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REVIEW AND ANALYSIS OF LAKE MICHIGAN WATER LEVELS AT MILWAUKEE, WISCONSIN

by David B. Kendziorski, SEWRPC Principal Planner

INTRODUCTION

Proper management of the Lake Michigan shoreline requires definitive knowledge of the lake levels and storm wave conditions which may occur. Such knowledge is necessary for the design of both onshore and offshore structures such as revetments, groins, piers, dock walls, navigation channels, and breakwaters; and for the sound exercise of land use regulations relating to the development of coastal areas. This fact was emphasized by the record high water levels experienced in 1986. Such definitive knowledge of lake levels and storm wave conditions is also required for certain technical analyses. For example, as part of the preparation by the Southeastern Wisconsin Regional Planning Commission of a shoreline erosion management plan for Milwaukee County, Wisconsin[1] wave modeling analyses were conducted to assist in the assessment of existing and proposed structural shore protection measures. Such assessment required careful consideration of the possible range in lake levels and of attendant wave heights.

Statistical analyses of systematically recorded actual water levels normally are considered to represent a sound basis for developing water level projections. However, since the historical record is relatively short—extending in the Milwaukee area back to 1819, with systematic records extending back only to 1860—geological and archaeological information, along with the results of mathematical simulation modeling analyses, should also be considered in the use of projections based upon historical monitoring records. These geological and archaeological data and simulation modeling results are also presented for verification and comparison purposes. Supplementing the statistical analyses with a review of recorded data, geological and archaeologic evidence, and simulation modeling results provides a more comprehensive evaluation of potential water levels.

The available long-term water level records for Lake Michigan at Milwaukee have been summarized by the Regional Planning Commission,[2] and statistical analyses conducted of the annual, quarterly, monthly, daily, and instantaneous maximum, minimum, and mean water levels. Stage-frequency analyses of the Lake Michigan water level records collected at Milwaukee are presented in SEWRPC Planning Report No. 37. Similar analyses have been conducted by the U. S. Army Corps of Engineers.[3] Prehistoric water levels based on geological information have been estimated by Larsen.[4] Past water levels based upon a review and interpretation of information compiled from several historical, archaeological, climatic, and geologic sources were also estimated by Bishop.[5] Bishop suggested a potential variation in Great Lakes water levels over the next 50 years. Potential water level changes

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[1]*SEWRPC Community Assistance Planning Report No. 163, A Lake Michigan Shoreline Erosion Management Plan for Milwaukee County, Wisconsin, October 1989.*

[2]*SEWRPC Planning Report No. 37, A Water Resources Management Plan for the Milwaukee Harbor Estuary, Volume One, Inventory Findings; Volume Two, Alternative and Recommended Plans, 1987.*

[3]*U. S. Army Corps of Engineers, Report on Great Lakes Open-Coast Flood Levels, Detroit, Michigan, 1977; and Revised Report on Great Lakes Open-Coast Flood Levels, Phase I, Detroit, Michigan, 1988.*

[4]*Curtis E. Larsen, Report presented at the Colloquium on Great Lakes Levels, Water Science and Technology Board of the National Research Council, Chicago, Illinois, March 17-18, 1988.*

[5]*Craig T. Bishop, Great Lakes Water Levels: A Review for Coastal Engineering Design, National Water Research Institute Contribution 87-18, Environment Canada, Burlington Ontario, 1987.*

under various climatic and water supply scenarios were examined by Hartmann[6] and Quinn[7] using a hydrologic response model. Using these primary data sources, this article reviews the range of water levels which may be expected to occur on Lake Michigan in the future.

FACTORS DETERMINING LAKE LEVELS

The primary factor that determines the still-water level of Lakes Michigan-Huron—which act with respect to levels as a single body of water—is the hydrologic cycle. Water inputs to the lakes include precipitation on the lake surface, stormwater runoff from the tributary drainage basin, inflow from Lake Superior, and groundwater inflow. Water outputs include evaporation from the lake surface, outflow through the St. Clair River outlet and the Chicago diversion, and groundwater outflow. These inputs and outputs vary seasonally and with long-term climatic changes. Although the Great Lakes constitute a highly complex system, mathematical models which simulate the hydrologic and hydraulic performance of the system have been developed by the Great Lakes Environmental Research Laboratory of the U. S. Department of Commerce, National Oceanic and Atmospheric Administration, and by the U. S. Army Corps of Engineers. These models may be used to estimate changes in water levels under stated assumptions concerning the climatic and man-made influences involved.

The results of the modeling conducted by researchers of the Great Lakes Environmental Research Laboratory are summarized herein. Similar models have been developed and applied by other researchers in the United States and Canada. The models applied by researchers at the Laboratory were used to simulate the water level impacts on the Great Lakes of several hydrometeorological and water management scenarios, including changes in the net basin water supplies, increased outflows from Lake Superior, modifications to diversions in the Great Lakes system, increases in the flow capacity of certain lake outlets, and climate changes. The models were used to estimate the water levels that may be expected to occur under each of the scenarios considered. Thus, the model results are not used to actually predict future water levels. Rather, the model results help identify those conditions that would produce relatively high or low water levels.

There are five modest artificial diversions on the Great Lakes which change the natural supply of water to the lakes or which permit water to bypass a natural lake outlet, as shown on Map 1. These are the Long Lac, Ogoki, and Chicago diversions; the Welland Canal; and the New York State Barge Canal. Both the Ogoki and Long Lac diversion divert into Lake Superior water from the Albany River Basin which would otherwise drain to Hudson Bay. These two diversions were developed for the primary purpose of generating hydroelectric power. The Chicago diversion from Lake Michigan serves to dilute sewage effluent from the Chicago Sanitary District and divert the effluent from the lake. The diversion also facilitates navigation on the Chicago Sanitary and Ship Canal and hydroelectric power generation in Illinois. The Welland Canal diverts water from Lake Erie across the Niagara Peninsula to Lake Ontario, thereby bypassing the Niagara River and Niagara Falls, primarily for purposes of navigation and hydroelectric power generation. The New York State Barge Canal diverts water primarily for navigation purposes from the Niagara River at Tonawanda, New York, ultimately discharging it to Lake Ontario.

The impact of each of the diversions is shown in Table 1. The Ogoki and Long Lac diversions increase the elevation of Lake Michigan by about 0.37 foot, while the Chicago and Welland Canal diversions

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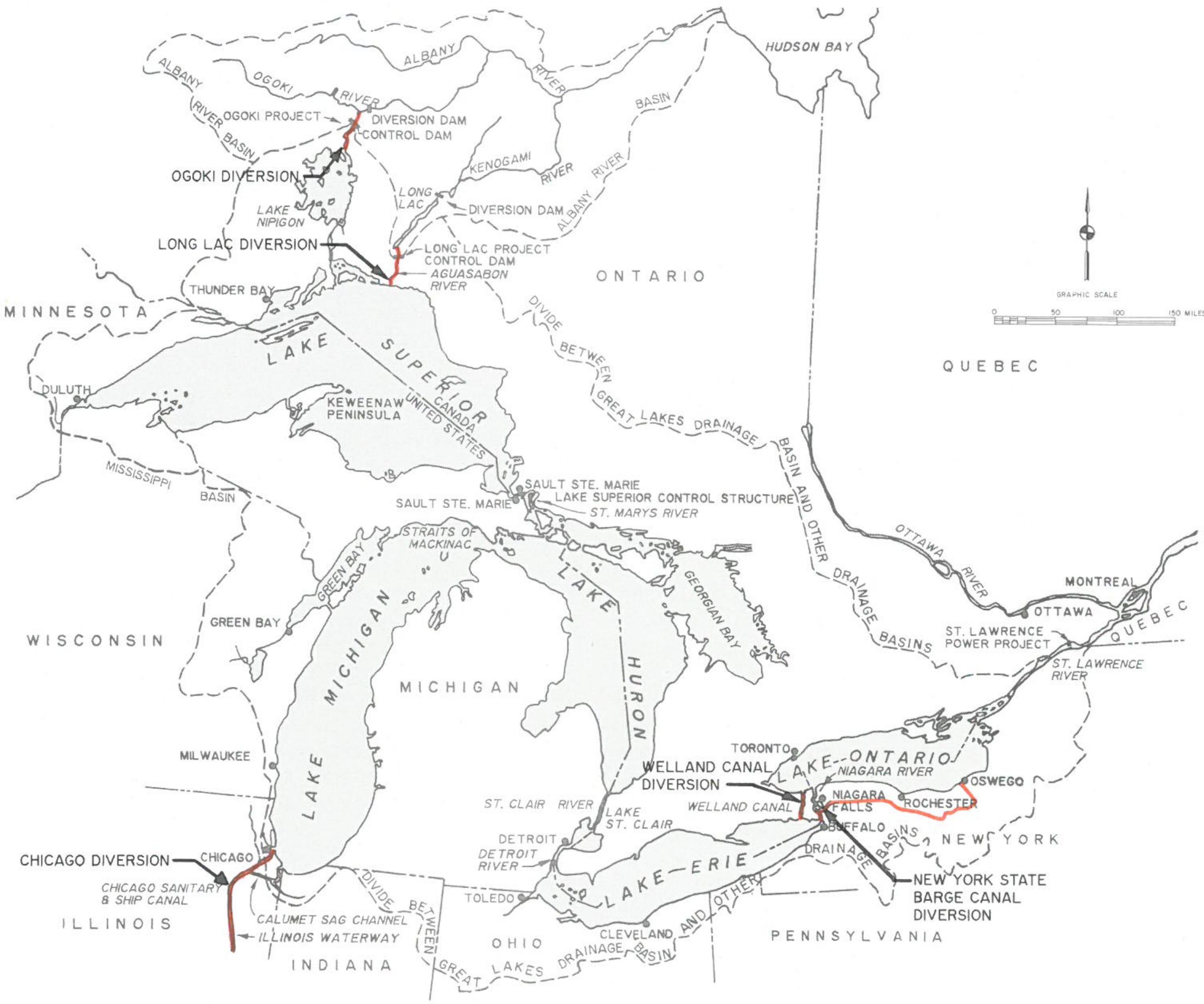
[6]*Holly C. Hartmann, Potential Variation of Great Lakes Water Levels: A Hydrologic Response Analysis, Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan, 1987.*

[7]*Frank H. Quinn, Likely Effects of Climate Changes on Water Levels in the Great Lakes, Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration. Presented at the First North American Conference on Preparing for Climate Change: A Cooperative Approach, Washington, D. C., October 27-29, 1987.*

Map 1

GREAT LAKES DRAINAGE BASIN AND ARTIFICIAL DIVERSIONS



Source: U. S. Army Corps of Engineers.

combined reduce the elevation by 0.39 foot.[8] The New York State Barge Canal has no significant effect on Lake Michigan water levels. Thus, the combined effect of the existing diversions is to reduce the elevation of Lake Michigan by 0.02 foot.

Water levels in the Great Lakes can be somewhat regulated by means of artificial outlet control structures. Currently, two of the Great Lakes, Superior and Ontario, are regulated under plans approved by the International Joint Commission. The regulation of Lake Superior affects the entire

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[8] *Frank H. Quinn, Great Lakes Water Levels, Briefing of U. S. Senators and Representatives from the Great Lakes Basin, Conducted by the International Joint Commission, Washington, D. C., July 1985.*

Table 1

ARTIFICIAL DIVERSIONS ON THE GREAT LAKES: 1988

Diversion	Average Flow Rate (cubic feet per second)	Impact on Lake Michigan (feet)
Long Lac and Ogoki	5,600	0.37
Chicago	3,200	-0.21
Welland Canal	9,200	-0.18
New York State Barge Canal . . .	700	0
Net Impact	- -	-0.02

Source: International Joint Commission.

Great Lakes system, whereas the regulation of Lake Ontario does not affect the other lakes because of the sheer drop in the water level at Niagara Falls. Additional regulation of water levels in Lakes Michigan, Huron, and Erie has been proposed as one method of alleviating shoreline erosion caused by high water levels. Increased regulation of the water levels could be accomplished by dredging to increase the hydraulic capacity of the lake outlet channels, by modifying existing diversions into and out of the lakes, and by constructing new diversions.

The governments of the United States and Canada, in August 1986, requested that the International Joint Commission undertake a comprehensive study of methods of alleviating the adverse impacts of changing water levels, ranging from very high to very low levels, on the Great Lakes/St. Lawrence River Basin.[9] The study involves two phases. The first phase of the study, scheduled for completion in May 1989, is to focus on the characterization of the lake level fluctuations and their consequences, inventory measures, and the development of a systematic and comprehensive framework for evaluating possible control measures.

The second phase, which is scheduled to be completed in September 1991, is to refine the data bases and provide a detailed and comprehensive evaluation of specific solutions identified in the first phase as having good potential. These solutions may include structural improvements, land use planning, and other management activities. In this regard, it should be noted that the governors of the Great Lakes states, as members of the Council of Great Lakes Governors, in 1986 voiced support for avoiding the further diversion of water from the Great Lakes. This opposition to further diversions will have to be considered in any study of the potential regulation of Lake Michigan. Because the International Joint Commission study is not yet completed, and because the implementation of any possible recommendations to provide for further regulation of the lake levels may be expected to take many years, it was assumed, for the purposes of this article, that the existing artificial diversions would continue to operate at their present levels.

A related study focusing on measures to alleviate the high-water-level crisis existing in 1985 and 1986 was initiated in 1986, and completed in October 1988 by a task force composed of International Joint Commission staff and specialists.[10] The report was limited to those measures that could be evaluated and implemented within approximately two years and that would not require significant new structural works. The measures evaluated to reduce Lake Michigan water levels included increasing the storage of Lake Superior; modifying river diversions, such as closing the Long Lac and Ogoki diversions, and increasing the rate of the Chicago and Welland Canal diversions; increasing Lake Erie outflows; modifying flows in the St. Clair and Detroit Rivers; and improving flows under the ice cover in the St. Clair River. However, the report estimated that by implementing all of the potential measures, Lake Michigan water levels may expect to decrease by only about 1.2 feet after two years, and by about 1.5 feet after five years. These results were confirmed by a study conducted by the U. S.

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[9]*International Joint Commission, Plan of Study Concerning the Reference on Fluctuating Water Levels into the Great Lakes-St. Lawrence River Basin, March 15, 1988.*

[10]*International Joint Commission, Interim Report on 1985-86 High Water Levels in the Great Lakes-St. Lawrence River Basin, October 1988.*

National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory, which noted that eliminating the Long Lac and Ogoki diversions and increasing the Chicago and Welland Canal diversions would reduce Lake Michigan water levels by only 0.8 foot after eight years, with half of that lowering occurring within two to three years.[11]

MONITORED DATA ANALYSIS

Long-term variations in Lake Michigan water levels are caused by changes in water inputs and outputs, while short-term variations result primarily from wind stress on the water surface. Water level records on the Great Lakes date back to as early as 1815.[12] As already noted, the earliest available measurements of Lake Michigan water levels at Milwaukee were recorded in 1819. From 1819 through 1859, the water level records were intermittent and irregular. The measured Lake Michigan water levels at Milwaukee from 1819 through 1859 are listed in Table 2. These early lake level measurements must be used with extreme caution because of the irregular nature of the data collection efforts; numerous datum changes; subsequent man-made modifications to the outlet of Lake Huron and the St. Clair River; and vertical earth crustal movements in the Great Lakes Basin (isostatic rebound). Modifications to the St. Clair River and the outlet of Lake Huron from 1856 to 1962 have apparently lowered the level of Lakes Michigan-Huron by about 1.2 feet.[13] About 75 percent of this lowering, or about 0.9 foot, occurred during the twentieth century.[14] Because the accuracy of the water level data collected prior to 1860 is unknown, stage-frequency analyses of these data were not considered to be reliable. Nevertheless, these early data do provide some valuable information on historical high and low water levels. For example, the maximum monthly mean lake level of 584.3 feet National Geodetic Vertical Datum (NGVD) recorded in June and July 1838 is 1.1 feet above the twentieth century record maximum monthly mean water level recorded in October 1986 of 583.2 feet NGVD. Correcting the 1838 data for crustal movement between Milwaukee and the Lakes Michigan-Huron outlet raises the elevation to about 584.9 feet NGVD, or 1.7 feet above the October 1986 level.[15]

In addition to the channel modifications, diversion developments, and earth crustal movements that have occurred over the past century, land use changes associated with urbanization and agricultural drainage yield significantly higher stormwater runoff for the same precipitation than occurred during the nineteenth and early twentieth centuries. This effect may somewhat compensate for the channel modifications in the St. Clair River and enhance the validity of the early recorded data.[16] The effect of land use changes on Lake Michigan water levels, however, has not been quantified.

In 1860, a regular program of recording daily water level readings of staff gages was instituted. For the period 1860 through 1905, daily water levels were measured at Milwaukee by the predecessor agencies of the National Ocean Service, National Oceanic and Atmospheric Administration. Stage-frequency analyses of the 1860 through 1905 period have not been conducted because instantaneous water levels—generally used to estimate flood levels—were not measured by the way the gages were read. Annual mean Lake Michigan water levels measured at Milwaukee over the period 1860 through 1987 are shown in Figure 1.

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[11]*Holly C. Hartmann, op. cit.*

[12]*Bishop, op. cit.*

[13]*SEWRPC, 1987, op. cit.*

[14]*J. A. Derecki, "Effect of Channel Changes in the St. Clair River During the Present Century," Journal of Great Lakes Research, Vol. 11, No. 3, 1985, pp. 201-207.*

[15]*Frank H. Quinn, Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, Letter to Mr. Kurt W. Bauer, Executive Director, Southeastern Wisconsin Regional Planning Commission, June 15, 1988.*

[16]*Derecki, op. cit.*

Table 2

LAKE MICHIGAN WATER LEVELS AT MILWAUKEE: 1819-1859

Year	January	February	March	April	May	June	July	August	September	October	November	December
1819	- -	577.68	- -	- -	- -	579.68	- -	- -	- -	- -	- -	- -
1820	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1821	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1822	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1823	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1824	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1825	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1826	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1827	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1828	- -	- -	- -	- -	- -	582.54	582.57	582.54	- -	- -	- -	- -
1829	- -	- -	- -	- -	- -	582.54	- -	- -	- -	- -	- -	- -
1830	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1831	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1832	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1833	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1834	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1835	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1836	- -	- -	580.37	- -	- -	583.36	- -	- -	- -	- -	- -	- -
1837	- -	- -	- -	- -	581.16	583.78	- -	- -	- -	- -	- -	- -
1838	- -	- -	- -	- -	- -	584.37	584.37	- -	- -	- -	- -	- -
1839	- -	- -	- -	- -	- -	- -	583.06	- -	- -	- -	- -	580.70
1840	579.87	- -	- -	581.29	581.42	581.49	581.75	581.49	581.13	580.99	580.80	580.57
1841	580.67	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	579.94
1842	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1843	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1844	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1845	- -	- -	- -	- -	- -	580.99	- -	- -	- -	- -	- -	- -
1846	579.97	579.94	580.11	580.57	580.93	580.93	580.99	580.70	580.24	579.98	579.71	579.32
1847	578.99	578.86	578.99	579.19	579.39	579.78	579.85	579.78	579.91	579.59	579.49	579.29
1848	579.09	579.03	579.03	579.35	579.06	579.32	579.91	579.91	579.71	579.65	579.55	579.59
1849	579.55	579.65	579.45	579.65	579.79	580.31	580.60	580.60	- -	- -	- -	- -
1850	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1851	- -	- -	- -	- -	- -	- -	581.78	582.08	- -	- -	581.95	- -
1852	- -	- -	- -	- -	- -	- -	- -	582.86	582.34	582.27	582.41	- -
1853	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -
1854	- -	- -	- -	580.67	581.32	581.59	581.91	581.88	581.75	581.19	580.93	580.80
1855	580.57	580.53	580.60	580.70	581.26	581.59	581.68	581.78	581.88	581.75	581.55	581.65
1856	581.72	581.22	581.26	581.39	581.81	581.75	581.81	581.62	581.49	581.29	581.26	581.03
1857	580.83	581.09	581.22	581.68	582.04	582.34	582.76	582.96	582.80	582.86	582.08	582.11
1858	582.04	581.75	581.65	582.19	582.67	583.09	583.49	583.42	583.03	582.90	582.57	582.57
1859	582.08	582.21	582.27	583.26	583.06	583.06	583.72	583.42	583.16	582.83	582.34	582.41

NOTE: All water levels are in feet above National Geodetic Vertical Datum (1929).

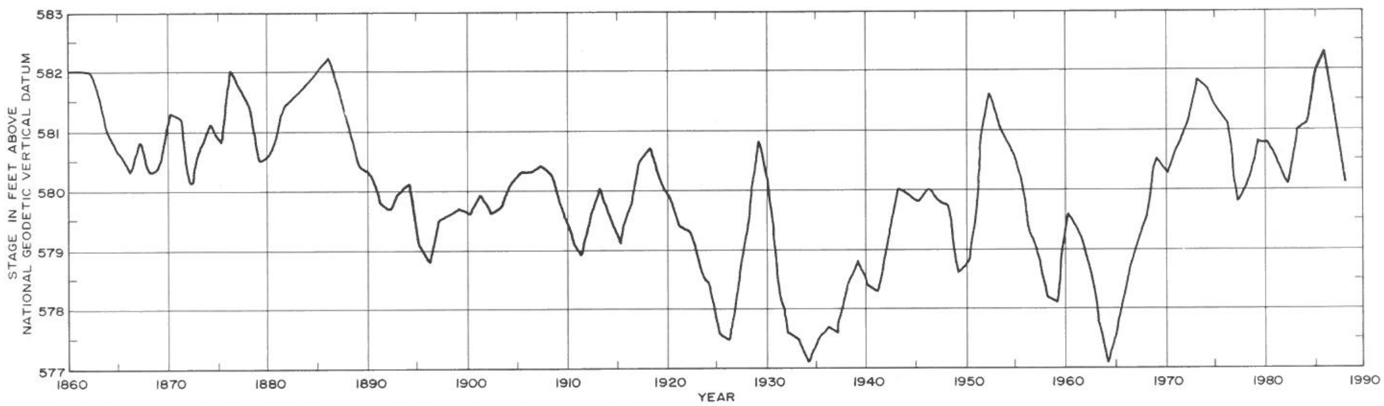
Source: U. S. Deep Waterways Commission (1897); Bishop (1987); and SEWRPC.

From 1906 through 1987, hourly instantaneous water level data were recorded at Milwaukee. Maximum and minimum instantaneous and annual monthly mean water levels at Milwaukee are shown in Figures 2 and 3. A summary of the maximum and minimum instantaneous, daily mean, monthly mean, and annual mean water levels recorded over the period 1906 through 1987 is presented in Table 3.

The water level data collected at Milwaukee subsequent to 1914 have been subjected to several frequency analyses by both the U. S. Army Corps of Engineers and the Regional Planning Commission. In the frequency analyses, the recorded water levels were adjusted as necessary to represent existing diversion, Lake Superior outflow, and outlet channel and structure conditions. Data collected over the period 1906 through 1914 were not used in the frequency analyses because the Corps of Engineers has not adjusted these data to existing diversion and outlet conditions. The adjustment factors used in the 1977 Open Coast study by the Corps of Engineers were derived by routing the

Figure 1

LAKE MICHIGAN ANNUAL MEAN WATER LEVELS AT MILWAUKEE: 1860-1987



NOTE: ELEVATIONS ARE IN FEET ABOVE NATIONAL GEODETIC VERTICAL DATUM. TO CONVERT TO INTERNATIONAL GREAT LAKES DATUM, SUBTRACT 1.34 FEET.

Source: SEWRPC.

1900 through 1974 net basin supplies through the Great Lakes under existing diversion and outlet conditions. Under the routing procedures utilized by the Corps, the lakes did not fully respond to the outlet and diversion changes until 1915. Thus, pre-1915 data were not adjusted to existing conditions. The statistical procedures for the frequency analyses described in Volume One of SEWRPC Planning Report No. 37 used the adjustment factors calculated by the Corps of Engineers for 1915 through 1974. For 1975 through 1985, the Commission adjusted the water levels to incorporate variable backwater effects from Lakes Erie and St. Clair. The revised flood levels published by the Corps of Engineers in 1988 used new adjustment factors derived by routing the 1900 through 1986 net basin supplies through the Great Lakes under the present diversion and outlet conditions.

The U. S. Army Corps of Engineers presented standardized frequency curves for use in determining design water levels for the Great Lakes.[17] As part of the analyses, water-level rise frequency computations were made using data collected at Milwaukee on an annual, quarterly, and monthly basis. Log Pearson Type III frequency analyses were conducted for the period 1915 through 1974. Recorded water levels were first adjusted to reflect existing diversions, outlets, and regulation schedules. This analysis resulted in a 100-year recurrence interval instantaneous maximum Lake Michigan level of 583.7 feet NGVD.

The water level data collected at Milwaukee were also subjected to several stage-frequency analyses by the Regional Planning Commission to estimate the probability of different lake levels occurring. This analysis utilized a Log Pearson Type III frequency analysis of data taken at four-year intervals in order to avoid potential autocorrelation effects. A prerequisite to the use of normal or log normal probability theory in the development of stage-frequency analyses is that the annual data be independent of one another. Autocorrelation of water levels measures the tendency of a level to be similar to the previous year's—or subsequent year's—level. Autocorrelation analyses of the annual stage series for Lake Michigan at Milwaukee found strong correlations between water levels in adjacent years, and in two-year lags. A four-year lag was found to produce little autocorrelation. The stage-frequency analyses were based on a period of record of 1915 through 1985, with the levels being adjusted for present diversion and outlet conditions as described above. The 10-, 50-, 100-, and

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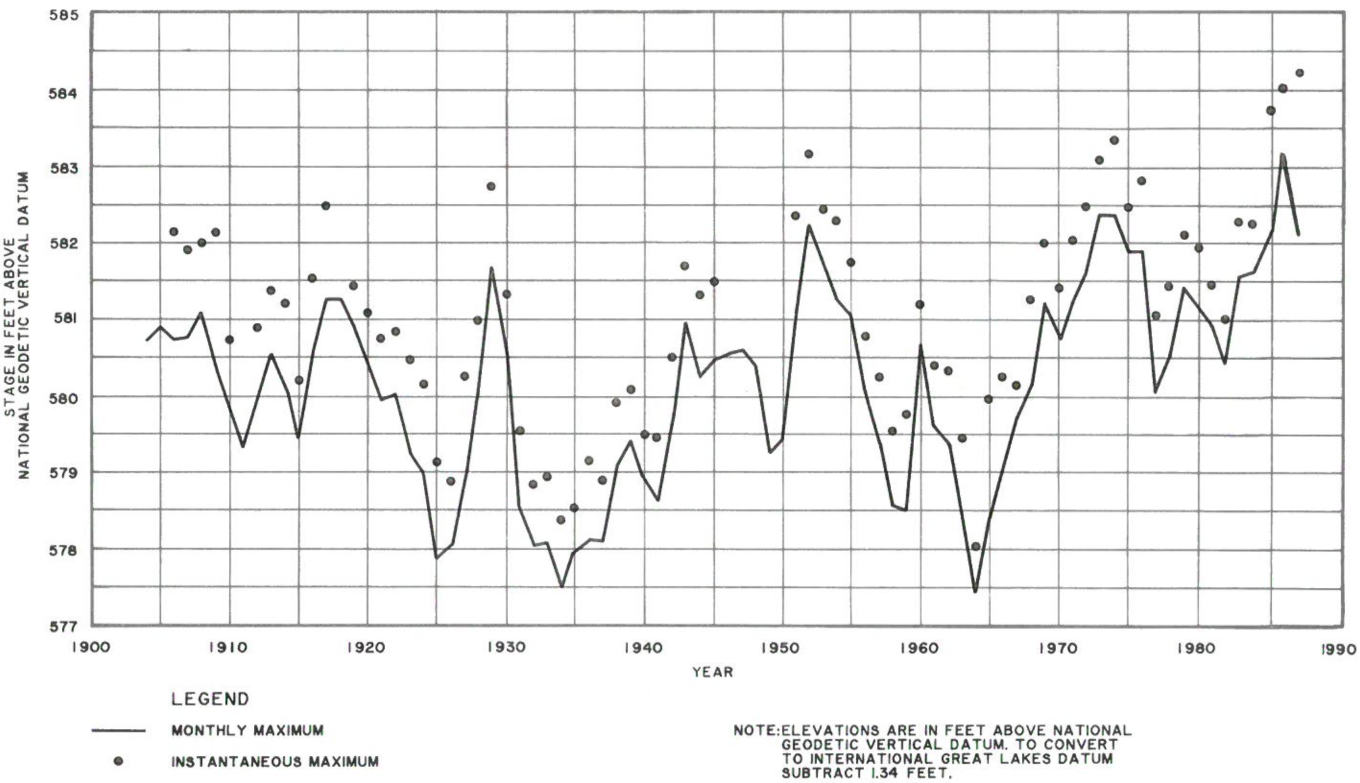
[17]*U. S. Army Corps of Engineers, Standardized Frequency Curves for Design Water Level Determinations on the Great Lakes, Detroit District, 1977.*

Figure 2

LAKE MICHIGAN ANNUAL MONTHLY MAXIMUM AND INSTANTANEOUS MAXIMUM STAGES AT MILWAUKEE: 1906-1987



Source: National Ocean Survey and SEWRPC.

