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EFFECT OF CHANNEL CHANGES IN THE ST. CLAIR RIVER SINCE 1900

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EFFECT OF CHANNEL CHANGES IN THE ST. CLAIR RIVER SINCE 1900[1]

Jan A. Derecki

Periodic man-made changes in the outlet of Lake Huron through the St. Clair River date back to the middle of the last century. These artificial channel changes are well documented during the present century and consist of dredging for commercial gravel removal in the upper river during 1908-25 and uncompensated navigation improvements for the 25-ft and 27-ft projects completed in 1933 and 1962, respectively. The total effect of these changes on the levels of Lakes Michigan and Huron (hydraulically one lake) and on the upper St. Clair River profile was determined with dynamic flow models. The ultimate effect of the above dredging was a permanent lowering of the lake levels 0.27 m, which represents a tremendous loss of fresh water resource (32 km^3). This total lowering of lake levels is 0.09 m higher than previous estimates, but present determinations represent a more sophisticated approach.

It is unfortunate that appropriate hydraulic data for the previous century are not available for the application of this method. In the late 1880's the levels of Lake Michigan-Huron dropped by 0.8 m. In contrast to the other Great Lakes, the levels of these two lakes remained depressed afterwards, producing controversy about the reasons for this unexplained drop, namely, reduced precipitation and/or dredging. Existing estimates for the lake level drop due to unspecified dredging prior to 1900 vary from under 0.1 m to over 0.4 m, an unacceptably large difference. Reduction of lake levels due to precipitation or dredging implies different lake level behavior in the future, which complicates water resource studies based on the analysis of lake levels and related outflows.

1. INTRODUCTION

The Great Lakes represent a tremendous fresh water resource, and information on their levels and outflows is becoming progressively more important for water resource planning purposes and the operation of the presently regulated lakes (Superior and Ontario). Currently, this information includes over 120 years, 1860 to date. Because of their size, the Great Lakes possess a large self-regulating capacity and the natural fluctuation of their levels is relatively small. During the 1885-1900 period, the levels of the Great Lakes below Lake Superior dropped sharply, with the most acute drops for Lakes Michigan and Huron (0.8 m), which hydrologically are considered to be one lake. This drop in lake levels was accompanied by a

[1]GLERL Contribution No. 307.

corresponding reduction of basin precipitation and eventually the levels Of lakes other than Lake Michigan-Huron rebounded to their normal state. The levels of Lake Michigan-Huron remained depressed below previously established normals for reasons that have remained unexplained for several decades.

The reasons could be either natural, namely, basin precipitation persistently below previous levels; artificial, caused by man-made changes in the lake outlet or drainage basin conditions; or a combination of both natural and artificial changes. Artificial changes in the Lake Huron outlet through the St. Clair River for navigation improvements date back to 1856, when a channel was cut across sand bars in the St. Clair Flats area of the lower river to provide a 9-ft draft (International Joint Commission, 1976). Changes in land use affecting runoff characteristics from the drainage basin also date back to the mid-1800's. The outflows from the Great Lakes are based on stage-flow relationships derived from periodic flow measurements made after 1900. Since navigation improvements and commercial gravel dredging in critical locations could make the channel more efficient, the application of the post-1900 St. Clair River stage-flow relationships to the previous period, as was actually done, would make the 1860-1900 flows artificially high. On the other hand, present regulation plans for Lakes Superior and Ontario, based on lake outflows determined for the post-1900 period, would fail under more severe natural conditions.

There is some controversy regarding the reasons for, and corresponding magnitudes of, the unrecovered drop in the lake levels during the 1880-1900 period. Brunk (1961, 1963, 1968) conducted investigations to determine the drop of Lake Huron levels using ratios of Great Lakes levels, St. Clair-Detroit and Niagara River flows, and basin precipitation records. He felt that previously published regional precipitation (Day, 1926) for Lake Huron was too high and modified these precipitation values. Brunk concluded that most of the drop in Lake Huron levels prior to 1900 was caused by dredging of the lake outlet in the St. Clair River and that published flows for the St. Clair-Detroit River prior to the drop (1860-1900) are excessive. The magnitude of dredging-related lowering of Lake Huron levels prior to 1900 determined by Brunk (1968) is 0.43 m (1.4 ft). Lawhead (1961), in a discussion of Brunk's (1961) results, concluded that most of the decrease in Lake Michigan-Huron levels during this period was due to precipitation changes and that only 0.09 m (0.3 ft) could be attributed to the St. Clair River channel dredging. Additional lowering of the Lake Michigan-Huron levels due to dredging after 1900 was not contested in the above studies. The additional drop in the lake's levels for the post-1900 period was estimated by the International Great Lakes Levels Board (1973) to total 0.18 m (0.59 ft). This total amount consists of uncompensated dredging for waterway improvements for the 25-ft and 27-ft navigation channels completed in 1933 and 1962, respectively, and commercial gravel dredging in the upper St. Clair River in the vicinity of Point Edward, Ont., between 1908 and 1925. The effect of gravel dredging is estimated by the Levels Board to be about 0.09 m (0.3 ft), which leaves about half (0.09 m or 0.29 ft) of the total lowering during this period to be attributed to uncompensated navigation dredging in the St. Clair River. Navigation dredging in the Detroit River was compensated by dikes.

The unresolved Brunk-Lawhead controversy over the pre-1900 drop of Lake Michigan-Huron levels complicates water resource studies involving lake level analysis. If the late 1800's levels were high because of above-normal precipitation, such high levels may occur again in the future; if the previous high levels resulted from a less efficient outflow channel, it is unlikely they will be repeated. This problem was addressed by Quinn and Croley (1981) in a study based on precipitation climatology, which used more recently determined precipitation data. Quinn and Croley concluded that dredging prior to 1900 (1893-99) may be responsible for about 25 percent (0.2 m) of the total lake level drop of 0.8 m during the late 1800's (1886-92) and that published St. Clair River flows for the 1860-1900 period are excessive. Most of the drop (0.6 m) was apparently caused by a long term change in precipitation. As in previous studies, their determinations involved assumptions and some rather weak input parameters, such as available rainfall/runoff regressions with low correlation coefficients (0.26-0.85). The accuracy of all these lake-level-drop determinations may be classified as relative, rather than absolute, and require further verification.

