Great Lakes Water Levels: Shoreline Dilemmas : Report on a Colloquium (1989)

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Preface

In 1985 the Water Science and Technology Board (WSTB) inaugurated a colloquium series, Emerging Issues in Water Science and Technology, to focus debate and attention on important scientific and engineering issues. Since then, the WSTB has organized and hosted such colloquia annually and has published reports on a variety of topics.

The fourth colloquium, held in Chicago on March 17-18, 1988, addressed hydrometeorological, engineering, and land management and policy issues related to fluctuations in Great Lakes water levels. The board felt that this topic would be of importance because of the possibilities of a rising sea level and the impacts of climate change on hydrology.

A steering committee of board members, working closely with WSTB staff, created and organized the colloquium format. Six formal papers were presented by recognized experts concerning aspects of lake level fluctuations, shoreline impacts of water level changes, alternative solution strategies, policy conflicts in existing laws, multijurisdictional issues, and the role of the private sector. In addition, panel discussions also focused on climate change and state coastal erosion management programs.

The steering committee carefully monitored the presentation of the papers by reviewing preliminary outlines and manuscripts in progress. Provocateurs and panelists were selected to stimulate debate and discussion after the authors presented highlights from their papers.

The report has three major sections: an overview, the issue papers by individual authors, and the panel discussions. Colloquium Chairman John J. Boland prepared the overview based on a review of the issue papers and the presentations made by the provocateurs and panelists. The entire report has been reviewed by a group other than the authors, but only the overview has been subjected to the report review criteria established by the National Research Council's Report Review Committee. The issue papers have been reviewed for factual correctness.

The WSTB acknowledges the generous contributions of time and expertise of all colloquium participants. Special thanks are extended to those who made formal presentations, to those who acted as provocateurs to stimulate discussion, and to those who participated as panel members.

Contents

Overview

The Great Lakes—Superior, Michigan, Huron, Erie, and Ontario, together with Lake St. Clair and connecting waterways—constitute a resource of uncommon beauty and value. Having existed scarcely 3,000 years in their present form, these artifacts of the last Ice Age now hold 20 percent of the world's fresh water. While the drainage area is modest compared to the vast expanses of water surface, some 40 million people occupy the catchment, including about one-third of the entire population of Canada. Major industrial and commercial centers dot the shores: Milwaukee, Chicago, Detroit, Cleveland, Buffalo, and Toronto, among others. It would be difficult to exaggerate the importance of these lakes to the human and physical environment of the United States or Canada.

The Great Lakes have many uses. Millions of people fish, boat, and swim in their waters. They provide a water transportation route from the Atlantic Ocean to the heart of the continent. Hydroelectric power is generated by exploiting the 180-m elevation difference from Lake Superior to the Gulf of St. Lawrence, and nuclear and fossil-fueled power plants draw cooling water from the lakes. Industrial activities of every description and cities of all sizes rim the shores of all five lakes, withdrawing water and discharging wastes. Recreational facilities, hospitals and universities, estates, farms, housing developments, and simple vacation cottages compete with beach grass and marsh for a place at the water's edge. Still, the lakes retain much of their natural beauty. Biological communities, although often under stress, largely have survived the intense human activity, and in some instances have recovered after decades of degradation.

But lakes must have shores and shores are, by their nature, in a constant state of change. Dunes migrate across flat areas, beaches wax and wane, bluffs are steadily undercut and eroded. A recent study estimated the mean rate of shoreline erosion for the Great Lakes as a whole at 0.7 m/yr, nearly identical to that for the Atlantic Coast (0.8 m/yr) or the Chesapeake Bay (0.7 m/yr) (May et al., 1983). Lacking the lunar tides or the frequent powerful storms of the ocean coasts, however, lake shores respond to a different set of hydrologic phenomena.

Of particular interest is the effect of deviations in net basin supply (NBS), defined as direct rainfall plus runoff and net groundwater inflow, less lake evaporation. The Great Lakes are connected by a series of narrow channels that operate at relatively uniform flow. Transient changes in NBS, therefore, lead to more persistent changes in lake levels. Since the Algama period, when the lakes assumed their present configuration, mean annual lake levels may have fluctuated through a range of as much as 4 m (Larsen, 1985). During the past 125 years, the maximum range of variation has been only 1.7 m (for the Michigan-Huron system). A total of five major diversions to and from the lakes have been implemented in that period, but they have had a small effect on lake levels (generally less than 0.1 m).

Added to the long-term changes in mean annual lake level are the short-term consequences of seasonal and episodic weather variation. Seasonal changes in precipitation and evaporation cause water levels to vary by as much as 0.5 m in a given year, while prolonged winds have been known to drive the water surface to as much as 2.4 m above mean level (e.g., in Lake Erie on December 2, 1985; Quinn, this volume). Storms occur in the Great Lakes, of course, and they are sometimes accompanied by water level surges and high-energy erosive wave action.

Since the indigenous biota as well as human activities generally have adjusted to long-term average water levels, episodes of high or low water have been associated with periods of damage and disruption. Low water levels dry out wetlands, expose large areas of mudflats, and disrupt fish spawning. Recreational access and water transportation are hampered, and hydroelectric output is reduced.

Conversely, high water inundates beaches, floods low areas, and accelerates shoreline erosion. Damages associated with storms are most extensive when they coincide with periods of high lake water.

In 1986, the Great Lakes approached record high levels for the modern period; Lakes Superior, St. Clair, and Erie exceeded prior observed highs (Quinn, this volume). Shoreline recession rates grew noticeably in many places; storm damage increased dramatically. A February 1987 storm left Chicago's well-known, armored shoreline in disarray, flooding streets and buildings along the North Shore. As in prior cases of high or low water level, political pressure for a solution became quickly apparent in both the United States and Canada.

One result of widespread public concern was the decision of the two countries to request the International Joint Commission (IJC) (a binational tribunal created in 1909 to negotiate solutions to problems between the United States and Canada) to initiate a study of methods to alleviate the adverse consequences of fluctuating water levels in the Great Lakes-St. Lawrence River Basin. Such studies had been conducted before, generally yielding proposals for engineering works designed to permit increased regulation of connecting channel flow and, therefore, lake levels. Controls implemented to date include the compensating works at Sault Ste. Marie, some channel modification in the Detroit, St. Clair, and Niagara rivers, and structures in the St. Lawrence River.

The planned IJC study, however, is not confined to hydrologic regulation or to crisis response. It will examine land use and management practices along the shorelines and review socioeconomic costs and benefits of alternative land use and shoreline management practices. As directed by the governments, and as elaborated by the IJC, the study plan describes, for the first time, a comprehensive examination of the interaction between the lakes and human activities (IJC, 1987). Although engineering solutions will be addressed, they are to be considered in the broader social framework of a multielement solution designed with explicit attention to cost-benefit tradeoffs.

Against this background, the Water Science and Technology Board (WSTB) selected the subject of Great Lakes levels for its fourth colloquium. The WSTB was intrigued by the complex and interdependent scientific issues underlying the IJC study, involving climatology, hydrology, hydraulics, shoreline processes, lake ecology, land use planning, economics, and sociology. In particular, it seemed useful to take the opportunity to engage some 65 persons with expertise and personal involvement in Great Lakes issues in a detailed discussion of policy options, especially when that discussion could be contemporaneous with the early stages of the IJC study.

The WSTB Colloquium on Great Lakes Water Levels: Shoreline Dilemmas was held in Chicago on March 17-18, 1988. The first day was devoted to an inspection tour of the Chicago shoreline and a slide presentation on its history, both led by Lee Botts, deputy commissioner for environmental protection of the city of Chicago, and a keynote address by Michael Ben-Eli, an expert on effective decision making in resource management planning. The colloquium resumed the following day, in the Founder's Room of the Field Museum of Natural History, for the presentation and discussion of the technical papers included in this volume.

The first presentations dealt with the nature of water level fluctuations (Quinn), the impacts of these fluctuations (Horvath), and the range of strategies for protecting shoreline development (Wood). After this comparatively straightforward progression of ideas, interdependencies and complexities were introduced in a discussion of policy conflicts (Pilkey) and legal and institutional issues (Tarlock). As an antidote to the usual tendency to invest public agencies with all the decision-making power, Philipsborn spoke of the response and decision-making role of the individual stakeholders.

Two distinct but clearly related topics were addressed in panel discussions. The first dealt with global climate change and its implications for future Great Lakes water levels and management options. The second panel provided an overview of coastal erosion control programs as they are practiced in selected Great Lakes, Atlantic Coast, and Pacific Coast states.

Spirited discussion followed each presentation, precipitated by the remarks of an invited provocateur and continued from the floor. Predictably, most controversy arose related to discussions of options for future management policy. Virtually every shade of opinion was represented, from those advocating gradual abandonment of nearly all shoreline to one participant who argued forcefully for "completing the regulation" of the lakes through engineering measures.

INVITED PAPERS

The people invited to present papers at this colloquium discussed a wide range of topics and brought diverse expertise. To begin, Frank Quinn was charged with the task of summarizing current knowledge of Great Lakes water level fluctuations. After contrasting the period of record (beginning in 1860) to available inferences about earlier periods, he continued with a detailed discussion of recent climatic influences and of anthropogenic lake level changes, principally diversions and limited regulation. He concluded that the period most often used in the past as the basis of design and policy (1900-1969) may not be representative of long-term normal behavior. Rather, the generally higher lake levels of recent years are more consistent with past data and may be a better predictor of the future. On the other hand, global climate warming may eventually lead to lower levels. It seems clear that future policy will have to consider a wider range of variation than has been thought necessary in the past.

Curtis Larsen, the assigned provocateur, presented additional data that served to emphasize several of Quinn's points. In particular, Larsen challenged the use of the term "normal" to describe any period of lake levels. Placing the recorded levels of the past 100 years into the context of a 2,000-year geologic record, he argued that historic fluctuations have been much larger, and recent mean levels much lower, than is generally believed.

These warnings of increased lake level fluctuation were followed by a discussion of the physical consequences of such fluctuations. This paper, prepared by Horvath, Jannereth, and Shafer and presented by Frank Horvath, reviewed impacts on shoreline morphology, fish and wildlife, water quality, recreation, commercial navigation, and hydroelectric generation. In considering these impacts, the authors noted that both adverse and beneficial effects result from extreme water levels. High water damages property but favors shipping and hydroelectric generation. Low water reverses some impacts but introduces new problems. Horvath also noted a potential for high water-related release of hazardous substances from former waste storage and industrial properties located near the shore. The authors concluded that lake level changes affect virtually every aspect of life in the region, but that society seems to forget quickly the consequences of not planning for extreme levels.

Provocateur Sarah Taylor, drawing on references to conflicting interests of various lake users, asked, "For whom will the lakes be managed?" Electric generation and shipping interests may have the most concentrated economic power, but property owners are more numerous and can claim riparian rights. She mentioned additional "silent" parties, including fish and wildlife interests. Lake level management would require setting priorities among these competing uses.

William Wood provided an introduction to the principles of shoreline protection. Reviewing coastal erosion processes, he noted that shoreline recession occurs under both high and low water conditions, and that landforms inundated by high water are not likely to reappear. He advocated the notion of a "natural" dynamic boundary for shoreland property, as opposed to the fixed property boundaries assumed by current law and practice. This policy envisions human activities that migrate ahead of receding shorelines, instead of the continual effort to anchor the shoreline. Lengths of unconstructed shore could be "punctuated with limited urban/industrial areas of heavily engineered shores." The application of these strategies could be determined by a system of coastal hazard classifications. Provocateur Bruce Mitchell supported many of Wood's points, while expressing reservations about the efficacy of the implied comprehensive planning approach.

The discussion of shoreline protection continued with the paper delivered by Orrin Pilkey (prepared by Pilkey, Clayton, and Neal). Pilkey defines the shoreline protection problem as the result of humans placing something permanent in the way of a moving shoreline. He notes that the shoreline processes and protection issues are much alike on the Great Lakes and on the ocean coasts, pointing particularly to New Jersey as a lesson for future shoreline management. The characteristics and policy issues associated with various methods of hard stabilization (e.g., seawalls, groins, and breakwaters, including their many variants), soft stabilization (e.g., beach replenishment), and relocation were reviewed. Pilkey discussed policy conflicts inherent in several federal programs, and mirrored in many state programs, in which one agency promotes and subsidizes shoreline development while other agencies try to discourage it. Atlantic Coast states have chosen different emphases for their programs, ranging from structural shoreline protection (New Jersey and Florida) to efforts to preserve natural beaches (North Carolina and Maine). Pilkey, like Wood, recommended a mixed strategy combining limited use of hard stabilization methods with beach protection and construction setback requirements, as well as relocation incentives.

The implied distinction between man-made and natural shorelines was challenged by Lee Botts, provocateur for the discussion of Pilkey's paper. Botts noted that the beaches and parklands along the Chicago shoreline are entirely man-made. She described a need for better understanding of the role of beaches in shoreline protection, based on increased attention to techniques for beach restoration, beach establishment, and beach nourishment. Botts noted that existing federal policies discourage most soft stabilization strategies.

The intensive use of the Great Lakes for all types of activity, including the residential development of fully 20 percent of the shorelands, gives rise to a bewildering array of legal and institutional issues, doctrines, and jurisdictions. Dan Tarlock reviewed these problems, noting examples of what he calls "our general confusion about the proper responses to natural hazards." Institutional problems begin at the highest level, with policy and coordination disputes between the United States and Canada. Additional levels of complexity are added by the responses of various agencies of each national government, and at the state or province level. Attention was focused on land use controls at the local government level, where incentives to develop shoreland often are created and protected. Any attempt to reverse these policies would, in fact, face substantial potential legal constraints. Tarlock concluded that much of public policy reflects the view that engineering works can eliminate the hazard; adaptation to the hazard (e.g., land use controls, relocation) has not yet been considered seriously within these institutions.

A note of caution was introduced by provocateur Orie Loucks, who reminded the audience that the most valuable infrastructure is concentrated in densely settled cities, where the adaptive solutions described by Tarlock generally are not feasible. Loucks also expressed concern over the "normal range of fluctuation" focus of much of the discussion. Water levels outside of the "normal" range, as contemplated by Quinn and Larsen, may still require water level regulation, irrespective of the effectiveness of other strategies.

Clancy Philipsborn directed attention away from public entities, stressing the role of private sector decision makers in the evolution of shoreland policy. He spoke of four types of private stakeholders whose responses contribute to that policy. Those directly affected by water level fluctuations (property owners, for example) are the first-level stakeholders; those indirectly affected (banks, insurance companies) occupy the second level. Third-level stakeholders include engineers and consultants who benefit from otherwise damaging events, and the fourth level consists of volunteers and others who participate in hazard management activities even though they are not directly affected. He stressed the need to anticipate the reactions of the private sector when formulating public policy. The kind of self-serving, risk-averting behavior that can be expected of most stakeholders can be used to promote public goals, rather than to frustrate them.

Provocateur John Stolzenberg moved from Philipsborn's discussion of public-private interactions to the notion of "acceptable risk." He noted that public risk management policy must reflect private perception of what is acceptable, even while that perception is formed by information and educational efforts originated by government. Stolzenberg also returned to Taylor's concerns about how priorities are to be set and which interest groups are to be served first.

A panel composed of Waltraud Brinkmann, Stanley Changnon, Richard Kosobud, Marie Sanderson, and Joel Smith addressed the controversial and sometimes elusive subject of global climate change. In particular, they were asked to consider the possible consequences of global climate change on Great Lakes water levels. The theories underlying the global warming hypothesis were discussed, along with the models and extrapolations used to predict effects. Much emphasis was placed on the high levels of uncertainty associated with all such predictions. Most panelists felt that the most likely outcome would be lower water levels in the Great Lakes (coupled with higher ocean levels). Generally, however, the conclusions of the panelists echoed those of Frank Quinn: future Great Lakes managers should be prepared to contend with wider variations in water level than have been seen in the past 125 years.

A second panel, composed of Martin Jannereth, Jeanette Leete, Richard McCarthy, and David Owens, was convened to discuss and contrast state coastal erosion management programs. The panelists represented the states of Michigan, Minnesota, California, and North Carolina, respectively. The discussion produced a useful comparison of management strategies, while underlining the essential similarity of coastal erosion problems. The major physical variables appear to be topography and geology, rather than the difference between lake and ocean. Taken as a whole, the panelists' descriptions of program elements made clear and specific what had been presented earlier in the day at a more general and abstract level. From a regulatory perspective, the states use similar approaches and work toward similar goals such as minimizing loss of life and property, preventing encroachment of permanent structures on beaches, and preventing shoreline erosion.

SUMMARY

As the papers in this volume attest, much is known about the causes, characteristics, and consequences of Great Lakes water level fluctuation. Nevertheless, human activities around the lakes have evolved in a way that exposes many people and structures to a hazard of substantial proportions. Every indication is that the magnitude of this hazard will increase in the future. Engineering solutions to minimize this hazard have been proposed but never have been implemented. After repeated studies, the effectiveness of these measures remains controversial, and their cost-effectiveness is in doubt.

Public policy toward the development and protection of shore lands appears to be at odds with the physical realities of the lakes. In fact, many of the experts involved in this colloquium argued that existing policy seems to assume the possibility, even the probability, of an engineered solution. Yet alternative policies, more reflective of the limits of technology and of sensible cost-benefit tradeoffs, face significant legal, institutional, political, and social constraints.

Many of these problems could be resolved, provided the need to do so is widely perceived for a sufficiently long period. In this case, however, the lakes are not cooperating. After reaching record high levels in 1986, water levels began to fall, and the public sense of urgency waned soon thereafter. Many colloquium participants referred to this relationship between water levels and levels of public interests. Perhaps the greatest challenge facing the IJC and the Canadian and U. S. governments, then, is to find a way to formulate and win acceptance for a sensible Great Lakes management policy in the absence of a water level crisis.

John J. Boland, Chairman

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Issue Papers and Provocateurs' Comments

1
Fluctuation of Great Lakes Water Levels

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INTRODUCTION

The Great Lakes (Figure 1-1) are one of the world's major water resources, containing about 20 percent of the world's fresh surface water supplies. The Great Lakes system includes about 761,000 km^2, of which about one-third is lake surface. The system includes the five Great Lakes, Superior, Michigan, Huron, Erie, and Ontario, and Lake St. Clair and their connecting channels. The system is naturally well regulated due to the large lake surface areas and constricted outlet channels. This has resulted in the lakes historically fluctuating through a very small range in levels, about 1.8 m. Because of the small range in fluctuations, the lake shore has been intensively developed, down to the shoreline in many areas, making riparian interests very susceptible to even small changes in water levels.

NATURAL LAKE LEVEL FLUCTUATIONS

The Great Lakes began to form around 11,000 years ago upon the retreat of the glaciers during the last ice age. For the first 6,000 years or so the water levels fluctuated over 100 m (Hough, 1958). Following the end of the Algoma stage, about 3,000 years ago, the system outlets stabilized, with the system being essentially in its present state. A perspective on Lake Michigan lake levels over the

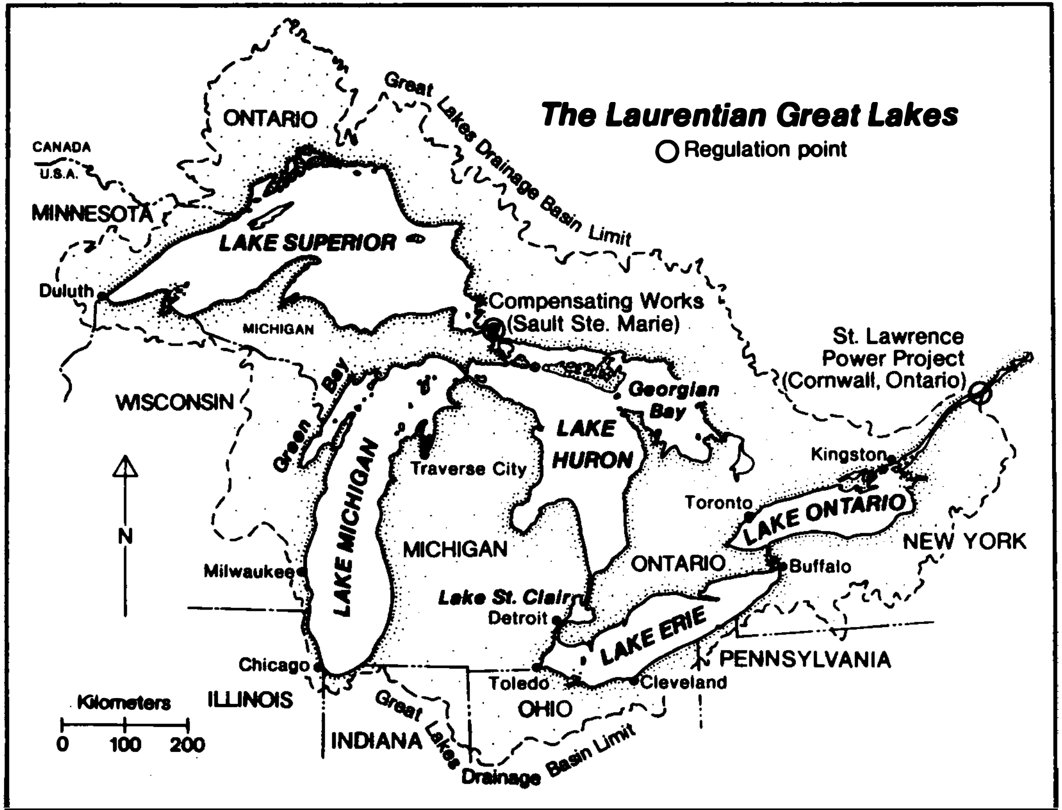

FIGURE 1-1 The Great Lakes System.

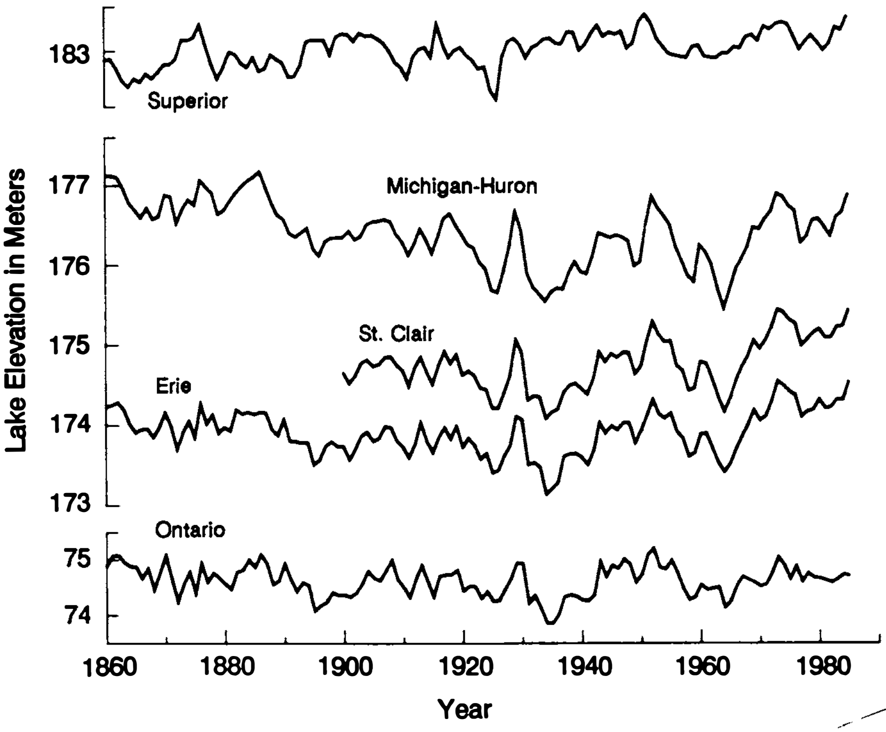

FIGURE 1-2 Great Lakes mean annual water levels.

past 3,000 years, reconstructed through geologic and archaeologic evidence (Larsen, 1985), indicates that over this period lake levels may have averaged much higher than at present, with three separate periods during which levels were 152 cm or more above the current long-term average.

The Great Lakes water levels have been continuously gaged since 1860, providing one of the longest time series of continuously measured hydrologic data in North America. Time scales of lake level fluctuations are multiyear, seasonal, and event-related. The annual lake levels illustrate the longer-term variability of the system (Figure 1-2). During 1986 the levels of Lake Michigan-Huron approached the records of the last century and would have exceeded the past records if not for anthropogenic changes. Record lake levels were set on Lakes Superior, St. Clair, and Erie during the recent high-levels regime. Prior record highs for this century were set in 1952 and 1973. Record lows were established in 1935 and 1964. Since 1970 the lakes

TABLE 1-1 Annual Level Statistics (1860-1986)

Lake	Maximum Level (m)	Minimum Level (m)	Mean Level (m)	Standard Deviation (m)
Superior	183.40(1986)	182.56(1926)	183.02	0.15
Michigan-Huron	177.17(1886)	175.46(1964)	176.42	0.40
St. Clair*	175.66(1986)	174.09(1934)	174.77	0.34
Erie	174.71(1986)	173.14(1934)	173.92	0.29
Ontario	75.22(1952)	73.86(1935)	74.62	0.27

*Period of record for Lake St. Clair begins in 1898.

TABLE 1-2 Seasonal Cycle (Monthly Mean Water Levels)

Month	Superior (m)	Michigan-Huron (m)	St. Clair (m)	Erie (m)	Ontario (m)
January	182.94	176.28	174.58	173.75	74.43
February	182.88	176.28	174.50	173.74	74.45
March	182.85	176.30	174.64	173.82	74.53
April	182.86	176.37	174.80	173.98	74.72
May	182.97	176.46	174.89	174.07	74.84
June	183.05	176.53	174.94	174.12	74.89
July	183.12	176.57	174.96	174.10	74.86
August	183.15	176.56	174.93	174.04	74.76
September	183.16	176.51	174.86	173.95	74.63
October	183.14	176.44	174.78	173.86	74.51
November	183.10	176.38	174.69	173.78	74.44
December	183.02	176.32	174.69	173.76	74.62

have been in a very high regime. A summary of the annual level statistics is given in Table 1-1.

Superimposed on the annual levels are the seasonal cycles, Table 1-2. Each of the lakes undergoes an annual seasonal cycle, the magnitude of which depends on the individual water supplies. The range in the seasonal cycle varies from about 45 cm on Lakes Erie and Ontario to about 30 cm on Lake Superior. In general, the seasonal cycles usually have a minimum in the winter due to increased fall and early winter evaporation from the lake surfaces. The levels then rise due to increased snowmelt, spring precipitation, and decreased evaporation, reaching a maximum in the summer.

Event-related fluctuations include storm range, wind setup, and pressure jumps. Major short-period fluctuations are common along the shallower areas of the Great Lakes, particularly Lake Erie, Saginaw Bay, and in some instances Green Bay. When the wind is blowing along the axis of the lakes or bays, the water may be piled up at one end of the bay or lake. For example, water level differences between the east and west ends of Lake Erie can exceed 490 cm during a severe storm.

ANTHROPOGENIC LAKE LEVEL CHANGES

Anthropogenic lake level changes are due primarily to diversions, modifications to the connecting channels, regulation, and consumptive use. Diversions have been a hydraulic feature of the Great Lakes since the early 1800s. At the present time there are two interbasin diversions and two intrabasin diversions in operation (International Joint Commission, 1985). The Lake Michigan diversion at Chicago is perhaps the most well known interbasin diversion, taking water from Lake Michigan and diverting it into the Illinois and Mississippi River drainage basins. The Lake Michigan diversion was begun in 1848 and averaged about 14 m^3s^{-1} through 1899. In 1900 the Chicago Sanitary and Ship Canal was completed with an initial diversion of 83 m^3s^{-1}, increasing to a maximum of 284 m^3s^{-1} in 1928. The present diversion of 91 m^3s^{-1} was established by a U.S. Supreme Court decree in 1967.

The Long Lac and Ogoki diversions were begun in 1941 and 1943, respectively; they divert water from the Hudson Bay watershed into Lake Superior. The combined diversions on an annual basis have ranged from 85 m^3s^{-1} in 1943 to a maximum of 227 m^3s^{-1} in 1964. At the present time the combined diversions average about 154 m^3s^{-1}.

The Welland Diversion and New York State Barge Canal are intrabasin diversions that transfer water from the Lake Erie to the Lake Ontario basin. A reconstructed Welland Canal was completed in 1882, which required the diversion of water from Lake Erie. The initial diversion requirements were about 11 m^3s^{-1}. The present diversion is about 260 m^3s^{-1}. The Barge Canal is a relatively minor diversion, taking approximately 28 m^3s^{-1} from the Niagara River at Buffalo and discharging it into Lake Ontario at four locations along the shoreline.

The diversions, with the exception of the New York State Barge Canal, have measurable impacts on the water levels, Table 1-3. The

TABLE 1-3 Impact of Existing Diversions on Lake Levels*

Diversion	Amount (m^3s^{-1})	Superior (cm)	Michigan-Huron (cm)	Erie (cm)	Ontario (cm)
Ogoki-Long Lac	159	+6	+11	+8	+7
Chicago	91	-2	-6	-4	-3
Welland	266	-2	-5	-13	0
Combined		+2	-1	-10	+2

*Data from International Joint Commission (1985).

effects on Lakes Superior and Ontario are dependent on the regulation plans in effect at any given time. The large surface areas and constricted outlets of the nonregulated lakes greatly moderate the effect of diversion changes. For example, it takes approximately 3 years to achieve 50 percent of the ultimate effect of changes in Lake Michigan diversion rates on water levels, with the ultimate effect being reached between 12 and 15 years.