500-year recurrence interval instantaneous maximum water levels for Lake Michigan at Milwaukee estimated by the Regional Planning Commission in SEWRPC Planning Report No. 37 are set forth in Table 4. A 100-year recurrence interval instantaneous maximum lake level of 584.5 feet NGVD was calculated. This level is 0.8 foot higher than the level determined by the Corps in its 1977 analyses. The higher level is probably due to the inclusion of water years in the 1970's and 1980's when the Lake Michigan levels were higher than normal.

The Corps of Engineers recently revised its 10-, 50-, 100-, and 500-year recurrence interval flood levels for the Great Lakes for the Federal Emergency Management Agency.[18] The analysis represented an update of the 1977 analysis described above, and used hourly instantaneous water level data from 1915 through 1986 collected at Milwaukee. The water levels were adjusted for present diversion and outlet conditions.

The Corps statistical analyses addressed frequency distributions, autocorrelation of the data, and regional skew values. The Pearson Type III frequency distribution was used for the analysis. Skew measures the distribution of the magnitude of the water levels. The Corps performed an extensive analysis of regional skew characteristics of the data and recommended that a skew of 0.2 foot be used for Lakes Michigan-Huron. This positive skew results in a greater frequency of extreme high water levels than if a skew of zero is used. The use of the recommended skew in the frequency analyses

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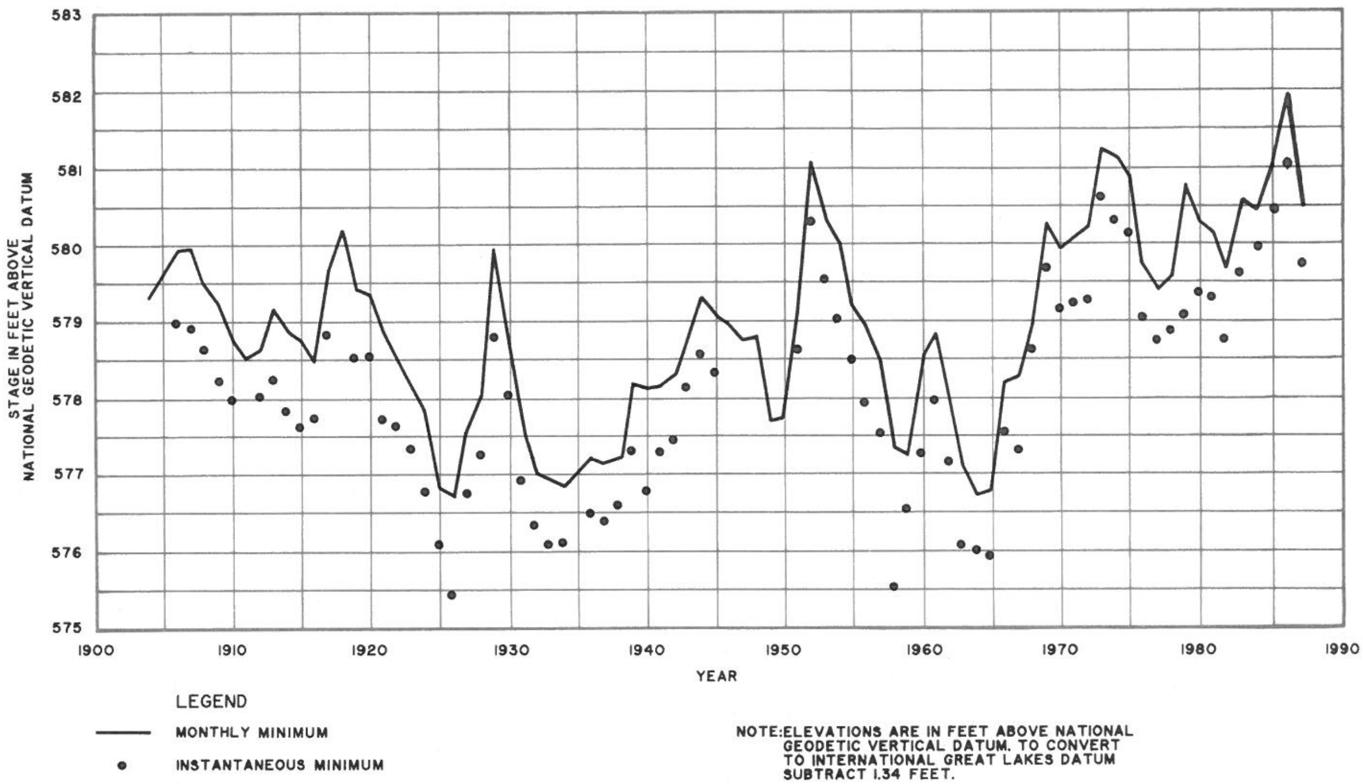
[18] *U. S. Army Corps of Engineers, Revised Report on Great Lakes Open-Coast Flood Levels, Phase I, Detroit, Michigan, 1988.*

Figure 3

LAKE MICHIGAN ANNUAL MONTHLY MINIMUM AND INSTANTANEOUS MINIMUM STAGES AT MILWAUKEE: 1906-1987



Source: National Ocean Survey and SEWRPC.

Table 3

MAXIMUM AND MINIMUM LAKE MICHIGAN WATER LEVELS AT MILWAUKEE, WISCONSIN: 1906-1987

Water Level	Maximum (feet)			Minimum (feet)		
	Date	IGLD	NGVD	Date	IGLD	NGVD
Instantaneous	March 9, 1987	583.0	584.3	January 23, 1926	574.2	575.5
Daily Mean	October 4, 1986	582.2	583.6	January 27, 1964	575.0	576.4
Monthly Mean	October 1986	581.9	583.2	February 1964	575.4	576.8
Annual Mean	1986	581.2	582.5	1964	575.8	577.1

NOTE: IGLD - International Great Lakes Datum (1955).
NGVD - National Geodetic Vertical Datum (1929).
At Milwaukee, NGVD = IGLD + 1.34, as determined by first order leveling by SEWRPC.

Source: National Oceanic and Atmospheric Administration and SEWRPC.

resulted in the 100-year recurrence interval flood levels being 0.1 to 0.2 foot higher than if a skew of zero had been used. Lakes Michigan-Huron showed the greatest autocorrelation in the yearly data of all of the Great Lakes. However, the Corps concluded that the effect of autocorrelation on the frequency distributions was insignificant because frequency distributions of even and odd year data were not materially different from the frequency distributions of the complete record of data.

The new Corps of Engineers flood levels for the sections of the Lake Michigan shoreline in southeastern Wisconsin—as shown on Map 2—are set forth in Table 5. The flood levels, or instantaneous maximum levels, developed by the Corps are essentially the same—within 0.2 foot—as the levels developed by the Regional Planning Commission using data from 1915 through 1985 for all recurrence intervals. As shown by comparison of Tables 4 and 5, the 10- and 500-year recurrence interval instantaneous maximum levels are within 0.1 foot of the levels estimated by the Regional Planning Commission. The 50-year and 100-year recurrence interval levels determined by the Corps are within 0.2 foot of the levels estimated by the Regional Planning Commission. The new Corps of Engineers values thus essentially confirm those developed by the Regional Planning Commission as published in 1987.

The Regional Planning Commission performed a frequency analysis of instantaneous minimum water levels using the same procedures used by the Corps of Engineers for the maximum water level analysis. Table 6 presents 10-, 50-, 100-, and 500-year recurrence interval minimum instantaneous water levels for Milwaukee based on a period of record of 1915 through 1986. Ninety percent confidence intervals are also presented in the table.

Table 4

INSTANTANEOUS MAXIMUM WATER LEVELS FOR VARIOUS RECURRENCE INTERVALS FOR LAKE MICHIGAN AT MILWAUKEE, WISCONSIN AS DEVELOPED BY SEWRPC[a]

Recurrence Interval (years)	Instantaneous Maximum Water Level (feet)	
	IGLD	NGVD
10	581.6	582.9
50	582.8	584.1
100	583.2	584.5
500	584.0	585.3

NOTE: IGLD - International Great Lakes Datum (1955).
NGVD - National Geodetic Vertical Datum (1929).
At Milwaukee, NGVD = IGLD + 1.34, as determined by first order leveling by SEWRPC.

[a]*Based on a period of record of 1915 through 1985.*

Source: SEWRPC.

LAKE LEVEL ESTIMATES BASED ON LONG-TERM GEOLOGICAL AND ARCHAEOLOGICAL EVIDENCE AND MATHEMATICAL MODELING ANALYSES

Because of the relatively short period of record available for use in statistical stage-frequency analyses, it is desirable to compare projected lake levels based upon the statistical analyses to historic and prehistoric lake levels as determined from archaeological and geological evidence, and to the results of mathematical modeling analyses conducted under certain hydraulic, hydrologic, and climatological assumptions.

Geological evidence is believed by some to indicate that within the last 1,500 years, there have been at least three episodes in which Lake Michigan water levels have substantially exceeded the 1986 record high annual mean lake level of 582.5 feet NGVD. Interpretation of such evidence is a complex and uncertain process given the crustal movement taking place in the Great Lakes area, and because of the uncertainties inherent in radiocarbon dating. As shown in Table 7, these episodes are believed to have occurred sometime during each of three periods: from 480 to 610 AD, 1000 to 1150 AD, and 1580 to 1720 AD.[19] The lake level estimates set forth in the table, which are based upon radiocarbon-dated stratigraphic studies of a beach ridge complex located along the southwestern shore of Lake Michigan, indicate that maximum levels over the past 1,500 years may have historically ranged from

[19]*Curtis E. Larsen, op. cit.*

one to nearly eight feet above the record high 1986 annual mean lake level.

Other researchers have concluded, however, based upon historical archaeological and geobotanical information generally more recent than Larsen's data, that the water levels of Lake Michigan during the seventeenth and eighteenth centuries and dating as far back as the 1640's were not significantly different from those recorded in the nineteenth and twentieth centuries. Bishop[20] concluded that the overall variation in the mean annual levels of Lake Michigan over the past 350 years has not differed substantially from the variation in levels recorded since 1860.

A recent study of historical summer—June and July—water supplies to the Great Lakes reconstructed from tree ring data concluded that variations in net basin supplies to the Great Lakes in the late eighteenth century and in the nineteenth century were similar to those that have been recorded in the twentieth century.[21] Although data presented in the study indicated the net basin supplies to some of the Great Lakes in the eighteenth and nineteenth centuries were at times greater than those that occurred in the twentieth century, the Lake Michigan peak net basin supplies were similar in the eighteenth, nineteenth, and twentieth centuries. The study identified a strong correlation between the individual Great Lakes in net basin supplies; i.e., there was a tendency for all of the lakes to have high supplies at the same time.

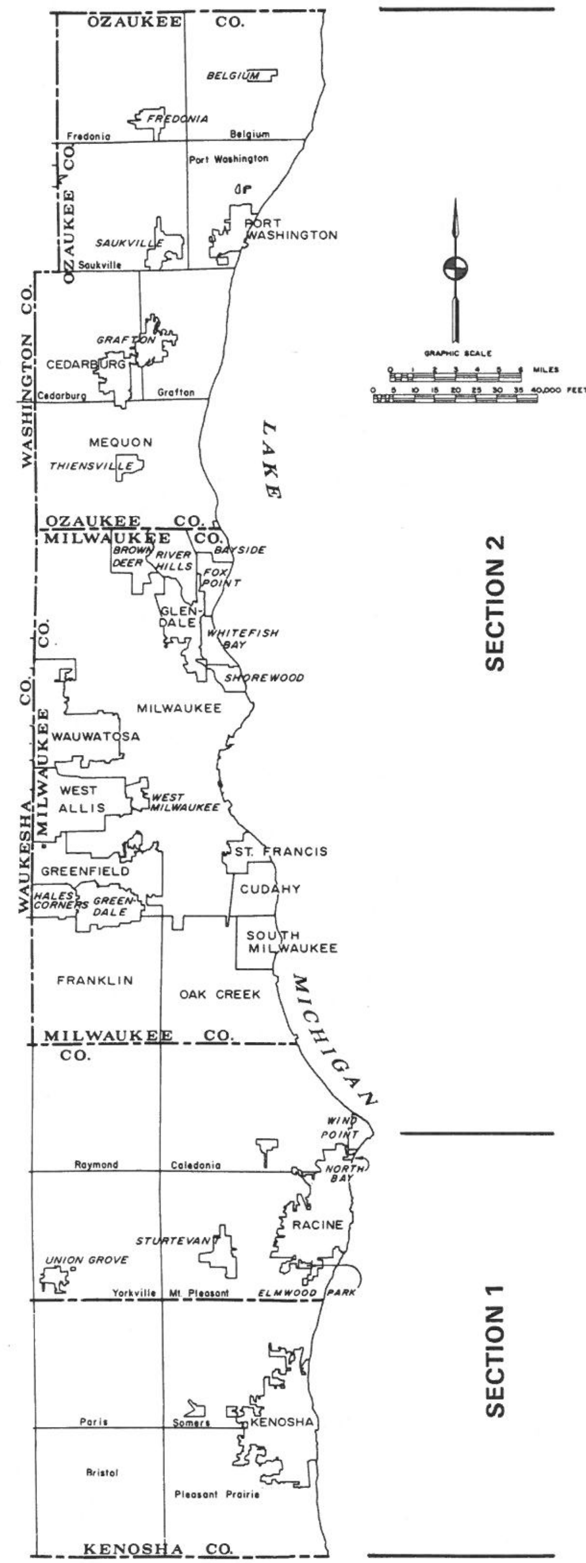
Because of the uncertainty associated with the geological evidence indicating that Lake Michigan levels could rise substantially above the high lake levels recorded in the early 1980's, the Regional Planning Commission conducted an analysis of possible future lake levels, assuming Lake Michigan to be in a long-term rising trend. These analyses, which were presented in SEWRPC Planning Report No. 37, concluded that there was a 50 percent probability that a

[20]*Bishop, op. cit.*

[21]*W. A. R. Brinkman, "Water Supplies to the Great Lakes-Reconstructed from Tree-Rings," Journal of Climate and Applied Meteorology, Vol. 26, No. 4, April 1987, pp. 530-538.*

Map 2

LAKE MICHIGAN SECTIONS IN SOUTHEASTERN WISCONSIN FOR U. S. ARMY CORPS OF ENGINEERS FLOOD LEVELS: 1988



Source: U. S. Army Corps of Engineers and SEWRPC.

Table 5

U. S. ARMY CORPS OF ENGINEERS FLOOD LEVELS FOR THE LAKE MICHIGAN SHORELINE OF SOUTHEASTERN WISCONSIN: 1988

		Instantaneous Maximum Water Levels (feet NGVD)							
		10-Year		50-Year		100-Year		500-Year	
Section	General Location	Level	90 Percent Confidence Interval	Level	90 Percent Confidence Interval	Level	90 Percent Confidence Interval	Level	90 Percent Confidence Interval
1[a]	Kenosha-Racine	583.1	582.8-583.5	584.2	583.8-584.7	584.6	584.1-585.2	585.6	585.0-586.3
2	Milwaukee-Port Washington	582.8	582.5-583.2	583.9	583.5-584.4	584.3	583.8-584.9	585.2	584.6-585.9

[a]Confidence intervals for Section 1 were not estimated by the U. S. Army Corps of Engineers because no water level gaging stations were located within the section. Therefore, the confidence intervals shown for Section 1 were interpolated by the Regional Planning Commission staff using confidence intervals calculated for the Milwaukee (Wisconsin) and Calumet Harbor (Illinois) gaging stations. Confidence intervals for Section 2 were calculated by the Corps of Engineers.

Source: U. S. Army Corps of Engineers and SEWRPC.

Table 6

INSTANTANEOUS MINIMUM WATER LEVELS FOR LAKE MICHIGAN AT MILWAUKEE[a]

Recurrence Interval (feet NGVD)							
10-Year		50-Year		100-Year		500-Year	
Level	90 Percent Confidence Interval	Level	90 Percent Confidence Interval	Level	90 Percent Confidence Interval	Level	90 Percent Confidence Interval
576.2	575.9-576.6	575.1	574.7-575.6	574.9	574.4-575.5	574.3	573.8-575.1

[a]Based on a period of record of 1915 through 1986.

Source: SEWRPC.

two-foot rise could occur, and a 10 percent probability that a four-foot rise could occur within the next 50 years under the assumption that Lake Michigan is in a long-term rising trend.

Mathematical simulation models may be used to estimate the potential for water level variations in response to a range of climatic conditions. The hydrologic response model developed by the Great Lakes Environmental Research Laboratory of the National Oceanic and Atmospheric Administration was used by the Research Laboratory to examine the potential lake level response to continued high water supplies for a 20-year period under four different scenarios: 1) a continuation of the recorded maximum monthly net basin supplies; 2) a 75 percent increase in the 1900 through 1985 mean net basin supplies; 3) a 50 percent increase in the 1900 through 1985 mean net basin supplies; and 4) a 25 percent increase in the 1900 through 1985 mean net basin supplies.[22] This 20-year period used for the modeling allowed the lakes to reach equilibrium and fully respond to the net basin supplies.

The lake levels estimated by applying the hydrologic response model are set forth in Table 8. The study noted that in order to raise Lake Michigan about three feet above its October 1986 record monthly level, net basin supplies, including Lake Superior outflows, would need to be increased by 50 percent above the long-term—1900 to 1985—average. Bishop concluded that, based on Hartmann's modeling results, an elevation of 583.7 NGVD could be considered a realistic maximum monthly level of Lake Michigan over the next 50 years.[23] Assuming an increase in elevation of 2.0 feet for wind setup and seiche, this would result in an instantaneous maximum level of about 585.7 feet NGVD.

Table 7

ESTIMATED LAKE MICHIGAN WATER LEVELS BASED ON GEOLOGICAL EVIDENCE

Period	Water Level (feet)	
	IGLD	NGVD
480-610 AD	582.3-589.2	583.6-590.5
1000-1150 AD	584.6-588.3	585.9-589.6
1580-1720 AD	584.6-588.3	585.9-589.6

NOTE: IGLD - International Great Lakes Datum (1955).
NGVD - National Geodetic Vertical Datum (1929).
At Milwaukee, NGVD = IGLD + 1.34, as determined by first order leveling by SEWRPC.

Source: Curtis. E. Larsen, Report presented at the Colloquium on Great Lakes Levels, Water Science and Technology Board of the National Research Council, Chicago, Illinois, March 17-18, 1988.

Bishop's realistic maximum level was based upon the results of modeled scenarios intermediate between those associated with persistent net basin supplies which are 25 percent above the long-term average and those of 1985. He considered anything more extreme as being unrealistic. However, while the precipitation in 1985 and 1986 was the highest of this century, the wettest recorded period in the Great Lakes region occurred in the mid-1870's to early 1880's.[24] If those climatic conditions recur, net basin supplies and lake levels could be even higher than occurred in the last century, owing to changed basin hydrology caused by urbanization and agricultural drainage.

Ultimately, any approach for estimating future lake levels based only on past levels or past net basin supplies limits consideration of basin hydrology, basin moisture storage conditions, heat storage in the lake which affects evaporation, and realistic meteorologic variability. These recently developed models enable consideration of the component hydrologic and meteorologic processes, and examination of the impacts of possible basin and meteorologic scenarios. However, because of the inherent limitations of the models, such results must be considered in combination with statistical analyses and geological and archaeological evidence.

Researchers at the National Oceanic and Atmospheric Administration Great Lakes Environmental Research Laboratory have expressed concern that a climatic warming resulting from an increase in carbon dioxide and other gases in the atmosphere could result in a 15 to 30 percent decrease in the average net basin water supplies to the Great Lakes.[25] This climatic warming is generally referred

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[22]*Hartmann, op. cit.*

[23]*Bishop, op. cit.*

[24]*Holly C. Hartmann, Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, Letter to Mr. Kurt W. Bauer, Executive Director, Southeastern Wisconsin Regional Planning Commission, June 20, 1988.*

[25]*Frank H. Quinn, Likely Effects of Climate Changes on Water Levels in the Great Lakes, Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration. Presented at the First North American Conference on Preparing for Climate Change: A Cooperative Approach, Washington, D. C., October 27-29, 1987.*

Table 8

LAKE MICHIGAN MONTHLY MAXIMUM MEAN WATER LEVELS ESTIMATED WITH A HYDROLOGIC RESPONSE MODEL ASSUMING INCREASED NET BASIN WATER SUPPLIES

Net Basin Supply Scenario	Water Level (feet)	
	IGLD	NGVD
1. A continuation of the recorded maximum monthly net basin supplies	593.4	594.7
2. An increase in the 1900 through 1985 mean net basin supplies by 75 percent	587.3	588.6
3. An increase in the 1900 through 1985 mean net basin supplies by 50 percent	584.6	585.9
4. An increase in the 1900 through 1985 mean net basin supplies by 25 percent	581.7	583.0

NOTE: IGLD - International Great Lakes Datum (1955).
NGVD - National Geodetic Vertical Datum (1929).

Source: Holly C. Hartmann, Potential Variation of Great Lakes Water Levels: A Hydrologic Response Analysis, Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan, 1987.

to as the "greenhouse effect." Based on hydrologic simulation modeling results, this decrease in net basin water supplies may be expected to result in a 2.5- to 5.0-foot decline in the average twentieth century Lake Michigan water levels. It was also reported that the annual variability of water levels may be expected to decline from 4 to 11 percent. Since the variability, and thus the range, of water levels would decrease, extreme minimum water levels may be expected to decline by less than the 2.5- to 5.0-foot decline provided for overall water levels, while extreme maximum water levels may be expected to decline by more than 2.5 to 5.0 feet. Therefore, the 100-year recurrence interval instantaneous minimum water level of 574.9 feet NGVD presented in Table 6 may be expected to decline by less than 2.5 to 5.0 feet.

A second, and more recent study conducted at the Great Lakes Environmental Research Laboratory has refined the estimated impacts of the "greenhouse effect."[26] The evaluation of three meteorologic modeling scenarios indicated that the higher air temperatures associated with doubling the carbon dioxide content of the atmosphere would result in higher evapotranspiration rates, lower stormwater runoff volumes, and earlier runoff peaks. The study concluded that net basin supplies to the Great Lakes could decline by 25 to 50 percent. Under the scenarios evaluated, Great Lakes water levels could be expected to decline by 2.5 to 8.0 feet.

Further analysis of the "greenhouse effect" should more clearly define the climatic warming which may be expected to occur over relatively small areas such as the Great Lakes drainage basin. It is also likely that any warming that does occur will be small initially, then escalate later in the twenty-first century. Thus, several periods of extreme high lake levels could occur even if long-term average lake levels are declining.

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[26] *Thomas E. Croley II and Holly C. Hartmann, Effects of Climatic Changes on the Laurentian Great Lakes Levels, Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, Ann Arbor, Michigan, Draft Report, August 1988.*

SELECTION OF WATER LEVELS FOR USE IN PLANNING AND DESIGN

A summary of the various lake levels discussed in this report is presented in Table 9 and Figure 4. While the lake level estimates presented herein suggest that lake levels up to six feet above the recently estimated 100-year recurrence interval lake level of 584.3 feet NGVD may be possible, it is considered extremely unlikely that the long-term net basin water supplies will ever be increased enough to produce these extremely high lake levels. Review of recent simulation modeling data indicates that lake levels could, in fact, become significantly lower than the historical long-term average.

For the Milwaukee County shoreline erosion management study,[27] five Lake Michigan water levels were selected for use in the wave modeling analyses to evaluate the performance of existing and proposed shore protection structures under various water level conditions. These selected water levels are set forth in Table 10. The first water level used in the analyses provided an upper bound in potential high lake levels. For this level, the upper 90 percent confidence limit of the 500-year recurrence interval instantaneous water level calculated by the U. S. Army Corps of Engineers in 1988, 585.9 feet NGVD, was selected.

The second water level selected for analysis, 584.3 feet NGVD, was recorded on March 9, 1987, and included a seiche and wind setup of 2.5 feet. The storm of March 9, 1987, was used for model verification by comparing the model results to observed wave conditions as shown in records and photographs taken by the Port of Milwaukee staff and in television news video tapes. This is also the same level as the new U. S. Army Corps of Engineers 100-year flood stage and essentially the same as the recommended regulatory 100-year recurrence interval instantaneous maximum stage developed by the Regional Planning Commission in 1987.

The third water level used in the analyses was the U. S. Army Corps of Engineers 10-year recurrence interval instantaneous maximum water level of 582.8 feet NGVD calculated in 1988, which is essentially the same—within 0.1 foot—as the revised 10-year recurrence interval instantaneous maximum lake level developed by the Regional Planning Commission in 1987. This lower lake level was useful for evaluating minor shore protection structures that are not protecting major facilities or public works improvements.

These three maximum instantaneous water levels represent a reasonable range of conditions appropriate for evaluating the performance of existing and proposed onshore and offshore protection structures. Each of these lake levels, together with 20-year and 50-year recurrence interval storm wave conditions, was used to evaluate shore protection structures in Milwaukee County.

Consideration was also given to two potential low water elevations. The first low water level considered was the 100-year recurrence interval minimum monthly mean level of 575.5 feet NGVD as developed by the Regional Planning Commission. A monthly low water level was selected since the impacts on structures due to exposure of normally submerged components, such as timber pilings, would be more severe under longer term periods. This monthly mean level is approximately 1.3 feet lower than the minimum monthly mean recorded lake level presented in Table 3. In this respect, the first low water level may represent the potential impacts of the "greenhouse effect," since the Great Lakes Environmental Research Laboratory studies indicated a potential 2.5- to 5.0-foot or more decline in overall Lake Michigan water levels as a result of the "greenhouse effect."

A second low water level considered was the 100-year recurrence interval instantaneous minimum level of 574.9 feet NGVD calculated by the Regional Planning Commission. This level is appropriate for the consideration of potential impacts, such as toe scouring, which can be aggravated by extremely low water levels. This level is within 1.1 feet of the lower limit of the 90 percent confidence level for the 500-year recurrence interval instantaneous minimum level and thus can be considered to be near the "worst case" low water level condition. Figure 5 summarizes the water levels used to evaluate existing and proposed shore protection structures under the Milwaukee County shoreline erosion management plan.

