Urbanization & Fragmentation of Agricultural/Forest Land
Electromagnetic Fields	High Level Radioactive Wastes	
Hazardous, Municipal, Industrial & Solid Wastes	Energy Production, Climate Change & Stratospheric Ozone Depletion	

(1) Relative Risk Task Forces as a function of regrouping of the 24 Relative Risk Issues by the Michigan Natural Resources Commission in 1992.

The "white paper" also lists ten hydrologic and engineering factors that need analysis to foster improved water-resources management decisions that will, in turn, reduce risks to human safety and the environment. All ten factors require more complete understanding and quantification of hydrologic processes as the basis of wise management decisions. In essence, they illustrate the need for a more detailed understanding of the water budget on a statewide basis. Efforts to quantify the distribution of water in Michigan can yield direct benefits by reducing the risk to Michigan's citizens from floods, drought, erosion, and other water-related damage. Indirect benefits of quantifying the distribution of the state's water relate to the importance of water in other environmental problems such as point and non-point source contamination. These and other related water-quality issues will not be considered in this report because they have been assigned their own task forces under the Relative Risk analysis program. This report addresses the data, analyses, and interpretations needed to better serve the needs of the people of Michigan, to quantify the state's water resources and to evaluate problems directly due to hydrologic processes.

Even the name Michigan, which is derived from the Native American words *Michi Gama* or place of great waters, illustrates the significance of water for the state (Institute of Water Resources, 1987). The Great Lakes cover about 40 percent of Michigan. Over 35,000 inland lakes cover about 1,000 square miles of the state and more than 200 rivers with a total length of 36,350 miles flow to the Great Lakes. Only small portions of the state fall outside of the Great Lakes watershed. Being placed so centrally to the world's largest supply of fresh surface water, Michiganians have a special responsibility to protect their water resources. Fresh ground water in Michigan constitutes almost as much water as found in the Great Lakes. The sheer volume of water on and in the state make “management” of this resource impossible in the usual sense of management. In truth, only a small portion of the state's water can be managed. Most of the water in the hydrologic cycle defies human control.

Knowledge of surface and ground water and their relations to weather and climate is essential to ensuring the well-being of Michigan's citizens and the viability of the state's economy. The quantity, quality, and distribution of water are becoming more critical to economic growth and people's health, safety, and comfort. Most areas of the state are experiencing increasing demands on water supplies because of population growth, industrial expansion, and agricultural practices. Shifts in population and changes in land use are placing new demands on existing water supplies. As a result there are new and growing needs for reliable hydrologic data to help make informed decisions that will assure the availability of enough good quality water at a reasonable cost. In addition, clean water is considered an essential element for ensuring a healthy environment. Knowing how much water is available and the rates at which it moves through the hydrologic cycle are necessary for analyzing water-quality data.

Because Michigan's water resources are so vast relative to many other parts of the U.S., the state has tended to pay less attention to them than have states with fewer water resources. However, as the population grows, water is utilized more, it becomes more expensive, and it is more likely to be contaminated. This report is designed to help Michigan's residents understand the complex ways in which the state's water resources are distributed and what types of information are needed to help make reasonable decisions about the state's water resources. The recommendations contained in this report are purposefully not prioritized since it was felt by the Task Force that state and local government would be able to determine better which initiatives could be implemented given current fiscal limitations.

WATER MANAGEMENT

Rivers and Streams

Modifications to Michigan's rivers and streams have traditionally been driven by single purpose projects, such as flood control, stream bank stabilization, or drainage improvement. While frequently successful for the intended purpose, there were often unintended consequences either upstream or downstream. A major change in water management philosophy to a holistic approach would dramatically reduce the risk associated with hydrologic modifications. What is needed is the implementation of watershed management.

Watershed Management

Watershed management is a process of decision making regarding uses and modifications of lands and waters within a watershed. This process provides a chance for communities to balance diverse goals and uses for local resources, and to consider how their cumulative actions may affect long-term sustainability of these resources.

Human modifications of lands and waters directly alter delivery of water, sediments, and nutrients, and thus fundamentally alter aquatic systems. People have varying goals and values relative to uses of local land and water resources. Watershed management provides a framework for integrated decision making and should strive to:

1. Evaluate the nature and status of the watershed ecosystem,
2. Define short-term and long-term goals for the system,
3. Determine objectives and actions needed to achieve selected goals,

4. Determine both benefits and costs of each action,

5. Implement desired actions,

6. Evaluate the effects, actions and progress towards goals, and

7. Re-evaluate goals and objectives as part of an iterative process.

As a form of ecosystem management, watershed management encompasses the entire watershed system, from uplands and headwaters, to floodplain wetlands and river channels. It focuses on the processing of energy and materials (water, sediments, nutrients, and toxics) downslope through this system. Of principle concern is management of the basin's water budget; that is, the routing of precipitation through the pathways of evaporation, infiltration, and overland flow. This routing of ground water and overland flow defines the delivery patterns to particular streams, lakes, and wetlands and largely shapes the nature of these aquatic systems.

Watershed management requires use of the social, ecological and economic sciences. Common goals for land and water resources must be developed among people of diverse social backgrounds and values. An understanding of the structure and function--historical and current--of the watershed system is required, so that the ecological effects of various alternative actions can be considered. The decision process also must weigh the economic benefits and costs of alternative actions, and blend current market dynamics with considerations of long-term sustainability of the ecosystem.

Many of the rivers and streams in the state are also established county and intercounty drains. There are additional statutory considerations involved in managing these reaches. An inventory of all county and intercounty drains should be continued cooperatively by state and county government. The inventory should include the drain name, whether it is county or intercounty, open or enclosed, the point of beginning, point of ending, established bottom width, easement width and side slopes. This will help to minimize potential conflicts over managing these resources.

An adequate understanding of the hydrologic system is required to analyze impacts of hydrologic modifications. This requires an adequate stream gauging network. Michigan has a cooperative program with the U.S. Geological Survey (USGS) to operate a stream gauging network. The USGS stream gauging program provides hydrologic information needed to help define, use, and manage the Nation's water resources. The program provides a continuous, well-documented, well-achieved, unbiased and broad-based source of reliable and consistent water data. Because of the nationally consistent, prescribed standards by which the data are collected and processed, the data from individual stations are commonly used for purposes beyond the original purpose for an individual station. Those possible uses include, but are not limited to, the following:

1. Providing data for forecasting and managing floods,

2. Characterizing current water-quality conditions,
3. Delineating and managing floodplains,
4. Operating and designing multipurpose reservoirs,
5. Setting permit requirements for discharge of treated wastewater,
6. Designing highway bridges and culverts,
7. Monitoring compliance with minimum flow requirements,
8. Scheduling power production,
9. Designing, operating, and maintaining navigation and recreational facilities,
10. Allocating water for municipal, industrial, and irrigation uses,
11. Defining and apportioning the water resources at international borders, and
12. Undertaking scientific studies of long-term changes in the hydrologic cycle.

Data for one or more of these purposes are needed at some point in time on virtually every stream in the country, and a data-collection system must be in place to provide the required information. The general objective of the stream gauging program is to provide information on stream flow characteristics at any point on any stream. Stream flow data are needed for immediate decision-making and future planning and project design. Data, such as that needed to issue and update flood forecasts, are referred to as “data for current needs.” Other data, such as that needed for the design of a future bridge or reservoir, are referred to as “data for future or long-term needs.” Some data, of course, fit into both classifications; a station that supplies data for flood forecasting and also provides data to define long-term trends clearly fits both classifications.

The number of stream gauging stations in Michigan is not adequate to define the hydrologic system. Expansion of the network would provide data to reduce risks associated with water-related development.

Water Use

Michigan residents and tourists enjoy an abundance of clean drinking and recreational water. Michigan farmers share the advantages of these same high quality waters for agricultural operations, such as irrigation or raising livestock, while businesses use these waters for industrial processes, such as food processing and pharmaceutical manufacturing. Agricultural products and industrial goods are purchased by consumers, who indirectly become the users of the water incorporated into these products.