The present study was initiated to provide verification for both the unexplained drop in Lake Michigan-Huron levels prior to 1900 and for the uncompensated dredging effects after 1900, using the St. Clair River dynamic flow models. Although there is generally no controversy regarding these later uncompensated dredging effects, with sufficient documentation (International Joint Commission, 1976; International Great Lakes Levels Board, 1973; U.S. Senate, 1955; Joint Board of Engineers, 1927), the use of flow models for this purpose represents a more sophisticated approach than those employed in previous estimates. The requirements for such a verification study with the flow models are the channel cross-sectional areas and channel roughness coefficients for the appropriate periods. Determination of channel roughness coefficients requires river flow measurements. Historic hydrographic surveys and flow measurements for the Great Lakes were made by the U.S. Lake Survey, a former Corps of Engineers District. Archive records for the hydrographic surveys are presently maintained by the National Ocean Survey, NOAA, while those for flow measurements are stored by the Detroit District, Corps of Engineers. The earliest hydrographic survey of the St. Clair River was conducted during 1867, providing cross-sectional areas prior to any significant channel changes, while a second survey in 1900 provided cross-sectional areas after the unexplained drop in Lake Michigan-Huron levels and before the known uncompensated dredging during this century (25- and 27-ft channels and gravel removal). Channel roughness for the second period was determined from flow measurements conducted during 1908-10. Flow measurements for the preceding period are not available. Although it was possible to estimate channel roughness coefficients that appear reasonable for this period, this was immaterial since analysis of the 1867 cross-sectional areas showed them to be grossly inadequate. Either the measurements were crude and inaccurate or the available small-scale field sheets did not permit reproduction of the areas with sufficient accuracy. In either case, this eliminated the first objective of the study concerning the channel changes during the previous century. Consequently, only the uncompensated channel changes during the present century are evaluated.

2. METHOD

The Great Lakes Environmental Research Laboratory (GLERL) dynamic flow models for the St. Clair River are described by Derecki and Kelley (1981). These models are one-dimensional transient flow models based on equations of continuity and momentum, with option for the surface wind stress effects. Disregarding wind stress effects, not used in this study, the equations of continuity and momentum are expressed in terms of flow and stage

$$\frac{\partial Z}{\partial t} + \frac{1}{T}\frac{\partial Q}{\partial X} = 0 \tag{1}$$

and

$$\frac{1}{A}\frac{\partial Q}{\partial t} - 2\,\frac{QT}{A^2}\frac{\partial Z}{\partial t} + \left(g - \frac{Q^2 T}{A^3}\right)\frac{\partial Z}{\partial x} + \frac{gn^2\, Q/Q/}{2.208\, A^2\, R^{4/3}} = 0, \tag{2}$$

where
- Q = flow rate,
- Z = stage above fixed datum,
- x = distance in the positive flow direction,
- t = time,
- A = channel cross-sectional area,
- T = top width of channel,
- g = acceleration due to gravity,
- R = hydraulic radius, and
- n = Manning's roughness coefficient.

The model solution uses an implicit finite-difference method with Newton-Raphson iterative algorithms for initiating the computations, which can be operated with variable time steps. Several versions of the models incorporating different river reaches are all confined to the upper one-third of the river, between a gage at Fort Gratiot, Mich., at the head of the river and a gage at St. Clair, Mich., 23 km downstream (fig. 1). This portion of the river contains most of the river slope and is usually free of ice concentrations during winter. The model programs are written in a generalized manner and can be easily modified or adapted to other rivers by appropriate substitution of physical characteristics (cross-sectional areas, channel widths, roughness coefficients, etc.) and boundary conditions (downstream and upstream controls). Model computations incorporate detailed channel definition to indicate the actual river channel (table 1).

For the purpose of this study, it was necessary to use a model that would cover the entire upper river reach between Fort Gratiot and St. Clair, two of the oldest river gages in the system. Since none of the existing operational models covered this reach, they were modified to obtain two desired models, each comprising upper and lower reaches with "mid-point" locations at the Mouth of Black River and Dry Dock gages. For future

