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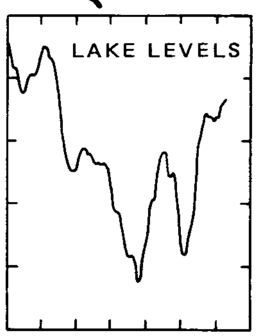
REPORT OF INVESTIGATION 110

STATE OF ILLINOIS

DEPARTMENT OF ENERGY AND NATURAL RESOURCES

Effects of Past Low Lake Levels and Future Climate-Related Low Lake Levels on Lake Michigan, Chicago, and the Illinois Shoreline

by STANLEY A. CHANGNON, STEVEN M. LEFFLER, and ROBIN SHEALY



ILLINOIS STATE WATER SURVEY

CHAMPAIGN

1989

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Title: Effects of Past Low Lake Levels and Future Climate-Related Low Lake Levels on Lake Michigan, Chicago, and the Illinois Shoreline.

Abstract: This study concerned 1) effects and adjustments resulting from the record-low levels of Lake Michigan during 1964-1965, and 2) the potential effects of future low water levels resulting from expected climate changes. The low lake levels of the 1960s did not cause many major impacts at the time they occurred. The two major imparts discerned, damage to shoreline structures and encroachment of structures onto areas closer to the lake, resulted because of a sequence in which the low water levels were followed by high levels. Climate scenarios based on three global climate model estimates showing a doubling of carbon dioxide (CO_2) in the atmosphere, and scenarios based on extreme annual precipitation values from a 133-year period on the Great Lakes basin, were used to determine potential future low lake levels. Possible economic impacts were then determined. If the lake level is reduced from current averages by 0.86 to 1.0 meter during the next 50 years, economic impacts should not be very severe and could probably be handled largely by normal maintenance and replacement costs. Illinois shoreline impacts would cost about $ 100 million. If the lake level is reduced from current averages by 1.25 or 2.52 meters, more sizable economic imparts will occur, costing up to an estimated $291 million and $545 million, respectively. Parts of these costs could be handled by normal replacement costs, particularly if a master plan for changing affected facilities is implemented. The degree of climate change and ensuing lake level will greatly affect the seriousness of the economic outcome, but the environmental and water resource effects are extremely serious under all the climate scenarios.

Reference: Changnon, Stanley A., Steven M. Leffler, and Robin Shealy. Effects of Past Low Lake Levels and Future Climate-Related Low Lake Levels on Lake Michigan, Chicago, and the Illinois Shoreline. Illinois State Water Survey, Champaign, Report of Investigation 110, 1989.

Indexing Terms: Chicago area, climate change, climate scenarios, economic impact, Great Lakes, Illinois shoreline, Lake Michigan, low water, policy needs, prediction, water level fluctuations, water levels.

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CHAPTER 1. INTRODUCTION

This investigation concerned 1) the effects and adjustments resulting from the record-low levels of Lake Michigan during 1964-1965, and 2) the potential effects of future low water levels resulting from expected changes in climate.

The data collection effort revealed that locating quantified data on the impacts of the low lake levels in the early 1960s was very difficult. Many original institutional records were destroyed or lost, and a newspaper content analysis was of only marginal value. Hence, it was impossible to do an in-depth quantified analysis of the direct, secondary, and tertiary impacts. We depended on structured interviews with local experts in various public and private sector positions to provide much of the information on the impacts and responses resulting from the 1964-1965 low levels, and to assist us in assessing future impacts of extreme climate change. We believe the analysis was sufficient to detect the significant impacts and to develop useful qualitative assessments of these. As in any study attempting to estimate future socioeconomic and physical effects of extreme climate conditions never before experienced since settlement of the Great Lakes, the estimated impacts and responses must be considered speculative.

Analysis of the physical factors affecting low water conditions revealed that the record-low lake levels in 1964-1965 would have been worse if precipitation over Lake Superior had been below average (it was near normal). A series of climate scenarios, based on 1) three global climate model estimates showing a doubling of carbon dioxide (CO_2) in the atmosphere, and 2) extreme annual precipitation values from a 133-year period on the Great Lakes basin, were used to derive estimates of potential low lake levels in future years. These provided a variety of estimates of lake-level lowerings ranging from 0.86 to 2.52 meters (2.82 to 8.27 feet), and were used for estimating future impacts. The interannual variability of lake levels in low-level (dry) periods was studied and found to be slightly greater than in extreme wet periods. This is an important factor needed for estimating future effects of low levels. The climate scenarios did not provide estimates of interannual variability or of long-term fluctuations apt to occur.

An important concept about the effects of low (or high) lake levels is the fact that neither extreme is desirable. In low-lake-level periods, detrimental shoreline effects are minimal compared to those in high-level periods, but during low-level periods, considerable economic loss is experienced by shipping and power generation interests across the basin. In general, the reverse of these situations occurs during high-lake-level periods.

Areas of Impact

Analysis of the effects of low lake levels during 1964-1965 along the Illinois shoreline of Lake Michigan revealed many areas of impact. Effects on shorelines and on recreation were mixed, and in general, local shipping, industry, and most commerce were hurt. Problems developed in the water management and water supply areas, along with problems in land use management that evolved during and after the low water period. Some institutional impacts were positive, but in general, the effects led to adjustments that were costly to local, state, and federal government entities.

The two major impacts discerned (damage to shoreline structures and encroachment of structures onto areas closer to the lake) developed during the 1964-1965 low levels, but both also resulted from a sequence of low and then high water levels. The city of Chicago's frontage repairs (necessitated partly because the low lake levels resulted in dry rot in wooden frontage structures) and the subsequent high-water wave action may result in repair costs of up to $800 million. Damage to buildings and houses built too close to the lake during the low-water periods has been excessive, with many damaged and a few destroyed.

In summary, the low lake levels of the 1960s did not cause many major economic impacts or adjustments at the time of their occurrence. The economic effects were mixed, with some gains and some losses. The low-water period was too short to lead to many adjustments. An important finding about impacts was the "low-high problem" relating to low lake levels followed by high levels. Impacts of future lower lake levels, when the climate changes occur to produce these, will depend extensively upon the degree of long-term (decadal) oscillations in lake levels that occur.

Potential Effects of Future Low Water Levels

The second major part of the study concerned what may occur in the next 30 to 70 years as the

Illinois area and the basin experience a warmer and drier climate than in the past 200 years. We had planned to estimate the future impacts, responses, and policy actions largely on the basis of the data/findings of the record low-water period of the 1960s. However, the data were poorer than we had hoped, and we learned that the low period was too short to cause many impacts or adjustments. Hence, our futuristic estimation had to be more speculative than planned. Several climate scenarios, each involving a different reduction in the level of Lake Michigan, were studied.

The economic impacts of future lake levels projected to be reduced from current averages by 0.86 to 1.0 meter (2.82 to 3.3 feet) during the next 50 years were not seen as very severe. It appears that such impacts can be handled largely by normal maintenance and replacement costs for affected facilities. Illinois shoreline impacts will cost about $100 million. However, the lake levels will be sufficiently low and the water quality will be sufficiently poorer that meeting water demands will be very difficult and controversial. A more arid climate will mean less water to serve Illinois areas beyond the basin, with attendant problems in meeting needs of the Illinois and Chicago River and canal systems, as well as in meeting public and industrial water requirements increased by population growth and a warmer/drier climate.

Increased diversion of lake waters will be sought but will be resisted by national and international interests; this will lead to increased use of ground water, already a partly depleted resource in the region. Impacts to the environment will include loss of Illinois wetlands and habitats if the lake falls too rapidly, and degradation of the quality of lake water and ground water in aquifers affected by the lake. Increased water temperatures will make cooling more difficult, and shipping of Illinois goods will become more expensive. The net effect will be extremely detrimental to the economy of Illinois and the future of the Chicago metropolitan region. The related policy implications are considered major.

If the average lake level is reduced from current averages by 1.25 or 2.52 meters (4.10 or 8.27 feet), even more sizable economic impacts will occur, costing up to an estimated $291 million and $545 million, respectively. Parts of these costs could be handled within normal replacement costs, particularly if a master plan for changing affected facilities is developed and implemented. *The degree of climate change and ensuing lake level will greatly affect the seriousness of the economic outcome,* but the environmental and water resource effects are extremely serious in all the climate scenarios. Development and use of a master plan for the Illinois area (and Great Lakes), possibly under the program of planning called for in the 1985 Great Lakes Charter, would be one important activity to launch now.

More specification about the nature of the climate-related lake change (rate of lowering, total amount of lowering, and variation around the new mean) is needed. Variations of levels of 3:1 from the models reveal sufficient uncertainty to make management actions based on any one of them difficult, yet some can begin.

Given current problems with transboundary issues on the basin, it appears that major policy issues will be created at the community scale up through the state, regional, national, and international levels. New approaches and institutions to deal with the problems will be necessary.

Further research is needed in several areas. Clearly, global climate models must be more thoroughly developed to achieve greater regional specificity and uniformity in their projected outcomes. Pressures will develop for increasing lake water supplies in prolonged low-level periods. This will call for research on subjects such as climate prediction, weather modification, and evaporation suppression. We lack sufficient information on how climate change affects our physical systems and economy; hence applied research in these areas is needed. Studies of policy options and institutions to address the problems and to manage the jointly shared resource of the Great Lakes also are in order.

CHAPTER 2. GOALS AND OBJECTIVES

This study addressed the physical and socioeconomic effects and responses along the Illinois portion of the Lake Michigan shoreline resulting from extremely low levels of Lake Michigan in past years (1964-1965).

The project had three objectives: 1) to measure the types of physical and socioeconomic effects resulting from the record-low lake levels, 2) to measure and assess the adjustments that the private and public sectors in Illinois have made as a result of these extremes, and 3) to speculate about the effects and adjustments resulting from future low lake levels caused by a warmer and drier climate.

Central Concepts of the Study

The first important concept is that a study of the effects of low lake levels on shorelines and the related socioeconomic impacts and responses along the 101-km (63-mile) Illinois shore was useful for two reasons. First, the Illinois shoreline (largely Chicago and suburbs) reflects the variety of lake frontages typically found in all metropolitan areas (harbors, intakes and outlets, diversion lockages, beaches, shore protection structures, parks, urban buildings, and residences). However, the shoreline does *not* have agricultural frontages and has only minimal natural environmental frontage (limited wetlands). Second, such an investigation by a state agency and university with easy access to institutional historical records and key individuals allowed for a meaningful analysis.

The second important concept of this study relates to its scope. The study was confined to the dimensions of the physical impacts and socioeconomic impacts and responses along the Illinois shoreline. This was *not* a study of the effects of low lake levels on Lake Michigan, and it did not address effects on water quality, effects on shipping or hydroelectric power generation on the Great Lakes, or environmental impacts beyond those identifiable along the Illinois shore. The issue of altered water quality in the Great Lakes is a central question related to a major change in climate leading to lower water supplies in the basin. However, analysis of this major issue was beyond the scope of this study.

The third central concept is that the study was designed 1) to investigate the impacts and responses to the record-low lake levels during the 1960s, and 2) to use these as a basis for estimating future impacts and desired policy actions related to presumed future climate changes. This approach was considered meaningful because the low-level period was sufficiently recent that its socioeconomic conditions are generally representative of present and near-future conditions. Hence, findings could be indicative of future effects on metropolitan areas of lower lake levels resulting from a warmer and drier climate.

Two Discoveries Affecting the Study and Its Findings

As the data collection and analysis progressed, we found two limitations that greatly altered the study's design, analytical approach, and findings.

The first major limitation related to the data on effects and responses during the low lake levels of 1964-1965. We were unable to locate many records of actions relating to low levels during 1964-1965 in the files of the city of Chicago, state agencies, or federal agencies. Most records of that period had been lost or destroyed. Our investigation of newspaper records revealed little useful information. Thus our major remaining source of information was the decision makers who held key positions in the public and private sectors during the 1960s. We designed the data collection around a structured interview approach. Through this process we learned that 1) the impacts and responses during 1964-1965 were largely negligible, but 2) major impacts related to the low levels occurred when lake levels reached record-high levels in the 1970s and 1980s.

Second, the analysis of effects of the record-low lake levels (which were limited to 1964-1965 and were followed by a rapid increase in levels) further revealed that the low-level period was too short to have caused many major impacts or responses. (The only major effects of the low levels occurred from the damages ultimately created when lake levels subsequently reached record-high levels in the 1970s and 1980s.) The lack of utility of the 1964-1965 sampling period forced a shift from the planned approach (*calculating* future effects of prolonged low levels on the basis of the 1964-1965 results) to an approach that was more *speculative* than data-based. Further, two of the three climate models that were used to estimate future lake levels generated levels much lower than that experienced in 1964-1965, requiring further speculation about future effects and responses. This situation led to a second round of structured interviews using questions based on *suspected* impacts. From the responses, estimations were made of potential impacts including their costs, and speculations were made about institutional/policy responses to deal with the impacts.

Chapter 3 describes the data collection efforts and the methods used in developing climate scenarios; the available results appear in chapter 4; and the interpretation and significance of these results are addressed in chapters 5 and 6.

CHAPTER 3. METHODS USED FOR DATA COLLECTION AND FOR DEVELOPMENT OF CLIMATE SCENARIOS

The project had two parts. The first of these was an assessment of the physical and socioeconomic impacts of the record-low lake levels occurring in Lake Michigan during 1964-1965, and of the ensuing adjustments.

The second part of the study was a determination of potential future lake levels in Lake Michigan, and of their likely effects. The most likely climatic change in the Great Lakes basin projected from global climate models is a change to drier and warmer conditions. This would lead to lower lake levels.

Data Sources

The collection of data on the effects and adjustments resulting from the record-low lake levels during 1964-1965 included five areas of activity: 1) telephone interviews and discussions with individuals who played key roles in affected organizations during the low-level period, 2) visits and structured interviews with certain experts to gather data, 3) searches of records of public agencies affected by the record-low lake levels, 4) a review of newspaper contents during this low-lake-level period, and 5) examination of aerial photographs of the shoreline, taken during low- and high-level periods.

Climate Scenarios

It was recognized as this study began that several climate impact studies, under the broad charge of the U.S. Environmental Protection Agency's Climate Change Program, were attempting to quantify, through use of various global climate models (GCMs), the effects of a very severe climate change due to large increases of CO_2 and other trace gases in the atmosphere. We decided to use the outputs (climate scenarios) of these GCMs in our study. These climate models have been based on assumptions made from data gathered during a regime of climate much less severe than that being projected by the models. This discrepancy causes decided uncertainties, as do any estimates of possible extreme future conditions. Three GCMs were used to project varying climate conditions for the Great Lakes basin. When these were used in lake-level models, they led to projections of the lowering of Lake Michigan water levels by 0.86, 1.25, and 2.52 meters (2.82, 4.10, and 8.27 feet).

For this study and as part of the international analysis of lake level problems under the U.S.-Canada Reference of 1986, "record-based" future climate scenarios were also seen as valuable for equating the impacts from the 1964-1965 low levels with those that may occur with more severe future dry conditions (which are seen as likely in the GCM projections due to doubling of the atmospheric content of CO_2). For these reasons, "climate scenarios" were developed for this project as estimates of likely extreme periods of low levels on Lake Michigan (and on the other Great Lakes, since their levels are interactive).

The scenarios aid speculations on the future impacts of low lake levels by providing estimates on likely low levels that could be experienced. Paleoclimatic research by Larsen (1985) suggests that extremes greater than those experienced in the past 140 years occurred as the result of climatic factors at several times during the past 2,500 years (see figure 2). It is not certain whether future extremes produced by natural causes will be matched or exceeded by the projected climatic changes due to human influences on the atmosphere. Given these uncertainties, we concluded that it was reasonable to investigate the effects of the record-low lake levels during the 1960s along the Illinois shoreline. From the types of impacts noted, we hoped to make *informed esti-*

mates of the types of effects and adjustments apt to result from future lake levels that might be lower than experienced in the 1960s.

Scenario Development Process

Climate scenarios, defined as descriptions of possible climate conditions at some unspecified future time, can be developed by various processes (Lamb, 1987). They may be generated from empirical analysis, from stochastic analysis, or from the physically based global climate models. Climate scenarios are not predictions but serve as plausible examples.

A set of climate scenarios was developed to describe possible future climate conditions in the Great Lakes basin. The scenarios were based on the use and interpretation of historical climatic data for the basin. We believe these scenarios are physically possible for the Great Lakes basin.

The following conditions relate to the climate scenarios selected:

1) They are not predictions of climate based on occurrence at any specific future time.
2) They have no specified probability of occurrence, and are not based on any frequency assumptions.
3) They are used with the recognition that the levels of the Great Lakes have ranged above and below those sampled over the past 120 years of usable climatic record.
4) They were developed to produce precipitation and temperature values needed as input for hydrologic models of the Great Lakes so as to generate lake levels and net basin supply (NBS) values.
5) They were constructed from the climatic extremes sampled over a 133-year period (that is, "instrument-based" values).
6) They represent a "snapshot" of conditions in a period that could occur, without their likelihood or time of occurrence being known.
7) They were constructed from extremes in annual precipitation data. The annual values from about 1854 to 1986, and their aberrations around the average, were used to define "extreme years." Temperature values for these selected years were also used.

From these "boundary conditions," climate scenario models were chosen to reveal one possible dry period, based on measured historical data from the Great Lakes basin. It was decided that these analog-type scenarios would involve 12-year periods of time, or composite climatic blocks (Wigley et al., 1986). The choice of 12-year periods was based largely on known response times in the climate-hydrologic models for the Great Lakes to reach equilibrium. This choice is also supported by harmonic-spectral analyses of midwestern historical precipitation data indicating, at varying levels of statistical significance, wavelengths of 10 to 13 years in length (Neill and Hsu, 1981).

These climate scenarios provide values for input to existing hydrologic models used to determine net basin supply (NBS) values for ultimate use in hydrologic models of the Great Lakes basin so as to project levels of Lake Michigan (and the other lakes). Since precipitation is a primary factor in determining NBS and lake levels, it was decided to develop the climate scenarios solely around precipitation conditions. Annual precipitation values for 1854-1986 were used in selecting the scenario periods, and actual monthly precipitation values from the selected years were then used as the input to the hydrologic models needed to obtain the NBS values.

The periods selected to portray extremely dry 12-year periods had to contain eight or more years with below-average precipitation. This criterion was based on the fact that the frequency of below-average annual precipitation has been shown to be the most critical factor for NBS (Quinn, 1986) and for lake levels (Changnon, 1987).

The next aspect considered was the selection of the temperature data. Temperature values were not chosen separately; instead, the precipitation-temperature relationships found in the actual historical data were retained. Actual daily and monthly data on temperatures (and on humidities, winds, and evaporation) were taken from the historical records for the years selected on the basis of their precipitation extremes. For years prior to the availability of daily data (which were needed in the scenarios for the hydrologic model), algorithms relating the precipitation values to temperature and other daily conditions from the 1948-1985 period were used.

The most extreme dry periods extending across the Great Lakes basin were selected. This was done by screening the historical annual precipitation values for each of the Great Lakes basins (1854-1986) and then selecting the values extending across the entire basin.

This initial screening identified all candidate 12-year periods based on the presence of eight or more years with below-average precipitation. The net departure from normal of the total precipitation in each candidate period was also determined, yielding negative values for the candidate dry periods.