Increasingly, multiple uses conflict with one another. Among those competing for Michigan water are instream uses, such as navigation and recreation, and off-stream or withdrawal uses, such as public drinking water supply, manufacturing, and irrigation. The goal of multiple use water management is to blend the concerns of the various users into a comprehensive system for compatible efficient use of water that does minimal harm to the environment.

Water use that involves the physical removal of ground water or surface water from its source is considered a withdrawal water use. When the water is returned to its source, it is a nonconsumptive withdrawal. A consumptive use occurs when water is not returned to its source. Water is considered to be consumed when it is no longer available to the watershed as a result of evaporation, transpiration, incorporation into products or crops, consumption by human beings or livestock, or is otherwise lost to the immediate waterbody.

Withdrawal uses are categorized for record-keeping purposes as public supply, thermoelectric power generation, industrial self-supply and irrigation. These four categories account for over 98 percent of the water withdrawn and used in Michigan. The other two percent is generally classified as rural water use such as rural homeowner wells, drinking water for livestock, and dairy sanitation. Most of this water is self-supplied and cannot be readily monitored for reporting purposes.

Utilities generating thermoelectric power at more than 90 fossil fuel and three nuclear power plants in Michigan withdraw more water than the other three uses combined. Power plants use the water for cooling equipment and to produce steam to drive turbines, and then return this water to the lake or river from which it was withdrawn. More than 98 percent of the water withdrawn for thermoelectric power generation is from the Great Lakes and connecting waterways. Only 1.3 percent of all water used in thermoelectric power generation is consumed, primarily through evaporation.

Industrial self-supply is water withdrawn by a user instead of being supplied by a public source. Over 9,000 industries are in this category, using water to manufacture cars, steel, chemicals and plastics and to make pulp and paper. About ten percent of the water withdrawn by self-supplied industries is consumed; the remainder is returned to the watershed, often following treatment that removes contaminants or heat.

Public water-supply systems provide water to homes, schools, and offices, and to industries and businesses that are not self-supplied. Domestic uses in homes include water for drinking, cooking, bathing, and other household uses as well as watering lawns. The average Michigan household uses 75 gallons of water/person/day. The average Michigan school uses 15 to 25 gallons of water/student/day.

Municipal water-supply systems provide most of the public drinking water in Michigan. In rural areas, ground water from private wells is the source of drinking water for many residents. Municipalities withdraw an estimated 1.2 billion gallons of water/day from the Great Lakes, ground water or, in rare instances, inland lakes and streams. The Great Lakes and connecting waterways supply about 80 percent of the total withdrawals by municipal systems for public supply.

Irrigators withdraw water for agricultural, recreational and commercial irrigation purposes. The 1992 Agriculture Census for Michigan showed that the number of irrigated farms increased to 3,823, irrigating 366,465 acres. Irrigation occurred in every county in Michigan during 1977, the only year for which detailed irrigation water-use data are available. During 1977, 2,812 irrigators used 2,852,483 acre-inches of water to irrigate 324,934 acres. Eighty-five percent of the irrigated acreage was agricultural, including field crops, truck crops, potatoes, tree fruits, hay and pasture, and other uses. Recreational irrigation used 9.2 percent of the total water, primarily for golf course and park irrigation. Commercial irrigation, accounting for approximately 4.4 percent, includes that for sod, flowers and nurseries.

Less than five percent of the entire quantity of water withdrawn from all sources is consumed. The majority of the water used for irrigation comes from ground water and inland lakes and streams, accounting for about 70 percent of the water withdrawn from these sources. Through the 1970's, irrigation water use increased at a faster pace than any other category. This was especially true in the southwestern parts of the state where irrigation continues to increase.

The Great Lakes Preservation Act requires users of any state water in quantities averaging 100,000 gallons/day for 30 days, to report on an annual basis how much they use with the Michigan Department of Environmental Quality (DEQ). DEQ Drinking Water and Radiological Division has notified water use registrants of the reporting requirements, and has developed a computer program that will allow Michigan to finally report its water use to the other Great Lakes states, as required by the Great Lakes Charter. Michigan is the only state that currently cannot report the volume and purpose of significant water uses to the region. The regional data are managed by the Great Lakes Commission.

The water use registration program in Michigan was developed to identify current uses, and is specifically not a regulatory or allocation program. Yet, it is very important that Michigan water users are registered and become a full participant in the regional agreement addressing shared resources. A consistent approach to resource stewardship in the Great Lakes basin states can protect the state's ability to decide if, when and how these waters can be used outside the basin. By documenting the existing needs and uses, and demonstrating responsible resource management, the states are less vulnerable to Congressional intervention in future decision-making about the use and protection of the Great Lakes waters.

The mandate for agricultural water-use reporting ended in 1995. This has left a major gap in water-use information since agriculture is a major source of consumptive water use and irrigation sometime conflicts with other water uses. The reporting mandate should be extended and made consistent with ongoing reporting requirements for industrial and thermoelectric power generation. The state is currently collecting water use data on all major uses except the agricultural uses; however, it is developing a computer model to assist in estimating irrigation use through cropping information. This should help the state fulfill the reporting requirements contained in Part 327, Great Lakes Preservation, of the Natural Resources and Environmental Protection Act, 1994

PA 451, as amended. The ability of DEQ to collect and provide these data to the regions depends on the development of a dedicated funding source.

Recommendations

The following four recommendations should be considered in order to help enhance the management of the state's waters:

1. Implementation of a holistic approach to water management with integrated decision-making,
2. Inventory of all county and intercounty drains, cooperatively undertaken by state and county government, to help minimize potential conflicts over their management,
3. Expansion of Michigan's stream gauging network to reduce risks associated with water-related development, and
4. Identification of current water utilization with the water use registration program including mandated agricultural water use reporting.

GREAT LAKES WATER LEVELS

Of all the Great Lakes states, Michigan's welfare is most intimately linked to that of the Great Lakes and their connecting channels. The state's borders are predominantly defined by the shorelines of Lakes Erie, St. Clair, Huron, Michigan, and Superior, and the Detroit, St. Clair, and St. Marys Rivers. The lakes and rivers are immeasurably important to the state, both economically and environmentally. The state's dependence on them makes it vulnerable to fluctuations in their water levels due to natural or anthropogenic effects.

Risks Associated with Fluctuating Great Lakes Water Levels

The adverse consequences of extreme Great Lakes water level fluctuations on public and private interests are well documented (Levels Reference Study Board, 1993). During low water level periods, such as those experienced in the 1920's, 1930's, and 1960's, commercial navigation suffers from loss of adequate navigation depths and reduced cargo capacity, hydropower generation is reduced, water intakes are exposed, and recreational use of the lakes is impaired. During high water level periods, such as those experienced in the 1950's, 1970's, and most recently in 1985 and 1986, riparians suffer property damage due to flooding and increased erosion, metropolitan sewer outfalls are submerged inhibiting discharge, and recreational use of beaches and marinas is impaired. Commercial navigation, which generally benefits from increased cargo capacity during high water periods, also experiences losses due to reduced speeds required to prevent shoreline damage from boat wakes in the connecting channels.

These adverse consequences can be compounded by other factors that affect lake levels. Natural factors are storms, ice jams in the connecting channels, and isostatic rebound of the earth's surface. Storms, with accompanying changes in barometric pressure and high winds, cause lake levels to fluctuate over a small time period (an hour to several days) through wind setup, storm surges, and waves. The magnitude of the short-term fluctuations vary depending on location and shoreline configuration, but can significantly exacerbate flooding and erosion during periods of high lake levels. Ice jams in the connecting channels can occur during the winter and early spring months, resulting in changes in lake levels and localized flooding along the river shores. In addition, isostatic rebound, the gradual rising of the earth's crust from the weight of the glaciers that covered the region during the last ice age, is resulting in a gradual increase in lake levels along the southern and western shores, and a corresponding decrease along the northern and eastern shores of the Great Lakes. For example, water levels at Marquette, Michigan are now 0.11 meters higher relative to the shoreline than at the beginning of the century for the same mean lake level (Lee and Southam, 1994). The effects of isostatic rebound have long-term implications for lake level management, municipal flood protection and drainage/sewer system design, and harbor maintenance.