A second major source of anthropogenic lake level changes has been due to channel modifications in the St. Clair, Detroit, and Niagara rivers. These modifications have usually taken the form of uncompensated dredging projects for navigation or for sand and gravel mining, filling in of constricted areas of the rivers, and construction of engineering works such as bridges across the channels. It is important to note that projects in the connecting channels have a permanent effect only on the upstream lakes (Quinn, 1986a). St. Clair River dredging for the 25- and 27-ft navigation projects in the mid-1930s and early 1960s, and sand and gravel dredging between 1908 and 1925, have lowered Lake Michigan-Huron by about 27 cm (Derecki, 1985). Uncompensated dredging projects were also undertaken between 1860 and 1900, concentrated primarily at the head of the river and in the St. Clair delta (Horton and Grunsky, 1927), with unknown effects.

The Detroit River also underwent navigation dredging between 1907 and 1913 in the lower river and between 1919 and 1921 in the Grosse Pointe Channel at the head of the river. The Detroit River was also dredged for the 25- and 27-ft navigation projects. Compensating works were designed and placed in the river to compensate for the projects. Prior to 1900 dredging projects in the Grosse Pointe Channel and at the Limekiln Crossing were undertaken and had an undetermined effect on lake levels on Lakes St. Clair and Michigan-Huron.

Channel modifications in the upper Niagara River include piers for the construction of the International Railway and Peace bridges and channel filling around Squaw Island and in the vicinity of Fort Erie. The net effect of the modifications has been an increase of 10 to 15 cm in the water levels of Lake Erie. Channel modifications to the St. Marys and St. Lawrence rivers have no impact on lake levels due to the upstream regulatory control works.

Regulation came to the Great Lakes with the completion of the Lake Superior compensating works in 1921. The goal of Lake Superior regulation was to reduce the natural fluctuations of levels from 107 cm to a desired range of 46 cm (Hartmann, 1988). Prior to implementation of the current regulation plan, Plan 1977, Lake Superior regulation was based solely on the water levels of Lake Superior. Plan 1977 provides for the relative balancing of Lake Superior with Lake Michigan-Huron. Lake Superior regulation through 1975 resulted in an average increase of 16 cm in Lake Superior water levels, with no apparent bias on the water levels of the lower lakes (Quinn, 1978a).

Lake Ontario has been regulated since 1960 with the construction of the St. Lawrence Seaway and Power Project. The primary regulatory structure is the Moses-Saunders Power Dam between Massena, New York, and Cornwall, Ontario. The basic regulation plan in use is Plan 1958-D. The regulation was extremely effective during the high water periods in the early 1970s and mid-1980s.

Large quantities of water are withdrawn from the Great Lakes for a wide variety of purposes, including manufacturing, power generation, irrigation, and municipal uses. The withdrawals in 1975 totaled 2,120 m^3s^{-1} (International Joint Commission, 1985). The portion of the water not returned is categorized as consumptive use. Overall 1975 consumptive use was about 140 m^3s^{-1}.

The system limits caused by human manipulation, including diversions, channel changes, and regulation, are therefore relatively small in comparison with the long-period natural fluctuations (with the exception of Lake Ontario).

HYDROLOGIC WATER BALANCE

The primary process that determines lake level fluctuations is the hydrologic cycle. The major components of the cycle are precipitation, runoff, and evaporation. The contribution of groundwater is negligible when compared to the other components. The net sum of these components, precipitation plus runoff minus evaporation, is known as the net basin supply (NBS). Although precipitation and temperature data have been available since the 1860s, adequate runoff and evaporation data have been available only since the 1940s. This limits meaningful analysis of trends in runoff and evaporation. However, trends in runoff follow the trends in precipitation, whereas there is no clear correlation between evaporation and precipitation. Lake Superior has shown a slight increase in evaporation over the past 20 years compared with the prior 25 years, while Lake Erie has shown a significant decrease for the same period.

Variations in air temperature also influence lake level fluctuations through lake evaporation and evapotranspiration from the basin. Higher air temperatures result in higher rates of transpiration and evaporation from the land surface. The annual mean air temperatures around the perimeter of the Great Lakes since 1900 indicate three distinct temperature regimes: a low-temperature regime from 1900 to 1929, a high-temperature regime from 1930 to 1959, and a low-temperature regime from 1960 through the present (Quinn, 1986b). The current regime is about 0.6°C lower than the previous warm regime.

The NBS component causing the major multiyear variations in lake levels is the precipitation. From 1900 to 1940, a low precipitation regime predominated. From 1940 to date, a relatively high regime has dominated, with extremely high precipitation from 1966 through 1986 (Quinn, 1981). For example, during 18 of the past 22 years, 1965-1986, the annual precipitation for Lake Michigan-Huron has been above the long-term mean (Figure 1-3). Despite record low precipitation on the upper lakes for the period November 1986 through July 1987, the precipitation is continuing at an above average rate.

GREAT LAKES WATER LEVEL MODELING AND SIMULATION

Mathematical models are an integral part of understanding and simulating lake level fluctuations. The basic framework for water level simulation consists of a hydrologic response or routing model for the unregulated portion of the system (Quinn, 1978b) coupled with the regulation plans for Lakes Superior and Erie. Input parameters for the routing models include either overwater precipitation, runoff into the individual lakes, and lake evaporation, or the lumped net basin supply for each lake in addition to diversions, rates of ice

FIGURE 1-3 Lake Michigan-Huron annual precipitation: Differences from the long-term mean (1900-1986).

retardation, and discharge equation parameters for the connecting channels. Model outputs are end-of-month and monthly mean lake levels for each lake and monthly flow rates in the connecting channels. At the present time there are two routing models in general use that differ primarily in their solution techniques but yield similar results (Hartmann, 1987). The response models are coupled to the Lake Superior Regulation Plan 1977 (International Lake Superior Board of Control, 1981) and the Lake Ontario Regulation Plan 1958-D (International St. Lawrence River Board of Control, 1963) to provide levels for the entire system.

A second model gaining widespread use throughout the Great Lakes is the Large Basin Runoff Model (Croley, 1983). It is an interdependent tank-cascade model that employs analytical solutions of climatic considerations relevant for large watersheds. The model couples mass balances for snowpack, two soil zones, groundwater, and surface water with physically based concepts of linear reservoir storages, partial area infiltration, complementary evapotranspiration and evapotranspiration opportunity based on available supply, and degree day determinations of snowmelt. The model has been calibrated and applied to each of the 121 subbasins draining directly into the Great Lakes. This model is extensively used for simulating and forecasting water supplies.

Most Great Lakes water simulation studies consist of routing the net basin supplies for the period of record, corrected for present channel conditions, through the routing models for assumed conditions of diversions, consumptive use, and so on. For regulation studies, two additional approaches to simulate net basin supplies have also been used (Megerian and Pentland, 1968; Yevjevich, 1976). These techniques, using multivariate analysis, failed to anticipate supply sequences approaching the high water supplies of the past 20 years.

Two prediction techniques in use for predicting water supplies and lake levels are a trend and regression procedure (DeCooke and Megerian, 1967) and a conceptual model-based technique (Croley and Hartmann, 1987). Both predict water supplies 6 months into the future that are routed through the system to provide the lake level forecasts. The trend and regression approach uses multiple linear regressions based on current and antecedent temperature and precipitation data to predict the NBS for each lake for the first month of the forecast. The net basin supplies for the second through the sixth month are then determined from a net basin supply trend analysis considering the long-term trend, seasonal variations, cyclic variations, and random fluctuations. An error assessment of the 6-month trend and regression forecast is shown on the monthly water levels bulletin (Corps of Engineers, 1987). The standard deviation of the long-term predictive error increases from about 3 cm for the first month to about 15 cm at the end of the sixth month.

The conceptually based technique uses the Large Basin Runoff Model and historical meteorologic sequences representing anticipated meteorology based on the National Weather Service monthly and seasonal outlooks for precipitation and air temperature probabilities. The generated runoff is combined with the precipitation and lake evaporation estimates from an evaporation model to provide the 6-month time series of net basin supplies. Net basin supplies for the first month can be forecast with a root mean square error of 40 mm, a bias of –5 mm, and a correlation of 0.80 (compare with actual supply means of 78 mm, with a standard deviation of 58 mm) (Croley and Hartmann, 1987).

Future Great Lakes levels scenarios can be developed on the basis of both normal climatic variability and the implications of global climatic warming. Higher lake level sequences could be expected in the future, based on the high precipitation sequence in the 1870s and 1880s being more severe in both duration and magnitude than the recent sequence. Additionally, simulation runs using a multiyear repeat of the 1972-1973 supplies indicate that Lake Michigan-Huron could rise about 50 cm above the 1986 highs, with Lake Erie about 20 cm higher. An extended multiyear reduction in net basin supplies exceeding the duration of the drought in the early 1960s could result in lake level decreases of up to 120 cm.

Climatic change, represented by global warming, could have a significant effect on the Great Lakes. A current concern is that a warming due to increases of CO_2 and other greenhouse gases could result in major changes to the hydrologic cycle. Estimates indicate that a temperature rise of about 4°C might be expected over the latitudinal range of the basin (National Research Council, 1983; Cohen 1986). In addition, changes in the amount and seasonal distribution of precipitation and major changes in wind velocities would probably occur. Simulation studies of the impact of climate warming on lake levels (Cohen, 1986; Quinn, 1987) indicate that equilibrium effects could involve lowering of lake levels by as much as 150 cm and 100 cm on Lakes Michigan-Huron and Erie, respectively.

CONCLUSIONS

Great Lakes water levels have varied significantly over the past several thousand years and can be expected to vary considerably in the future. The current normals, as usually represented by the records from 1900 to 1969, may not be indicative of longer-period normals. The wet and cool climatic conditions that led to the recent record lake levels may be more indicative of longer-term normals than the conditions occurring earlier this century. This could be offset by climate warming, which would have the opposite effect on lake levels. It is, therefore, important that policy analysis consider a wide range in water levels rather than concentrating only on the high lake level conditions of the past two decades.

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PROVOCATEUR'S COMMENTS

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I'm a provocateur for Frank Quinn's paper, but there is no need to provoke Frank; I trust his data. We've worked together before, and the paper he has provided is something that can be used as a ready reference for understanding Great Lakes levels. What I wish to do is to provoke thoughts and ideas about our concept of normal and especially long-term normal into studies of Great Lakes levels. To begin, I will show a series of four slides that show variations in Great Lakes levels on several time scales. The first slide shows the 1860-1985 historic record of Lake Michigan and Lake Huron levels. The two horizontal lines on this chart are static average. The 1860-1985 average, 176.52 m (578.78 ft), is the upper of the two lines. The lower one, 176.38 m (578.28 ft), represents the 1900-1985 average level. The difference between them is 14 cm (about 6 in.).

If you follow the monthly bulletin of lake levels published by the Corps of Engineers to describe the variability of the current levels with respect to normal, you will find that "normal" begins in 1900. I was curious to see why the earlier record of higher levels prior to 1900 was not considered in the calculation. I know from reading various publications that in many cases the actual flow characteristics measured for the connecting channels between the lakes are not comparable before this time, and clearly man-made channel changes have since lowered the lakes. The reason for the choice of the year 1900 was more obscure. I began to telephone the various agencies to try to find a reason for the choice of 1900; I began with the International Joint Commission. I asked why 1900 had been chosen as the beginning point for the normal period and they replied that they weren't certain, but that the first time it was specified was in the plan of regulation for Lake Ontario in 1958. The plan called for the use of the historic lake level record and 1900 was chosen at that time (1956). It was used again for the plan of regulation for Lake Superior, this time using a record from 1900 to 1976. Average lake levels for both of these periods are both slightly lower than that shown here for 1900-1985. The IJC's answer didn't answer the question of why 1900 was chosen as the beginning of the historic record. After contacting both NOAA and the Corps of Engineers, the answer began to appear that 1900 was chosen because comparable Canadian lake level gage data did not go back as early as the American lake level gages. So, by convention, we chose 1900 to keep in concert with the Canadian gage data. In many cases, we tend to derive such criteria on an ad hoc basis in agreement with other governments or between ourselves as scientists. Often times the data set we choose becomes firmly planted in the minds of all of us in the society as "normal."

I want to move on to another slide; this is the 5,000-year record of lake level change in southern Lake Michigan, a study I have worked on for some years. This is the long-term record of fluctuating lake levels. The highest level shown to the left is at 183 m (600 ft), about 7 m above the present level. Over the past 2,000 to 3,000 years there have been a series of shorter-term fluctuations that are greater in magnitude than those of the historic record. For comparison, the historic record is the scriggly line on the right of the slide. These fluctuations are related to past climate changes in the Great Lakes basin. The highs are related to periods of apparent cooler temperatures and greater precipitation and the lows are warmer, more arid periods.

To zero in on the past 2,000-year record, the next slide shows a range of fluctuating levels on the order of 3 to 5 ft higher than the present. At the same time, the historic record of lake level change shown on the first slide fits neatly into the trough of the most recent low period. It appears that we settled the region during a period of climate change when temperatures were rising and lake level was falling. We began measuring lake level while the lakes were on the downward trend of a natural climate episode. When we view the historic and 2,000-year geologic record together on the final slide, we recognize that what we consider as normal may be consistently low in the geological sense and on a scale that minimizes the 27 cm (about 11 inches) of man-made lowering of Lake Michigan and Huron due to channel changes.

What I wish to provoke is reconsideration of our concept of normal. In the short term I would like to find a way for those of us in scientific and policy-making roles to splice these types of longer- and short-term records so that we don't entirely base our design criteria on a very short time period.

2
Impacts of Water Level Fluctuations

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INTRODUCTION

So intense and extensive are the effects of extreme water levels that four times in the past 25 years these effects have captured binational attention for extended periods. During the early 1970s and more recently in mid-1980s record high levels caused hundreds of millions of dollars in property damage and lost commerce. The cry went out to lower lake levels. During the early 1960s, low levels caused so much consternation that the whole basin was begging for rain. A violent, abrupt, and very short-term impact of extreme fluctuations achieved international notoriety when, on December 2, 1985, a seiche occurred on Lake Erie that resulted in a 16-ft water level difference between Toledo, Ohio, and Buffalo, New York. High water on the New York shoreline caused major flooding and damage.

There are almost 40 million people residing in the Great Lakes Basin (Environment Canada and U.S. Environmental Protection Agency, 1987), with projections of a million new residents each year (IGLLB, 1973c). Urban development along the United States shoreline accounts for between 15 percent (Lake Superior) and 58 percent (Lake Erie) of the shoreline (Monteith et al., 1978). This considered, it is little wonder that virtually every aspect of life in the Great Lakes Basin is either directly or indirectly affected by fluctuating water levels. If a riparian owner's house falls into the lake because of accelerated erosion from high levels, that person is directly, immediately, and severely affected. When a consumer buys a new car and the price is is higher because low lake levels have made shipping iron ore from Minnesota more expensive, the consumer is indirectly affected.

Much of what we know about lake level fluctuations and their effects has resulted from Canadian and United States government studies, and those government-sponsored studies coordinated by the International Joint Commission. Interestingly, all these studies have followed periods of extreme water levels on the lakes when basin residents have been acutely affected and have reacted with demands to alleviate the problem (Boyd, 1979). Consistent with this trend, the recent record high levels are being followed by another set of studies, "The Great Lakes Levels Reference" of 1986 to the International Joint Commission, for which the technical agencies from both Canada and the United States are being mobilized. This broad-based and deeply emotional reaction is a strong indication of the spectrum of effects and the diverse interests that are touched by lake level changes.

LAKE LEVEL FLUCTUATIONS

Water levels of the Great Lakes are constantly changing. Those who have studied this phenomenon have recognized four main categories of fluctuations (COE, 1979a): (1) short-period fluctuations caused by meteorological events that can last from a few hours to several days (e.g., storm surges and seiches); (2) seasonal fluctuations that reflect the annual hydrologic cycle from the summer high level to the winter low; (3) long-term fluctuations spanning several years, decades, or centuries that result from long-term precipitation trends or geologic events; and (4) fluctuations that result from artificial regulations of levels by control works at the outlets of Lakes Superior and Ontario. When severe spring and fall storms are superimposed on record high water levels, many impacts related to erosion, flooding, and navigation are greatly intensified.

Overall, fluctuations exert an impact primarily at the shoreline and in shallow-water areas. Most of these effects are difficult to measure, and they occur to most human activities and ecological processes in the coastal zone. Offshore effects are much less obvious and even more difficult to measure than shallow-water effects.

Impacts are both subtle and obvious. Shoreline erosion, occurring constantly, is hardly noticed in many places but is rapid in many others. The intensity of impacts is highly variable with season and location and on the affected object. Many factors, including shore physiography, offshore bathymetry, and the intensity of human development, influence the nature and extent of effects. The east shore of Lake Michigan, for example, is mainly erodible high bluff where erosion is the primary concern. The west shore of Lake Huron, however, is mostly low lake plain where flooding and storm surge are main concerns.

Fluctuations exert both adverse and beneficial impacts depending on the activity. High water is a generally desirable condition for power production and shipping, whereas it is a plague to shoreline dwellers when erosion and flooding become devastating.

Most impacts and effects are very difficult to quantify because of the size of the resource and complexity of interactions. We have a poor understanding of coastal processes, and we lack consistent methodologies for quantifying effects. It is relatively easy to calculate the gains or losses to cargo capacity of freighters, but it is nearly impossible to determine the loss of sport fish production when a marsh washes away.

Our collective perception of impacts, and the myriad institutional responses to them, are strongly influenced by those impacts that can be quantified and by those that have well-organized constituencies. The shipping, power production, and recreational boating interests were some of the first to advocate lake level regulation (i.e., control of lake level changes). Their interest is to preserve optimal depths for navigation and power production. Riparian owners have more recently become better organized. They have become highly vocal in their demands for lake level regulation (mostly for stable and low conditions) and for public subsidies that will allow them to sustain a life style on hazardous and unstable shorelines. Fish and wildlife and their natural habitats (e.g., coastal wetlands) have had few outspoken and organized advocates representing their needs.

It is our experience that, as a culture, we seem to have learned to accommodate "normal" seasonal fluctuations. We have difficulty, though, with extreme fluctuations such as may occur when long-term levels are high (as occurred in the early 1970s and mid-1980s) and when seasonal fluctuations are higher than anticipated (1985-1986).

Effects are acute and severe when, for example, "normal" storms occur during such a period.

A major difficulty in coping with effects is the limitation of our collective memory. Few people who suffered through the high water of the early 1970s recalled that the "crisis" was low water just a decade before. Many shoreline residents who successfully weathered the high water of the 1970s had dismantled their "protective" structures by the early 1980s and then were caught unprepared when the water rose again. Turnover of shoreline ownership and the crisis orientation of government institutions shorten our memory and make effective responses much more difficult. We apparently have a need periodically to flood out, erode away, or become stranded to remember the inevitability of high water and the consequences of forgetting.

IMPACTS OF LAKE LEVEL FLUCTUATIONS

The impacts of lake level changes all derive from three fundamental phenomena: flooding, erosion, and stranding. For this discussion, we consider stranding to occur whenever the depth of water is inadequate to allow an activity to proceed "normally" or in a desired manner. Impacts seldom occur from a single cause; they result from complex factors and circumstances.

For this discussion we have organized effects as they occur to (1) shore property, (2) fish and wildlife, (3) water quality, (4) recreation, (5) commercial navigation, and (6) power generation.

Impacts on Shore Property

Effects to shore property resulting from lake level fluctuations are those associated with (1) inundation from direct overland flooding, or wind-generated waves, or a combination of these; (2) erosion; and (3) stranding (GLBC, 1975). Inundation and erosion are more significant during high water, stranding during low water. Damage to shore property occurs during inundation or from wave impact and is confined to low-lying areas and to the lower reaches of tributary streams that are affected by backwater from high lake levels (IGLLB 1973b; EC/OMNR, 1975). Inundation occurs when still (static) lake levels are high and may also occur, or be aggravated by, storm surge and wave run-up (Yee and Cuthbert, 1985). Figure 2-1 shows those areas of the Great Lakes that are flood prone. In the state of

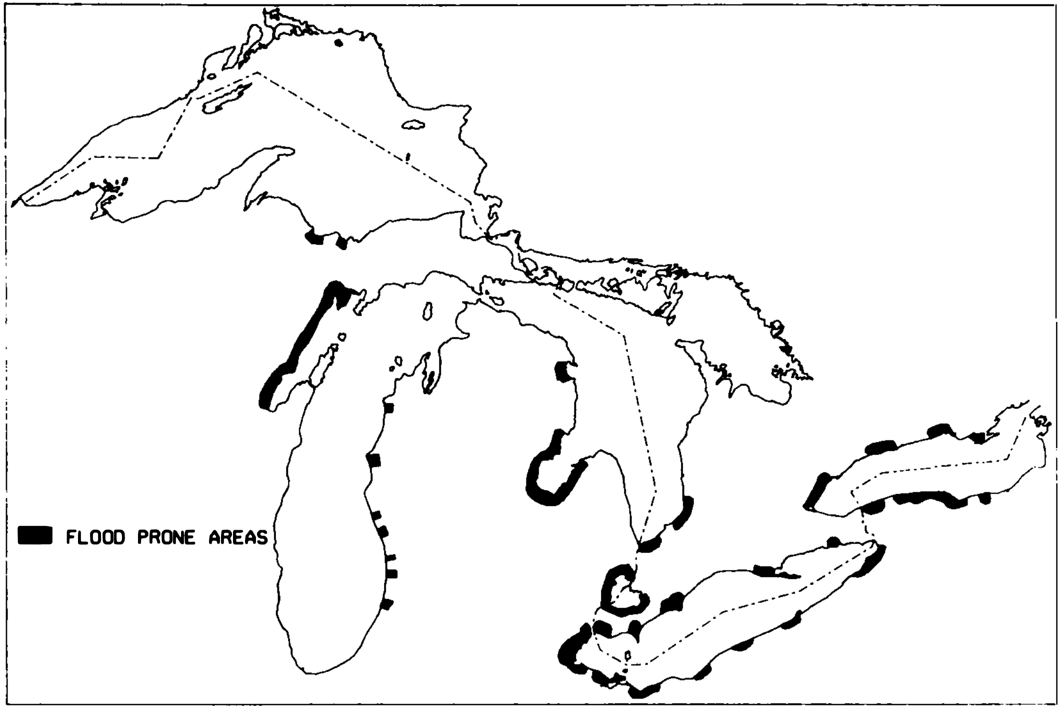

FIGURE 2-1 Flood prone areas of the Great Lakes shoreline (modified from COE, 1987).

Michigan, parts of over 30 counties, constituting approximately 10 percent of the state's Great Lakes shoreline, are subject to flooding by the Great Lakes (MDNR, 1974).

Erosion along the Great Lakes shore is a major concern. Of the 84,240 miles of shoreline in the United States, approximately 24 percent is classified as subject to "significant erosion," but of the Great Lakes' U.S. shore, 34 percent has that distinction (COE, 1971). Figure 2-2 illustrates Great Lakes erosion prone areas. Sixty-four percent of the state of Michigan shoreline is erodible and experiences land loss. Eleven percent is classified as "high-risk erosion area" because it erodes at a rate of 1 ft/yr or greater.

Erosion of the shore occurs at all lake levels. It is a continuous process that is accelerated significantly during high levels (ODNR, 1959; Berg and Collinson 1976). Low levels expose wider beaches providing a means to dissipate wave energy. High levels bring this energy into direct contact with the toe of bluffs and produce accelerated rates (ODNR 1959; DSCZMP, 1978).

Erosion is a complex process that, although accelerated by high water, results from many factors, including loss of bluff vegetation, occurrence of naturally erodible earth materials, starvation of littoral drift, and inadequate shore protection (Berg and Collinson, 1976). Erosion accelerates during high water and may continue for several years after lake levels retreat as bluff slopes come to equilibrium with the new condition.

Approximately 8.4 percent of the U.S. coastal area is plowed (Monteith et al., 1978). Much of this agricultural land is adversely affected by high water levels. Farmers abandon many unprotected fields during high water as they flood and become open water or revert to wetlands. Protection structures (dikes) are eroded and require maintenance during high water. Even fields with well-maintained dikes must be drained by pumping in order to bring crops to successful harvest. During low water, cultivation becomes practicable as fields dry out enough to support farm equipment.

Property damage from flooding and erosion is significant and is difficult to quantify and compare. During high lake levels between 1972 and 1976, COE (1979a) estimated that U.S. shoreline property damage totalled $231 million; damage to shore protection measures totalled $170 million (1973 dollars).

Coastal structures are adversely impacted by both extreme high and extreme low levels. Extreme low levels expose submerged substructures to air, which may result in deterioration and often restricts

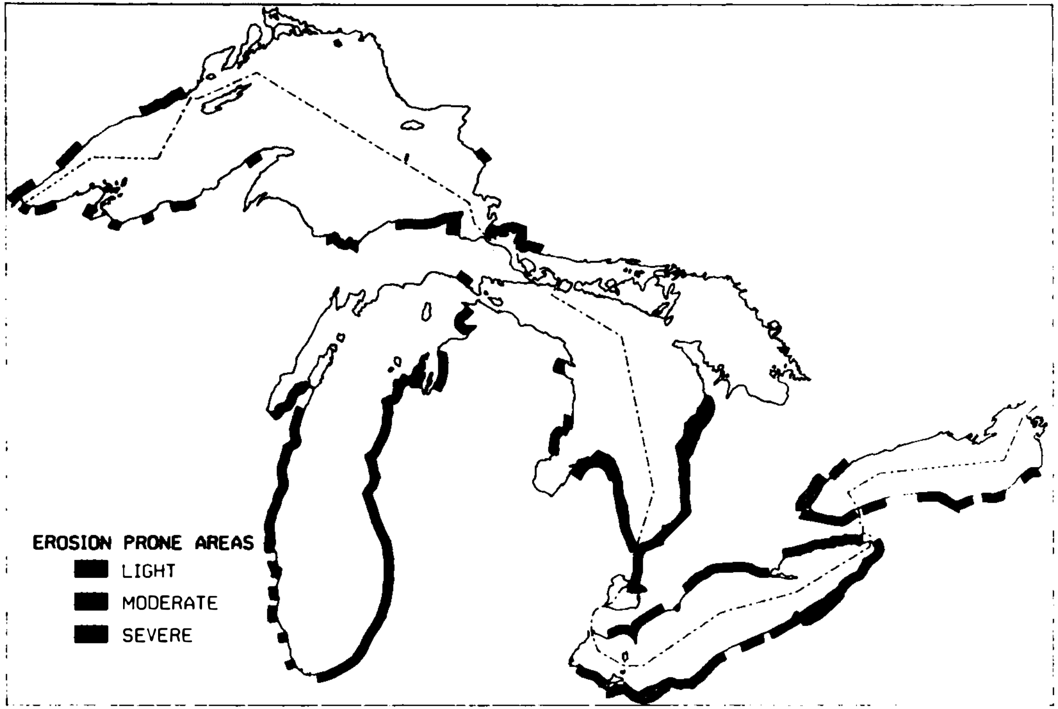

FIGURE 2-2 Erosion prone areas of the Great Lakes shoreline (modified from COE, 1987).

access to harbors and piers. Thomson (1964) notes that during the low levels of the early 1960s many small boat launch sites were unusable and many channels, boat slips, and fixed-height docks became unusable or marginally usable, with subsequent loss of commerce and recreational benefit. Shoreline moorings became unavailable during the 1960s and many boat owners were forced to anchor as far offshore as one-half mile.

Water intakes and wastewater discharges are impacted by both extreme high and low water. IGLLB (1973b) found that virtually all such structures were designed to accommodate the recent "average" seasonal range of fluctuations and experienced no loss of utility. However, during extreme levels, significant impairment occurred at some municipal and industrial facilities. Many facilities experienced some structural damage due to erosion and storm damage during high water. A survey of Canadian water intakes found that during low water, 15 percent experienced a head loss that diminished pumping capacity and increased costs and, although the intakes never ran out of water, reduced dilution and depth in the nearshore zone resulted in increased turbidity, with a general decline in water quality. In winter, fouling by frazil ice became more serious. At U.S. facilities, 32 percent of potable water intakes and 1 percent of industrial discharges experienced similar problems.

The impairment experienced from extreme levels in the last 30 years could be alleviated in the future if new structures are designed to accommodate wider ranges. The issue will remain important as reliance on Great Lakes water grows. For example, IGLDCUSB (1985) projected that by the year 2000, consumptive water uses in the basin would be double the 1975 estimate of 4,950 cfs.

In addition to impairments to coastal structures and facilities, we are becoming aware of another potentially serious situation posed by flooding. There are thousands of hazardous waste disposal, transfer, and storage sites in the Great Lakes Basin. Many of these were established decades ago, long before our awareness of the potential hazard of toxic materials. Many are located along the shoreline and may be in a zone subject to periodic or long-term inundation. We have recently become aware of the existence of these sites and do not fully understand the hazard that short- or long-term inundation may pose to area residents, surface and groundwater resources, or other cultural and natural resources.