Once the candidate periods and their two measures of severity (the number of extreme years in the 12-year period, and the total precipitation departure) were determined for the basin of each lake, these periods were intercompared between basins. Those found to be common or present for all four basins were the final candidates for the actual period scenarios for the Great Lakes basin. They are listed in table 1.

Each period on each lake basin was ranked, as shown, on the basis of the magnitude of the 12-year cumulative precipitation departure. For example, in the Lake Superior basin, the 1914-1925 value of -9,242 mm, or-370 inches (table 1), was the highest-ranked dry value. The four basin rankings thus achieved for each candidate 12-year period shown in table 1 were summed to obtain a "basin-wide rank score." As shown in table 1, this score for 1914-1925 was 7, the lowest of the six candidate dry periods.

Hence, 1914-1925 was selected to represent the driest 12-year period in the Great Lakes basin. This 1914-1925 period became the basis for the initial climate scenario developed. The values used for this period were modified as follows:

1) The rankings of dry years were retained according to the sequence in which these dry years occurred across the entire Great Lakes basin, as based on the sum of the annual departures for each lake basin. For every annual precipitation value in the 1914-1925 period that was below average, a more extreme value (based on the lowest annual values during 1854-1986) was substituted.
2) The non-dry years in the 12-year dry period were not altered.
3) The process of substitution of more extreme values began with the ranking of the basin-wide mean departures from normal precipitation for each year in the 12-year period, as shown in table 2b. For example, the 1914 basin-wide value was -3,992 mm (-160 inches), and it ranked as the fourth-largest of the 12 values during 1914-1925 (the year 1923, with -5,668 mm [-227 inches], was top-ranked).
4) Annual values (departures) for the Great Lakes basin for 1854-1986 were used to select the 12 years with the largest negative values (the driest years). Each of the 12 values was ranked, as shown in table 2a. For example, the greatest 1-year value was -8,004 mm (-320 inches) in 1931 (rank 1), and the fourth-highest-ranked value was —4,890 mm (-196 inches) in 1936.
5) These 12 ranked values for the driest years (negative departures) were matched with the rankings of the actual years of the *12-year period 1914-1925* (as described in step 3 above). Then values (and years) were substituted according to matching of the ranks. For example, in the Great Lakes basin, the mean precipitation departure in 1914 was -3,992 mm, and this value ranked fourth among the 12 values in the 1914-1925 period (table 2b). The year with the fourth-greatest departure during 1854-1986 (table 2a) was 1936 with -4,890 mm (-196 inches). Hence, 1936 became the "substitute" year for 1914 (both ranked as fourth)(see table 2c).
6) Once these annual substitutions were identified for each year (except for the two wet years in 1914-1925), *the actual precipitation values in each lake basin for the substitute years were used in determining lake levels.*
7) This "climate scenario" selected out of the past had, as initial conditions, those that actually preceded it (1910-1913). These established the net basin supply (or NBS) when the period began.

Through this process, annual extremes were used to increase the departures that were experienced in the actual driest 12-year period in recorded history (1854-1986), and a climate scenario was developed on the basis of historical values. The adjusted values are considered realistic for helping to define potential extreme dry periods. The scenario was designed to retain the mix of dry years that occurred (and that are possible) in the driest period, but with a magnification of the annual values.

This approach allowed for interannual variability during such extreme events as well as for persistence of conditions during extreme dry periods. The underlying physical assumption is that the atmospheric conditions producing the extremely dry years (moved to the selected 12-year sequence) were possible for this period. That is, temporal transposition of more extreme events is within physical reason.

The extreme 12-year dry scenario was used with the Great Lakes Environmental Research Laboratory (GLERL) hydrologic models of the Great Lakes to calculate lake levels under current (1988) hydrologic conditions. These calculations projected a potential lowering of Lake Michigan of 1.0 meter (3.3 feet) below the 1951-1980 average.

Table 1. 12-Year Dry Periods Common to All Great Lakes*

	Superior			*Michigan-Huron*			*Erie*			*Ontario*			*Basin-wide*
Period	*No. dry years*	*Cumulative departure, mm*	*Rank*	*No. dry years*	*Cumulative departure, mm*	*Rank*	*No. dry years*	*Cumulative departure, mm*	*Rank*	*No. dry years*	*Cumulative departure, mm*	*Rank*	*rank score*
1910-21	**9**	**7503**	**4**	**8**	**2104**	**6**	**8**	**5191**	**4**	**9**	**6130**	**4**	**18**
1913-24	**9**	**8270**	**3**	**8**	**2646**	**5**	**8**	**4042**	**5**	**9**	**6019**	**5**	**18**
1914-25	**10**	**9242**	**1**	**9**	**5944**	**2**	**9**	**5834**	**2**	**10**	**7092**	**2**	**7**
1916-26	**10**	**8992**	**2**	**9**	**5856**	**3**	**9**	**5402**	**3**	**10**	**6162**	**3**	**11**
1916-27	**10**	**6331**	**5**	**8**	**3774**	**4**	**8**	**3949**	**6**	**9**	**4282**	**6**	**21**
1930-41	**7****	**1001**	**6**	**10**	**9287**	**1**	**8**	**6107**	**1**	**10**	**7513**	**1**	**9**

**Based on 8 or more years with annual precipitation below average for 1854-1986*

***Included because of severity in all other basins*

Table 2. Rankings and Departures from Average Precipitation for Dry Years in the Great Lakes Basin

a) Twelve driest years, 1854-1986

Rank	*Year*	*Basinwide departure, mm*
1	1931	-8004
2	1934	-5760
3	1923	-5668
4	1936	-4890
5	1925	-4502
6	1918	-4426
7	1963	-4303
8	1909	-4072
9	1910	-4062
10	1914	-3992
11	1915	-3959
12	1941	-3810

b) Rankings of mean annual departures from normal precipitation, 1914-1925

Year	*Basinwide departure, mm*	*Rank*
1914	-3992	4
1915	-3959	5
1916	3064	-
1917	-1196	10
1918	-4426	3
1919	-1300	9
1920	-2527	7
1921	-2911	6
1922	1181	-
1923	-5668	1
1924	-1876	8
1925	-4502	2

c) Years (1854-1986) whose values were substituted for those from 1914-1925 in developing the climate scenario

Substitute year used in climate scenario	*Superior*	*Michigan-Huron*	*Erie*	*Ontario*
	(Departures from avg. precipitation, mm)			
1936	-618	-1394	-1788	-1090
1925	-851	-1395	-1793	-463
1916	824	416	846	978
1914	-1047	-1090	-733	-1122
1923	-1463	-1063	-1370	-1772
1910	-1400	-1210	-439	-1013
1963	-687	-1164	-1430	-1022
1918	-1269	-1169	-1252	-736
1922	-169	1217	175	-42
1931	-1346	-2448	-2141	-2069
1909	-1550	-890	-377	-1255
1934	-411	-1675	-2430	-1244

CHAPTER 4. RESULTS: IMPACT OF LOW LAKE LEVELS IN 1964-1965

Data Sources

Each of the five sources of data regarding the effects and adjustments resulting from the record-low lake levels during 1964-1965 provided interesting information. The newspaper content analysis (described in Appendix A) revealed that few of the impacts determined from other data sources found their way into local newspaper reports in 1964-1965. Results suggest either that a "newspaper content analysis" of effects of record-low lake levels is not a suitable means of collecting extensive data on effects, or that the effects were so marginal that they were non-newsworthy.

A second finding about data sources related to records in public and private agencies. Most private, state, and federal agencies that were impacted by the activities of the early 1960s have since lost or destroyed the detailed records of activities and financial expenditures that are necessary to develop detailed measurements of effects. Furthermore, individuals currently responsible for corporate or institutional records generally were not interested in the project and/or were unwilling to locate such records if they exist. This avenue of investigation was greatly hindered by the unavailability of many activity/financial records for assessment.

A primary means for gathering data on the effects and adjustments resulting from the record-low lake levels came through interactions with individuals who were in responsible positions with private and public organizations during the time (1964-1965) of the low lake levels. Interactions with these individuals were complicated because most had retired and moved away from the Chicago area. Extensive telephoning and letter writing were necessary to locate key individuals.

The interactions typically consisted of extensive telephone interviews (the interview format is described in Appendix B). The interview process was greatly aided by the fact that most individuals contacted were aware of the scientific Surveys in Illinois, and thus most were willing to take time to assist us. These semi-structured interviews typically consisted of an hour or two of telephone conversation with each individual. In addition, four trips were made to the Chicago area for interviews with individuals who had extensive data and information, and for whom extensive telephone interviews were impractical. Altogether, interviews were held with 19 individuals from the private sector (shipping, harbor and dockage construction and maintenance, and consulting engineering), and from local, state, and federal agencies (experts in parks/beaches, water management, water quality, regional planning, environmental sciences, water policy, harbor and canal maintenance, and water supplies).

Because the 1964-1965 data on impacts and responses were so limited, we had to estimate future issues. For this purpose, a list of potential future problems/issues resulting from a drier climate (and lower lake levels) was developed. Several of those interviewed about 1964-1965 conditions were interviewed a second time concerning this list of future problems. Views about these problems were gathered, additional issues were identified, and cost estimates for addressing problems were gathered for the areas of expertise of the people interviewed.

The Illinois State Geological Survey has had a long-standing program of studying lakeshore erosion and geology. Their historical files, publications (Larsen, 1985), and aerial photograph library were invaluable sources of useful information. A recent inventory of lake-related research (Holms, 1987) was also of use.

The Physical Setting: Climate and Other Factors Relevant to Lake-Level Extremes

Assessment of the effects of extremely low lake levels on the Illinois shoreline and on human activities had to be based on a clear understanding of the factors that helped to create the extremely low levels. Furthermore, since this analysis was also conducted to speculate about effects of future low lake levels, including those possibly lower than the historical record has experienced, it became important to consider and investigate, to some extent, the physical factors affecting lake levels, the past behavior of lake levels, and potential future climate conditions that might create extremely low conditions.

Climate Influences on Levels of Lake Michigan

Three categories of water level fluctuations exist on Lake Michigan, each caused by weather and climatic fluctuations: short-period fluctuations (hours to days); seasonal fluctuations; and longer-term fluctuations (multiple year), which are of particular concern in this overall study of low levels.

Short-period fluctuations are caused by weather disturbances. Differences in atmospheric pressure and winds over the surface of Lake Michigan can create temporary imbalances in the water levels at various locations, with a resulting seiche (oscillation of the lake surface) wherein water literally piles up on one side of the lake. These types of fluctuations are superimposed on the more rhythmic seasonal fluctuations and the less rhythmic long-term fluctuations of lake levels.

Seasonal fluctuations of the levels of Lake Michigan result from the annual hydroclimatic cycle. This cycle is characterized by higher supplies (greater precipitation) during the spring and early summer, and lower supplies during the remainder of the year (lesser precipitation and higher evaporation). The magnitude of the seasonal fluctuation is relatively small, averaging about 30 cm (1 foot) on Lake Michigan. Seasonal fluctuations are about one-fourth the size of the long-term fluctuations, and are superimposed on the long-term fluctuations.

Longer-term fluctuations, which are of greatest concern in this study, are the results of persistent low or high precipitation conditions within the basin that can culminate in extremely low levels, such as were recorded in 1964-1965, or in extremely high levels such as recorded in 1972-1973 and again in 1984-1986 (Changnon, 1987). Figure 1 presents graphs based on the levels of Lake Michigan from 1860 through 1986. The annual values (figure 1a) reveal many "saw-tooth" type variations, and one notes the extremely low values for the early 1920s, 1930s, and early 1960s. Figure 1b presents the moving average of annual lake values based on 11-year periods, again showing the generally low values in the 1920s and 1930s, the low values in the early 1960s, and interspersed higher levels. Statistical analysis of these fluctuations did not reveal any regular, predictable cycles in lake levels or in precipitation. The intervals between the periods of extremely high and low levels, and the lengths of such

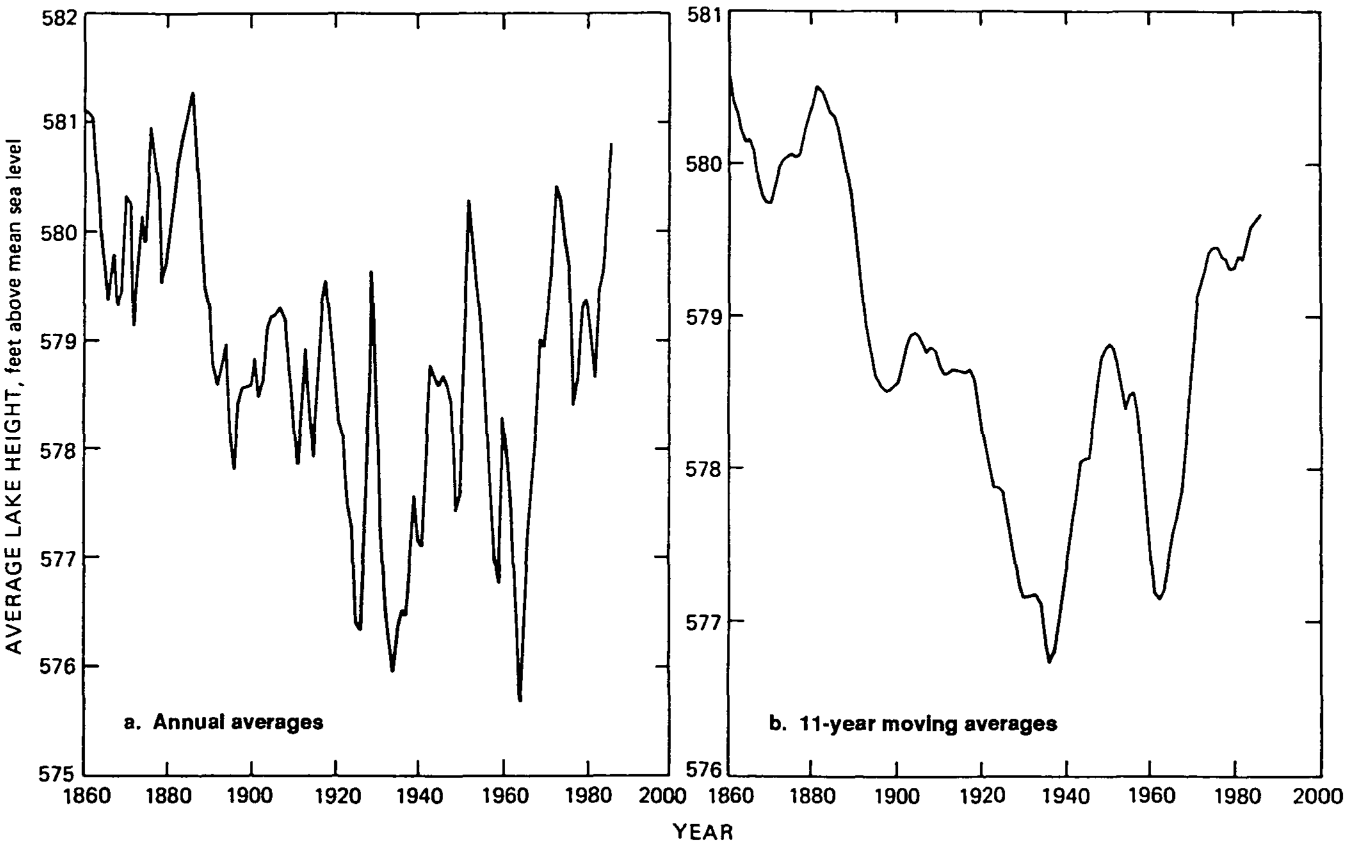

Figure 1. Lake Michigan levels (1860-1986)
based on annual averages and 11-year moving averages

periods, vary widely and erratically over a number of years.

The maximum recorded range of levels from the extreme high to the extreme low is approximately 1.5 meters (4.9 feet) on Lake Michigan. Importantly, the record annual lows (figure la) in the 1960s were followed within 10 years by record high levels. It should be noted that the data prior to 1900 are suspect for comparison to later years because of changes made in the connecting channels to the other lakes in the 19th century, which effectively lowered the level of the lake by about 20 cm (7.8 inches).

Of great concern to the analysis of extreme low and high levels of Lake Michigan (or any of the Great Lakes) is the climatic pattern. Inspection of figure 1 reveals major fluctuations in the lake levels over the last 120 years. Examination of the values of figure lb for the period of about 1900 to the present (that period unaffected by the changes in lake levels mentioned above) shows a period of generally increasing levels since 1940. This observation is substantiated by a recent analysis of precipitation on the Lake Michigan basin from 1896 to 1985 (Changnon, 1987), which suggested a regime of increasing precipitation over the last 50 years. This climatic regime is part of a period that moved towards ever wetter conditions, which also included increased cloudiness and reduced over-lake evaporation.

Another feature of the climatic conditions, particularly in recent years, is the high frequency of extreme events, suggesting a shift to greater climatic variability. Comparison of the annual values (figure la) for 1900 through 1940, as compared to those from 1941 to 1985, reveals that the earlier period had fluctuations but that they were not as large as those in the latter period. This is reflected in high levels in the 1950s, early 1970s, and mid-1980s, intermixed with the record lows in the 1960s. As will be shown in the effects analysis, such fluctuations in climate are as important as the general trend to wetter or drier conditions.

Other Factors Influencing Levels of Lake Michigan

The vast surface areas of the Great Lakes, which are equal to nearly half the land areas that contribute runoff to them, constitute an important factor in their water levels. Small differences in lake levels represent enormous quantities of water. Both the seasonal and long-term fluctuations in lake levels are the result of changes in lake volume. The variation in the supply of water, which is primarily the difference between the precipitation on the lakes and their basins and the evaporation from them, is the primary cause of the seasonal and long-term fluctuations. Net monthly water supplies to the Lake Michigan basin, for example, range from a maximum of 594,000 cfs/month to a minimum of-86,000 cfs/month. The negative value indicates that losses from evaporation and outflow exceed the supply from precipitation and inflow (runoff) to Lake Michigan. However, large variations in supplies to the lake are absorbed and modulated to such an extent that its outflow is remarkably steady. Because of the large size of Lake Michigan (and the other lakes), and the very limited natural discharge capacities of the outflow rivers from them, extremely high or low levels (and flows) persist for some considerable time (months and years) after the factors which have caused them have changed or ceased.

Precipitation over Lake Superior and the amount of water in Lake Superior that drains into Lakes Michigan-Huron are of considerable importance to the levels of these two lakes. That is, the advent of a dry period on Lake Michigan leading to a lowering of lake levels can be either enhanced or ameliorated depending upon the precipitation conditions (and basin supply) of Lake Superior. The worst possible situation in terms of low lake levels, of course, is to have dry conditions on both lakes at the same time, as well as on the other lakes. The correlation coefficient between the average annual precipitation values of the Lake Superior basin and those of the Lake Michigan basin was +0.68 for the 1901-1986 period.

The analysis of the precipitation conditions on the two lakes was based on data for 1854-1900 (when few weather stations existed) and 1901-1986 (when more stations existed and the data are considered better). Table 3 presents an analysis based on the 12-year periods for which the Lake Michigan precipitation conditions were classed as either dry or wet.