Anthropogenic factors compounding adverse consequences due to Great Lakes fluctuating water levels include lake regulation, diversions and consumptive uses, connecting channel encroachment or excavation, urbanization and other land use changes, and the potential for a changed climate. Table 3 shows the estimated impact of some of the modifications to the natural system made to date.

Table 3. Estimated impact of modifications to the natural Great Lakes system (meters) (IJC, 1989).

LAKE	IMPACTS OF CHANNEL DREDGING/FILLING		IMPACT OF CURRENT DIVERSIONS			IMPACT OF REGULATIONS		ACCUMU-LATED IMPACTS
	MICHIGAN & HURON	ERIE	LONG LAC & OGOKI	CHICAGO	WELLAND	SUPERIOR	ONTARIO	
SUPERIOR (1)	0	0	0.09	0	0	0.17	0	0.26
MICH./HURON	-0.38	0.04	0.11	-0.06	-0.04	0	0	-0.33
ERIE	0	0.12	0.07	-0.04	-0.12	0	0	0.03
ONTARIO	0	0	0.07	-0.04	0	0	-0.09	-0.06

1. Impacts of Lake Superior Regulation are taken from Quinn (1978).

Data, Information, and Analyses Needed to Reduce Risks Due to Great Lakes Water Level Fluctuations

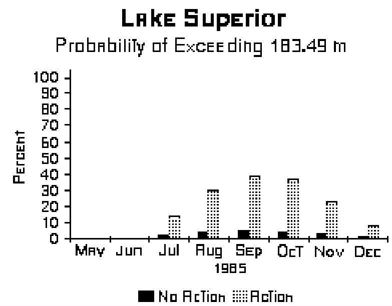
Improving Water Level Forecasts and Quantification of Risk. Although much is known about the physical processes that affect Great Lakes water levels, the greatest risk arises from an inability to predict the magnitude and timing of annual and seasonal fluctuations, with satisfactory accuracy, more than one month into the future. Presently, water level forecasts are made one to six months into the future. Recent analyses of state-of-the-art Great Lakes water level forecasts have shown that these forecasts are only marginally better than using long-term average changes in lake levels superimposed on beginning-of-month water levels (Croley and Lee, 1993; Lee, 1992). Furthermore, the forecast accuracy cannot be significantly increased without improvements in long-range (30 days or more into the future) weather forecasting. The water level forecasts currently available to the public provide a deterministic "most probable" forecast and/or a range of expected levels (USACE, 1994; Canadian Hydrographic Service, 1994). Probabilities of exceedance or non-exceedance are not explicitly given.

During periods of extreme water levels, governments (local, state, and federal) and commercial and private interests are faced with making decisions regarding what actions, if any, they should take to avoid or mitigate damages and losses. They must weigh the risks of taking action versus no action. They must also decide when to take action. Because many measures take time to implement (i.e., construction of shore protection) or to become effective (i.e., deviations from lake regulation plans), decisions must be made well in advance of reaching critical water levels. These decisions must be made with little certainty of future water levels. Thus, in addition to the state's inability to predict levels, it is unable to quantify the risks involved in its decisions with the forecasts currently disseminated.

How then, can people affected by fluctuating Great Lakes water levels make decisions that depend on knowledge of future water levels? In addition, how do they measure the risks associated with their decision? As suggested by Croley and Lee (1993), the answer lies in the use of probabilistic forecasts. A probabilistic forecast gives the decision-maker a range of outcomes with their associated probability of occurrence.

Lee, Clites and Keillor (1997) have developed a simple technique for producing probabilistic water level forecasts and have demonstrated its application to several case studies of decision-making during periods of extreme water levels. One case study, particularly relevant to Michigan, examined the 1985 International Joint Commission (IJC) decision to store water in Lake Superior to reduce high levels on Lakes Michigan-Huron, Lake St. Clair, and Lake Erie. However, the decision to store water on Lake Superior exacerbated high water conditions on that lake, and its water level exceeded the upper regulation limit in October and November. The risk of this occurrence was not quantified a priori. Lee, Clites and Keillor (1997) retrospectively generated probabilistic forecasts for Lake Superior and Lakes Michigan-Huron and used them to quantify the risks of exceeding Lake Superior's upper regulation limit (183.49 m) and

Lakes Michigan-Huron's previous record water level (177.10 m). Figure 1 summarizes the risks for May through December, 1985, based on the probabilistic forecasts for each lake. From this figure, it can be seen that by reducing Lake Superior outflows, the probability of Lakes Michigan-Huron exceeding 177.10 meters decreased, especially for June through October. The monthly exceedance probabilities were reduced for these months from a range of 12 to 59 percent to two to 34 percent.



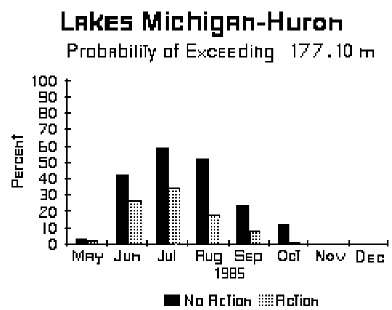


Figure 1. Change in risk of Lake Superior and Lakes Michigan-Huron exceeding upper water level limits with and without reductions in Lake Superior outflows Great Lakes seasonal water level fluctuations

However, the risk of Lake Superior exceeding its upper regulation limit of 183.49 meters was correspondingly increased, significantly for July through December. For these months, the probability of exceeding 183.49 meters increased from a range of two to six percent to nine to 40 percent. With the reduction in outflows, the risk of Lake Superior exceeding its upper regulation limit became greater than the risk of Lakes Michigan-Huron exceeding its previous record level for August through December.

With the risks of the action quantified, the decision to take action becomes a policy decision. Should a particular group's risk be increased to decrease the risk of another group? Can the risks be related to potential gains or losses by users of the lakes (e.g., Michigan citizens)? To do this, reliable estimates of damages due to fluctuating water levels must be developed. Such estimates can be combined with the probabilistic forecasts to quantify the risks associated with lake management decisions and mitigative actions.

Until the skill of state-of-the-art water level forecasts significantly improves (and this depends on improved long-range weather forecasts), probabilistic water level forecasts should be used by state resource managers for anticipation of and preparation for crisis conditions, and for quantifying risks (costs) associated with mitigative actions. In addition, Michigan should develop reliable estimates of damages due to fluctuating lake levels for use with the probabilistic forecasts in assessing risks. Probabilistic forecasts should be requested as a special product from the U.S. Army Corps of Engineers (USACE), who now have the primary authority for issuing lake level forecasts.

Improving Identification and Management of Flood Hazard Areas. Flooding along the Great Lakes shoreline and connecting channels is one of the consequences of fluctuating seasonal and annual water levels, compounded by storm-induced water level fluctuations (storm surges, seiches, and wave runup) or ice jamming. Flood hazard areas for the Great Lakes shoreline of Michigan have been partially identified by the Federal Emergency Management Agency's (FEMA) National Flood Insurance Program. A report prepared by the USACE (1988) under contract to FEMA, *"Revised Report on Great Lakes Open-Coast Flood Levels,"* provides 100-year flood levels for reaches of the Great Lakes open-coast and connecting channels (neglecting flooding due to ice jams). Flood levels are not defined for shorelines protected by the presence of islands, or bays subject to additional wind setup. Major areas of Michigan's coastline for which flood levels are not given in the report are summarized in Table 4. However, several special studies have been done to determine flood levels for many of these areas, including Little and Grand Traverse Bays, and Saginaw Bay.

Maps of flood hazard areas are available from Michigan for those communities which participate in the National Flood Insurance Program. The state maintains a list of participating communities. However, not all flood hazard areas are mapped, and some mapped areas have not been revised in accordance with the new flood levels of the *Revised Report on Great Lakes Open-Coast Flood Levels*. The flood levels of the revised report take into account the record water levels of 1985 and 1986. Differences in flood levels between the earlier 1978 report and the revised report differ by as much as 0.37 meters, with the largest differences occurring on Lake Michigan, Lake St. Clair, and Lake Erie. Map revisions could be substantial. In addition, those reaches along the connecting channels prone to flooding due to ice jams should be mapped.