[27] *SEWRPC, 1989, op. cit.*

Table 9

COMPARISON OF LAKE MICHIGAN WATER LEVELS DEVELOPED BY VARIOUS SOURCES

Instantaneous Water Levels	Monthly Average Water Levels	Annual or Long-Term Average Water Levels	Source
Maximum			
- -	594.7	- -	Hartmann 1987; Continuous Monthly Maximum Record Net Basin Supplies
- -	- -	590.5	Larsen 1988; Geologic Evidence 480-610, Upper Limit
- -	- -	589.6	Larsen 1988; Geologic Evidence 1000-1150 and 1580-1720, Upper Limit
- -	588.6	- -	Hartmann 1987; Increase Monthly Net Basin Supplies by 75 Percent
585.9	- -	- -	U. S. Army Corps of Engineers 1988; 500-year, Upper 90 Percent Confidence Level
- -	585.9	- -	Hartmann 1987; Increase Monthly Net Basin Supplies by 50 Percent
- -	- -	585.9	Larsen 1988; Geologic Evidence 1000-1150 and 1580-1720, Lower Limit
585.3	- -	- -	SEWRPC 1988; 500-year Level
584.9	- -	- -	U. S. Army Corps of Engineers 1988; 100-year, Upper 90 Percent Confidence Level
- -	- -	584.7	Bishop 1987; Archaeological Evidence 1628-1715, Upper Limit
584.5	- -	- -	SEWRPC 1988; 100-year Level
584.4	- -	- -	U. S. Army Corps of Engineers 1988; 50-year, Upper 90 Percent Confidence Level
584.3	- -	- -	National Oceanic and Atmospheric Administration; Maximum Recorded Level: 1906-1987; and U. S. Army Corps of Engineers 1988; 100-year Level
584.1	- -	- -	SEWRPC 1988; 50-year Level
- -	583.7	- -	Bishop 1987; Reasonable Maximum Level Upper Limit for Next 50 years
- -	- -	583.6	Larsen 1988; Geologic Evidence 480-610, Lower Limit
583.2	- -	- -	U. S. Army Corps of Engineers 1988; 10-year, Upper 90 Percent Confidence Level
- -	583.2	- -	National Oceanic and Atmospheric Administration; Maximum Recorded Monthly Mean: 1906-1987
- -	583.0	- -	Hartmann 1987; Increase Monthly Net Basin Supplies by 25 Percent
- -	- -	583.0	Bishop 1987; Archaeological Evidence, 1628-1715, Lower Limit
582.9	- -	- -	SEWRPC 1988; 10-year Level
- -	- -	582.5	National Oceanic and Atmospheric Administration; Maximum Recorded Annual Mean: 1906-1987

Table 9 (continued)

Instantaneous Water Levels	Monthly Average Water Levels	Annual or Long-Term Average Water Levels	Source
Minimum			
- -	- -	577.1	National Oceanic and Atmospheric Administration; Minimum Recorded Annual Mean: 1906-1987
- -	576.8	- -	National Oceanic and Atmospheric Administration; Minimum Recorded Monthly Mean: 1906-1987
575.9	- -	- -	SEWRPC 1988; 10-year, Lower 90 Percent Confidence Level
575.5	- -	- -	National Oceanic and Atmospheric Administration; Minimum Recorded Level: 1906-1987
574.7	- -	- -	SEWRPC 1988; 50-year, Lower 90 Percent Confidence Level
574.4	- -	- -	SEWRPC 1988; 100-year, Lower 90 Percent Confidence Level
- -	574.3	- -	Quinn 1987; Decrease Monthly Net Basin Supplies by 15 Percent
573.8	- -	- -	SEWRPC 1988; 500-year, Lower 90 Percent Confidence Level
- -	571.7	- -	Quinn 1987; Decrease Monthly Net Basin Supplies by 30 Percent

NOTE: All water levels are in feet above National Geodetic Vertical Datum (1929).

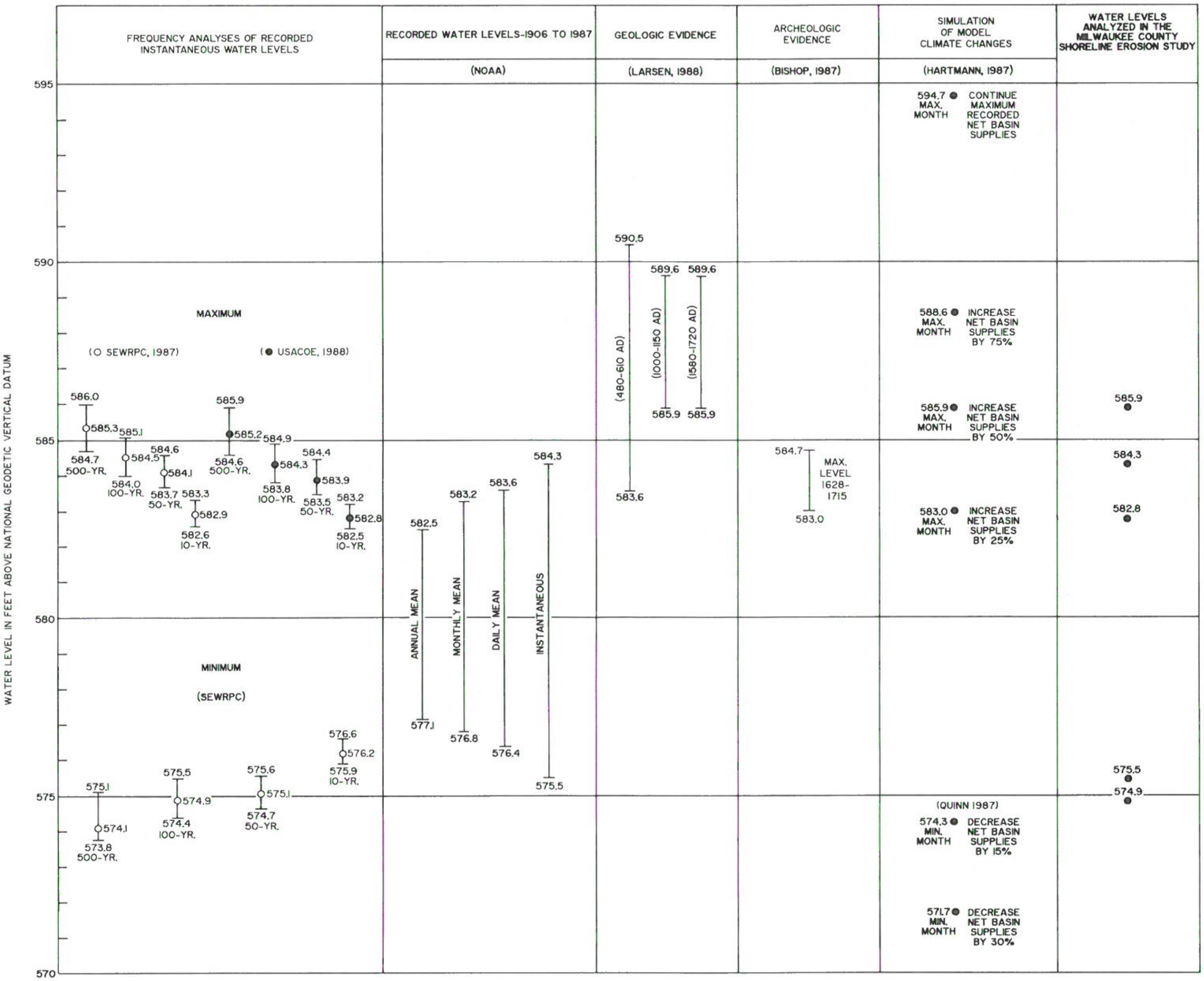
Source: SEWRPC.

CONCLUSION

Proper management of the Lake Michigan shoreline and the proper planning, design, and construction of private and public works in the area along that shoreline require definitive knowledge of the lake levels and storm conditions which may occur. Such knowledge is necessary for the proper evaluation of existing shore erosion, bluff recession, and stormwater drainage problems, and for the exercise of sound land use regulations such as zoning, official mapping, and land subdivision control along the shoreline. Such knowledge is also necessary for the design, among other private and public works, of offshore as well as onshore structures to abate storm damage and shoreline erosion and bluff recession; of navigation improvements and related channel and harbor dredging projects; of street and highway and park improvements in the shoreline area; and of separate and combined sanitary and storm sewers in the shoreline area. In such design, it is necessary to consider a range of both high and low lake level conditions. High lake levels are always an important consideration in the design of both onshore and offshore structures and can have a significant impact on bluff stability. Furthermore, extreme high lake levels can impact the capacity and operation of utility systems such as separate and combined sanitary and storm sewer systems. Low lake levels can have an impact on navigation and, in some cases, on the stability of structure foundations.

Figure 4

LAKE MICHIGAN WATER LEVELS DEVELOPED BY VARIOUS SOURCES



Source: SEWRPC.

As part of the work required for the preparation of the Lake Michigan shoreline erosion management plan for Milwaukee County, the Regional Planning Commission developed a range of lake levels for use in evaluating the performance of shore protection structures in Milwaukee County, Wisconsin. The range of lake levels developed was based upon careful consideration of recorded water level data, statistical analysis of such data, geological and archaeological evidence of previous water levels, and the results of hydrologic and hydraulic simulation modeling.

The lake levels developed include a 100-year recurrence interval instantaneous minimum water level of 574.9 feet above National Geodetic Vertical Datum (NGVD); a 100-year recurrence interval minimum monthly mean water level of 575.5 feet NGVD; a 10-year recurrence interval instantaneous

Table 10

LAKE MICHIGAN WATER LEVELS USED TO EVALUATE THE PERFORMANCE OF EXISTING AND PROPOSED SHORE PROTECTION MEASURES IN MILWAUKEE COUNTY

Description	Water Level (feet)	
	IGLD	NGVD
1. The upper 90 percent confidence limit of the 500-year recurrence interval instantaneous maximum water level (also represents the instantaneous maximum level assuming a two-foot increase in overall water levels under the scenario whereby Lake Michigan is in a long-term rising trend)	584.6	585.9
2. 100-Year Recurrence Interval Instantaneous Maximum Water Level (also represents March 9, 1987, storm event)	583.0	584.3
3. 10-Year Recurrence Interval Instantaneous Maximum Water Level	581.5	582.8
4. 100-Year Recurrence Interval Minimum Monthly Mean Water Level	574.2	575.5
5. 100-Year Recurrence Interval Instantaneous Minimum Water Level	573.6	574.9

NOTE: IGLD - International Great Lakes Datum (1955).
NGVD - National Geodetic Vertical Datum (1929).

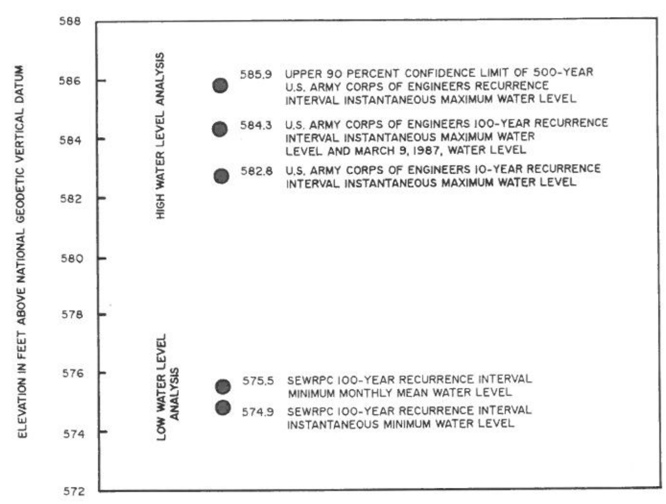
Source: SEWRPC.

maximum water level of 582.8 feet NGVD; and a 100-year recurrence interval instantaneous maximum high level of 584.3 feet NGVD, the same level as was recorded on March 9, 1987. The extreme high level represents the upper 90 percent confidence level of the 500-year recurrence interval instantaneous maximum water level and is estimated at 585.9 feet NGVD.

These levels were developed as a guide to property owners, engineers, and contractors engaged in and responsible for planning, designing, constructing, and maintaining shore protection structures. In addition, these levels should be considered in the development of channel improvement and dredging projects and of marina facilities; in the design of selected separate or combined sanitary and storm sewers; in the design of flood control and storm damage abatement works; and in the design of street and highway and park improvements in the shoreline area, as well as in the application of land use control measures in that area and in the establishment of street and building grades.

Figure 5

LAKE MICHIGAN WATER LEVELS USED TO EVALUATE THE PERFORMANCE OF EXISTING AND PROPOSED SHORE PROTECTION STRUCTURES UNDER THE MILWAUKEE COUNTY SHORELINE EROSION MANAGEMENT PLAN



Source: SEWRPC.

LAKE LEVELS AND DATUM DIFFERENCES

By Kurt W. Bauer,[1] SEWRPC Executive Director

INTRODUCTION

In engineering surveying, elevation is defined as the vertical distance above a known datum or reference surface. While definitive elevations are required for the proper design of most engineering structures, such elevations are particularly critical for the design of hydraulic structures, such as sanitary and storm sewers, stormwater drainage channels, water supply pipe lines, pumping stations, harbor facilities, and shoreline erosion control structures. Elevations are also required for the proper delineation of flood hazard areas and the regulation of land use development in relation to such hazard. Leveling is the surveying operation for determining the elevation of different points below, on, or above the ground. The determination of elevation is one of the simplest surveying concepts when considering low accuracy, short lines, small areas, or small differences in elevation, but one of the most difficult when considering high accuracy, long lines, large areas, or large differences in elevation.

The planning and design of engineering structures and the administration of land use regulations, with respect to the Lake Michigan shoreline in southeastern Wisconsin, require careful consideration of the elevation of various possible lake levels, of the elevation of the shoreline, and of the elevation of existing and proposed engineering structures in both the on and offshore areas. Such consideration is complicated by the fact that a number of different reference surfaces are in use for the determination of elevations. The mean water level of Lake Michigan is one of the reference surfaces so used.

BASIC CONCEPTS

Good engineering practice would dictate that elevations be determined relative to mean sea level. Conceptually, mean sea level is the level that the oceans would take if all currents and tides ceased to exist.[2] It is projected under the land surface. Also conceptually, mean sea level is an equipotential surface—that is, a surface on which measurements of the force of gravity would all produce the same value. In this respect, it should be noted that local mean sea levels at different locations may not be on the same equipotential surface owing to differences in water densities, atmospheric pressures, and water currents, among other factors. As a level surface, mean sea level is everywhere perpendicular to the direction of gravity and is, therefore, a curved surface approximating the geoid, and therefore ellipsoids of reference fitted to the geoid, a fact which may appear counter-intuitive. In engineering surveying it is necessary to distinguish between level surfaces and horizontal surfaces, the former being geoidal or ellipsoidal and the latter plane. Elevations are determined by measuring vertical distances between level and not horizontal surfaces. Since instruments equipped with plumb lines, pendulums, and spirit levels define horizontal surfaces, direct instrumental measurements of

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[1]*Special acknowledgement is due Mr. Harry A. Lippencott, Chief, Great Lakes Acquisition Unit, Office of Oceanography and Marine Assessment, and Mr. David B. Zilkoski, Chief, Vertical Network Branch, National Geodetic Survey, Office of Charting and Geodetic Services, Physical Oceanography Division, National Ocean Service, National Oceanic and Atmospheric Administration, U. S. Department of Commerce, for their review of, comment on, and contribution to this article.*

[2]*A technically more precise definition of mean sea level is the average location of the interface between ocean and atmosphere over a period of time sufficiently long so that all random and periodic variations of short duration average to zero. The National Geodetic Survey has set this period of time with respect to the use of tide gages at 19 years.*

differences in elevation must be corrected for the curvature of the datum surface in order to obtain true elevations; or, as in precise leveling, fore and back sights must be balanced to eliminate the effect of this curvature.

Because of the eccentricity of the earth—that is, its ellipsoidal shape—and gravity field irregularities, the vertical distance between equipotential surfaces varies—that is, the level surfaces are not "parallel." The vertical distance from mean sea level to any point below, on, or above the earth's surface is known as its orthometric height and is determined by applying an orthometric height correction to observed differences in elevation as determined by the use, for example, of a spirit level. The orthometric height correction is a function of the gravitation force which, in turn, is related to the elevation, latitude, and longitude of a point, and to the distribution of the earth's mass with respect to that point.

DATUMS IN USE WITHIN THE REGION

Although the Regional Planning Commission has for more than 27 years recommended the use of the National Geodetic Vertical Datum of 1929 (NGVD 1929)—formerly known as Mean Sea Level Datum of 1929—as the basis for all elevations within the Region, there are still a large number of local datums in use within the Region, some of these being entirely arbitrary and established utilizing plane surveying techniques. The latter regard plumb, or vertical, lines as parallel lines, and level surfaces as parallel planes, assumptions which are not, of course, in accord with reality. For example, the vertical datum used by the City of Milwaukee is referred to the elevation of the Milwaukee River in March 1836. According to the City Engineer, there is no reference indicating whether the elevation was at low, mean, or high water. Nor is there a specific location identified where the elevation was established. The elevation has been promulgated by bench marks including, historically, a stone monument set in the center of E. Water and Wisconsin Streets, which was 11.5 feet above the referenced water elevation. Currently, the elevation is promulgated by a city bench mark located at the City Hall and by supplementary bench marks located throughout the City.[3] Precise level lines run by the Regional Planning Commission have verified that the zero elevation of the city datum is equal to elevation 580.603 feet above NGVD 1929, as determined by earlier level surveys by the U. S. Coast and Geodetic Survey. Even this value, however, will vary throughout the City because of the uncertainties and errors inherent in leveling surveys.

In spite of the preponderance of engineering opinion that all elevations within the Region should be referred to NGVD 1929, a second major vertical datum is in use within the Region which has particularly important implications for planning and engineering work related to Lake Michigan. That second datum is known as the International Great Lakes Datum of 1955. This datum is referred to mean sea level at the outlet of the Great Lakes-St. Lawrence River system at Pointe-au-Pere (Father Point), Quebec, Canada. This datum replaced a number of other datums which had been used on the Great Lakes prior to 1955 as references for water levels, hydrographic charts, and river and harbor

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[3] *It should be noted that the document entitled "Report of United States Deep Waterways Commission," Government Printing Office, Washington, D. C., 1897, makes reference to original records of Dr. Increase A. Lapham—one time City Engineer—which indicate that "Milwaukee City zero" is low water Milwaukee River, March 1836. This report puts Milwaukee city datum at elevation 580.34. The difference between this value and the currently promulgated value of 580.603 may be attributed to any number of factors, including errors in the transfer of the river elevation to bench marks, errors in the perpetuation of the bench mark elevations over time, and differences in the national datum through adjustments such as the 1929 adjustment.*

improvements, including the U. S. Lake Survey Datum of 1903, the U. S. Lake Survey Datum of 1935, and the Georgian Bay Ship Canal Datum.[4]

Because, as already noted, level surfaces of the earth are not parallel, being farther apart at the equator than at the poles, the orthometric elevation will vary from point to point on a given level surface above the reference surface. This is perceived as a problem with respect to the determination of elevations in relation to large bodies of water like the Great Lakes, since orthometric elevations do not represent the lake surfaces as level and do not give a true hydraulic representation of river slopes. Simply employing instrumental differences to determine elevations is also perceived to be a problem since the elevation of a point determined by an instrument survey made along one route will be different from the elevation of that point determined along a different route.

The situation is further complicated by the crustal movement taking place within the Great Lakes basin. That movement is due to the rebounding, or general uplifting, of the earth's crust after being compressed by the weight of massive continental glaciers thousands of years ago. This crustal movement is occurring at differential rates within the Great Lakes area, the rates being higher in the northeastern than in the southwestern portions of the basin. As a result, water levels are generally increasing relative to the land surface along the eastern shoreline of Lake Michigan south of Green Bay. These changes are relatively gradual. As shown on Map 1, the elevation of the surface of the land in the vicinity of Milwaukee is declining at the rate of about 0.5 foot per century relative to the outlet of the lake. This differential movement of the earth's crust will over time cause water level gages on the Great Lakes to show appreciable differences in water surface elevation until an equilibrium develops.

Because of these perceived problems with the use of orthometric elevations in the Great Lakes basin, the governments of the United States and Canada agreed to establish a dynamic datum for the determination of elevations in the Great Lakes basin. Such a datum expresses the differences in the elevation of points, not in terms of linear measurements, but in terms of the work—expressed in foot-pounds—required to raise a mass of one pound against the force of gravity from the ellipsoid of reference to the level surface in question. Although the dynamic elevations are commonly expressed in feet, it should be understood that in reality the unit of measurement is the foot-pound, the latter being defined as the normal force of gravity on a one-pound mass at sea level at latitude 45 degrees north.

Both the orthometric and dynamic elevations of a point are definite values associated with that point; and, if errors in observation and changes in the elevation of the earth's crust are ignored, redetermination of those values at any time by any method should always yield the same results. As already noted, instrumental differences in the elevation between points, however, are functions not only of the end point but of the routes along which the lines of levels are run. Therefore, instrumental differences can be compared only when the same route is followed in each case.

The use of dynamic elevations has certain advantages when dealing with the Great Lakes system. In crustal movement studies, differences in dynamic elevations from lake to lake may be compared regardless of the route along which the leveling is done. This is also possible with orthometric elevations, but not with instrumental differences. Differences in "true" dynamic elevations give an accurate measure of the potential hydraulic head between two points. This is not true of either orthometric elevations or instrumental differences. Nor is it precisely true for normal dynamic heights because such heights are based upon normal gravity at latitude 45 degrees north. Finally, if the mean

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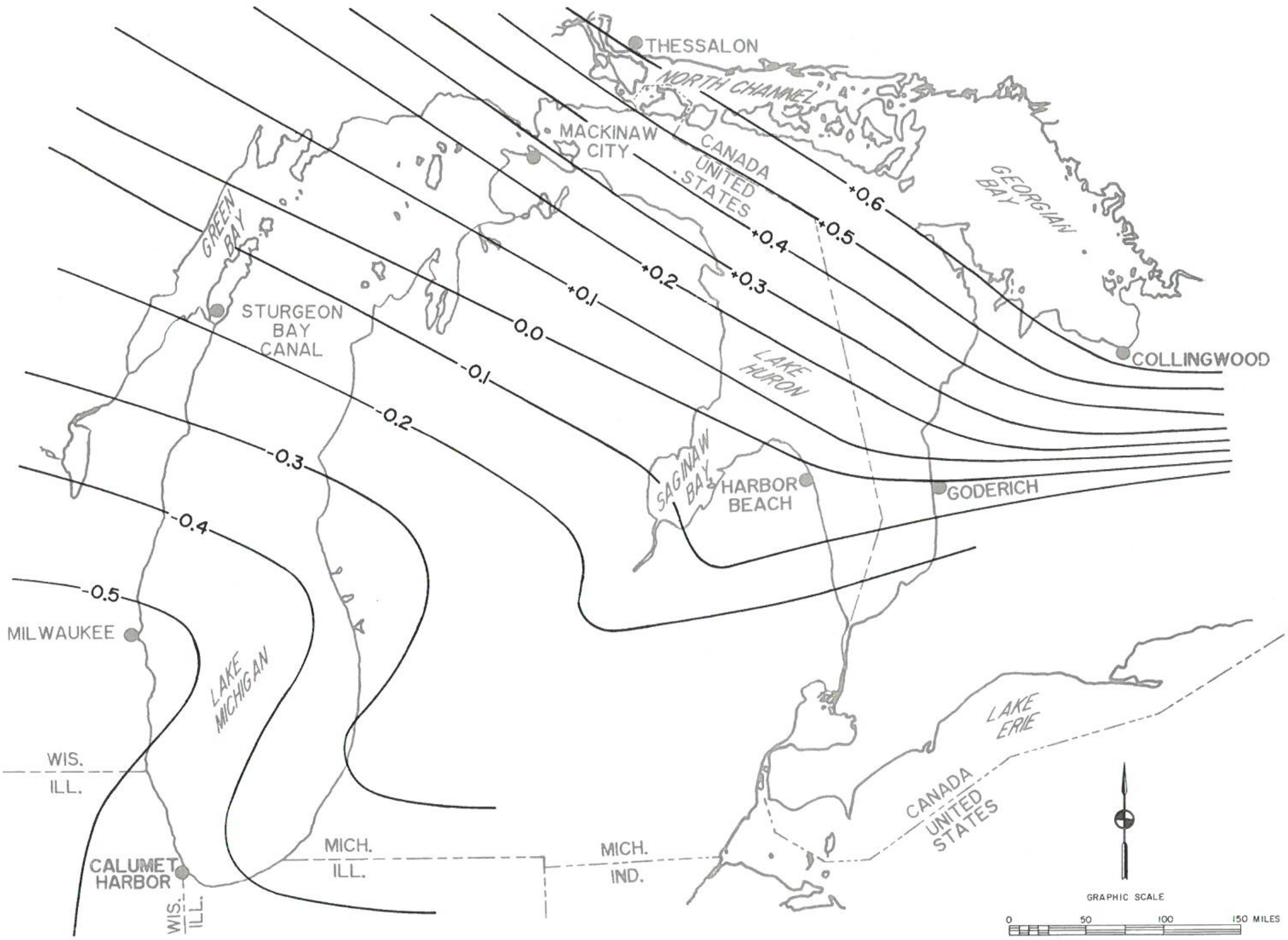
[4] *Because the International Great Lakes Datum was intended to correct for changes in elevation caused by crustal movement, it was intended that the datum be adjusted approximately every 20 years. Such an adjustment is currently being computed by the two federal governments concerned and will produce a new International Great Lakes Datum of 1980.*

Map 1

APPARENT VERTICAL MOVEMENT RATES BETWEEN OUTLET AND SELECTED SITES ON LAKES MICHIGAN-HURON



LEGEND

—+0.5— DENOTES APPARENT RATE OF MOVEMENT IN FEET PER CENTURY RELATIVE TO OUTLET. POSITIVE VALUES INDICATE RISE IN ELEVATION WITH RESPECT TO OUTLET.

Source: "Apparent Vertical Movement Over the Great Lakes," The Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data; Detroit District, U. S. Army Corps of Engineers, July 1977.

surfaces of the Great Lakes are indeed level, every point on those surfaces will have the same dynamic elevation. This is not true of orthometric elevations, nor necessarily of instrumental differences.

The International Great Lakes Datum of 1955 was established by running level lines from Father Point to Lake Ontario; from Lake Ontario to Lake Erie; from Lake Erie to Lake Huron; and from Lake Huron to Lake Superior. The gaps in the level lines were bridged by water level transfers over the lakes concerned, assuming the mean lake surfaces to be level surfaces. The level observations were used to arrive at instrumental elevations for bench marks along the lines. These instrumental values were then converted to orthometric elevations by applying the appropriate correction. The orthometric elevations so determined were, in turn, converted to dynamic elevations by applying a second appropriate correction.

PRACTICAL APPLICATION AND IMPLICATIONS

Because all topographic maps and related vertical control surveys and the elevations of all in-shore engineering structures are, or should be, in accordance with good engineering practice—referenced to National Geodetic Vertical Datum of 1929; and because Lake Michigan water level elevations are referenced to International Great Lakes Datum of 1955, accurate determination of the difference between these two datums becomes necessary. Information published by the National Ocean Service of the National Oceanic and Atmospheric Administration generally indicates that, at Milwaukee's water level station, the difference in the two datums is 1.302 feet.