The dry and wet periods were selected on the basis that eight or more of the years in the 12-year period experienced below (for dry) or above (for wet) average precipitation. The results in table 3 indicate that when a 12-year dry period exists on Lake Michigan, it is highly likely that one exists on Lake Superior, too.

A dryness index was defined (the number of years of below-normal precipitation in any given 12-year period), and these indices on Lake Michigan for periods during 1901-1986 were correlated with those on Lake Superior. Since the dryness index takes on values of 0 to 12 (years) and the relationship is not linear, the actual index value for each lake was

Table 3. Precipitation Conditions on the Lake Superior Basin during Excessively Dry and Wet 12-Year Periods on Lake Michigan

	Lake Superior conditions for same 12-year periods (percent of total)		
	Dry	*Wet*	*Neither*
12-year dry periods on Lake Michigan			
Early, 1854-1900	**54**	**13**	**33**
Recent, 1901-1986	**85**	**6**	**9**
12-year wet periods on Lake Michigan			
Early, 1854-1900	**0**	**79**	**21**
Recent, 1901-1986	**0**	**100**	**0**

replaced by its rank value in terms of its population. The correlation of these ranks (by Spearman's test) produced a coefficient of +0.75, higher than the all-years correlation of +0.68. Thus, when atmospheric conditions produce below-average precipitation on the Lake Michigan basin, similar below-normal conditions are very apt to occur on the Lake Superior basin.

The mean levels and the outflows of Lake Michigan will also change progressively with time as a result of other factors. Included in these is the steadily increasing consumptive use of water in the basin, and a nearly imperceptible movement of the earth's crust in the region of the Great Lakes basin. The tilting of the earth's crust across the basin produces slow but measurable effects on lake levels. The effect on Lake Michigan, for example, is that in the northeastern portion, land is rising with respect to land at the south end at a rate of about 30 cm (1 foot) per century. This is considered to be due to the rebounding of the earth's crust from the weight of the Ice-Age glaciers. The net effect of this tilting is to gradually increase the mean water elevation of Lake Michigan. These factors, in addition to climate fluctuations and trends, affect the lake level.

Climate Conditions during 1964-1965

The record low lake levels (monthly and annual values) experienced in 1964-1965 were a direct result of below-average precipitation on the Lake Michigan basin beginning in 1961. The greatest departures from the average annual precipitation in the basin (3,401 mm, or 136 inches) occurred in 1963 (-1,164 mm, or -46.6 inches) and 1964 (-1,168 mm, or -46.7 inches), but values were also below average in 1961 (-955 mm, or -38 inches), in 1962 (-244 mm, or -10 inches), and in 1965 (-134 mm, or -5 inches). Record-low lake levels did not occur until the winter of 1964-1965 because of the slow response of the basin system, as described above.

It was fortuitous that during this extremely dry period on Lake Michigan, near-normal precipitation conditions occurred on Lake Superior. The Lake Carriers Association (1964, 1965) notes how the Lake Superior waters were used to try to minimize the fall of the Lake Michigan levels. Their 1965 report states, "Fortunately this very serious situation (1964 low levels) was mitigated to some extent by completion of the connecting channels program and the higher level of Lake Superior."

During the latter part of 1964, outflows from Lake Superior were substantially increased by a series of ever-increasing openings of the gates in the compensating works that limit the flow of water down St. Mary's River (connecting the two lakes). This program commenced on July 6,1964, and was increased gradually until November 10, 1964, when all 16 compensating gates (separating Superior from Michigan-Huron) were opened for the first time in a decade. The outflow reached 125,000 cfs, aiding the navigation in St. Mary's River (below the locks going into Lake Huron). Wide use was made of the water level prognostications issued by the U.S. Lake Survey.

Variability of Lake Levels

Of considerable importance to the consideration of the impacts of low (or high) lake levels on shorelines and shore activities is the amount of year-to-year variation in lake levels. Global climate models used to estimate future low lake levels resulting from a doubling of CO_2 do not provide a valid measure of this important condition or of the type of long-term fluctuations that will accompany these extreme levels. Some modelers believe that the interannual and longer-term fluctuations will be greater than those previously experienced.

To obtain estimates of possible variability, the lake-level data from the high- and low-lake-level periods on Lake Michigan were analyzed so intra-annual (seasonal) longer-term variations could be determined. Table 4 presents results of a statistical analysis based on selecting the ten 3-year and 5-year periods with the lowest lake levels and the ten 3-year and 5-year periods with the highest lake levels. In calculating these variations, the average of the yearly mean lake height for each 3-year and 5-year period from 1860 to 1986 was computed. The ten non-overlapping 3-year and 5-year periods with the lowest average lake heights were then computed, as well as the ten non-overlapping periods with the highest averages. Table 4 shows four summary measures. Inspection of the medians for the coefficients of variation (CV type 1) reveals that the medians for the ten periods with the lowest lake levels exceed the medians for the ten periods with the highest lake levels, in the case of both the 3-year and 5-year periods. The difference in variances (type 1 or type 2) between wet and dry periods is negligible. The differences in medians for the coefficients of variation

Table 4. Measures of Intra-Annual Variation in the Lake Levels of Lake Michigan during Periods of High and Low Lake Levels*

Measures of variation for the ten 3-year periods with the lowest lake levels

From	*3-yr average (ft)*	*CV type 1*	*Variance type 1*	*CV type 2*	*Variance type 2*
1933	576.17	1.29	0.91	0.15	0.12
1963	576.19	1.74	1.14	0.33	0.20
1925	576.63	2.21	1.14	0.31	0.16
1936	576.70	2.07	1.27	0.31	0.22
1957	577.12	2.23	1.09	0.28	0.16
1939	577.27	1.41	0.80	0.15	0.11
1930	577.47	3.55	1.20	1.16	0.15
1922	577.64	2.20	1.22	0.34	0.22
1966	577.70	1.97	1.20	0.32	0.18
1948	577.81	2.59	1.52	0.48	0.29
	Medians	*2.14*	*1.17*	*0.32*	*0.17*

Measures of variation for the ten 3-year periods with the highest lake levels

From	*3-yr average (ft)*	*CV type 1*	*Variance type 1*	*CV type 2*	*Variance type 2*
1860	581.10	1.53	1.36	0.18	0.18
1884	581.08	1.54	1.08	0.15	0.13
1876	580.66	1.94	1.11	0.25	0.21
1985	580.60	2.06	1.27	0.25	0.18
1863	580.54	2.25	0.90	0.29	0.11
1881	580.40	2.24	1.26	0.26	0.21
1973	580.20	1.61	1.18	0.22	0.18
1887	580.03	2.26	1.25	0.38	0.17
1869	580.01	2.64	1.85	0.56	0.41
1873	579.93	2.00	1.34	0.27	0.26
	Medians	*2.03*	*1.25*	*0.26*	*0.18*

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indicate that the intra-annual variation is greater during low-lake-level periods than during high-lake-level periods.

An analysis of the rate of change in Lake Michigan levels prior to low-level periods was also made. There were eight discrete 5-year low-level periods during the 1860-1986 period, and these are listed in table 5 along with the average lake levels during each period. These periods were selected as being isolated, or discrete, without temporally adjacent low periods. The departures from average levels for the 3-, 5-, and 10-year periods preceding each such period are also shown. These reveal downward trends for all the 3- and 5-year preceding periods, and the periods with the lowest levels (1923-1927, 1933-1937, and 1962-1966) were preceded by the largest rates of change in the 3 and 5 years preceding them. This indicates that some information on the development of singular low-level periods is contained in the rate of change in levels in the periods preceding lows.

The changes in levels prior to low-level periods were tested against all other changes by use of the

Table 4. Concluded

Measures of variation for the ten 5-year periods with the lowest lake levels

From	*5-yr average (ft)*	*CV type 1*	*Variance type 1*	*CV type 2*	*Variance type 2*
1933	576.29	1.29	0.90	0.15	0.11
1962	576.65	2.56	1.14	0.58	0.17
1923	576.94	2.44	1.13	0.40	0.17
1937	577.08	2.36	1.06	0.30	0.18
1958	577.49	3.28	1.28	0.56	0.24
1929	577.66	4.80	1.32	2.05	0.23
1946	578.14	2.89	1.54	0.57	0.30
1941	578.18	2.86	1.23	0.65	0.25
1966	578.21	3.15	1.21	0.66	0.19
1954	578.27	3.80	1.23	1.03	0.19
	Medians	*2.88*	*1.22*	*0.58*	*0.19*

Measures of variation for the ten 5-year periods with the highest lake levels

From	*5-yr average (ft)*	*CV type 1*	*Variance type 1*	*CV type 2*	*Variance type 2*
1860	581.08	1.53	1.19	0.15	0.15
1883	580.91	2.29	1.30	0.25	0.20
1874	580.41	2.56	1.09	0.31	0.18
1984	580.29	2.59	1.25	0.47	0.18
1862	580.14	2.80	1.08	0.52	0.16
1879	580.08	2.42	1.12	0.35	0.17
1972	579.99	2.56	1.39	0.33	0.25
1870	579.92	2.58	1.56	0.50	0.32
1866	579.65	2.50	1.45	0.39	0.26
1887	579.63	3.06	1.17	0.56	0.16
	Medians	*2.56*	*1.22*	*0.37*	*0.18*

**Explanations:*
Col. 1: start year
Col. 2: average of yearly average lake level for the 3- or 5-year period
Col. 3: coefficient of variation (maximum in period less minimum in period)
Col. 4: variance of monthly levels in period
Col. 5: average annual CV (maximum less minimum in one-year period, averaged over all years in the period)
Col. 6: average annual variance over period

Wilcoxon test. The rates of changes for 3- and 5-year periods before 5-year lows were found to be larger than the usual changes, and the differences were highly significant, with P-values of 0.01. Hence, multi-year decreases in levels of the type shown in table 5 should be indicative of a potential 5-year low in lake levels.

Land Use

The land uses found along the relatively short Illinois shoreline of Lake Michigan (101 kilometers, or 63 miles, in length) are relevant to the interpretation and transfer of the findings from this case study of the effects of low lake levels on the Illinois shoreline. Table 6 shows the land uses along the shoreline and how they compare with the land uses around the remaining parts of Lake Michigan. Most of the shore is beach Gargely man-made), although about 30 kilometers (18.6 miles) are glacial bluffs.

All major land uses except agriculture are represented along the Illinois shoreline, the focus of this study. Thus, certain results relating to recreation, industry/commerce, and residential frontages should potentially be transferable to other urban areas around Lake Michigan (and the other lakes). An example of the small, undeveloped shoreline area along the Illinois shoreline near Zion is portrayed in figure 2. These largely undisturbed areas further reveal the effects of periods of higher and lower lake levels. The "beach ridges" from periods of oscillating lake levels in the past 2,000 years are revealed by the land forms and the alignment of the land cover. The periods when lake levels may have been extremely higher or lower due to climatic fluctuations over the last 2,500 years have been investigated by Larsen (1985).

Effects and Adjustments Resulting from Low Lake Levels in 1964-1965

The data limitation problems already noted, and the general lack of detailed historical records of ac-

Table 5. Average Rates of Lake-Level Change in 3-, 5-, and 10-Year Periods Preceding 5-Year Periods of Low Lake Levels in Lake Michigan

Period		*Average*	*3-year prior period,*	*5-year prior period,*	*10-year prior period,*
From	*To*	*level (ft)*	*departure from avg (ft)*	*departure from avg (ft)*	*departure from avg (ft)*
1878	**1882**	**580.02**	**-0.09**	**-0.05**	**0.03**
1895	**1899**	**578.28**	**-0.05**	**-0.12**	**-0.22**
1911	**1915**	**578.28**	**-0.07**	**-0.14**	**-0.06**
1923	**1927**	**576.94**	**-0.35**	**-0.36**	**-0.17**
1933	**1937**	**576.30**	**-0.21**	**-0.35**	**-0.06**
1946	**1950**	**578.14**	**-0.17**	**-0.01**	**0.12**
1962	**1966**	**576.65**	**-0.24**	**-0.25**	**-0.27**
1977	**1981**	**578.94**	**-0.14**	**-0.21**	**0.03**

Table 6. Percentage Distribution of Shoreline Land Use on Lake Michigan

Land uses	*Illinois shoreline*	*Lake Michigan total shoreline*
Recreation	**43%**	**11%**
Industry/Commerce	**19%**	**6%**
Residential	**34%**	**33%**
Agricultural	**0%**	**20%**
Forests/Undeveloped	**4%**	**30%**

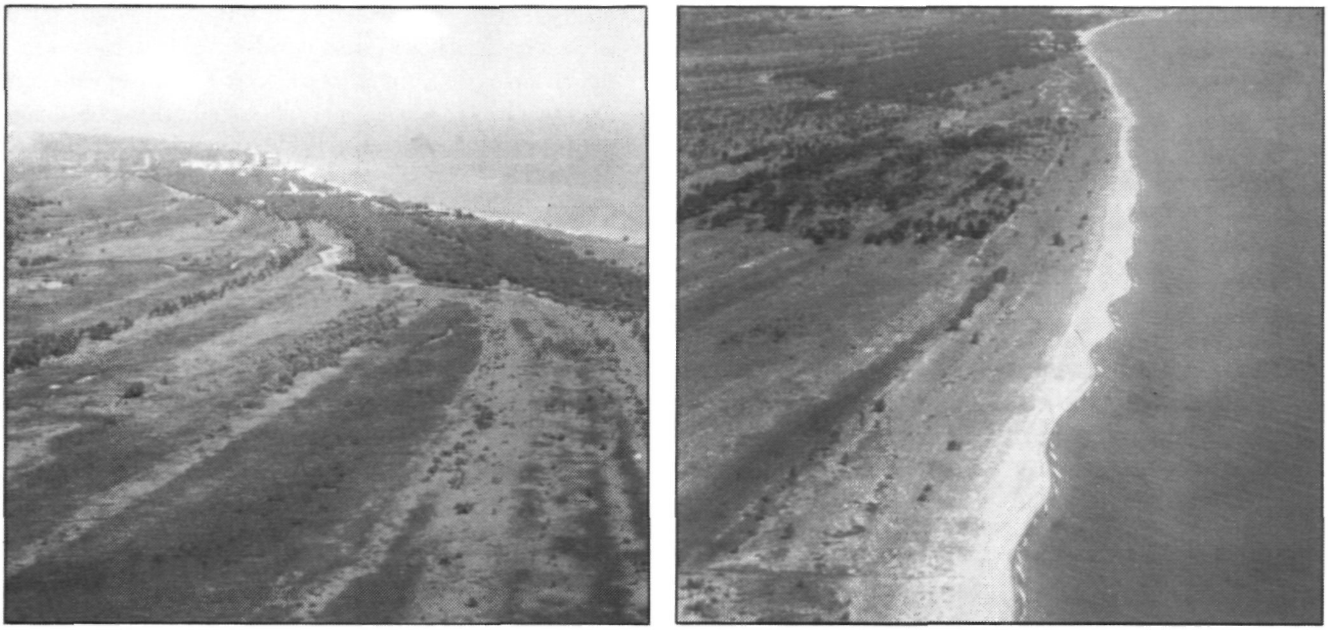


Figure 2. Beach ridges near Zion, Illinois, left by periods of higher lake levels due to climate fluctuations in the past 2,500 years

tivities by corporate and most public institutions, made it impossible to carry out an extensive, highly quantitative assessment of all the effects of the low lake levels. However, we were able to perform two types of analyses: 1) a general effects analysis, based primarily on the information gained in interviews (with some support from the newspaper content analysis and public records); and 2) detailed socioeconomic analyses for areas for which detailed loss and adjustment data could be obtained. Thus, a general, semi-quantitative descriptive assessment of the effects in all areas has been developed, and a more detailed socioeconomic assessment of effects has been conducted for two areas: damage to shoreline protection structures, and encroachment land use problems. These are described in subsequent sections. The results of the newspaper content analysis appear in Appendix A.

General Effects on the Great Lakes

Before considering the specific impacts of the 1964-1965 low lake levels on the Illinois shoreline area and lake-related activities, it is appropriate to consider the broader context of low (as well as high) lake levels throughout the Great Lakes basin. *Society has now so developed its use of the Great Lakes that any fluctuations in lake levels create problems.* Low lake levels are both advantageous and disadvantageous to different impacted physical and human sectors. High lake levels act to reverse the impacts, in general. No one lake-level condition is seen as optimum, other than the unlikely possibility of achieving a single level that remains essentially constant except for seasonal variations. In general, high lake levels are of value to two major sectors (navigation and shipping) and to hydroelectric power generation. Conversely, most shoreline owners benefit from low lake levels. However, the existing shoreline environmental conditions (wetlands, shallow ground-water levels, and habitats) suffer from lower levels. These types of general basin-wide impacts of lower levels on the lakes should be taken into consideration when examining the impacts from the 1964-1965 low lake levels on the 101-km (63-mile) Illinois frontage along Lake Michigan.

Effects and Adjustments along the Illinois Shoreline

The effects and related adjustments along the Illinois shoreline that resulted from the low lake levels during 1964-1965 were sorted and categorized into seven groups:

1) Shore and near-shore physical effects
2) Effects on transportation and shipping
3) Recreational impacts

4) Effects on industry and commerce
5) Impacts on water management, supplies, and drainage
6) Effects on land use
7) Institutional impacts and adjustments

The effects on *physical features* and related structures along the shoreline were extensive and of mixed value. One of the positive effects was the expansion of the beaches. Figure 3a shows this type of expansion around the groins of one Chicago-area beach.

Another physical impact along the shoreline that was caused by the lower lake levels, coupled with onshore winds, was the movement of beach sand and the formation of dunes, as shown in figure 3b. These new dunes later protected the shore against high-water conditions and storms. The effects on the wetlands and habitats north of Chicago were considered insignificant, largely because the period of low water was confined to two years.

Several negative effects of low levels along the shores were found. These included decreased depths in harbors and their inlets, and effects on pleasure boat and ship traffic. Figure 3c shows an entrance to one of the urban harbors that had become sufficiently silted to require dredging for use. Figure 3d shows the same area in a period of near-average lake levels. The results of this problem are treated further in the discussions of shipping and recreational issues.

A greater physical effect on structures along the shoreline concerns damage to harbor and shore protection structures. The impact on the protection structures of low and then high lake-level interactions was so great that a separate special investigation of this problem was conducted. It is reported on in the next section of this chapter, "Damage to Shoreline Protection Structures."

The primary effects on *transportation and shipping* related to the low lake levels in harbors and canals, which necessitated dredging in certain harbors, presumably in addition to the normal annual dredging. Records of the Corps of Engineers (1964, 1965), who handle the dredging in major ports, make no mention of the effects of the low water on their harbor maintenance operations for Calumet Harbor, Chicago Harbor, the Chicago River, or Waukegan Harbor. However, assessment of the annual dredging costs for Calumet Harbor showed an increase of $160,000 in 1965 over those in 1964 ($284,000), a 56% increase. Special 1965 dredging costs for Waukegan Harbor were $38,000 in April-May 1965, presumably as a result of the low-water problems. No evidence of added costs for dredging in Chicago Harbor or the Chicago River was found. Furthermore, no beach erosion control projects were launched during this period, evidence that beach erosion was not a problem in these low-water periods.