Our ability to manage shoreline resources is being enhanced by new high-technology approaches to data management. The state of Michigan, and several other Great Lakes jurisdictions, are developing computerized geographical information systems (GISs) to map and catalog shoreline resources accurately. Figure 2-3 is a typical section of Saginaw Bay (Lake Huron) shoreline illustrating high-resolution nearshore bathymetry and the 100- and 500-year flood zones. With additional data such as land use (Figure 2-4) and critical habitats, we would be better able to evaluate the consequences of management scenarios.

Impacts on Fish and Wildlife

Perhaps the most significant characteristic of the Great Lakes is the abundance and diversity of living natural resources. The recreational opportunities presented by astounding physical beauty and pleasant climate are complemented by many forms of water-related sports that center around hunting and fishing. The necessity to protect, preserve, and wisely use this invaluable resource prompts concern for the impacts of changing water levels.

Our concern for the well-being of living resources stems from two main considerations: (1) the overall environmental quality of the Great Lakes is directly reflected in the status of living resources; and (2) we derive many of the benefits of the "Great Lakes life style" from them. Their absence would severely diminish our quality of life.

The shallow nearshore littoral zone of the lakes is extremely important to the maintenance of diverse and abundant fish and wildlife stocks because this zone, with its diverse habitats, is used extensively for reproduction, rearing, and resting. In fact, over half of the 117 species of fish known to inhabit the Great Lakes use marshes and wetlands as spawning and nursery sites (Manny, 1984) and most of these spawn in water 6 to 9 inches deep. Waterfowl, including many species that annually migrate through the Great Lakes, depend on the littoral zone for most or all of their life functions.

The shallow shoreline environment (beach, wetland, and tributary mouth) is very sensitive to changes in water level. A change of a few inches can inundate or dry out critical habitats and drastically alter the suitability of the area for use by shoreline fish and wildlife. The effects of water levels and their duration on Great Lakes fish stocks are as follows (IGLLB, 1973c):

Water Level Condition	*Effects*
High and stable	The most beneficial condition
High and unstable	Adverse or beneficial—site specific
Low and stable or unstable	Least beneficial

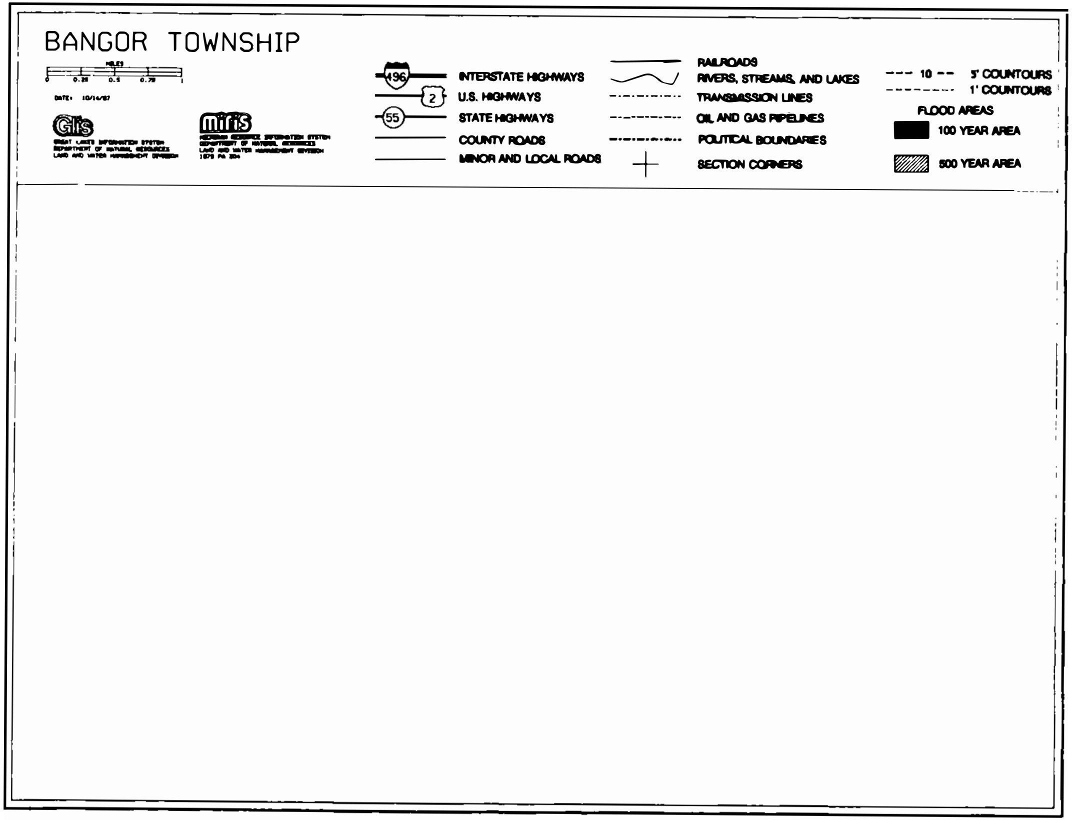

FIGURE 2-3 Great Lakes shoreline (Bangor Township, Saginaw Bay, Lake Huron). Produced from data in a computerised geographical information system.

FIGURE 2-4 Land use of the same area shown in Figure 2-3. Produced from data in a computerized geographical information system.

Generally, water level change has little or no effect on species inhabiting deeper open water but exerts great impact on shore zone species, since both the quality and quantity of habitat are greatly dependent on water levels.

Our understanding of the effects of fluctuations on coastal wetlands is incomplete. We know, however, that impacts are highly site specific and are both adverse and beneficial. High water benefits the productive condition of some wetlands and diminishes others depending on shore profile and antecedent conditions (Herdendorf et al., 1981; Jaworski and Raphael, 1978). Wetlands may be rejuvenated when periodic drying aerates soils and decaying vegetation replenishes nutrients (Harris and Marshall, 1963). The same low-water conditions may kill off some species and allow upland forms to migrate lakeward (Burton, 1985).

Examination of aerial photographs from periods of high and low water has indicated that coastal wetlands contract during periods of high water. Lyon and Drobney (1984) found that wetland complexes in the Straits of Mackinaw between Lakes Michigan and Huron were greatly reduced in size during high water. At the highest lake level examined, there was only 13 percent of the maximum wetlands and beaches available compared to the lowest lake level studied. Geis (undated) examined aerial photos of the Jefferson County, New York (Lake Ontario), shoreline from the high water period in 1973-1974 and found widespread dieback of emergent vegetation and a reduction in wetland acreage. Observations during subsequent low water in later years found variable recovery. Primary production recovered quickly, but plant species diversity was reduced from its original state.

It is certain that coastal wetlands, a critical component of the Great Lakes ecosystem, are disappearing and that fluctuating water levels are, among many other factors, a contributing cause. Jaworski and Raphael (1978) studied coastal wetland values in the state of Michigan's Great Lakes and found that wetlands were being lost at an accelerating rate. For the complexes studied, only 40 percent of the historical wetland remained, representing a loss of $45 million, with an estimated loss for fish, wildlife, and nonconsumptive recreation of $20 million.

Many undisturbed coastal wetlands have been observed to reconstitute when water levels decline following episodes of inundation and erosion (Geis, undated; Jaworski and Raphael, 1978; Williamson, 1979). The natural resiliency of wetlands seems to accommodate these cycles, and water level change appears necessary to maintain optimum productivity. However, cultural disturbances to the shore, such as bulkheading and shore protection, interfere with the natural cycle and limit the upland migration of wetlands during high water and, during low water, prevent the upland-to-wetland movement of replenishing materials.

Loss of coastal wetlands began in earnest in the late nineteenth century as coastal areas were "reclaimed" and drained for agricultural use during low water. Remaining lakeward fringe areas became inevitable casualties of flooding and erosion during high water. Barrier beaches were inadvertently destabilized by disturbances on the shore and eroded away, and the inner marshes became vulnerable to the open lake.

Impacts on Water Quality

At least three studies have concluded that changing water levels have little effect on water quality. COE (1979a), Sweeney et al. (1980), and IJC (1983) estimate that low water levels may result in decreased dilution capacity nearshore and in shallow embayments. Increased concentration of nutrients brings the potential for increases in the nuisance alga, Cladophora. However, these effects were estimated to be slight and short lived. The opposite effects were associated with high levels.

Impacts on Recreation

The effects of changing water levels on recreational values derive from most of the effects previously discussed. Recreational boating is adversely impacted by both high and low water when harbor, dockage, and access facilities are flooded, eroded, or stranded. Fishing and hunting, a major motivation for recreational boating, are dependent on robust fish and wildlife stocks. Extreme water levels certainly detract from aesthetic qualities when beaches erode and scenic overlooks fall into the lake. Beach availability and access are diminished with both extreme low and high water depending on the physiography of the beach. Armstrong et al. (1977), in a survey of shore recreation, found that over half of the people contacted regarded high water to have diminished the recreational opportunities of the shore. It is our experience that residents often adapt their recreational use of the beach to accommodate water level changes.

Impacts on Commercial Navigation

High lake levels are generally regarded as beneficial to navigation, low water as adverse. High levels accommodate deeper drafts from vessels in harbors and ports and through the connecting channels. This translates into heavier cargo and lower transportation costs. On larger vessels, an inch decrease in water level reduces capacity by 200 tons (IGLLB, 1973d).

Clearly, high levels (in moderation) are preferred by the shipping industry (Hirshfield, 1964), but this condition also has adverse effects. The Lake Carriers Association (LCA, 1986) points out that recent (1985-1986) high levels have required reduced vessel speed limits in the connecting channels and harbor areas to minimize wake and wash. Longer transit times somewhat offset the advantage of larger cargoes. Also, stronger currents in the channels pose additional hazards to navigation and high levels accelerate deterioration of navigation, aids and harbor facilities through increased erosion and storm damage.

Effects on Power Generation

IGLLB (1973e) found that, in general, higher lake levels are an advantage to hydroelectric power production because of greater hydraulic heads. Lower levels are a disadvantage. Within the design range of the facilities, increases in power production from increased levels are insignificant relative to total generating capacity. Even small production changes, though, are significant in absolute dollar amounts. Extreme high levels can significantly diminish production capacity if facilities flood or are damaged.

Steam electric generating facilities that depend on lake water for cooling and production are affected by changing lake levels in the same manner as marine facilities overall. As discussed earlier (see Effects on Shore Property), some facilities reported diminished capacities or tenuous operating conditions during extreme lake levels. In general, normal level changes are accommodated by the design of the plants.

SUMMARY

Lake level changes affect virtually every aspect of life in the Great Lakes. Vast amounts of time and resources have been invested in the commercial, residential, and recreational development of the

Great Lakes. Vast amounts are invested, perhaps unnecessarily, to maintain the style and standard of living afforded by this invaluable natural asset.

Our society seems to have accommodated "normal" seasonal lake level changes, but we seem to quickly forget the consequences of not planning for inevitable extreme levels. We need to recognize that extreme levels have, and will, occur and we must plan our activities and developments in consideration of these limitations. Several initiatives may assist us to become better prepared and may diminish the need for costly and marginally effective public works projects intended to regulate lake levels and eliminate extremes:

1. Engender a shore ethic that includes enlightened use of hazard-prone areas and nonstructural shoreline protection.
2. Relocate and redesign structures that are subjected to extreme levels.
3. Institute wetland protection and restoration programs, including long-term research on wetland processes, to ensure an abundance of living resources.
4. Develop enlightened harbor and channel maintenance dredging practices that consider preservation of critical wildlife habitats.
5. Develop a better understanding of physical processes such as erosion, littoral drift, and storm effects and develop better data on the physical characteristics of the nearshore zone. These data would be useful for designing, locating, and predicting the success of shore protection structures.
6. Perform environmental mapping of the shoreline and nearshore zone to include delineation of hazard-prone areas, critical habitats, and land use. Implement computerized geographical information systems to store and manipulate these data. This information would be useful for refining land use regulations that would discourage construction in hazard-prone areas or critical habitats.

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PROVOCATEUR'S COMMENTS

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I'm glad I learned this morning what a provocateur is; it's someone who is to provoke. However, considering I'm coming from a coastal estuarine environment and most of you in the room are from the Great Lakes, I know that if I provoke, I might be run out of town on a rail. So instead, I'll choose what I thought it meant, and that was to *say* something provocative.

When I read the paper that was presented, I made several observations. First, the impacts of sea level rise were quite comprehensively stated in the paper. Second, there were many similarities in dealing with the sea level rise problem that we faced with respect to the Chesapeake Bay, and the pollution in the bay. The groups and the affected interests were the same. What particularly interested me was the way in which those interests became involved in the issue of fluctuating water levels in the Great Lakes. In the paper it was clearly stated that recreational boating, transhipment, and power were in favor of high water levels. Other interests, namely the property owners, favored a low or stable water level. Then there were several groups that I would call the "silent interests," those being the fish and wildlife interests who appeared to be trying to contend with the water level situation early on but did not vocalize their concerns. Also of interest was the way in which group involvement or interest varied, almost as much as the fluctuation of the water level itself. Transhipment, power, and recreational boating appeared to be the first vocal interests expressing concern with water level rise in the Great Lakes. Then the property owners entered the picture and became a little bit more organized. The fish and wildlife interests were almost nonvocal again, and it disturbed me to read that these interests were not all that actively involved in the beginning, although I understand that they eventually did get involved.

In reading the paper, I was also led to ask a number of questions,

questions that all of you in this room have asked at one time or another. For whom will the lakes be managed? Do we emphasize power and transhipment, because we have the economic basis upon which funds could be expended in "resolving" the problem? Do we emphasize riparian ownership, and the property owner's right to use the water no matter what happens? Do we manage for the environment—for the fish and wildlife habitat?

I reviewed the six summary statements made in the paper discussing the types of initiatives that are needed to gain a better understanding of how to "manage" lake fluctuation and was trying to figure out who or what interests were the beneficiaries of this "management." Should we undertake at once all of the initiatives, these being shoreline ethics, nonstructural shore erosion protection, relocation and redesign of structures, wetland protection, and restoration? Are we really going to understand anything to any greater degree as a result? Or is there a need to focus on specific initiatives and direct the initiatives toward specific interests? The paper posed no answer to these questions.

While the paper seemed to support a comprehensive approach involving all of the interests (e.g., transhipment, recreational boating, property owners, and wildlife and waterfowl groups) through the six initiatives, I noted that there was a lack of looking to the future. What would need to happen next, if trade-offs must be made as a result of these initiatives? In other words, what are we going to do if we have to forfeit habitat for, say, structural protection for the property owner? I do know that the experience on the Chesapeake Bay has been this: we have had to redirect our data gathering to the resources themselves (e.g., fish and shellfish), counting on positive spinoffs to occur for other interests who use the bay. We have also had to look at the demand to live and locate along the water because that has a significant impact on those resources. I would suggest that management for the resources be the focus for the Great Lakes initiatives. I would also suggest that population pressure and the demand to live near the water be factored into the investigation. Both recommendations may help in the implementation of a better plan or program for management, because I'm not completely sure that in the long run, you will be able to attain the results you want with the information you intend to develop.

3
Strategies for the Future Development of Great Lakes Shorelines

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INTRODUCTION

Great Lake's coastlines were subjected to record-high lake levels in 1985 and 1986, just 10 years after experiencing previous record high levels for this century. The negative impacts of these record levels were manifested in coastal recession, coastal erosion, coastal flooding, and structural failure.

Interestingly, economic and sociologic trends during the latter portion of this century have also created an increasing pressure on Great Lakes coastlines. By the early 1970s (period of first record high lake level for the century) the United States coastal population had grown to a point where 50 percent lived in a county bordering on the Atlantic, Pacific, Gulf of Mexico, or Great Lakes. Presently, that percentage of population living in first-tier coastal counties has grown to over 60 percent and is projected to exceed 85 percent by the end of this century.

The second largest coastal population and the largest manufacturing concentration in the United States are present along the shores of the Great Lakes. This population and its commerce have created a coastal situation that is characterized by areas of highly concentrated urbanized coastline separated by extensive lengths of rural shore. Commerce at the coast demands ports, harbors, and significant engineering structural works, while rural shores connote "natural" unaltered beaches, dunes, and wetlands. Urbanization of Great Lakes coasts produces needs for fresh water for industrial and consumptive use, while rural water needs tend to be more recreational and less stressful in the environment. Urbanization creates demands for removal and dispersion of wastes, which all too often find their way into the dynamic coastal zone of the Great Lakes and subsequently to the rural shore downdrift.

Physical descriptions of the Great Lakes coastlines tend to focus on terms such as high or low bluff, erodible or nonerodible bluff, high or low sand dunes, erodible or nonerodible low plain, and wetlands (Hands, 1979; Great Lakes Basin Commission, 1975). Less familiar to these descriptions are terms like high or low seawall, extensive groin structures, fully armored shoreline, and impacting harbor structures. Emphasis tends to be placed on natural shorelines, most often with the total exclusion of engineered shorelines. However, the need for recognition and understanding of engineered urban shorelines is urgent, especially given the aforementioned coastal population growth expected to the end of this century.

Engineered urban shorelines are not a new concept, nor should they be viewed as a coming Armageddon at the coast. Admittedly, the outcome of many previous urban shoreline developments is appalling and disquieting to a perception of environmental compatibility.

As poignantly expressed by Wesley Marx (1967) in *Waterfront: The Clear Reflection in the Frail Ocean*:

> In Chicago I reached that rewarding stage in boyhood in which I could swim over by head. And so I would slip out of the hot summer and into Lake Michigan at will, lolling beyond the slight surf line, hearing the muted chatter of picnickers, gasing at ore-barges on one horison and, on the other, the skyscrapers, the bold index fingers of wealth. It seemed quite natural that picnickers, ore barges, Sunday fisherman, and boys that swam out over their heads could coexist on a city waterfront.
>
> Only after leaving Chicago did I discover that the common urban waterfront is hardly approachable, much less swimmable, encrusted with wharves, switching yards, sewage outfalls, and other industrial barnacles. It is the true civic outcast, the ghetto of ghettos, familiar only to longshoremen, sanitary engineers, and carp.

Compounding the problems of many urban waterfronts is infrastructure deterioration. Engineering works constructed along the shorelines have yielded to the forces of waves, currents, and corrosion.

Harbors and channels have physically degenerated to a state where they no longer meet the demands of commercial industry and shipping. In places where commerce has failed, these structures remain as a rotting coastal rind. In places where commerce thrives, these problems pose with enormous rehabilitation costs. The recent Chicago Shoreline Protection Commission report on Preliminary Protection Options and Alternatives (1987) estimates a basic rehabilitation cost for Chicago's waterfront in excess of $500 million. Clearly, coastal urbanization demands and costs place inordinate responsibility on decision-making bodies to develop comprehensive strategies for the future development of Great Lakes shorelines. Concurrent with this urban coastal development is the need to develop greater responsibility in management of rural Great Lakes shorelines.

CONCEPTS AND MISCONCEPTIONS

To design strategies for wise development of shorelines, it is imperative to understand shoreline processes and their responses to natural forces or engineering alternatives. Of the many concepts related to the shoreline process/response system, three important ones are frequently misunderstood. These three concepts are the central focus of the following sections.

1. *Great Lakes shorelines are not the "edge of a soup bowl."* During periods of rising lake level, there is a popular misconception that falling lake levels will result in an exposure of beach equivalent to that which existed before lake level rise. This "edge of a soup bowl" analogy leads to the idea that just as a creamy soup covers from view the bowl's edge, draining that soup will reveal the edge in its original form. Nature has a contrary idea. Figure 3-1 shows the spatial shoreline change associated with rising lake level. The spatial loss of shoreline, which is analogous to the soup bowl edge, is labeled encroachment. However, wave and current activity, translated shoreward by elevated lake levels, results in net loss from the profile, indicated by the region of recession (Figure 3-1). The summation of these two effects is the coastal retreat to which most coastal landholders react.

It is important to recognize the quantitative difference between recession and encroachment in order to appreciate why the soup bowl concept fails. Hands (1979) and Wood and Davis (1986) showed that recession exceeded encroachment by a factor of 4. Hands (1979) also showed that the average gain of profile after lake level fall was about

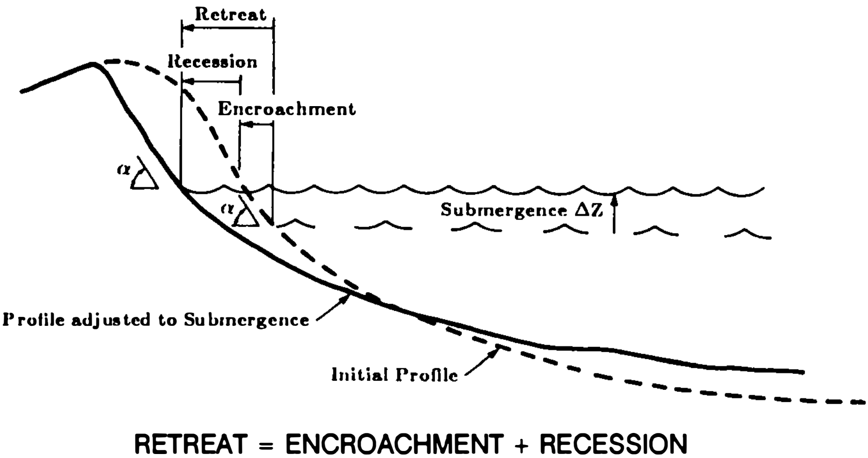

FIGURE 3-1 Schematic of spatial shoreline change in response to rising lake level. SOURCE: Wood and Davis, 1986.

20 percent of the original profile. Recognition of this concept of irreversible coastal retreat on time scales of tens of years is critical to formulation of strategies for shoreline development.

2. *"Rising" lake levels are not the only periods of shoreline recession.* Another misconception concerning both shoreline retreat and engineering structure performance is that falling lake levels directly correlate with periods of shoreline and structural stability. The problem with this idea is that on Great Lakes coastlines where mean water level fluctuations are of the order of tens of centimeters to more than 1 m in just a few years, equilibrium beach profile conditions are difficult to achieve. Consequently, recession will continue to occur even on falling or lower average lake levels. This point is well supported by Hands' (1979) finding that the mean rate of shoreline recession at Pentwater, Michigan, from 1919 to 1969 was 0.3 m/yr, while the actual lake level in 1969 was 0.5 m lower than in 1919. Conversely, Hands (1979) found that the mean rate of recession from 1967 to 1976 was 0.25 m/yr at that same location, while lake level rise was more than 1 m. Similar results were obtained by Wood and Davis (1986) for the Indiana coastline. It is important to note that this paradox in the relation of rising and falling lake levels to mean rates or recession is exaggerated in the areas where harbors and jettied inlets occur at the shore.

3. *Harbor and inlet impact may exceed lake level rise impact.* A great deal of broad public attention is directed toward shoreline recession in response to lake level rise. Likewise, in areas where harbor and jettied inlets occur, local attention is given to shoreline impacts due to updrift sand trapping and downdrift sand starving. What has not been widely recognized, until recently, is that the magnitude of total shoreline impact due to harbors and jettied inlets may well exceed that of natural recession resulting from lake level change. Figure 3-2 shows a dramatic example of a jettied inlet and harbor impact on the downdrift community of Ogden Dunes, Indiana. Net shoreline recession immediately downdrift from this structure (first 0.5 km) exceeds the total recession of the continuing 9 km of adjacent shoreline. This concept of extreme local recession impact exceeding net lake level or "background" recession on the Great Lakes is important to strategies of development for urban versus rural shorelines.

STRATEGIES FOR SHORELINE DEVELOPMENT

In this attempt to identify strategies for the future development of Great Lakes shorelines, a clear distinction will be made between strategies for urban/industrialized and rural shorelines. Some strategies are common to shore elements with both types of shorelines. However, the underlying philosophy upon which this division is made assumes that certain finite lengths of shoreline must be engineered to meet the demands of our coastal population. Equally as strong in this philosophy is the assumption that most of the Great Lakes coasts should be left in, or returned to, a natural state.

Shoreline Ownership, Use, and Access

Perhaps the most difficult task in the process of establishing policy for the shoreline is defining ownership at the water's edge. The classic idea of fixed property boundaries needs to be abandoned in favor of a "natural" dynamic mobile boundary concept. This concept requires two ownership constraints. First, no action may be taken to anchor or harden a shore along the extensive lengths of rural Great Lakes coastlines. Second, no building may take place lakeward of a fluctuating line defined as the distance landward from highest high water, determined by the product of background erosion rate and anticipated lifetime of the building plus 50 percent of that distance to

FIGURE 3-2 Burns/Portage Waterway entrance (a) in 1967, (b) in 1969, and (c) in 1982. SOURCE: Wood and Davis, 1986.

allow for storm erosion effects. The position of this "coastal construction control" line should be reestablished by appropriate authorities every five years. Some Great Lakes states already have established regulations to deal with this second constraint, but none has set policy to address the first. This concept of maintaining a "natural" dynamic coastal boundary is well supported by contemporary knowledge of ocean coastal dynamics and engineering. This concept is also applicable to all but the finite lengths of urban/industrialized coastlines.

Use of the shoreline should be based on an assessment of natural coastal hazard in the longshore and cross-shore directions. This concept of natural coastal hazard is predicated on the assumption that evaluation of coastal geomorphology, hydrodynamics, and environmental setting will result in a reasonable determination of the risk associated with human use alternatives. Longshore coastal hazard would be determined from factors such as dune and bluff height, beach composition, beach width, and vegetation coverage. Cross-shore coastal hazard would be determined from factors such as bottom slope, bottom composition, breaker location, and longshore current profiles. Applying multidimensional analysis to a matrix of these coastal factors, differentially weighted by their relative importance in the coastal setting, would provide a quantified value of coastal hazard. Those lengths of coast evaluated to be at highest risk should be set aside as parks and natural areas. Those at lowest risk could be, if necessary, apportioned to new urban development.

Access to the coast should be unlimited except in those areas where human intervention has resulted in an unuseable shoreline. Highly industrialized areas, hazardous landfills, and heavily constructed shores are generally unsafe and usually undesirable lengths of coast. Use of other lengths of coast should be facilitated by providing reasonable access to the shore regardless of ownership.

Development of Urban and Rural Coasts

Urban/industrialized development has in many areas exceeded the bearing strength of the coast. Most of these areas evolved from a series of uncoordinated local coastal uses expanding to form the harsh reality of our urban/industrialized coast. Held in industrial bondage, these coastlines are stained with industries' excretions. Transportation shreds coastal wetlands, real estate distorts and buries the shoreline, (and the buried shoreline accommodates industries that use the abundant lake waters).

An urban coastal blight set upon or protected by a deteriorating infrastructure characterizes most of the Great Lakes urban shorelines. Future problems related to Great Lakes levels are climatological in time scale and regional in spatial scale. This combination of factors provides a ready opportunity to evolve regionally based master development or redevelopment plans for urban coasts. Landfills, waste disposal sites, and industrial storage at the coast should no longer be incorporated in development strategies. More creative use of hard and soft coastal engineering alternatives must be applied to rehabilitation of urban/industrial coasts. Let the vision of Daniel Hudson Burnham infuse all urban coastal development strategies for the future so that all of Chicago's sister cities share her "clear reflection."

Rural development has, in all too many areas, also exceeded the bearing strength of the coast. However, this perspective of the rural shore is seldom recognized. Instead the rural shore is viewed as a durable resource that may be used in a manner prescribed by its owner. Objects from substantial engineering structures to broken pavement, chained tires, and auto bodies punctuate the otherwise pristine shore. Until recently, very little regulatory attention was paid to these "fixes" at the shoreline, and when they failed no one cared about the stench of their "rotting" remains.

The past two decades of rising lake levels have perhaps created an atmosphere for change in strategies for coastal use and development. Frustration to financial ruin have confronted the coastal landowner as "fix" upon "fix" was built and then felled by the energy of lake storms brought shoreward by rising lake level. The so-called "New Jerseyization" of Great Lakes shores had become a recurring strategy for coastal development. Unfortunately, there were almost as many homes lying atop or scattered throughout coastal protection structures as standing behind them. Hopefully, this experience of two decades of high and rising lake levels has convinced landowners of the futility of trying to halt coastal recession or wall off the advancing lake. Such recognition may lead to acceptance of the concept of a mobile coastal boundary. Rural shorelines should be left to wander as they have for centuries, free of human influence. Native Americans had the good sense to remain mobile when they settled by the lake, moving their communities in response to the changing lake levels. Contemporary Americans could benefit from developmental strategies predicated on that old philosophy. The coast is by nature dynamic, and human intervention will not alter that truth. Future development strategies should encourage isolated coastal construction where it is necessary to facilitate recreational boating or similar uses. However, the remaining coastline should be left to vary with the "waves of time."

SUMMARY AND CONCLUSION

It is difficult to predict the trend in Great Lakes levels that will persist into the decade of the 1990s. Even more difficult to predict is the trend in local, state, and regional policy related to lake level effects at the shore. In the past these two dilemmas of prediction have been interrelated by the argument that policy cannot be set in a context of lake level impact if in fact lake level cannot be well predicted. This argument is badly flawed because shoreline policy decision need not be predicated on relative lake level.

Three major concepts presented earlier in this paper help to explain why this policy argument is incorrect. First, high lake levels are not the only period of shoreline impact. Serious recession and erosion occur at all lake levels. Second, the coastal beaches are not simply covered with water during high lake levels such that low levels will result in their emergence and in subsequent restoration of the shore. As much as 80 percent of their original profile is gone, with approximately 20 percent recovery anticipated during typical low lake level periods. Third, harbor and jettied inlets, constructed at any lake level, may create a coastal impact due to erosion and deposition effects that will exceed the impact of high lake level.