In order to verify and more precisely determine the differences between International Great Lakes Datum of 1955 and National Geodetic Vertical Datum of 1929 at the Kenosha, Milwaukee, Port Washington, and Racine Harbors, the Commission ran second-order level lines between U. S. Coast and Geodetic Survey—the predecessor agency to the National Geodetic Survey—bench marks which were known to be stable and the International Great Lakes Datum system bench marks in the harbor areas. The average difference in elevation between the two datums in the Kenosha Harbor area as of February 1988 was found to be 1.282 feet. This difference is to be added to the International Great Lakes Datum of 1955 to obtain elevations referred to National Geodetic Vertical Datum of 1929. The average difference in elevation in the Milwaukee Harbor area was found to be 1.338 feet; the average difference in the Port Washington Harbor area was found to be 1.179 feet; and the average difference in the Racine Harbor area was found to be 1.256 feet. These differences are very close to the differences promulgated by the National Geodetic Survey of 1.272, 1.302, 1.217, and 1.238 for Kenosha, Milwaukee, Port Washington, and Racine, respectively, and thus these nationally promulgated figures can be used.

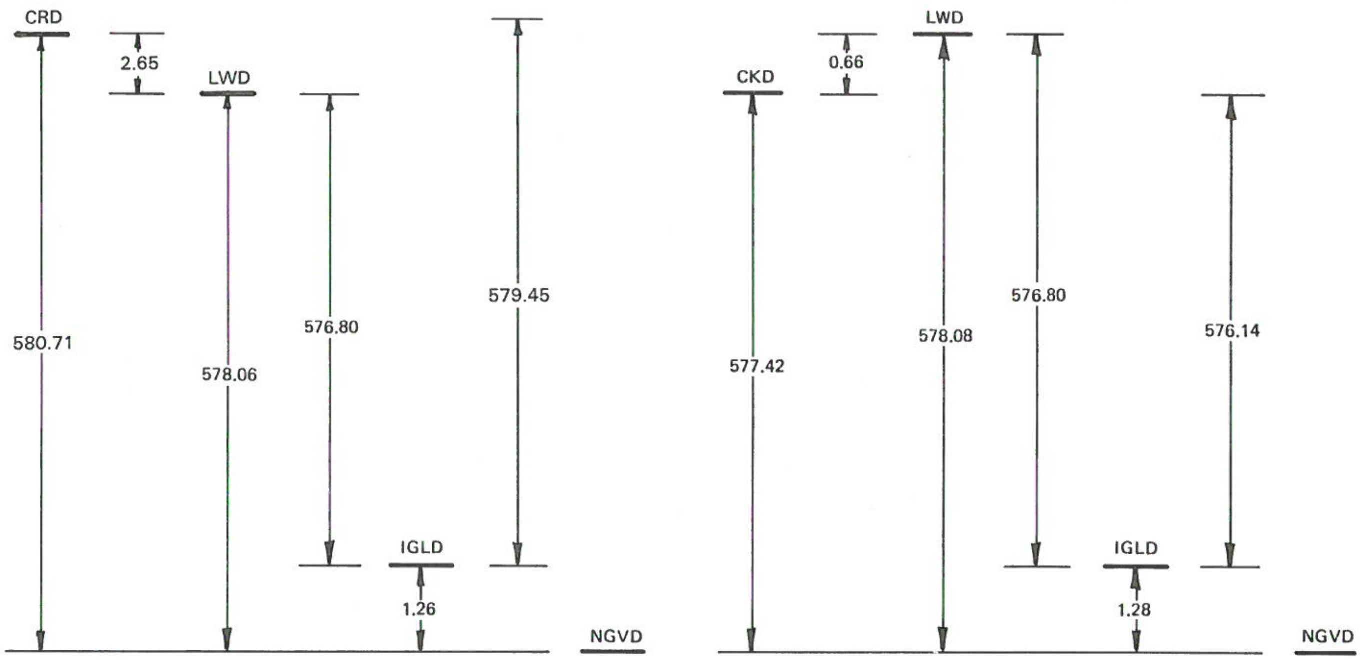
The differences represent instrumental—or observed—differences and involve no conversions to orthometric or dynamic elevations. The distances involved, however, were all small, with no connection between a U. S. Coast and Geodetic Survey and an International Great Lakes Datum system bench mark exceeding three miles. The differences as determined by the Commission precise level surveys, and the comparable differences as promulgated by the National Ocean Service, are set forth in Table 1. The relationships between the selected vertical survey control data planes in the Kenosha, Milwaukee, Port Washington, and Racine Harbor areas are shown in Figure 1.

It should be noted that the figure shows, in addition to the relationship between International Great Lakes Datum of 1955 and National Geodetic Vertical Datum of 1929, the relationships to the most commonly used local datum and the relationship to a third datum used with respect to lake levels, the Low Water (Chart) Datum, the datum used in the preparation of hydrographic charts for navigation purposes. It should also be noted that Table 1 and Figure 1 give the differences between International Great Lakes Datum—a dynamic datum—and National Geodetic Vertical Datum—an orthometric datum. If the comparison is made in the same type of datum—that is, if the heights referred to the dynamic datum are first converted to heights referred to the orthometric datum—the results will be different, as shown in Table 2.

Figure 1

RELATIONSHIP AT SELECTED VERTICAL SURVEY CONTROL DATUM PLANES

RACINE, WISCONSIN | KENOSHA, WISCONSIN



RACINE, WISCONSIN

COMPUTATION OF NGVD GIVEN CRD, LWD, OR IGLD

NGVD = CRD + 580.71
NGVD = LWD + 578.06
NGVD = ILGD + 1.26

COMPUTATION OF CRD GIVEN NGVD, LWD, OR IGLD

CRD = NGVD - 580.71
CRD = LWD - 2.65
CRD = ILGD - 579.45

COMPUTATION OF LWD GIVEN NGVD, CRD, OR IGLD

LWD = NGVD - 578.06
LWD = CRD + 2.65
LWD = ILGD - 576.80

COMPUTATION OF IGLD GIVEN NGVD, CRD, OR LWD

ILGD = NGVD - 1.26
ILGD = CRD + 579.45
ILGD = LWD + 576.80

NGVD REPRESENTS NATIONAL GEODETIC VERTICAL DATUM OF 1929.
CRD REPRESENTS CITY OF RACINE DATUM.
LWD REPRESENTS LAKE MICHIGAN LOW WATER DATUM (CHART DATUM).
IGLD REPRESENTS INTERNATIONAL GREAT LAKES DATUM, 1955 ADJUSTMENT.

Source: SEWRPC.

KENOSHA, WISCONSIN

COMPUTATION OF NGVD GIVEN CKD, LWD, OR IGLD

NGVD = CKD + 577.42
NGVD = LWD + 578.08
NGVD = ILGD + 1.28

COMPUTATION OF CKD GIVEN NGVD, LWD, OR IGLD

CKD = NGVD - 577.42
CKD = LWD + 0.66
CKD = ILGD - 576.14

COMPUTATION OF LWD GIVEN NGVD, CKD, OR IGLD

LWD = NGVD - 578.08
LWD = CKD - 0.66
LWD = ILGD - 576.80

COMPUTATION OF IGLD GIVEN NGVD, CKD, OR LWD

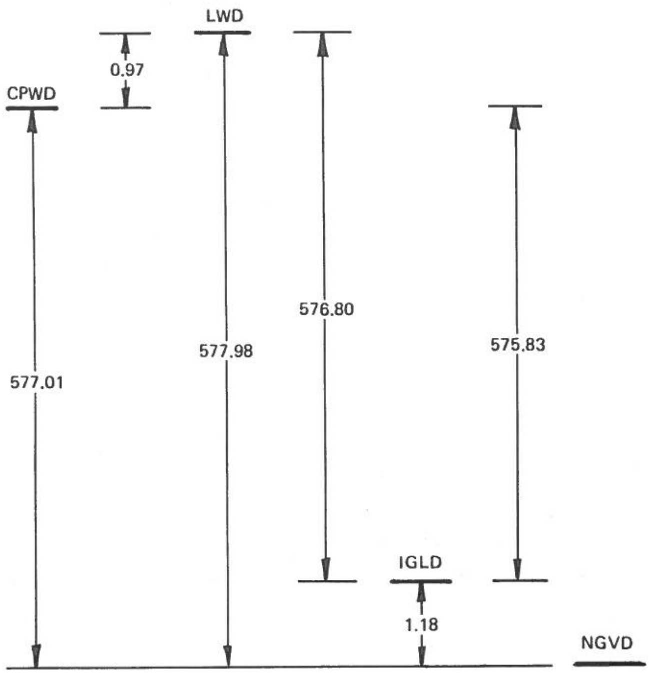
ILGD = NGVD - 1.28
ILGD = CKD + 576.14
ILGD = LWD + 576.80

NGVD REPRESENTS NATIONAL GEODETIC VERTICAL DATUM OF 1929.
CKD REPRESENTS CITY OF KENOSHA DATUM.
LWD REPRESENTS LAKE MICHIGAN LOW WATER DATUM (CHART DATUM).
IGLD REPRESENTS INTERNATIONAL GREAT LAKES DATUM, 1955 ADJUSTMENT.

Source: SEWRPC.

Figure 1 (continued)

PORT WASHINGTON, WISCONSIN



COMPUTATION OF NGVD GIVEN CPWD, LWD, OR IGLD

NGVD = CPWD + 577.01
NGVD = LWD + 577.98
NGVD = ILGD + 1.18

COMPUTATION OF CPWD GIVEN NGVD, LWD, OR IGLD

CPWD = NGVD - 577.01
CPWD = LWD + 0.97
CPWD = ILGD - 575.83

COMPUTATION OF LWD GIVEN NGVD, CPWD, OR IGLD

LWD = NGVD - 577.98
LWD = CPWD - 0.97
LWD = ILGD - 576.80

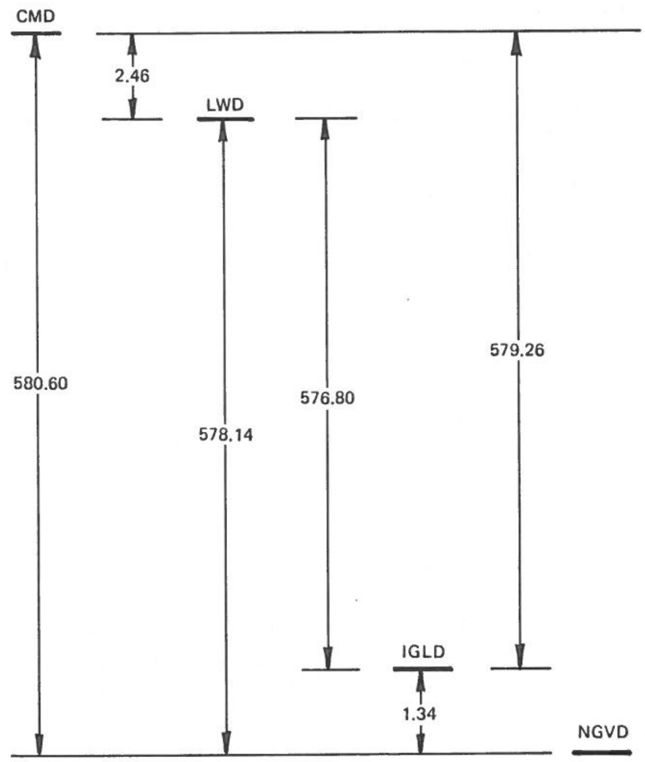
COMPUTATION OF IGLD GIVEN NGVD, CPWD, OR LWD

ILGD = NGVD - 1.18
ILGD = CPWD + 575.83
ILGD = LWD + 576.80

NGVD REPRESENTS NATIONAL GEODETIC VERTICAL DATUM OF 1929.
CPWD REPRESENTS CITY OF PORT WASHINGTON DATUM.
LWD REPRESENTS LAKE MICHIGAN LOW WATER DATUM (CHART DATUM).
IGLD REPRESENTS INTERNATIONAL GREAT LAKES DATUM, 1955 ADJUSTMENT.

Source: SEWRPC.

MILWAUKEE, WISCONSIN



COMPUTATION OF NGVD GIVEN CMD, LWD, OR IGLD

NGVD = CMD + 580.60
NGVD = LWD + 578.14
NGVD = ILGD + 1.34

COMPUTATION OF CMD GIVEN NGVD, LWD, OR IGLD

CMD = NGVD - 580.60
CMD = LWD - 2.46
CMD = ILGD - 579.26

COMPUTATION OF LWD GIVEN NGVD, CMD, OR IGLD

LWD = NGVD - 578.14
LWD = CMD + 2.46
LWD = ILGD - 576.80

COMPUTATION OF IGLD GIVEN NGVD, CMD, OR LWD

ILGD = NGVD - 1.34
ILGD = CMD + 579.26
ILGD = LWD + 576.80

NGVD REPRESENTS NATIONAL GEODETIC VERTICAL DATUM OF 1929.
CMD REPRESENTS CITY OF MILWAUKEE DATUM.
LWD REPRESENTS LAKE MICHIGAN LOW WATER DATUM (CHART DATUM).
IGLD REPRESENTS INTERNATIONAL GREAT LAKES DATUM, 1955 ADJUSTMENT.

Source: SEWRPC.

Table 1

COMPARISON OF HEIGHTS REFERRED TO DYNAMIC (IGLD) AND ORTHOMETRIC (NGVD) DATUMS AT KENOSHA, RACINE, MILWAUKEE, AND PORT WASHINGTON

Harbor Area	Bench Mark	IGLD 1955 (feet)	NGVD (feet)	Difference as Promulgated by NOS (feet)	Determined by SEWRPC Level Surveys (feet)
Kenosha, Wisconsin	WL 245	586.872	588.148	1.276	1.28
Racine, Wisconsin	WL 246	593.587	594.825	1.238	1.26
Milwaukee, Wisconsin	City Hall	593.185	594.487	1.302	1.34
Port Washington, Wisconsin	C 87	617.758	618.975	1.217	1.18

NOTE: Add differences to IGLD to obtain NGVD.

Source: U. S. Department of Commerce; National Oceanic and Atmospheric Administration, National Ocean Service, Office of Oceanography and Marine Assessment; and SEWRPC.

Table 2

COMPARISON OF HEIGHTS CONVERTED TO ORTHOMETRIC DATUM AT KENOSHA, RACINE, MILWAUKEE, AND PORT WASHINGTON

Harbor Area	Bench Mark Designation	IGLD Heights				NGVD 29	NGVD-IGLD Feet
		Dynamic Number		Orthometric			
		Feet	Meters	Meters	Feet	Orthometric Feet	
Kenosha	Park	600.305	182.9733	183.0192	600.456	601.592	1.136
	WL 245	586.872	178.8789	178.9237	587.019	588.148	1.129
	Cross	582.355	177.5022	177.5465	582.501	583.630	1.129
	Kenosha Light	603.185	183.8512	183.8973	603.336	604.475	1.139
	Water	588.263	179.3029	179.3478	588.410	589.546	1.136
	Tank	585.327	178.4080	178.4527	585.473	586.503	1.030
Average	- -	- -	- -	- -	- -	- -	1.116
Racine	Shop	590.864	180.0957	180.1385	591.004	592.123	1.119
	North	584.782	178.2419	178.3842	584.921	586.042	1.121
	WL 246	593.587	180.9257	180.9687	593.728	594.825	1.097
	Bohn	589.367	179.6394	179.6820	589.507	590.569	1.062
Average	- -	- -	- -	- -	- -	- -	1.100
Milwaukee	W 1	619.033	188.6816	188.7216	619.164	620.369	1.205
	B	594.927	181.3341	181.3723	595.052	596.254	1.202
	Flushing	586.540	178.7777	178.8153	586.663	587.872	1.209
	W 6	622.237	189.6582	189.6984	622.369	623.594	1.225
	City Hall	593.185	180.8031	180.8412	593.310	594.488	1.178
	Printing	591.832	180.3908	180.4287	591.957	593.068	1.111
	Hansen	589.430	179.6586	179.6964	589.554	590.778	1.224
Average	- -	- -	- -	- -	- -	- -	1.193
Port Washington	WL 249	595.961	181.6493	181.6815	596.067	597.145	1.078
	Light	586.432	178.7448	178.7765	586.536	587.582	1.046
	Works	587.930	179.2014	179.2332	588.034	589.105	1.071
Average	- -	- -	- -	- -	- -	- -	1.065

Source: U. S. Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service, Office of Charting and Geodetic Services; and SEWRPC.

Table 3

VALUES OF THE DYNAMIC CORRECTION FOR LATITUDE (D_1) AND THE DYNAMIC CORRECTION FOR ELEVATION (D_2) AT KENOSHA, RACINE, MILWAUKEE, AND PORT WASHINGTON

Harbor Area	Latitude	D_1	D_2
Kenosha	42° 35' 18"	0.000222	0.0000001574
Racine	42° 44' 01"	0.000209	0.0000001574
Milwaukee	43° 01' 31"	0.000182	0.0000001574
Port Washington	43° 23' 12"	0.000149	0.0000001574

Source: U. S. Coast and Geodetic Survey Special Publication No. 240, "Manual of Leveling Computation and Adjustment"; and SEWRPC.

The relationship of dynamic number (H) to orthometric elevation (h) is given by:

$$H = h\text{-}D_1\ h\text{-}D_2h^2 = h(1\text{-}D_1, \text{-}D_2h)$$

and of orthometric elevation to dynamic number by:

$$h = \frac{H}{1\text{-}D_1\text{-}(D_2H)}$$

where (D_2h) approximately equals (D_2H), and where H and h are expressed in meters.

Values for D_1 and D_2 are tabulated in U. S. Coast and Geodetic Survey Special Publication 240, pages 142 to 147. Values of D1 and D2 at Kenosha, Racine, Milwaukee, and Port Washington are given in Table 3.

A BACKWARD GLANCE—A HISTORY OF STORM DAMAGE AND PROTECTIVE MEASURES IN MILWAUKEE HARBOR

by Bruce W. Jordan, M. A.

INTRODUCTION

The City of Milwaukee, from its earliest days up to the present, has been one of Lake Michigan's leading port cities. Milwaukee is located on the western shore of Lake Michigan, approximately 85 miles north of Chicago. The Milwaukee harbor is formed by Milwaukee's three rivers (Milwaukee, Menomonee, and Kinnickinnic), which flow together and empty into Milwaukee Bay. The three rivers essentially formed the Milwaukee harbor until, in this century, the introduction of larger ships forced the development of port facilities in Milwaukee Bay. Today, most of the port activities occur in Milwaukee Bay.

This article will focus on two major areas: the construction of Milwaukee's port facilities and the effect of Lake Michigan storms on those facilities.

GENERAL HARBOR HISTORY

Original Geographic Aspects

The City of Milwaukee is located along the shoreline of Milwaukee Bay roughly at the center of the curve of the Bay. The Bay is roughly six miles wide and three miles deep, and indents the shoreline in a semi-circular manner. Steep bluffs, ranging from 30 to 150 feet in height, dominate the shoreline along the northern and southern parts of the Bay. Originally, the central portion of the shoreline was low, marshy ground around the mouth of the Milwaukee River, with sand spits forming the sides of the river's mouth. These were formed by the prevailing littoral currents and were anchored by strands of trees. The river's flow carved a shallow channel between the sand spits, with a depth of only 4.5 feet[1] (see Map 1). Solomon Juneau, Milwaukee's founding father, describes the river mouth: "the beach on the lake on either side of the Milwaukee River was covered with sandbanks between fifteen and twenty feet high, which were separated from the marsh by a belt of heavy timber."[2]

Upstream from the sand spits, the river channel divided into a south channel and a north channel. The south channel soon bent sharply to the west, forming a small basin ringed by marsh. Bois Gris Creek, later named the Kinnickinnic River,[3] entered the basin in the middle of its southern edge.

The path of the north channel, or the Milwaukee River, went in a generally north-northwesterly direction from the River's mouth. However, this channel meandered through several bends above the harbor area. Juneau founded Milwaukee on the high ground north of the river mouth, between Lake Michigan and the River, near where Wisconsin Avenue now crosses it. Roughly 6,000 feet up this northern channel from the river mouth, the Menomonee River flowed into the Milwaukee River from the west. The path of the Menomonee River is almost due west-east from the Milwaukee River to Lake Michigan. Above the confluence of the two rivers, the Milwaukee River continues upstream in

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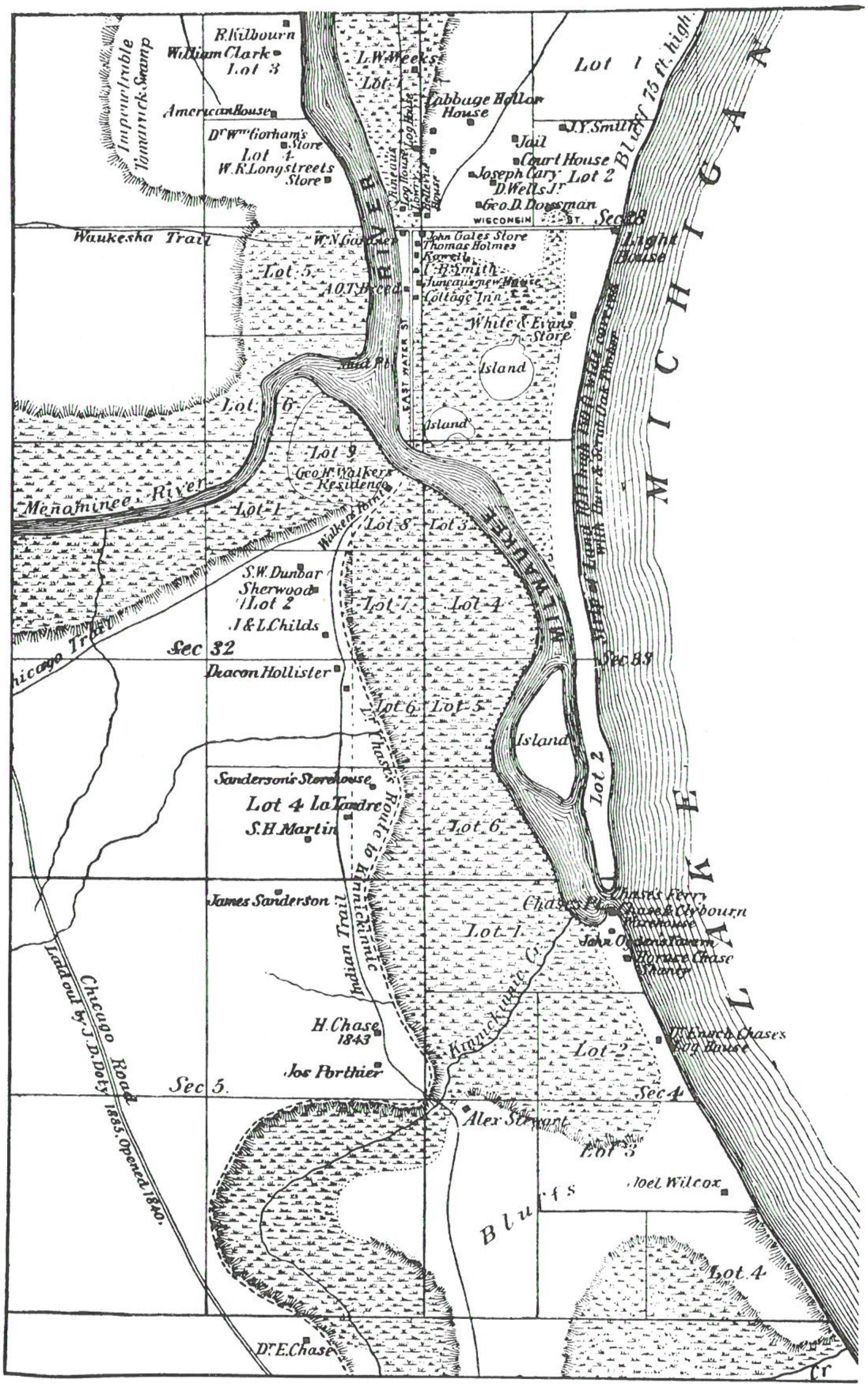
[1] *Jerome K. Laurent, The Development of Harbors, Waterborne Shipping and Commerce of Six Wisconsin Ports on Lake Michigan Through 1910 (Indiana University, 1973), p. 296; William E. Derby, History of the Port of Milwaukee 1835-1919 (Ann Arbor, 1963), pp. 10-15.*

[2] *Milwaukee Sentinel, July 23, 1870, p. 1.*

[3] *U. S. Engineer Office, History of Milwaukee Harbor, Wisconsin (Milwaukee, 1937). This is a single-page, unpaginated map in the map section in the rear of the book.*

Map 1

MAP OF MILWAUKEE IN 1836 AS RECALLED BY EARLY SETTLERS



Source: Bayrd Still, Milwaukee—The History of a City.

a northwesterly direction for many miles. Both the Menomonee River and the lower Milwaukee River had marshy areas along their banks.[4]

Once vessels passed the sand bars at the river mouth, they found safe anchorage in the Kinnickinnic Basin and the lower Milwaukee River in water ranging from 10 to 14 feet in depth. However, above the junction of the Milwaukee and Menomonee Rivers, the depth of both river channels was irregular and too shallow for most ships of the early period. The river banks afforded many places where piers and wharfs could be constructed. Ships anchored in the Bay were protected in any storm except from those from the east. Protection from easterly storms could be found in the river channels inside the sand spits. This was the only harbor on the whole western shore of Lake Michigan to offer such protection[5] (see Map 2).