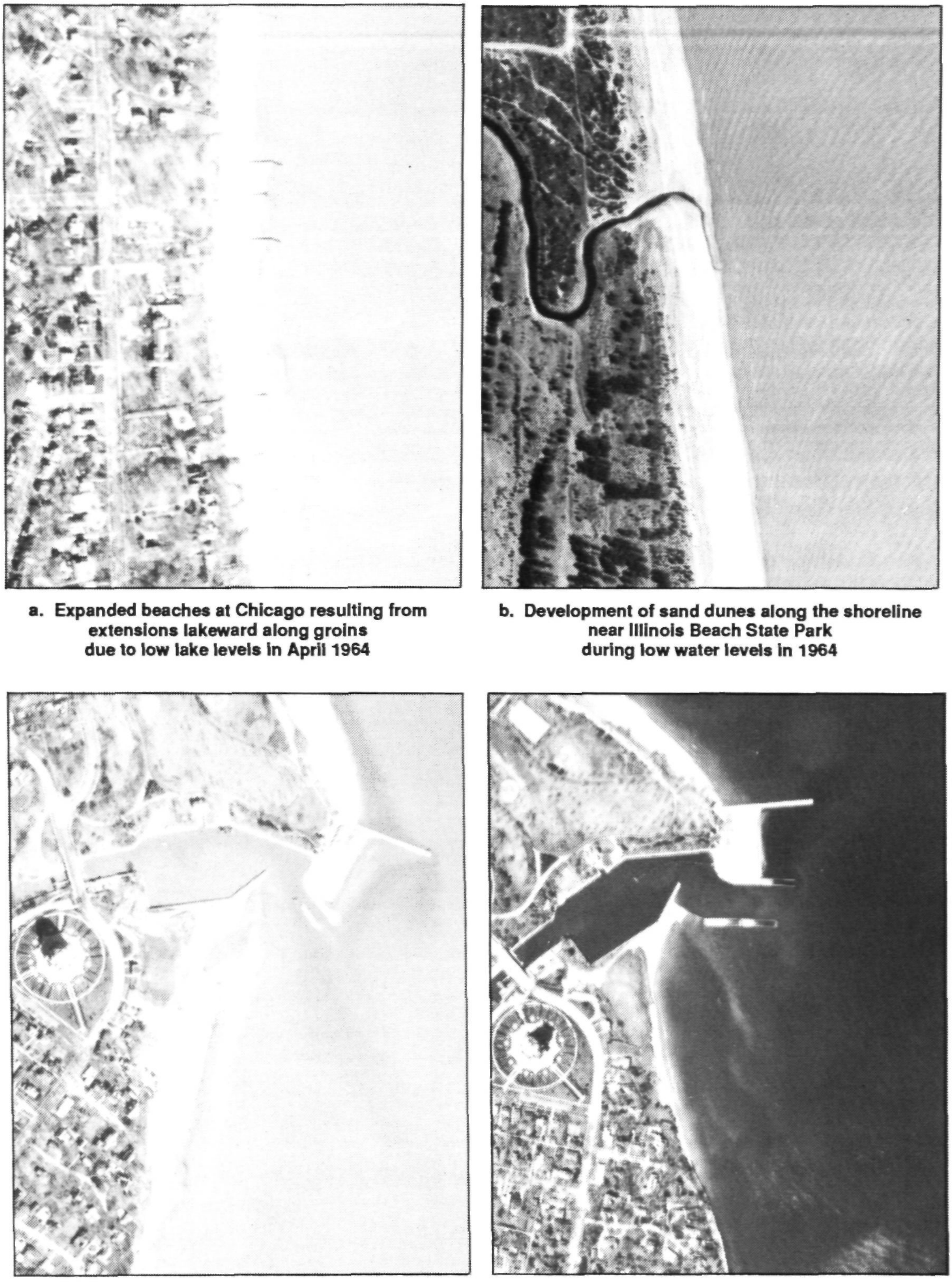
A second impact partly relating to transportation was inflow of water into the Chicago River and the canal diversion system. This system diverts Lake Michigan water to help sustain sufficient flow and water levels in the Illinois River system for barge transportation and sanitation needs. The lowest lake levels were such that minor problems occurred in sustaining adequate diversion during early 1965.

A third impact related to lower ship loads. Records could not be obtained for various lake carriers for this period, but experts indicated that loads carried on lake carriers were reduced between 5 and 10%, necessitating more frequent trips and higher costs. Problems due to the low flow of St. Mary's River (which connects Lakes Superior and Michigan-Huron) were reported (Lake Carriers Association, 1964, 1965). These problems existed on the Michigan-Huron side and were addressed by greater diversion of water from Lake Superior by the Corps of Engineers.

Recreational activities received mixed impacts. Problems were related to shallow water for pleasure craft in harbors and their inlets. Additional dredging was carried out in some private and local urban inlets and small-craft harbors, including Montrose, Belmont, and Jackson Harbors of the Chicago Park District. Docking was a problem, as shown in figure 4. Some docks were extended, and some were lowered. Ladders were constructed to get from the existing docks to boat level, generally at individuals' expense.

On the positive side, the swimming beaches along the Chicago shoreline were widened. A major new beach (Montrose Beach) was constructed on the north side of Chicago during the early 1960s, with the aid of large volumes of imported sand, but subsequent higher lake levels in the 1970s led to the erosion of this expensive new beach. Sand from this beach has been scoured and moved several hundred meters out from the lakeshore, and plans are being developed to pump this sand back to the beach. Another recreational problem related to the launching ramps for pleasure craft, several of which had to be extended to reach the edge of the water.

Impacts on *private industry and commerce* were difficult to isolate. Clearly, entities depending heavily upon lake carriers to obtain or ship supplies or products were hurt. Shipments were more frequent



a. Expanded beaches at Chicago resulting from extensions lakeward along groins due to low lake levels in April 1964

b. Development of sand dunes along the shoreline near Illinois Beach State Park during low water levels in 1964

c. Wilmette Harbor during low levels in April 1964, showing siltation at the harbor entrance and wider beaches

d. Wilmette Harbor during near-average lake levels, April 1968

Figure 3. Examples of effects of low lake levels In 1964 on **the** Illinois shoreline (Photographs from C. Collinson, Illinois State Geological Survey)

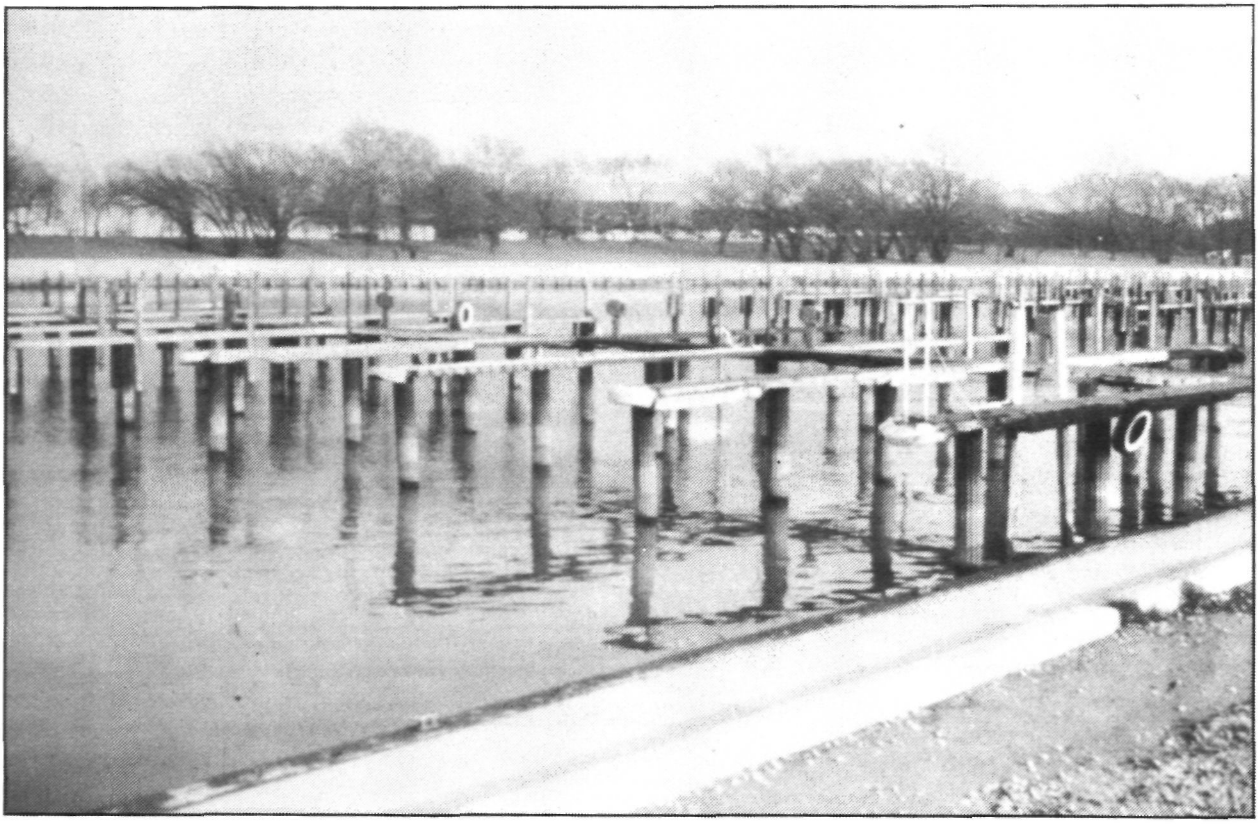


Figure 4. Docking facilities at Wilmette Harbor during record-low lake levels In April 1964

(with lighter loads), and the cost of raw materials and supplies reportedly increased by between 10 and 15%. Local lake shipping companies were hurt. The loads carried had to be reduced because of the shallower harbors, and experts reported that these problems led to the carrying of some raw materials on regional railroads rather than on lake carriers.

Dredging companies benefited because of increased amounts of harbor dredging. However, problems developed because of the difficulty of finding proper areas for disposal of harbor sediment that was considered polluted. This added to the costs of dredging and disposal and in turn cost the local communities and local and state governments more for dredging than in past years.

Effects on *water management and exchange systems* were considerable. In certain cities that depended on lake water supplies, such as Evanston, intakes had to be extended. In certain instances, intake levels had to be lowered, and additional water intakes were built for three communities. Outfalls for stormwater drainage were also exposed in certain communities. At Highland Park, a major drainage line had to be extended 2,000 meters (1.2 miles) at a cost of $400,000. Certain cooling ponds along Lake Michigan also had to be dredged because of insufficient depth.

The primary impact on *land use* related to the wider beaches caused by the lower lake levels. As noted above in the discussion of impacts on recreation, the size of public and private beaches along the lakeshore was increased. However, the additional beach space offered the opportunity to construct various structures closer to the lakeshore. This "encroachment" occurred at locations along certain of the suburbs north of Chicago. The socioeconomic and policy ramifications of this encroachment during low lake levels were so considerable that they too were the subject of a separate detailed investigation. As with the problem involving lakeshore protection systems, this problem developed because of the low lake levels followed by higher lake levels. Thus, a "delayed effect" was seen. Persistent future lower levels of Lake Michigan would produce "delayed effects" in environmental conditions, with lowered ground-water levels and greatly altered wetlands.

The *institutional impacts and adjustments* resulting from the low lake levels were considerable and occurred at all levels of government. Concerns about the low-lake-level problems led to conferences in both the United States and Canada during 1964. As a result, the International Joint Commission (IJC) convened hearings in May 1964 in Chicago and Sault Ste. Marie. The U.S. and Canadian governments assembled and called for a "reference," an in-depth study by the IJC of the problem along with a presentation of possible solutions. The reference was issued in October 1964. In turn, the IJC established an International Great Lakes Levels Board on December 2,1964 (International Great Lakes Levels Board, 1973). This board was to undertake necessary investigations to provide in-depth advice on lake levels and their control. This assignment took nearly 10 years to complete, with the report issued in 1973. Interestingly, by the time of publication, the lake levels had gone from the record lows of 1964-1965 to new record-high levels in 1973, the year the report was issued. The report provides information about the broad impacts of low lake levels, and in particular about the economic effects of variations about the mean levels of the Great Lakes.

Most communities along the lakeshore had to react to the low lake levels in various ways, both positive and negative. Increased costs of local dredging and harbor adjustments were met, and water management systems were altered. Mayors, city engineers, and water and sewage treatment officials had to deal with a variety of problems and advantages related to the bigger beaches and more difficult problems of water exchange.

The city of Chicago, the Metropolitan Sanitary District of Greater Chicago, and the state of Illinois dealt with concerns and adjustments relating to the diversion needs and low lake levels. The Chicago Park District installed a new major beach (Montrose Beach). The Corps of Engineers was involved in more dredging.

The Center for the Great Lakes instituted a series of meetings related to the lower lake levels, and developed a long-term program to assess land management techniques and to provide information on which types of lakeshore techniques had failed and which had succeeded (Great Lakes Reporter, 1987). Basically, this report was related to the "delayed" impact of the low lake levels of the 1960s and the subsequent high levels in the 1970s and 1980s, and to the necessity to consider methods (including structures) to deal with problems at both the low and high end of the spectrum of lake levels.

In private institutions, some of the impacts and adjustments noted were the increased profits of private dredging firms; however, after the period of low lake levels, the number of such firms decreased. Consulting engineering firms dealing with lake issues (harbors, docks) received more business, and the number of these firms increased. Certain small shipping companies were sufficiently hurt that they closed or were amalgamated into larger firms.

Illinois' diversion of lake water, used to aid the Chicago and Illinois River systems and to provide water supplies in the Chicago urban area, was not affected by the low lake levels. The Illinois diversion has been an issue of contention among the lake states since the 1920s. The U.S. Supreme Court reduced the diversion, which was 10,000 cfs in the 1920s, to 3,100 cfs by 1938, following the Court's decree of 1930. Subsequent decrees have set the diversion at 3,200 cfs, including domestic pumpage. This amount of diversion accounts for an annual decrease of 0.07 meter (0.23 foot) in the level of Lake Michigan. The diversion depends upon gravity flow from the lake into the river and canal system. If lake levels had fallen somewhat lower than they did in 1964-1965, natural inflow to the rivers would have been difficult in the cold-season (winter) period of lower lake levels. *Lowering of Lake Michigan in the future could cause major impacts at Chicago, requiring major pumping systems, extensive dredging, and costly new lockages to put Lake Michigan water into the drainage system.*

In summary, the institutional impacts were diverse and generally were very troublesome, costly, and long-lasting. The situation, given only a two-year low-lake-level period, suggests that future persistently lower levels will create institutional problems beyond the ability of our current institutions to address in any satisfactory manner.

Damage to Shoreline Protection Structures

One of the major effects of the record low levels in the 1960s and the subsequent increases in the lake levels to much above average levels during the early 1970s and mid-1980s has been that most of the wooden shore protection works of Chicago suffered major damages.

In the early part of this century and extending up through the 1920s, the city of Chicago spent more than $100 million on the development of its shoreline park system. Roughly $1 billion was spent on landfill along the Lake Michigan shoreline and on construction of the park system (Mayer and Wade, 1969). This transformation of Chicago's lakefront ranks as one of the world's most vast public works relating to waterfronts and to the development of parks, recreational facilities, and transportation systems (Real Estate News, 1927).

Much of the 38-kilometer (24-mile) frontage owned by the city of Chicago along the lakeshore (nearly 40% of the total Illinois shoreline) was extended from its pre-settlement shoreline eastward, ranging in distance from tens of meters to more than 3,000 meters (3,280 yards) eastward in certain locations. More than 1,300 acres of new park lands were added south of the city center (the Loop), where no parks had existed.

This was accomplished by constructing a series of protection works of varied structural design, often built of wood and steel and filled with rock and cement, along the entire 38-kilometer (24-mile) frontage. Behind these protection devices, the area was filled with sands brought in from the lake, and with soil. Extremely valuable new property was created.

Those portions of the shoreline devices that essentially remained below water from the time of their construction (1890-1930) up to the low-water period of the 1960s were exposed to the air during the 1964-1965 low water period. Dry rot set into the planking at that time. Subsequent lake levels that increased to record high levels in the early 1970s and then to ever higher levels in the 1980s, with accompanying wave action from storms, have acted on the weakened wooden areas that experienced dry rot, helping lead to destruction of many of the wooden pilings.

The city of Chicago has established an investigatory commission (Chicago Shoreline Protection Commission, 1988), which has made an in-depth assessment of the damages to the shoreline protection structures along the 38-kilometer (24-mile) lakefront owned by the city. This report sets forth a range of technical options and alternatives for obtaining a new, long-term shoreline protection system. It cites the "rapid and effective emergency responses by the city, the Chicago Park District, and the Army Corps of Engineers" to protect the public from immediate threats and to keep the city functioning during critical storms, and it calls for a program of local, state, federal, and private sector cooperation to begin the process of comprehensive repairing of the accumulated damage.

Again, this damage is partly the result of two factors: 1) the sequence of record-low lake levels in the 1960s (and the dry rot to the wooden support structures), and 2) the subsequent high water levels of the 1970s and 1980s, coupled with the incidence of major storms during the higher lake levels. That is, the high water levels increased the power of the lake to erode the shoreline, particularly during storms.

Wind and wave action of the lake erode the shoreline regardless of water levels, and systematic maintenance and repairs are needed as erosion occurs. The Commission's report also notes that the shoreline protection system has not been systematically maintained since its completion in the late 1920s. As a result, it has been severely weakened and undermined.

A single storm during the high-water levels (on February 8, 1987) with high winds (60 miles per hour) caused enormous flooding along the lakeshore, causing the closure of major avenues and Meigs Airfield, the evacuation of property along the shore, and the flooding of sewers, basements, and underpasses, including Navy Pier and a major Chicago water purification plant. Severe shoreline damages occurred, with much park land eroded. The costs to Chicago of emergency responses and cleanup were substantial, exceeding $2 million. Physical damage to city property such as Navy Pier and the water purification plant exceeded $1 million.

The portion of these damages, or of the costs to repair them, that resulted directly from the rot that developed during the low lake levels cannot be assessed independently. It is a part of the problem. Estimates indicate that more than 60% of the lakeshore devices made from wood were initially damaged by the dry rot incurred during the 1964-1965 low lake levels. These will eventually have to be replaced. The latest figures indicate that the estimated construction cost for rebuilding the damaged shoreline protection system is $843 million.

Encroachment Land Use Problems

The lowering of lake levels during 1964-1965 resulted in new wide beaches. This highly valuable "new land" led to the construction of buildings closer to the new beach areas, primarily houses, apartment buildings, and condominiums built along the lakeshore north of Chicago. These structures subsequently suffered extreme damages when higher lake levels occurred in the 1970s, within a decade after the record lows. Again, as shown in the prior section on effects on lakeshore protection works, the long-term (decadal) oscillations of lake levels (low and then high) have led to this encroachment problem.

One area of encroachment along the lakefront was investigated in detail to determine the effects on the shore, the owners, and the community where the encroachment occurred (see Appendix C). Permitting procedures relating to lakefront land-use changes have been tightened, and this issue promises to be a future key issue in a future with lower lake levels.