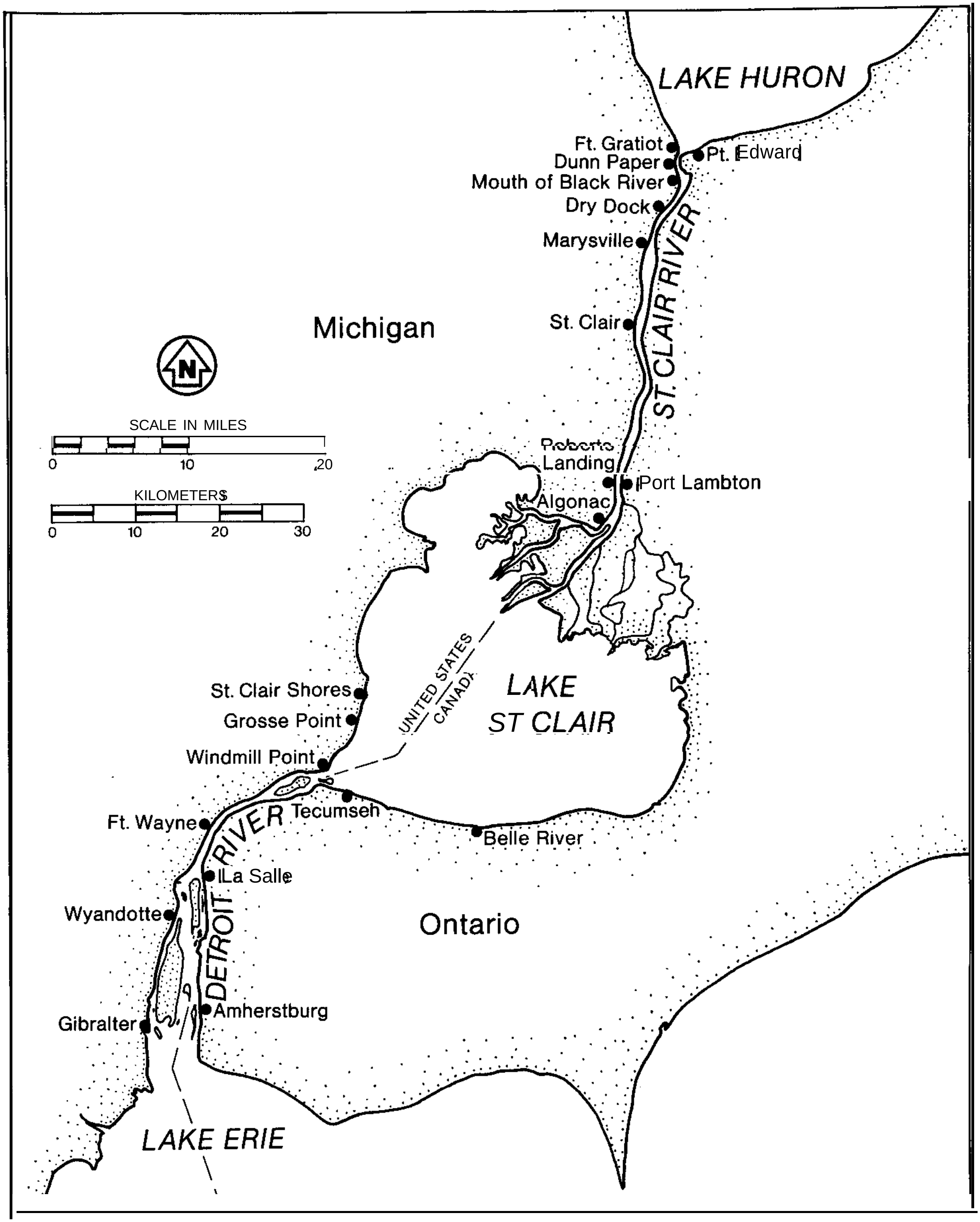

FIGURE 1.--St. Clair-Detroit River system with location of water level gages.

TABLE 1.--*St. Clair River hydmutic parameters for the present channel*

Gage location	station (ft)	Width (ft)	Length (ft)	Azimuth (°)	Reference elevation IGLD (1955)*	Base area (ft^2)
Fort Gratiot	207,970	1,800	---	30	576.7	57,500
	207,640	1,320	330	30	576.5	45,800
Dunn Paper	207,090	1,000	550	30	576.4	40,800
	206,790	1,000	300	30	576.4	33,100
	206,350	1,000	440	30	576.3	35,000
	206,030	920	320	30	576.3	34,700
	205,320	880	710	30	576.1	28,800
	205,030	940	290	3	576.1	32,100
	204,600	1,000	430	3	576.1	33,400
	204,280	1,220	320	3	576.1	44,000
	203,970	1,360	310	3	576.1	49,700
	202,920	1,480	1,050	3	576.1	55,200
	202,570	1,520	350	161	576.1	65,600
	202,140	1,480	430	161	576.1	64,900
	200,840	1,400	1,300	161	576.0	48,200
	200,530	1,320	310	161	576.0	47,300
	199,520	1,360	1,010	143	575.9	53,100
	199,240	1,360	280	143	575.9	50,200
	197,790	1,620	1,450	143	575.8	49,300
	196,410	2,590	1,380	14	575.8	67,800
Mouth of Black River	195,410	2,630	1,000	14	575.8	76,000
	193,480	2,500	1,930	14	575.7	76,000
	190,400	1,840	3,080	31	575.7	50,700
Dry Dock	182,480	2,180	7,920	44	575.4	58,800
	170,920	1,890	11,560	14	575.1	57,100
Marysville	166,980	2,250	3,940	14	574.9	68,400
	166,480	2,400	500	18	574.9	68,300
	165,930	2,630	550	18	574.9	64,400
	163,380	3,490	2,550	18	574.9	70,700
	162,810	3,290	570	18	574.9	71,600
	161,350	2,660	1,460	18	574.8	64,300
	155,470	2,640	5,880	177	574.7	62,600
	151,480	3,120	3,990	177	574.7	75,600
	148,430	2,420	3,050	10	574.5	65,900
	145,980	1,840	2,450	10	574.4	54,600
	144,970	1,960	1,010	10	574.4	61,500
	135,330	3,080	9,640	8	574.2	77,800
	134,290	2,760	1,040	a	574.1	65,600
St. Clair	132,270	2,280	2,020	a	574.1	66,300

*IGLD--International Great Lakes Datum. Data in this table are listed in English units since all computations are done in English units and the final results listed in either the English or the SI system.

reference, these models are identified by a three-gage system as FG-MBR-SC and FG-DD-SC.

The procedure employed in determining channel changes involved computing river flows with the present channel configuration, using current water level gage data, then matching these flows with the previous channel configuration modified by appropriate cross-sectional areas and channel roughness coefficients. The difference in water levels for the same flow with present and previous channel configurations represents the effect of channel changes due to dredging. The ultimate effect of channel changes on the water levels should be nearly the same during periods of low or high water supply. This is demonstrated by computing the channel-change effects for 1970, a year of mid-range or average water levels, and for 1973, a year of high water levels. To eliminate possible ice effects, the computations were limited to the open-water season and, furthermore, were restricted to the June-August period, which represents annual peak water levels.

The channel cross-sectional areas prior to the uncompensated channel changes during this century were determined from the 1900 hydrographic survey and used to evaluate dredging effects by both models. The 1867 cross-sectional areas were similarly determined, but as mentioned previously, they were found to be inadequate, producing illogical results, and so were discarded. The upper St. Clair River hydraulic parameters for the 1900 channel are given in table 2. Basic input data are listed in English units since all computations are done in English units and the final results listed in either English or SI units. Comparison of the 1900 and present areas at the section corresponding to the Mouth of Black River gage location is shown in figure 2. As indicated, the present channel at this section has a nearly uniform depth as a result of substantial dredging over most of the width. It is apparent that at least final stages of this dredging were connected with the 27-ft (8.2-m) navigation project completed in 1962. The present navigation channel at this location covers slightly over half of the river on the United States or western side. It is a common practice to provide approximately 2-ft (0.6-m) overdraft in deepening the navigation channels. During both the 25-ft and the 27-ft projects, dredged material was deposited in river areas where it would not interfere with navigation to partially offset some of the effects on upstream water levels. This explains the filling of the deeper portion of the river along the eastern bank. Thus, present river depth in this location is approximately 8.8 m (29 ft), with the exception of a reduction in depth to 7.9 m (26 ft) along the eastern boundary of the navigation channel and the overbanks. The assumption of a 2-ft overdraft is verified by the average depth of the present channel at this section, which is also about 8.8 m (29 ft). This compares with a value under 7.6 m (25 ft) in 1900, giving an la-percent increase in the cross-sectional area for the present period.