In the recently completed IJC *Levels Reference Study ...*, an analysis of land use by the Land Use and Shoreline Management Task Group found that the general trend in the basin over the last several decades has been an increase in shoreline development, primarily for residential use at the expense of natural areas and agricultural land. Examinations of future trends found that this increase in development will continue (Working Committee 2, 1993). This trend, along with unmapped or outdated maps of hazard areas, has the potential for development within flood zones and future flood damages.

Michigan should ensure that all shoreline flood hazard areas are identified, adequately mapped or revised, and policies implemented for the management and development of these areas. The Land Use and Shoreline Management Task Group found the following measures to be effective where already implemented in the Great Lakes - St. Lawrence River Basin:

1. Setback and flood-proofing requirements in undeveloped areas,
2. Setback and flood-proofing requirements in developed areas when lots are redeveloped and in combination with other measures such as dwelling relocation,
3. Acquisition or relocation of properties and structures where justifiable due to significant infrastructure at risk, or where shoreline areas exhibit unique shoreline characteristics or habitat, and
4. Properly designed shore protection that considers potential negative impacts on adjacent and downdrift property.

These shoreline management alternatives must be evaluated and undertaken considering unique site specific conditions.

Preventing Connecting Channel Encroachment. As previously shown in Table 3, past dredging and infilling activities in the St. Clair and Detroit Rivers have had significant impact on lake levels. In recent years, there have been many new proposals along the St. Clair and Detroit Rivers involving fills or other channel modifications. A number of these proposals are related to fisheries habitat and wetland enhancement or creation as part of the St. Clair and Detroit River Remedial Action Plans. At the same time, there have been other development proposals ranging from municipal park development (involving shore hardening and infilling), in-river dredge disposal sites, and marina developments. In nearly all cases the proponents have argued that the hydraulic effects would be small, however, in the long-term, many fills and channel alterations will have an accumulative effect with significant impacts on lake levels, and flows, ice and sediment transport through the rivers (Brown, 1995).

A joint U.S. and Canadian project has been proposed (Brown, 1995) to perform a holistic assessment of the potential impacts of habitat enhancement and development along the entire course of the St. Clair and Detroit Rivers. The assessment would involve federal, provincial/state, and local jurisdictions. The Michigan Department of Natural Resources (DNR) has participated in preliminary meetings of the proposed joint project. Michigan should continue its involvement and support to the project, and assist in implementing findings and recommendations.

Table 4. Portions of Michigan's shoreline for which 100-year flood levels are not specified in the *Revised Report on Open-Coast Flood Levels* (USACE, 1988).

LAKE	SHORELINE REGION	LAKE	SHORELINE REGION
Superior	Whitefish Bay	Huron	Saginaw Bay[1]
	Grand Island		Thunder Bay
	Huron Bay		Straits of Mackinac
	Keweenaw Bay		LesCheneaux Islands
	Chequamegon Bay		Drummond Island
	Apostle Island		St. Joseph Island
Michigan	Little Traverse Bay[1]	Erie	Maumee Bay
	Grand Traverse Bay[1]		
	Straits of Mackinac		

1. Special studies have been performed to determine the flood levels of these areas.

Improving Accounting of Consumptive Water Uses. Present consumptive use of Great Lakes waters is a small, but essential part of the water balance. Currently, consumptive use basin-wide (U.S. and Canada) is estimated to be of the same order as the Chicago Diversion, about 85 cubic meters/second (3,000 cfs) (Great Lakes Commission, 1992). Estimates of consumptive use are required to determine their impact on Great Lakes levels and flows, and on which to base projections of future consumption. In 1987, the Great Lakes Regional Water Use Database Repository was established to collect and store U.S. and Canadian water use information, and is maintained by the Great Lakes Commission.

Of the Great Lakes states, Michigan is the largest withdrawer of Great Lakes waters (VanTil, 1995), However, it did not pass legislation until 1990 requiring the reporting of water withdrawals by major use categories (thermoelectric power generation, public water supply, irrigation, and industrial). The state subsequently established a Water Use Information System, under the jurisdiction of the DEQ, which was funded by a three-year grant. The grant expired at the end of the fiscal year 1996. The activity will continued under a water user fee basis until December 1999, when the program will be reassessed. Consequently, there is a need to explore other funding sources. The development of the Water Use Information System has made significant strides in establishing baseline estimates of Michigan withdrawals and consumptive uses. However, to continue its development, including projections of future uses, adequate funding of the Water Use Information System, equal to that of other Great Lakes states' funding levels, will need to be provided.

Implementing the Recommendations of the Levels Reference Study Board. As a result of the heavy damage and widespread public concern that resulted from the record high Great Lakes water levels of 1985 and 1986, the Canadian and U.S. governments requested on August 1, 1986, that the IJC examine methods that could alleviate the problems associated with fluctuating water levels. After several years of intense study and public involvement, the Levels Reference Study Board (1993) presented its final report to the IJC. Forty-two recommendations for actions on water level issues were made. Many of these recommendations require participation or action at the state level. Michigan should review these recommendations and act upon them as appropriate. Of the 42 recommendations, the following are perhaps the most relevant to Michigan (Levels Reference Study Board, 1993): Recommendation one concerning the adoption of Guiding Principles; Recommendations 11 - 17 concerning land use and shoreline management; Recommendations 18, 22 - 23 concerning emergency preparedness; Recommendation 24 concerning expansion of the Lake Superior Board of Control membership to include representation from citizens, states and provinces; and Recommendations 31 - 36, 38 - 42 concerning management and operational improvements including meteorological observations, hydraulic and hydrologic modeling, coordination of hazard mapping, flood damage surveys, and climate change impacts.

Potential for Climate Change - the "Greenhouse" Effect. Many people greet this topic with skepticism, confusion, or indifference. The scientific uncertainty surrounding climate change due to the "greenhouse" effect and the inability of an individual to observe climate change, make it difficult for the average person to synthesize the available information and relate it in a meaningful way to daily living. However, according to Mahlman (1991), scientists are certain that emissions resulting from human activities are impacting the atmospheric concentrations of the greenhouse gases, carbon dioxide, methane, chlorofluorocarbons, and nitrous oxide. Since the industrial revolution, the combustion of fossil fuels and deforestation have led to an increase of 26 percent in carbon dioxide concentration in the atmosphere. Scientists are also certain that these increases will enhance the natural greenhouse effect, resulting on average in an additional warming of the Earth's surface. With a scenario that assumes little or no action is taken to reduce greenhouse gas emissions, the Intergovernmental Panel on Climate Change (IPCC, 1990) has predicted that the global mean temperature will increase about 0.3 degrees centigrade per decade over the next century, resulting in a one degree centigrade increase above the present value by 2025, and three degrees centigrade before the end of the next century. Reductions in emissions from human activities of greenhouse gases of over 60 percent would be required to stabilize their concentrations at today's levels.

The IPCC includes the caveat that there are many uncertainties in its predictions with regard to the timing, magnitude and regional patterns of climate change, due to incomplete understanding of sources and sinks of greenhouse gases, clouds, oceans, and polar ice sheets, and their complex interactions. It does not rule out that surprises may occur as scientific understanding increases and modeling capabilities improve.

The effect of doubling of "greenhouse" gases on Great Lakes hydrology was initially explored by the Great Lakes Environmental Research Laboratory at the request of the USEPA (1989), and more recently, as part of the IJC's *Levels Reference Study* ... report (Task Group 2, 1993). As discussed in Croley (1991), water supplies to the Great Lakes under a changed climate were developed based upon simulations from various general circulation models (GCMs). Lake levels were obtained by routing the net basin supplies derived from the climate change scenarios through a Great Lakes regulation and routing model until steady-state conditions were obtained. The relative differences in the average annual steady-state levels under the changed climate from the present conditions are summarized in Table 5.