The movement of the lake edge from 1964 to 1987 was measured by using aerial photographs from the files of the Illinois State Geological Survey. An example of their map analyses of shorelines in the Zion map quadrangle is shown in figure 5, which depicts both the 1964 and 1987 shorelines. This area last was typically 150 meters (492 feet) wide, and the total amount of land in the mapped area that was available in 1964 and underwater in 1987 is 0.9 square kilometer (0.35 square mile). This helps illustrate the problems of encroachment.

Significance of Findings, and Research Needs

A review of the findings indicates that the most significant social and economic impacts resulting from the record-low lake levels of Lake Michigan during the early 1960s occurred as a result of the subsequent return to higher water levels 10 to 20 years after the low levels occurred. The two largest effects (extensive damages to shoreline protection facilities, and the encroachment of buildings and facilities onto the new beach areas) both occurred because of the low levels and then the upward swing of lake levels to 1.5 meters (4.9 feet) above the record-low levels of the early 1960s.

Clearly, if lake levels had remained low after 1964-1965, with normal seasonal oscillations of 30 centimeters (12 inches), the impacts to the existing shoreline property would have been much less. However, other detrimental effects would have developed in terms of ground-water conditions, wetland and shoreline habitats, shipping, harbors, and amount of water available for diversion and other uses.

Two important aspects of this study and its results are relevant to the general issue of climate impact assessment. First, it was impossible to get adequate, extensive, quantitative historical data to make in-depth economic assessments of many effects. Newspaper content analysis is inadequate, and necessary records of public and private institutions are essentially unavailable (lost or destroyed). It would be particularly beneficial to assess the impacts of the prolonged low lake levels from the 1920s to the 1930s, if the data existed. This suggests the need to develop and use economic models to simulate the effects of low levels.

Another apparent significant result relates to the general economic impacts of "low lake levels." Although hard to quantify, those relating to the low lake levels of 1964-1965 did not appear to be very large. The more costly impacts related to encroachment of structures onto the exposed beach areas. The damage to the shoreline protection structures occurred only as a result of the combined action of high lake levels (and storm-enhanced wave action) following the low lake levels within a few years. Thus, *the greatest economic impacts are a result of large lake-level fluctuations, not just of low levels.*

The physical assessment of the low lake levels performed for this study showed that the period from about 1910 to 1940 would be an informative period to model for estimating physical effects of low lake levels. Although this period did not have the lowest levels on record, it involved a prolonged period of 20 years of decline followed by a 12-year period (1930-1941) of prolonged low lake levels. Research on effects during this time period should be considered.

CHAPTER 5. POTENTIAL IMPACTS OF FUTURE LOW WATER LEVELS

Climatic Uncertainties Affecting Future Projections

Estimations of potential impacts of conditions caused by lower lake levels in future years are difficult to quantify with certainty. Values from three global climate models for the Great Lakes (based on increased atmospheric CO_2 and other trace gases) and the climate scenarios all indicate future lower lake levels, but they indicate widely varying heights. The predicted future levels of Lake Michigan from the models for the Illinois shoreline, in number of meters (feet) below the 1951-1980 average or base level, are: 1) 0.86 meter (2.82 feet), 2) 1.25 meters (4.10 feet), and 3) 2.52 meters (8.27 feet). The climate scenario based on the driest 12-year period of 1900-1985 yielded a level of Lake Michigan that was 1.0 meter (3.3 feet) below the average.

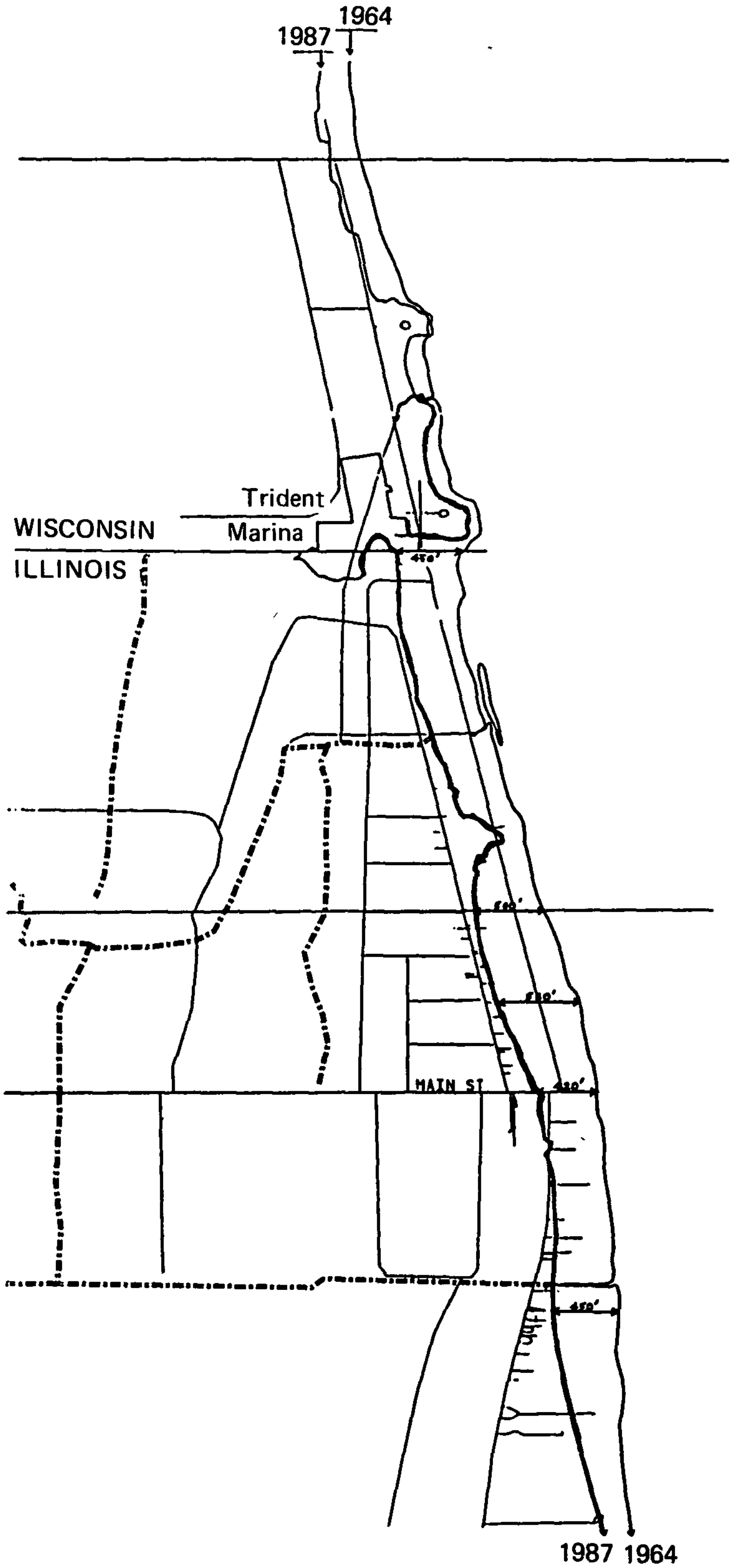


Figure 5. Comparison of the 1964 and 1987 shorelines as displayed on the ZIon map quadrangle (Illinois State Geological Survey)

Speculations offered herein about future impacts and adjustments resulting from these lower levels must be considered within the context of several limitations in the global climate models. Thus a short discussion of important key features of all three models is offered as an aid to determining the likelihood of the estimated impacts and adjustments offered herein. All models are broad treatments of regional conditions, and most modelers are skeptical about using the model-derived values for estimating regional changes. Regardless, for the Great Lakes basin all models show more moisture in the atmosphere, an increase in high clouds, and a 4°C increase in air temperature. Their predictions of precipitation levels differ greatly in both the magnitude and the locations of change. One model shows a basin-wide increase in precipitation of 10%. Some models show increased precipitation in the west (Superior and Michigan basins) and decreased precipitation in the east (Ontario basin). One model projects greater interannual variability of precipitation than in today's climate regime. The interdecadal variations will probably be large as the climate changes rapidly.

In conclusion, the projected changes in climate (and in lake levels) by all models could be incorrect, and their use is considered scientifically risky at the regional level. Because of these uncertainties and the lack of other relevant information, we had to make a number of assumptions before we could estimate certain future impacts.

First, the doubling of CO_2 and the changes in future climate conditions leading to predicted future levels of Lake Michigan will be achieved by a process that produces a near-linear, continuing decrease of lake levels requiring at least 50 years and as much as 100 years to achieve.

Second, since the decadal os cillations around these future levels are not predicted with any certainty in these models, and since this is very important in the impact analyses, the oscillation was assumed to be in the current range, 1.5 meters (4.9 feet) between the maximum and minimum values over any 100- or 200-year base period, or + 0.75 meters (2.46 feet) around the mean level.

A third assumption is that current laws and regulations pertaining to shoreline impacts will be retained: society will continue its current trend toward more control and regulation of natural resources.

A fourth major assumption is that the use of immediate frontage on Lake Michigan for beaches and harbors will continue, as will the use of the lake for water supplies and for deposition of storm runoff.

Further, we remind the reader that the study was limited to the Illinois shoreline with its largely urban-type frontage. Also, we have not addressed the water quality issue in any substantive way because of the magnitude of the issue and the lack of information on the quality of lake waters under the climate scenarios.

Impacts in Specific Areas

The model prediction of a future lake level of 0.86 meters below the 1951-1980 average closely matches the lake level achieved during the 1964-1965 record-low period (0.92 meters below average). Of course, an oscillation around that future average would exist at times, occasionally driving the level more than 1 meter below the current average. Most adjustments made to the low levels during 1964-1965 are known (see chapter 4). Experts in harbors, lakeshore facilities, and water facilities concluded that the 1964-1965 adjustments would largely satisfy the needs produced by the 0.86- or 1.0-meter predicted decreases in level. There would be increased harbor dredging, slightly expanded beaches, and alterations in slips and piers. Relatively few adjustments would be required to serve water exchange needs (intakes and outfalls). Moreover, many adjustment costs would be met as normal facility replacement costs. Increased dredging and new facilities would lead to from $75 to $100 million (in 1988 dollars) in added costs over 50 years.

The effects of the predicted future lake levels of 1.25 and 2.52 meters below average were more difficult to quantify and required more speculation since these were beyond levels experienced since settlement of the Great Lakes area. As noted in the discussion of assumptions, attainment of these values is assumed to occur after at least 50 years of gradual lowering of lake levels. This assumption is very important in estimating potential economic effects. Efforts to speculate on effects of the 1.25- and 2.52-meter lower levels focused on the direct effects on the shoreline and its immediate facilities.

Recreational Facilities and Harbors

Lakeshore experts who were consulted agreed that major impacts would occur to pleasure boat harbors and facilities. Many harbors have wooden slips and docks, and the continuing exposure over time of the below-water portions of these structures would produce dry rot. A major impact is that at 1.25- or 2.52-meter decreases in lake levels, all slips and docks would have to be replaced.

A calculation of the replacement costs at one recreational harbor facility showed a cost (in today's dollars) of $2 million. However, considering the time of change involved (50 or more years) and that the lifetime of these structures is typically 30 to 40 years, at least one replacement would normally be necessary anyway during the 50-year period of changing climate. Thus the cost of modifying slips and docks to adjust to the lower lake levels could be handled partly by normal replacement costs instead of by new, additional costs. Knowledge of the continuing shifts in water levels was seen as likely to lead to the acquisition of floating docks. In fact, these could be seen as becoming common at the pleasure boat facilities along Lake Michigan.

The second major area of impact on the pleasure boating facilities would relate to the harbors. Some experts predicted that some pleasure boat harbors would become "unusable," particularly with the 2.52-meter reduction. All harbors could be adjusted to handle the 1.25-meter reduction. Specific harbors considered to be nearly unusable without major dredging were Wilmette, North Point, and Winter Harbor. The cost of deepening harbors through dredging was seen as necessary and quite high for both predicted future levels. Costs for dredging and deposition of harbor materials considered to contain toxic materials would be 20% higher (in 1988 dollars) than costs for handling nontoxic materials.

Estimated values for the 1.25-meter reduction were $3 to $5 million per harbor, and for the 2.52-meter departure, $5 to $10 million per harbor. One expert estimated that pleasure harbor dredging in Illinois to address the 2.52-meter reduction in level would cost $100 million. The estimate presented in table 7 is $75 to $100 million, which is based on the assumption that all harbors would be dredged and maintained.

A third area of impact to harbors for pleasure boat facilities related to bulkheads. In many areas, harbor edges must be defined by vertical metal sheeting. In the case of both predicted future levels, it was estimated that all existing sheeting along about four miles of harbor shores would need to be driven to

Table 7. Estimated Economic Impacts of Lowerings of the Levels of Lake Michigan over a 50-Year Period (1990-2040)

(Costs in millions of 1988 dollars needed to address future lake levels at indicated depths below average level of Lake Michigan, 1951-1980)

	1.25 meters lower	*2.52 meters lower*
1. Recreational harbors		
Dredging	30 to 50	75 to 100
Sheeting	15	35
Slips/Docks	20*	40*
2. Commercial harbors		
Dredging	108	212
Sheeting/Bulkheads	38	38
Slips/Docks	40*	90*
3. Water supply sources		
Extending urban intakes	15	22
Wilmette Harbor intake	1	2
4. Beaches		
Facility relocations	1-2	1-2
5. Outfalls for stormwater		
Extensions and modifications	2	4
Totals	$270 to $291 million*	$519 to $545 million*

**Some costs could be partly covered by normal replacement expenditures over the 50-year period* deeper levels at a cost of $750 per foot. In those harbors with natural shorelines, new piling would be needed along another four miles of shoreline to maintain harbor size. The calculated costs range from $15 million (1.25-meter reduction) to $35 million (2.52-meter reduction).

Hotels and restaurants dependent on lake frontage for "lake access" for attracting patrons would suffer. No economic estimate of this impact was developed, but it could be a major problem to selected businesses.

Commercial Harbors

Commercial harbors would also experience major effects. We assumed that all must maintain a 2.4-meter (8-foot) draft to be effective for lake carriers. The costs of dredging and modifying the major commercial harbor facilities (Calumet, Chicago, and Waukegan) would be sizable.

One expert indicated that the high cost of keeping the harbor open at Waukegan (at the 2.52-meter reduction in lake level) might not be justified by the values gained, leading to its closure, and that the Chicago harbor costs might not equate to its value, leading to its closure. The cost of dredging the harbor at Waukegan ($5 per yard) was calculated to be $3 million to meet the 1.25-meter reduction in level. Furthermore, breakwaters would be difficult to support, and new supports would have to be constructed. The dredging costs for the commercial harbors and canals, as accumulated over time, were calculated at $108 million for a reduction in lake level of 1.25 meters, and $212 million for a reduction of 2.52 meters (see table 7).

Dredging in all commercial harbors and canals would be a problem, particularly the dredging of the polluted materials in their bottoms. Costs would be greatly increased for disposal of the polluted material. This would be a particular problem for the two local "areas of concern": Waukegan Harbor and the Grand Calumet River. These were identified in 1973, along with 40 other locations, as particularly heavily polluted areas (Great Lakes Water Quality Board, 1987). Costs of dredging (table 7) would include higher costs for dredging the polluted sands in these two areas.

All slips and docks in commercial harbors would have to be rebuilt as a result of dry rot and lower access levels. However, replacement would normally be needed anyway because of obsolescence and normal depreciation over 50 years or more, with costs not totally related to the climate-induced reduction in lake levels. The estimated replacement costs shown in table 7, as indicated, include normal replacement costs. The values in table 7 include costs of driving existing bulkheads deeper, which were calculated as $35 million over the 50-year period. New bulkheads in a few areas would cost $2.6 million.

Beaches

Recreational beaches would also be affected. In this study, we assumed that the lowering of lake levels would not lead to construction of major new shore protection works to protect beaches. The benefits of lower lake levels to beaches are not insignificant. The underwater slopes away from current Illinois beaches along Lake Michigan range from 2:1 in fine-grain areas to 40:1 in coarse sand areas, with an average of 20:1. Detailed bathymetric maps (showing the depth of the lake bottom from lake levels) were used to calculate the amount of land to be gained from the lower lake levels.

Figure 6 shows the contours below the low water datum, the current shoreline, and the historical (pre-1932) shoreline of Lake Michigan before barriers were built and fill was used. Calculations for the beachfront gained between Fullerton Avenue and Ohio Street (on this map) indicated 0.1 square kilometer for the 1.25-meter drop in lake level, and 0.5 square kilometer for the 2.52-meter drop. The calculated increase for the 43 kilometers of beach frontage based on the decrease of 1.25 meters in lake level was an additional beach area of 1.12 square kilometers, and the 2.52-meter reduction would create 3.24 square kilometers of additional beach area. Certain beach facilities would be relocated and/or constructed at an estimated cost of $1 to $2 million (table 7). No monetary benefit was assigned to the added beaches.

The benefits of the lower levels would also be appreciable in the bluff shore area north of Chicago, where expensive residential areas exist and where major bluff erosion occurs in high waters. Major expenditures (>$20 million) by communities and individuals have occurred in the recent high-level periods (Changnon, 1987), and these would end.

Environmental Impacts

Several of the aforementioned impacts relate to problems of an environmental nature. This includes the issue of dredging and disposal of polluted sediments/sands of harbors and canals. A major environmental problem resulting from lower lake levels will be changes in the hydrologic cycle. The shallow and deeper ground waters interacting with the lake will be reduced over time. Lowered ground-water levels

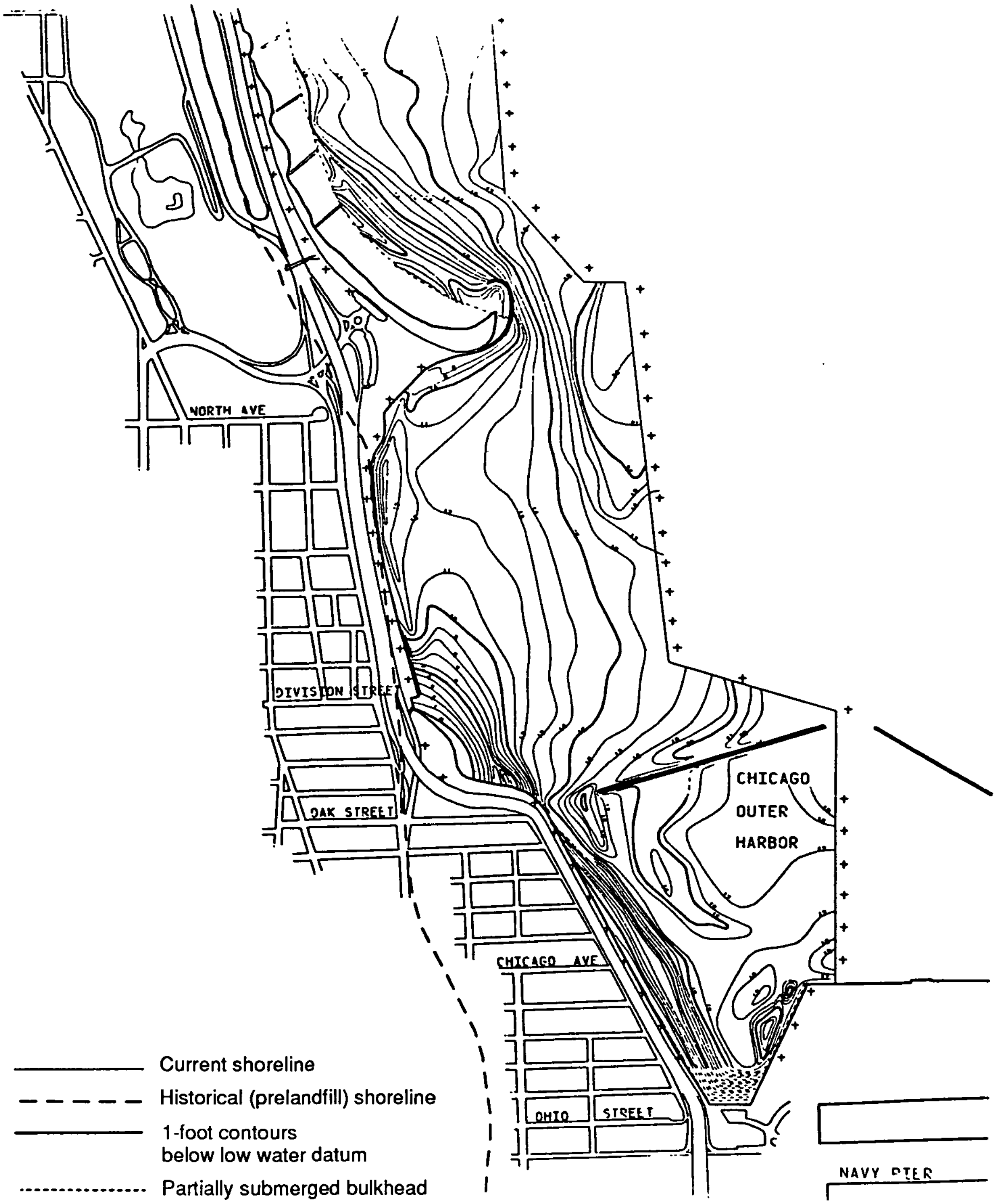


Figure 6. Nearshore bathymetry, Chicago northside lakefront (Illinois State Geological Survey)

will detrimentally affect existing wetlands and will lessen ecosystem production. Over time, new wetlands will develop if the rate of lake-level fall is sufficiently slow.

