Chapter 17

VARIATION IN GREAT LAKES LEVELS IN RELATION TO ENGINEERING PROBLEMS

W. E. McDonald
Great Lakes Division, Corps of Engineers
Chicago, Illinois

INTRODUCTION

Throughout the recorded history of the Great Lakes, the fluctuation in their water levels has created engineering problems generally unique in relation to coastal engineering. In periods of low water, demands are heard from navigation and power interests to raise the levels. In periods of high water appeals are made by shore property owners to lower the levels. Such conflicting interests present major engineering problems, the nature of which during a given period of time reflect the long-range upward and downward trend in lake levels due to natural phenomena.

High waters on the Great Lakes during the past few years, particularly in 1951 and 1952, have again focused attention on the fluctuation of the levels of the Great Lakes and the effects of such fluctuations on the three major interests concerned with the waters of these lakes, namely navigation, power, and owners of shore properties.

In this paper I wish to present first a general description of the Great Lakes system and an explanation of the fluctuation in lake levels with reasons therefor. With this background in mind, I wish to conclude my discussion by explaining in general terms the engineering studies related to the variations in lake levels now being undertaken by the Corps of Engineers. Other papers which follow will, I understand, discuss in more detail some of the engineering problems and possible solutions.

IMPORTANCE OF GREAT LAKES

From an historic, geographic, and economic standpoint the Great Lakes with their connecting channels form the most important bodies of fresh water in the world and these waters have played a vital part in developing the midwest into an industrial empire. The enormous deposits of iron ore found in the Lake Superior region, the large deposits of lime-stone located along the lake shores, together with the vast coal fields of the Upper Ohio River Valley, are the major sources of the raw materials required in the production of our basic industrial commodity steel.

The exploitation of all the natural resources in the Great Lakes Basin paralleled the growth and development of the country. The Great Lakes and their connecting rivers formed a natural artery for the economic transportation of raw materials which comprise the basis of the present vast industrial complex of the region.

As industry expanded and the population grew, there followed logically the development of hydroelectric power plants at the outlets of Lake Superior and Lake Erie and also increasing use of the attractive lake shores for residential and recreational use.

The Great Lakes - St. Lawrence River drainage system extends from the Gulf of St. Lawrence to the headwaters of the St. Louis River in northern Minnesota, a distance of some 2,000 miles or almost half-way across the North American continent. The entire drainage basin has an area of approximately 325,000 square miles of which nearly one-third is water surface. The five Great Lakes constitute one-third of all of the fresh water area in the world and cover an area nearly twice the size of Illinois.

Lake Superior, the largest and deepest of the lakes, has a water surface area of 31,820 square miles. The outlet of Lake Superior is the St. Marys River which flows for a distance of some 70 miles with a drop of 23 feet before emptying into Lake Huron. The average discharge from Lake Superior through the St. Marys River is 73,000 cubic feet per second.

Lakes Michigan and Huron are one lake hydraulically because the Straits of Mackinac which connects the two lakes are so broad and deep the water surfaces of the two lakes stand at the same level. Lake Michigan has a surface area of 22,400 square miles and Lake Huron has an area of 23,000 square miles. The outflow from Lake Huron passes through the St. Clair River, Lake St. Clair, and Detroit River to Lake Erie, a distance of 87 miles with a drop in water surface of about 8 feet. The average flow through these connecting channels is 175,000 cubic feet per second.

Lake Erie, the shallowest of all the Great Lakes, is considerably smaller than the three lakes above it, having an area of only 9,940 square miles. The Niagara River, connecting Lakes Erie and Ontario, drops 326 feet in its length of 36 miles. Fifty (50) feet of this drop occur in the Cascades immediately above the Falls, 172 feet occur at the Falls, and 93 feet from the foot of the Falls to Lake Ontario. The Niagara River averages 194,000 cubic feet per second.

Lake Ontario, 326 feet below Lake Erie and 356 feet below Lake Superior, is the smallest of the Great Lakes with a surface area of 7,540 square miles. It may be of interest to note here that the deepest point of Lake Ontario is some 525 feet below sea level and the deepest point of Lake Superior is about 700 feet below sea level.

The outlet of all of the Great Lakes is the St. Lawrence River. The first 116 miles of the river is on the international boundary between Canada and the United States, the remainder of its course is in Canadian territory. The fall from Lake Ontario to Montreal Harbor is approximately 226 feet of whic some 92 feet occur in the 46-mile long International Rapids section. The flow of the St. Lawrence River at Ogdensburg, N.Y. averages 231,000 cubic feet per second.