Calibration of the models for both periods consisted of computing roughness coefficients for each reach of the river bounded by water level gages. The roughness coefficients were determined from Manning's formula

TABLE 2.--St.Clair River hydraulic parameters for the 1900 channel

Gage location	Station (ft)	Width (ft)	Reference elevation IGLD (1955)"	Base area (ft^2)
Fort Gratiot	207,970	2,100	575.52	65,720
	207,640	1,600	575.52	55,680
Dunn Paper	207,090	1,040	575.52	43,045
	206,790	960	575.52	40,700
	206,350	920	575.52	35,115
	206,030	880	575.52	33,678
	205,320	780	575.52	34,460
	205,030	800	575.52	33,555
	204,600	1,000	575.52	37,965
	204,280	1,150	575.52	38,395
	203,970	1.250	575.52	41,855
	202,920	1,420	575.52	44,163
	202,570	1,480	575.52	45,155
	202,140	1,420	575.52	45,805
	200,840	1,200	575.52	41,100
	200,530	1,300	575.52	45,850
	199,520	1,100	575.52	42,915
	199,240	1,150	575.52	42,970
	197,790	1,580	575.52	49,245
	196,410	2,600	575.52	67,430
Mouth of Black River	~195,410	2,600	575.52	63,720
	193,480	2,400	575.52	57,430
	190,400	1,800	575.52	51,525
Dry Dock	182,480	2,000	575.52	57,665
	170,920	1,840	575.52	60,155
Marysville	166,980	2,200	575.52	68,800
	166,480	2,400	575.52	68,720
	165,930	2,650	575.52	66,860
	163,380	2,950	575.52	68,980
	162,810	2,860	575.52	68,225
	161,350	2,530	575.52	70,045
	155.470	2,820	575.52	70,600
	151,480	2,700	575.52	74,555
	148,430	1,950	575.52	63,630
	145.980	1,920	575.52	66,530
	144,970	2,020	575.52	68,455
	135,330	2,900	575.52	80,980
	134,290	2,480	575.52	75,700
St. Clair	132,270	2,050	575.52	70.380

*IGLD-International Great Lakes Datum. Data in this table are listed in English units since all computations are done in English units and the final results listed in either the English or the SI system.

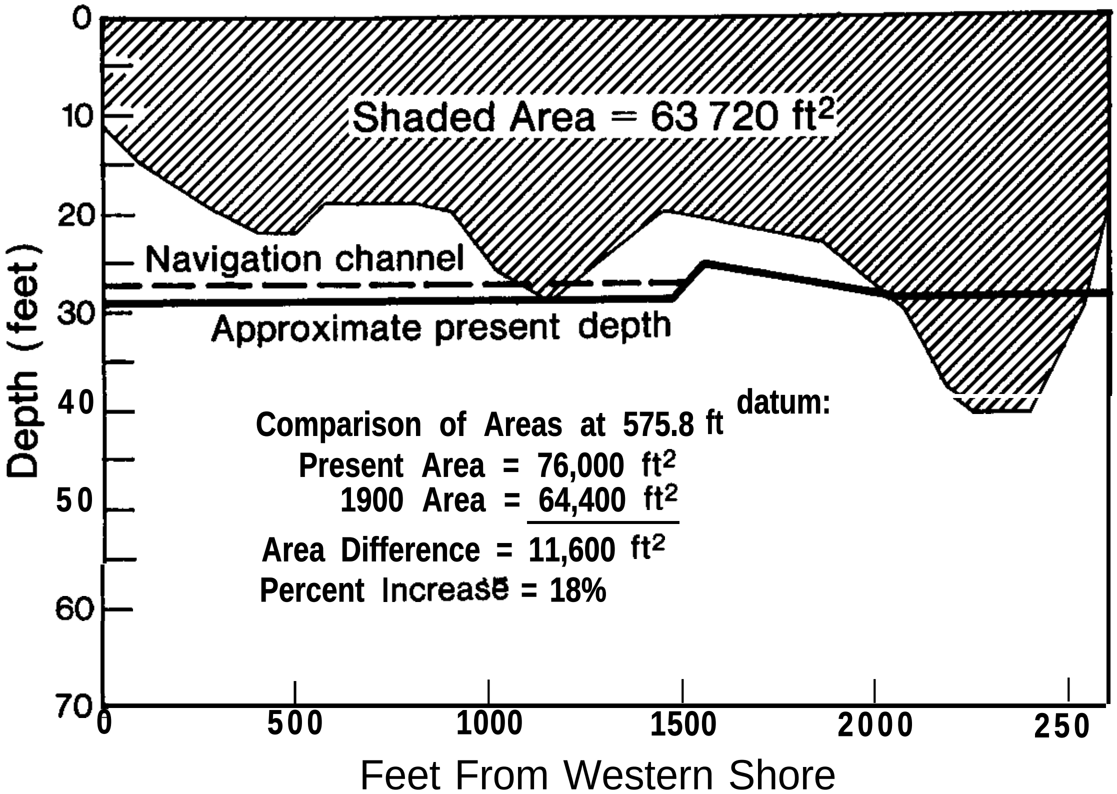

FIGURE 2.--*Comparison of 1900 and present areas at the Mouth of Black River gage section.*

$$n = \frac{1.486\ A\ R^{2/3}}{Q}\left(\frac{Z_u - Z_d}{L} + \frac{Q^2\ \Delta A}{32.2\ L\ A^3}\right)^{1/2}, \qquad (3)$$

where n = Manning's roughness coefficient,
A = mean channel area,
R = hydraulic radius,
Q = flow rate,
Z_u = water surface at upstream gage,
Zd = water surface at downstream gage,
AA = change in channel area between gages, and
L = length of channel reach between gages.