Strategies for the future development of Great Lakes shorelines can and should be established independent of lake level trends. Development of these strategies should be predicated on the idea of maintaining extensive lengths of unconstructed natural shore punctuated with limited urban/industrial areas of heavily engineered shores. A quantified system of coastal hazard classification should be established for use in determining appropriate areas for new urban coastal development necessitated by population trends.

Most important to the success of these or any other strategies for future shoreline development of the Great Lakes is the recognition that policy must be coordinated at the regional level. The basis for this contention is that any problems related to climatic scenarios are by definition a regional problem. The broad economic advantages and disadvantages created by climatic extremes, reflected in lake level, preclude local policy solutions. Until this type of policy development is adopted, local solutions will be hard to achieve and often ineffectual in ameliorating negative impacts and losses.

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PROVOCATEUR'S COMMENTS

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In responding to this paper, I would like to remind you that I'm a member of a faculty of environmental studies in a university that probably has 45 percent of its faculty in engineering. When I received this paper and realized it was by an engineer, I walked across the campus and talked to colleagues in civil engineering. I asked them to review it to assure me that it was "good" engineering, and they did. That was great because that made me believe that I could focus on other aspects about which I felt more knowledgeable.

As I read the paper, six points stood out for me, particularly with regard to the idea of strategies for the future development of Great Lakes shorelines. First, the strategies that Bill was advocating seem to focus on understanding shoreline processes and the responses to natural physical processes through engineering alternatives. Second, it is necessary to distinguish between urban/industrialized and rural uses of shorelines. Third, there's a belief that some shoreline segments should be engineered and others should be left in or returned to their natural state. Fourth, and I agree with this, there's a belief that strategies can and should be established independently of lake level trends. Fifth, ownership at the water's edge must be established. And sixth, policy must be coordinated at the regional level. I would just like to comment on a couple of these ideas.

I would like to suggest that the statement that perhaps the most difficult task is defining ownership at the water's edge should be modified a little bit. I really think we have to make a distinction between "ownership" and responsibility for "control," "management," or "regulation." If I own an automobile, I have ownership of it, but I accept regulations when I go out on the highway. It seems to me that the most difficult problem is therefore not ownership but rather control or regulation. In many instances the individual owners will have specific and valid perspectives that aren't necessarily in the collective interest. Therefore, I do believe that the public agencies have a role and responsibility regarding control. We have to recognize that situation. Of course, the problem is that it is very difficult to determine who has the responsibility for regulatory control. This is an aspect that could be considered a little bit more.

Secondly, I was interested that not very much was said in Bill's paper about the cost of alternative strategies. It seems to me that if we're talking about strategies for the future development on Great Lakes shorelines, it is important to know the cost and cost effectiveness of alternative strategies. And not just the cost is important. We also need to know who will, should, or could pay because obviously that is where a lot of sensitivity emerges. Will it be the individuals or the communities or the states and provinces or the federal government? If cost information is not provided, then even if a broad range of alternatives is identified, they are not easily differentiated in terms of relative priority without cost information. Clearly, cost is just one consideration, but it is very important.

A third point made in the paper was that policy must be coordinated at the regional level. I agree completely with that. I think it is probably one of the most fundamental issues addressed in the paper. However, no indication is given as to how such coordination is to be achieved. Again and again at meetings one hears that we must do a better job of coordinating, but we don't seem to be hearing very much as to how this is to be done. It seems to me that we should be focusing on this as we look ahead.

Just to assert the need for coordination doesn't take us very far. I look at the Great Lakes and see so many stakeholders and so much vertical and horizontal fragmentation. As a result, I wonder if perhaps the institutional aspects or the institutional arrangements are one of the major barriers we have. I know that some of the papers later today address that. At the same time, it seems to me that we could take too much time in trying to design the perfect institutional structure because what we are really talking about is how to overcome "boundary" or "edge" effects. In other words, the reality is that we do have many legitimate participants and stakeholders and we have a lot of legitimate public agencies with an interest in shoreline development.

A debate as to whether we should move towards a single, larger, comprehensive, multifunction management agency (which internalizes the boundary problems) or towards a greater number of smaller, more specialized or focused agencies (which sharpens the boundary problems among agencies) is a bit sterile. The reality is that boundary or edge effects will always exist. I think we have to get smart enough to make a management approach work, recognizing that those edge effects are always going to be there. We're never going to eliminate them altogether, and there's not one perfect organizational or institutional approach. Each alternative we put forward will have strengths and weaknesses, and ultimately we'll just have to move forward.

The last comment I would make relates to what we really mean by the term "strategy." Without being too academic about it, this could be more sharply defined. Bill's paper suggests that engineering considerations are important, and of course they are. But there are other dimensions. I very much like Gilbert White's idea of multiple means, and multiple participants. I think that his idea is captured in some of the papers that come later, which deal with the private sector.

In that regard, I have one reservation about trying to broaden out the strategy (which I think most of us would endorse) by using structural and nonstructural measures together and using a comprehensive approach. My worry involves the attempt to pursue a "comprehensive" approach. In Canada whenever we have tried to take a comprehensive approach, there often has been disappointment and frustration because the planning exercise has taken considerably longer than people thought was reasonable. By being comprehensive and trying to look at a huge range of things, we lost a sharp focus. As a result, at the end of the exercise, the product, the planning document, has not been very useful. I think that somehow it is necessary to look in a comprehensive way but then perhaps to try to be more focused and think in terms of an "integrated" approach. You can integrate two things, or three things, or four things. You can integrate without having to be comprehensive. If the key is to consider the interrelationships of different aspects of shoreline development along the Great Lakes, we can do this in an integrated way without being comprehensive. If we talk, as was suggested last night, about a comprehensive approach, we almost overwhelm ourselves with the complexity with which we are dealing. We can too easily go into a big black hole and never come out of it. It is this concern that worries me about an unqualified commitment to a "comprehensive" approach. Have people really thought through what it means, or alternative ways in which that approach can be defined?

4
Policy Conflicts in the Management of Retreating Shorelines

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INTRODUCTION

Beach communities of the East Coast of the United States have had much experience with costal erosion problems. Beginning with the establishment of the Cape May, New Jersey, resort in the late 1700s, the pattern of oceanfront development along the Western North Atlantic Ocean has been one that hugs the receding shoreline. Where development has crowded the shoreline for a long time, there is, almost without exception, an erosion problem. Where development does not exist, as on our national seashores and on a few uninhabited barrier islands, there is rarely an erosion problem even though the shoreline is retreating just as rapidly as on the developed shorelines.

This difference in our perceptions of shoreline retreat on developed and undeveloped islands illustrates a very important principle. The principle states that *shoreline erosion is entirely a man-made problem*. Putting it another way: *there is no erosion problem until man puts something "permanent" in the way of the moving shoreline.* Such structures serve as convenient markers by which to measure shoreline movement and are the catalysts that transform a heretofore benign natural process into an alarming natural threat.

In this and most other respects the shoreline erosion problems of the Great Lakes and the U.S. East Coast differ very little. As a result, the coastal managers of Great Lakes shorelines can learn much from the experiences of their oceanic counterparts, and vice versa. That exchange is the purpose of this paper: to explore and recount various science and policy aspects of the East Coast shoreline management experience, with the hope of applying those lessons to the Great Lakes problem.

WHAT'S THE DIFFERENCE BETWEEN A LAKE AND AN OCEAN?

When viewed in the short term of single storm events or seasonal responses of beaches, there are significant but not fundamental differences in salt and freshwater shorelines. Lunar tides in the oceans are one obvious and important difference. Some of the differences in the evolution of tideless and tidal beaches were discussed long ago in the classic paper by Fox and Davis (1976). In addition, average wave energy, which is proportional to wave height, is generally higher on open ocean shorelines, but storm waves can attain impressive energy levels on lake shorelines, especially on reaches with significant fetch.

Thus, to a certain extent, lessons learned in shoreline management can be transferred both ways. For example, shoreline erosion problems exist in both ocean and lake systems, and buildings stand in the way of shoreline erosion along both our Great Lakes and oceanic shorelines. Beaches respond in similar fashion to storms and water level changes, and the fundamental principles of surf zone sand transport apply to both cases.

In all considerations of shoreline processes, however, it is important to distinguish between the various shoreline types. Processes that prevail on a sandy beach (lake or ocean) may be quite different from those that are important on a bluffed shoreline (whether the bluff is along a lake or ocean shore). Similarly, principles of shoreline management that work along one type of shoreline may not work elsewhere.

On a longer time scale, on the order of years or decades, the differences between lake and ocean shorelines become much more important. These differences are especially pertinent to coastal management considerations. For example, along the Great Lakes, awareness of the shoreline erosion problem and public pressure for action to solve the problem come and go with the rise and fall of the lakes. Heated rhetoric aside, lake levels are basically due to precipitation within the lake drainage basins (Carter et al., 1987). Periods of high rainfall produce periods of high lake levels; periods of low rainfall produce periods of low lake levels.

On the other hand, problems on the oceanic shoreline never go away. There, the sea level slowly rises at a rate of about 1 ft per century along the Gulf and Atlantic coasts. The level of the ocean, in the short-future geologic time frame of importance to mankind, will apparently be controlled by the melting of Antarctic ice. This is in response to an atmospheric warming caused by man's consumption of oil and coal and the consequent introduction of excess carbon dioxide (CO_2) into the atmosphere. This process of atmospheric warming is part of the much-publicized "greenhouse effect." According to the scenarios produced by the U.S. Environmental Protection Agency, (Barth and Titus, 1984), the most likely sea level rise scenario is 4 to 7 ft above the present level by the year 2100. This 100-year rise in ocean level, which is expected to cause incalculable damage on our heavily developed and gently sloping barrier island shorelines, is of the order of magnitude of the single most recent cycle of Great Lakes fluctuation!

THE NEW JERSEY STORY

New Jersey is America's oldest developed shoreline. As a result, there are many lessons to be learned from the relatively long-term experience in shoreline management there. These lessons have great application to the Great Lakes shorelines.

The first shoreline resort advertisement in the United States is believed to have emanated from Cape May, New Jersey (Kaufman and Pilkey, 1983). It was published in the Philadelphia *Daily Aurora* in 1801. The advertisement went like this:

> The subscriber has prepared himself for entertaining company who use sea bathing, and he is accommodated with extensive house-room, with fish, oyster, crabs and good liquors. Care will be taken of gentlemen's horses. Carriages may be driven along the margin of the ocean for miles, and the wheels will scarcely make an impression upon the sand. The slope of the shore is so regular that persons may wade a great distance. It is the most delightful spot that the citizens may retire to in the hot season.

Even assuming that some liberties were taken by the enthusiastic ad copy writer, the contrast between this early description and the present situation is extreme. Now, *no* beach fronts the city of Cape May; instead, there is only a massive rock seawall upon which the

FIGURE 4-1 "New Jerseyization."

waves directly break, even at low tide. The community's original raison d'être no longer exists. The seawall, a form of hard stabilization, has resulted in fixing the shoreline in one place, which is most desirable from the standpoint of protection of the buildings hugging the shoreline. However, from the standpoint of preservation of the recreational shore, construction of a fixed wall is most undesirable, since walls ultimately destroy beaches in the long run. The endpoint of hard stabilization frequently is called "New Jerseyization" (Figure 4-1) in recognition of the many miles of walled, beachless shoreline in New Jersey. New Jersey went there first, and the rest of the nation need not make the same mistakes.

Sea Bright, New Jersey, is considered by some to represent an endpoint in the process of New Jerseyization. The community is small, occupying an area of about 1 square mile on the spit of land connecting the mainland community of Monmouth Beach with Sandy Hook. Sea Bright is frequently flooded by bay waters from the back side. The seaward side of the island is a large, continuous, 17-ft-high seawall facing the ocean.

In March of 1984, a severe northeasterly storm struck Sea Bright. The community received minor flood damage from waters lapping into the community, and the wall was breached in a couple of places. Overall, damage to buildings was slight. As reported in the *New York Times*, the community assessed its total damage at $82 million, which was slightly higher than the assessed total value of all buildings in town. The damage was said to involve mainly the "seawall and beaches."

Obviously, when a community reaches the stage where damage from a single storm does more damage than the town is worth—without substantially damaging the town proper—some major decisions are in the offing. Is continued maintenance of the seawall justified, especially if most of the funds to do so will be from governmental levels other than the local community? Has the time come to gradually abandon or relocate Sea Bright?

The Sea Bright story is not without application to Great Lakes shorelines. For example, during the recent high lake levels, a number of property owners on every one of the lakes and on both sides of the U.S.-Canadian border found that the cost of stabilization structures adequate to provide long-term protection for their houses approached the cost of their homes. Are such expenditures worthwhile? Do better alternatives exist?

MANAGEMENT ALTERNATIVES

The New Jersey experience showed us long ago that a community with an eroding shoreline has three basic alternative management approaches. These options are (1) hard stabilization, (2) soft stabilization, and (3) relocation.

Hard Stabilization

Hard stabilization refers to the emplacement of "permanent" structures designed to halt shoreline retreat. Structures built parallel to the shoreline include seawalls, revetments, and bulkheads. These structures are designed to halt shoreline erosion by providing a fixed line of defense against which storm waves will occasionally impact. A secondary role of many of these structures is to "shore up" and hold back beach bluffs or dunes.

Advantages of a seawall, one form of hard stabilization:

1. Protects property by reducing erosion.
2. Increases stability of landward slope.

Disadvantages of a seawall:

1. Increases rate of erosion in front of wall.
2. Increases rate of erosion of adjacent beaches.
3. Limits access to beach.
4. Reduces the aesthetic value of the shoreline.
5. Is costly and requires periodic maintenance.

Advantages of a groin, another form of hard stabilization:

1. Reduces erosion of beach updraft of the structure.

Disadvantages of a groin:

1. Causes downdrift erosion.
2. Reduces aesthetic value.
3. Appropriate only in selected oceanographic situations (i.e., areas of high supply).

Advantages of a breakwater, another form of hard stabilization:

1. Builds up beach behind structure.

Disadvantages of a breakwater:

1-3. Same as for groins.

Hard stabilization is generally the most widely used approach to stabilization in all of the Great Lakes (Figure 4-2). As mentioned, however, seawalls can have significant environmental impact (Walton and Sensabaugh, 1983). As a direct result of the use of this environmentally insensitive approach, many miles of beach have been degraded or lost along Great Lakes shores. Beach destruction has occurred as a result of (1) sand loss due to the interaction of seawalls and storm waves and (2) beach use loss due to the piles of rubble scattered about after destruction of pre-existing walls. A fundamental problem in this respect is that along much of the Great Lakes shoreline, construction of walls or other structures capable of lasting more than a large storm or two is generally within the financial reach of a community, but not within the reach of individual homeowners.

Another interesting aspect of the hard stabilization approach is the abundance of entrepreneurial erosion "solutions." As a result of the high lake levels, a large number of "one-device" shoreline engineering companies have sprung up, which operate almost exclusively in the Great Lakes. These companies market a single approach or a single contraption for threatened shorelines. Some of the devices are intended to halt shoreline erosion with no regard for the beach. Others are said to halt shoreline erosion while simultaneously building

FIGURE 4-2 Hard stabilization along the Lake Erie shore.

up the beach. The number of available devices and the conflicting claims about them can be very confusing to individuals or communities seeking relief from an erosion problem.

Most of the structures are gravity structures; that is, they are sitting on the surface of the beach or on the nearshore submarine surface, and they do not extend below the sediment water interface.

This type of structure may be susceptible to undermining by erosive forces, but also has the advantage of being more easily removed if the need arises. The structures generally serve a two-fold function: that of a seawall and a breakwater.

A seawall is generally designed to repel wave attack. A breakwater is some variety of structure placed offshore for the purpose of reducing wave energy. On a large scale, (e.g., off Cleveland), breakwaters serve as harbor protection. On a smaller scale, as in the case of most of the devices being used on Great Lakes shorelines, their function is to cause sand to accumulate in the wave "shadow" of the breakwater.

The confusing array of available devices can be sorted out somewhat by classifying the various devices according to their fundamental mode of operation. For example, is the function to repel wave attack? If so, then the device is basically a seawall. Is the function to trap sand? If so, then the device is basically either a groin (shore-attached, perpendicular to the shoreline) or a breakwater (offshore, shore-parallel) (Table 4-1).

The maze of available prepackaged shoreline stabilization devices is uniquely a Great Lakes problem. As mentioned previously, the Great Lakes shoreline has a very wide variety of shoreline environments because of the wide range of shoreline rock types, fetches, water depths, and numerous other factors. The important point from the standpoint of the local property owner is that a particular device may work for a while as intended at a particular location, but this may have little bearing regarding its success elsewhere.

Most companies can claim some success somewhere in stabilizing a shoreline, but these successes are frequently short term, such as for a single season or a single year. Other apparent successes may be due to the erosion control structures' settling into the sand under the force of their own weight, or due to lowered lake levels; both situations would show (in before-and-after photographs, for example) an apparent build-up of sand. In the absence of a comprehensive consumer protection program to oversee and monitor "solution" claims, the individual property owner must take responsibility for researching and verifying claims of success.

Soft Stabilization

Temporarily halting shoreline retreat by pumping up or trucking

TABLE 4-1 Examples of Erosion Control Devices on the Great Lakes Market

Name	Design	Actual Structure
Wavebuster		Seawall/breakwater (sloping)
Automatic Wave Breaker and Beach Builder	Horizontal timber tiers held by stainless steel supports	Seawall/breakwater (Z-shaped)
Waveblock	Modularized, permeable, reinforced concrete units (3 tons)	Seawall/breakwater (gravity structure)
Surgebreaker	Modularized, permeable, reinforced concrete pyramidal units (2 tons)	Placed as walls, breakwaters or groins (gravity structure)
Wave Wedge	Similar to the above (2-1/2 tons)	As above
Sand Grabber	Concrete blocks held by steel rods	Seawall/breakwater
Erosion Control Systems	Concrete-filled bags, anchored	Groin and/or wall combination
Seascape	Plastic "seaweed"	Breakwater
Natural Beach Restoration	Wire coils anchored with steel rods	Breakwater

in new sand falls into this category. A number of states with oceanic shorelines have declared this approach to be the preferred way to go.

Advantages of soft stabilization:

1. Recreates or enhances the width of the recreational beach.
2. May increase attractiveness of a previously beachless shore.
3. Affords some storm protection for the community.
4. Allows natural system to function.
5. Leaves open the possibility of pursuing other management options in the future.

Disadvantages of soft stabilization:

1. Is costly.
2. Is temporary; sand must be emplaced repeatedly.

3. May have adverse ecological impacts.

Soft stabilization has not been used extensively in the Great Lakes. It is likely, however, that this alternative will become an increasingly important form of shoreline management in the near future, just as it has become on oceanic shores.

On the open ocean shoreline of the East Coast, beach replenishment is costly and must be repeated often. As a broad generalization, a community can expect to spend $2 million per mile for a beach lasting on the order of 5 years. Great Lakes beaches will likely last somewhat longer, but the lake replenishment data are sparse so far.

The Muskegon Park replenishment project illustrates a common Great Lakes replenishment problem. A $1.2 million nourishment project lost significant amounts of sand in less than 1 year. Now the U.S. Army Corps of Engineers has proposed using heavy sand, i.e., gravel. Undoubtedly, gravel will be more durable than sand, but what about the quality of the beach for swimming purposes? What will be the priorities for the next artificial beach, and how will we resolve the conflicting grain-size requirements of a recreational beach versus a longer-lived beach?

Judging from the experience on oceanic beach replenishment, Great Lakes beach replenishment projects should be viewed as experiments, at least the first time around. As stated in the draft report of a recent workshop on Great Lakes coastal erosion research needs, "The fundamental mechanisms of sediment transport have yet to be understood" (Michigan Sea Grant College Program and The University of Michigan, 1987). Our ability, therefore, to predict artificial beach durability is poor, and experience at a given location is the best teacher. It is particularly important for communities to understand the presently poor state of our knowledge with regard to predicting beach success before committing community resources to a long-term replenishment project.

Relocation

Relocation is an approach that involves moving structures inland to new locations, letting them fall in, or demolishing them when their time comes. In effect, the states that have chosen to prohibit or restrict hard stabilization are looking at this management approach in the long-term future.

Advantages of relocation:

1. Preserves the recreational beach for future generations.
2. In the long run, is less costly than stabilization.

Disadvantages of relocation:

1. Does not stop erosion.
2. May be politically difficult if individual homeowners insist on governmental assistance.

The relocation alternative was perhaps an inconceivable approach to shoreline management a mere decade ago. However, recent warnings of an impending dramatic sea level rise (National Research Council, 1987; Devoy, 1987) and increasing awareness of the rapidly burgeoning costs of beach stabilization (hard and soft) along oceanic shorelines have played a role in changing public attitudes toward this approach. Perhaps the situation is best summed up in a position paper circulated by a group of coastal scientists, engineers, economists, environmentalists, attorneys, and policy specialists in 1985 (Howard et al., 1985). The summary of this position paper states,

> Sea level is rising and the American shoreline is retreating. We face economic and environmental realities that leave us two choices: (1) plan a strategic retreat now, or (2) undertake a vastly expensive program of armoring the coastline and, as required, retreating through a series of unpredictable disasters.

There are several ways to strategically relocate away from the shoreline. One route is to simply let buildings fall in. A second general approach is to demolish those beachfront structures whose design lives have been reached or exceeded. A third approach is to physically move buildings inland from the receding shoreline. Each of these approaches, with the possible exception of the first, will likely require some governmental incentive program to be put into effect.

The Great Lakes state of Michigan has instituted just such a program; through the Emergency Home Moving Loan Program, the state offers low-interest loans for relocation out of hazardous areas. Connecticut also administers a program to subsidize relocation costs. Maryland, as well, offers financial assistance for relocation.

On the federal front, the most significant development is the recent congressional passage of an amendment to the administration of the National Flood Insurance Program (NFIP), (House Report 100-426). Heretofore, NFIP claims were paid out only to houses already destroyed or heavily damaged by floodwaters. Under the new rules, homeowners can qualify for federal assistance for relocation of their threatened homes *before* any actual damage occurs. The

TABLE 4-2 Regulatory Agencies and Laws in the Coastal Zone

Issue/Activity	Agency and Law
Flood plain management	Federal Emergency Management Agency, Federal Flood Insurance Act State Coastal Management Programs, Coastal Zone Management Act
Shoreline erosion	State Coastal Management Programs, Coastal Zone Management Act U.S. Army Corps of Engineers
Sea level rise	Environmental Protection Agency
Coastal barriers	Department of the Interior, Coastal Barrier Resources Act
Public access	State Coastal Management Programs, Coastal Zone Management Act

Source: Millemann (1986). (Reprinted by permission from Coast Alliance.)

rationale behind this change is recognition of the cost-effectiveness of paying for loss *prevention*, as opposed to paying for actual loss claims, especially since loss claims are sometimes paid out repeatedly to a single structure as the structure is damaged and rebuilt, damaged and rebuilt.

THE FEDERAL SPLIT PERSONALITY

No mention of federal involvement in coastal zone policy would be complete without at least a quick glance at the other federal agencies or laws with some jurisdiction over coastal issues (Table 4-2).

The U.S. Army Corps of Engineers assumes responsibility for mitigation of the effects of shoreline recession. These efforts are aimed at the preservation of existing structures, regardless of the degree of wisdom or folly displayed in the siting of those structures. In attempting to hold the shoreline static, the Corps has traditionally turned to hard stabilization; today, soft stabilization is the preferred, but not universal, choice. The Corps' efforts were given a recent boost by the passage of the Water Resources Development Act of 1986, which authorizes or extends federal participation in many coastal stabilization projects around the country.

The Federal Emergency Management Agency administers NFIP. This program provides federal flood insurance to residents of communities meeting certain minimum floodplain management standards.

The Coastal Zone Management Act (CZMA) was passed in 1972 and is administered by the National Oceanic and Atmospheric Administration. This act offers federal incentives to those coastal states that volunteer to design and manage a coastal management program under the federal guidelines. Of the 35 eligible states and territories, only 6 are not currently participating in the CZMA program. (Four of those are Great Lakes states.)

The Coastal Barrier Resources Act of 1982 (CBRA) is administered by the Department of the Interior. Congress, in recognition of the drain on federal monies created by development in erosion-prone, high-hazard areas, passed this act to prohibit further federal expenditures on undeveloped coastal barriers. While not eliminating or even significantly limiting coastal high-hazard development, the act at least withdraws federal tax dollars from such undertakings. Great Lakes problems with high lake levels could perhaps be alleviated by incorporation of Great Lakes barriers into the CBRA system or into a similar state system (as in Massachusetts).

It is obvious that the federal government is of two minds concerning coastal development. On one hand, the programs of the U.S. Army Corps of Engineers promote and encourage federal spending in the coastal zone. The aim and effect are to preserve and promote coastal development, with little regard for meaningful standards of development or planning. On the other hand, the CBRA program eliminates altogether federal expenditures in designated coastal areas. Somewhere in the middle ground lie CZMA and NFIP, which provide for federal expenditures in the coastal zone, but only for programs or development meeting certain minimum standards. Clearly, the federal government must address the question of across-the-board consistency in charting the course of future federal policy initiatives.

HOW ARE OCEAN STATES RESPONDING?

Ocean states are responding to the challenges of shorefront development in a variety of ways. The general trend overall has been one of increasing recognition of the importance of beach preservation, concurrent with a growing realization of the threats that shorefront development and stabilization pose to natural shores and public coffers. Mentioned below are a few highlights of Atlantic and Gulf state programs.

The control of new development is often managed through the use of construction setbacks. Florida and North Carolina both have such programs, based on present shoreline position plus historical erosion rates. North Carolina's regulations, the more far-reaching of the two, stipulate that all new buildings must be set back from the shoreline at a distance at least equal to 30 times the average annual erosion rate. Further, multiunit buildings (e.g., condominiums) must be set back a distance of at least 60 times the average annual erosion rate. No building may be built within 60 ft of the shoreline.

Setbacks are an important first step in controlling future development. On the ocean shore, however, they only postpone severe problems to a few years down the road, since the receding shoreline will eventually catch up with the set back building (Figure 4-3). Setback on lake shores would be more effective, since shoreline changes there are cyclical fluctuations, rather than continuous landward encroachments. Historical records of past lake levels and shore positions could provide a guide for the mapping of lake setbacks.

A more difficult problem is that of existing development. Two states, New Jersey and Florida, are already densely developed, and their coastal management programs focus on shoreline stabilization, in order to protect the existing development. New Jersey's comprehensive *Shore Protection Master Plan* focuses on the combination of maintenance and upgrading of existing seawalls and groins plus beach replenishment. Florida, while continuing to allow seawall construction, has also introduced a $500 million statewide beach restoration initiative.

Other ocean states are unwilling or unable to invest huge sums of public money in stabilizing the shoreline or re-creating beaches lost to hard stabilization. North Carolina and Maine both prohibit hard stabilization altogether in order to preserve the natural beaches. In the absence of a major replenishment program, this ban translates into a de facto relocation or retreat policy, and serves to (1) allow the natural beaches to maintain themselves and (2) leave responsibility for building preservation in the hands of the property owners.

New York approaches relocation via a different avenue. By restricting the rebuilding of severely storm-damaged buildings, the state allows high-hazard areas to identify themselves and then prohibits continued redevelopment in those areas. Texas administers a

FIGURE 4-3 The problem with ocean setbacks. Sea Vista Motel, Topsail Beach, North Carolina. This motel was originally set back at least 300 ft from the shoreline.

relocation program tied to the natural vegetation line. The most effective management tool for Texas has been the state's Open Beaches Act of 1959. Originally designed to ensure public access to the state's beaches, the act has become, in effect, a "rolling easement." Because the act prohibits construction seaward of the vegetation line or within 200 ft of the mean low water line, structures must migrate landward apace with the receding shoreline.

The most far-reaching coastal legislation has been proposed (but not adopted) in South Carolina, which presently administers a relatively ineffective coastal management program. The report recently issued by the state's Blue Ribbon Committee on Beachfront Management (1987) outlines a gradual 30-year plan for retreat from the coast. Building setbacks, restrictions on coastal armoring (which is presently used extensively and is rapidly expanding) and post-storm reconstruction, and selective beach replenishment are all components of the proposed plan for selective retreat. Such a progressive program, however, faces a difficult political battle in the state legislature. If passed, South Carolina's blue ribbon plan could serve as an example to coastal states everywhere.

CONCLUSIONS

Water level is of great importance on both the ocean and Great Lakes shores. The problem is worse, however, on the lakeshores, because the amplitude of a single cycle of change in the levels of the Great Lakes is greater than the anticipated ocean sea level rise for the next *century*.

The cyclicity of high lake levels also offers unique opportunities unavailable to oceanfront shoreline managers. Because the Great Lakes problem is sporadic, attention to the problem is also sporadic. However, lowstands can be used in the future as planning "breathing spaces." Those are precisely the times to be planning and preparing for the coming high waters (e.g., by installing sand fencing and building protective dunes).

The Great Lakes do face the unique problems of very rapid, high-amplitude lake level changes, a general dependence on hodgepodge hard stabilization techniques, and a crowd of eager "one-device" salesmen waiting in the wings to provide "*THE* solution." Conflicting governmental policies also contribute to the problem.