The flow in all of the outlet channels is remarkably uniform, the ratio between the maximum and minimum being only in the order of about two to one.

LAKE LEVEL VARIATIONS

The levels of all of the lakes fluctuate from year to year. The over-all long-range fluctuation over a period of years based on the range between the high and low monthly average levels varies from a little over 4 feet on Lake Superior to over 6.5 feet on Lake Ontario. The levels of the lakes also follow a yearly seasonal pattern with highs occuring in the summer and lows in the winter or early spring months. These seasonal variations average from 1.1 feet on Lakes Michigan-Huron to 1.8 feet on Lake Ontario. Through a period of record since 1860 the Lakes have departed widely, however, from their average seasonal behavior both as to the magnitude of the fluctuations and the timing of the highs and lows.

The principal natural factors which affect seasonal and yearly fluctuations of the levels of each of the Great Lakes are precipitation, evaporation, and flow in the rivers connecting the lakes.

Precipitation falling directly on the lake surfaces immediately becomes a part of the volume of water in the lakes and has a direct effect of raising levels by the depth of precipitation. Precipitation falling on land surfaces of the drainage basin produces a variable effect on lake levels due to the variations in runoff.

Evaporation from the lake surfaces lowers the lake levels by the number of inches of evaporation, but unfortunately no accurate means has been devised for measuring this evaporation. The depth of water removed directly from the lakes each year by evaporation is estimated to vary from approximately 1.5 feet on Lake Superior to as much as 3 feet on Lake Erie.

Flows in the connecting rivers have direct effects on levels of the lakes, inflow from the lake above tending to raise levels and outflow to the lake below tending to lower levels.

The abnormally high stages prevailing in 1951-1952, when Lake Erie and Ontario reached all-time highs, are attributable to the persistent trend of above-normal rainfall during the preceding 10 years. During this 10-year period the annual precipitation was 2.23 inches above the average for the years since 1900, and in 1950 and 1951 the precipitation was nearly 6 inches above the average.

A number of attempts have been made to find cycles in the rise and fall of lake levels and to correlate them with cycles of other phenomena. Our studies have failed to find any consistent cycle pattern in the long-range rise and fall of lake levels nor has any evidence been found to relate the lake level fluctuations to the waxing and waning of sun spots or other physical phenomena.

Short-period fluctuations are superimposed on the long-range and seasonal fluctuations. They result from an unbalance or tilting of the lake surfaces induced primarily by winds and differential barometric pressures. These fluctuations reach their maximum in periods ranging from a few minutes to several days and remain at or near the maximum for about the same periods of time. The maximum temporary rises recorded range from 8.4 feet on Lake Erie to 2.5 feet on Lake Huron. Fluctuations of this magnitude occur at infrequent intervals but temporary changes in levels of from 1 to 2 feet are common.

Another natural factor which must be considered in relation to lake levels is the crustal movement of the earth. It has been shown rather conclusively that the coasts of all of Lake Ontario, all of Lake Erie, most of Lake Michigan, and the southerly shore of Lake Superior are sinking in relation to the lake outlets, due to a crustal movement of the earth, so lake levels there are rising. The coasts of most of Lake Huron, the northeasterly part of Lake Michigan, and the northerly shore of Lake Superior are rising in relation to the lake outlets and the lake levels there are lowering. The maximum changes in lake levels due to this cause occur at Port Dalhousie on the westerly end of Lake Ontario where the water is rising at a rate of 1.1 feet per hundred yards and at French River in Georgian Bay on Lake Huron where the water is falling at a rate of 0.7 foot per hundred years. Rates at many other places on the Lakes are almost as great.

Artificial factors affecting the levels of the Great Lakes are diversions into and out of the lakes, and alterations of flows in the connecting channels by artificial means such as dredging or by compensating or regulating works.

Diversions in the Great Lakes today consist of the Long Lake-Ogoki diversions from Hudson Bay watershed into Lake Superior, the Chicago Sanitary and Ship Canal diversion from Lake Michigan to the Mississippi River basin; and the Welland Canal and the New York State Barge Canal diversions out of Lake Erie into Lake Ontario. Regulating works are in operation at St. Marys Falls at the Soo to control the levels of Lake Superior. The other four lakes are not regulated.