Milwaukee's Harbor: 1823-1852

Undoubtedly many ships anchored in Milwaukee Bay prior to 1823, but in that year the first vessel to call at the Bay on a semi-regular basis was the 30-ton packet Chicago. Soon Milwaukee was the regular stop for much of the Lake Michigan shipping, despite the young port's several problems. The first problem was the aforementioned sand bar at the mouth of the Milwaukee River. Only ships of the shallowest draft could pass over the bar, head up the river, and safely reach Juneau's trading post. The second problem was poor landing sites, due to the nature of Milwaukee's lakeshore. The shore at the center of the Bay was swampland, while at either end were steep bluffs. Neither extreme offered easy access to the young city.[6]

Milwaukee's development created two other problems. The exact location of the City had yet to be established. Three different factions were contending for their location to be the "official city." Solomon Juneau and his group wanted the City to be between Lake Michigan and the Milwaukee River, north of the river mouth. Bryon Kilbourn and his friends wanted Milwaukee to be west of the Milwaukee River and north of the Menomonee River. George Walker and his adherents wanted the City to be south of the Menomonee River and west of the river mouth. The harbor location was dependent upon the outcome of this struggle. In 1837, the two northern factions called for a channel to be cut through a narrow portion of the sand spit north of the river mouth. This would place the harbor entrance closer to their locations. The southern faction, wanting the harbor developed in their part of town, supported improvement of the river mouth. In this early period, both sides eventually got the harbor they wanted.[7]

The other problem the city fathers were beginning to face was that ships needed a reason to stop in Milwaukee. Merely providing protection from lake storms would not bring the City a large profit. Nor would providing wood fuel for lake steamers enable Milwaukee to survive. Only trade with inland areas would ensure Milwaukee survival as a port. Hence, the citizens of Milwaukee had to build roads, not only out to the surrounding countryside, but also to the lead mining areas of southwestern Wisconsin and to the Mississippi River.[8]

During the 1830's and 1840's, Milwaukee citizens went to work solving those problems. First they turned to the U. S. Congress for aid in building a harbor. Several reasons were advanced in support of the application for federal aid: the growing amount of western commerce and shipping; destruction

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[4] *Ibid.*

[5] *Derby, op. cit., pp. 10-16; U. S. Engineer Office, ibid.*

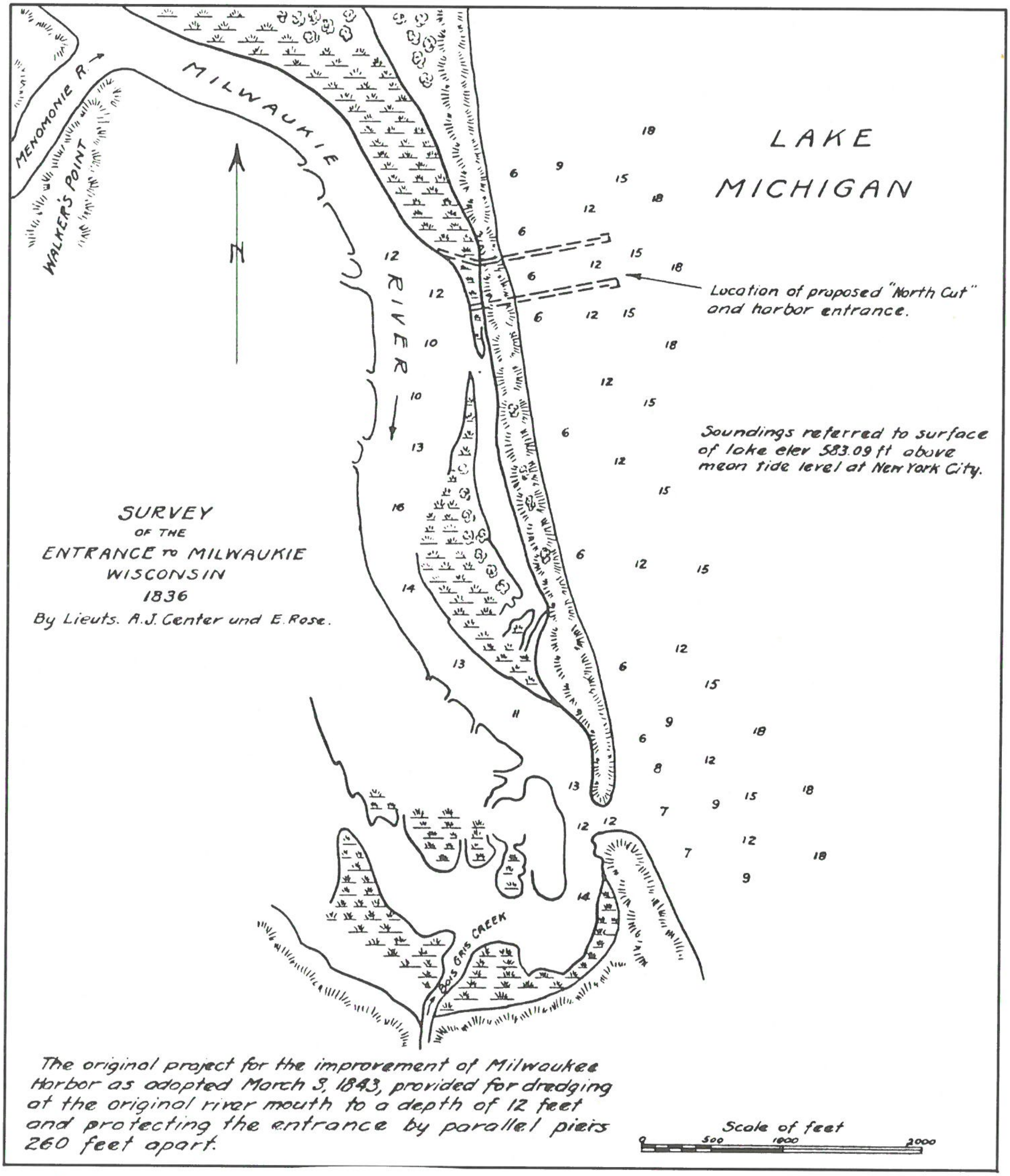
[6] *Derby, op. cit., pp. 19-25.*

[7] *Bayrd Still, Milwaukee—The History of a City (Madison, 1946), pp. 3-49.*

[8] *Still, op. cit., pp. 44-48; Derby, op. cit., pp. 36-40.*

Map 2

MILWAUKEE HARBOR, WISCONSIN: SUMMER OF 1836



Source: U. S. Engineer Office, Milwaukee, Wisconsin, September 30, 1936.

of vessels by lake storms; Milwaukee's status as the only port of refuge north of Chicago; national defense against Canada; and a return of taxes paid. The Milwaukee Sentinel called for Congressional harbor funds, pointing to the damages resulting from lake storms, such as the storm of October 19-20, 1839, when six ships went aground in Milwaukee Bay for lack of a proper harbor. After several years of fruitless applications, the U. S. Congress in 1843 finally granted Milwaukee $30,000 for harbor improvement. However, the improvement was proposed for the river mouth, not the new channel known as the "Straight Cut."

This choice was made on the recommendation of the U. S. Army Corps of Engineers. Captain Thomas J. Cram, the government surveyor, who lived in Racine and promoted Racine's interests, believed development of the river mouth would be cheaper, serve the whole lake commerce better, and avoid any local compilations resulting from river diversion. Milwaukee's leaders, knowing about Cram and his personal interests, had Captains James Kearney, W. G. Williams, and J. McClellan resurvey the harbor area. The new survey proved earlier harbor surveys inaccurate. The channel depths of the northern stretches of the Milwaukee River were shallower than thought and had to be dredged to handle ships of the size then in common use on Lake Michigan. The new survey also indicated that the "Straight Cut" would cause the eventual filling in of the Kinnickinnic Basin, an area needed for anchorage as Milwaukee's trade expanded. Construction of a pier on each side of the river mouth and the dredging of a channel between them began in 1843.[9]

Believing the government-sponsored project would take too long, several local merchants began, also in 1843, to construct privately owned piers. Before this, local private enterprise had developed a system to bring passengers and goods from vessels anchored in the Bay to either the lakeshore or up the Milwaukee River to the center of the City in smaller craft drawing less water. Each bank of the upper Milwaukee had a collection of wharves and docks, built by the various merchants and industrialists to facilitate the handling of goods, and thus to reduce transportation costs. A lakeshore pier would eliminate the need for lighters and their attendant costs and would attract a large share of the passenger trade as well. In April 1843 the firm of Tufts and Kendall began construction of the first lakeshore pier, completed by June. Realizing the profitability of lakeshore piers, others shortly afterward began building piers. Some early piers were "Old North Pier," 1,200 feet long (500 feet in 12 feet or more of water) and 44 feet wide, built by Horatio Sevens at the foot of Huron Street; "New Old Pier," 800 feet long to the ten-foot depth contour line, 48 feet wide, 300 feet south of the "Old North Pier"; and another "South Pier," was build by Dr. Weeks at the foot of Erie Street. The latter had warehouses at the offshore end of the piers and were secured by a gate across the shore end. These piers were successful for several years, but became obsolete when the "Straight Cut" was completed in 1857.[10]

By 1844, the government improvements at the river mouth had opened the Milwaukee River to lake traffic. The sandbar blocking the river mouth had been dredged away, providing a channel depth of ten and one-half feet. Although a major part of the protective piers at the sides of the river mouth had been built, a new problem arose. The Milwaukee River was shallower than expected and had to be dredged in places to provide a uniform ten and one-half-foot channel. The Army Engineers, however, were limited by governmental policy to the construction of improvements at the river mouth, and, therefore, could not dredge the river channels. Ships that used to go aground at the river mouth now went aground in the shallower portions of the River. The City had to spend its own money—what little of it there was—to dredge the river channels. On the Milwaukee River, the City only had to dredge just past the Humboldt Street bridge. A dam had been constructed there in 1837 to aid in the construction of Byron Kilbourn's Milwaukee and Rock River Canal. Congress provided another

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[9] *Laurent, op. cit., p. 297; Derby, op. cit., pp. 49-61.*

[10] *Derby, op. cit., p. 70; Milwaukee Sentinel, November 29, 1869, p. 1.*

$20,000 in 1844 to complete the river mouth project, but, again, none of the appropriation could be used for the dredging of the river.[11]

When completed, the harbor entrance channel had been dredged to an average depth of ten and one-half feet between the two protective piers (see Map 3). The northern pier extended completely across the land spit and thence out into the lake. From the land side out to the lake, this pier's first 150 feet ran to the southeast, then east for the remaining 1,162 feet. The south pier started halfway across the land spit and extended eastward, parallel to the northern pier, for a distance of 562 feet. The cost of constructing this harbor entrance was $50,000.[12]

The 1846 completion of the river mouth project provided Milwaukee with three developing harbors: the estuarine basin, the lakeshore piers, and the upper Milwaukee River (the section upriver from the confluence with the Menomonee River to the Humboldt Street dam.) The lower river basin project, or the government harbor, was a good harbor of refuge and encouraged the development of facilities in that area, which delighted Walker's constituents. Unfortunately, most of the shoreland was swamp. The lakeshore piers were effective in the handling of freight and passengers, but were poorly protected from storms and relied upon the good will of the western wards of the City for good connections to the western hinterlands. (This good will had not always existed; there had been a bridge and street "war" between the eastern and western wards of the City, evidence of which can still be seen in the skewed bridge over the Milwaukee at Wisconsin Avenue.) The upper Milwaukee River harbor was located in the heart of the City, but had poor access to the Lake.[13]

A correspondent for the New York Courier and Enquirer described Milwaukee's harbor in 1846:

> The approach to it is marked by a long line of high yellowish-looking clay bluffs timbered to the edge with hardwood and as yet little cleared, except within the bay, which forms a crescent—of which the horns project far seawards. . . .In the center of the curve as it were stands Milwaukee, indicated by its lighthouse—its numerous piers thrown out into the lake—its spires, cupolas, and clustered dwellings. The U. S. have constructed a pier at the mouth of the river, which discharges into the lake considerably south of the town plot, and to this pier resort is only had in weather too rough to admit of boats touching and lying at others, which individual enterprise has constructed at the points indicated by the present wants of the town. The U. S. pier, however, serves to form a harbor of refuge against bad weather, similar to all lake harbors—which are nothing more than the outlet of natural water courses, deepened and made secure against the sweep and the swell of water, by long parallel piers thrown out into it—with such curves as are at once bends, calculated to break the force of the seas and winds, and at the same time to prevent the deposit of sand at the outlet of the rivers. The mouth of the Milwaukee River is used by steamboats only in bad weather. At other times the piers built from the shore around the center of population directly into the lake, receive all the business—these piers have multiplied lately—there are now 4 or 5 of them—2 years ago there were only 2—

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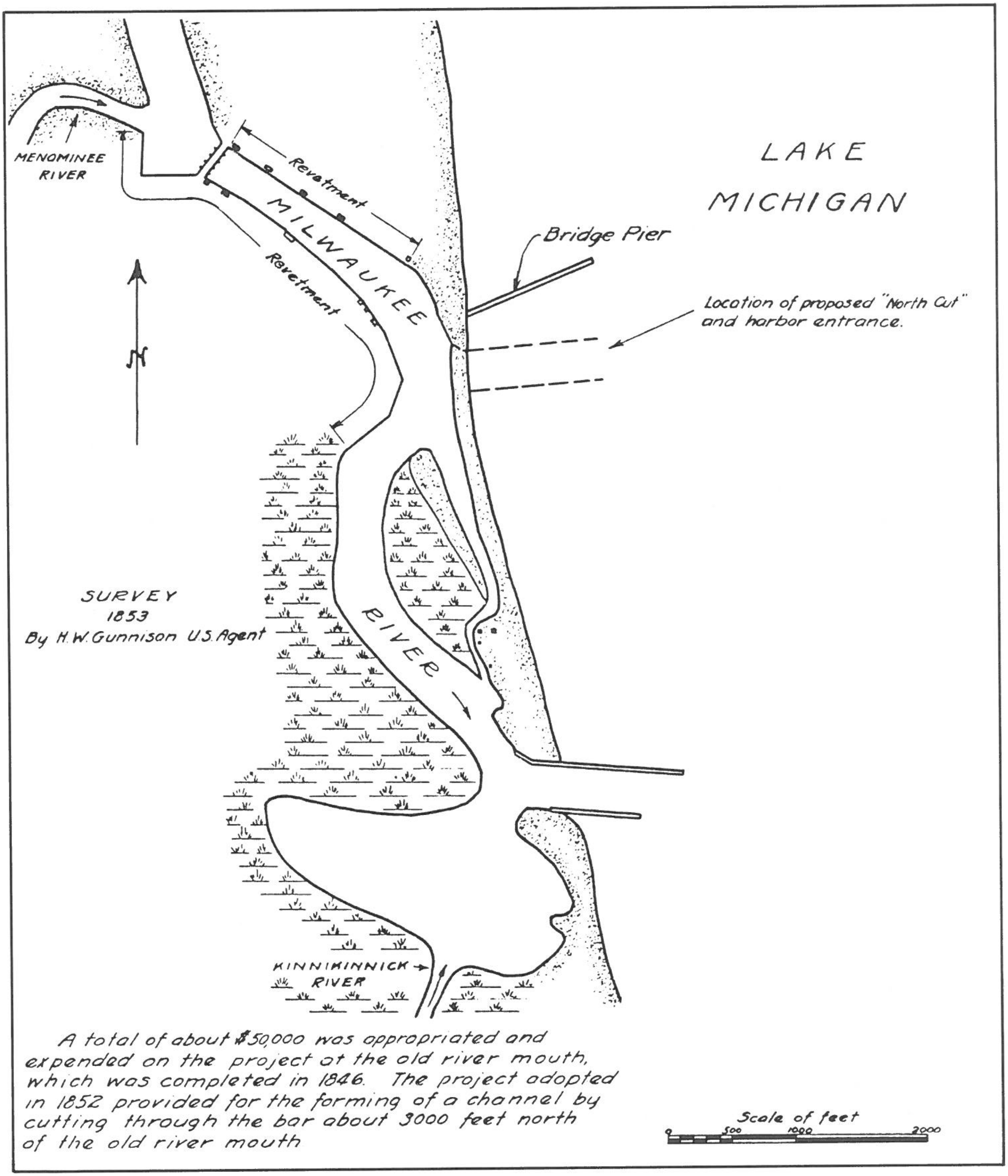
[11]*Derby, op. cit., p. 109; Laurent, op. cit., p. 297; Frank A. Flowers, History of Milwaukee from Prehistoric Times to the Present Date (Chicago, 1881), p. 1170; James E. Seybold, "A Backward Glance—The Milwaukee and Rock River Canal," in SEWRPC Technical Record (Waukesha, 1964).*

[12]*Alice E. Smith, general editor, The History of Wisconsin, Vol. 1, From Exploration to Statehood (Madison, 1973), p. 447; H. W. Gunnison, Survey, 1953 (Milwaukee, 1853). The latter is a single-page map.*

[13]*Derby, op. cit., p. 95; Still, op. cit., pp. 39-41.*

Map 3

MILWAUKEE HARBOR, WISCONSIN: AUGUST 1853



Source: U. S. Engineer Office, Milwaukee, Wisconsin, September 30, 1936.

but they proved to be such good property from wharfage rates, that others were tempted to make investment—there being business for all.[14]

The government project had improved Milwaukee's harbor, but more work was still needed. A major step toward further improvement of the harbor was taken when Milwaukee's leaders drafted the city charter in 1846. The charter helped unify the previous three factions into an organized government. Under the charter, the new city government was to coordinate harbor activities. Still, old factional feelings were difficult to overcome. In 1849, Alderman Alanson Sweet sponsored an ordinance allowing the Fifth Ward to dredge and dock their section of the river and assess the waterfront property owners for the costs. This ordinance led to an 1852 charter revision ruling that any alderman could order dredging and dock construction where needed, and the abutting property owner would have to pay for it. These actions had two major results. First, the City's rivers could now be dredged, allowing lake traffic to enter the commercial district. Second, for many years to come, Milwaukee's major harbor costs were for the dredging of its rivers upstream from the government project.[15]

In addition to these harbor efforts, the citizens of Milwaukee also improved their connections with central and southern Wisconsin. The southwestern corner of Wisconsin was an important lead producing area when Milwaukee was being settled. If Milwaukee's merchants could supply the lead miners with food and salt, the profits could help pay for Milwaukee's development. The rich agricultural lands of southern Wisconsin attracted many immigrants. By supplying those new farmers and by marketing their produce, Milwaukee's merchants could further add to their profits. But, in order to make those profits a reality, good roads were needed.

Although several military and territorial roads had been built in Wisconsin, none of these connected Milwaukee with potential markets. The government road nearest Milwaukee crossed southern Wisconsin from Racine on Lake Michigan via Janesville to Sinipee on the Mississippi River. In May 1844 Milwaukee's committee on road improvements raised $2,000 to extend the Milwaukee to Muskego road southward to connect with this southern government road. The committee also promoted plank road and railway development.

Partially because of their efforts, plank road fever swept southern Wisconsin between 1846 and 1852. By the end of 1852 there were over 150 miles of plank roads from Milwaukee toward Watertown, Waukesha, and Janesville. The combination of plank roads, an improving harbor, and the aggressive city merchants soon made Milwaukee the leading market for farm product. The produce, especially wheat, was then shipped east. Milwaukee's improving economic situation increased the need for harbor improvements.[16]

The need for harbor improvements had become apparent once the river mouth project was completed. Maintaining the river for the long sail from the mouth up to the heart of the City placed a heavy burden of dredging costs upon the City. The shallow ten and one-half-foot channel depth made it difficult for steamers of deeper draft to use the new harbor. The narrow clearances between the government's piers created problems for ships attempting to reach this harbor of refuge during stormy weather. Numerous accidents occurred around the government piers during storms.

During an easterly gale on November 6, 1847, the brig Orleans went aground between the government piers, and the schooner Cherokee struck the lighthouse at the end of the northern pier and carried away the lantern. In another November gale, on November 23-24, 1849, three ships went aground

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[14] *Milwaukee Sentinel, September 18, 1846, p. 2.*

[15] *Derby, op. cit., pp. 111f., 155-161.*

[16] *Derby, op. cit., pp. 76-135; R. E. Rehberg, "A Backward Glance—Early Toll Roads in Southeastern Wisconsin," in SEWRPC Technical Record (Waukesha 1965).*

between the government piers. The steamer Lexington entered the harbor and went aground on a sand bar at the inner end of the piers. The schooner Baltic was following and hit the Lexington, blocking the harbor entrance. The schooner Twin Brothers came in later, and to avoid the other vessels, hit the pier and went aground.[17]

Storms also affected the privately-owned piers along the lakeshore. The Milwaukee Sentinel recorded one storm on February 3, 1848:

> During Wednesday night the wind blew with great violence from the Northeast and a very heavy sea came rolling into the Bay. There was a good deal of ice along shore and large cakes lifted by the waves and hurled against the piers, did a great deal of damages. Clean breaches were made in two or three places, thro' the North Pier, Kellogg, Strong & Co.'s and Higby's Piers; railings, planks and piles having been swept away; and fifty or hundred feet of the outer end of Higby's pier were also carried off.

Fierce storms struck Milwaukee in 1850 and 1851. A particularly destructive one struck on August 29-September 1, 1850. The waves washed over the piers and threw spray 20 feet in the air. Land as far west as Jefferson Street was covered with water. The rivers rose so high as to almost carry away the city bridges. Several ships went aground near the government piers. The schooner Churubusco's cable parted and she went aground inside the harbor of refuge. When the storm subsided, the Lake had made a complete breach through the land spit above the northern pier, 30 feet wide and deep enough for the passage of ships.[18]

Another severe storm struck on September 14-15, 1851, "tumbling a heavy sea into the Bay, swelling the river, and flooding the streets, lots, and cellars in the lowest levels of the city. The water was very high, both in the river and the lake, and the sea made a clear breach through the Lake Shore, driving out the inmates of the houses near the beach." By the next day, "the piers were all more or less damaged by the violence of the waves, and the Grocery at the inner end of the South pier was fairly washed away into the lake, with all its furniture." Several vessels struck the piers, but none went aground.[19]

About a month later, on November 13, another storm struck Milwaukee.

> Fears were entertained for the safety of the South Pier—as every wave swept over and through it, and there was considerable freight in the sheds at the outer end. The river rose to a higher point than we have ever seen it. The low grounds in the 3rd Ward were overflowed and Erie Street, between them and the river, was diminished to half its legitimate width. The cellars of the stores on East Water Street suffered somewhat with their contents. . . .Dame Nature, in such moods as she has been this week, is doing what she can "in her poor way" to show our Government authorities what they ought to have done at the "Straight Cut"—the waves made a clean breach through yesterday, and the lake and the river shook hands together to the accompaniment of their thunderings.[20]

The government piers and channel had other problems besides those presented by these storms. After the April 18, 1848, storm, a Mr. Lane took soundings in the channel and found that sand had washed

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[17] *Milwaukee Sentinel, May 12, 1846, p. 2; June 2, 1846, p. 2; November 9, 1847, p. 2; November 26, 1849, passim.*

[18] *Milwaukee Sentinel, September 2, 1850, p. 2.*

[19] *Milwaukee Sentinel, September 15, 1851, p. 2; September 16, 1851, p. 2.*

[20] *Milwaukee Sentinel, November 14, 1851, p. 2.*

from the beach into the river, forming a bank along the inner extremity of the North Pier. Based on his soundings, the best way to enter the harbor was to enter the channel close to the North Pier; then about half way down the North Pier, to slip over to the South Pier; and then to sail along that pier into the river. A year later "Dame Nature" presented the City a gift of a fortnight of fast river currents. The result of these fast currents was that the City did not have to spend any money on dredging that year. Still, the Milwaukee Common Council appropriated $250 from general funds to repair and protect the river mouth harbor.[21]

By 1851, few repairs had been made and the harbor was "in shockingly bad condition, the government piers dilapidated. . .and several sand bars obstruct the channel."[22] Several thousand dollars were necessary to restore the government project. The channel could handle ships with a draft of up to nine and one-half feet. The land had slipped into the channel and was settling inside the North Pier. The North Pier inner side pilings had given way, releasing the fill under that pier. Each successive gale brought a rapid current through the pier, depositing sand in the channel. Ships still had to shift from the north side to the south side partway down the channel.

Realizing there were serious problems, the Common Council raised $3,000 to repair the harbor. However, a year later, in 1852, the Common Council voted city funds to build the "Straight Cut."[23]

The "Straight Cut": 1852-1870

The first call for the "Straight Cut" came in 1837, and the idea was not forgotten even during the execution of the government project at the river mouth. Over the years, the leaders of city government either tried to raise the money for the "Straight Cut" locally or petitioned the Congress to appropriate the necessary money. In 1849, Milwaukee's Common Council passed an ordinance to sell $12,000 of city bonds to pay for the construction of the "Straight Cut." The City was hard pressed for money from financing growing municipal operations and extending credit, first to plank road companies and then, later, starting in 1851, to railroad companies. In 1852, Senator Issac P. Walker of Wisconsin obtained a Congressional appropriation of $15,000 to build the "Straight Cut" and $5,000 to rebuild the lighthouse on the new North Point site. But the U. S. Army Corps of Engineers refused to build the "Straight Cut."[24]

Colonel Abert, Chief Topographical Engineer, advanced several reasons as to why this cut should not be made. He believed the original site was better; the "Straight Cut" would cause the silting up of the harbor of refuge, that is, the Kinnickinnic Basin; there would be less protection from storms for ships anchored in the rivers. He also felt the City did not provide enough money for the construction, since the $15,000 Congressional appropriation would barely cover the initial costs.[25]

City leaders, however, were determined to build the "Straight Cut." Its proposed site was roughly 3,000 feet north of the Milwaukee River mouth. Since the Congress never paid for dredging of rivers, construction meant 3,000 feet less river channel to dredge annually. The savings in dredging costs, over a long period of time, could be greater than the construction costs of the "Straight Cut" and its maintenance. Once the City finished the work, city leaders believed the Corps of Engineers would maintain it instead of dredging the river mouth, since the Corps was obligated to maintain harbor entrances. Seeing he could not change the city officials' minds, Colonel Abert recommended that the

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[21] *Milwaukee Sentinel, April 20, 1848, p. 2; March 22, 1849, p. 2; March 27, 1849, p. 2.*

[22] *Milwaukee Sentinel, February 10, 1851, p. 2.*

[23] *Milwaukee Sentinel, March 17, 1851, p. 2; July 18, 1851, p. 2.*

[24] *Milwaukee Sentinel, September 21, 1852, passim; Derby, op. cit., p. 138.*

[25] *Derby, op. cit. p. 178.*

old harbor entrance be kept serviceable, the navigable water south of the "Straight Cut" not be infringed upon, and the channels be dredged to the proper depth by the local authorities.[26]

The design for the "Straight Cut" sited it, as mentioned, about 3,000 feet north of the river mouth. It was to be 260 feet wide, with protective piers on each side lakeward to the twelve-foot contour line (see Map 4). Starting in 1854, three contractors contributed to the building of the "Straight Cut." The first two apparently did little except take the City's money. The third, Issac Hasbrouck, completed the project. Although ships could pass through by 1855, the work was not completed until fall of 1857.

Now, city officials refused to pay Hasbrouck's bill for $95,000. They thought it was over the contracted amount, and averred that the channel had not been dredged to the required depth since several ships had gone aground in the new channel. Hasbrouck sued the City. The case went all the way to the U. S. Supreme Court—where Milwaukee lost. In 1867 the Supreme Court awarded Hasbrouck over $200,000—the original debt plus ten years of accumulated interest.[27]

During the construction, several storms occurred. In April 1856, a storm swept the construction area and carried away some of the protective pier cribs. Some were found beached below the river mouth, and one was found on a sandbank between the government piers. A year later, on the same day Hasbrouck stated he would finish the project in two to three more weeks with good weather, a fierce northeaster developed. By noon the waves were making a clean sweep over the breakwater and the end of the North Pier. Two vessels, the scow-schooner Signet and the sloop Wunx, struck the government piers and went aground. Another schooner, the Mary Ann, also hit the piers, but managed to stay afloat.[28]

During the period in which the "Straight Cut" was abuilding, there were several changes in local conditions. In the early 60's the fertility of the soil in southern Wisconsin, after many repeated wheat crops, became depleted and wheat yields per acre declined. To remain a primary produce market, Milwaukee merchants had to obtain harvests from wider areas, including southern Minnesota and northern Iowa. To speed those harvests to market, Milwaukee merchants promoted railway expansion. The political leaders of Milwaukee, under pressure from the merchants, sold $1,614,000 in city bonds during the 1850's to help finance railway expansion from Milwaukee to the agricultural hinterlands.