Experience with shoreline erosion and policy experimentation and implementation on ocean shores indicate that the following steps could reduce erosion losses and preserve recreational beaches on Great Lakes shores:

- Recognize the importance of beaches for both protection and recreation, and take steps to protect these critical buffers;
- Limit the indiscriminate use of hard stabilization, (as do North Carolina and Maine);
- Maintain a healthy skepticism about ever "new and improved" engineering schemes;
- Institute construction setbacks (as does North Carolina); and
- Offer relocation incentives (as does Michigan).

In terms of an overall solution, citizens of the Great Lakes must recognize that we're dealing with long shorelines and a large problem. Any "solution" lies outside reasonable economic limits unless consistency and flexibility are built in. A program of coordinated and selective strategies (e.g., stabilize here, replenish there, relocate there) is an approach that could offer some relief from the damaging effects of future high water levels.

ACKNOWLEDGMENTS

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PROVOCATEUR'S COMMENTS

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In reading Orrin Pilkey's paper I was struck by the emphasis on preservation of natural shorelines and the lack of attention to ways to preserve natural characteristics in man-made shorelines. I believe there would be a consensus in this room that in the Great Lakes the issue is how to adapt to fluctuations in lake levels and that one question is whether we have a natural shoreline.

We may have a consensus that the best way to adapt to fluctuating lake levels would be to preserve those natural shorelines where they exist. The problem is that in the Great Lakes we have 40 million people, the great majority of whom live in a number of large cities on the shorelines of the Great Lakes. Here at the south end of Lake Michigan, as demonstrated by the satellite photo that Bill Wood showed us, we have about one-fifth of the population of the Great Lakes concentrated around the south end of Lake Michigan. We don't have the luxury of preserving our natural shoreline.

How can we apply the understanding that we have about the value of beaches as shoreline protection in those areas? There is an urgent need for the coastal experts to give us the technical information that we need to learn how to establish beaches and park lands, or to preserve beaches and park lands on developed shorelines, not just the undeveloped shorelines. You saw examples on the Chicago shoreline yesterday where we have a totally man-made shoreline. We have had extensive beaches and we need information now about the best way to restore beaches from a technical standpoint. On the economic side, we need a lot more attention to the value of beaches and park lands, and the economic benefits of applying techniques there. We need to compare the value of so-called soft approaches versus the cost of the hard approaches, which include off-shore structures, seawalls, and ever higher piles of rock.

Existing federal policies really undermine, for the most part, the attempts to use beaches and park lands as shore protection rather than to use hard structures. The implications of what I'm saying would require that we call upon the U. S. Army Corp of Engineers to change their fundamental approach to shoreline protection. Such an approach also requires a long-term view and a regional approach. If there is any agency at present that has the capability to take the regional approach that's been called for here on the shoreline, it would be the Corps of Engineers. Yet we find that the way the Corps of Engineers operates is strictly locally.

They address immediate situations, they are reacting after the fact, and their advance measures program is a short-term program with a maximum design life of 15 years. I don't believe that the general public, including those property owners that turn to the Corps of Engineers for help, understands the extent to which the Corps of Engineers uses a band-aid approach rather than a long-term approach.

Finally, I've made no secret of the fact, as some of you saw on the field trip with me yesterday and most of you saw in the slide presentation last night, that I have a vested interest in the fact that this meeting is taking place in Chicago. I'm very much hoping that the discussion at this meeting and your experience in looking at Chicago shoreline will convince you that there is an opportunity to learn about how to deal with urban shorelines. In Chicago we have an experience where engineers designed a shoreline, and built it. Now 30, 40, 50 years later there is an opportunity to see what has happened to that shoreline and to learn from it as we try to answer some of the technical, economic, and policy questions that we have to address in this colloquium. To sum up, it is time for the engineers to address the issue of beach restoration, beach establishment, and beach nourishment. We must have more information on the comparative cost of using and maintaining beaches versus piling up rocks and pouring concrete.

5
Multijurisdictional Issues

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INTRODUCTION: FLUCTUATIONS AND SHORE USE

Water levels in the Great Lakes fluctuate, and these fluctuations, which have no mean, have created a major regional land use problem. Fluctuating lake levels have been identified as a natural hazard that creates unacceptable societal risks. Unstable lake levels can have substantial adverse effects on littoral and adjacent property and may even threaten human life. We no longer consider natural disasters acts of God; society now considers them risks that should be eliminated or minimized. Pressure for relief from the risks of the hazard is intense in both Canada and the United States. Large populations have clustered along the shores the Great Lakes to maximize the value of the lakes for a variety of uses.[1] One-third of Canada's population and one-seventh of the U. S. population lives in the Great Lakes Basin.

Fluctuating levels are primarily a problem for those on Lakes Michigan, Ontario, and parts of Superior, but these first two areas include substantial portions of the population concentrated along the lakes, so substantial numbers of people are exposed to the adverse consequences of fluctuating lake levels. High levels erode the shore and flood urban areas, destroying private property and municipal infrastructures. Low lake levels impair commercial navigation, recreation, and hydroelectric power generation. The risk of damage is substantial because the shores of the Great Lakes have attracted all major land uses. Cheap transportation for lumber, grain, and iron ore drew industry to the lakes. Harbors have been constructed all around the lakes, and water-dependent industries have located around these harbors. Lake shores are an attractive place to live. The moderating influence of the lakes on the region's harsh climate and their great and varied beauty have attracted extensive high-valued primary and secondary home development. Twenty percent of the shoreline has been developed as residential property.[2] Public and private recreational use along the lakes is intense for these same reasons.

Until the 1980s there was comparatively little concern over lake levels because fluctuations were not extreme. The outflow from each lake is steady, and normal lake levels fluctuate from 1 to 2 ft in a single year. There has been comparatively little alteration of the natural drainage patterns of the lakes.[3] The Great Lakes are not a physically managed water resource compared to the Colorado and Missouri rivers. There are five major diversions from the basin: Long Lac, Ogoki, Chicago, and the Welland and New York State barge canals. These diversions "have produced changes in Great Lakes levels and outflows, . . . [but] the hydraulic effects are small in relation to the natural ranges on the lakes."[4] Outlets for two of the lakes, Superior and Ontario, have been altered, but the outlets from Michigan, Huron, and Erie remain natural. There has also been some dredging of connecting channels.

FLUCTUATING LEVELS: RESPONSE STRATEGIES

High water levels in 1985-1986 have generated pressure to eliminate the risk of property damage from high water levels. Lake levels reached the highest recorded levels in the Fall of 1986, and powerful storms in 1985-1987 caused substantial property damage along the shores. Previous high water levels on Lake Erie between 1972 and 1975 caused $110 million worth of property damage.[5] The driest period on Lakes Huron, Michigan, and Superior since 1900 has provided immediate relief; levels fell 18 inches between November 1986 and June 1987. The long-term problems of fluctuating levels remain, and lake front property owners, commercial interests, and municipalities continue to press for protection to avoid future damage. Two basic strategies have emerged: (1) physical fixes and (2) risk adaptation.

Physical fixes are a continuation of traditional responses to natural hazards. Prior to the 1960s, it was assumed that there were only two flood strategies, either risk bearing or structural elimination of the risk.[6] These assumptions are wrong, because any adequate response requires a mix of structural and nonstructural strategies, but the legacy of supposed quick fixes exerts a powerful influence on the politics of disaster prevention. In the 1930s, the U. S. Army Corps of Engineers began to construct large flood control or multiple-purpose reservoirs on major rivers and their tributaries. These reservoirs generated the expectation that floods could be eliminated. This tradition has been carried forward in the response to the 1985-1987 lake flooding. There are proposals to pull the plug by increasing diversions,[7] to deepen connecting channels of Lakes Michigan-Huron and Erie to speed the flow to the St. Lawrence, or to construct the "Great Wall of the Great Lakes" around urban areas by a series of barrier islands and other structures. For example, the wealthy Chicago suburb of Lake Forest spent $8.7 million to construct a chain of artificial islands to protect its Lake Michigan beaches.

The second strategy, risk management through adaptation to the occurrence of natural hazards, is a truly radical strategy because it cuts against the grain of the institution of private property and supporting local regulation to try to deflect intensive uses that have historically clustered along the shore, away from the shore. This strategy has emerged from pervasive criticisms of the effectiveness of exclusive reliance on structural solutions to reduce the risks of natural hazards.[8] The shift of responsibility for flood prevention almost entirely to the federal government led to excessive reliance on large-scale federal structural solutions that were often ineffective, decreased or eliminated incentives for individuals or local units of governments to take adaptive action, and overly constricted the range of choice of disaster adaptation. The core principle of risk management is that risks of natural hazards to people and property can be minimized by a combination of structural solutions and the deflection of human settlement from vulnerable areas.[9]

Risk management includes the regulation of land to limit waterfront development for residential and other vulnerable uses, the reduction or elimination of public subsidies that encourage intensive shoreline development, and the compensation of existing shoreland owners to roll back exposed development. For example, in both rural and urban areas it might be cheaper to buy out buildings that are damaged or subject to high risks than to construct the structures necessary to protect them. Risk management also includes structural solutions such as flood proofing buildings and smaller-scale shore protection works.

Risk management is the only real option for the Great Lakes. Fluctuating lake levels are not subject to substantial artificial manipulation. The ultimate policy choice is between constant and expensive "nourishment" projects and expensive structural solutions to armor the shore in the hopes of stabilizing it, and land use planning and controls. There is growing recognition that the focus must be on shore use, not on the manipulation of lake levels. The 1986 IJC reference on fluctuating lake levels directs the commission to determine, to the maximum extent practicable, the socio-economic costs and benefits of alternative land use and shoreline management practices and compare these with the revised costs and benefits of lake regulation schemes. This paper examines the major institutions and regulatory jurisdictions that have a voice in Great Lakes level regulation and shoreland use through the lens of these two policies to determine which institutions promote or impede the achievement of these policies.

INSTITUTIONAL RESPONSES: FRAGMENTED AND CONFLICTING?

To implement any strategy to respond to risks of fluctuating lake levels, it is necessary to understand the existing institutions that influence lake level maintenance and shoreline use. The problem is conventionally framed as the appropriate response each level of government should make to the problem and how different regulatory jurisdictions and missions can be harmonized. This is a useful perspective, but the problem is much more complicated. The approach can lead to single-purpose responses to the problem that do more harm than good over the long run.[10] It is essential to recognize that private choice drives public responses to fluctuating lake levels. In brief, the Anglo-American tradition that ownership of property includes the privilege to use it as the owner chooses unless the use causes harm to nearby users has led to the characterization of the process of wave action along the shore as erosion—a problem to be "solved."[11] The main task is to reduce the incentives for intensive shoreline use. This involves both the regulation of coastal development and the modification of public and private subsidies that support it.

All levels of government have a role to play in the responses to fluctuating levels, and the harmonization of regulatory jurisdictions and missions is a formidable task. Binational, national, state, and local jurisdictions can respond to lake level maintenance, and multijurisdictional responses may both complement and conflict with rational response policies. Lake level stabilization, to the extent that it is possible, is pursued by binational cooperation and by the federal and state or provincial governments, of the United States and Canada. Hazard avoidance is primarily the function of local, state, or provincial governments, because this is where land use controls have been vested in both Canada and the United States, but the federal government of the United States has asserted a limited interest in shoreline management.

The coastal zone was not identified as a fragile environmental area that needed special protection from intensive development until the 1970s.[12] States such as California,[13] Florida, Maine, North Carolina, and Washington enacted laws to regulate coastal development. In 1972, Congress passed the first federal land use planning statute, the Coastal Zone Management Act (CZMA), and legislation has been introduced to include erosion control grants in the CZMA.[14] The CZMA applies to the Great Lakes, but coastal management has been slower to take hold in the Great Lakes states compared to the Atlantic and Pacific Coast states cases as has the environmental movement generally.[15] Illinois, Indiana, Minnesota, and Ohio are not part of the national CZMA program. For example, Illinois undertook an intensive planning program in the 1970s, but legislation to implement that program was blocked in the state legislature by property owners along the north shore of Lake Michigan.

The most important lesson that can be learned from an examination of the two-decade effort to protect the "thin edge" of our ocean and inland coastlines is that single-objective programs must be viewed with extreme skepticism for three basic reasons. First, they are likely to compromise important competing values. For example, erosion protection may come at the expense of other values such as public access, a longstanding coastal management goal.[16] Second, different regulatory jurisdictions have different missions that increasingly operate to constrain single-purpose solutions. Third, single-purpose solutions draw public attention away from the basic but difficult to accept truth that shoreland management is a long-term problem that will require fundamental changes in the use of shoreline resources.

BINATIONAL JURISDICTION

Four of the Great Lakes form part of the Canadian-United States border, and thus both nations have an interest in the use of the lakes. Canada and the United States have elected to develop their joint interests through binational cooperation; the two nations signed the Boundary Waters Treaty of 1909. This treaty sets forth general principles of lake use and creates the International Joint Commission (IJC) to deal with binational issues. Lake Michigan is not covered by the treaty because it is not a boundary water. The joint interest of the United States in lake levels can be defined as lake level stability to protect navigation, although the incidental environmental benefits of this goal are being increasingly appreciated. Article II of the treaty seems to adopt the principle of equitable utilization,[17] and Article III requires IJC approval, subject to limited exceptions, of diversions that raise or lower the level of a lake. Reciprocal rights to stable lake levels have been recognized by the United States Supreme Court in the Chicago diversion case and later binational agreements. Both the binational agreements and Canadian-U.S. implementation of them express the core principle of stable, "natural" lake levels.

The two nations cooperate on lake level stabilization through the IJC, but the potential for fluctuation stabilization is limited.[18] There are only three major diversion points on the system that can be manipulated to influence lake levels. The Long Lac and Ogoki diversions on Lake Superior divert water from the James Bay drainage basin into the lake for hydroelectric power generation and to transport pulpwood logs. Illinois diverts 3,200 cfs from Lake Michigan into the Mississippi River drainage basin for water supply, sewage disposal, hydroelectric power generation, and navigation. Water is diverted from Lake Erie to Lake Ontario through the Welland Canal in Ontario for hydroelectric power generation and navigation. Lake Superior's outflow is controlled by a dam on the Saint Marys River, and the IJC has adjusted outflows to balance the effects of high levels between Lake Superior and Lakes Michigan-Huron. Land owners on Lake Huron have sued the U. S. Army Corps of Engineers for "dumping" water from Superior into Huron pursuant to an IJC action. The court held that the basic decision to balance lake levels was unreviewable, but the manner in which the Sault Ste. Marie flood gates were operated could be the basis of a Federal Tort Claims Act suit.[19]

A 1977 IJC reference studied several management scenarios. The most extreme concluded that if the Long Lac and Ogoki diversions were reduced to zero and the Chicago and Welland canal diversions increased by 7.3 cfs together, "there would be a lowering of the maximum level of Lake Superior by 3.0 cm (0.10 ft), of Lakes Michigan-Huron by 17.4 cm (0.57 ft), of Lake Erie by 13.7 cm (0.45 ft), and of Lake Ontario by 52.7 cm (1.4 ft)."[20] The kicker is that the benefits of $7.8 million to coastal zone interests and recreationists would be offset by a net $73 million loss to navigation, hydroelectric power generation, and recreational navigation. Modest net benefits are produced when the Long Lac and Ogoki diversions are held to 5,000 cfs and when Chicago remains at 3,200 cfs and the Welland Canal at 9,000 cfs.

Lake level management has been undertaken by Canada and the United States within the framework of the Boundary Waters Treaty, and neither the treaty nor principles of international or domestic law currently impose major constraints on lake level management. The major exception is the Chicago diversion. Both the United States and littoral states concerned about the effect of lower levels on navigation sued to enjoin the diversion. Wisconsin v. Illinois[21] held that the Chicago diversion was not authorized by the federal government, and the Supreme Court did not reach a decision on the issue of the reciprocal rights of the littoral states. There is, however, a clear suggestion in the opinion that the states had a quasi-sovereign interest in normal lake levels.

The tail end of the energy boom of the 1970s and early 1980s has sparked considerable interest among the Great Lakes states in water management to prevent interstate diversions. In response to proposals to bail out the depleted Ogallala aquifer with Lake Superior water, the Great Lakes states and the provinces of Ontario and Quebec signed the Great Lakes Charter. The charter is a good-faith effort to prevent large-scale diversions by consultation among the signatory states and provinces backed up by unilateral state and provincial conservation of the lakes and tributary waters. Large-scale diversions are less a threat than many assume, but the concern against draining the lakes[22] bears on the problem of responding to fluctuating lake levels. The concern over diversions underscores the need to maintain natural levels to protect the lakes and associated shorelands and provides counter pressures against proposals to alter natural (and fluctuating) levels to protect shoreland uses. One, perhaps unintended, consequence of the charter is that greater interstate and Canadian cooperation will be required for any large-scale lake level modification plan.

FEDERAL RESPONSES

The federal government can influence shoreland protection strategies in two basic ways. First, it has plenary power to regulate the use of the Great Lakes. This power has primarily been exercised to promote navigation, but the federal government has the constitutional power to manage the use of Great Lakes water as it chooses, subject to the sovereign interests of Canada. Second, the federal government is a source of funding for erosion control and other shoreline protection problems. Federal money can be used both to subsidize intensive shoreland use and to deflect it. The federal government continues to subsidize erosion control structures, and this policy is a major influence on private, state, and local shoreland initiatives. However, in other areas of the country, such as the Carolina coast, the withdrawal of federal and state subsidies is being used to discourage shoreland development.

The U. S. Army Corps of Engineers has the authority to study beach erosion[23] and to construct beach erosion control projects, although often these projects are stopgap measures or merely shift sand from one area of a lake to another. Costs must be shared between the federal government and states or units of local government.[24] At the present time, the corps has complete discretion to decide where to build a project and what kind of project to build. Small erosion-control projects may be constructed without specific congressional authorization.[25] Neither the standards imposed by Congress on the corps nor the law of inverse condemnation provides sufficient incentives for the corps to consider the impact of their erosion-control projects on the shoreline as a whole. Federal loan guarantee programs to encourage the construction of protection measures by residential property owners along the lakes have been proposed.[26] The federal navigation servitude immunizes the federal government from liability to property owners who claim that their property has been damaged by erosion control structures.[27] Thus, there are no legal constraints to counter the political pressures for structural solutions.

The federal government can also contribute to shoreland management by acquiring parcels of property for the national park system and other federal reservations. The Department of the Interior has a coastal barrier program that targets land for federal acquisition. At the present time, the Great Lakes and Pacific Ocean are excluded from this system. However, legislation has been introduced in Congress to extend the coastal barrier resources system to the Great Lakes.[28]

STATE AND LOCAL LAND USE CONTROLS

The best response to fluctuating lake levels is to minimize exposure to their adverse effects. New shoreline development subject to damage from fluctuating levels must be deflected, and existing development must be rolled back. Adaptation is easy to articulate in principle but is difficult to implement. Rollback policies, however rational in theory, are even more difficult to implement. There are at least three major reasons why it is difficult to deflect shoreland development:

1. The market creates incentives for shoreland development, and these incentives have been reinforced by government subsidies such as federal erosion control programs, flood insurance and disaster relief, and infrastructure construction. It will be necessary to reverse these incentives.
2. Adaptation must be implemented primarily by units of local government, so responses and commitments may vary considerably. For example, many communities in states such as Ohio have opted to encourage shoreland property owners to create special improvement districts. These districts may use local government bonding authority to generate a beach erosion-control loan fund. Some communities may compete for development to build up the local tax base, while others may try to discourage it. In the 1970s some states preempted local land use controls, but "the quiet revolution" has stalled, although the issue of the protection of areas of state and region-wide importance remains. In addition, many land use regulations require considerable geologic and other scientific expertise to formulate and implement.
3. Both the deflection of new development and the rollback of existing development are subject to substantial potential legal constraints. The federal and state constitutions prohibit the taking of private property without just compensation. Regulations that

severely limit development options to protect sensitive environments or require that existing land uses conform to new use standards may be challenged as a taking of property without due process of law.

These problems are difficult but not insurmountable. For historical reasons, the ownership of littoral land has always been less absolute than that of dry land because the public generally owns the bed of submerged lands below the mean high water mark. This tradition provides an added basis for coastal management. A number of important coastal management initiatives are in place at all levels of government that can form the basis for a shoreland adaptation policy, but they must be complemented by compensation programs in appropriate cases. Two problems of special interest, the public trust and innovative land use regulation, are discussed below.

The Special Nature of Littoral Ownership

Littoral ownership is less exclusive than ownership of nonwater-related land, because public and private ownership overlap. The beds of the Great Lakes are owned by the states in trust for the people of the states, but the shoreline is not. State ownership extends to the high water mark in most Great Lakes states.[29] Landward of this line, the shore is capable of private ownership. The consequences of this division of public and private ownership are substantial. Submerged beds are subject to public rights of commercial and recreational navigation, fishing, and swimming, and they are subject to the public trust. Public ownership is not limited to land overlain with water but extends to land that would naturally be flooded. For example, the Wisconsin Supreme Court recently prohibited the construction of a condominium near Lake Superior because the land would be covered with water were it not for an artificial barrier.[30] Land beyond the high water mark may be used by the owner subject to state and local regulation.

The public trust is a vague but important doctrine, which originated in a suit over a conveyance of the Chicago lake front by the state to a railroad, which restrains the use and conveyance of trust lands to protect public trust purposes.[31] Historically, the trust has been used to promote navigation. But the trust does allow courts to scrutinize carefully the proposed uses of submerged lands, especially exchanges and transfers to private parties, to determine if the use serves a public purpose. For example, plans to armor the shore of

Chicago raise important public trust issues because they may impair both aesthetic enjoyment and public access to the shore.

Land Use Regulation

To deflect incompatible land uses from the shore, new development that is at risk from erosion must be prevented and existing uses must, in some cases, be rolled back. There are two basic strategies to deflect new development. Land use controls can prohibit development too close to the shore, and subsidies for coastal development can be eliminated.

Setback and Hazard Area Regulations

Setback regulations are the basic regulatory tool to prevent shoreline development in the zone of erosion risk. Setback regulations are one of the most basic zoning techniques, and they have been adapted to coastal development. Pending legislation ties federal funds for Great Lakes erosion control to the existence of adequate setback requirements. States and local communities on the ocean and lake coasts have adopted minimum shore setbacks and dune protection standards. For example, Michigan has adopted bluff setbacks based on the rate of erosion, and pending legislation provides for a minimum setback line of 45 ft from the bluff along the state's nonbedrock coast. Setback regulations are appropriate for low-density areas. Urban areas require more sophisticated regulatory tools along the lines of the Chicago Lakefront Protection Ordinance to limit development in hazard risk areas.

Coastal setbacks are controversial and subject to legal challenges as uncompensated takings because they may extend a considerable distance inland and thus reduce the value of coastal property. For example, Florida bases dune protection setback lines on a simulated wave surge during a 100-year storm. A Florida court recently approved the Department of Natural Resources' decision to define a "beach-dune" system as any part of the coast that might be affected by a 3-ft wave regardless of whether or not there were actually beaches or dunes in the area.[32] Local communities now have considerable experience with hazard area land use regulations such as flood plain zoning. These regulations are presumably constitutional because they respond to a serious hazard that is aggravated by poor location choices. Current Supreme Count takings law requires a rational nexus between the problem caused by the land owner and the regulation.[33] The cases are not uniform, but the majority of courts have upheld restrictions on development in hazard areas against taking challenges.

Efforts to roll back development raise more difficult constitutional issues. Land use regulations may be applied retroactively, but as the cost and scale of compliance with new standards rises, basic fairness, reinforced by the constitutional prohibition against the taking of property without due process of law, demands that the owners of property be compensated. In situations where development occurred before an environmentally sensitive or hazard area was defined, the usual solution is to buy out property located in a zone of risk. The crucial question is valuation. To be fair to the property owner, the value of the property must be based on its value at a time before the property value was decreased because of the hazard.

Subsidy Elimination

Until recently, federal and state governments have created incentives to locate in hazard areas by constructing the infrastructure to support growth, by providing extensive post-hazard emergency relief, and by providing state grant programs for beach erosion control. These subsidies need to be better targeted or eliminated. For example, federal flood insurance is available to residents of flood prone areas. In 1968 Congress made the decision to subsidize flood insurance conditioned on the adoption of local land use controls to deter development in high-risk areas. In practice, the availability of flood insurance has often hastened the pace of shoreland growth because flood plain maps have been inaccurate or have been gerrymandered. In 1982 Congress took a major set to eliminate subsidies that encourage shoreland growth by barring further federal flood insurance for barrier islands along the Atlantic and Gulf coasts and eliminating other federal subsidies that encourage development.

Post-disaster relief is provided by the Federal Emergency Management Agency (FEMA). Congress and the Executive Branch have tried to tie FEMA relief to adequate land use controls, and thus FEMA has considerable potential to complement other shoreland protection policies. For example, in February 1988 Congress authorized FEMA to make insurance payments for structures in imminent danger of collapse because of erosion provided that, if the structure were relocated, there would be appropriate setbacks. FEMA and several states, including Michigan and North Carolina, also have relocation programs.

CONCLUSION

Institutional responses to fluctuating lake levels reflect our general confusion about the proper responses to natural hazards. Many strategies continue to reflect the view that engineering works can eliminate the hazards. Newer strategies reflect the scholarly consensus of the last two or three decades that we must adapt to hazards.[34] The overview of this report indicates some of the strategies that need to be modified or reversed and others that need to be strengthened.

NOTES

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PROVOCATEUR'S COMMENTS

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I enjoyed Professor Tarlock's paper for the good news that was in it. By this I mean it is an articulate assertion in line with what many of us think is intellectually the right thing to do: rely on having the relevant jurisdictions and institutions prevent further development in high-hazard areas in the future. In effect this suggests that we will solve the problem by future action, to the extent we can buy out the problem or resolve existing problems over a period of time.

There's a bad news perspective in this paper, however, which fits with the pragmatic bent that I think exists in each of us in the communities around the Great Lakes. This is that by far the most valuable coastal zone infrastructure is in the cities and cannot be bought out or moved. Bridges and highways, such as Lake Shore Drive here in Chicago, cannot be moved, but the same applies to harbors, canal systems, and sewer systems such as in Cleveland, whose outflow is at or below the recent high-water levels. It is possible to say that these were poorly designed, and we will have to replace them anyway. However, they would have very large retrofit costs even in comparison to the high rise developments Professor Tarlock has described. They do pose a problem for us, and present a serious question as to classification of high hazards zones.

Another concern I have with Professor Tarlock's paper, and with several of the others, is that it relies considerably on the notion of some normal fluctuation, and that we can zone land uses so as to live within these fluctuations. I question the concept of normal fluctuation. We've already seen in the paper by Curtis Larsen and others that there is no good basis for the assumption that fluctuations occur about some historical mean. Instead, lake levels seem to have moved from one long-term equilibrium state, fluctuating about a rather high mean in the nineteenth century, to fluctuating around a much lower mean in the middle part of this century. Apparently, the lake has shifted to a new higher equilibrium about which it is fluctuating now. It is worth remembering that we have not seen an occurrence of even an average water level on Lake Michigan, Lake Huron, and Lake Erie from 1966 to 1988.

The question is not just that the system seems to shift from one equilibrium to another over a short period, followed by an interval around which there is a "normal" fluctuation. It is whether or not we may enter into a new equilibrium, one with appreciably higher (or lower) water levels then we've seen at least since the mid-nineteenth century. Thus, the shoreline management problem is not just one of adapting to periodic fluctuations. We must deal as well with the longer-term shifts in the system as a whole.

Principally, however, I want to comment on the ability of our institutions and jurisdictions to adapt to change, i.e., consider evolving institutions. Is it possible to create new forms of multi-institutional jurisdictions for situations such as the Great Lakes shorelines? Here I want to draw on the experience of the Great Lakes Water Quality Agreement, some of which was summarized in the National Research Council/Royal Society of Canada committee report of 1985. During the 1950s we saw the most serious results of water quality problems around the cities, particularly in the form of diseases. Cities with the local responsibility were asked to deal with the problem first, under very marginal state, provincial, or federal regulations.

In the 1972 Water Quality Agreement we began a process of improving water quality, but we had not yet created significant changes in the institutions. By 1978 we had extended the Great Lakes Water Quality Agreement's concern with toxics to the entire lake basin, and to substances in the lakes. The Water Quality Board was created, including representatives of state, provincial, and federal governments. Although it is not a new governmental institution, the board is a new type of institution, coordinating programs between states, between provinces, and between the federal governments. It participates in making decisions on financial support from all of those jurisdictions.

What might we learn from this process in relation to water level problems? Let me suggest three principles that I think have operated in the case of emergence of new institutions for water quality. First, there has been resort to higher-order principles, equity, trust doctrine, or something related, to guide articulation of the need for those functions that might be performed by a new institution like the Water Quality Board. The principles may exist for water levels in the 1909 treaty, as they clearly did in the treaty for water quality questions. However, there may be other kinds of principles that derive from legal questions, perhaps of intergenerational equity, that would help to articulate consensus in the scientific and public communities as to some overarching institutional arrangement of utility here.