The net total effect of all existing diversions and control structures on lake levels is in the order of less than 2 inches, except on Lake Ontario where the Gut Dam in the Galop Rapids of St. Lawrence River raised Lake Ontario levels approximately an additional 7 inches. However, this structure was removed in January 1953 so the levels of Lake Ontario are dropping accordingly.

The net effect of artificial factors is of extremely small magnitude when compared with the natural phenomena of long-period fluctuation of from 4 to 6 feet and when compared with short-period fluctuations.

ENGINEERING AND ECONOMIC MATTERS RELATED TO VARIATIONS IN LAKE LEVELS

With this condensed explanation of the various natural and artificial factors that affect the variations in lake levels, and bearing in mind that higher lake stages are favorable to navigation and power but that lower lake stages are favorable to shore interests, let us now briefly examine the economic effect of fluctuations in lake levels on each of these three major uses of water and then consider the engineering studies related to each.

LAKE LEVELS AND DAMAGES TO SHORE PROPERTY

The damages which occur to shore property by wave action are dependent not only on levels of the Lakes but also on the number and severity of storms.

Damage to shore properties is relatively minor at low lake stages since the uplands are generally protected by wide beaches at these stages. However, during high lake stages, the beaches are largely under water and the back shore is subject to direct wave attack from even moderate storms. The maximum damage occurs when a severe storm is accompanied by a large temporary rise in lake levels at a time when the lake levels are on the high side of their fluctuation range as they have been during the past two or three years.

During high lake stages many low-lying areas along the lake shores are flooded. In general, many of these areas were developed during extended periods of low lake levels which condition furnished a false sense of security from the hazards of future high water stages. As an example, extensive areas around the westerly end of Lake Erie, including several hundred homes, were flooded in 1952.

During the recent period of high lake levels when unusually stormy weather prevailed from the spring of 1951 to the spring of 1952, the damage along the United States shores of the Great Lakes is estimated to have been in excess of $61,000,000, of which $50,000,000 was caused by wave action and $11,000,000 by flooding of low lying areas.

The present and prospective future increased extensive utilization of shores of the Great Lakes make the matter of damage to shore properties a subject of serious concern in the entire Great Lakes region. It affects directly hundreds of thousands of people. Consequently, the damaging effect of high lake stages on shore properties is more apparent to the general public than are the effects of variations in lake levels on the two other major water uses of navigation and power.

Unlike a flood from a river when the damage comes and goes in a short period of time, lake shore owners are faced with floods or are threatened with floods for many consecutive months. Accordingly, the interests of shore property owners are best served by regulating lake stages within narrower limits than occur naturally so that some optimum upper limit will not be exceeded.

LAKE LEVELS AND NAVIGATION

Extensive improvements have been underway by the Corps of Engineers since 1825 to provide adequate through connecting channels and harbors for the lake fleet. One of the most vital of these improvements has been the Soo Locks for by-passing the rapids in the St. Marys River.

The channels in the St. Marys River as well as in the St. Clair River, Lake St. Clair, and in the Detroit River have been deepened to 25 feet in downbound and 21 feet in upbound channels. Deepening of these connecting channels has been a major undertaking.

To by-pass the Niagara River the Canadian Government has built the Welland Canal with 7 lift locks with depths of 30 feet over the sills and with the canal presently dredged to 25 feet to accomodate modern lake freighters. Canada has also provided a series of canals and locks for

14-foot navigation to by-pass the rapids in the St. Lawrence River between Lake Ontario and Montreal.

Today we have 60 active commercial harbors on the Great Lakes, 14 of which handle in excess of 7,500,000 tons of cargo annually. As compared to this, the active commercial salt water ports of the United States number about 155 of which 31 handle more than 7,500,000 tons annually. Based on the total commerce handled in 1950, four of the ten largest ports in the United States are on the Great Lakes.

During the calendar year 1950 the total waterborne commerce in the United States was 820,600,000 tons. Of this total, 199,200,000 tons or approximately 24 per cent was carried on the Great Lakes. The bulk of the traffic is carried during the eight and one-half month navigation season from about April 1 to December 15 at a rate of over 20,000,000 tons per month.

Most of the commerce on the Great Lakes consists of bulk raw materials such as iron ore, coal, stone, grain, and petroleum products. Of the total of 199,200,000 tons carried in 1950 about 44 per cent, or about 87,000,000 tons was iron ore carried from upper lake ports to the lower lakes. In the 1953 navigation season it is expected that about 100,000,000 tons of iron ore will be transported on the lakes.