The changes in lake levels reflect the profound impacts that could occur to Great Lakes basin hydrology as a result of global warming. Higher air temperatures under the climate change scenarios would lead to higher over-land evapotranspiration and lower runoff to the lakes. Earlier runoff peaks would occur since snowpack is reduced and the snow season is shortened. This would result in a reduction in available soil moisture. Water surface temperatures would peak earlier and would be higher with larger amounts of heat resident in the deep lakes throughout the year. Buoyancy-driven turnovers of the water column would not occur as often on all lakes except St. Clair. Currently, they occur twice a year on all lakes. Ice formation would be greatly reduced over winter on the deep Great Lakes, and lake evaporation would increase. The average steady-state net basin supplies to all lakes would be greatly reduced (20% - 100% under the Canadian Climate Center scenario) (Croley, 1991). These impacts would require significant adaptation and would affect every aspect of human health and the state's environment and socioeconomic institutions.

Table 5. Relative differences in average annual lake levels under a changed climate, as predicted with data from various GCMs (meters).

LAKE	GISS[1]	GFDL[2]	OSU[3]	CCC[4]
Lake Superior	- 0.46	-	- 0.47	- 0.30
Lakes Michigan-Huron	- 1.31	- 2.48	- 0.99	- 1.76
Lake St. Clair	- 1.21	- 2.12	- 0.87	- 1.60
Lake Erie	- 1.16	- 1.91	- 0.79	- 1.49
Lake Ontario[5]				- 1.40

[1] Results based on GCM output from Goddard Institute for Space Studies (Hartmann, 1990)
[2] Results based on Geophysical Fluid Dynamics Laboratory (Hartmann, 1990)
[3] Results based on Oregon State University (Hartmann, 1990)
[4] Results based on Canadian Climate Center (Lee and Quinn, 1992)
- Levels were not computed due to failure of the regulation plans with these scenarios.

Changnon (1995) recently provided a review of states' involvement to date in the global climate change issue. Of the 50 U.S. states, 22 have taken some action on the climate change issue. According to Changnon (1995), the 22 states have primarily acted upon two basic policies put forth by the 1989 National Governors' Association Task Force on Global Climate Changes (NGA, 1990):

1. Mitigation of potential climate change through control of greenhouse gas emissions, primarily through energy policies, and

2. Use of states' influence over emissions through their utility, land-use, transportation, taxation, and other authorities.

Additionally, nine of the 22 states have encouraged and/or organized in-state research focusing on climate change. To date, Michigan has not developed a policy which is specifically targeted at global warming issues. It has, however, continued to reduce its emissions through several other policy initiatives (Harrison, 1997).

Changnon (1995) also presented the Illinois' response in detail, which is broader in scope than that of other states, and goes beyond mitigation alone. He reported that Illinois has tried to address other questions including the scientific certainty of climate change; the potential impacts of climate change on Illinois; adaptation and mitigation to deal with the change; and the influence of Illinois policies on federal policies. Illinois' actions included the establishment of the Global Climate Change Office at the Illinois State Water Survey. The Office developed plans to foster research on the physical, socioeconomic, and policy aspects of climate change in Illinois; to encourage new methods and systems for measuring climate change and its effects on the hydrologic cycle of Illinois; and to provide information on climate change to the general public, scientific university/college staff and students, and state policy makers. The Governor of Illinois also established an Illinois Task Force on Global Climate Change that ultimately identified five major issues relating to state policy, and made significant recommendations that could be enacted now through existing state agencies. The Illinois General Assembly also established a permanent climate change task force to provide continuing policy guidance.

Changnon (1995) presents arguments as to why states can no longer afford to ignore the climate change issue:

1. Federal program interest in and support of state and regional impacts and adaptation research is inadequate,

2. Although scientific uncertainties still exist, it is clear that national and international policies are being developed and state policy is emerging in its formative stages,

3. There is a growing national and state realization that states must play a pivotal role in the development of local and state programs and regulations relating to the issue, and

4. States need to assess the policy aspects of the issue if they are to have an organized voice in the ongoing national policy debate on the issue.

Michigan should evaluate the available scientific information (both pro and con) regarding climate change and its potential impacts, and formulate policies for adaptation, mitigation and further research as appropriate. Michigan should review the approach adopted by Illinois as a model for the development of a more focused program to address the concerns of possible climate change.

Recommendations

The following addresses some of the data, information, and analyses needed to reduce risks due to Great Lakes water level fluctuations. Many other needs exist, but may be more appropriately addressed at the federal level than at the state level. In summary, the major recommendations are:

1. Until the skill of state-of-the-art water level forecasts significantly improves (and this depends on improved long-range weather forecasts), probabilistic water level forecasts should be used by state resource managers for anticipation of and preparation for crisis conditions, and for quantifying risks associated with mitigative actions. In addition, Michigan should develop reliable estimates of damages due to fluctuating lake levels for use with the probabilistic forecasts in assessing risks. This type of forecast should be requested as a special product from the USACE, who now have the primary authority for issuing lake level forecasts,

2. Michigan should ensure that all Great Lakes shoreline flood hazard areas are identified, adequately mapped (new or revised), and policies implemented for their management and development,

3. Michigan should continue its involvement with and its of support to the binational project to assess and prevent encroachment due to dredging and filling upon the St. Clair and Detroit River channels, and assist in implementing findings and recommendations,

4. To obtain accurate accounting of Michigan water withdrawals and consumptive use of Great Lakes water, including projections of future uses, adequate funding of the Water Use Information System must be provided,

5. Michigan should review the recommendations of the IJC's Levels Reference Study Board (1993) and act upon them as appropriate, and

6. Michigan should evaluate the available scientific information (both pro and con) regarding climate change and its potential impacts, and formulate policies for adaptation, mitigation and further research as appropriate. Michigan should review the approach adopted by Illinois as a model for the development of a more focused program to address the concerns of possible climate change.

GROUND WATER

Ground Water Use is Increasing

Ground water residing in aquifers below the surface of the earth is one of Michigan's most valuable natural resources. It is the source of water for 43 percent of Michigan's population and nearly all households not supplied by public systems (Bedell, 1982). The principal aquifers in Michigan are in glacial deposits and sedimentary bedrock. Aquifers that produce sufficient water for domestic supplies are present in nearly all parts of the state. The four largest metropolitan areas supplied by ground water are Lansing, Kalamazoo, Battle Creek, and Jackson. Lansing uses water from the Saginaw aquifer, Kalamazoo from aquifers in glacial deposits, Battle Creek from the Marshall aquifer, and Jackson from both the Saginaw and Marshall aquifers. Ground water is also the source of 38 percent of the total water used for irrigation (Bedell and VanTil, 1979) and, thus, is critical to agricultural development in Michigan.

Withdrawal of ground water is expected to rise in the coming century as the population increases and available sites for surface-water reservoirs become more limited. For example, a study done for the Ground Water Management Board in the Lansing Metropolitan Area indicates that average ground water pumping will increase from 44 to 57 million gallons/day between 1995 and 2020. Increased demand, reduced ground water quality, and inability to find sufficient supplies of ground water have caused some municipalities to withdraw water from the Great Lakes for supply if the community is close enough to the lakes to make a connection cost effective.

Ground water plays another important, but less known, role in the hydrologic cycle. Ground water contributes water to streams, lakes, and wetlands during periods of low surface runoff. This baseflow is the reason that streams continue to flow during periods of low rainfall or snowmelt. By maintaining a relatively consistent baseflow to surface water, the ground water flow system helps streams support wildlife and an aquatic habitat that is essential for a healthy environment.

Only a Fraction of the Available Ground Water is Pumped

To help define the ground water flow system, it is useful to estimate an average regional water budget. This hydrologic budget balances precipitation with the sum of evapotranspiration, overland flow to streams, and baseflow of streams.

Precipitation averages about 32 inches/year in the Lower Peninsula of Michigan and ranges from 28 to 40 inches/year. Total stream runoff averages about 12 inches/year and ranges from eight to 16 inches/year. Baseflow averages eight inches/year, which is approximately the amount of water recharged to the ground water system on a long-term basis (Holtschlag, 1995). Therefore, evapotranspiration averages about 20 inches/year in the Lower Peninsula. Similar data are not readily available on a statewide basis.