The Milwaukee & Mississippi Railroad, built westward from Milwaukee, reached Waukesha in 1851, Janesville in 1852, Madison in 1854, and Prairie du Chien in April 1857. Its route traversed the most populous and productive areas of the State. By 1858 the LaCrosse & Milwaukee Railroad completed its line between those two cities, giving Milwaukee two railway connections to the Mississippi River. By the end of 1858 there were over 750 of railroad track in Wisconsin, most of them benefitting Milwaukee. Expansion of the railway network spelled the end of the plank roads. The railroads brought the crops to market faster and were more durable than the plank roads.[29]

Great Lakes navigation also improved during this period. In 1855, the Buffalo, New York, Board of Trade dredged a canal through the St. Clair flats, breaking open the bottleneck between Lakes Erie

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[26] *Derby, loc. cit.; Laurent, op. cit., p. 198; Gunnison, loc. cit.*

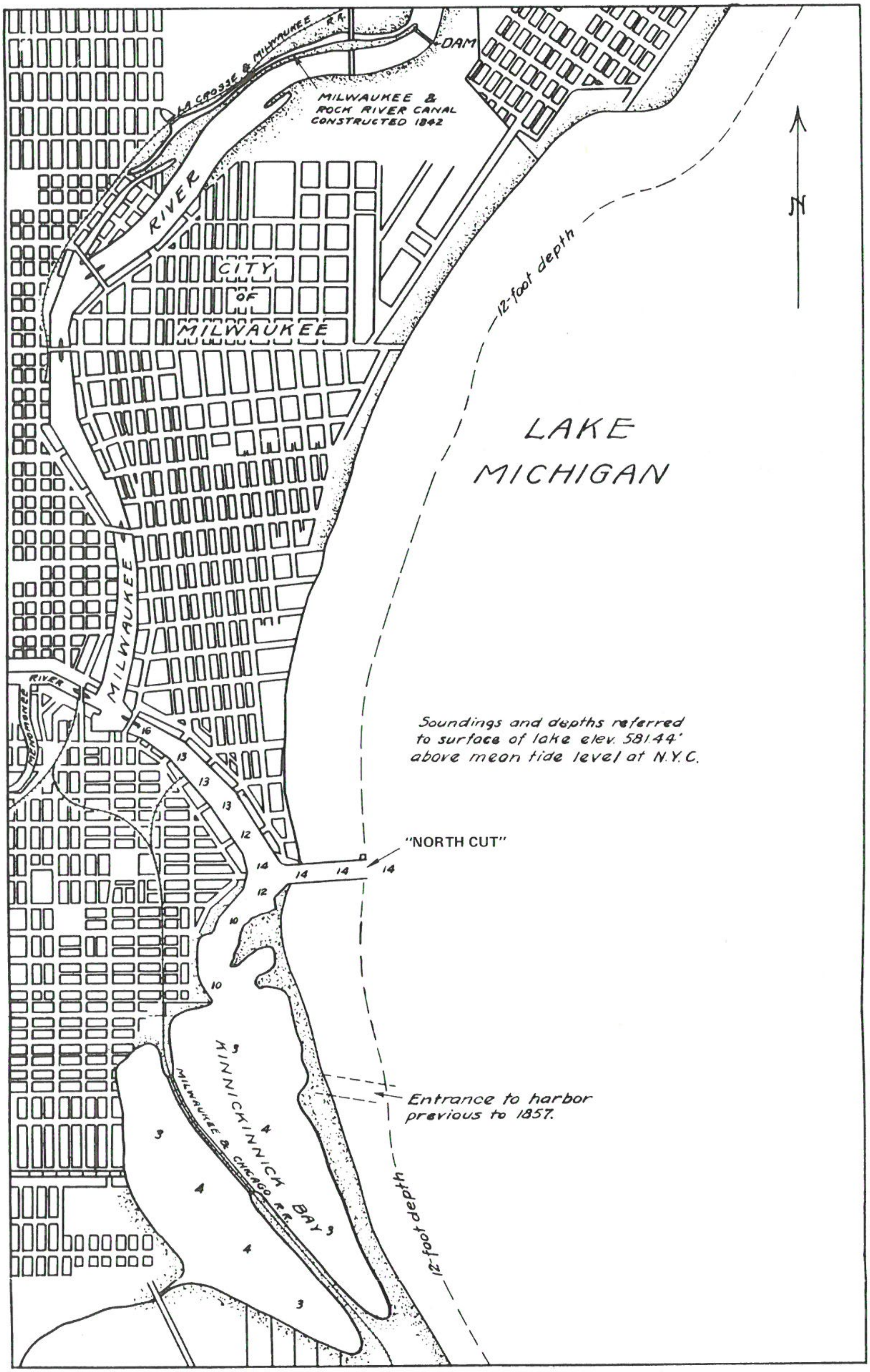
[27] *Derby, op. cit., pp. 179f.; Laurent, op. cit. p. 298.*

[28] *Milwaukee Sentinel, February 3, 1854, p. 2; April 30, 1856, p. 3; April 3, 1857, p. 2.*

[29] *Derby, op. cit. pp. 135-138, 170-175; Patricia A. Tegge, "A Backward Glance—Railroad Transportation in Southeastern Wisconsin," in SEWRPC Technical Record (Waukesha, 1964/1965).*

Map 4

MILWAUKEE HARBOR, WISCONSIN: NOVEMBER 1867



Source: U. S. Engineer Office, Milwaukee, Wisconsin, September 30, 1936.

and Huron. The Sault Sainte Marie Canal was also completed in that year, giving the four lower Great Lakes access to Lake Superior.[30]

With the completion of the "Straight Cut," the Milwaukee River became the focus of Milwaukee's port. Below the Wisconsin Avenue bridge the docks handled general cargo and passenger traffic. Above the bridge the banks were lined with retail coalyards and industries. Ships coming to this part of the river handled mostly bulk commodities.[31]

As the "Straight Cut" took away most of the harbor traffic from the river mouth, little was done to maintain that stretch. In the spring of 1858, the old harbor entrance "presented a most dilapidated appearance. Of the South Pier scarce anything remains but the piles, while the North Pier is fast going to ruin, and the last storm made a clear breach through it. If these piers are not rebuilt by the present season there will be nothing left of them by next year."[32]

The city government promised the new Milwaukee Board of Trade, later called the Chamber of Commerce, that the old harbor entrance would be dredged and kept repaired. That promise, an additional strain on the City's already overburdened budget, was not kept. Without dredging and pier repair, the piers continued to deteriorate and the entrance filled in. By 1865 there was little evidence that there was ever an entrance at that site.[33]

Except for dredging, the City of Milwaukee spent little money on port improvements through the turn of the century. In 1861, just prior to the Civil War, the City had $2,571,250 of bonded indebtedness with an assessed value of real estate and personal property of approximately twelve million dollars. To keep Milwaukee from going bankrupt, the Wisconsin Legislature passed the Readjustment Act, prohibiting Milwaukee from assuming any new debt until the old indebtedness was under $500,000. In 1872 that limit was reached, but the City then assumed $1,885,401.39 of new debt to build the city water works. Providentially, by that time the U. S. Army Corps of Engineers assumed the costs of dredging the "Straight Cut." From 1855 to 1870, the City spent $445,971.50 on harbor improvements, $238,355.79 on the "Straight Cut" alone. From 1823 to 1866, the U. S. Congress spent $80,500 on Milwaukee's harbor; however, during the next four years the Congress appropriated an annual average of $48,000. These appropriations were used to add another 250 feet to the protective piers flanking the "Straight Cut" and to keep that channel dredged to a twelve-foot depth.[34]

Except for one bad storm—April 14, 1858—the only problems experienced with the "Straight Cut" up to 1870 were overcoming sand bars across the harbor entrance, maintaining the required channel depth, and keeping ships off the piers. The April 14, 1858, storm did little damage to the "Straight Cut," but much damage to the Third Ward, Jones Island, and the old harbor entrance. Of the damages:

> a considerable part of the beach embankment between Wisconsin and Huron Streets had been undermined by the waves, and large portions had fallen down and been washed away. Within

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[30] *Richard N. Current, The History of Wisconsin, Vol. 2, The Civil War Era 1848-1873 (Madison, 1965), p. 16.*

[31] *Donald Alfred Gandre, Land Use Changes in the Milwaukee Port Area 1920-1963 (Madison, 1965), p. 32.*

[32] *Milwaukee Sentinel, April 16, 1858, p. 1.*

[33] *Derby, op. cit., pp. 178-180.*

[34] *Laurent, op. cit., p. 299; Comptroller's Report, City Documents, 1867-1868, pp. 41, 151; 1868-1869, pp. 55, 171; 1869-1870, p. 118; 1870-1871, pp. 25f., 159; 1871-1872, pp. 26, 73; The Secretary's Report for the Board of Water Commissioners, City Documents, 1874-1875, pp. 42-44.*

the past few months the lake has encroached considerably upon the boundary of the 3rd Ward and unless some protection work is provided, it will probably do serious damage to the property along the beach in this vicinity. It has already done considerable damage about the foot of Huron Street. For a distance of several rods the street is entirely washed away. . . .The waves dashed with terrible fury over the beach, completely inundating the whole lower part of the 3rd Ward, and making desparate [sic] havoc amongst the shanties on the shore. . . .on the island below the Straight Cut, considerable damage was done by the gale. The sea broke over it, and washed away a large portion of it. It was almost completely under water for two days. . . .The Government or Old Harbor suffered considerably. Large portions of the piers are carried away, and as it is at present, it must be about useless.[35]

During an April 1864 storm, a sand bar formed across the mouth of the "Straight Cut," causing several ships to go aground. The Pride of America, arriving somewhat later, hit one of the already grounded ships, the Cream City, and both filled with water. Eventually, all of the grounded ships were pushed up onto the beach. In October 1868 storms gradually built up another sand bar across the entrance, so that by the end of the month, twelve ships could not leave harbor.[36]

Dr. Increase A. Lapham, a noted civil engineer and surveyor, observed that, along with the man-made changes in Milwaukee's harbor, the area had changed greatly over the past twenty years. He thought the marshy areas surrounding the Kinnickinnic Basin and the lower Milwaukee River were once part of Milwaukee Bay. Starting about 1846, the Lake began to rise again, enlarging the Kinnickinnic Basin into a true harbor of refuge. (Note the changes in the Kinnickinnic Basin on Maps 2-4.) As the water rose, the wave and storm actions washed away the sand banks Solomon Juneau mentioned and destroyed the forest stands along the edges of the marshes. The same wave and storm action weakened the bases of the bluffs, causing slides, and made those bluffs "as near perpendicular as the nature of the material will permit." A newspaper writer, commenting on Dr. Lapham's report, thought Lake Michigan was adopting the spirit of the age and moving westward.[37]

Through a combination of rail and ship traffic, Milwaukee had managed to stay ahead of Chicago in the grain trade. In 1862, Milwaukee was the world's largest primary wheat market. Milwaukee's grain dealers controlled the steamboat lines plying the upper Mississippi River; hence all the wheat grown in that area flowed into Milwaukee. Those steamboat lines began to diminish in importance when the first Mississippi bridge was built at Clinton, Iowa, due west of Chicago, in 1865. Although Milwaukee's total wheat tonnage did not peak until 1875, Chicago's advantage of being the railway connection between the west and the east soon drew a greater volume of wheat than Milwaukee. Since railroads could operate the year round, that advantage was increased by the closure, by ice, of the Straits of Mackinac four to five months of the year. Milwaukee had the best harbor ever, but Milwaukee needed to attract trade for that harbor if the City were to remain competitive with Chicago.[38]

The Menomonee River Valley and Lakeshore Improvements: 1870-1881

The Valley: By the end of 1870, the City of Milwaukee had eight miles of docks, all privately owned. Milwaukee's first publicly owned dock was not built until 1933. Milwaukee merchants were handling increasingly larger amounts of wheat, and the City was continuing to grow. More dock space was needed, but where could it be found? The Milwaukee River had been developed as far upstream as possible. After the old dam collapsed in 1866, a new dam had been built on the Milwaukee River

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[35]*Milwaukee Sentinel, April 15, 1858, p. 1.*

[36]*Milwaukee Sentinel, April 28, 1864, p. 4; October 30, 1868, p. 4.*

[37]*Milwaukee Sentinel, July 23, 1870, p. 1.*

[38]*Derby, op. cit., pp. 177, 229-267.*

between Humboldt and North Avenues for sanitary and health reasons. (The slight overflow from the dam would speed up the sluggish river flow, and the increased speed would "flush" the river clean.) Since most of the harbor effort and city growth was to the north, the Kinnickinnic River and Basin were ignored. This meant expansion for the Menomonee River Valley.[39]

The Menomonee River and its valley separated the northern part of Milwaukee from the southern part. The valley was marshland and swamp—considerably lower than the land the City was built on. The Menomonee River was very shallow and meandering. However, the valley was centrally located, and there were no previous developments to clear. Feeling the advantages outweighed the disadvantages, some of the City's leading businessmen agreed in 1868 to plan the development of the Menomonee Valley. The plan that provided the most dock footage was to build east-west canals, paralleling the direction of the river valley. Once the businessmen agreed upon this plan, they presented it to the Common Council. Obtaining the Council's approval, the businessmen asked the Wisconsin Legislature to authorize the improvements. The resulting act had three provisions. Three canal commissioners were to be appointed by the Mayor of Milwaukee to design and construct a system of canals in the Menomonee River Valley. They were to have final authority over the width and dock lines of the Menomonee River. There was to be no charge to the City for constructing the canals. (There could be no charge because the City had not yet gone under the $500,000 limit imposed by the Readjustment Act.)[40]

In February 1869 Mayor Edward O'Neill appointed General F. C. Winkler, F. S. Blodgett, and D. J. Whittemore as Canal Commissioners. Whittemore was chief engineer for the Chicago, Milwaukee & St. Paul Railroad, and his skills greatly aided the project. While the ground was still firm with winter frost, the valley was surveyed and the desired improvements laid out. The City's Board of Public Works then absorbed the canal commissioners' responsibilities through a change in the city laws, and the commissioners retired. The Menomonee Valley canal system was completed by 1874, at a cost of about $200,000, adding 13,700 feet of dockage to Milwaukee's harbor. Again, all the new dock footage was privately owned.[41]

The canal system was designed with four major east-west canals, and one major north-south canal (see Map 5). The northernmost east-west canal was called the Kneeland Canal (for James Kneeland, one of the major promoters of the Valley) and was cut into the marsh, containing no part of the Menomonee River within it. The next east-west canal south was called the Menomonee, or North Menomonee, Canal. The Menomonee River made a southerly U-shaped loop beginning at about 3rd Street, turning back north at about 14th Street, and then turning back west. The Menomonee Canal was parallel to the Kneeland Canal, and connected the top of the U to the original Menomonee River channel. The third, called the South Menomonee Canal, followed the original river channel at the start of the U, just over 1,100 feet southerly, made a bend to the southwest, briefly retouched the original river channel, and then gradually swung westerly, ending at 14th Street. The southernmost canal was called Burnham's Canal, after the Burnham brothers, among the developers of the Menomonee project, and their abutting brickyard. It followed the original river channel from the South Menomonee Canal southwesterly for about 1,000 feet and then swung westerly, ending about 14th Street.

The major north-south canal was called the Holton Canal, after the businessman who wanted the canal system to be oriented in a north-south direction. It was located just west of 6th Street and

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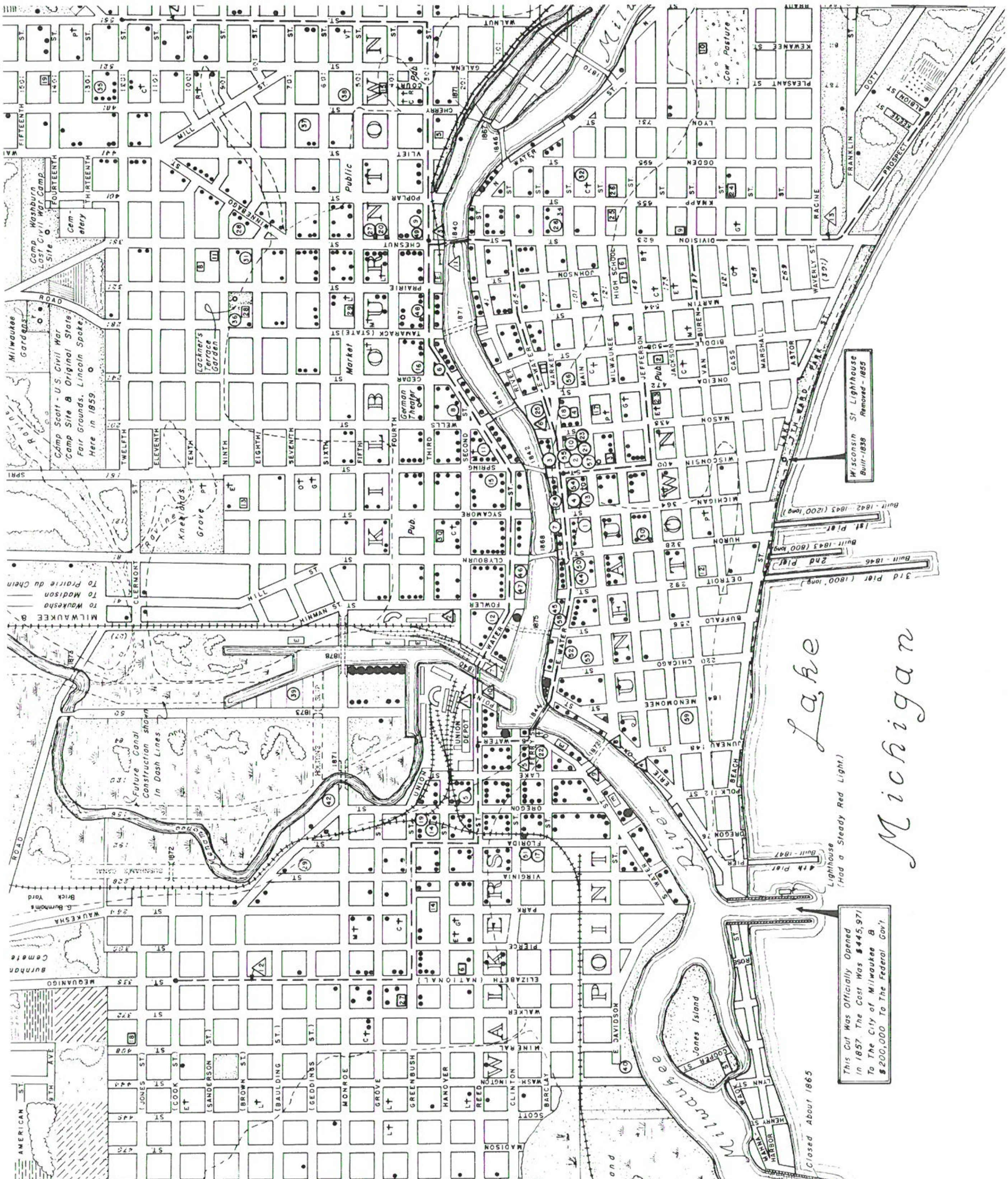
[39] *Laurent, op. cit., p. 300; Derby, op. cit., p. 249.*

[40] *Derby, op. cit., p. 283; Howard Louis Conrad, editor, History of Milwaukee, Vol. 2 (Chicago, 1895), p. 11; Flowers, op. cit., p. 473.*

[41] *Derby, op. cit., loc. cit.; Conrad, op. cit., loc. cit.; Flowers, op. cit., loc. cit.*

Map 5

MENOMONEE VALLEY CANAL SYSTEM



Source: Mackie Westbrook, The Quest for Milwaukee's Port Policy 1900-1920; Donald Alfred Gandre, Land Use in the Milwaukee Port Area 1920-1963; and Milwaukee Public Library.

connected the North and South Menomonee Canals. Several north-south slips were added to the South Menomonee Canal west of the Holton Canal. From east to west, these slips were called the Vogel Slip, located about 500 feet west of the Holton Canal; the Wagner Slip, located about 500 feet west of the Vogel Slip; and the Pabst Slip, located about 700 feet west of the Wagner Slip.[42]

These canals were quickly put to use. The swampy land between the canals was raised by fill. The Chicago, Milwaukee & St. Paul Railroad freight yards and rolling stock maintenance facilities occupied much of the new area. The lower reaches of the canal system handled mostly grain and package freight. The upper reaches of the canal system were occupied mostly by coalyards. Package freight included goods shipped in various containers, such as sugar, salt, and grain. A substantial portion of the South Menomonee Canal served meat-packing and leather-tanning industries. The Menomonee Valley soon handled the largest tonnage among port subareas.[43]

The Lakeshore: The only other harbor work the City of Milwaukee did from 1870 to 1881 was to increase the depth of all the channels. In 1868, the standard channel depth was twelve feet. During the 1870's, it was fourteen feet. In 1880, the depth was increased to sixteen feet. With deeper channels, dredging became increasingly expensive. The city government appropriated $40,000 on dredging in 1880, and that covered only part of the needed work.[44]

During this period, the U. S. Army Corps of Engineers maintained only the piers and channel of the "Straight Cut." The North Pier was lengthened 350 feet, 1870-1872, and the entire length, 1,656 feet, received a new superstructure over the stone-filled timber cribs. From 1875 to 1877, a stone cap superstructure was placed over the western, or land, end a distance of 672 feet. In 1878 and 1879, a concrete cap superstructure was placed on the next 393 feet. The South Pier, also of stone-filled crib construction, was lengthened 500 feet between 1870 and 1872, reaching a total of 1,635 feet. This new section received a timber superstructure at that time. In 1877, the original 1,035-foot timber superstructure of the south Pier was replaced with a new timber superstructure. In addition to working on the piers, the Corps of Engineers continued to dredge the "Straight Cut" for the City, but not west of the shoreline.[45]

The most significant work of the 1870 to 1881 period was done by the Chicago & North Western Railway. Prevented from using the Union Depot on Reed Street, the railroad built its own depot on the lakeshore at the foot of Wisconsin Avenue. To reach the new depot, the railroad ran along the lakeshore. When storms off the lake struck Milwaukee, this rail line was subject to wave damage (see Figure 1). An October 29, 1873, northeaster submerged 300 feet of track south of Buffalo Street. By the next storm, November 13, 1873, the railroad had raised its tracks and protected them with stone riprap. To protect the line further, the railroad sank stone-filled timber cribs 100 feet offshore. By 1877, this breakwater system covered the entire stretch of beach from North Point southward almost to the "Straight Cut," costing the railroad over $150,000 (see Figure 2). Although the

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[42]*Gandre, op. cit., map appendix; Mackie Westbrook, The Quest for Milwaukee's Port Policy 1900-1920 (University of Wisconsin-Milwaukee dissertation, 1965), map appendix. The canal locations are coordinated with the streets north of the Menomonee River Valley. I could not find the exact dates for the construction of the three slips on the South Menomonee Canal.*

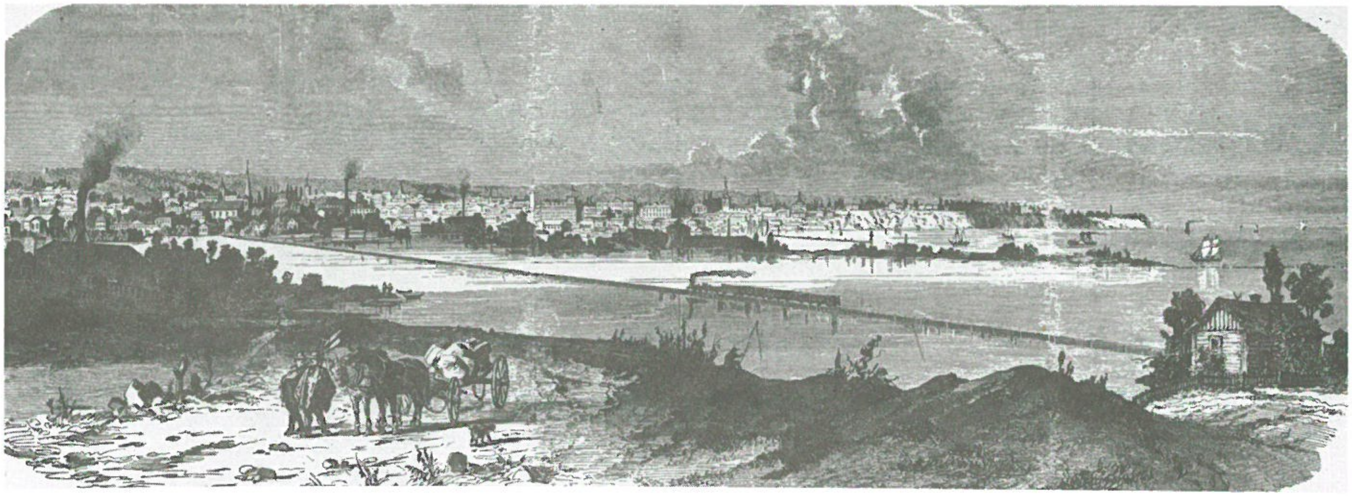
[43]*Gandre, op. cit., p. 31.*

[44]*Derby, op. cit., p. 298.*

[45]*U. S. Engineer Office, op. cit., graphs on North and South Piers.*

Figure 1

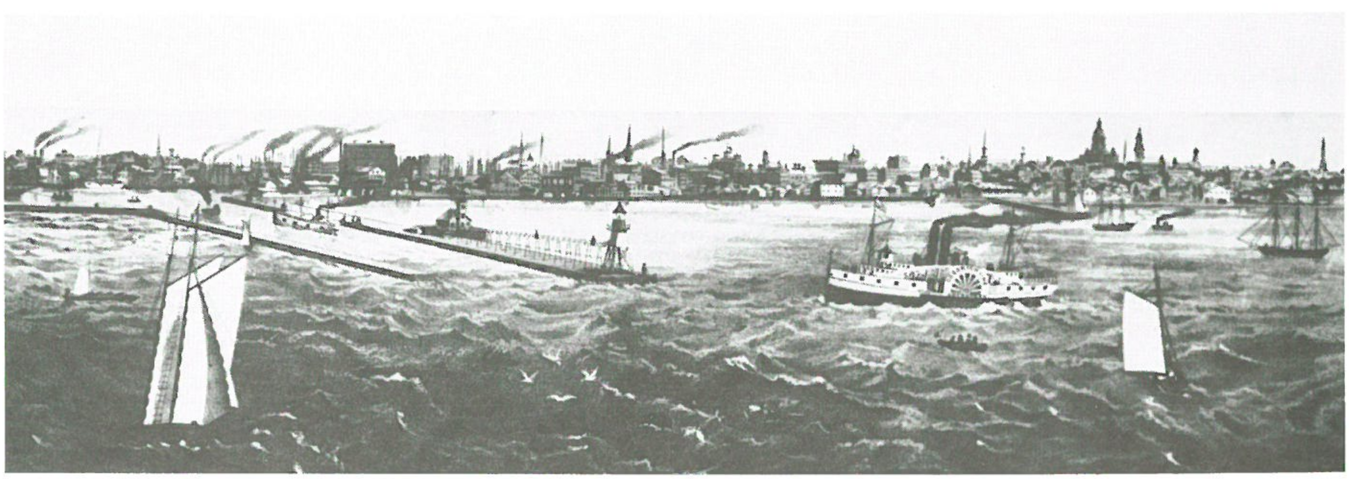
MILWAUKEE HARBOR, WISCONSIN: 1860



Source: Wisconsin Marine Historical Society Collection, Milwaukee Public Library.

Figure 2

MILWAUKEE HARBOR ENTRANCE: CA. 1872



Source: Wisconsin Marine Historical Society Collection, Milwaukee Public Library.

breakwater was built to protect private corporate assets, it also reduced the impact of storms on the lower public lakefront portions of the City.[46]

Severe storms continued to affect Milwaukee. The same northeaster that submerged the North Western Railway line also inundated much of the Third Ward. Several feet of water covered the area south of Buffalo Street east of Milwaukee Street. Citizens had to use boats as the waves flowed down the streets. These were so strong that houses were pushed off their foundations.