Prior to World War II the largest vessels on the lakes were about 600 feet long with maximum drafts of about 22 feet. The connecting channels and major harbors served by this fleet had adequate depths except when the lakes were at low stages. Since 1942, 43 U.S. vessels have been built or are under construction for the Great Lakes with maximum permissible drafts of from 24 feet 6 inches to 26 feet 10 inches. It is expected that this trend toward construction of larger vessels and retirement of the smaller vessels will continue. These larger vessels have a cargo capacity of up to about 20,000 tons as compared to about 12,000 tons for the larger boats of a few years ago.

It is apparent that these vessels can load to their maximum drafts only when the lakes are at extreme high stages. When lakes are at average or low stages they must reduce their drafts by as much as 3 or 5 feet because of the restricted depths in the connecting channels and in the improved harbor channels. The larger vessels carry over 100 tons per inch of draft so at low lake level stages they are required to lighten their loads upwards of 4,000 tons per trip.

Thus we see that the fluctuation in lake levels have a significant effect on navigation. During high lake stages the carrying capacity of the fleet is much greater than when they are low with resulting savings in the cost of transportation. It follows logically then that the interests of navigation are served best by high lake stages.

LAKE LEVELS AND POWER DEVELOPMENT

Hydroelectric power is generated in the St. Marys River at Sault Ste. Marie and in the Niagara River at Niagara Falls. The large and remarkably steady flow from the Great Lakes resulting from their tremendous storage capacity makes the outlet rivers from these lakes extremely valuable as a source of water power. The present installed capacity at Niagara Falls is 445,000 KW in the United States and 848,000 KW in Canada for a total of 1,293,000 KW. Canada now has under construction an additional development of 1,200,000 KW. In a study in 1951 the District Engineer, Corps of Engineers, at Buffalo concluded that an additional development of 1,300,000 KW could be made in the United States at the Falls. In the International Rapids section of the St. Lawrence River a proposed development of about 1,880,000 KW is to be divided equally between the United States and Canada. It is needless to say that power interests are best served by high lake levels.

ENGINEERING STUDIES RELATED TO LAKE LEVELS

Taking into account the physical and economic factors of the Great Lakes which I have discussed, we see that natural variations in lake levels, both from a long-range and seasonal point of view, prove to be favorable at times to some interests and yet are also unfavorable to others at the same time. Since high and low lake stages will continue to occur under natural conditions in the future at various intervals, the economic impact therefrom will become increasingly more significant in relation to the growing need for more power, the construction of larger vessels for navigation, and desirability of relief from damages to shore properties.

In recognition of these circumstances, certain comprehensive engineering studies have been initiated in an effort to reduce the growing economic losses caused by the fluctuations in lake levels.

In response to directives of the Congress, the Corps of Engineers is now engaged in two major studies of the Great Lakes problems. One deals directly with the variations in lake levels, the other is concerned with navigation.

The first study is concerned with determining the feasibility of a plan of regulation of the levels of the Great Lakes that will best serve the interests of all water uses, particularly in regard to the reduction of damages to shore properties, the use of the Great Lakes for navigation, and the use of the storage and outflows from the Great Lakes for power development. It is significant to note that numerous lake regulation studies have been made in the past 57 years by various Boards, Commissions, private individuals and others which contemplated regulation to maintain high lake levels in the interests of navigation and power. The current study is the first to give full consideration also to shore property owners.

Since the Great Lakes form one of the most complex hydraulic systems in the world and since the requirements of navigation, power, and shore property uses, in respect to lake levels and outflows from the lakes, are not entirely compatible, considerable time will be required to complete these lake regulation studies.

These studies are being coordinated with the eight other Great Lakes states and interested Federal Agencies to arrive at an overall solution which will serve best the interests of all concerned. In this regard before any system of lake regulation can be adopted it will of course be necessary to coordinate and obtain agreement with Canada as all of the lakes except Lake Michigan are boundary waters between the two countries.

Another phase of this investigation will consider the advisability of providing local flood protection works to protect low-lying areas from inundation. An interim report on this phase of the study has been submitted to the Congress recommending Federal participation in the cost of providing protection to three localities on the western end of Lake Erie.