Polluted ground waters in the urban area will percolate into the lake, and in turn polluted lake waters will percolate into aquifers; the net result will be reduced lake and ground-water quality. Thus it seems likely that unless agricultural and urban pollutants now entering the lake are greatly reduced, the overall quality of the waters of Lake Michigan at Chicago will be further diminished under a drier/warmer climate scenario.

Water Intakes

Another area of future impact relates to water intakes in the lake to serve municipal and industrial water supplies. Most of these are positioned well beneath the lake surface so they will be free of ice and will maintain sufficient head for pressure (needed because they are gravity-fed). Fourteen major intake systems are located along the area north of Chicago (several cities have two intakes at different locations). Analysis of these in terms of varying future levels of Lake Michigan revealed different outcomes. At the level 1.25 meters below the current average, three intake systems would have to be altered at a total cost of $2.8 million. With a reduction in lake level of 2.52 meters (the worst possible outcome), we find that six systems would require a range of extensions adding up to a cost of $7.4 million. These and other costs for water intake modifications are shown in table 7.

Water Supplies

Water supplies will be greatly affected by the predicted warmer and drier climate, lower lake levels, and poorer water quality. Population growth and the more arid climate will increase usage and demands for water for a number of purposes: 1) to serve Chicago and its suburbs, 2) for industrial processing, 3) for cooling of power plants (such as at Zion), 4) for shipping needs in the Chicago River and canal system and the Illinois River, 5) for sewage treatment, and 6) for hydroelectric power generation at Lockport (southwest of Chicago). Cohen (1987) projected 30 to 40% increases in municipal water uses in the Great Lakes basin as a result of the predicted climate change.

The lake as a source would be hard-pressed to meet these increased needs. Pressures from the other lake states and Canada to maintain lake levels would cause serious national and international controversy over any Illinois requests for increased diversions of lake water. Increased diversion seems an unlikely outcome, as revealed by the controversy and strong opposition to the idea of increasing diversion during the summer drought of 1988 to help temporarily increase the flow of the Mississippi River.

The effects on demand/supply of water supplies would then extend to ground-water sources. For example, the suburban communities would likely turn to ground-water sources (most have wells) to supplement the inadequate lake supplies that would prove difficult to obtain and at best would be very expensive. This shift, if sizable, would lead to decreased ground-water levels and to more mining (already occurring in some suburbs). This impact also would create interstate conflicts related to increased ground-water use and the effect on lake supplies.

Another area of impact from greatly lowered lake levels and decreased runoff relates to the Chicago River and canal system. This complex system now depends largely on gravity flow from Lake Michigan for maintenance of water levels. Problems with the low lake levels in 1964-1965 led to the installation of a major pumping system at Wilmette Harbor to ensure the supply of water out of the lake into the upper reaches of the system. The predicted reductions of lake levels by 1.25 and 2.52 meters below average would necessitate deepening the Wilmette Harbor system, including its entrance, and lowering the pumps. The operation of the river system with lower lake levels would be affected by loss of water at the Chicago River outlet, leading to possible restrictions on the frequency of entry and exit of boat and ship traffic. Another effect would be reduced water released for power generation at Lockport. Costs for the Wilmette Harbor adjustments in pump levels are shown in table 7.

A related problem that will develop from the warmer-drier climate conditions will be the effects on the hydrologic cycle of the streams and rivers in the Illinois River basin. Presumably this area adjacent to Lake Michigan, and tied to the lake through the water diversion at Chicago, will experience substantially decreased runoff as a result of the suspected climate changes. The Illinois River is a major transportation artery controlled by a series of locks and dams between Lockport (near Chicago) and its junction with the Mississippi River near St. Louis. The level of flow in the river to satisfy barge usage is maintained by the diversion of 3,200 cfs of water at Chicago, the maximum amount allowable under the current U.S. Supreme Court decrees. Basin runoff for the arid, climate outcomes will be reduced by at least 20%. *This will make the river system, including the locks, unusable (as currently structured).*

Alternatives include deepening the river and rebuilding the lockages, diverting more water from Lake Michigan, or losing barge transportation. The first case represents an exorbitant expense. The added diversion seems unlikely with the lower lake levels and extreme pressures against increased diversion. The resulting inability of the river system to function in its current fashion might lead to increased shipping by railroad. Pressures would be great to change the lockages and dredge the navigation channel. Costs for these impacts were not estimated but would be sizable.

Water supplies from Lake Michigan for public usage and certain industrial needs could be seriously affected by major degradations in water quality if they occur with the projected lowerings of lake levels. The magnitude of this potential problem is unknown, but it would increase water treatment costs. A warmer climate and lower levels of the lake would also cause lake water temperatures to become higher than at present. The amount of change is unknown, but if sizable, it could affect cooling water needs of power plants and industry.

In the net, the future warmer and drier climate will lead to increased needs for water to serve Chicago and the Illinois area. However, the ability of Lake Michigan to provide added water for these demands (or to sustain the current diversion level) likely will be blocked by institutional forces in the Great Lakes basin. Further, deep ground-water aquifers in northeastern Illinois, already subjected to excessive drawdowns, will not be able to meet the future needs. This situation could have a very adverse effect on the growth and economy of the Chicago region. It seems likely that development of new sources in the more shallow ground-water aquifer (heavily mineralized and partly polluted) will be pursued as an alternative resource.

Outfalls

Another effect relates to outfalls and outlets for storm rainwater for communities along the lakeshore. For both the 1.25- and 2.52-meter reductions in lake levels, all 28 existing major outfalls (1 meter or larger diameter) would have to be extended, ranging from 50 to 150 meters in length. As shown in table 7, this would lead to additional costs to local communities of from $2 to $4 million.

Encroachment

The final area of potential impact that was analyzed relates to encroachment of buildings, thoroughfares, and other structures onto the newly formed beach areas. This regulatory/policy issue would, under current regulations, be controlled by the facts that Chicago has a lakefront ordinance and that the state of Illinois vigorously enforces the lakefront usage permit process. The state of Illinois claims ownership of all lands to the edge of the "record high water level." Thus, private landowners cannot modify or replace land lost because of high-water erosion.

If strong governmental control were maintained over the more than 50 years required for the predicted lake reductions, the newly formed lands would remain under governmental control and free from serious encroachment by buildings and other structures. However, is this a likely societal outcome? Will this type of protective legislation develop around other shoreline areas?

A key to this issue will be vigorous enforcement. During recent high lake levels, several "self-help" construction projects were carried out without permits, and the state did not prosecute.

Other Possible Impacts

Another implication that can be speculated about relates to the possible advent of a widespread warmer and drier climate in the United States. If this occurs, an "out migration" from the Sun Belts, which will become more like "Hot Belts," can be expected. This migration will undoubtedly include movement into the Great Lakes basin. A warmer climate will reduce ice coverage on Lake Michigan, including shore ice, and this may lead to more rapid shoreline erosion than currently occurs.

Another potential impact of much lower lake levels and their detrimental effects on basin-wide shipping would be an increase in shipping by railroads. Commercial lake fisheries would presumably be hurt by lower lake levels, warmer water, and fewer fish.

Table 7 presents the best, albeit qualitative, estimates of the economic impacts of the two model predictions of greatest reductions in lake levels. In summary, these show that along the Illinois shoreline (101 km, or 63 miles), the effects of lower levels on harbors, water supply sources, beaches, and urban outfalls would lead to costs (in 1988 dollars) of between $270 and $291 million for the 1.25-meter fall, and between $519 and $545 million for the 2.52-meter reduction. Experts in lakeshore issues consider these costs to be justified for maintaining the highly valued harbors and beaches of this major urban area.

Conclusions

The economic effects of a prediction based on one global climate model of a mean lake level 0.86 meters below the current average, accomplished gradually over 50 years, is seen not to have serious economic consequences (about $100 million over 50 years) and to be partly accommodated by normal maintenance/replacement activities and costs. However, the potential effects on water demand and supplies would be serious. Maintaining supplies to meet increased demands with less lake water (and with water of poorer quality) would lead to interstate and international controversy and, in turn, to increased usage of ground water from an already meager source.

A projected climate change leading to a reduction of the mean lake level by 2.52 meters would produce much more serious economic impacts. Hence, the character and magnitude of the economic impacts relating to a changing climate and the lowering of lake levels are very sensitive to the amount of decrease predicted to occur, and in turn to the seasonal/decadal climate-related fluctuations in levels envisioned around the new mean lake level.

Results of this study establish that the magnitude of the effects of lower levels of the Great Lakes will likely depend heavily on the magnitude of the longer-term (decadal) oscillations of lake levels around the new mean low level that will accompany a significant climate change. The oscillations in levels mean that controls on land use will have to be developed (see chapter 6, "Policy Implications"). The ability to set wise limits for structures and thoroughfares attempting to encroach on the new exposed land area will depend on the expected future oscillations of lake levels around the lower average levels. This will be made difficult by the fact that the lower levels will probably develop over decades, as was the case in the slow decline in the lake level from 1900 to 1940 (see figure 1).

These various results reveal that the global climate models and the climate scenarios developed from them (and their related assumptions) for the Great Lakes basin are extremely critical to estimating future impacts, adjustments, and policy actions. Differences in these models lead to projections of very major differences in the impacts. Hence attempts to undertake major revisions of policy at this time in response to the future increases in trace gases and their effects on climate appear difficult, at least as far as the Lake Michigan-Illinois situation is concerned. Economic impacts based on the different climate models range from essentially a manageable level to major extremes, greater than $0.5 billion along 101 kilometers of shoreline.

These widely different outcomes in lake levels reveal considerable atmospheric uncertainty and in turn suggest that it would be very risky to develop policy actions at this time. More firm and consistent predictions of change in climate are needed, along with indications of the type of change. Future climate modeling studies need to address the subject of possible climate fluctuations; then calculations can be made of lake level oscillations apt to occur with any given lake level (high or low). Such results are essential to a reasoned approach to 1) developing means for reacting to fluctuations in lake levels, and 2) limiting encroachment. Climate modeling of atmospheric changes and effects on the physical (hydrologic) conditions beyond the basin is essential. However, all levels of change will create serious water supply problems and issues requiring policy actions.

One reason for recommending a cautious reaction to this situation, in terms of the Illinois shoreline, is that the rates of lake-level change in the models do not all exceed the rate that normal replacement costs, or economic life, could handle for harbor and beach facilities. In other words, a major portion of the dockage changes needed to address major reductions in lake level could be handled over a 50-year period by normal replacement costs. *However, this would require recognition and acceptance of the ongoing change.* Regardless, with the replacement costs removed, the economic effects from the two most severe predicted lake-level reductions, 1.25 meters and 2.52 meters, would result in costs of about $200 million and $400 million, respectively (table 7).

Major problems would be realized in the harbors and canals (dredging, bulkheads, slips, and docks) and in the disposal of polluted wastes. The costs for improving harbors and their facilities and for extending intakes and outfalls would presumably be met largely by local communities, the state, and the federal government. Ultimately these costs would be transferred to the public.

The gains to be realized by the lower lake levels would be wider beaches ranging from 30 to 60 meters (98 to 197 feet), with an addition (depending on the lake-level reduction) of between 1 and 2 square kilometers (0.4 and 0.8 square miles) of beach area in Illinois. Fortunately, the widened beach area is not likely to increase sufficiently to result in major expansions into the beach area, with the ensuing need for construction of new shorefront protection systems. The wider beaches themselves will help protect the shoreline. The private dredging and construction firms that handle harbors and their facilities, and that deal with water intakes and outfalls, would be beneficiaries of the major reductions in the lake levels.

Future Adjustments

The potential exists for lake levels to be much lower than those experienced in 1964-1965. The predictions by the global climate models, and the climate scenarios designed for this study, all seen as possible, show a potential for levels that will be anywhere from about 0.8 to 2.5 meters lower than levels experienced in 1964-1965. What are the potential adjustments that may and should occur?

A primary adjustment relates to the need to incorporate, in all aspects of harbor and shoreline structures and related land use, a "design for lake level fluctuations." A more permanent lower level will provide recognized gains in valuable lands, particularly along urban frontages of all the Great Lakes. This could benefit communities, recreation, and certain industries. There will likely be a major push into these lands, which must be carefully weighed.

A second series of adjustments that can be predicted relates to the real and perceived needs for increased water supplies in the Great Lakes to serve the needs of shipping, urban and industrial water supplies, and hydropower generation. This demand will create calls for increased diversion into the Great Lakes, presumably from sources in Canada, and for decreased diversion at Chicago and elsewhere. Under current institutions and legal agreements, it seems unlikely that such shifts involving interstate and international negotiations and agreements can be realized.

The additional water needed could also potentially be realized through new technologies to increase precipitation through weather modification and to reduce evaporation through various physical and chemical techniques. Exploratory and developmental research will occur in these areas.

Similarly, there will be an increased need to improve predictions of lake levels during a more stressed lake regime. Research will be conducted to develop better capabilities, in climatology and hydrology, to predict climate and lake-level fluctuations around a lower mean level.

In summary, a comparison of the more direct economic losses with the apparent gains indicates that even the worst of the projected lake-level reductions will not cause unaffordable economic problems along the valuable Illinois shoreline. All the changes can be handled in an economically effective manner, often by employing normal replacement and maintenance procedures *if master planning for these changes is implemented and if the decrease occurs gradually over several decades.* The Great Lakes Charter (1985) contains the charge to develop a "cooperative water resources agreement program for the Great Lakes Basin." It could serve as the basis for proceeding.

The other impacts on Illinois water supplies and on environmental conditions will cause major problems. The increased water demand vs. less available lake water (and water of poorer quality) could greatly affect mining of the local and regional ground-water supplies. We lack the institutional arrangements and laws to address the magnitude of these problems in Illinois or in the other lake states. The water quality problem of Lake Michigan will likely become a major issue for Illinois shoreline interests and will affect water for public consumption, industrial uses, and recreation.

CHAPTER 6. POLICY IMPLICATIONS

The future incidence of lower lake levels will undoubtedly affect policy at the international, national, state, and community levels. Potential problems relating to lower water levels and less adequate water supplies will lead to needs, real and perceived, to divert additional supplies into the Great Lakes from Canadian sources. It will also lead to desires to increase diversion at Chicago, with resulting controversies reaching the Supreme Court and international forums. The climate change will also reawaken concern over the current amount of water diverted at Chicago, which will be contested. The likely inability to provide waters of desired quantity and quality from Lake Michigan to serve Chicago, its suburbs, and the Illinois-Chicago Rivers system will lead to increased usage of ground water. Deep aquifers will be further depleted, leading to disagreements over water mining between Illinois and adjacent states (Wisconsin and Indiana).

The effects of lower levels will reinstate dredging of all recreational and commercial harbors. Major added costs for recreational harbor maintenance and intake/outfall extensions will fall largely to local communities, which will probably seek state and/or federal support. Disposal of the polluted harbor materials from dredging will be costly and of great environmental concern, and will affect federal and state policies and enforcement strategies.

Increased widening and deepening of certain major connecting channels in the Great Lakes to allow shipping loads can be envisaged to develop as regional policy issues. All of these concerns/activities will relate to national policies and in turn to actions by federal agencies such as the Environmental Protection Agency, the Corps of Engineers, and their Canadian counterparts.

The need to resolve the problems of lower lake levels will also lead to research on atmospheric and hydrologic issues. This will impact the federal agencies that support research in these areas, such as the National Science Foundation and the National Oceanic and Atmospheric Administration.

It seems likely that problems with encroachment onto beaches, coupled with large lake-level oscillations, will develop. This will require federal and/or state regulations concerning land use activities along the shores of Illinois and the rest of the Great Lakes.

Several factors could greatly alter the impacts and the policy adjustments postulated as related to the lowering of Lake Michigan levels. First, if the changes in climate lead to step-wise shifts creating sharp drops in lake levels rather than gradual changes in levels, the problems will increase materially, and crisis management seems likely. We need better institutional mechanisms *now* to deal with the recent fluctuations (record-high lake levels in 1985-1986, and now precipitous declines).

Another factor that could alter the postulated impacts and policy actions concerns the amount of variation around the future mean lake levels. In this study of potential impacts, we have assumed that the fluctuation over time (>100 years) would be equivalent to the current ± 0.75 meter; if this fluctuation is much greater, a variety of other more serious impacts and different policy actions could occur.

The third factor that could greatly vary the impacts and ensuing policy actions concerns the possibility of diverting sizable amounts of water into the Great Lakes in Canada to help ameliorate the effects of the lower levels. This would certainly reduce impacts and affect policy actions, but is probably unlikely in a more arid climate. The issue of water diversion, both in and out of the basin, will hinge on the new future values of the hydrologic cycle (precipitation, runoff, evaporation), both in and out of the basin. A drier and warmer climate in Illinois and Wisconsin will lessen runoff to the Illinois River transportation system. This will lead to needs for more lake water for diversion and to greatly altered channels and lockages, both of which are *major technical and policy issues.* A drier climate will heighten controversies over the lake diversion at Chicago.

If new water-adding technologies were developed (weather modification or evaporation suppression), the levels of impacts and policy reactions would be changed. Warmer and drier conditions elsewhere in the United States might also lead to efforts to divert waters from the Great Lakes for irrigation and public water supplies. Any permanent reduction in lake levels, whether 0.8 or 2.5 meters below today's base level, will necessitate dredging to deepen commercial and recreational harbors and channels. Since toxic materials have been deposited in all commercial harbors (and some recreational harbors), the ultimate deposition of these large volumes of polluted sands and other bottom materials will be a major policy problem and one requiring both physical research and socioeconomic studies.