This estimate of the hydrologic budget provides a basis for developing a conceptual model of the hydrologic cycle for Michigan. It is interesting to note that municipal pumpage of ground water in the Lower Peninsula is less than 0.1 inch/year (Baltusis, Quigley and Mandle, 1992) which indicates that there are large untapped amounts of ground water in Michigan. This does not imply that there are no problems related to pumping ground water.

Untapped Ground Water Resources

Sand and gravel deposits of glacial origin in the northern Lower Peninsula are as much as 300 m thick in places. Such deposits are excellent aquifers. Base flow to streams in this area is constant and a large portion of total streamflow. Recharge rates are among the highest in the state. Because this area is not heavily populated and much of the land is used for timber production, little is known about the full extent of aquifers in this area except that they clearly constitute a large supply of fresh ground water.

Aquifers in limestone and dolomite rocks of the northern Lower and southeastern Upper Peninsulas also contain potentially large supplies of fresh ground water. Because they have a more complex geologic setting, less is understood about these aquifers.

Barriers to Development of Ground Water Resources

Despite Michigan's large ground water resources, equal quantities of water are not available throughout the state. At some locations, water does not readily flow to wells; at others, it is possible for one well to pump about 1,000 gallons/minute. Limitations for ground water resource development are discussed below.

Saline water intrusion occurs naturally in parts of Michigan and is accentuated due to pumping in certain locations. For example, parts of the lowland area near Saginaw Bay have ground water with higher dissolved-solids concentrations in shallow aquifers than in other parts of Michigan. These concentrations are probably mostly due to naturally occurring processes. In Lansing, however, during the 1960's, high concentrations of chloride in the Saginaw aquifer were found to be due to an improperly plugged deep well that acted as a conduit for saline water intrusion when nearby municipal wells were pumped.

Hydraulic properties of aquifers in parts of the state limit the ability to pump water from the aquifer. The geologic material at these locations restricts water flow. For example, the igneous rocks in parts of the Upper Peninsula have little pore space to store or transmit water to wells. At these locations, fractures and cracks in the rocks are the primary conduits for water flow. These are generally not abundant.

In a few locations overpumping has lowered the water level in wells enough that there is insufficient water available for the purposes desired. For example, in the late 1960's water levels in the northern part of Lansing were lowered by as much as 52 m because of nearby water-supply wells. Reduced pumping in this area has caused the water level to revover by nearly 30 m.

Contamination of ground water from human causes is one of the most discussed reasons that ground water cannot be used. Many sites of ground water contamination are related to improper handling of petroleum products or solvents. Often these problem areas coincide with population centers and compound problems that might otherwise cause less concern for human health.

Current ground water protection programs in Michigan include:

1. Wellhead protection and source water protection,
2. Statewide ground water database,
3. Water-supply monitoring,
4. Michigan Ground Water Stewardship Program,
5. Farm*A*Syst/Home*A*Syst,
6. GEM centers established by a Kellogg Foundation program,
7. County well permits,
8. Watershed councils, and
9. Local efforts.

In addition, the state is starting a source water assessment program that is required for all public water supplies as part of the federal Safe Drinking Water Act amendments of 1996. It is planned to incorporate an effort to map the depth to first water into this project. This effort will assist in filling some of the data gaps in water level knowledge in the state.

Recommendations

There are several additional ground water data collection efforts that will improve the state's ability to wisely use its ground water resources. This information will also assist in coordinating environmental aspects of ground water conditions. The state's understanding about ground water needs to be improved in the following three general areas:

1. *Water-level Data.* There is currently no coordinated network of observation wells to obtain data that will help answer questions about changes in ground water levels. The network should be constructed so as to address as many of the following general questions as possible:

    a. How much change in ground water levels is due to increases and decreases in the amount of precipitation?

b. How much change in ground water levels is due to pumping or other human caused stress on the aquifers?

c. How much water recharges aquifers in the state?

d. How much water is available for use from the ground water system without causing reductions in stream flow, excessive drawdown, or environmental damage?

2. *Aquifer Mapping*. Little is known about the hydraulic and storage properties of many of the state's most productive aquifers. It is important to begin a long-term program to assess the thickness, extent, and hydraulic properties of the state's most used and most extensive aquifers. This program would consist of the following:

   a. Mapping aquifers in glacial deposits to determine the location and extent of aquifer material,

   b. Mapping aquifers in rapidly developing areas of Michigan, particularly the carbonate rock aquifers in northern Michigan,

   c. Determine hydraulic properties of mapped aquifers by conducting state-of-the-art hydraulic and geophysical tests,

   d Determine long-term recharge rates to aquifers to help assess long-term yields and potential for contamination, and

   e. Determine the degree of confinement of the aquifer to help assess vulnerability to contamination.

3. *Ground Water/Surface Water Interaction.* Many wells are located adjacent to streams. Pumping for public supply, industry, or irrigation may cause changes in the amount of water flowing to or from streams and wetlands to the ground water system. To more accurately assess these ground water/surface water interactions, a program is needed to more clearly define the relationships between ground water and surface water and illustrate the interconnected nature of surface and ground water systems.

WETLANDS

<u>Wetland Functions in the Michigan Context</u>

Wetlands serve several well-known and vital functions. Aquifer recharge, flood control, water quality improvement, and support of wildlife and diversity are generally the most important. If lost, each of these would cause significant economic impacts in Michigan. A recent major international conference concluded that "sustainable development is not possible without wetlands because of their critical role in water quality and quantity and biodiversity" (Global Wetlands - Old World and New, 1992). In spite of increased recognition of these important functions, their destruction continues.

Flood Control

The flood events of 1993 and 1995 in the Mississippi and Missouri river drainages underscored the importance of floodwater storage and release in wetlands and other bottomlands. There is no question that the loss of temporary water storage caused major increases in flood damage. The rapid accumulation and transit of floodwaters to downstream locations via channelized and levied stream corridors greatly exacerbates problems in many communities. Wetland storage can lower flood crests, and provide for a more normal timed release of large amounts of runoff.

Water Quality Improvement

The detention of runoff and floodwaters in wetlands also provides time for sediment settling, and thus provides for fewer quality problems in downstream locations. Degradable pollutants spend sufficient time in the biologically active ecosystem to be significantly reduced. Indeed, exploitation of this attribute in newly constructed wetlands has been found to be economically attractive for the treatment of many kinds of point source and non-point source discharges. Michigan is sensitive to polluted water discharges, because it is surrounded by its Great Lakes receiving waters, as well as being permeated with recreational streams and lakes

Habitat and Biodiversity

Michigan's high quality wetlands provide a pool of genetic stock for a large number of valuable and rare species. Many of Michigan's fisheries and wildlife resources rely heavily on wetlands. They provide nesting and resting opportunities for waterfowl, winter shelter for deer, and spawning grounds for fish. Michigan's wetlands form a vital and integral basis for a large fraction of outdoor recreation and the tourism it supports.

The Role of Wetlands in the Water Cycle

Wetlands serve as collectors of precipitation, and return a good share of that water to the atmosphere via evapotranspiration. The surplus recharges the ground water, or serve as runoff sources high in the watershed. In the floodplains, wetlands provide temporary storage of large runoff events, and permit their gradual release to downstream locations.

The Role of Wetlands in the Carbon Cycle

Wetlands often serve as collectors of carbon, in the form of new accretions of peat and organic sediments. Atmospheric carbon dioxide is utilized in building plant biomass, which is in part stored in new peats after plant death. This represents the first step in replacing the fossil fuel reserves whose depletion contributes to carbon dioxide in the atmosphere.

Wetlands in the Landscape

The effectiveness of a particular wetland function is strongly related to its position in the watershed, including other land uses. The character and distribution of wetlands in a particular basin determine whether some or all of the potential functions are realized.

Its position in the drainage area determines what effects it may have on flood storage. Its location relative to point or non-point discharges determines whether it can serve to clean those waters. And, the character of the surrounding land use has a strong bearing on the quality of habitat it provides.