The roughness coefficients for the present channel are based on 14 sets of flow measurements taken by the Corps of Engineers during 1959-77. For the 1900 channel, seven sets of flow measurements made during 1908-10 were used. Although commercial gravel dredging in the upper St. Clair River started in 1908, there are no indications that channel changes in the first

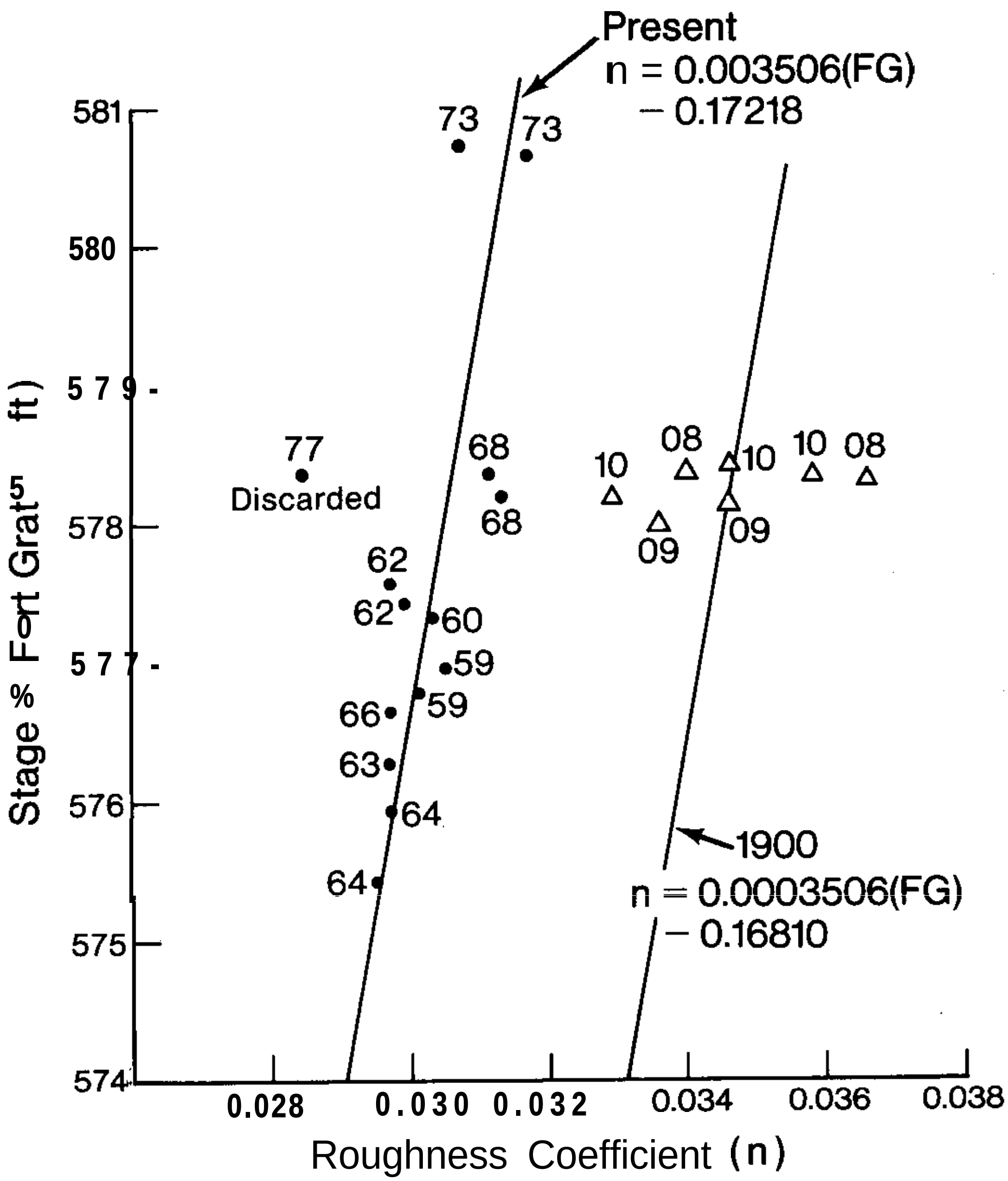

FIGURE 3.—*Manning's roughness* coefficient8 for *FG-MBR reach.*

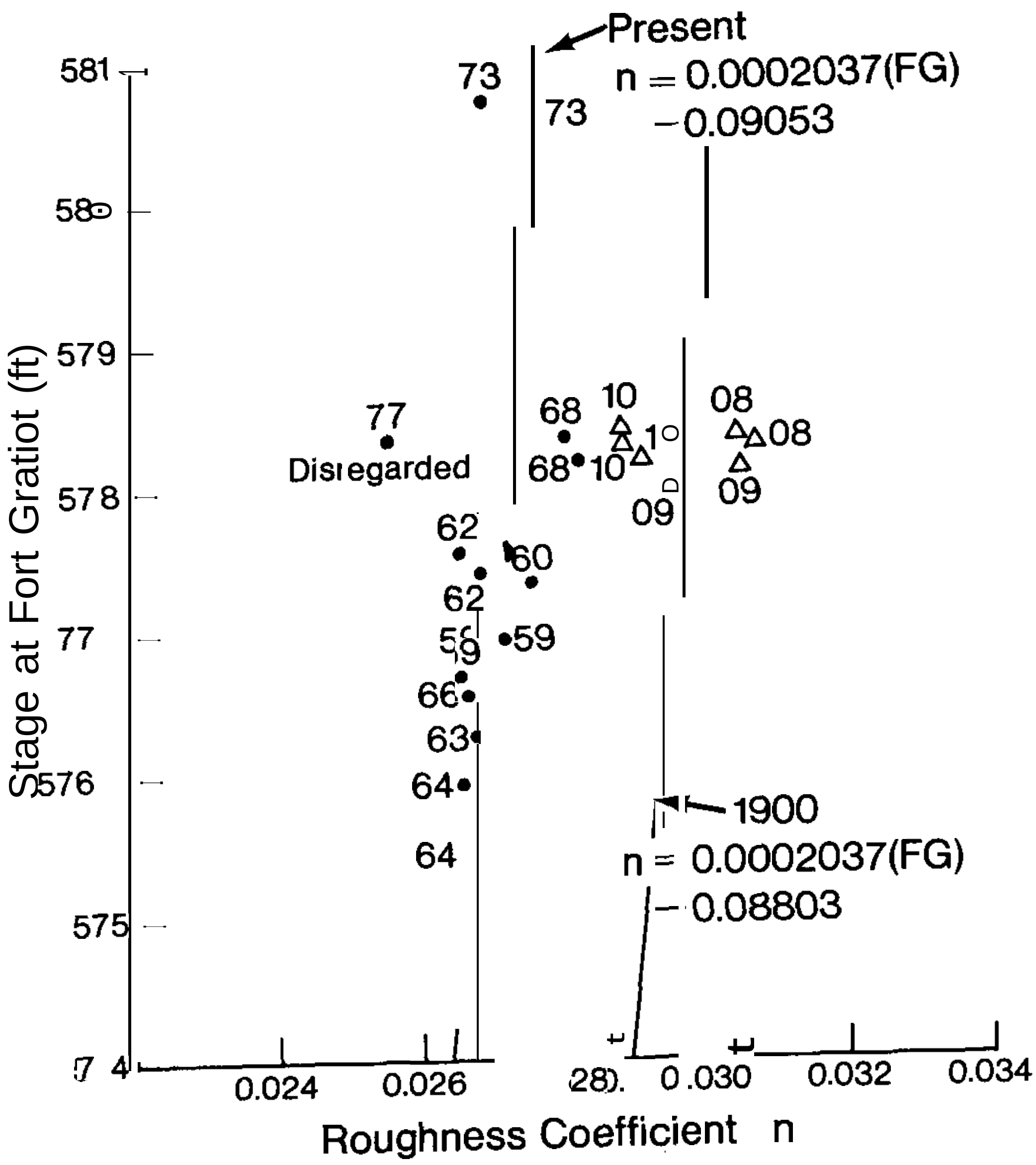

FIGURE 4.—*Manning's roughness coefficients for FG-DD reach*

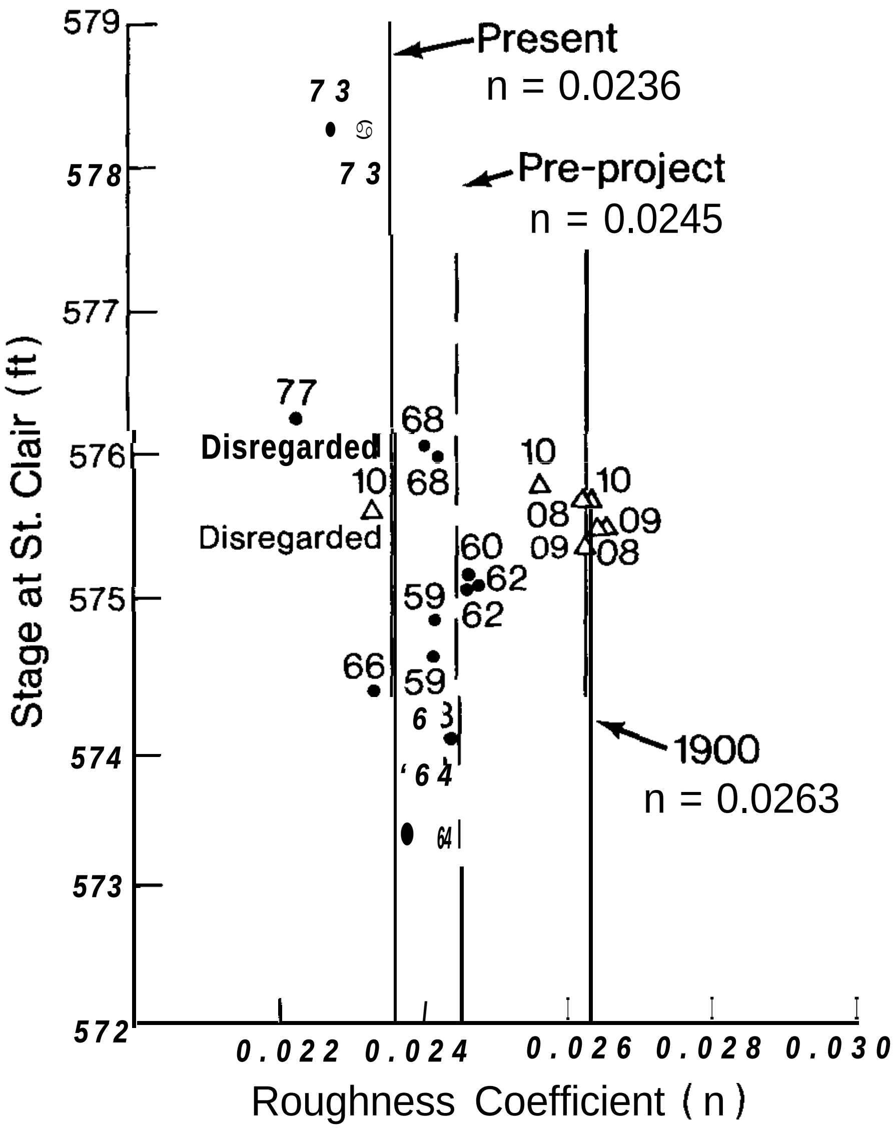

FIGURE 5.--Manning's roughness coefficients for MBR-SC reach.