A further factor that could influence the policy outcomes relates to societal attitudes towards the use and protection of lake frontage; should these change drastically, the policy outcomes could be altered greatly from those predicted herein.

Consideration of the impacts and adjustments related to harbors, beaches, intakes, outfalls, and transportation reveals that two types of understandings (wide acceptance of the ultimate reduction of lake levels over 50 or more years, and recognition of the need for normal replacement of facilities and maintenance of harbors) could be sensibly combined in a "master engineering plan" for the area. That is, wide acceptance by the scientific and engineering communities that the lake level will be falling gradually by a rate of 0.03 meters (0.1 foot) per year, and that by 2050 the average level will be 2 meters (6.6 feet) lower, would be the basis for in-depth planning of all future lake-related activities.

For example, normal replacements of harbor facilities, including the slips and docks, maintenance of the breakwaters, and installation of bulkheads could be geared to the downwind shift in lake level. Replacement of locks in the river and channel navigation systems would take into account the ongoing climate shift. Many adjustments could be made in a most cost-effective manner over the 50-year period. However, a master plan would need to be developed to guide these activities on the basis of wide agreement over convincing evidence of a change. This would be a major policy issue.

In the Great Lakes Charter (1985), the governors of lake states and the premiers of the provinces committed themselves to the development of a "Great Lakes Basin Water Resources Management Program." This could become the basis for addressing the many policy issues raised by a changing climate.

We recommend that policy action for implementing such a plan, as well as immediate action in other policy areas, should begin. The wide variations of model outcomes, showing lake levels ranging from 0.86 to 2.52 meters lower than today's average level, produce differences in the magnitudes of the economic effects, but they all indicate severe water quantity and quality issues calling for policy development.

A basin-wide climate change to more arid conditions in 50 years will create problems similar to those predicted for Chicago at *all* the metropolitan areas around the Great Lakes. One envisions large expenditures to maintain shoreline structures and facilities, as well as enormous conflicts over water supplies and environmental effects. The inability of the United States, Canada, and existing institutions to deal effectively with recent transboundary pollution (air and water) problems in the Great Lakes basin suggests that major policy actions must occur and new institutions must develop to meet the challenge of the envisioned climate change. The Boundary Waters Treaty of 1909 will certainly require modification.

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APPENDIX A

Newspaper Content Analysis for 1964-1965

by Steven M. Leffler

Introduction

During low-water periods, several problems commonly arise. These problems include the encroachment of buildings onto high-risk areas, difficulties with shipping and harbor maintenance, damage to drainage systems, and even damage to shoreline protection devices. Though these problems are well known, some are difficult to document. Building encroachment problems and damage to shoreline protection devices become apparent as the water level rises, but it is quite difficult to document drainage-systems damage, harbor maintenance, and shipping problems. In the years since the record-low lake levels of 1964-1965, most official records (surveys, repair cost reports, appraisal studies, etc.) have been destroyed or misplaced, or are otherwise irretrievable. Likewise, most of the knowledgeable personnel during that period have retired or cannot be located.

A search through the newspapers of the 1964-1965 period was one method used to document impacts of the low lake levels. Newspapers are a potentially good medium to search because they are easily accessible and cover a wide range of topics. As we learned, many of the impacts of low lake levels were not perceived as problems at that time, and those that were problems may not have been perceived as important enough to warrant a newspaper article. Therefore this approach was impractical for studying the social impacts of low lake levels. Few articles are written about too much beachfront.

The objective of this newspaper content search was to attempt to document the physical, social, and economic impacts of the low lake levels. This included looking for any incurred costs due to repairs, dredging, etc. As a secondary objective, we also attempted to identify persons who might be interviewed for more detailed information.

Methods

A thorough examination of the *Chicago Tribune* (CT) and *Chicago Sun-Times* (CST) was conducted for most of 1964 and portions of 1965. Both newspapers were available on microfilm at the University of Illinois. Unfortunately, no indexes were available for this time period, and thus the tedious task of searching each page of the newspaper was needed. A file at the Illinois State Geological Survey, based on newspaper clippings on lake-related topics going back to 1970, also was analyzed. This file was used for documenting high-water problems and for further documenting low-water impacts. This file was composed mainly of CST and CT articles, but also included articles from several smaller neighborhood newspapers and a few articles from newspapers of other big cities.

Newspaper Search Coverage for 1964 and 1965

Month (64/65)	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*J*	*F*	*M*	*A*	*M*
Chicago Trib.	√	√	√	√	√	√	√	√	√	√	√	√	√	√			√
Chic. Sun-Times			√	√			√	√	√		√			√			√

Data

Many articles during the low-lake-levels period (1964-1965) reported that the lakes had reached another "record low." These articles were often accompanied by discussions of the amount of water diverted into the Mississippi through the Chicago River or notes on the meetings of the International Joint Commission. There were 21 articles of this type (in 15 months).

The following section presents analyses of the seven articles found that were relevant to impacts. The articles were found through both the 1964-1965 search and the State Geological Survey file. Portions of most of these articles were quite irrelevant. Articles 1 through 4 discuss shipping and harbor management problems that resulted from low lake levels. These articles were found during the search of 1964-1965 newspapers. The remaining articles discuss problems with Chicago's seawall, which were not discovered until recently. They stem from the low lake levels, which exposed the wood pilings in the shore protection devices to air and thus subjected them to dry rot.

Analysis

Article 1 discusses both positive and negative impacts of the low lake levels. It implies that shipping was reduced significantly as a result of low lake levels, especially the shipping of "heavy commodities." This supplies a clue as to which industries were most impacted by low lake levels. By checking with the harbor, we learned which companies were shipping ore and limestone during this time and then contacted those companies for more information. Though only iron ore and limestone were reported on, coal mining is a significant part of Illinois' economy, and it would be interesting to explore how the coal industry was affected. Also mentioned in this article are a few social impacts of the low lake levels, including increased beach size and easier access to rivers by pleasure craft.

Article 2 links low lake levels with a loss of shipping business at the Port of Chicago. It reports that overall shipments were down 20% from the previous year. This loss was mostly in the form of "general cargo" (i.e., machine goods). The cause of the decline in shipments was given as "insufficient water depth in the Calumet River" and increased competition. It should be noted, however, that the business of other port facilities was reported as up, implying that this may be an isolated case.

Article 3 reported mainly on the causes of the low lake levels. It also gave a good rule that could be used to help estimate the total amount of business lost: for each inch the water level dropped, ships lost 100 tons of cargo they could otherwise have carried.

Article 4 discusses the deepening of the Calumet River in an attempt to curb the 20% loss of shipping at the Port of Chicago (Article 2). The total cost of the project was estimated to be $3.5 million.

Article 5 reports on the findings of a panel of engineers who recently (1987) examined Chicago's seawall. They found that "11 miles of seawall and 2.5 miles of breakwater need immediate repair." An estimated total cost of $200 million was given. This is the first article that directly linked low lake levels to the deterioration of the seawall. It reported that "during a low water period in the 1960's, the pilings were exposed to air and dry rot set in."

The final two articles discuss the findings of an underwater survey of Chicago's seawall, which was conducted by using sonar aboard the research vessel "Neecho." Article 6 reports that the deterioration of the wall allowed waves to scour caves 12 feet into the shore and wash large fill rocks out 40 feet from beneath the seawall. Article 7 reports that repair work on the seven worst miles will cost "between $37 million and $111 million."

These articles also supplied us with the names of important contacts to whom we referred for further information.

Results and Discussion

The purpose of this search was to analyze newspapers as a help in documenting the physical, social, and economic impacts of low lake levels. We found that the number of articles was disappointingly low, and that the existing articles barely documented the many impacts of low lake levels.

By far the most costly impact of the low lake levels was the damage caused to Chicago's seawall. This impact was not detected, or at least not perceived as a problem, until record-high lake levels began to cause major damage. However, once this problem was detected, it drew significant attention.

Probably the second most costly impact of the low lake levels was the difficulties inflicted upon the shipping industry. These problems manifested themselves in the form of a decrease in the shipments of manufactured goods and also in the form of increased harbor maintenance. This problem received attention during the period of low lake levels. The articles found on this subject helped define the problems.

During the recent high-water period, the subject of water encroaching on housing structures received coverage but was never linked to low lake levels. The low lake levels led to these problems by lulling people into building in areas perceived as low-risk. None of the articles written on this subject discuss when the housing unit(s) were built. The newspaper content analysis yielded no evidence to show that the low lake levels caused problems with drainage devices or water supply systems. The search did identify some of the social impacts such as valued larger beaches.

APPENDIX B

Interview Procedures for Assessing Effects of Low Lake Levels

A semi-structured interview process was used with people who were involved in various lake-related activities during the period of low lake levels in the early 1960s. These interviews were largely conducted over the telephone, although some person-to-person interviewing was done.

In the initial phase of the interview, we established institutional credentials. We then described the project, including its goals and objectives, and explained why the person interviewed had been selected. At this stage, we sought the person's willingness to proceed with the interview.

Following a statement of willingness to be interviewed, a well-known example of an impact was presented, typically a case of encroachment of buildings onto lakeshore areas. This was used to illustrate that the impacts could be direct (physical), could have occurred at the time of the low water levels or later, or could be secondary or tertiary in the socioeconomic fabric. This portion of the interview was used to allow the person being interviewed to think and recall events of that time.

At this stage of the interview, obvious or possible impacts in the person's area of expertise were mentioned as introductory statements to general questions about events of 1964-1965. Depending upon the interviewee's willingness, further probing questions were then asked. These questions typically focused on specific phenomena, periods of time of resulting events, ensuing costs (or gains), and adjustments. Another area of inquiry after the open discussion questioning related to the availability of records that could be investigated to allow us to find more specific details regarding dates and financial impacts.

At the end of the interview, two standard questions were asked. One of these questions related to the person's willingness to have us make a personal visit or another telephone call to get more information. If a visit was seen as desirable, a date and a place were arranged. The other ending interview question related to any thoughts about persons or places we could consult to get further information on the subject.

APPENDIX C

A Case Study: The Socioeconomic Impacts of Variable Lake Levels at Wilmette, Illinois

by Steven M. Leffler

Introduction

This case study examines the economic and social impacts of extremely variable lake levels at Langdon Park in Wilmette, Illinois. The discussion centers around a controversy over the building of the condominium at 1420 Sheridan Road, a location adjacent to the park.

Langdon Park is a 5-acre, wedge-shaped recreational park owned by the village of Wilmette, a high-income lakeside suburb north of Chicago. The park is located between Lake Michigan to the east and Sheridan Road (a major artery) to the west. To the north of the park are high-rise condominiums and to the south is single-residence housing. The park serves as a buffer zone between the two housing zones.

In Langdon Park off Sheridan Road there is a small playground with many large oaks and cottonwoods. The playground extends eastward approximately 150 feet to the point where a lake bluff drops 8 to 10 feet to the beach of Lake Michigan. With the rises in lake levels during the 1980s to record-high levels (Changnon, 1987), this bluff receded through erosion. The amount of beach also varies depending on the level of the lake. Figure C-1 is a map of Langdon Park and the properties in its immediate vicinity. Erosion of the beach and bluff appears to have been exacerbated by a seawall that extends well into the lake.

Methods of Data Collection

Much of the information for this study came from interviews with several persons. Those who contributed included Terrence Porter of the Wilmette Park District, Larry Donoghue of Ralph Burke & Associates engineering firm, Michael Newbery of Harza Engineering Company, and the building superintendent at 1410 Sheridan Road. Documentation studied included the microfilm files on 1420 Sheridan Road at the village of Wilmette, a report on Langdon Park done by the U.S. Army Corps of Engineers (COE), and maps of the area.

For the purposes of this study all governmental committees, permits, personnel, etc., should be assumed to be officials of or actions officially sanctioned by the village of Wilmette, unless specifically stated otherwise.

History of Langdon Park and Its Environs

The area's history relevant to this study begins in 1956, when land was purchased by Wilmette for use as a boat-launching facility and public beach. At that time there was approximately 300 feet of beach between the lake bluff and the shoreline, and the land to the north was undeveloped.

In 1959, the village decided to rezone the undeveloped land to the north as multiple-residence housing (condominiums). On October 20, 1959, an ordinance was adopted regulating the sizes of these lots as follows:

> Article 2, section 2, sub-section (37): Lot Area: The area of a horizontal plane bounded by the vertical planes through the front, side, and rear, lines, but not including any area occupied by the waters of Lake Michigan.

Another subsection stated that the backyards of these condominiums were to have a depth of no less than 50 feet. According to statements in a letter from John F. Scapin to Charles A Nixon on December 18, 1964, and in the reply by Nixon on December 23, 1964, this distance was later changed to 70 feet.

In a November 18, 1964, memorandum to the President and Board of Trustees of the village of Wilmette, John Scapin, who was Village Engineer and Director of Planning, Zoning, and Building, wrote that the 1959 ordinance had been interpreted to mean that the rear lot line was the shore of Lake Michigan and that the rear yard was measured from the water's edge to the building. At the time of adoption of these zoning ordinances, it was pointed out that this would make the rear lot line variable as the level of the lake rose and fell, but the zoning committee did not feel this was a major concern and the warning was ignored.

As the lake's level began to drop from the relatively high levels in the mid-1950s, the interpretation of this ordinance became troublesome. Thus, it

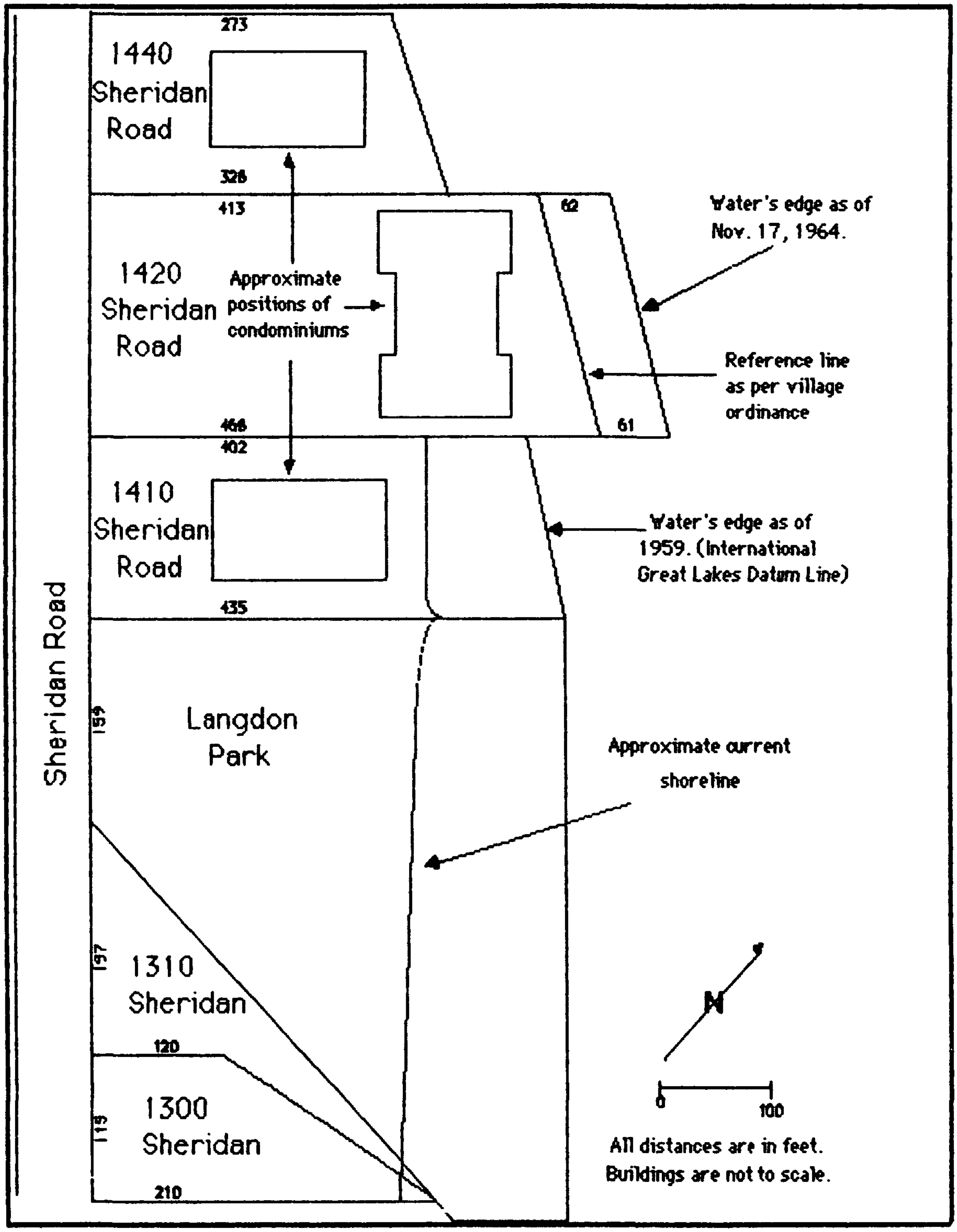

Figure C-1. Langdon Park and vicinity, showing past and present shorelines was ruled that the lakeshore would be established by a recent survey or plot of the lot. According to statements made by John Scapin, the survey or plot was to be not more than one year old at the time of application for a building permit.

Four condominiums were built under these conditions. On January 11, 1961, a permit was granted to the 1400 Sheridan-Wilmette Corporation (1400 SWC) to build a condominium at 1410 Sheridan Road, which would be situated 140 feet from the lakeshore of that time. Two lots north, at 1440, a building permit was issued on May 2, 1962, for the construction of a condominium to be placed 70 feet from the water's edge. The two other condominiums that received permits during this period are unrelated to this study.

As the lake level approached its historic low in the early 1960s, even the use of a recent survey or plot to determine the shoreline seemed inadequate. Thus, it was suggested that the shoreline be established as a fixed line by ordinance. This suggestion was taken up by the Special Zoning Committee in 1962, but according to John Scapin, no action was ever taken.

It was under these conditions that in January 1964, Charles A Nixon began planning a condominium at 1420 Sheridan Road. Nixon purchased the land in February 1964, prior to which he checked the village zoning ordinances for the land. Later, in his December 23, 1964, letter to John Scapin, he wrote:

> We came specifically to determine the placement of the building on the property and especially to establish the distance required from the edge of the lake to the eastern face of the proposed building. Mr. Branscom [Administrative Assistant] assured us that if we complied with the 70 foot set-back from the water's edge, this would fulfill the requirements of the zoning ordinance.

On February 18, 1964, a survey of the lot at 1420 Sheridan Road was undertaken to determine the rear lot line along the shore. A copy of the survey was given to Mr. Branscom, and he again reassured Nixon that it was okay, thus prompting further building plans to be drawn at a cost of $25,000. As stated in Nixon's December 1964 letter, all of these studies, surveys, and conversations occurred before the deal was closed in April 1964.

During the next several months of 1964, Nixon met at least three times with village officials, including Branscom and Scapin, to present architectural renderings and to discuss the general program. Nixon's December 1964 letter states that throughout these meetings, he was assured that all plans were fine.