Secondly, in the case of the water questions, there has been an emergence of a collegial relationship among scientists, particularly among university-based academics in the region. Their ability to sit down without the baggage of particular jurisdictions, state, city, or federal, and develop a consensus as to what could be done was very important in the early work leading to the 1972 agreement. Much the same applied in pursuing the principle of an ecosystem approach in the middle 1970s, leading to the 1978 agreement. This collegial process was extended to include government scientists, civic leaders, political leaders, and government officials, finally becoming a critical mass for consensus development. Can we do the same thing in relation to water levels? Perhaps. Obviously, the cities around the lakes will be big players in the questions of water levels, because of their infrastructure investment, just as states and provinces were major players in the evolution of institutional arrangements for water quality.

The third, and most difficult local area, concerns the potential role of new institutions for water levels. This took time to develop, a great deal of time, in the case of water quality institutions. Initially (after 1978), there was little agreement as to the appropriate function of the Water Quality Board. However, it evolved into a leadership function because there was a need, a need that was not being met by existing institutions. What might be the equilavent in the case of water levels? We don't know yet, but we may well begin to see it if the public and urban leaders seriously want protection, and it has to be coordinated across the political structures of the region. We have seen at least one example, the experiment set in motion by the Great Lakes Water Quality Agreement.

As I reflect on these questions, I reach the conclusion that we may need a mix of structural and regulatory measures for water levels, as well as the soft strategy of land use control and other accommodations to nature. If the lakes keep moving toward new equilibria, either higher or lower, but different from anything we have been before, regulatory approaches may be needed to try to keep us within the historic pattern of water level fluctuations. This would keep us within the range where soft measures will probably work to dampen down the extremes. As the public and political leadership recognizes the potential consequences of climate change, however, and processes that move the system toward higher or lower levels are recognized, the people and jurisdictions in the basin may be pushed toward the creation of alternate approaches.

6
Private Sector Roles and Responses

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THE CONCEPT OF THE PRIVATE SECTOR AND HAZARD REDUCTION

Not surprisingly, the existing documentation of private sector roles and responses to fluctuating lake levels is extremely limited. The little information that does exist relates to smaller, closed-basin lakes (which the Great Lakes are not), and to public sector opportunities and strategies available to mitigate, or minimize, the enormous and devastating impacts. While there is a broader data bank that identifies options to somewhat similar oceanic processes, it too is primarily intended for the public sector. In fact, inclusion of the private sector on this colloquium agenda is an astute and progressive initiative that is indicative of a growing emphasis within the profession of emergency management. The comments, inferences, concepts, tools, and approaches that this discussion is based upon are drawn from the more documented fields of emergency management, hazard mitigation, and my personal experiences with fluctuating lakes, disasters, and contributing roles of the private sector.

In order to examine the roles and responses of the private sector, we must begin by establishing a foundation upon which we can build our conclusions, and that is the concept of private sector involvement in hazard management activities. For example, why would the private sector become involved with these types of actions?

First, is an economic interpretation of human behavior; the motivation of money. People, whether they are boat owners, homeowners, business owners, or any private entity that might have an investment at risk, react when they fear they have something to lose. Whether stakeholders have sustained an actual loss, or merely perceive that the risk to their investment is unacceptable, they are motivated to undertake any action that will either reduce the risk of suffering a loss or limit those losses to those already suffered. While the emphasis, leadership, and experience in the field of hazard mitigation developed on the federal government level, the incentive to reduce hazard losses is the same; it costs too much, more than one can afford to lose, particularly if the loss has a chance of being repetitive.

The antithesis of this fear-of-loss analysis is the action-for-profit motive. There are many private sector entities, engineering firms for example, that become involved in hazard management activities at the request of both public and private interests because they earn their livelihood by being paid to analyze, design, develop, and evaluate systems that will protect their investments.

When the perspective of time is considered, financial incentive actions provide additional reasons that private sector interests become involved in hazard management activities. Commonly referred to as a "time-horizon," the duration of one's investment often dictates the level of response that those at risk undertake. Clearly, those who have an investment that is exposed to risk over a greater length of time, are more apt to undertake protective actions. Those with a short time horizon are more apt to perceive a threat as an acceptable risk. A developer, for example, has a short time horizon if a structure can be built and sold within a few years. The purchaser, on the other hand, is more likely to undertake mitigation actions, since the owner's time horizon may closely match the length of the mortgage, commonly 30 years. Similarly, the financial institution holding that mortgage will protect their investment through requiring the purchase of insurance.

When the design of infrastructure, such as culverts or bridges, is considered, time horizons can be even longer. It is common to determine an acceptable level of protection over the life of the structure, perhaps 70 to 100 years. Conversely, even when a solution exists, short political time horizons can interfere. If there is public concern over the cost of a protective measure, or who derives the benefits, it is not uncommon for a waning politician to defer any decision to the next set of elected officials, saving himself from potential embarrassment. Finally, a time horizon is merely an interpretation of the risks, and one that may not be accurate.

An equally important force that economically stimulates hazard reduction activities is our litigious society. Liability, either by fear or pursual, often spurs the private sector into action. A developer, either because of regulation or fear, may utilize certain construction techniques known to withstand erosional, wind, and water forces that have been identified as having a certain probability of occurring, in order to be protected from suit in the event a structure is impacted and fails. The owner of a lakefront complex may undertake additional precautions, such as a warning and evacuation system, to ensure that reasonable and prudent measures have been initiated to protect the occupants, and simultaneously limit the liability for failing to do so.

Conversely, private sector interests may utilize the other edge of that liability sword and file suit against a private or public entity, claiming that the other party's actions or inactions were directly related to the damages that the first party's investment suffered. Even this situation can be reversed. There exist numerous citations of suits where private entities became involved in hazard management as a result of a suit brought by a public entity. Public agencies have demonstrated that private interests caused or complicated the impacts of certain events. In other instances, subrogation cases have sought to recapture expenditures made necessary by a third party. In even another arena, activities intended to reduce the impact of events are often alleged to constitute an illegal taking of another's rights, and just compensation or an end to the activities is sought.

A subset to this field of liability provides yet another impetus for private sector involvement, and that is perceived, or real, inaction on behalf of the public sector. Public officials may claim that a particular problem is not within their realm of jurisdiction or responsibility, whether they are accurate or not. Public officials may acknowledge some duty to perform, yet rest their inaction on their inability to fund the necessary activities. Private sector interests often react, again whether correct or not, due to the perception that nothing is being accomplished that solves their problem. There is a sense that inadequate measures are being taken, and only their own intervention will lead to accomplishment of their goals.

This introductory discussion identifies an array of economic reasons why the private sector becomes involved in developing roles and responses to a hazard such as fluctuating lake levels. To complement this background development it is necessary to examine the different phases at which private sector involvement is likely to occur.

Emergency management activities are categorized into four different arenas: preparedness, response, recovery, and mitigation. While there is some overlap of components, each functional area addresses a distinct set of problems. Likewise, each category indicates a phase of the emergency management cycle that could stimulate particular actions by private or public entities.

As axiomatic to emergency management as these four phases is that the first line of defense against emergencies or disasters is at the local level, more specifically, at the individual-private sector level. When damage is occurring and the "heat of battle" begins, it is those being impacted that act first. Not only do their actions serve to protect their investments, but as a matter of practicality, they are necessarily first responders. They are already on-site at the point of impact. No mobilization is required. It is the lack of resources (such as equipment and work force) that creates the need for each level of government to activate and provide supplemental assistance, from the bottom up. Hence, the first point where private sector interests begin to define their roles and responses is during the initial response phase. When impacts affect people, they respond, in whatever fashion is available.

Following an event, two trends occur. First, there is a thrust to recover and return to normal activities. This is the recovery phase. There is a strong desire, coupled with little alternative incentive, to replace the physical and social threads of societal fabric just as they were. This is joined with an emphasis to be ready the next time, to be better prepared. This is preparedness. An example might be to preidentify and position sandbags. Now that it is clear which portions of Lake Shore Drive will flood first, it should be easier to prepare for flood fighting and for redirecting traffic.

The mitigation, or impact reduction phase, enters into decision-making when at least one of the following impressions have been made. The impacts suffered were too costly. We cannot afford to suffer these same impacts again. The risk to our investment is unacceptable. Of course, this would also depend on one's time horizon and the severity of impacts. As logical as this appears, it is not what occurred in Chicago following the February 8, 1987, storm. The city spent close to $2 million to replace structures as they were, in order to open the public beaches on time. Apparently the community goal of providing recreation facilities outweighed the risk of losing the same facility again.

When, or if, impacts are repetitive, the emphasis on mitigation increases greatly. The decision to change approaches becomes readily apparent when an earlier decision proves to bear no influence on the outcome. In fact, it was this repetitive cycle of damage-reconstruction-damage-reconstruction that led the federal government to reconsider the manner in which disaster assistance is provided. Simply helping people and communities regain their footing to equal a predisaster condition merely reestablishes the original vulnerability so that it could happen again. The private sector responds in a similar economic fashion. They will respond to protect their investments. If substantial or repetitive losses are suffered, adjustments are mandated.

The Decision-Making Environment of the Great Lakes Private Sector

I have frequently, and intentionally, used the concept of "acceptable risk." This concept, a combination of simple and sophisticated relationships, is at the heart of any decision to undertake any hazard-induced response, mitigative or not. With every natural process—flooding, tornadoes, earthquakes, hurricanes—there is a certain degree of risk, based on probability, that is derived from geophysical facts. It is more likely to flood next to a river than far away from it. One is more likely to experience the effects of a hurricane in a coastal community than in one that is 1,000 miles inland. An earthquake is more probable in California than in North Dakota.

Separate from risk is vulnerability. While risk identifies a calculable certainty that an event may occur, vulnerability identifies the exposure of systems and investment to that risk. For example, there is always a risk that a dam, say in Wyoming, may fail. However, if there is no development downstream from that dam, there is little or no vulnerability to that risk, since any resultant flood will occur without causing any damage.

Tornadoes occur frequently in the Midwest. We can identify the conditions within which they are likely to form, and we can identify them, sometimes, on radar in time to provide a 1- to 20-min warning. We can even design structures to better withstand the extreme forces of a tornado. However, there is a randomness to their distribution that subjects people to a posture of defenselessness beyond these measures. There is a feeling of having limited our vulnerability to an acceptable level, despite the annual destruction and disruption tornadoes cause.

Along coastal areas susceptible to hurricanes, new construction is often regulated so that it occurs set back behind frontal dunes and elevated above known or expected inundation heights. Coupled with sophisticated construction requirements, the vulnerability to impacts has been significantly decreased simply through the reduction of the exposure to risk. In specific locations across the country, the purchase and demolition, or relocation, or prohibition of structures in repetitively impacted high-hazard flood zones have entirely eliminated the vulnerability to risk. It still floods, and there is a given risk to that flooding occurring. However, the removal of systems and structures exposed to that risk eliminates the vulnerability. The cost, or potential cost, of the existing vulnerability was too much to pay; the risk, given that vulnerability, was unacceptable. In the tornado example, the risk and vulnerability have been balanced. In the dam failure scenario, there was no vulnerability to begin with. Both situations are examples of "acceptable risk."

This is critical to any analysis of private (or public) sector roles and responses to the changing scenario of the fluctuating levels of the Great Lakes. Since there is a benefit and a cost to any adjustment that is undertaken, it is crucial to be able to determine, to the best extent feasible, what the risks and vulnerabilities are, and what level of each is "acceptable."

Unfortunately for the decision makers who need to make these determinations, the previous presentations in this colloquium have described the range, variety, and uncertainty of available data to support them. Will the lakes continue to fluctuate? Which direction? At what rate? To what extent? When? What is the range of expected impacts, for both high and low water levels? Whose interests will be affected, public or private? Will the impacts be short term and isolated, or long term and widespread? How does one choose an action among such uncertainty? How can one determine an acceptable level of risk without the answers to these questions?

Compounding this dilemma, we have heard analyses of the techniques and strategies available once a decision to address an "unacceptable risk" has been made. When are structural techniques more appropriate than nonstructural techniques? What methods are favorable in determining costs and benefits within each field of techniques? How are location, timing, and cost implications addressed in selecting strategies? How can the realm of possibilities be coordinated so that the most appropriate choices surface?

We have reviewed apparent policy conflicts. Often, the little assistance that is available promotes repair or replacement that is susceptible to repetitive impacts, or can only provide limited protection in limited areas where there is an imminent threat. What is available often excludes the private sector or is not coordinated with the diverse, often competitive, interest of the private sector. What policies exist that require certain actions? What incentive exists to encourage private sector participation?

We have examined the multijurisdictional interests and coordination. Incentives and restrictions to private sector interests vary from jurisdiction to jurisdiction, as does the cumulative impact of their actions on others. Hazards do not recognize political, administrative, or economic boundaries. Obviously, different interests, vulnerabilities, incentives, and constituencies can only further complicate the options.

Who is the Private Sector?

Identifying the Stakeholders

Having reviewed the fundamentals of emergency management to determine why and when hazard management activities are pursued, and having reviewed the uncertain environment within which risk must be reconciled with vulnerability, I have established the framework to move towards defining private sector roles and responses.

Fundamental to successful hazard mitigation responses is following a hazard assessment with a stakeholder analysis. In order to develop, design, and implement any successful hazard management strategy, it is imperative that all of the stakeholders and their interests be identified. Only then can a concept or strategy that maximizes the most benefits to the most people be determined. It is the process for creating "win-win" situations.

First-level private sector stakeholders are those directly impacted by the fluctuations of the Great Lakes surface elevations. Most obvious are those property owners adjacent to the lakes. Wind and wave action has increased erosion rates such that significant property losses have occurred, both to raw land and structures. Shoreline businesses suffer, as do recreation users. High water (as well as low) causes direct effects on many interests, from shipping to utility systems.

Second-level private stakeholders are those that are not affected directly but suffer the consequences of the impacts in other than direct damages. The banking and insurance industries are prime examples. Their offices are not commonly located along the shoreline and thus do not suffer direct impacts. In fact, many of these second-level stakeholders may not be located in shoreline states. The effects, however, are quite real. Where policies allow, the damages that do occur are paid for by insurance companies. Where they do not, mortgages and business loans are jeopardized. Tourist support industries are impacted by damage to recreational facilities, or even just the perception of damage. Commuters who use damaged roads suffer delays. In times of low water, the economic impact on shipping, and thus on sales and manufacturing, would be easily felt.

Third-level private sector stakeholders are those who are not impacted negatively, but rather derive a benefit. The opportunities of engineers, consultants, and planners to earn a livelihood are increased as others seek protection from the onslaught of high waters. Construction firms profit from the need for protective measures. These benefits are increased further in an environment where local and state governments have chosen privatization as a means of increasing productivity while decreasing liability. Another brand of third-level stakeholder is the growing number of private sector interests that contribute to a community's goals in order to improve good will, be responsible residents, enhance their promotional character, and perhaps earn a needed tax deduction. Dow Chemical and Coors and Miller breweries have done so.

Fourth-level private sector stakeholders can be described as those who are not directly impacted and derive no benefits, yet still choose to participate in hazard management activities. The mainstays of this category are service, volunteer, and church organizations. There are even examples of the private sector going to such lengths as setting aside funds specifically designated to assist those impacted by disasters. There is a growing trend toward the participation of special foundations.

So the set of stakeholders, the private sector interests that are affected by the impact of fluctuating lake levels, is a much broader group than one might first anticipate. Of course, this further complicates the identification of private sector roles and responses. Each entity's priorities and needs will vary, as will its perception of its vulnerability, options, and its determination of what is an acceptable risk.

Roles and Responses

As discussed in earlier presentations, there exists a wide array of available options. They do not necessarily vary from the public to the private sector, other than in the speed with which they can be accomplished once decided upon. The primary deterrents to private responses, though, are providing a benefit for others that may not be willing to share in the cost, the inability to develop a response that doesn't adversely affect others, and the difficulty in coordinating and funding projects large enough to solve the concerns of a larger group.

The solution will lie in a shared public-private responsibility, and that is an area where the private sector can play a tremendous role, particularly if combined with the goals and objectives of economic development. Experience has demonstrated that hazard mitigation initiatives are more readily accepted by both private and public sectors when a multiobjective planning approach is considered. Since normal planning activities already take place in nearly every community, and since community values and goals dictate the direction and priority of these activities (for example, capital improvement and improved recreation), a most natural merging of objectives can also accomplish hazard management goals without the need to raise additional capital and increase staffs.

Responses, as well as roles, also deserve closer inspection. There has been much discussion around the Great Lakes of building islands, creating landfills, constructing breakwaters, building revetments, stabilizing shoreline banks and bluffs, and restoring beaches. For the most part, these would be major public projects, but small protective structures could be undertaken by industries, homeowners, condominium associations, marinas, and the like. Smaller-scale options could also include individuals elevating or relocating structures, or more likely, changing the manner in which a structure is utilized. Referred to as "wet floodproofing," this strategy allows water to interact with structures but minimizes impacts by relocating utilities and personal property to a location above the level of anticipated inundation. Other techniques include protecting access, setting back new development, and purchasing insurance.

A major obstacle to any innovative response is the amount and value of existing investments. In areas of intense development, like Chicago, there may be no options other than structural protection on a sporadic basis, or no action. Many communities now approach hazard management with preimpact and postimpact plans. They do what can realistically (technically, legally, politically, and economically) be accomplished prior to any damage, and they plan for the redevelopment of those areas that will eventually be impacted, either as a result of destruction or decay. The result is an improved use of the land and an appropriate use of existing resources. When these postdisaster redevelopment plans have been designed, discussed, revised, and approved in the less stressful environment of predisaster times, the chances for successful implementation, when necessary, are greatly improved. As with any other planning strategy, there is also a middle range of compromise. Retrofitting structures with certain protective measures upon attrition of the property is one such example.

Similarly, lending and insurance institutions could explore the feasibility of limiting the availability and increasing the cost of their services in identified high-risk areas. Without restricting development, an incentive for sensible construction and land use could be developed that would protect and preserve everyone's interest. Conversely, lending institutions could establish reasonable loan programs specifically for the elevation, relocation, or approved protection of vulnerable structures.

In areas of less intense development, strategies such as the Transfer of Development Rights (TDR) should be explored. This simple concept actually allows for the implementation of public goals and objectives at the voluntary expense of the private sector. Given the right scenario, TDR creates an ideal win-win situation where an open-space buffer zone can be created, and development and enterprise can occur in a profitable manner.

While private sector support and adherence to existing codes and regulations could lessen some impacts, there must be a long-term alliance of the public and private sector to allow space for natural processes to occur. As long as our actions, policies, and laws are significantly influenced by our economic system, one can never reasonably expect an end-all solution. Add to this the complexity of the jurisdictional issues, and the no-action alternative deserves serious consideration. The difficulty, if not impossibility, of a coordinated set of solutions lies in the high degree of uncertainty of events, as well as responses and the differing perspectives of the stakeholders. Those fluctuating lakes that have been successfully managed (and there are some) reflect the accomplishment of these objectives through public regulation, primarily of infrastructure that supports further intensified use of identified hazard areas. Common to each, though, was a clear definition of both the risk and the vulnerability, limited jurisdictional issues, and community concurrence on an unacceptable risk.

WHAT DOES THE FUTURE HOLD?

When approximating private sector roles and responses to fluctuating lakes or any hazard, we can reasonably expect that the private sector will do what it does best: react in an economic decision-making fashion and seek whatever public financial assistance is available. However, whenever the situation warrants (which is when a determination of unacceptable risk has been made), we can expect actions to be undertaken that are specifically intended to serve and protect the private sector's own interests. The results will often be independent, unrelated, and uncoordinated efforts that could easily complicate further the opportunity to mold a unified and comprehensive approach. However, such an approach may be impossible in any event.

If that is a realistic appraisal of the private sector, then at most there are three options for the public sector to pursue: (1) adopt regulations designed to protect ourselves from ourselves, (2) create incentives that encourage and stimulate private sector participation and contribution towards meeting public objectives, or (3) do nothing. Ideally, regulations that provide a positive incentive to private interests would stimulate measures to be undertaken that serve not only private interests but also the public welfare.

There are several current legislative initiatives that will have some bearing on private sector responses. Amendments to the National Flood Insurance Act of 1968 were signed into law recently (February 5, 1988) as part of the Housing and Community Development Act of 1987. These amendments allow the National Flood Insurance Program to purchase structures that are condemned by state or local authorities because they are "subject to imminent collapse or subsidence as a result of erosion of undermining caused by waves or currents of water exceeding anticipated cyclical levels." This law addresses a serious problem of those concerned with coastal flooding and erosion by effectively purchasing and removing flood-prone structures rather than paying for damages, debris removal, and associated emergency response costs. However, this effort provides only the incentive to purchase insurance at a low cost in time to provide extensive coverage for damages. While there is a two-year purchase and maintenance caveat and a $185,000 cap on this particular coverage, this legislation provides a substantial subsidy to a few at the expense of many more taxpayers, while creating additional concerns in the process. It forces an insurance program to pay for damages that have not occurred, and while it partially restricts the reuse of that newly vacated land, it does so with setback standards inconsistent within its own purview, and with the rest of the program as well. Also, it is unlikely that a structure that is truly in imminent danger can be condemned by local government, assessed and settled by the federal government, and relocated in a time frame that would prevent destruction.

Other legislation that carries significant impacts are the proposed amendments to the Disaster Relief Act of 1974. First, states would be eligible to receive limited matching funds to allocate specifically toward mitigating future damages, a source of funding that has been sorely lacking for years. Second, available federal disaster assistance for property owned by government agencies or private nonprofit organizations located in identified special flood hazard areas would be reduced by the maximum amount of flood insurance that was available, regardless of whether or not it was purchased and in force.

Regulation, as a response to fluctuating lakes, may be a typical recourse. When a risk becomes unacceptable to the public, regulation occurs. An innovative programmatic example comes from the state of Michigan, where a low-interest loan program was authorized to improve a structure owner's ability to elevate or relocate disaster-prone lakefront property. While the effectiveness of this program is questionable, that is related more to the restrictive program requirements than to the interest or intent.

At best, governments should strive to provide incentives, establish priorities, develop strategies, and demonstrate leadership that encourages and stimulates private sector activities that protect those interests, while contributing to the greater task of the protection of the health, safety, and general welfare of the public. Authorizing funds for loan programs, banking a transfer of development rights, coordinating or conditioning disaster assistance with other programs, directing subsidies of development supporting infrastructure, or providing tax incentives each contributes to this process.

Hazard mitigation planning models vary, but they all include the same primary element, hazard identification and risk assessment. Before effective action can take place on a scale as large as the Great Lakes, whether by individuals or by public programs, there needs to be a definite determination of the hazard. As suggested, I do not think this has occurred. I am not sure it is possible. So, how does this affect one's choices? There is still time to evaluate all of the available information and make a decision regarding one's particular vulnerability. Governments should consider, out of practicality and expense, exploring joint private and public efforts, and developing incentives for action, but taking little other action on behalf of private sector interests.

After all, why should erosion be a surprise or a problem? Weren't the Great Lakes formed by erosion, albeit on a much grander scale? How often have damages to improved property occurred, and who is really at fault? How much havoc did the damage create? Was there a distinct separation of impacts to private and public sectors? Is it more effective, at present, to allow Lake Shore Drive to be flooded once every few years, and simply close it and implement a standby traffic plan? Does it make sense to consider a new landfill, with a new road, to protect the old landfill and old road? When was the last time humans truly, successfully, out-built Mother Nature on a grandiose scale?

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PROVOCATEUR'S COMMENTS

John Stolzenberg
Wisconsin Legislative Council

Because I find that a lot of people don't know what the Legislative Council is, let me start by explaining that it is a nonpartisan service agency of the Wisconsin state legislature. Thus, I'm not an academic but a policy adviser to the Wisconsin legislature.

In general, I agree with what Clancy Philipsborn said. He has a *very* broad subject to address, and it's interesting to see it through the eyes of a hazards mitigation manager. I want to comment on three things. One is to add a consideration on "acceptable risk" to his discussion of what the future holds. Second, I'd like to elaborate on what I feel are some of the interesting facets of the interplay between public and private responses as they relate to private interests affected by fluctuating lake levels. And third, I will conclude with a comment on program priorities.

In terms of "acceptable risk" and the section of his paper headed "What Does the Future Hold?", I would submit that a private party's perception of the risk from an extreme lake level, and how he or she responds to that risk, that is, how the person makes it "acceptable," will be influenced by a number of things in addition to the public sector regulations and incentives mentioned in this part of the paper. In particular, a person's perceptions of what are viable alternatives for dealing with a lake level problem aren't fixed. They can and do change over time, and this, in turn, means that there's another role for the public sector. I'm referring to the third major role of government, which I am sure participants here today are very much aware of, namely, education. As we all know, education will influence affected peoples' perceptions of what are acceptable alternatives and risks.

In Great Lakes issues, education already plays a major role. To see examples of organizations fulfilling this role, one has only to look at the efforts of Sea Grant, Coastal Zone Management, and the Great Lakes Commission.

Turning to the interplay between public and private responses relating to private interests, I note that the paper starts by focusing on aspects of the private sector roles. I agree that often these roles can't be separated. So why do private parties, especially landowners, often seek the help of the public sector, and how and why does the public sector respond? I think these are points that deserve further research.

As a starting point, I submit that landowners typically would like to solve their lake level problems on their own and not be hassled by other people. However, they quickly realize that, as a result of the three deterrences identified by Philipsborn as well as potentially large out-of-pocket outlays and the perception, correct or not, that a preferred solution is controlled by government actions, they are literally swamped by "the solutions."

So how does a public sector decision maker, like a state legislator, respond to shore owners' pleas for help? I think the decision maker takes into account a number of factors that are worth mentioning.

One factor that will certainly be considered is the politics. I mean, if I represent a lakeshore district and my constituent approaches me about a problem, I'm going to respond differently than if I live in LaCrosse and am approached about Milwaukee residents' problems.

Second, a decision maker would also look at the "public benefits" of helping the private property owners. This is a subject that needs more examination. What are the public benefits for taking public actions on or in relation to private land? I've identified five benefits; I'd hope others could expand the list. Certainly, one area is to protect public investments in public facilities. For example, if you build a sewage treatment plant or redo a park beach and then somebody updrift wants to put in some hard structures, that is going to influence your investment. A second reason is to preserve the tax base. There are some communities, such as a sparsely populated, unincorporated town, where a significant portion of the town's tax base may come from the lake front property owners. Here public shoreline protection actions help indemnify the town against a decrease in its tax base. Another reason would be to hold down future costs, once the government has made an initial commitment to protect the private property. Then there's the murky area of economic development and the role of shorelines in tourism and real estate development. More and more, economic development is cited in the legislature as justification for public actions on private areas. Finally, another public benefit relates to fish and wildlife management on private land. I'm not sure of the relative importance of this public benefit, as I don't know how much of the coastal wetlands are owned by private parties. Also, at least in the Wisconsin legislature, most of the Great Lakes fishery issues focus on offshore fisheries.

A third factor that a decision maker will consider in providing public support for private facilities and property, is the type and scale of the regulatory quid pro quo that may be imposed as a condition of providing the financial assistance. The controls that accompany national flood insurance are an example of such an exchange.

A fourth and final factor that a public sector decision maker would consider, perhaps implicitly, involves the decision maker's perception of the risk being borne by the affected private parties. I would submit, for example, that how the public will respond through its elected bodies to helping a private landowner with an expensive fluctuating lake level problem is going to be considerably different from how a government responds to someone who has a well contaminated with toxic chemicals. The contaminated well may cost less to fix than shoreline controls, but the well is a much greater health threat, and this changes the perceptions of the risk.

The final observation that I would like to make is that there's a lot of discussion and development of programs under way relating to fluctuating Great Lakes water levels. An underlying assumption in these efforts seems to be that we need a coordinated, comprehensive policy to help us move forward in dealing with these problems. I agree with the desirability of a comprehensive policy, though I'd make a distinction between development of the plan in a coordinated and comprehensive manner and the implementation of the plan. Quite simply, implementation is not going to come in one fell swoop. The resources are not there, and the responsible institutions couldn't handle it even if the necessary resources were available all at one time. So I pose these questions to the Great Lakes experts:

1. What should the priorities be? For example, which shoreline areas should be addressed first, those that will protect public land

or public facilities or any area with the highest erosion potential, irrespective of ownership? and

2. How much time is available before "unacceptable" damages are likely to be incurred?

Answers to questions such as these will help both public and private decision makers concerned with fluctuating Great Lakes water levels.

Panel Discussion: Global Climate Change

Climate Change in the Great Lakes Region

WALTRAUD A. R. BRINKMANN
University of Wisconsin-Madison

The Great Lakes region is small enough so that temperature anomalies are generally of the same sign basin-wide. The long-term trends in temperature that have occurred in the Great Lakes region during this century have been very similar to the trends in the average surface air temperature for the Northern Hemisphere. The early part of this century was relatively cold; this was followed by a period of above average temperatures from the 1930s to the mid to late 1950s, followed by a return to lower temperatures. There is some indication of a swing back toward higher temperatures in recent years.

Precipitation changes in the Great Lakes basin have been more complex because precipitation is generally much more variable over space as well as over time as compared to temperature. Specifically, there is a climatological—a precipitation—boundary that divides the region into a northwestern and a southeastern portion; the boundary is a result of shifts in the importance of the two major storm tracks across the basin. This has led to precipitation trends over the two portions that have often been in opposition and sometimes been similar.