Two weeks later, on November 13, 1873, a southeaster, complete with snow, flooded the Third Ward again. Tragedy now struck at the "Straight Cut." About 10 p.m., the schooner Eliza Gerlach hit the trestle work on the North Pier and lost her headgear. Although she quickly dropped her anchor to prevent further damage, the storm left her lying north-south on her anchor line, blocking the channel. When the later arriving schooner Challenge could not avoid the Eliza Gerlach, and struck her on the starboard quarter, the Challenge lost her topmasts and everything forward, quickly filled with water, rolled over, and sank. Fortunately, only one man died, but the channel was blocked. The Challenge's remains were cleared away before the next season started.[47]

Storms continued to strike Milwaukee for the rest of the decade. An April 1874 northeaster was so strong that several ships inside the harbor were damaged. The wind and wave action caused anchors to drag and captains to misjudge their anchoring. Another northeaster, September 11, 1875, produced the heaviest seas in sixteen years. The waves went over the Chicago & North Western Railway's breakwaters, across the beach, and into the Third Ward. Despite flooding, the Third Ward suffered little damage because the breakwaters absorbed much of the waves' force. The bark Tanner lost its canvas during the storm and had to be towed into port. When the towline parted, the Tanner hit the pier pilings and sank. On October 20, 1877, another storm struck Milwaukee. The Milwaukee Sentinel reported "huge waves sweeping over the north harbor pier, and at intervals striking the lighthouse crib with such force that as the spray shot upward the keeper's building was almost hidden from view." By June 1878 the cribs which the lighthouse stood on were so storm-damaged they needed immediate repair. In August of that year, repairs were made and a stone superstructure was placed over the wooden cribs.[48]

Despite its growth during the 1870's, Milwaukee's port faced an uncertain future. Milwaukee's chief rival, Chicago, continued to expand its rail network, and took more traffic from Milwaukee. With the opening of the Sault Sainte Marie Canal, a new rival, Duluth, sprang into the trade wars, further diminishing Milwaukee's share of the grain trade. Duluth was closer to both the western wheat fields and the Twin Cities' flour mills. The rail rates were also cheaper, since the grain did not have to be shipped across Wisconsin. Milwaukee's port had problems, since the use of larger ships also required expensive harbor improvements to accommodate them.[49]

The Harbor of Refuge: 1881-1900

The period from 1881 to 1900 was important for the Milwaukee Harbor. Up to this time, the community's leaders pursued economic growth and sought to make the port a major influence in that growth. The grain trade—primarily wheat—made Milwaukee and its port grow. City merchants did not realize that 1875 would be the high point—27,878,727 bushels—for their wheat trade, but they

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[46] *Milwaukee Sentinel, October 29, 1873, p. 8; November 13, 1873, p. 6; August 23, 1876, p. 8; September 9, 1876, p. 8; April 14, 1877, p. 8.*

[47] *Milwaukee Sentinel, October 29, 1873, pp. 6, 8; November 13, 1873, p. 6; November 22, 1873, p. 6.*

[48] *Milwaukee Sentinel, April 13, 1874, p. 4; September 11, 1875, p. 1; October 20, 1877, p. 2; June 11, 1878, p. 8; August 20, 1878, p. 8.*

[49] *Derby, op. cit., pp. 227, 234-238, 288f.; Westbrook, op. cit., pp. 53-55.*

might have realized that a problem was developing. In 1873 more grain was shipped from Lake Superior than from Milwaukee, and more flour was milled in the Twin Cities than in Milwaukee.[50]

During this period, the port's emphasis began to shift. At the beginning of the period, most of the port's promotional efforts focused on exports, primarily wheat and flour. During the 1880 to 1900 period, however, the promotional emphasis began to change. Rather than return to Milwaukee with empty holds after carrying out wheat and flour, captains began to carry bulk items like lumber, coal, and salt to Milwaukee. Milwaukee's needs, too, were changing. The coal fueled Milwaukee's growing industries and served for heating. Milwaukee's economy was shifting from an agrarian-mercantile economy to a heavy-industry economy. Lumber was needed for construction, since the City was rapidly expanding. As a result, the port began to handle more imports than exports—a reversal from the beginning of the period.[51]

In the 1880's and 1890's Milwaukee's Inner Harbor was dormant. In 1881 the outer harbor channel depth was increased from 16 to 18 feet, but nothing was done in the Inner Harbor until 1895, when the channel depth was increased to 19 feet. Annual city expenditures on the harbor averaged $24,000—mostly for dredging. However, the private companies improved their own docks, developed some facilities in the Kinnickinnic Basin and River, and maintained about 22 miles of docks in the Inner Harbor.[52]

The focus of attention from 1881 to 1900 was on Milwaukee Bay. In 1880, and again in 1881, the federal government offered to construct a better harbor of refuge at Milwaukee. Two plans were considered. The first plan called for the harbor of refuge to be placed in an improved Kinnickinnic Basin and River. That plan was found to be impractical because the enlargement of the Kinnickinnic Basin and River would be too costly. The second plan was to build a long breakwater from North Point out into the Milwaukee Bay (see Map 6). This plan appealed to both the Milwaukee Chamber of Commerce and the U. S. Army Corps of Engineers. The former supported the plan because it offered to provide the most immediate gain for Milwaukee's shipping. The latter liked the plan because the breakwater could protect more ships than the Kinnickinnic Basin plan could, and the breakwater might help prevent the perennial accumulation of silt at the mouth of the "Straight Cut." This second plan was approved by a Board of Engineers and, in 1881, Congress appropriated $100,000 to begin construction of the breakwater.[53]

The U. S. Army Corps of Engineers began construction of the breakwater in 1881. The River and Harbor Act of March 3, 1881, called for a breakwater 7,650 feet long, including an opening of 400 feet. The northern section extended from a point about 1,000 feet east of the Milwaukee Yacht Club in a southeasterly direction for a distance of 2,450 feet and was completed by 1885. An additional. 1,000 feet was constructed by 1889 to the point of the proposed 400-foot gap. The remaining 3,780-foot section was completed by 1900. The breakwater protected 540 acres, which was dredged to a twelve-foot depth. To pay for the project, Congress appropriated another $100,000 in 1882, and $60,000 annually until 1900, a total of about $1,000,000.[54]

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[50]*Derby, op. cit., pp. 285-289, 412-421.*

[51]*Derby, op. cit., pp. 308-366.*

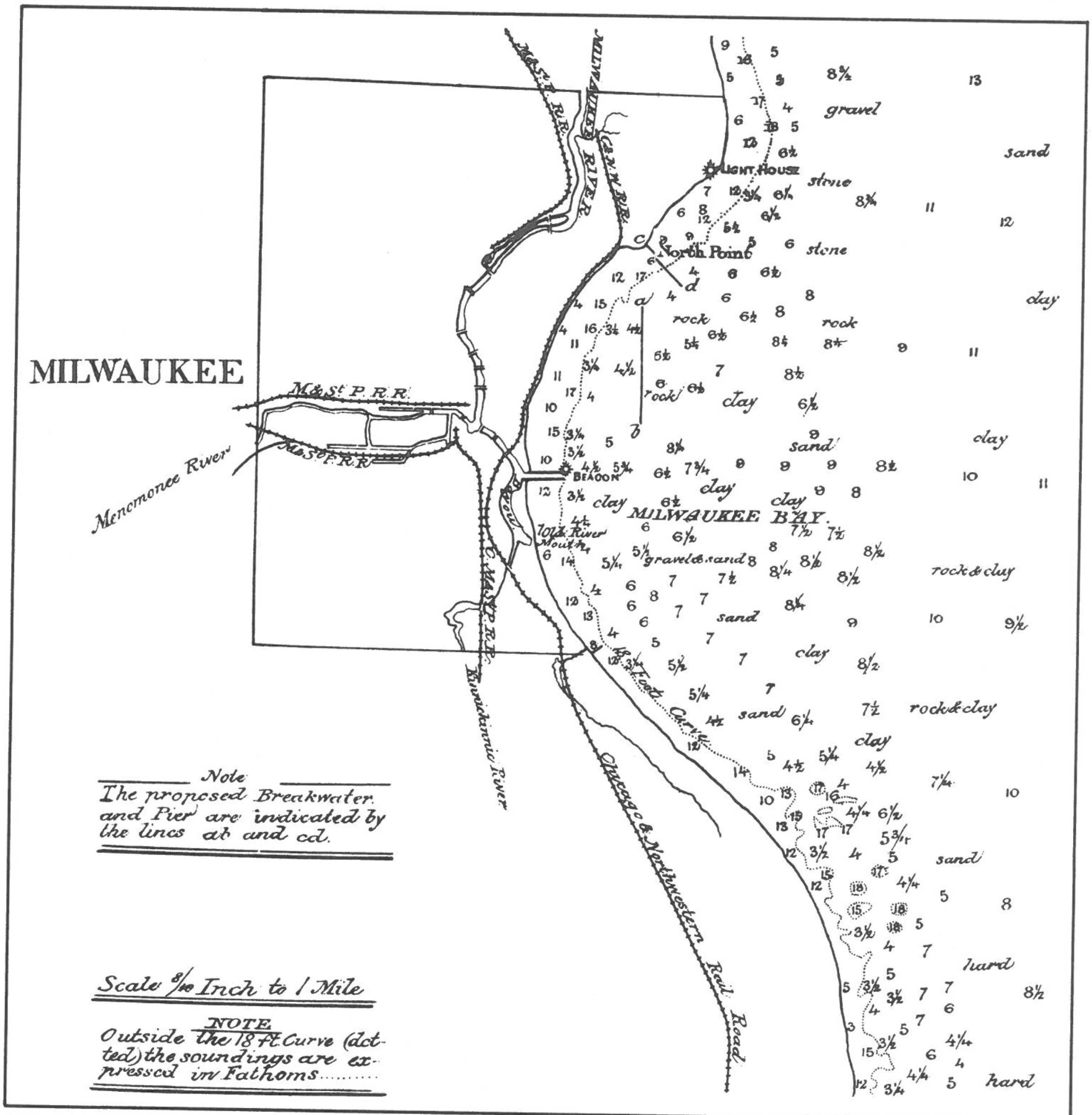
[52]*Laurent, op. cit., pp. 302-304.*

[53]*Derby, op. cit., pp. 229f.; Laurent, op. cit., pp. 302-305; U. S. Engineer Office, op. cit., graph on the North Breakwater.*

[54]*Ibid.*

Map 6

MILWAUKEE BAY PIER AND BREAKWATER PLAN: 1880-1881



House Ex. Doc. No. 43, 3rd Sess, 46th Cong.

Source: 46 Congress, 3 Session, House Executive Documents No. 43, Serial No. 1968, Washington, D. C., 1881, and Milwaukee Public Library.

When the breakwater was completed, an Army Engineers spokesman commented on its advantages: "First, if affords considerable protection from north and northeasterly winds; second, it arrests the shore drift and thereby retards the depositing of materials in the vicinity of the harbor entrance, rendering less dredging necessary to maintain the required depth of channel."[55]

While no precise accounting exists of how many vessels used the harbor of refuge during storms, it was generally used as a good anchorage when the Inner Harbor was congested with traffic. The only other federal work on Milwaukee harbor was provided for in the River and Harbor Act of 1899, when the "Straight Cut" was authorized to be dredged to a depth of 21 feet. This depth was becoming necessary since the Great Lakes ships were becoming larger to accommodate efficiently more bulk cargoes.[56]

Although Milwaukee's port facilities continued to grow after the addition of this harbor of refuge, Milwaukee's port continued to fall behind its chief competitors, Chicago and Duluth. In order to capture a larger share of the new ore traffic, Chicago built the Calumet Harbor. Duluth build a new harbor to handle the new bulk ore carriers. Milwaukee, on the other hand, still relied on its old river-based harbor, which was rapidly growing too narrow for the newer ships. During the 1880's a decline in Milwaukee's total shipping began. The harbor, once a leader on the western shore, was steadily falling behind its competitors.[57]

Milwaukee's Search for a New Harbor: 1900-1920

By the beginning of the twentieth century, Milwaukee had changed in many ways. The City had moved from being a purveyor to the east of western agricultural produce into a producer of durable goods. Milwaukee had also changed from an export port into an import port. Her export commerce had changed from shipping all over the Great Lakes to carferry service across the Lake and to coastal shipping. Although a good harbor had been built, it was not fully used, nor were its facilities adequate for the new lake trade. Fortunately some Milwaukeeans were planning for the revitalization of the harbor.[58]

The grain merchants and railroad companies made large profits during the heyday of Milwaukee's grain trade. They dominated the Chamber of Commerce and could sway city government. But a new group was rising to challenge their control. Milwaukee's industrialists and manufacturers formed their own organization, the Merchants and Manufacturers Association. This new group urged that the harbor become more responsive to current needs. The harbor, in their view, should be centered in Milwaukee Bay, where the new large steel-hulled bulk carriers would have ample room to maneuver. They also wanted easier and less expensive railway access to the harbor from their manufacturing plants. The association gained an indirect ally in Milwaukee's Socialist Party, which capitalized on the growing resentment of the city voters toward the railways.[59]

In the River and Harbor Act of June 13, 1902, Milwaukee's Inner Harbor—the rivers, canals, and attendant docks—and the harbor of refuge were consolidated. This permitted the U. S. Army Corps of Engineers to work on the Inner Harbor. Using their influence, the Chamber of Commerce pushed for, and obtained funds for, a renovation of the Inner Harbor through the River and Harbor Act of

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[55] *Laurent, op. cit., p. 305.*

[56] *Annual report of the Chief of Engineers,* U. S. Army on Civil Works Activities 1914 *(Washington, D. C., 1915), p. 1490; Derby, op. cit., p. 376.*

[57] *Derby, op. cit., pp. 376-388.*

[58] *Derby, op. cit., pp. 376-392.*

[59] *Derby, op. cit., p. 399; Westbrook, op. cit., pp. 62-66.*

March 3, 1905. Renovation of the Inner Harbor would delay for years any improvements on the harbor of refuge. Even though the federal government would pay for most of the project, the Merchants and Manufacturers Association and the Socialist Party formed an alliance and blocked any work on the Inner Harbor through a series of lawsuits. The conflict of interest between these two groups now became open.[60]

In 1909 the Merchants and Manufacturers Association hired a civil engineer, Isham Randolph, to design the best harbor Milwaukee could have. Presented on December 27, 1909, Randolph's plan developed Jones Island into the new major docking area of the harbor (see Map 7). The western, or inner, side of Jones Island was to have 9,100 feet of docks. The part of the Island facing the Kinnickinnic Basin was to have one long dock consisting of five freight sheds. Just north of the freight sheds were to be two carferry slips. North of the carferry slips, at the end of Jones Island, on the site of the present Jones Island Sewage Treatment Plant, were to be three slips and corresponding piers. On the eastern, or lake, side of Jones Island, there were to be six slips for three general cargo docks, an elevator dock for grain, a salt dock, a coal dock, and a lumber dock. These eastern docks would add 17,750 feet of new docks. The whole eastern side would be pushed out into the Lake by landfill and bulkheading to make room for railway access lines to these docks. Randolph wanted the northern breakwater to be extended and a new southern breakwater to be built in order to protect Jones Island. He estimated the whole project to cost about eight million dollars.[61]

The Randolph Plan came under immediate attack by both the Socialists and the Chamber of Commerce. The Socialists thought the cost was both too high and estimated too conservatively. The Illinois Steel Company, which owned the southern end of Jones Island, also opposed the plan. If the plan were adopted, they would have to sell the land back to the City. The Chamber of Commerce, and especially the railroad companies, opposed the plan for a number of reasons. Randolph proposed a municipally-owned railway line to control access to the new docks and a municipally-owned railway constructed around Milwaukee so that harbor goods could easily be collected or distributed to or from Jones Island and the City. This would break the railroad companies' hold over access to the harbor. But the final blow to Randolph's plan came in 1910 when the federal government refused to fund the project.[62]

Then, in 1912, the Merchants and Manufacturers Association and the Outer Harbor plan had a stroke of good luck. Dr. Gerhard Bading, a member of the association, was elected Mayor. He saw to the creation of a new Harbor Commission in August 1912 and placed William George Bruce in charge. Bruce, understanding the opposition, called for a balanced approach to harbor development. He stressed new developments for the Inner harbor, but also called for beginning work on the development of an Outer Harbor (see Map 8). Bruce and Bading's successor as Mayor, Daniel Hoan, spent the rest of the decade promoting the development of the Outer Harbor, seen as essential for the larger ocean-going vessels that would call in Milwaukee when the St. Lawrence Seaway was finished. This project was originally proposed to be built in the 1910's. Hoan and Bruce also managed to remove legal entanglements blocking the Outer Harbor development.[63]

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[60] *Westbrook, op. cit., pp. 65f.; Annual Report of the Chief of Engineers 1938 (Washington, D. C., 1939), p. 1462.*

[61] *Isham Randolph, Report of Isham Randolph, C. E., on the Jones Island Harbor Project (Milwaukee, 1909).*

[62] *Westbrook, op. cit., pp. 68f.; Randolph, op. cit., p. 19.*

[63] *Westbrook, op. cit., pp. 70-75.*

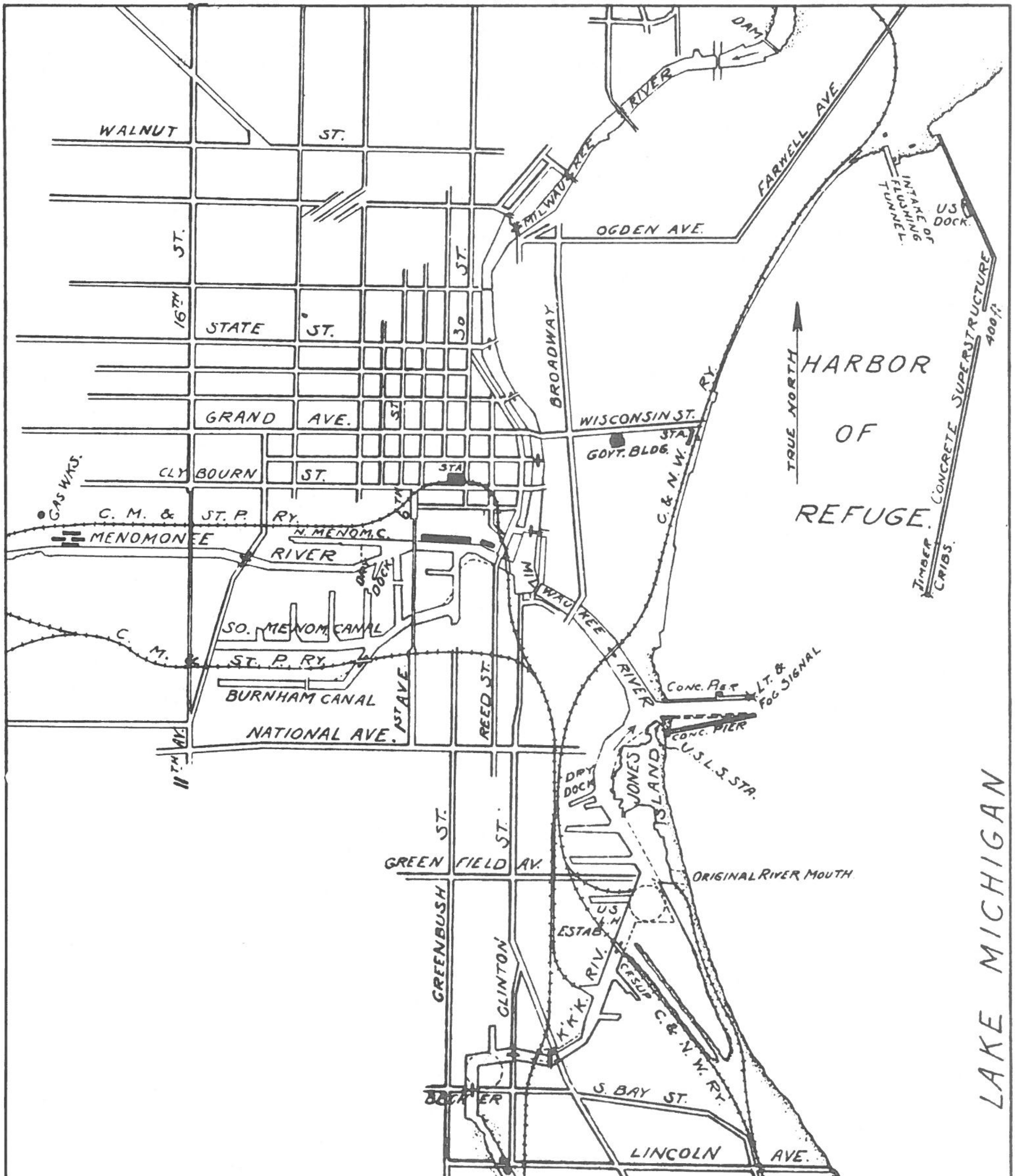
Map 7

PLAN FOR MILWAUKEE HARBOR

Source: Isham Randolph, Report of Isham Randolph, C. E., on the Jones Island Harbor Project, and Milwaukee Public Library.

Map 8

MILWAUKEE HARBOR, WISCONSIN: JUNE 1911



Source: U. S. Engineer Office, Milwaukee, Wisconsin, September 30, 1936.

Figure 3

TERMINAL DEVELOPMENT PLAN: 1920

Source: Port of Milwaukee.

By 1919, attitudes were so favorable towards development of the Outer Harbor that Hoan and Bruce brought in a civil engineer, H. McClellan Harding, to prepare a second harbor plan for Milwaukee. On January 20, 1920, Harding presented his plan to the Harbor Commissioners and the Common Council (see Figure 3). Similar to Randolph's plan, Harding's plan reflected more recent developments in shipping and urban development. The northern end of Jones Island, where Randolph had proposed two carferry slips and three regular slips, had become the site of a sewage treatment plan; hence, the land was no longer available for docks and slips. The Kinnickinnic Basin had been enlarged to handle bigger ships, removing much of the area Randolph had planned for docks. Harding also calculated Milwaukee had only 10 miles of frontage available for modern ships, even though the harbor had 20 miles of frontage. Ten miles of frontage were lost because the rivers were too narrow or the frontage inadequately developed. His plan would add another three miles of frontage.[64]

Like Randolph, Harding proposed the breakwater be extended to protect Jones Island. Jones Island would have docks built on the lake side for bulk freight such as coal, lumber, and salt. Unlike Randolph, Harding wanted to build docks and facilities north of the "Straight Cut" along the lakeshore. These docks would handle the passenger traffic and the quickly usable goods, such as foods. These docks were very close to Milwaukee's central business distinct and wholesale distribution center. There were also plans to build a lakefront recreation pier for Milwaukee's citizens to enjoy the lake and harbor activity. He planned for barges and small vessels to use the Inner Harbor so that the City could build more economical fixed bridges instead of movable bridges. Harding produced no cost estimates since he was unsure of the timetable for construction.[65]

Harding's plan was accepted by the Harbor Commission and the Common Council, and became the basis for Milwaukee's port development up until today. It crowned Hoan's and Bruce's vision of the harbor.[66]

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[64] *Gandre, op. cit., p. 50; McClellan Harding, Proposed Terminal Development of the Port of Milwaukee (Milwaukee, 1920), passim.*

[65] *Gandre, op. cit., p. 50; Harding, op. cit., passim.*

[66] *Gandre, ibid.*

Through the contention between the Inner Harbor and Outer Harbor advocates, Milwaukee Harbor continued to change. The breakwater forming the harbor of refuge was extended another 980 feet by 1910; then no additional work was done until the mid-20's. The River and Harbor Act of March 2, 1907, provided funding for that breakwater extension and a new pier at the "Straight Cut." The new pier replaced the southern "Straight Cut" pier since the "Straight Cut" was to be improved to accommodate larger ships and to help prevent surging in the Inner Harbor. While the "Straight Cut's" outer dimensions between piers was 360 feet, the inner width was expanded to 550 feet. The new pier, 1,608 feet long, was built in 1909 and 1910. The outer 1,407 feet of the old pier were removed in 1910 and the remaining 228 feet were finally removed in 1929 and 1930. The Inner Harbor channel depth, dredged to a 21-foot depth since 1903, was ready for larger ships. However, the rivers were too narrow for larger ships to turn around. The U. S. Army Corps of Engineers proposed construction of three turning basins in the Inner Harbor, two in the Kinnickinnic Basin and River, and one in the Menomonee River. For the turning basins to be built, the City of Milwaukee had to provide the necessary land, build the needed docks, and alter the bridges for the larger ships. Since the City never provided the land necessary for the turning basins, they were never constructed.[67]

Conditions outside the harbor were also changing. In 1912, the Panama Canal Act was passed, which prohibited land common carriers from directly regulating, controlling, or owning water common carriers. Carferries, however, were exempt from the law. The railroads retaliated in several ways. They dropped the rates for hauling cargo below that for ships, delayed or gave low priority to ships' cargoes when bringing them overland to port, and charged discriminatory rates for usage of terminal and transfer facilities. The latter was possible since the railroads owned most of those facilities and still could operate them under the new law. Therefore, the average annual tonnage of lake traffic dropped from 1,674,000 tons in 1911-1915 to 688,000 tons from 1916-1920.

Another change was the growing number of trucks taking the coastal package freight away from ships. Trucks were more dependable in all types of weather than ships were. By 1919, Milwaukee's flour mills, which at one time supplied much of eastern United States, had collapsed to the point where they could not supply Milwaukee's needs. The shift to durable goods kept Milwaukee's economy growing, but crippled the lake trade. Not only were the raw materials shipped in by railway, but the finished products were also shipped out by railway. Milwaukee's booming lumber trade also shifted from ship to rail by 1920. The reason for this transportation change was that the Wisconsin forests were becoming depleted and lumbering was moving farther inland, away from cheap lake transportation.[68]

<u>The Outer Harbor: 1920-1983</u>

Once Harding's harbor plan was approved, the development of the Harbor entered a new era. Previously, it had always been located inside the shoreline, along Milwaukee's rivers. Now the main harbor was to be located on the shoreline and out into Milwaukee Bay (see Map 9). In developing its new harbor, Milwaukee had to overcome its old problem—lack of potential traffic.

The first step of Harding's plan, the extension of the breakwater to protect Jones Island, was provided for in the River and Harbor Act of September 22, 1922, providing for the 1,722-foot extension of the northern breakwater to a total length of 9,954 feet. Also called for was construction of a southern breakwater 9,671 feet in length. An inner entrance channel, 600 feet wide, was established, and went 2,850 feet from the "Straight Cut" eastward into the Lake, dredged to a depth of 21 feet. From bottom to top, the new breakwaters were built with stone foundations, concrete caissons instead of timber cribs, and concrete superstructures over the caissons. The main entrance to the harbor, east of the

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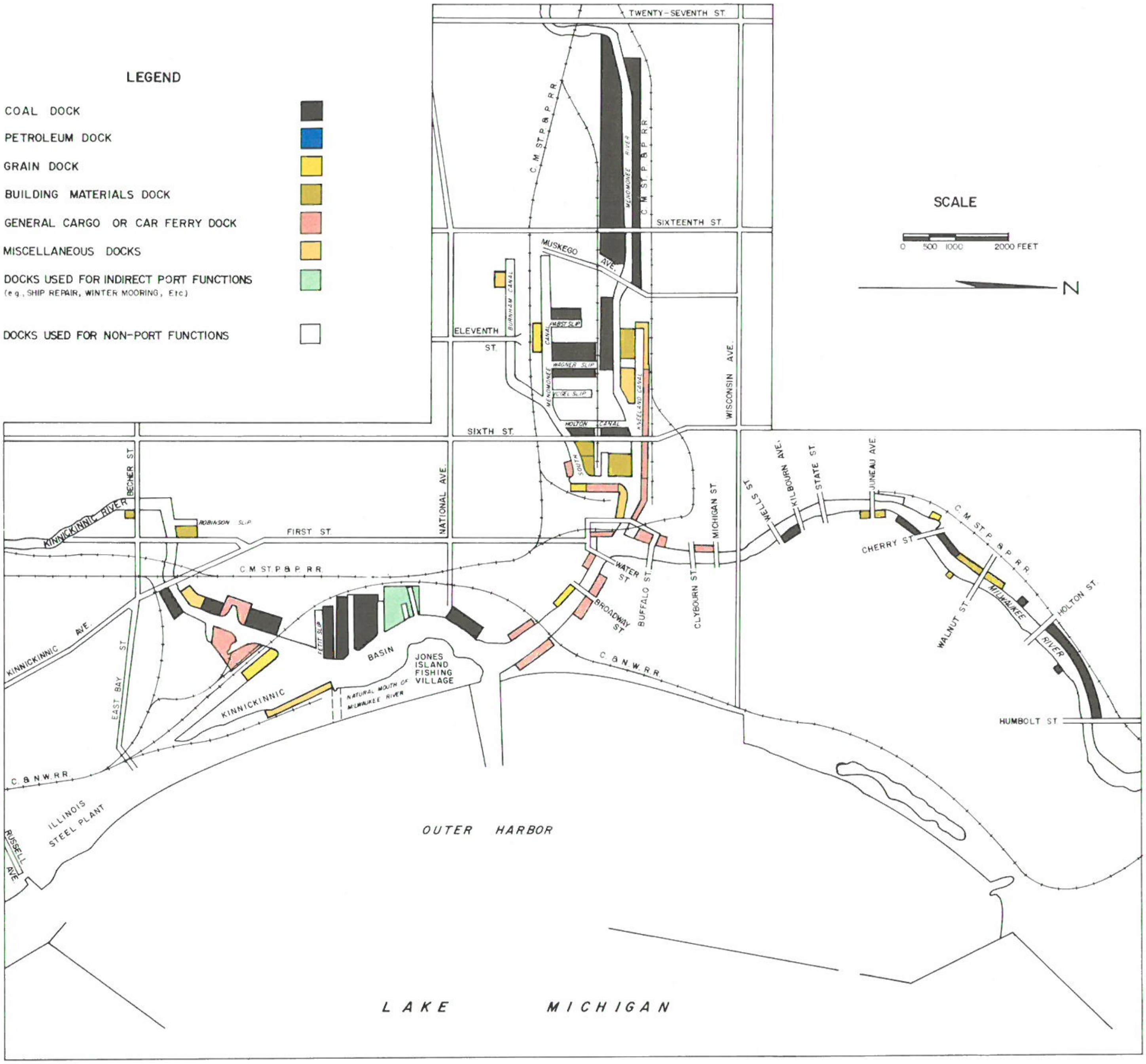
[67]*Annual Report of the Chief of Engineers 1938, loc. cit. I know that lake storms continued through the 1900 to 1920 period, and caused some damage. But no accounts have surfaced for this period. Some historians, especially Westbrook, have accused the Harbor Commission of boosterism and of hiding anything that might look bad for harbor development. Some damages, especially to the lakefront area, would be reduced somewhat when the harbor of refuge's breakwaters were extended southward.*

[68]*Derby, op. cit., pp. 351-364; Westbrook, op. cit., pp. 77-110.*

Map 9

HARBOR LAND USE, PORT OF MILWAUKEE: 1920



Source: Donald Alfred Gandre, Land Use Changes in the Milwaukee Port Area 1920-1963.