Associated with these hydraulic studies are such investigations as long-range forecasting of lake levels; and the analysis of the individual factors governing supplies of water to the lakes, such as precipitation on land and water surfaces, runoff, groundwater, outflow in connecting channels, and evaporation. Because both the United States and Canada have each measured the hydraulic factors of the Great Lakes independently, the Corps of Engineers and technical agencies in Canada are now in the process of seeking agreement on the basic hydraulic and hydrological data.

The second major study by the Corps of Engineers concerns consideration of the need for improvements in the connecting channels to accommodate the increasing number of large vessels of the United States Great Lakes fleet. The Congress has directed that previous reports by the Corps of Engineers be reviewed to determine the advisability of proceeding at this time with improvements in the Great Lakes connecting channels to provide a channel depth of at least 27 feet below low water datum and to prepare up to date estimates of the costs of such improvement.

As mentioned above the connecting channels include the St. Marys River, between Lakes Superior and Huron; the Straits of Mackinac, between Lakes Michigan and Huron; and the St. Clair River, Lake St. Clair and Detroit River between Lakes Huron and Erie. Deep draft navigation between Lakes Erie and Ontario is now provided by the Welland Canal. These channels now provide 25 feet in downbound and 21 feet in upbound channels. The Welland Canal is dredged to 25 feet and has depths of 30 feet over the lock sills.

Allowing 2 to 3 feet of underclearance for safe navigation it is clear that the present project depths of 21 feet and 25 feet are no longer adequate for the growing number of vessels with designed drafts of 24 feet or more.

The study now underway to consider deepening of the connecting channels is of course immediately concerned with the fluctuation of lake levels, the present and future make-up of the fleet, the compensation needed in the channels to balance the deepening effect so as to not adversely affect lake levels and comprehensive economic analysis to determine the economic justification of the improvements at this time.

One other type of study should be mentioned, that is, studies for protection of the shores and beaches by means other than by regulation of the levels of the lakes. Cooperative beach erosion control studies are authorized by Public Law 520, 71st Congress, approved July 3, 1930, as amended and supplemented, wherein the United States may cooperate with States, Municipalities, or other political subdivisions in making studies with a view to devising effective means of preventing erosion of the shore of coastal and lake waters by waves and currents. In these cooperative studies the cost is divided equally between the United States and the cooperating agency. Public Law 727, 79th Congress, approved 13 August 1946 established policy whereby, with the purpose of preventing damage to public property and promoting and encouraging healthful recreation of the people, the United States may assist in construction, but not the maintenance, of works for the improvement and protection against erosion by waves and currents of the shores of the United States owned by States, Municipalities, or other political subdivisions; Provided, that the Federal contribution toward the construction of protective works shall not in any case exceed one-third of the total cost. There is no provision for Federal participation in the cost of construction of protective works for privately-owned property.

Of the 4,000 miles of mainland shoreline of the Great Lakes in the United States, about 450 miles have been studied and reported on by the Corps of Engineers. Each report provides type-designs for works to protect privately owned property and detail designs for the protection of the publicly-owned property. The shoreline covered by the reports are: On Lake Michigan, the entire shoreline state of Illinois, and Milwaukee and Racine Counties, Wisonsin; on Lake Erie, the entire shoreline of the State of Ohio and Presque Isle Peninsula, Pa.; and, on Lake Ontario, Niagara County, N.Y. Now under study is the shoreline of four State of New York Parks on Lake Ontario; and,the shoreline of Kenosha, Wisconsin and that from the North City limits of Two Rivers, Wisconsin to the south city limits of Manitowok, Wisconsin on Lake Michigan.

CONCLUSION

In conclusion we in the Great Lakes region have been confronted continuously with coastal and related engineering problems of major importance to all users of the Great Lakes including shore property owners. These problems are aggravated by the large fluctuations of lake levels.

These fluctuations may be reduced on certain of the lakes as a result of some of the studies now underway and also on Lake Ontario as a result of the works proposed in the plans for the development of the St. Lawrence River. Although the fluctuation range may be reduced, the present pattern will always remain, that is, high stages in summer and low stages in winter and with cycles of generally high or low stages over a period of years depending on the amount of precipitation in the basin. It is too early to predict the outcome of our lake regulation studies but certainly we know that any action which can be taken to reduce the natural fluctuation ranges of the lakes will have the effect of mitigating our coastal engineering problems by only a relatively minor degree. We do believe, however, that any reduction in the fluctuation ranges of the lakes which can be justified by lake regulation will provide wide-spread benefits to shore properties and to other users of the Great Lakes waters.