Climate changes determine natural changes in that portion of the total water supply to a lake that is generated within the lake basin itself (the sum of lake precipitation plus runoff minus lake evaporation)—referred to as "net basin supplies." Changes in precipitation onto the basin will result in changes in lake precipitation as well as in the amount of runoff. Changes in temperature will also have an effect on net basin supplies since temperature is in a complex way related to lake evaporation. However, evaporation removes less than half of the natural water input (from lake precipitation and runoff) into the Great Lakes. It is therefore precipitation that drives the system. There is, consequently, a poor and sometimes opposite association between the net basin supplies to Lake Superior and supplies to the lower lakes (particularly for moderate supplies); and it is this that makes Lake Superior useful as a reservoir—one of the bases of current lake level management. Extreme net basin supply events have, however, been basin-wide at times, and these have led to the low waters of the 1930s and 1960s, and the high waters of the 1950s, 1970s, and 1980s.

What about the future? We are still not very good at making forecasts for decades in advance. Perhaps the recent trend of alternating extremes in water supplies will continue; but we do not really know. At a longer time scale, the effect of increasing atmospheric carbon dioxide concentrations will become important. But here, too, there is uncertainty. The uncertainty is not with the trend in carbon dioxide but with the effect of this on the climate over the Great Lakes region. All general circulation models predict an increase in temperature over the region with a doubling of carbon dioxide, although the magnitude of the predicted increase varies somewhat from model to model. An increase in temperature could lead to an increase in evaporation. Concerning precipitation—the climate parameter that drives the system—the models do not even agree on the sign: some predict an overall increase, and others predict an increase for one season and a decrease for another.

The predicted changes in precipitation are to some degree related to predicted shifts in circulation patterns. Therefore, another important question to consider is how circulation shifts will affect the lack of association or sometimes out-of-phase association between the upper and lower lakes that has been a characteristic of the net basin supplies to the lakes.

Climate Change: The Knowns and Unknowns

STANLEY A. CHANGNON, JR.
Chief Emeritus
Illinois State Water Survey

I have considered herein the climate change issue within the context of the Great Lakes. Hence, I have focused my comments more on regional than global scale change and I have reviewed some major knowns and unknowns from my perspective. I am an applied climatologist and have principally studied the climate of the past 100 years in the Midwest and North America; I am not a global climate change expert nor modeler. As an applied scientist for the past 35 years, I have interacted with a wide variety of private and public sector representatives at the local, state, regional, national, and international levels. Thus, my comments about climate change are based on my own scientific research and on observations about what current knowledge of climate change means to those who function in the region.

Obviously, we know that the earth without human influences has experienced some extremely wide shifts in climate; here where Chicago stands there have been past epochs with tropical forests and others with glaciers nearly a mile thick; hence, people and their waste products are not needed to change the climate dramatically. Natural forces, as yet poorly understood, have made and are making the climate change.

I see four major uncertainties relating to the issue of global climate change that have specific reference to the Great Lakes (or any other region). These are:

1. In what way, in the near climatic future (50 to 100 years), will various climate conditions depart from their 50- to 100-year current averages, and more importantly, what will be the change (if any) in interannual and interdecadal variability?

2. How rapidly can or will the climate conditions shift, either in their averages and/or in their extremes?

3. Can man somehow affect the natural climatic processes and will natural forces tend to counteract or amplify the signal?

4. Can our society adjust its most weather-sensitive activities (agriculture and water resources) to the changes? Most experts in impacted sectors believe that if the future shifts are moderately slow (multidecadal) and the future variability does not become too great, satisfactory adjustments can be made. . . . Is it true?

The three most common questions posed to me by those in weather-sensitive activities are: Will the climate change that some atmospheric scientists are predicting occur? Why is there no specificity at the regional (action) scale over what weather conditions will change, the magnitude of change, and when? Third, will the changes *really* bring on severe impacts and require such adjustments that society cannot adapt to the change in a satisfactory manner?

What do we really know? Based on the past 140 years of water level records on the Great Lakes, we know that the climate has fluctuated considerably, sufficient to produce a 3-ft range in lake levels around the long-term average. We also know that the record extremes have occurred quickly, within a period of 20 years, and we also know that shorelines and human activities have been considerably impacted by these shifts.

Furthermore, we know that climate conditions in the Great Lakes Basin prior to the past 100 years have been more extreme than anything we have sampled. In fact, during the last 2,000 years climate conditions have been both much wetter/cooler and warmer/drier than anything we have experienced since 1860. Interestingly, if one uses Larson's historical lake level reconstructions, one can project that the Great Lakes Basin is in a period that will be wetter and cooler over the next 100 to 200 years. This possibility for natural conditions is in opposition to a future drier climate that the carbon dioxide models seem to predict for the area over the next 100 years. If both tendencies alone are correct, how will the two interact? This is an interesting scientific issue and one that is unresolved.

We further know that the climate in the Great Lakes Basin over the past 100 years reveals a distinct trend, particularly emphasized during the last 50 years, to a cloudier, cooler, and wetter regime. The past 15 years have been the wettest period in the modern history of the Great Lakes; as a result, two periods of record high levels have been experienced (1970s and 1980s). Given this evidence, it is not surprising that it is difficult for those impacted by weather in the region to get too concerned over a predicted change in climate of uncertain magnitude and timing.

Most climatologists agree that current science lacks the capability to make climate predictions for periods beyond a few months ahead, and that without this capability, the past is the best predictor of the future. The past at this time is not indicating a shift in climate in the direction that many climate modelers claim will occur. Thus, predictions of an indeterminant change in regional climate based on models limited by the data included and the assumptions used appear out of place and without much skill. But, we know that there have been marked regional and large-scale changes in climate.

What do we know more specifically about inadvertent (man-made) climate change? Major urban areas in the basin such as Chicago and Detroit, modify every aspect of their climate and change clouds and precipitation 100 km beyond them. We also know that large industries, cooling facilities, and jet contrails increase clouds, but if other man-made climate changes exist, they are lost in the noise of natural variability of climate.

I believe that those who predict a man-induced climate change of severe proportions over the next 25 to 75 years must provide more compelling evidence than exists now and must become much more definitive about the spatial and temporal features of change before climate change will become a major regional issue leading to action. When will the change occur? Will it be warmer or cooler, wetter or drier, over all or portions of the basin? Will there be more or less variability, and greater extremes of wetness and dryness than those of the past 100 years? Convincing answers to such questions must be provided before major decisions and plans are made.

Economic Research, The Greenhouse Effect, and Fluctuating Great Lakes Water Levels

RICHARD F. KOSOBUD
University of Illinois at Chicago

Economic research into long-run climate change induced by atmospheric trace gas accumulations has sought to develop frameworks for appraising the contributions of economic activity to these accumulations and the feedback impacts of changing climate on economic activity and welfare. The ultimate aim is to evaluate policy choices. Three frameworks, or models, have been developed that continue to be actively studied and that have potential application to a study of changing climate implications for hydrologic systems such as the Great Lakes. My object is to describe, briefly, these models and their potential applications. I must state right off that, in my view, the results to date of research just begun do not lead to deterministic predictions of catastrophic difficulties nor to policy prescriptions such as heavy taxes on fossil fuels; rather, these frameworks at present provide an interesting way to think about the long-run future, shrouded in many uncertainties as it is and smudged with our present state of ignorance. These frameworks can also direct our attention to critical areas for our research effort.

Economists have so far applied mathematical programming (MP), computable general equilibrium (CGE), and midlevel sectoral (MS) models to possible greenhouse effects and their consequences. Each has strengths and weaknesses that I can hint at by describing the essential stages of the problem that the models must investigate. First, I will introduce some economic jargon because here it is useful: I will define an environmental quality function to be a relationship showing how economic activity affects the states of nature or human affairs beyond the market or central planner calculations. The economic models must be extended to take these externalities into account. I will define an environmental damage function to be a relationship showing how we could, in principle, attach benefits or costs to these external impacts, including impacts on Great Lakes variables.

All three models contain detailed specifications showing how, over the long run, global and regional economic activity consumes fossil fuels that emit carbon dioxide and perhaps other trace gases into the atmosphere. To projections of economic activity of these economic models must be added environmental quality submodels indicating how trace gases accumulate, how this leads to changing climate, and how changing climate affects the Great Lakes, among other systems. Finally, an environmental damage submodel must be added to permit benefit-cost calcuations and policy appraisal. All this is no small order!

The MP model maintained at the University of Illinois contains less detail on the economy but more information on energy technolgies and changing least-cost use of these resources over time as prices rise, e.g., for depleted oil. The MS model maintained at the Oak Ridge National Laboratory contains great detail on energy sectors and regions, but must be solved for future time paths in stages. The CGE model maintained at Vanderbilt University permits appraisal of impacts on different income groups, but is limited as to size.

All models permit projections of long-run economic growth paths with attendant demands for energy consumption and trace gas emission. Aspect of the models can be varied to reflect the range of expert opinion so that the range of projections that result enable us to measure uncertainty, a vital task in this uncharted area. Granting these uncertainties, how do we specify the environment quality and damage functions?

Concentrations of trace gases in the atmosphere depend on complex interactions among the atmosphere, oceans, and biota. Most of the models, for example, assume a carbon cycle in which slightly less than half of the carbon dioxide emitted remains in the atmosphere. Trace gas accumulations give rise to the well-known greenhouse effect and hence to changing climate. Many uncertainties remain about how the stochastic processes of climate will be affected, and what weather manifestation changes, such as observable precipitation, temperature, cloudiness, and wind patterns, will result. Much research effort is being put into general circulation modeling of changing climate both globally and regionally, and economists look to further results with great interest because adding this submodel is crucial.

For our purposes, what is important is the impact of these changes on climate-sensitive sectors that are likely to include agriculture and hydrological systems, among others. What we can add to our framework models are those hydrological models that allow for climate variable impacts on water levels, run-offs, and other characteristics. Continuing to focus on impacts on the hydrologic system, we may append to our frameworks a specification of the water supply dependence on such variables as precipitation and evaporation (the latter in turn depending on temperature). This relationship can be intricate, and its parameters can be highly uncertain. Many observable manifestations of climate besides precipitation and temperature may be important, for example, cloud cover and wind patterns. Our framework permits experimentation with alternate specifications so that we can study the consequences of changing one feature, and then another in order to project long-run implications. This ability to simulate alternatives is the great merit of our approach, given the enormous gaps in knowledge.

My own survey of hydrological research indicates a number of models under development that we can add to and test within our frameworks. A particularly difficult hydrological issue is the variability question of changing climate and its relationship to fluctuating water levels. The variance rather than the level of these variables may be important, and it will be challenging to estimate changes of variances within our projection framework. However, we can examine the historical record and we can by careful study "transplant" to the Great Lakes area other regional climates that may be closer to future long-run patterns and in this way "think about" fluctuating water levels.

Our final stage is to estimate benefits and costs of these altered hydrologic, and other sectoral, patterns and hence provide a guide to appraisal of public policies. Most research into the greenhouse effect has gone into earlier stages such as the carbon cycle and the issue of changing climate. I argue that what is needed now is an increase in the share of effort devoted to studying the later stage long-run impacts of changing climate on systems such as the Great Lakes and the consequences for human welfare and for policy. Preliminary work has begun. I suggest that sustained research is called for. The economic frameworks I have outlined provide, in my view, a promising approach.

Climate Change and Great Lakes Levels

MARIE E. SANDERSON
University of Windsor

The Great Lakes Institute of the University of Windsor has completed two research contracts on topics related to climate change and Great Lakes levels. The first was for the Atmospheric Environment Service (Environment Canada) on possible climate change and the impact on lake levels, navigation, and hydroelectric power generation on the Great Lakes (summary appeared in Climate Change Digest #3, 1987). The second (just completed) was for the Donner Canadian Foundation on future lake levels and the hydrologic, environmental, and political impacts.

In the first study, the Canadian Climate Centre of Environment Canada provided to the researchers a projection of climate conditions in the Great Lakes Basin with an atmospheric carbon dioxide (CO_2) concentration twice that of preindustrial times ($2 \times CO_2$). The data on monthly temperature and precipitation represented the modified output of the Goddard Institute of Space Studies' (GISS) General Circulation Climate Model. The average annual warming in the Great Lakes Basin projected by this model is approximately 4.5°C, slightly more in winter and less in summer. Annual precipitation is projected to increase approximately 8 percent for points in the central and western basin, but to decrease by 3 to 6 percent in the eastern basin. There are, of course, many assumptions and uncertainties in such large-scale models, and the outputs are very tentative estimates of future climate for any specific area. An additional problem in applying the output of the model to the Great Lakes Basin is the fact that there are only 10 data points in or near the basin.

Our researchers were also provided with three sets of data from a Great Lakes hydrologic model from the Inland Waters Directorate, Environment Canada. The years 1900-1976 were used as the basis-of-comparison period (BOC). The BOC data showed average annual lake levels and flows that would have occurred during the period 1900-1976 under current diversions, regulation practices, and physical conditions of the lakes and connecting channels (diversions include 142 m^3s^{-1} into Lake Superior via Long Lac and the Ogoki River, 91 m^3s^{-1} out of Lake Michigan at Chicago and 198 m^3s^{-1} from Lake Ontario through the Welland Canal). Thus, with these assumptions, the variability seen under BOC conditions is due to changes in climate only. During the BOC period, the variability of average annual levels ranged from 0.99 m for Lake Superior to 2.14 m for Lake Ontario.

A second set of data gave the levels and flows (for the period 1900-1976) that would occur under the GISS $2 \times CO_2$ climate scenario. The average level of Lake Superior was seen to decrease by 20 cm, of Michigan-Huron by 60 cm, Erie by 44 cm, and Ontario by 85 cm. A third set of data gave lake level and flow data for $2 \times CO_2$ climate plus the impact of increased consumptive use of Great Lakes water as projected by the International Joint Commission in 1981 for the year 2035. In this scenario, average lake levels decreased by an additional 10 to 20 cm. The graph (Figure 1) shows the levels that would have occurred on Lake Erie during the period 1900-1976 under these three scenarios. It is seen that the frequency of occurrence of extreme low levels as in the 1930s and 1960s could increase to 75 percent of the time.

For the Donner study, we continued and expanded our modeling work on climate change and lake levels. We used the Geophysical Fluid Dynamics Laboratory (GFDL) as well as the GISS model output and refined the net basin supply models. In the Great Lakes Basin, the projected average GFDL monthly temperature change is 1.5°C less than in the GISS model. Our refined runoff model gives monthly as well as the annual runoff amounts previously obtained for the GISS model. For Lake Erie we found that runoff during the BOC period averaged 81 cm depth on the lake surface, whereas under GFDL conditions it was 68 cm, and under GISS condition, 61 cm.

New estimates of over-lake evaporation under the two climatic change scenarios were also determined, and increases over BOC conditions were seen, especially in the high-evaporation period

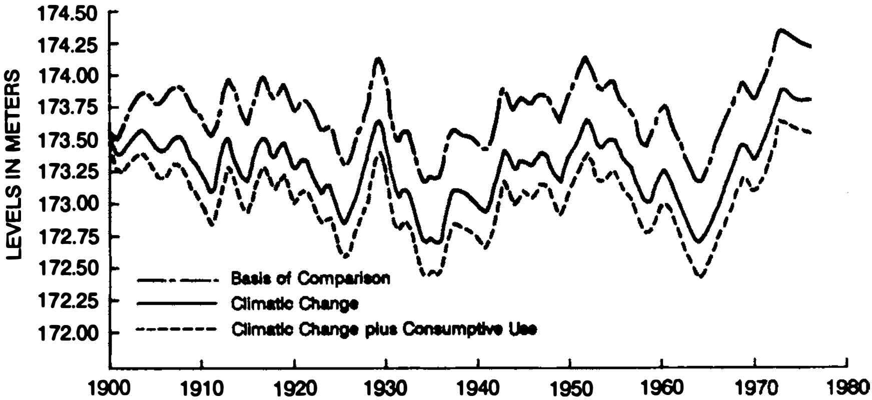

FIGURE 1 Lake Erie levels, 1900-1976.

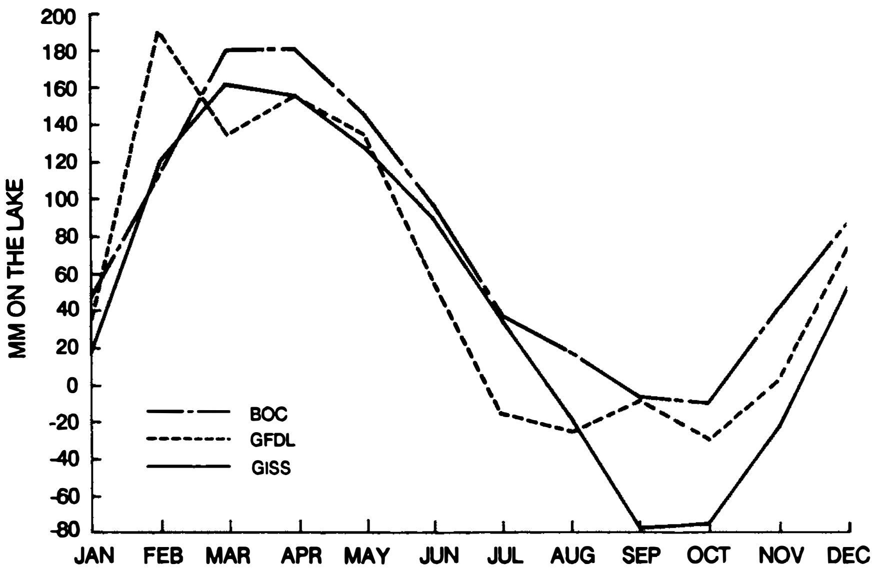

FIGURE 2 Lake Erie net basin supply. Monthly averages, 1958-1983.

September-December. Overall, net basin supplies were found to decrease (as in Figure 2) with GFDL showing less decrease than GISS projections.

In addition, we examined the potential effects on Great Lakes levels, under climate change scenarios, of large-scale diversions into the basin, such as the Grand Canal scheme. We found that a diversion of 1560 m^3s^{-1} into Lake Huron from James Bay would increase Lake Erie levels and compensate for the lowering of the levels under the GISS scenario. Under the GFDL scenario, Lake Erie levels would be raised 45 cm above historic levels, thus introducing the possibility of the export of water southward. It is seen from the above results that our Great Lakes hydrologic response model permits many different future scenarios of Great Lakes levels to be explored.

Preliminary Results From EPA Study of Impacts of Global Warming on the Great Lakes Basin

JOEL B. SMITH
U.S. Environmental Protection Agency

In 1986, Congress asked the Environmental Protection Agency to conduct two studies on global warming. The first study would examine options to limit emissions of greenhouse gases. The second study, which will be referred to as the Effects Report, ". . . should examine the health and environmental effects of climate change. This study should include, but not be limited to, the potential impacts on agriculture, forest, wetlands, human health, rivers, lakes and estuaries as well as other ecosystems and societal impacts."

My presentation to the Colloquium on Great Lakes Water Levels will review some of the preliminary results from the Effects Report relevant to the Great Lakes Basin. Since the results have not been peer reviewed, they will not be available for citation or quotation.

GOALS FOR THE EFFECTS REPORT

The goal of the Effects Report is to try to give a sense of the possible direction of changes from a global warming as well as the magnitude. We are examining some of the following issues:

- The range of effects under different warming scenarios;
- Sensitivities of systems to changes in climate;
- Regional differences among effects;
- Interactions among effects on a regional level;

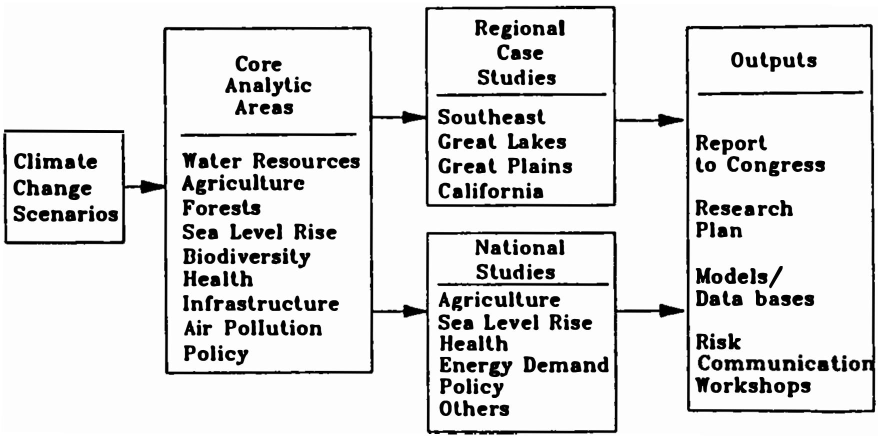

FIGURE 1 Elements of Effects Report.

- Uncertainties; and
- Policy implications.

ELEMENTS OF THE EFFECTS REPORT

The elements of the Effects Report are displayed in Figure 1. We will use climate change scenarios (described below) to examine potential changes in core analytic areas on a regional and, in some cases, national level. We are studying impacts in these analytic areas in the Great Lakes, California, the Southeast, and the Great Plains. In addition, we are conducting national studies on agriculture, sea level rise, energy demand, human health, and other issues.

The Environmental Protection Agency (EPA) plans to summarize and discuss the implications of these studies in a report to Congress. We intend to deliver the report before the end of 1988. The EPA will continue research into the impacts of climate change after this report is completed. Our Office of Research and Development is preparing a research plan to help guide our efforts.

METHODOLOGY AND SCENARIOS

These studies are being conducted by leading researchers in academia and government. They will generally use "off-the-shelf" models of the relationship between climate and their analytic area. For example, the Great Lakes Environmental Research Lab (GLERL) is using its hydrologic model of the Great Lakes to study possible impacts of climate change on lake levels. In some cases, we have engaged the services of experts to conduct literature reviews and workshops on specific issues.

We developed a consistent set of scenarios to be used in the analysis of the potential impacts of climate change. The researchers are using these scenarios as inputs to their models. The scenarios combine outputs from General Circulation Models (GCMs) with historic climate data.[1] Specifically, the scenarios use average monthly outputs from the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamic Laboratory (GFDL), and the Oregon State University (OSU) GCMs, which have doubled concentrations of greenhouse gases. Those results are combined with actual meteorologic data from 1951 to 1980. This assumes that average temperature, precipitation, winds, and other factors change, but that daily, interannual, and spatial climate variability remain the same.

Goddard Institute for Space Studies also has run a transient experiment in which trace gases are gradually increased from the 1950s until the middle of the next century. This transient run shows how climate may change in the near future. We also combine this run with historic data to create a transient scenario. In some cases we will also use the 1930s as an analog of short-term warming.

GREAT LAKES CASE STUDY

The Great Lakes are the largest body of freshwater in the world. The lakes are a source of water for consumption, transportation, hydropower, and recreation. Recent high lake levels demonstrate the sensitivity of the lakes to changes in climate. The lower lakes, especially Lake Erie, have had serious pollution problems, but have shown improvement in recent years.

The focus of the Great Lakes case study is on the lakes themselves, but we also examine other impacts of climate change on the region. Changes will be estimated for the lake levels for all lakes and for ice cover on Lakes Superior and Erie. The potential effects on the thermal structure of Lakes Erie and Michigan will be examined and results will be used to study possible impacts on Great Lakes fish. We will look at the impacts of recent high and low lake levels on Great Lakes shorelines, and the potential impacts of climate change on hydropower in the region and on shipping on the lakes.

An agriculture study will give crop yield estimates for the region.

In addition, we are looking at potential response to climate change by farmers, such as extending the growing season or adding irrigation. Another study examines changes in nonpoint source runoff from farms.

Possible changes in forests in the region will be studied through the use of stand simulation models to demonstrate long-term equilibrium changes in species composition, and through the analysis of paleovegetational data to estimate the response of forests to past climatic change.

Finally, we will attempt to identify the institutions and policies affected by all of these changes.

PROJECTS

The specific projects in support of this case study are as follows:

Title	*Researcher*	*Institution*
Changes in Lake Levels	Croley	Great Lakes Environmental Research Lab
Changes in Ice Cover	Assel	Great Lakes Environmental Research Lab
Thermal Structure of Lake Michigan	McCormick	Great Lakes Environmental Research Lab
Thermal Structure of Lake Erie	Blumberg	Hydroqual, Inc.
Great Lakes Fisheries	Magnuson Regier	University of Wisconsin University of Toronto
Impacts on Shorelines	Changnon	Illnois State Water Survey
Impacts on Shipping	Keith	Engineering Computer Optecnomics
Crop Yields	Ritchie	Michigan State University
Farm Level Response	Easterling	Illnois State Water Survey
Stand Simulation Modeling	Botkin	University of California, Santa Barbara
Pollen Response Surfaces	Overpeck	Lamont-Doherty Geological Observatory
Seedling Distribution	Davis	University of Minnesota
Policy Implications	Brah	Center for the Great Lakes

NOTE

1. The GCMs simulate the physics and dynamics of the global atmosphere. They can be used to simulate current climate and to simulate climates with different atmospheric constituents, such as increased concentrations of greenhouse gases. These models will estimate climate on a regional scale, although each grid box may be several hundred miles wide.

Panel Discussion: State Coastal Erosion Management Programs

Michigan's Coastal Erosion Management Program

MARTIN R. JANNERETH
Michigan Department of Natural Resources

Michigan's Coastal Erosion Management Program really began in 1955 with the passage of the Great Lakes Submerged Lands Act, Public Act 247, as amended. While Act 247 had a very narrow perspective of erosion management (the regulation of shore protection on Great Lakes bottomlands), at the time shore protection was the almost exclusive approach to erosion problems. Even today, Act 247 has a strong impact on Michigan. What is permitted under Act 247 determines what structural approach to erosion control the property owner has at his or her disposal. What is approvable under the minor permit category and issued relatively quickly, is of even greater importance in the decision-making process when water levels are threatening. In 1986, a record 2,057 applications were received under Act 247.

The late 1960s began a movement that was sufficient to pass the Shorelands Protection and Management Act, Public Act 245 of 1970. Act 245 made Michigan's coastal erosion management a broader-based program by including the "land side" issue of using building setbacks to reduce future erosion losses. Basically, Act 245 calls for studies to determine the rate of shoreland recession. Any area receding 1 ft or more per year is classified as a high-risk erosion area and requires, after formal property owner and local official notification, 30-year building setbacks.

The shore protection expertise developed under the regulatory authority of Act 247 and the recession rate data gathered under Act 245 naturally led Michigan to a technical assistance role for property owners.

Today nearly all high-risk erosion areas in the state have been identified and designated. About 8 percent of the Great Lakes shoreline is under high-risk erosion area regulation. Just over 7,000 private parcels are under regulation. We receive 75 to 125 permit applications each year for construction activities. Another 3 percent of the shoreland is also high risk but is in public ownership. Since construction on public land is unlikely, detailed studies are not undertaken unless a specific development proposal is made.

Seventeen years of administration of the high-risk erosion area program plus the recent experience of the record high water period have shown the need for several administrative rule changes. Consequently, the following changes are presently proposed to improve the regulatory program:

1. Clarify terminology.
2. Change wording to correctly reflect the scientific standards used in the measurement of long-term shoreland recession.
3. Require a greater setback for large buildings that cannot be relocated away from the erosion hazard.
4. Require all "small" structures to be movable to provide the property owner the option of relocation when the structure becomes threatened by bluff erosion.
5. Place a limit on the amount of setback the department can waive on a substandard lot.
6. Require the establishment of an escrow account for future shore protection for those large, nonmovable buildings, such as condominiums, which are permitted on substandard lots. Since the buyers of these buildings are going to experience early erosion problems, we believe the developer should share the burden of future shore protection needs.

Additional program changes have been identified that cannot be made by administrative rule. As a result, two legislative amendments have been introduced in the Michigan legislature to amend Act 245:

1. The first legislative amendment calls for disclosure of the high-risk erosion area designation to the buyer. The seller must provide notification on a separate instrument conveyed with the deed of the fact that the property is designated as a high-risk erosion area. If the deed is recorded, the separate instrument must also be

recorded. If notice is not provided, the sale may be voided at the buyers option.

2. The second legislative amendment would establish a minimum setback along all of Michigan's nonbedrock coast, approximately 85 percent of the shore. The minimum setback requirement would be 45 ft from the bluffline for all structures. In addition, large structures having a foundation size of over 3,500 sq ft or more than four individual living units would have a minimum setback requirement of 90 ft.

In 1985 the governor and legislature of Michigan, in response to high water levels, authorized the expenditure of up to $2 million for the relocation of homes in imminent danger of damage or destruction from Great Lakes erosion. If the home could not be relocated, the funds could be used for approved shore protection. The funds were also available to elevate homes threatened or damaged by Great Lakes flooding. The funds were provided as a 3 percent interest rate subsidy on loans up to $25,000 for up to 30 years. During the first program in 1985-1986 we received 273 applications in erosion areas, of which 199 were determined to be eligible for state assistance. Seventy-two persons took action and received interest subsidies totaling approximately $267,000. The program was renewed in 1987. This time a lump sum payment of up to half the cost, not to exceed $3,500 in state funds, was provided as an alternative to the loan subsidy. We received 48 applications under the 1987 program, of which 25 were approved. Final payment figures will not be available until August 1988.