"Straight Cut," was a 500-foot gap between the north and south breakwaters. The south breakwater was constructed in three stages, starting in 1925 and ending in 1929. A small gap in the breakwater was left at the southeast angle of the south breakwater to facilitate water circulation. A storm on October 22 and 23, 1929, knocked a 756-foot hole in the middle section of the south breakwater, which was repaired at a cost of $164,460.24 by the end of 1932.[69]

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[69]*Annual Report of the Chief of Engineers 1932 (Washington, D. C., 1933), p. 1403; Annual Report of the Chief of Engineers 1938, pp. 1462-1465.*

In addition to enlarging the breakwaters, other changes were made during the 1920's (see Map 10). On Jones Island, the City obtained riparian rights, built two docks on the inner, or westerly, side, and continued landfilling. In order to obtain federal cooperation in building the Outer Harbor, the City had to agree to acquire the lakefront land between Russell and Wisconsin Avenues solely for harbor purposes and to obtain enough land for probable future as well as current harbor needs. The City filled in two large lakefront areas, one on each side of the "Straight Cut." Portions of the Kneeland and South Menomonee Canals in the Menomonee Valley and the Robinson Slip on the Kinnickinnic River were also filled. Although there was little improvement in the Inner Harbor during the 1920's, changes in harbor use occurred (see Table 1).[70]

During the 1920's, the use of the Milwaukee River declined, the use of the Menomonee Valley remained stable, and the use of the Kinnickinnic Basin increased. The decline of the Milwaukee River was caused by the increasing number of street bridges needed to handle the rising amount of automobile traffic, the narrowness of the river for large vessels, and the increasing costs to maneuver ships up the river by tugboat. The Menomonee Valley continued to specialize in bulk traffic, losing some coal docks but gaining some building material docks. The Kinnickinnic Basin grew in importance because it continued to handle the carferry traffic and gained a growing traffic in petroleum products.[71]

The U. S. Army Corps of Engineers completed its breakwater work in the early 1930's by placing large and small riprap—that is, blocks of stone—around the breakwater to protect it from waves. Then, for the rest of the decade, the Corps' work was limited to dredging and maintenance. The City of Milwaukee was, on the other hand, quite busy during the 1930's. The River and Harbor Act of August 30, 1935, allowed the City to dredge an area in the Outer Harbor from Wisconsin Avenue to E. Bay Street and 50 feet eastward of the pierhead line to a depth of 21 feet. Once this area was dredged, the City would be reimbursed roughly 10 cents per cubic yard and the Corps would maintain that depth.[72]

While the North Harbor Tract—that is, the lakeshore harbor area north of the "Straight Cut," reserved in Harding's plan for passenger and package freight—remained unimproved, the South Harbor Tract received much attention during the 1930's. Sixty-five acres of landfill were added to this tract, which finally filled in the original river mouth completely. By 1933, the Municipal Transit Shed Number 1 and South Pier Number 1 were built and put into operation, marking Milwaukee's first public pier and terminal facilities since the City began harbor development a century previously. They were constructed to handle both overseas trade when the St. Lawrence Seaway was completed and domestic movements of petroleum products. They added 3,203 feet of dock frontage. More than a mile of riparian rights were added when the City purchased the Illinois Steel Company's property in 1938 for $2,744,000.[73]

There were no significant changes in Milwaukee's Inner Harbor since the 1930's. The Milwaukee River continued to decline in use. Coal tonnage increased slightly during the 1930's in the Menomonee Valley. Only the Kinnickinnic Basin changes when its winter mooring capacity was increased from 10 to 12 vessels to 25 to 30 vessels. The additional winter mooring capacity increased the port's revenue.[74]

Few harbor improvements occurred during the 1940's. World War II diverted attention from harbor improvements during the first half of the decade. In addition to routine dredging and maintenance, the U. S. Army Corps of Engineers, under the River and Harbor Act of March 2, 1945, now dredged

[70]*Gandre, op. cit., pp. 49-110. The table was prepared from Gandre, op. cit., pp. 47f., 110, 208.*

[71]*Gandre, op. cit., pp. 72-74, 90, 110.*

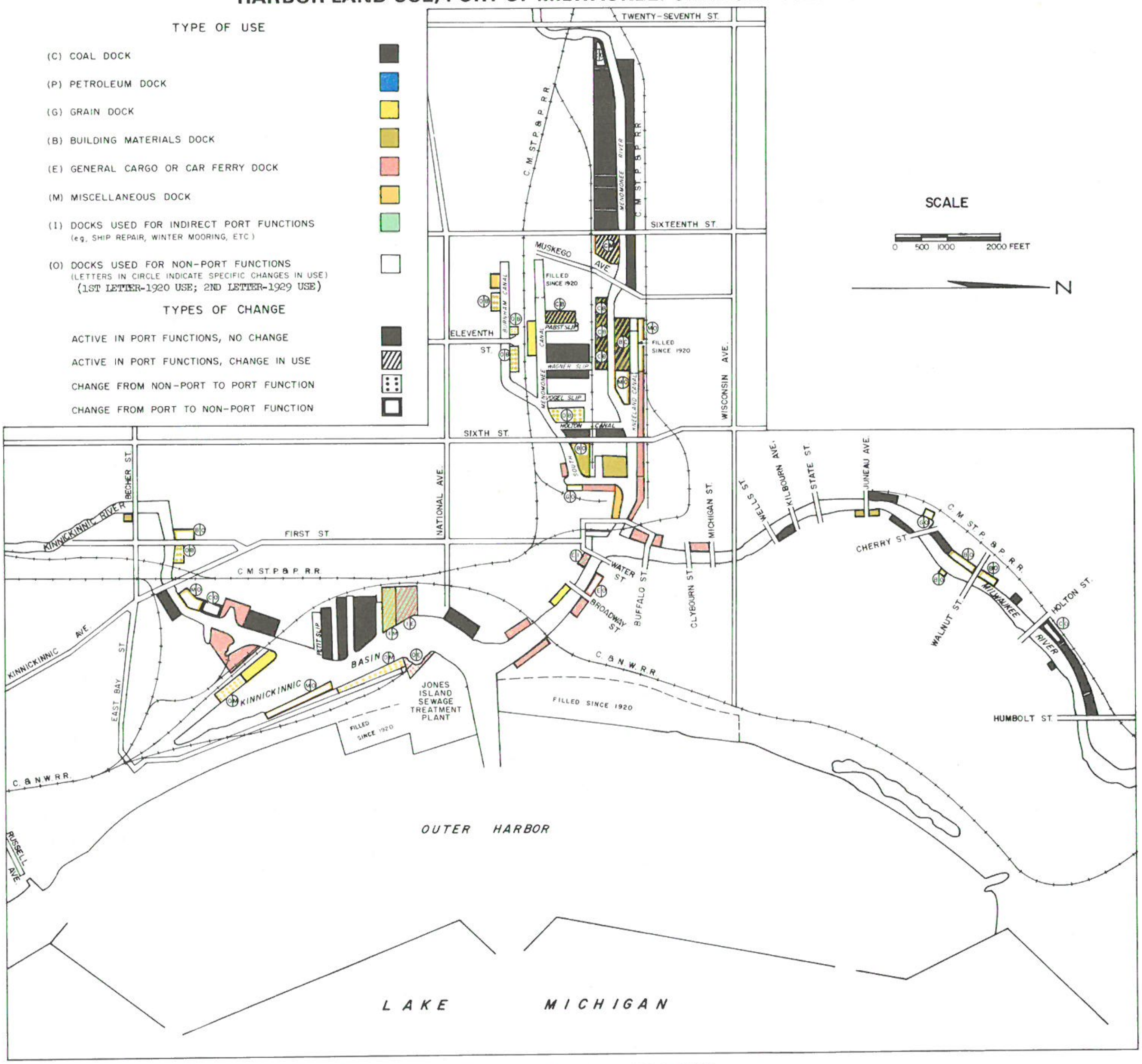
[72]*Annual Report of the Chief of Engineers 1932, pp. 1401-1405; Annual Report of the Chief of Engineers 1938, pp. 1962-1965.*

[73]*Gandre, op. cit., pp. 111-113.*

[74]*Gandre, op. cit., pp. 115-156.*

Map 10

HARBOR LAND USE, PORT OF MILWAUKEE: CHANGES 1920-1929



Source: Donald Alfred Gandre, Land Use Changes in the Milwaukee Port Area 1920-1963.

the river channels to a depth of 21 feet. A shortage of construction materials and the fact that the existing facilities were able to accommodate all of the traffic kept the City from major harbor construction work. The only such work consisted of the addition of tank farms for petroleum storage on Jones Island. The number of active docks in the entire port area decreased from 69, in 1939, to 53, in 1949, but there was increased traffic at each remaining dock. The dock decline was partly because by 1942 the shipment of package freight was handled entirely by trucks.[75]

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[75]*Annual Report of the Chief of Engineers 1945 (Washington, D. C., 1946), pp. 1737-1741; Annual Report of the Chief of Engineers 1951 (Washington, D. C., 1952), pp. 1763-1766; Gandre, op. cit., pp. 160-197.*

Table 1

CHANGES IN THE USE OF HARBOR AREAS

Location	Percent of Shipping Handled		
	1920	1939	1962
Outer Harbor	0.0[a]	1.5	15.4
Menomonee River and Canals	41.0	39.0	33.3
Milwaukee River	24.0	9.5	1.0
Kinnickinnic Basin and River	35.0	50.0	50.3
Totals	100.0	100.0	100.0

[a]*The Outer Harbor had not yet been built.*

Source: Donald Alfred Gandre, Land Use Changes in the Milwaukee Port Area 1920-1963.

The period 1950 to 1965 saw the final expansion of the harbor facilities (see Map 11). Municipal South Pier Number 5, south of Municipal Pier Number 1 in the South Harbor Tract, was completed in 1950 to handle the increase of petroleum products entering the harbor. Pier Number 5 was located adjacent to the Jones Island tank farms. Another South Tract pier, Municipal South Pier Number 2, was completed in 1961, designed specifically for salt water shipping coming through the newly completed St. Lawrence Seaway. Terminal Number 2 was on the north side of Pier 2 and Terminal Number 3 on the south side. Both terminals were for the shipment and receipt of general cargo. The City also filled in and straightened the dock lines between E. Bay Street and E. Russell Avenue during 1956. In the North Harbor Tract, the Municipal Passenger and Auto Pier was completed in 1960. Also in the North Harbor Tract, the City filled the north side along the North Pier of the "Straight Cut" by 1965, adding about eight acres of land. With the completion of these piers, the Outer Harbor shifted operations to serving overseas general cargo, domestic tanker traffic, and cross lake passenger and carferry movements. The shift had several causes. Milwaukee's need for coal tapered off as natural gas replaced coal for space heating and industrial use. Petroleum shipments also declined when the West Shore Pipe Line was completed from Whiting, Indiana, to Green Bay, Wisconsin. After years of courtroom battles, the City finally won free access to the Outer Harbor from the Chicago & North Western Railway in 1950. At last, cargo could move quickly and cheaply from the port to the City.[76]

With the increase of trade through the Outer Harbor, the Inner Harbor continued to decline in importance. By 1960 there were no active docks in the Upper Milwaukee River. Its riverbanks were used for parking structures and recreational-oriented uses. The importance of the Menomonee Valley declined as coal use dropped and economies of scale could not be achieved. The Chicago, Milwaukee, St. Paul & Pacific Railroad controlled 13,400 feet of dock space in the Valley, and either held dock space back for future development or kept it at a low level of use. The other property owners in the Valley possessed frontage too small to be used effectively. Other problems in the Menomonee Valley were the sharp bends in some of the channels, numerous bridges, and restricted channel depths. In 1955, the southern half of the Holton Canal was filled in because it could no longer handle large cargo ships. Use of the Kinnickinnic River also declined, with only three docks functioning by 1963. Its problems were the same as the other rivers', but the Kinnickinnic Basin continued to flourish because it had enough space to handle the larger ships and diversified its docks to handle petroleum products, salt, and cement.[77]

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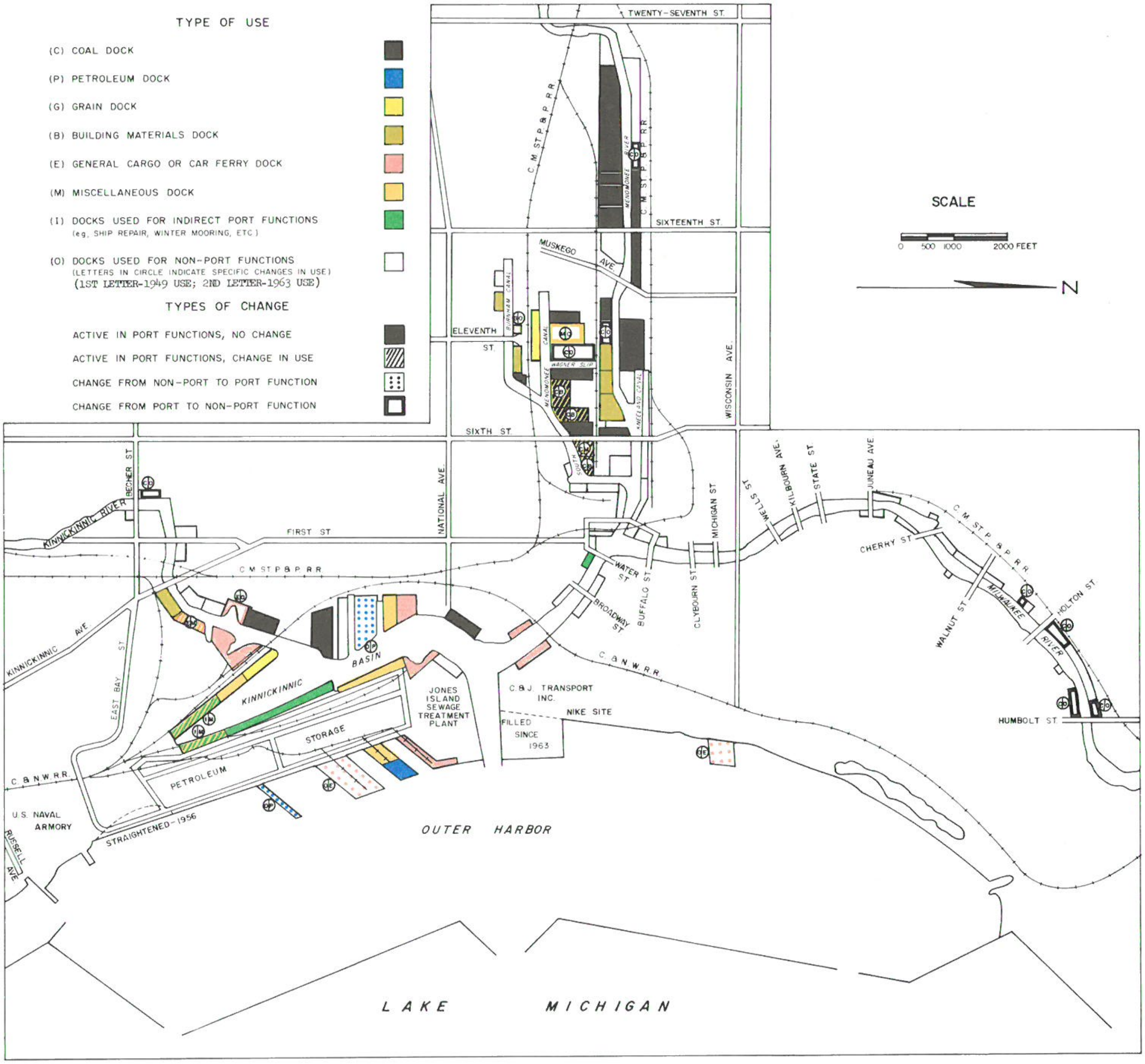
[76]*Gandre, op. cit., pp. 201-217; Westbrook, op. cit., p. 89.*

[77]*Gandre, op. cit., pp. 217-252.*

Map 11

HARBOR LAND USE, PORT OF MILWAUKEE: 1949-1963



Source: Donald Alfred Gandre, Land Use Changes in the Milwaukee Port Area 1920-1963.

The U. S. Army Corps of Engineers continued to maintain and repair the existing works and dredge the harbor. The River and Harbor Act of July 14, 1960, authorized the Corps to deepen the Burnham and South Menomonee Canals to 21 feet. The River and Harbor Act of October 23, 1952, authorized the Corps to provide a 30-foot-deep approach channel to the harbor, deepen the "Straight Cut" and Outer Harbor to 28 feet, and deepen the Milwaukee and Kinnickinnic Rivers for short sections to 27 feet. The timber cribs on the North Breakwater began to wear out and were replaced during the early 1960's.[78]

From 1965 to 1983, there was little change in Milwaukee's harbor. Its use continued to gradually decline. In 1969, the harbor handled only 12 percent of its potential. The Corps of Engineers continued to dredge and to repair and maintain the existing works, but no new projects for the harbor have been approved. Only two construction projects were undertaken by the City. At the shore end of the North Breakwater, the City built a park and recreational marina. In the South Harbor Tract, the City built a 53-acre containment basin for the Corps of Engineers' polluted dredging spoils. This basin will take approximately 10 years to fill and then become Fisherman's Park.

By 1977, the Municipal Passenger and Auto Pier in the North Harbor Tract was recognized as having failed in its purpose and became the site for the Harbor Commission's offices. The land just south of that pier had permanent buildings constructed on it for Milwaukee's annual summer and ethnic festivals. In the South Harbor Tract half of the original city terminal, Municipal Transit Shed Number 1, was razed in 1982 because it was beyond repair. The fate of the other half will be determined at a later date. An April 9, 1973, storm pushed a dislodged piling through the concrete deck of the South Pier Number 5, the Liquid Cargo Dock, as it is called. The cost to repair that damage and the damage to the rubble mound breakwater protecting the North Harbor Tract was approximately $280,000.[79]

The Harbor's Future

The future for Milwaukee's harbor was examined in 1982 by a private consulting firm, Simat, Helliesen & Eicher, Inc., which made recommendations to the City about the harbor. The consultants felt the present municipally-based organization should be converted into an autonomous corporation. The City, surrounding counties, and the State would be the major participants in this new corporation. The existing general cargo terminals should be leased to some aggressive group; the container storage areas should be maintained; and the petroleum leaseholds should be reserved for substantial project use or removed if not in use. Several projects were suggested by the consultants. Terminal Number 1, a safety hazard, should be demolished. There should be terminals for exporting coal and grain. The Greenfield property should be reserved for a bulk terminal, and the former Grand Trunk Carferry site along the Kinnickinnic River should be acquired for those bulk operations. For easier access to that site, the City should negotiate with the Chicago & North Western Railway to remove the railroad bridge adjacent to the carferry site.[80]

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[78] *Annual Report of the Chief of Engineers 1951, loc. cit.; Annual Report of the Chief of Engineers 1954 (Washington, D. C., 1955), pp. 1080-1083; Annual Report of the Chief of Engineers 1962 (Washington, D. C., 1963), pp. 1385-1389; Annual Report of the Chief of Engineers 1963 (Washington, D. C., 1964), pp. 1232f.; Annual Report of the Chief of Engineers 1965 (Washington, D. C., 1966), pp. 1114f.*

[79] *Annual Report of the Chief of Engineers 1971 (Washington, D. C., 1972), pp. 30f.; Milwaukee Harbor Commission, Harbor Commission's Annual Report for 1973 (Milwaukee, 1973), passim; Port of Milwaukee, Annual Report for 1982 (Milwaukee, 1973), passim; Robert G. Nesbit, Wisconsin—A History (Madison, 1973), p. 503.*

[80] *Port of Milwaukee, op. cit., pp. 2f.*

SUMMARY AND CONCLUSIONS

Milwaukee's harbor began with an initial advantage—the best natural harbor of refuge on the western shore of Lake Michigan. This advantage was both exploited and improved as Milwaukee's citizens used the harbor to bolster the City's economy. Both early harbor efforts—the river mouth project and the "Straight Cut"—provided an improved harbor of refuge and easier access via the Milwaukee River to the heart of the City. The latter effort was deemed better, since it was closer to the City and reduced the cost of river dredging. Incoming ships brought settlers and manufactured goods. The latter Milwaukee merchants sold to inland farmers in return for their wheat, which was then shipped east on the returning vessels. Maintaining that early advantage over her competitors with a better inland road and railway network, Milwaukee became the largest port on the Lake. In an effort to retain that advantage, dock frontage was expanded through the improvements of the Menomonee River Valley and the mouth of the Kinnickinnic River.

In spite of this early success, problems began to affect the harbor. All of the harbor's development was based on the improvement of the City's three rivers through expansion, terminals, and easier, safer access to the rivers from the Lake. Although the removal of sand bars and dredging the river channel improved access to the harbor, the narrow entrance at both the river mouth project and the "Straight Cut" caused many accidents when ships tried to enter the port during storms. By the 1880's, the rivers were becoming too small for the increased size of Great Lakes ships. Milwaukee's primary market, the farmer and his wheat, had gradually moved westward as the frontier moved west when local soil became depleted. Railways became important for rapid long distance hauling of the crop. With the rise of a national railway network, Milwaukee lost much of its trade to her competitors, Chicago and Duluth. The railways hastened the harbor's decline by handling the importation of raw materials for Milwaukee's new industries and the exportation of the finished products. The railways also controlled access to the port and owned most of the key terminal areas.

Other factors also contributed to the harbor's decline. During the years her competitors built new harbors to accommodate the larger ships, Milwaukee maintained her river-based harbor, which already had become too small for the ships and too limited in terminal capacity. Instead, the City merely built a larger harbor of refuge in the Milwaukee Bay for ships to anchor until they could enter the river areas. However, the new harbor of refuge reduced storm damage to the lakefront areas of the City. By the time Milwaukee started construction of a harbor for large vessels in Milwaukee Bay, her competitors had already surpassed her. Milwaukee's economy also changed. Once one of the nation's largest wheat and flour purveyors, Milwaukee began to shift to heavy industry during the 1870's. Because of that shift, the harbor was limited to importing bulk items and handling the coastal trade with smaller Lake Michigan ports.

At the start of this century, advocates of a new harbor wanted it built along the lakefront rather than improving the old river-based harbor. Two plans were developed for a new harbor, the Randolph Plan in 1909 and the Harding Plan in 1920. The latter plan has been used to improve Milwaukee's harbor up to the present. However, only part of this plan has actually been carried out. The main reason for this partial completion has been the lack of harbor traffic throughout most of this century. The coastal traffic has declined with the improvement of the highway system and the expansion of the trucking industry. The same two factors reduced the dependence of inland cities on Milwaukee's harbor. Bulk traffic has declined because coal has been replaced by oil and natural gas as a heating and power-producing fuel. Oil and natural gas arrive by pipeline, not by ship. Although the dream of constructing the St. Lawrence Seaway was finally realized in the 1950's, it did not transform Milwaukee into a heavily used international port. Recently Milwaukee's industries have declined, which has further reduce harbor traffic.

Lake storms helped cause improvements of Milwaukee's harbor. Sand bars and the rivers' shallow channel depth caused problems for ships trying to reach the harbor of refuge. Once these problems were dredged away, the narrow entrance between the piers of the river mouth and the "Straight Cut" caused many vessels to strike the piers during storms. Easterly and northeasterly storms created the greatest problems for ships trying to enter port, as well as for the lower lakefront areas of the City.

Even today, with the protection of the breakwaters, storms from these directions can still wreak havoc in the harbor area. While there are many reports of storm damages, actual dollar amounts of these damages are found in only a few of the most recent reports.

Several conclusions can be reached from this historical study. When ships were the fastest and most economical means of transportation, Milwaukee's port flourished. Simultaneously, Milwaukee's founding fathers and merchants aggressively pursued policies to funnel the hinterlands' products and trade through the City. Subsequent improvements in transportation, such as the railroad, coupled with the closing of the Lake by ice for at least one-third of the year, reduced the port's traffic no matter how well the harbor was built. The aggressiveness of Milwaukee's business community was rechanneled into expanding the City's rail network. The harbor was not given the same forward-looking effort that went into the railways. Only when the harbor's strongest competitors had surpassed Milwaukee did a truly modern plan for the harbor emerge. While the main pieces of that plan were built, many of the dock and terminal areas have not been constructed. However, there is little incentive to build a modern port when port traffic is so low (only 12 percent of present capacity).

Until Milwaukee's economy increases the demands on the Harbor, the City should follow the U. S. Army Corps of Engineers' example and merely maintain the present facilities. Then, if demand should increase, the port's facilities could be altered to meet that demand. Possibly the greatest value of the present harbor has not been evaluated in this paper. The recreational and aesthetic values of the Harbor may suggest the lines along which Milwaukee's harbor will grow and be protected from the Lake in the future.

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The author is a native Milwaukeean, with a B.A. in History from the Citadel, Charleston, South Carolina, and an M.A., under the tutelege of Dr. Frederick I. Olson, from the University of Wisconsin—Milwaukee (1983). In 1983, Mr. Jordan was retained by the Commission to develop historic data on flood and storm damages in the Milwaukee Harbor for use in the Milwaukee Harbor Estuary study. The historic data were incorporated into the plan and used in the development of alternative anchorage, dockage, and flood protection measures. Incidental to the development of the historic damage data, Mr. Jordan also produced the historical background information set forth in this article.

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