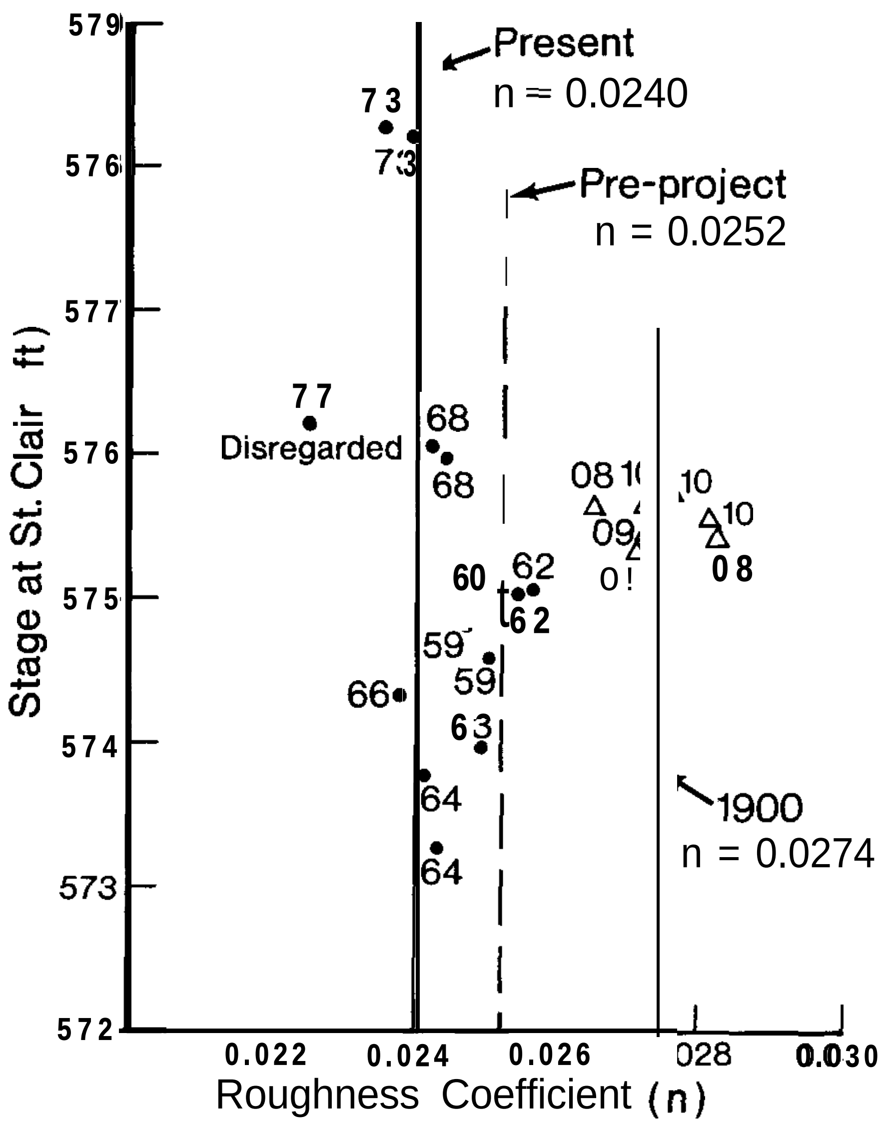

FIGURE 6.—*Manning's roughness* coefficients for *DD-SC reach.*

few years were significant and these measurements should provide satisfactory indication of channel roughness conditions for the 1900 period. The relationships between computed roughness coefficients for channel reaches along the upper St. Clair River and the river stages at adjacent water level gages for the FG-MBR, FG-DD, MBR-SC, and DD-SC reaches are shown in figures 3-6, respectively. Best-fit relationships were derived for each reach by regression analysis (least squares) or graphic plots (means), as shown in the figures. Some points were omitted in this derivation to eliminate possible gage errors or questionable flow values. Since the 1908-10 flow measurements were made during similar river stages, they give no indication of the variation in roughness with depth. The 1900 best-fit lines for the upstream reaches ware estimated using mean values for the 1908-10 measurements and slopes from the present channel. The relationships for downstream reaches during the 1959-77 flow measurements were affected by regimen changes associated with dredging for navigation improvements. For these reaches, separate best-fit roughness coefficients were derived for each regime, representing 1900, pre-project (through 1963), and present (starting in 1964) conditions. The calibrated roughness coefficients for the four reaches are summarized in table 3.

TABLE 3.--St. Clair River Manning's roughness coefficients for present and 1900 channel conditions

Reach.	Channel	Flow measurements	Roughness coefficient (n)
FG-MBR	Present	1959-77	n = 0.0003506 (FG) - 0.17218
	1900	1908-10	n = 0.0003506 (FG) - 0.16810
FG-DD	Present	1959-77	n = 0.0002037 (FG) - 0.09053
	1900	1908-10	n = 0.0002037 (FG) - 0.08803
MBR-SC	Present	1964-77	n = 0.0236 (starting 1964)
	Pre-project	1959-63	n = 0.0245 (through 1963)
	1900	1908-10	n = 0.0263
DD-SC	Present	1964-77	n = 0.0240 (starting 1964)
	Pre-project	1959-63	n = 0.0252 (through 1963)
	1900	1908-10	n = 0.0274

Gages: FG = Fort Gratiot
MBR = Mouth of Black River
DD = Dry Dock
SC = St. Clair.

3. RESULTS

Results for the effects of channel changes in the upper and total St. Clair River by dredging during the present century (since 1900) for commercial gravel removal (1908-25) and navigation improvements (1933 and 1962) are presented in tables 4 and 5. These tables show June-August average values for an average water level year (1970) and a high water level year (1973), respectively, given by two dynamic flow models developed specifically for this purpose. Results from the two models agree closely, with a maximum variation of 0.01 m, which is well within limits of expected accuracy. Flow measurement accuracy for the Great Lakes connecting channels is generally considered to be 2 percent, which is about 100 $m^3 s^{-1}$ for the normal St. Clair River range of flows and is equivalent to about a 0.03-m difference in head or water levels. These values represent zero computational errors and may be doubled for acceptable errors. The agreement for the 2 years is also very good, with maximum deviations at Fort Gratiot of 0.01 m, showing that the effect of channel changes on water levels is nearly the same, regardless of water supply conditions. The effect of

TABLE 4.--*Results of computations for upper St. Clair River profile with present and 1900 channel conditions during average water levels (1970)*