Final building and site plans were submitted to the village in October 1964, showing the east face of the building 70 feet from the water's edge. Mr. Scapin approved, stating that this complied with the village ordinance. Feeling secure that he had complied with all village requirements, Nixon initiated detailed structural, mechanical, and architectural plans, bringing his estimated investment to about $751,800, according to his December 1964 letter.

Apparently, after a meeting with Nixon about the final plans, Scapin started to have some doubts about the placement of the building. On November 18, 1964, in his memorandum to the Village President and Board of Trustees, Scapin wrote the following:

> We now have an apartment building in the planning stage whereby the developer intends to use the minimum rear yard which, combined with the substantial recession of the shoreline in comparison with several years ago, will place the front of this proposed building to the rear of the two existing buildings (this will not violate the existing ordinance).
>
> This will obstruct the lake view of these buildings, to say the least, and raises the question of structural safety when the lake regains its normal level and the shoreline advances.

Scapin wrote on to suggest that consideration again be given to reestablishing some sort of reference line for the rear lots, but noted that, as planning was in the advanced stages, it would be difficult to make any change in the ordinance applicable to Nixon's property.

In his letter dated December 18, 1964, Scapin informed Nixon of his concerns and advised him of an upcoming public hearing to discuss a proposed change in the zoning ordinance which would establish a permanent reference shoreline.

Nixon was outraged. In his letter to Scapin dated December 23, 1964, he wrote, "Your letter of December 18th, coming after so many months of planning and consulting with you and your office, is an unbelievable shock, both unfair and unwarranted." Nixon went on to give a chronology of the events surrounding the planning of the building. He concluded by writing:

> We respectfully submit that our project designs are completed and they reflect the exact direction of all those officials, including yourself, charged with the administration of building and zoning codes in the Village of Wilmette, and that acting in reliance upon the existing building code, we cannot now be subjected to changes of substances which would destroy this work.

On January 25, 1965, the Special Zoning Committee met to discuss these issues. Specifically, the hearing addressed a proposed amendment to the Wilmette Zoning Ordinance as follows:

> Article 2, section 2, sub-section (37): "Lot Area: The area of a horizontal plane bounded by the vertical planes through the front, side, and rear, lines, but not including any area occupied by the waters of Lake Michigan; except that, in determining the area of any lot, no part of such lot which lies below Mean Low Water Datum for Lake Michigan, which is 576.8 feet above International Great Lakes Datum (1955) shall be included (Parsons et al., 1965a).

The Committee came to the following conclusions:

1) There is a need to establish a definite reference shoreline, and that the lack of such has caused considerable problems.
2) That four buildings have been constructed on the basis of the existing ordinance.
3) That any definite reference line should attempt to permit the existing buildings to be as conforming as possible to the requirements, and to be equitable, should not adversely affect the remaining undeveloped property, or to make the existing buildings non-conforming to any considerable degree.
4) That the modifications [to the amendment] that were proposed would adversely affect the undeveloped property, or make the existing buildings non-conforming and would not resolve the variable lot size problem.
5) That the reference line is equitable and that it comes close to permitting the existing buildings to conform and does not adversely affect the remaining buildings.
6) That some proposed modifications of the amendment would be more restrictive on undeveloped property than the present regulations that have been applied to the property that has already been developed.
7) That one of the buildings received a zoning variation to allow it to build within 10 feet of the shoreline.
8) That one of the buildings could have been constructed closer to the lake.
9) That the proposed development would not in any way cut off light and air to adjoining properties.
10) That the proposed amendment utilizing the mean low water datum for Lake Michigan is a definite logical and recognized elevation (Parsons et al., 1965a).

Thus the Zoning Committee recommended the adoption of the amendment to the President and Board of Trustees. In April 1965, the Village Board approved the amendment and, to the dismay of his neighbors, Nixon was able to construct his building in accordance with his plans.

On June 29, 1965, Nixon was granted Permit 10673 by the Department of Public Works and Building, Division of Waterways of the State of Illinois, to construct a seawall along Lake Michigan. This seawall was to be approximately 8 feet high and would be backfilled all the way to the bluff so as to make the lot level. This permit was signed by John C. Guillou, Chief Waterway Engineer. This permit contained a stipulation which reads:

> This permit does not in any way release the Permittee from any liability for damage to persons or property caused by or resulting from the work covered by this permit, and does not sanction any injury to private property or invasion of private rights or infringement of any Federal, State or Local laws or regulations.

On September 21, 1965, Nixon obtained Building Permit 4202 from John Scapin. Eight days later, on September 29, 1965, the Village received a Notice of Appeal to the issuance of Nixon's permit from 1400 SWC. The Grounds of Appeal were as follows:

a) The permit ... will allow the applicant to violate the provisions of the zoning ordinance governing lot area and depth of rear yard.
b) The permit authorizes a building which will violate the only reasonable interpretation of the ordinance.
c) The permit does not cover the bulkhead which is to be built by applicant and which is a necessary, integral part of the building for which the permit is granted. The construction of the bulkhead will violate provisions of the zoning ordinance.
d) The language [of the zoning ordinance]... is so inconsistent, ambiguous, and vague that its enactment and the attempt in the present case to apply it to applicant's property deprived the appellant of due process of law and to equal protection of the laws and constitute special legislation ... [forbade by the Constitution]. The amendment of the ordinance permits the applicant to build its building in a juxtaposition to Lake Michigan that was forbidden to the appellant.

e) The granting of the permit under the ordinance permits the inclusion in applicant's property of land that belongs to the State of Illinois in trust for all people of the State of Illinois; discriminates in favor of the applicant and against all other property owners by thus giving applicant the advantage of the use of areas not owned by the applicant; and deprives the appellant and other property owners in Wilmette of property without due process of law and of the equal protection of the laws and constitutes special legislation violation of the United States and Illinois constitutions cited above.

On November 22, 1965, a public hearing was held by the Zoning Board of Appeals to consider the request of 1400 SWC to appeal the issuance of Nixon's building permit.

Both Nixon and Scapin submitted written statements to the Zoning Board of Appeals. Nixon, of course, denied all allegations upon which the grounds of appeals were made, and Scapin's response also rebuffed many of the grounds of 1400 SWC's appeal. Concerning the seawall permit, Scapin wrote:

> Paragraph 12 refers to the construction of a bulkhead or seawall. Permission to construct a seawall is within the province of the State of Illinois in circumstances such as these. The bulkhead is not a structure within the interpretation of the Zoning Ordinance by the Building Commissioner. Therefore, it would not violate the 70 feet rear yard requirement.

The Zoning Board of Appeals voted in favor of Nixon (Parsons et al., 1965b), but 1400 SWC did not give up. Attempts to obtain the files concerning what happened next were fruitless, but from interviews, the following set of circumstances has been developed.

Illinois law states that before a permit is issued for the construction of a seawall, the adjoining property owners must be officially notified and a public hearing must be held (L. Donoghue, personal communication, 1988). Neither event occurred before the 1964 permit was issued. When the lawyers of 1400 SWC realized this had happened, they threatened litigation, and a public hearing was held. The hearing was presided over by John C. Guillou, the same person who had signed the permit. The ruling went in Nixon's favor, and apparently there were no more attempts at stopping the construction. If there were any, they were unsuccessful, because Nixon's building stands precisely where he planned for it to be located.

Effects of Nixon's Building on Langdon Park and Its Neighbors

As the lake level rose over the next 15 years, Nixon's building began to be closer to the water. This created significant problems for landowners to the south. The longshore current flows south, carrying a heavy load of sediment, but this current was deflected into the deeper waters by the new building and seawall. There the sand has settled permanently. Wave action is unable to return the sediments to the beach, thus starving the downstream beaches (USCOE, 1983). Inspection from the top of these buildings reveals a large sandbar clearly visible about 500 feet offshore where the sediments have settled. In addition to these problems, the building also set off eddies, which caused significant erosion just south of the building (T.M. Groutage, letter to Lt. Colonel Christos A. Dovas, District Engineer, USCOE, June 9, 1983).

With a net loss of sand, the beach and then the lake bluff of Langdon Park and its neighboring buildings began to recede significantly. There are severely varying accounts of how much land has been lost. The earliest report came from Ray Vanderwall, then Director of Parks and Recreation, in a January 23, 1980, letter to Ltc. Howard Nicholas, District Engineer of the COE. He wrote:

> During a storm last December approximately twenty five (25) feet of bluff was lost; over the previous ten (10) years an additional one-hundred (100) feet have been lost. This has caused the park district to have to move its sailing operation out of the area. This sailing operation had been in existence at this site for the past nineteen (19) years and housed over 200 small craft per year.

In a March 28, 1980, letter to the COE, R. Greenberg, Administrative Assistant of the Park District, wrote that since 1962 approximately 120 feet of beach had been lost. In addition, Greenberg pointed out that:

> The area of the park which is east of Sheridan Road is made up of fill material and as the vegetation is eroded from the bluff this material becomes increasingly vulnerable to rapid erosion from the top as well as from the lake. It is quite conceivable that if the erosion of Langdon Park is not stopped it will eventually reach Sheridan Road.

These letters and others prompted an examination of the problem by the COE. In a 1983 report of its study, the COE wrote that:

> Since 1978, approximately 50,000 square feet of beach area have been lost through erosion caused by wave action. In 1978, the beach had an approximate width of 100 feet. In 1982, the beach width varied between 10 and 25 feet, with most of the beach having an average width of less than 15 feet. The current rate of erosion has been estimated to be approximately 4 to 6 feet per year. This rate will vary with lake levels and the number and severity of storms. The loss of the beach area has severely curtailed swimming and fishing as recreational activities. The loss of the beach has also led directly to the erosion of the bluff as the beach acted previously as a buffer zone, absorbing the wave energy before reaching the bluff.

By 1986, the lake had reached a historic high level. Photographs that were taken by M. Newbery during this period show that the waves of the lake crashed directly upon the bluff of the park. In a 1988 interview, Terrence Porter said that by 1986 Langdon Park's beach had lost 300 feet of beach and 75 feet of bluff. Though other Chicago area beaches had also lost significant amounts of land, Porter said that the losses at Langdon Park were unusually high.

Preventive Measures

The Wilmette Park District was quite inventive, experimenting with several stopgap measures in attempts to stop the erosion. According to a 1988 statement by Terrence Porter, these included the use of sandbags filled with gravel (which disintegrated and created quite a mess), barrels filled with gravel, plastic seaweed, and the piling up of cement street light bases as a revetment.

In its 1983 study of the park, the COE recommended a beach nourishment program with periodic renourishment to control the erosion. The appropriation for this project was approved at the federal level, but was ultimately turned down by the village. Federal law states that the cost of the project should be split 70/30 (federal/local) up to $1 million. Apparently, according to Terrence Porter, the village feared that, with periodic renourishment, the costs might eventually run over $1 million, at which point they would be responsible for an open-ended expense over which the COE had ultimate control.

In 1986, the village decided that some type of shoreline protection had to be installed at Langdon Park. They entered into an agreement with the neighboring landowners to split the protection costs and hired the Harza Engineering Company to plan and implement some type of shoreline protection. Along the southern border of the park a road was cut through the bluff down to the beach (figure C-2) so that heavy equipment could be brought in. Harza placed large boulders along the base of the bluff to absorb the impact of the waves.

At 1410 Sheridan Road a groin had been put in several years earlier and, more recently, a seawall was put in. Harza backfilled the seawall with gravel and large rocks. Harza also built a small revetment at 1310 Sheridan Road (1310 actually did not have waterfront access until just recently). At a later date, 1410 had another contractor build a bulkhead at a point even with Nixon's seawall. Figure C-2 shows the improvements to each of the properties.

Social Impacts

The degradation of Langdon Park has caused a significant decline in the use of the park. In a March 26, 1981, letter to Martin Kotch, COE Study Manager, describing the past park usage, R. Greenberg wrote:

> In past years of operation this park has had approximately 500 sailors per week use the facility for a season total of around 10,000. Picnickers have equaled about 2000 for the season with approximately 2000 fisherman and 2000 waders using the area. In addition, there is annually approximately 5000 passive users that came to this park.

Partially on the basis of these figures, the USCOE (1983) used the methods of *The Water Resources Council's Procedures for Evaluations of NED Benefits and Costs* to calculate "user day values." These values were used to translate park user decline into annual "social" losses. A summary of their findings is shown in table C-1.

Economic Impact

The actual capital losses at Langdon Park have also been high. The value of the land there, according to a 1981 estimate by R. Greenberg, is between $150,000 and $175,000 per acre. By using Porter's estimate that 300 feet of beach has been lost, along with the fact that the beachfront is about 500 feet in width, one can calculate that 150,000 square feet of land has been lost. This translates to roughly 3 acres of land. At $175,000 per acre, the total property loss is $525,000.

Shore protection at Langdon Park has also been expensive. According to M. Newbery, Harza charged

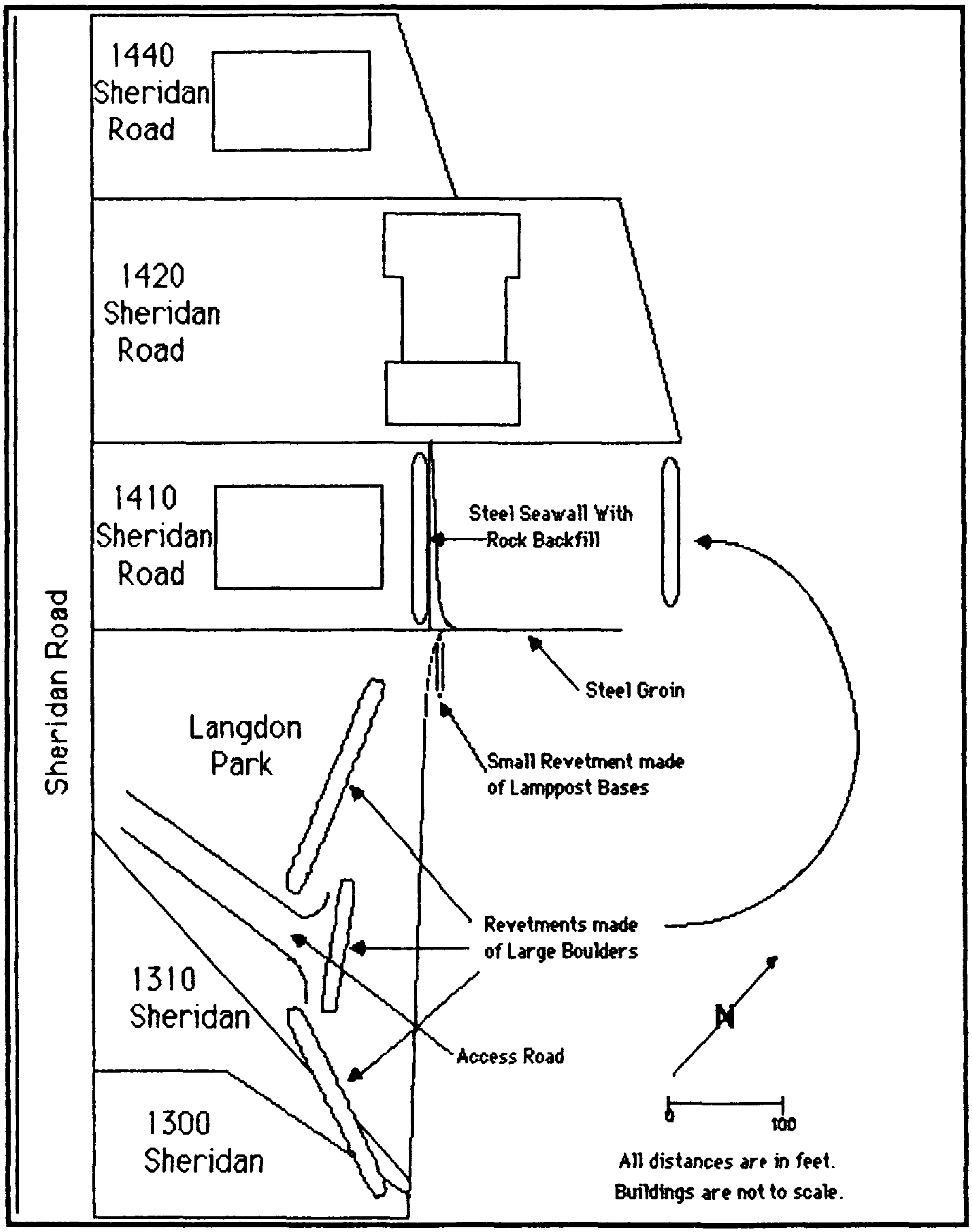

Figure C-2. Shoreline protection around Langdon Park

Table C-1. Estimated Social Costs of the Decline in Use of Langdon Park*

Activity	*User day value*	*Number of user days per season*	*Annual losses*
Picnicking	2.82	3,600	$10,200
Swimming	2.82	4,000	11,300
Boating	8.72	10,000	87,200
Sightseeing	2.82	5,000	14,100
Fishing	2.82	1,900	5,400
		Total	*$128,200*

*From USCOE (1983)

the village $72,323 for the construction work done at Langdon, along with a $13,000 consulting fee. Additionally, the owners of 1310 and 1410 Sheridan Road paid $20,944 for construction work and $1,000 for engineering fees.

Also lost at Langdon Park was a substantial amount of equipment, including picnic tables and boat ramps. In his 1980 letter to the COE, R. Greenberg summarized these losses, which are included in table C-2. It should be noted, though, that the worst damage to the park was done in the six years following Greenberg's letter, so his total loss values are lower than the actual losses to date.

Using these figures we can estimate that, over the last ten years, the total economic losses and costs related to Langdon Park and its neighbors are just over $2 million. This amount does not include miscellaneous expenses such as the time of the village employees that was spent in writing letters, reports, and memos related to their concerns on this matter. Nor does it include the time and effort spent in the efforts of the village to stop the erosion (for example, the cost of the plastic seaweed and the labor involved).

Table C-2. Estimated Losses of Capital Associated with the Erosion of Land at Langdon Park

Land lost:	
Approximately 3 acres @ $175,000/acre	$525,00
Shore protection:	
Construction by Harza	72,000
Engineering by Harza	13,000
Equipment lost:	
Launching ramp rail systems (2)	12,000
Boat racks (200)	10,000
Storage sheds (2)	1,500
Walkways	2,000
Fencing (500' of 12' chainlink)	10,000
Mercury vapor lights (2)	2,000
Steel jetty	30,000
Retaining wall (Barrell type)	8,000
Trees	8,000
Drinking fountain	600
Picnic tables (6)	850
Barbecue grills (4)	500
Sandbags	17,000
Total	$712,750

Conclusion

Over the past ten years, Langdon Park and its adjoining properties have suffered at least $2 million in social losses and economic costs. These losses could have been avoided if the zoning board had 1) had the foresight to envision these problems when they first adopted the set-back ordinance, or 2) heeded the warnings of their building commissioner and amended the ordinance at an earlier date. The problem apparently was rooted in a lack of understanding about the possible range of levels of Lake Michigan, how placement of structures affects lake circulation, and how these two factors should be incorporated in the design and location of shoreline structures. This case study should serve as a useful lesson. The condominium appears to have been the cause of the ensuing lake damage to Langdon Park and adjacent properties.

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