Recommendations

Trends in changing land use patterns continue to cause wetland losses, and to cause changes in their type and distribution. Urban sprawl changes runoff patterns, and changes the setting of the wetlands in that region. The accumulated effects of intensified agricultural practices create worsening surface and subsurface water quality in the vicinity. Escalating land values create new economic pressures for wetland conversion.

Continued wetland losses will undermine the foundation for the recreational and tourism industries of the state. The quality of life for residents will decrease, due to disappearance of green space, clean waters, and the associated wildlife. This is an insidious process, in that damage can result from the cumulative impacts of small changes occurring over long time spans. The following recommendations should be adopted in order to help reduce the risks associated with the loss of wetlands in the state.

1. State, county and local governments should commit to a program to ensure that agricultural, regulatory, fiscal and other policies support the conservation, re-establishment and wise use of wetland resources,

2. No governmental policy should contribute to a net loss of wetlands in the state,

3. State, county and local governments should commit to support projects that advance the causes of wetland conservation and sustainable utilization, and

4. The academic scientific communities should be encouraged by state government through grants (if possible), data sharing and in-kind contributions to further current and new wetlands research and existing wetlands management technology in order to meet the needs of the state.

IRRIGATION

Irrigation Influence on Surface Water

Irrigation is increasing in Michigan and it reduces surface water availability. Historically, irrigation and its impact on surface water have been of minor interest in Michigan and other parts of the northeastern quarter of the U.S.. Recently, however, the potential for conflict has been increasing in Michigan because the economic value of irrigation has become apparent and water withdrawals supporting supplemental irrigation have been increasing (Bedell and VanTil, 1979). While irrigation use is not likely to be of statewide significance, it has basically the same effect in all watersheds, it reduces the amount of surface water that is available for other uses. Water used for irrigation is taken directly from surface water or it may be pumped from aquifers. In either case, water removed for irrigation ultimately reduces the amount in streams, rivers, lakes, and wetlands.

Irrigation water use is naturally in conflict with other water uses and a rational use of water resources requires resolution of water-use conflicts. The water in streams, rivers, and lakes is essential to maintain their recreational value, it supports the fisheries, boating, and swimming and is important for dilution of certain wastes that are discharged to receiving waters or reach these waters despite the state's best efforts. Water supply to wetlands is essential to their survival. Irrigation demands are generally greatest during the summer months when surface water is naturally low. Furthermore, irrigation demands generally increase during droughts while surface water availability is further reduced. These conflicts are going to be difficult to resolve in Michigan because riparian law governs water use and it will be difficult to prove a significant degradation as the result of a single irrigation withdrawal. The impacts on surface water features are cumulative. Irrigation water use will increase over a period of years so that its impact on surface water will be masked by natural variations and because it can take a long period of time for the effects of some ground water withdrawals to influence surface water availability. The effects of extensive irrigation in limited areas of the state could have major local impacts on water levels. These effects should be investigated further. It is anticipated that the irrigation computer model will assist in accomplishing this.

Study should be focused on critical areas of the state. The potential for water use conflict is not the same throughout the state and it is possible to identify areas that should be selected because of the existing or potential high irrigation water use and the impacted or potentially impacted surface water features have other highly valued use. Data on existing and new irrigation water use should be collected. This includes location of the withdrawal and the rate and duration of withdrawal on a daily basis. Areas likely to be irrigated must be identified. These are areas where the land is suitable for irrigation, where an economical water supply is available and crops would benefit from irrigation. Areas in close proximity to valued surface water features are unique because irrigation withdrawals produce the highest instantaneous impacts. In streams, the cumulative impact of many such irrigators simultaneously removing water is directly experienced as an equal reduction in stream flow. Areas more remotely located will likely pump ground water. The same irrigation withdrawal in this situation removes water at a lower rate from surface water because it continues to be removed even after pumping has stopped. Here the impact is averaged over a longer time. While these impacts are more difficult to analyze, they have the problematic character that they continue impacting surface water features long after it becomes apparent that irrigation has produced an unacceptable situation.

Recommendation

As previously indicated, the mandate for agricultural water-use reporting ended in 1995. This mandate should be extended in order to ensure the continued existence of a database from which the impacts of existing and new irrigation may be evaluated.

DAMS AND RESERVOIRS

History of Dams and Reservoirs in Michigan

There are about 2,400 dams in Michigan. Over 100 are hydroelectric dams, and are regulated by the Federal Energy Regulatory Commission. They impact 49 river systems, including almost every major river system in Michigan. These facilities prevent, at minimum, anadromous fish movement into 2,063 mainstem river miles, dewater 57 river miles, directly impound 623 river miles, and impact 733 river miles through their operation. The total reservoir area impacted by these facilities is approximately 123,000 acres. The impacts of the remaining 2,300 dams have not been quantified.

Over 300 dams are used to maintain legal lake levels. In addition, over 700 additional dams are two meters or more in height and impound over five surface acres. The dams are regulated by the state's Dam Safety Act. The Act requires permits for the construction, reconstruction, alteration, repair and removal of dams. Its purpose is to protect the public, property, and natural resources through a technical review of proposed work on dams. In addition, the Act requires periodic inspection of dams by licensed professional engineers to assure the continued safety of a dam. The owners of dams with a high or significant hazard potential rating are required to develop an emergency action plan to address safety in the event of a dam emergency. A dam's hazard potential rating is based on downstream development that could be affected by a dam failure and is not related to the dam's condition. More than half the dams in the state are too small to fall under dam safety regulations.

Impact of Dams

Dams have a number of impacts on aquatic resources. Hydropower operations impact the state's water resources by:

1. Altering normal streamflows for generating purposes,
2. Dewatering river channels by diversion or peaking operations; and

3. Fluctuating reservoir levels for either peaking operations or for storage purposes.

The impacts of a peaking operation include the flushing of riverine reaches by generating with flood flows during the peak power periods and dewatering of riverine reaches at other periods. The dewatering of riverine habitat reduces the algal and aquatic plant life which are important as food for aquatic insects and which provide important fish nursery areas. Further, it reduces fish growth and survival by reducing available habitat and stranding fish, and changes the benthic invertebrate community to smaller, less useful, fish foods. The fluctuations cause downstream erosion and sedimentation, which destroys fish habitat and can disrupt fish migratory patterns. In addition, peaking operations cause reservoir fluctuations, which dewater and disrupt fisheries habitat in the same fashion as the tailwater habitats.

Run-of-the-river hydro-power projects mimic a natural unimpounded river and have the least direct environmental impact and do not show the same adverse impacts as found at peaking or semi-peaking operations. However, because reservoirs do alter water quality, aquatic life below dams is different from unimpounded reaches.

Hydro-power projects that divert water around river reaches or from one river basin to another, dewater the bypassed river reaches and change the natural flow pattern of the bypassed river reach. These perturbations cause:

1. A direct loss of aquatic habitat by drying up large sections of rivers,

2. Disruptive changes in fish behavior which waste energy, alter migratory patterns and curtail reproductive activities,

3. Benthic organism community composition changes similar to those discussed for peaking operations,

4 Loss of key high gradient habitat areas, and

5. Decreased overall productivity of the system.

Dams disrupt fish movement. Isolated fish stocks can decrease genetic diversity. Fish are directly impacted by turbines, and, in some cases, spillways.

Dams also impact aquatic resources by changing the water quality characteristics of the river system. The major problem areas are:

1. Low dissolved oxygen from dam releases which usually occurs in stratified reservoirs with deep intakes,

2. Temperature changes from the ponds acting as heat sinks,

3. Changes in ground water inputs to the river system which also change the temperature of the system,

4. Mobilization of contaminants which can occur in stratified lakes, and

5. Changes in nutrients and the type and amount of entrained plankton.

All of these factors can greatly impact and constrain the management of river systems.

Recommendation

In order to minimize the risks associated with dams, federal, state and local programs should be continued which ensure periodic dam inspection and proper maintenance, and encourage operation of hydroelectric facilities as run-of-the-river, design discharge to minimize temperature and dissolved oxygen problems, and provide fish passage where appropriate.

REFERENCES

Baltusis, M.A., M.F. Quigley and R. J. Mandle. 1992. *Municipal Ground Water Development and Withdrawals in Central Lower Peninsula of Michigan, 1870 - 1987*. U.S. Geological Survey, Open File Report 91-215. 89p.