Coastal Erosion Management in Minnesota

JEANETTE H. LEETE
Hydrologist
Minnesota Department of Natural Resources

There is a common misconception that the North Shore of Lake Superior is a stark rock cliff, high, dry, and solid. In fact, the geology of Minnesota's North Shore is varied: it consists of red clay areas, cobble beaches, layered lava flows, and resistant igneous rock. Erosion will have a noticeable long-term impact on all these types of shoreline, even on the sheer rock outcrops.

Erosion damage sustained during the recent high water levels included the loss of previously stable cobble beaches and the collapse of sea caves due to undermining of layered lavas. Damages are greatly accelerated when the level of Lake Superior exceeds 602.0 ft (IGLD, 1955), and the effects of seiche and wave run-up compound the problems.

Assessment of the extent of recent damages began with a survey of shoreline residents. Answers to the questionnaire revealed that erosion problems on the North Shore are not new and that the lack of extensive shoreland development in the past has kept erosion damages low. One North Shore resident, whose cabin is only 10 ft from the bank, had moved his cabin away from the receding shoreline three times already.

The public's perception is that erosion is currently occurring at faster than normal rates. Unfortunately, there has been very little quantitative information upon which to base the calculation of erosion rates, either current or long term. The University of

Minnesota-Duluth's Natural Resources Research Institute has obtained funding from the national Sea Grant program to undertake a quantitative remote sensing analysis of the North Shore's erosion rates. This information will provide a basis for the classification of shoreline segments into different erosion hazard classes.

Minnesota does not have a single program for the management of coastal erosion. At the state level, the Minnesota Department of Natural Resources administers two programs, the flood plain management program and the shoreland management program, which regulate land use and shoreland development and thus can control coastal erosion damages. The three North Shore counties, Cook, Lake, and St. Louis, participate in the national flood insurance program, but flood plain maps do not reflect the effect of storms on lake levels. The shoreland management program has been active since the 1970s but does not specifically address the unique issues of the North Shore.

Management programs that originate at the state level and that are imposed upon the local units of government have caused resentment and lack of compliance in the past. Due to the adverse local reaction to a shoreland regulation program (which was not specifically intended for the shore of Lake Superior but for the shores of our more than 15,000 inland lakes) and due to the critically high water levels, the local units of government along the North Shore have formed the North Shore Management Board. This novel local solution is likely to be accepted and to carry out its mandate successfully.

The North Shore Management Board has received funding from Minnesota's legislature through the Department of Natural Resources (DNR) for development of a management plan. By next fall a draft of the shoreland management plan is due to be completed. The Arrowhead Regional Development Commission is providing staff, and working groups, consisting of technical staff of several state and federal agencies and of citizens, have formed to deal with specific issues.

The DNR has signed a memorandum of understanding with the North Shore Management Board and is serving as a liaison and providing technical assistance. It is too early to speculate on the results of the planning process, but it is hoped that a comprehensive strategy for development of the North Shore will result. This could include planning for nodal development with defined lake access points, controlled by innovative zoning regulations (e.g., setbacks based on the life of the structure and the known erosion hazard).

There are still some missing pieces in this puzzle—for example, the issue of implementation has yet to be dealt with. The counties may have to hire a "Coastal Cop" to implement and enforce their management plan. The formation of the North Shore Management Board upon local initiative is such a unique approach that we are optimistic about its success. Continuing funding from the Minnesota legislature is to be expected, and local support of the board's management decisions is likely.

Summary of California Coastal Commission Shoreline Erosion Policy

RICHARD J. MCCARTHY
California Coastal Commission

INTRODUCTION

The constant erosion of California's 1,100-mile coastline has received widespread media attention since the end of World War II. The winter of 1982-1983 brought to light the coastal problems that exist not only in California but throughout the entire coastal United States. Media coverage during that winter centered on the impacts of large storm-induced waves and extreme run-up heights. Unfortunately, milder winter storms and continued sea level rise will also have a dramatic impact on the thousands of single family dwellings, public structures, and oil facilities located along California's shoreline.

CALIFORNIA COASTAL COMMISSION POLICY ON SHORELINE EROSION

The storms of January and March of 1983 caused over $100 million in damage to structures and utilities located along the California coastline. Most of the structures damaged were constructed before the passage of the California Coastal Act of 1976. In order to minimize or prevent damage from storms such as those that battered the state in 1983, the California Coastal Commission has attempted to regulate the design of structures in potentially hazardous areas such as coastal bluffs. The Statewide Interpretive Coastal Act Guidelines contain a section that defines coastal bluff top areas that will require detailed geologic and/or engineering studies before a development permit can be issued by the commission.

Section 30253 of the Coastal Act states that "New development shall: (1) Minimize risks to life and property in areas of high geologic, flood and fire hazard; (2) Assure stability and structural integrity, and neither create nor contribute significantly to erosion, geologic instability, or destruction of the site or surrounding area or in any way require the construction of protective devices that would substantially alter natural landforms along bluffs and cliffs."

As required by Coastal Commission guidelines, geotechnical studies are required within the "area of demonstration." The "area of demonstration" includes the base, face, and top of all bluffs and cliffs. The extent of the bluff top consideration should include that area between the face of the bluff and a line described on the bluff top by the intersection of a plane inclined at a 20-degree angle from the horizontal passing through the toe of the bluff or cliff, or 50 ft inland from the edge of the cliff or bluff, whichever is greater. In areas of known geologic stability or instability (as determined by adequate geologic evaluation and historic evidence) the commission may designate a lesser or greater "area of demonstration."

All geotechnical reports for structures proposed to be located within the "area of demonstration" must consider, describe, and analyze the following:

1. Cliff geometry and site topography;
2. Historic, current, and foreseeable cliff erosion, including investigation of recorded land surveys and tax assessment records in addition to the use of historic maps and photographs available and possible changes in shore configuration and sand transport;
3. Geologic conditions, including soil, sediment and rock types and structural features such as bedding attitudes, faults, and joints;
4. Evidence of past or potential landslide conditions, the implications of such conditions for the proposed development, and the potential effects of the development on landslide activity;
5. Impact of construction activity on the stability of the site and adjacent areas;
6. Ground surface water conditions and variations, including hydrologic changes caused by the development (i.e., introduction of sewage effluent and irrigation water to the groundwater system);

7. Potential erodibility of the site and mitigating measures to be used to ensure minimized erosion problems during and after construction;
8. Effects of marine erosion on sea cliffs;
9. Potential effects of seismic forces resulting from a maximum probable earthquake; and
10. Any other factors that might affect slope stability or littoral transport.

SHORELINE PROTECTIVE WORKS

Because of the adverse impacts so commonly associated with large coastal protective devices (groins, breakwaters, etc.), the commission has favored the use of beach nourishment to reduce shoreline recession rates. However, the commission has decided that in some instances, large coastal structures are the only viable alternative to solving a severe shoreline erosion problem. For example, in May of 1983, Chevron Oil Company applied for a permit before the commission to install a 900-ft-long, semipermeable rock and concrete groin at the southern boundary of its waterfront refinery in El Segundo, California. Chevron preferred this structure over other options for two reasons. First, a groin with accompanying fill would help provide assurance that pipelines to offshore tanker berths would remain buried during the winter storm months. Erosion had been severe at the site since 1960, and Chevron believed that a filler of 500,000 cubic yards of sand (from an offshore borrow site) placed immediately upcoast of the groin would best protect the pipelines from scour and prevent future storms waves from damaging the upland facilities. To minimize downdrift impacts, 75,000 cubic yards of sand would help nourish adjacent beaches. And second, groins had been previously selected as an acceptable means to mitigate coastal erosion within the Santa Monica Littoral Cell.

Leaders of California coastal cities are aware of the potential downdrift erosion caused by such structures. As a result, Coastal Commission permits for large coastal protective devices typically have had conditions that attempt to satisfy the concerns of parties located immediately down drift of the proposed structure. In the Chevron case, the following permit conditions were required by the commission and accepted by Chevron:

- State Lands Commission approval;
- Utilization of aerial photographs to monitor project impacts;

- Beach profile readings at designated locations during specific times of the year;
- Sand tracer studies;
- Downdrift nourishment;
- Commitment to mitigate any adverse impacts to surfing conditions in the project vicinity;
- A planned maintenance program;
- A monitoring program to determine if fill material had migrated back to the offshore borrow site;
- Review of data by unbiased third party;
- An assumption of risk to indemnify and hold harmless the California Coastal Commission against any and all claims, demands, damages, costs, expenses, or liability arising out of acquisition, design, construction operation, maintenance, existence, or failure of the permitted groin project; and
- The above mentioned conditions dealing with sand supply monitoring will exist for a period of 10 years.

PLANNING FOR SEA LEVEL RISE

The state of California has not adopted an overall plan or policy on how to deal with the long-term impacts of sea level rise over the next century. Reinhard Flick of the California Department of Boating and Waterways has conducted studies that have focused on the impacts of past El Niño events combined with the secular increase in relative sea level at San Diego. Studies such as these that center on the processes and forces that contribute to extreme sea levels will not only help engineers in the design of shoreline protection works but can also guide local and state governments in producing development guidelines that will minimize storm surge losses to future generations.

On January 18 and 19, 1988, during a +7.1 tide, large waves caused massive damage to structures situated along portions of the sourthern California coastline. These waves, in combination with extreme sea levels due to meteorological forcing, are a reminder that severe winter storms and extreme sea levels are already having a dramatic impact on California's developed shoreline areas.

Addressing Coastal Erosion in North Carolina

DAVID W. OWENS
North Carolina Division of Coastal Management

SETTING

North Carolina has 320 miles of ocean shoreline. While 50 percent of this shoreline is in public ownership, primarily in two national seashores, the remaining half of the coastline faces substantial pressure for increasing levels of development. While no areas of the coast contain the concentration of high-density development of Miami Beach, few beach areas in the state retain the low-density, scattered cottage atmosphere of the Nags Head of the 1940s.

Over the past 50 years, over half of the state's ocean coast has experienced average annual erosion rates of 2 ft/yr or greater, with 20 percent exceeding 6 ft/yr. Additional short-term fluctuations of the shoreline due to storms is also common.

MANAGEMENT PROGRAM

These two factors—increasing development and a dynamic shoreline—led the state over the past 10 years to develop a coordinated shorefront development program that uses regulations to manage new development; restrictions on shoreline erosion control practices; planning for redevelopment and relocation of damaged and threatened structures; and nonregulatory tax, land acquisition, and public education programs to carefully manage use and development of this critical area.

The first step in the development of this management program was setting clear goals for the program. After considerable public debate and discussion about the physical, economic, and social factors affecting oceanfront development, the Coastal Resources Commission (the 15-member citizen policy making for the program) adopted these three goals for the management program:

1. Minimize loss of life and property resulting from storms and long-term erosion;
2. Prevent encroachment of permanent structures on public beach areas; and
3. Reduce the public costs of inappropriately sited development.

NEW DEVELOPMENT

North Carolina adopted a statewide minimum oceanfront setback for all new development in 1979. After several refinements in the early 1980s, the minimum setback in place at this time requires all new development to be located behind the furthest landward of these four points:

1. The erosion rate setback (30 times the annual erosion rate, measured from the vegetation line, for small structures, 60 times the erosion rate for structures with more than 4 units or more than 5,000 square feet total floor area);
2. The landward toe of the frontal dune;
3. The crest of the primary dune (the first dune with an elevation equal to the 100-year storm flood level plus 6 ft); or
4. A 60-ft (120 ft for larger structures) minimum, measured from the vegetation line.

Limited uses that do not involve permanent substantial structures (such as clay parking areas, tennis courts, and campgrounds) are allowed between the vegetation line and setback line, but no development is allowed seaward of the vegetation line.

Other regulatory provisions limit the intensity of development near inlets, set minimum construction standards, limit the construction of growth-inducing infrastructure in hazard areas, and restrict dune alteration.

EROSION CONTROL

Even though the above standards provide some degree of safety for new development, North Carolina has thousands of older structures increasingly threatened by coastal erosion and storms. Also, even new development will eventually face similar threats with the passage of time.

Since the ocean beaches are a vital economic resource (being the foundation of a tourism economy) and a key publicly owned recreational resource, the state has adopted a strong policy of protecting its beaches.

Effective January 1985, no erosion control devices designed to harden or stabilize the ocean beach's location are allowed in North Carolina. Bulkheads, seawalls, groins, jetties, and rip rap are prohibited. Temporary sandbags are allowed, as is beach nourishment.

REDEVELOPMENT AND RELOCATION

The state has also attempted to fashion an effective strategy for dealing with existing development that is damaged or becomes endangered.

Effective in 1983, all coastal local governments have been required to include a poststorm element in their mandatory land use plans. These elements are to include measures for prestorm migration, evacuation and recovery plans, and poststorm rebuilding policies. The latter are to give particular attention to relocation to safer locations of damaged roads, water and sewer lines, and other public investments.

The state began urging in 1983 that the flood insurance program be used to facilitate preloss mitigation by covering the relocation of imminently endangered structures as a loss payment. This was seen to be a cost-effective and environmentally sensitive measure, as it would reduce payments for future total loss payments and avoid repetitive claims, thereby reducing both rates for flood insurance premiums and the likelihood of future public tax subsidies. It would also meet a pressing need in the state, given over 800 structures expected to become endangered in North Carolina alone over the next 10 years. Congress enacted this proposal as part of the 1987 Housing Act signed by the President in February 1988. It is therefore expected that relocation of endangered structures will become an important part of the state's overall management program.

OTHER NONREGULATORY MEASURES

In addition to the above, the state uses a variety of additional nonregulatory measures to promote efficient long-term use and development of the ocean shoreline.

The state's beach access program gives an explicit statutory priority to the acquisition of those lands that are unsuitable for permanent structures but that could be useful for beach access and use. Natural areas containing undeveloped beaches have also been acquired. A state income tax credit was adopted to encourage the donation of beach access and natural areas. Finally, public education has been a major priority, ranging from providing mandatory hazard notices and information to each permit applicant to broad community education on issues such as sea level rise, barrier island dynamics, dune and beach functions, and the like.

FOR MORE DETAILED INFORMATION ON THE NORTH CAROLINA PROGRAM

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Appendixes

Appendix A
Biographical Sketches of Principal Contributors

PRESENTERS

FRANK HORVATH is the chief scientist of the Great Lakes Information System, Michigan Department of Natural Resources, where he is responsible for consolidating natural resource and environmental quality data on the Great Lakes into a form accessible and usable by natural resource managers. Mr. Horvath holds an M.S. in aquatic biology and has worked for over 15 years on environmental quality issues in the Great Lakes. He is active on several committees of the International Joint Commission.

ORRIN H. PILKEY, JR., received his Ph.D. in geology from Florida State University. Currently he is professor of geology at Duke University. Previously he was associate and assistant professor at the Marine Institute at the University of Georgia and U.S. Geological Survey in Woods Hole, Massachusetts. His area of expertise is in marine geology. His areas of research include geological oceanography, continental rise and deep basin turbidite sedimentation, and shoreline conservation. Dr. Pilkey is a member of the Geological Society of America and the International Association of Sedimentology.

CLANCY PHILIPSBORN has been involved with disaster research, mitigation, preparedness, response, and recovery since 1975. After working under the direction of Dr. Gilbert White while a graduate student at the University of Colorado, Boulder, Philipsborn accumulated extensive on-site disaster experience with the Federal Emergency Management Agency (FEMA) between 1978 and 1986. He has represented FEMA Region VIII as hazard mitigation officer, federal hazard mitigation coordinator, and federal interagency hazard mitigation team leader. Currently, he is president of The Mitigation Assistance Corporation, which he founded in 1985.

FRANK H. QUINN is head, Lake Hydrology Group, Great Lakes Environmental Research Laboratory, NOAA, where he is responsible for planning, conducting, and managing a broad-based research program on hydrologic and ice research in the Great Lakes and similar systems. He has been the acting laboratory director since 1980. He received a Ph.D. in civil engineering from the University of Michigan in 1971. Prior to that, he served as civil engineer, Los Angeles District, Corps of Engineers; hydraulic engineer, Lake Survey Center, Detroit District, Corps of Engineers; chief, special studies section, Lake Survey Center, Detroit District, Corps of Engineers; and chief, lake hydrology branch, limnology division, Lake Survey Center, NOS, NOAA.

A. DAN TARLOCK received his LL.B. from Stanford University. His professional experience includes private practice, San Francisco, 1966; professor in residence at a law firm in Nebraska, summers of 1977-1979; and consultant. He has been a professor of law at Chicago Kent College of Law since 1981. He has authored and coauthored many publications and articles concerning water resources management and environmental law and policy. Mr. Tarlock served as a member of a National Research Council committee on pest management and coauthored one of the basic casebooks in water law.

WILLIAM L. WOOD received a Ph.D. in geophysics (oceanic science) from Michigan State University in 1971. He is associate professor, school of civil engineering, and director, Great Lakes Coastal Research Laboratory, Purdue University. Dr. Wood's research has focused on coastal hydrodynamics, boundary layer processes, and ocean dynamics. Specific interests have been shallow-water wave transformation, wave instabilities and breaking, vertical and horizontal structure of longshore currents, generation of short-crested waves and their transformation at a coast, sediment entrainment in turbulent boundary layers, stability of coastal profiles in response to storm waves and lake-level variation, and dynamics of submarine canyons. Dr. Wood serves on the National Research Council's Committee on Coastal Engineering Measurement Systems.

PROVOCATEURS

LEE BOTTS was educated at Oklahoma State University. She is currently working as an independent environmental consultant whose recent projects have included development of recommendations for strengthening the city of Chicago's environmental programs and a five-year program strategy for the Great Lakes Office of the Environmental Protection Agency. In 1986 she organized a regional conference to assist local officials with long-term planning in response to rising lake levels, and is currently a consultant to the Chicago Shoreline Protection Commission. She has been codirector of the Environmental Policy Program at the Center for Urban Affairs and Policy Research, Northwestern University; chairman, Great Lakes Basin Commission, Ann Arbor; executive director of the Lake Michigan Federation; and coauthor of *An Atlas of Great Lakes Resources* published by the EPA and Environment Canada in 1987. She has been named by the United Nations' Environmental Program as one of 500 members of "The Global 500," a list of persons who have made a difference for preservation of the environment.

CURTIS E. LARSEN is a research geologist with the USGS, where he specializes in the recognition and interpretation of ancient beach deposits. In his present position, he is concerned with the reconstruction of past sea level changes along the Atlantic Coast of the United States as a tool for locating mineral resources. He received his B.S. in geology from the University of Illinois and later studied geological oceanography at the University of Washington. He completed a joint program in anthropology and coastal studies at Western Washington University and completed his doctorate in anthropology at the University of Chicago. He maintains an active research interest in the Great Lakes region.

ORIE LOUCKS received his B.Sc. and M.Sc. at the University of Toronto and his Ph.D. in botany at the University of Wisconsin in 1960. He taught at the University of Wisconsin until 1978, where his research interests were in environmental studies, watershed systems modeling, and land/water interactions. He is now director of the Holcomb Research Institute at Butler University in Indianapolis, a former member of the Water Science and Technology Board, and former chairman of the Committee to Review the Great Lakes Water Quality Agreement, and he is currently a member of the Committee on USGS Water Resources Research.

BRUCE MITCHELL professor and chairman, Department of Geography, University of Waterloo, received a Ph.D. in 1969 from the University of Liverpool. His professional interests encompass natural resource management, especially water and fisheries; policy and program evaluation; institutional arrangements; and decision making and citizen involvement. He is president-elect of the Canadian Water Resources Association and vice chairman of the Canadian Association of Geographers.

JOHN STOLZENBERG received his Ph.D. in environmental studies from the University of Wisconsin-Madison in 1975. He has been with the Wisconsin Legislative Council since 1975. He supervises the science component of the Legislative Council staff and costaffs the council's Special Committee on Telecommunications. He also staffs the Senate Energy and Environmental Resources Committee and the Assembly Committee on Economic Development. His major projects at the Legislative Council relate to control of acid rain, management of low-level radioactive waste, development of an air pollution permit program, and solid- and hazardous-waste management. He was a member of the National Research Council's Committee to Review the Great Lakes Water Quality Agreement from 1984 to 1985.

SARAH J. TAYLOR is executive director of the Chesapeake Bay Critical Area Commission. From 1979 to 1985, she was director of the Coastal Resources Division, the coordinating agency for Maryland's Coastal Zone Management Program. Prior to that appointment, she worked as a project manager for Water Supply and Wastewater Management with the Baltimore District, U.S. Army Corps of Engineers. Ms. Taylor received her Ph.D. in 1976 from the Maxwell Graduate

School of Syracuse University and the New York State College of Environmental Sciences and Forestry, specializing in natural resources administration and organizational development. She is also on the executive board of the Coastal States Organization and is an active member of the American Society for Public Administration.

PANEL ON GLOBAL CLIMATE CHANGE

WALTRAUD AUGUSTA BRINKMANN received a Ph.D. in geography, with an emphasis in climatology, from the University of Colorado. She is presently professor of geography at the University of Wisconsin, Madison. She holds memberships in the Association of American Geographers, American Meteorological Society, American Quaternary Association, American Association for the Advancement of Science, and Canadian Association of Geographers.

STANLEY A. CHANGNON, JR., was chief of the Illinois State Water Survey from 1980 through 1985, and is now chief emeritus and a principal scientist at the Survey. He served from 1954 to 1968 as a research scientist on the staff of the Illinois State Water Survey. He was head of the atmospheric sciences section from 1969 to 1970, and is also a professor of geography at the University of Illinois. He is a member of Sigma X, Pi Mu Epsilon, Illinois Academy of Science, American Geophysical Union, American Association for the Advancement of Science, Weather Modification Association, American Association of State Climatologists, and the American Meteorological Society. He has served on three panels for the National Academy of Sciences.

RICHARD F. KOSOBUD is associate dean for research development and professor of economics at the University of Illinois at Chicago. He received a Ph.D. in economics in 1963 from the University of Pennsylvania. His fields of expertise encompass economic theory; macroeconomic policy; and energy, resource, and environmental economics. He is a visiting scientist at Argonne National Laboratory.

MARIE E. SANDERSON is director, Great Lakes Institute, and professor of geography, University of Windsor. She received a Ph.D. in geography in 1965 from the University of Michigan and has been affiliated with the department of geography since then, offering courses in climatology, applied climatology, hydrology, and history of geographic thought. She was instrumental in the founding in 1981 of the Great Lakes Institute, the only University-based research facility in Canada devoted to Great Lakes research. Her research has been chiefly in the field of toxic contaminants in the St. Clair-Detroit River region, and more recently in water quantity, and future water levels in the Great Lakes, and their socio-economic impacts.

JOEL B. SMITH is an analyst at the U.S. Environmental Protection Agency's Office of Policy, Planning and Evaluation. He is currently coordinating EPA's Report to Congress on the effects of climate change on the United States. Mr. Smith has been with EPA since January 1984 and began working on the greenhouse reports in April 1987. He served as an analyst examining oceans and water regulations, and most recently was a special assistant to the assistant administrator for policy, planning and evaluation. Mr. Smith received a Master of Public Policy degree from the University of Michigan in 1982.

PANEL ON STATE COASTAL EROSION MANAGEMENT PROGRAMS

JEANETTE H. LEETE is an adjunct faculty member, geology department, Macalester College, St. Paul, Minnesota, where she teaches hydrogeology and environmental geology. Since 1985 she has been senior hydrologist, ground water management specialist with the Ground Water Unit, Division of Waters, Minnesota Department of Natural Resources. In this capacity her responsibilities encompass carrying out studies and independent investigations of groundwater and groundwater/surface water interactions, e.g. studies of high lake water levels in terminal lakes. Since 1980 Dr. Leete has been president, Watershed Research Inc., where she has developed interactive hydrogeologic programs that run on IBM-compatible microcomputers. In 1986 she received a Ph.D. in hydrology from the University of Minnesota, St. Paul.

MARTIN R. JANNERETH received a M.S. in forest ecology with emphasis on soil science and ecology from Michigan State University in 1972. He is presently in charge of the Shorelands Management Unit, Michigan Department of Natural Resources, where he implements, administers, and enforces the Shorelands Protection and Management Act. He also consults with local officials, state and federal agencies, and the public on planning assistance, shoreland zoning, and technical assistance on Great Lakes related issues. He plans regulatory measures, conducts shoreland recession rate studies, delineates high-risk erosion areas, establishes setback requirements, makes official regulatory designations of high-risk erosion areas, and administers appeals of designation.

RICHARD J. MCCARTHY received a M.S. in geology from San Diego State University in 1973. He is senior marine geologist for the California Coastal Commission where he administers the offshore/onshore geological hazards program and supervises the geohazard element of local coastal programs for coastal communities. He is also involved in the use of submersibles, both manned and remotely operated, to identify offshore sand sources for beach nourishment projects.

DAVID W. OWENS is director, Division of Coastal Management, North Carolina Department of Natural Resources and Community Development. His major areas of work include policy guidance and administrative leadership for the agency; representation of the state's coastal management interests with the federal government, other states, local governments, the media, and the public; executive secretary to the state's Coastal Resources Commission; and policy advice and support to the Governor and Department Secretary. He received a Juris Doctor in 1975 and a Master of Regional Planning in 1974 from the University of North Carolina at Chapel Hill.

Appendix B
Attendees at Colloquium

JEANNE AQUILINO, National Research Council, Washington, D.C.
RICHARD BARTZ, Ohio Department of Natural Resources, Columbus, Ohio
MICHAEL BEN-ELI, The Cybertec Consulting Group, New York, New York
JOHN BOLAND, The Johns Hopkins University
LEE BOTTS, Department of Consumer Services, Chicago, Illinois
WILLIAM BRAH, The Center for the Great Lakes, Chicago, Illinois
WALTRAUD BRINKMANN, University of Wisconsin, Madison
STEPHEN BURGES, University of Washington
CAROLE B. CARSTATER, National Research Council, Washington, D.C.
STANLEY CHANGNON, Illinois State Water Survey, Champaign, Illinois
JIM COLQUHOUN, New York State Department of Environmental Conservation, Albany, New York
RICHARD A. CONWAY, Union Carbide Corporation, South Charleston, West Virginia
GLENDA DANIEL, Lake Michigan Federation, Chicago, Illinois
SHEILA D. DAVID, National Research Council, Washington, D.C.
JAMES M. DAVIDSON, University of Florida

STEPHEN E. DAVIS, Indiana Department of Natural Resources, Chesterton, Indiana
ROBERT DAY, Renewable Natural Resource Foundation, Bethesda, Maryland
RUTH DEFRIES, National Research Council, Washington, D.C.
CHRIS ELFRING, National Research Council, Washington, D.C.
A. P. LINO GRIMA, University of Toronto
HARRY HAMILTON, State University of New York at Albany
JAMES HEANEY, University of Florida
ROBERT HIRSCH, Department of the Interior, Washington, D.C.
FRANK HORVATH, Michigan Department of Natural Resources, Lansing, Michigan
DANIEL INJERD, Illinois Department of Transportation, Chicago, Illinois
MARTIN JANNERETH, Michigan Department of Natural Resources, Lansing, Michigan
MICHAEL KAVANAUGH, James M. Montgomery Consulting Engineers, Oakland, California
PHILIP KEILLOR, University of Wisconsin at Madison
RICHARD KOSOBUD, University of Illinois
CURTIS LARSEN, U.S. Geological Survey, Reston, Virginia
SHEILA A. LEAHY, The Joyce Foundation, Chicago, Illinois
JEANETTE H. LEETE, Minnesota Department of Natural Resources, White Bear Lake, Minnesota
ORIE LOUCKS, Butler University
G. RICHARD MARZOLF, Kansas State University
RICHARD MCCARTHY, California Coastal Commission, San Francisco, California
WENDY L. MELGIN, National Research Council, Washington, D.C.
DAVID MILLER, Great Lakes United, Buffalo, New York
BRUCE MITCHELL, University of Waterloo
DAVID MOSENA, Department of Planning, Chicago, Illinois
MARSHALL MOSS, U.S. Geological Survey, Reston, Virginia
BRIAN MRAZIK, Federal Emergency Management Agency, Washington, D.C.
DAVID OWENS, North Carolina Department of Natural Resources and Community Development, Raleigh, North Carolina
ROBERT OZANNE, University of Wisconsin
STEPHEN D. PARKER, National Research Council, Washington, D.C.

BRENT PAUL, Bureau of Reclamation, Washington, D.C.
CLANCY PHILIPSBORN, The Mitigation Assistance Corporation, Boulder, Colorado
ORRIN PILKEY, JR., Duke University
DAVID POLICANSKY, National Research Council, Washington, D.C.
KENNETH W. POTTER, University of Wisconsin-Madison
FRANK QUINN, National Oceanic and Atmospheric Administration, Ann Arbor, Michigan
GORDON ROBECK, Water Consultant, Laguna Hills, California
WILLIAM ROPER, Office, Chief of Engineers, Washington, D.C.
PATRICIA ROSENFIELD, The Carnegie Corporation of New York
MARIE SANDERSON, University of Waterloo
JOEL SMITH, U.S. Environmental Protection Agency, Washington, D.C.
CHRISTIAN J. STEWART, Environment Canada, Burlington, Ontario
JOHN STOLZENBERG, Wisconsin Legislative Council, Madison, Wisconsin
A. DAN TARLOCK, Chicago Kent College Law School
SARAH TAYLOR, Chesapeake Bay Critical Area Commission, Annapolis, Maryland
FRANK THOMAS, Federal Emergency Management Agency, Washington, D.C.
WILLIAM L. WOOD, Purdue University