Bedell, D.J. 1992. *Municipal Water Withdrawals in Michigan*. Water Management Division, Michigan Department of Natural Resources, Lansing. 43p.

Bedell, D.J. and R.L. VanTil. 1979. *Irrigation in Michigan, 1977*. Water Management Division, Michigan Department of Natural Resources, Lansing. 37p.

Brown, D. [1995]. St. Clair/Detroit River Hydraulic Encroachment Analysis to Assess Potential Cumulative Impacts of Fisheries Creation Projects, and Other Shoreline and In-Channel Developments on Levels, Flows and Conveyance, A Draft Proposal to the Great Lakes Clean Up Fund. Water Issues Division, Environmental Services Branch, Environment Canada, Burlington, Ontario.

Buchberger, S.G. 1991. *Conditional Frequency Analysis of Great Lakes Open-Coast Flood Levels.* U.S. Army Corps of Engineers, Detroit District, Detroit, Michigan.

Canadian Hydrographic Service. 1994. *Water Levels*. Canadian Hydrographic Service, Burlington, Ontario.

Changnon, S.A. 1995. State roles in the global climate change issue. *Bulletin of the American Meteorological Society,* 76(2):227-233.

Croley II, T.E. 1991. CCC GCM 2xCO_2 hydrological impacts on the Great Lakes. *In Climate, Climate Change, Water Level Forecasting and Frequency Analysis*, Volume 1 - Water Supply Scenarios, Task Group 2, Working Committee 3, Phase II, International Joint Commission Levels Reference Study, Great Lake Environmental Research Laboratory, Ann Arbor, Michigan.

Croley II, T.E. and D.H. Lee. 1993. Evaluation of Great Lakes net basin supply forecasts. *Water Resources Bulletin,* 29:267-282.

Derecki, J.A. and F. H. Quinn. 1986. Record St. Clair River ice jam of 1984. *Journal of Hydraulic Engineering,* 112(12):1182-1194.

Global Wetlands - Old World and New. [1992]. (Conference) September 1992, Columbus, Ohio.

Great Lakes Commission. 1992. *1990 Annual Report of the Great Lakes Regional Water Use Data Base Repository*. Great Lakes Commission, Ann Arbor, Michigan.

Harrison, K.G. 1997. Personal communication. Michigan Environmental Science Board, Lansing.

Hartmann, H.C. 1990. Climate change impacts on Laurentian Great Lakes levels. *Climatic Change*, 17:49-67.

Holtschlag, D.J. 1997. *A Generalized Estimate of Ground Water Recharge Rates in Lower Peninsula of Michigan.* U.S. Geological Survey, Water-Supply Paper 2437. 37p.

IPCC. 1990. *Climate Change, The IPCC Scientific Assessment*. Intergovernmental Panel on Climate Change. Cambridge University Press, New York, New York.

IJC. 1989. *Living with the Great Lakes: Challenges and Opportunities*. International Joint Commission, Washington, D.C.

Institute of Water Research. 1987. *An Introduction to Michigan's Water Resources.* Michigan State University, East Lansing, Michigan.

Lee, D. H. and C. F. Southam. 1994. Effect and implications of differential isostatic rebound on Lake Superior's regulation limits. *Journal of Great Lakes Research,* 20(2):407-415.

Lee, D.H. and F.H. Quinn. 1992. Climate change impacts on Great Lakes levels and flows, pp 387-396. *In Proceedings of 28th Annual Conference and Symposia of the American Water Resources Association on Managing Water Resources During Global Change*, November 1-5, 1992, Reno, Nevada.

Lee, D.H. 1992. An Evaluation of Deterministic Great Lakes Water Supply and Lake Level Forecasts. Open file report, Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan.

Lee, D.H., A.H. Clites and J.P. Keillor. 1997. Assessing risk in operational decisions using Great Lakes probabilistic water level forecasts. *Environmental Management,* 21(1):43-58.

Levels Reference Study Board. 1993. *Levels Reference Study, Great Lakes-St. Lawrence River Basin*. International Joint Commission, Washington, D.C.

Mahlman, J.D. 1991. Assessing global climate change: when will we have better evidence? pp 17-31. *In* Rosen, L. and R. Glasser (eds.). *Proceedings of the International Conference on Global Change: Its Mitigation through Improved Production and Use of Energy,* October 21- 24, 1991. Los Alamos, New Mexico.

NGA. 1990. *A World of Difference, Report of the Task Force on Global Climate Change.* National Governors' Association, Washington, D.C.

Potter, K.W. 1990. Estimating the probability distribution of annual maximum levels on the Great Lakes, pp 279-290. *In* Hartmann, H.C. and M.J. Donahue (eds.). *Proceedings of Great Lakes Water Level Forecasting and Statistics Symposium Great Lakes Commission*, Ann Arbor, Michigan.

Quinn, H. F. 1978. Lake Superior Regulation Effects. *Water Resources Bulletin,* 14(5):1129-1142.

Rustem, W.R., W.E. Cooper, S. Harrington and A.S. Armoudlian. 1992 *Michigan's Environment and Relative Risk, July 1992.* Michigan Department of Natural Resources, Lansing. 50p.

Rustem, W.R., W.E. Cooper, S. Harrington and A.S. Armoudlian. 1992 *Michigan's Environment and Relative Risk (White Papers), July 1992.* Michigan Department of Natural Resources, Lansing. 240p.

Task Group 2. 1993. *Climate, Climate Change, Water Level Forecasting and Frequency Analysis*, Main Report and Supporting Volumes 1 - 4. Report of Task Group 2, Working Committee 3 to the International Joint Commission Levels Reference Study, Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan.

USACE. 1994. *The Monthly Bulletin of Great Lakes Water Levels.* U.S. Army Corps of Engineers, Detroit District, Detroit, Michigan.

USACE. 1988. *Revised Report on Great Lakes Open-Coast Flood Levels*, Phase I, Phase II and Appendices. U.S. Army Corps of Engineers, Detroit District, Detroit, Michigan.

USEPA.. 1989. *The Potential Effects of Global Climate Change on the United States*, Appendix A, Water Resources, EPA-230-05-89-051. U.S. Environmental Protection Agency, Washington D.C.

VanTil, R.L. 1995. Personal communication to Deborah H. Lee. Michigan Department of Natural Resources, Lansing.

Working Committee 2. 1993. *Levels Reference Study, Great Lakes-St. Lawrence River Basin, Annex 2, Land Use and Management*. International Joint Commission, Washington, D.C.

Blank

APPENDIX I

ALTERATION OF SURFACE AND GROUND WATER HYDROLOGY TASK FORCE MEMBERSHIP ROSTER

Norman Grannemann, Chair
U.S. Geological Survey
6520 Mercantile Way, Suite 5
Lansing, Michigan 48911

Jeffrey Friedle
Department of Agriculture
P.O. Box 30017
Lansing, Michigan 48909

Roger Gauthier
U.S. Army Corps of Engineers
Great Lakes and Hydrology Branch
477 Michigan Avenue
Detroit, Michigan 48226

Dave Hamilton
Land & Water Management Division
Department of Environmental Quality
P.O. Box 30458
Lansing, Michigan 48909

Robert Kadlec
Wetland Management Services
6995 Westbourne
Chelsea, Michigan 48118

Deborah H. Lee
Great Lakes Environ. Research Lab.
2205 Commonwealth Blvd.
Ann Arbor, Michigan 48105-1593

Eric Ditschman
Clinton River Watershed Council
1970 East Auburn Road
Rochester Hills, Michigan 48307

Dr. Roger Wallace
Complex/Engineering
Michigan State University
East Lansing, Michigan 48824-1326

<u>TASK FORCE PROJECT STAFF</u>

Jesse Harrold
Office of Special Environmental Projects
Department of Environmental Quality
P.O. Box 30680
Lansing, Michigan 48909

Keith Harrison
Office of Special Environmental Projects
Department of Environmental Quality
P.O. Box 30680
Lansing, Michigan 48909

Blank