Model	Flow $m^3 s^{-1}$	River gages	Elevation in meters: Present channel	1900 Channel upper	1900 Channel total	Dredging effects (m): Upper river	Total river
FG-MBR-SC	6014	FG	176.49	176.67	176.76	-0.18	-0.27
		MBR	176.27	176.35	176.44	-0.08	-0.17
		SC	175.75	175.75	175.87	0	-0.12
FG-DD-SC	6023	FG	176.49	176.66	175.75	-0.17	-0.26
		DD	176.15	176.21	176.31	-0.06	-0.16
		SC	175.75	175.75	175.87	0	-0.12
Combined	6019	FG	176.49	176.66	176.75	-0.17	-0.26
		MBR	176.27	176.35	176.44	-0.08	-0.17
		DD	176.15	176.21	176.31	-0.06	-0.16
		SC	175.75	175.75	175.87	0	-0.12

Gages : FG = Fort Gratiot
MBR = Mouth of Black River
DD = Dry Dock
SC = St. Clair.

TABLE 5.--*Results of computations for upper St. Clair River profile with present and 1900 channel conditions during high water levels (1973).*

Model	Flow $m^3 s^{-1}$	River gages	Elevation in meters: Present channel	1900 Channel: upper	1900 Channel: total	Dredging effects (m): Upper river	Dredging effects (m): Total river
FG-MBR-SC	6567	FG	176.99	177.18	177.27	-0.19	-0.28
		MBR	176.75	176.83	176.93	-0.08	-0.18
		SC	176.23	176.23	176.35	0	-0.12
FG-DD-SC	6586	FG	176.99	177.17	177.26	-0.18	-0.27
		DD	176.63	176.69	176.79	-0.06	-0.16
		SC	176.23	176.23	176.35	0	-0.12
Combined	6577	FG	176.99	177.17	177.26	-0.18	-0.27
		MBR	176.75	176.83	176.93	-0.08	-0.18
		DD	176.63	176.69	176.79	-0.06	-0.16
		SC	176.23	176.23	176.35	0	-0.12

Gages: FG = Fort Gratiot
MBR = Mouth of Black River
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SC = St. Clair.

dredging in the upper St. Clair River on the levels of Lake Huron, indicated by the Fort Gratiot gage at the head of the river, is a lowering of lake levels by 0.18 m. Computed effects by the FG-MBR-SC and FG-DD-SC models vary, respectively, from 0.18 m to 0.17 m for 1970 and from 0.19 m to 0.18 m for 1973. These effects at the Mouth of Black River and Dry Dock gages, about 4-km and 8-km downstream, respectively, are reduced to a lowering of river stages by 0.08 m and 0.06 m.

The above determinations for the upper river dredging effects on lake Huron levels agree well with previous total estimates published by the International Great Lakes Levels Board (1973). The Board lists the overall effect for the total river as 0.59 ft (0.18 m), about half of which or 0.3 ft (0.09 m) is attributed to commercial gravel removal and 0.29 ft (0.09 m), to uncompensated lowering of lake levels by the 25-ft and 27-ft navigation projects. The uncompensated dredging in the lower St. Clair River, especially the construction of the Cutoff Channel in the St. Clair Flats area for the 27-ft project, is bound to have some negative effect on the levels of the upper river and Lake Huron. This is verified in a study conducted by the U.S. Lake Survey (1961) which, although indicating lower overall effect, with similar amounts for the two navigation projects, shows that while the effects of the 25-ft project are restricted mostly to the upper river. those associated with the 27-ft project occur mainly in the mouth of the river. The total dredging effect published by the Levels Board appears, therefore, to be substantially underestimated.

The lower St. Clair River is below the physical limits of the available models and the dredging effects in this reach of the river have to be supplied as a model input before the total effects can be computed with the models. This value was determined from a gage relationship based on available data that shows that the water level at the St. Clair gage was about 0.12-m (0.4-ft) higher during 1900. With this input, the total dredging effects were recomputed and show about 0.09-m (0.30-ft) additional drop in Lake Huron levels due to dredging in the lower river. The ultimate effect of dredging in the entire St. Clair River since 1900 for gravel removal and the two navigation projects is a lowering of lake levels (Fort Gratiot) by 0.27 m (0.88 ft). The amount of lowering is reduced downstream to 0.18 m and 0.16 m at the Mouth of Black River and Dry Dock gages, respectively. Maximum deviations due to model accuracy or water supply conditions are 0.01 m, as indicated previously for the upper river dredging effects. The upper St. Clair River water surface profile for the present and 1900 channel conditions computed for both years are shown in figure 7. The profiles are nearly identical despite large differences in flows and water levels.

It is regrettable that a more detailed 1867 hydrographic survey is not available for more precise determination of cross-sectional areas of the St. Clair River channel during that period. Present determinations for the post-1900 period indicate that the flow model method employed would be very useful in resolving the controversy about the causes and respective magnitudes of the Lake Huron drop in water levels before 1900. Existing estimates for the dredging effects for that period vary from 0.43 m (Brunk, 1968) to 0.09 m (Lawhead, 1961), with the most recent estimate of 0.2 m by Quinn and Croley (1981). If the last estimate is correct, the levels of Lakes Michigan and Huron were lowered permanently by roughly similar amounts during both the present and the previous centuries, with the total artificial lowering due to dredging amounting to nearly half a meter (about 0.47 m). This depth superimposed on the combined area of the lakes (117,400 km^2) represents a volume of 55 km^3, a tremendous amount of permanently lost water resource. The loss exceeds approximately 16 times the volume of Lake St. Clair (3.4 km^3), which is a large inland body of water by any standards but those of the Great Lakes proper.

4. CONCLUSIONS

Artificial channel changes in the St. Clair River since 1900 include dredging for commercial gravel removal between 1908 and 1925 and uncompensated navigation improvements for the 25-ft and 27-ft projects completed in 1933 and 1962, respectively. These channel changes increased the efficiency of the Lake Michigan-Huron outlet through the St. Clair River and caused permanent lowering of the lake's levels. The total effect of these man-made channel changes is the lowering of the levels of Lake Michigan-Huron by 0.27

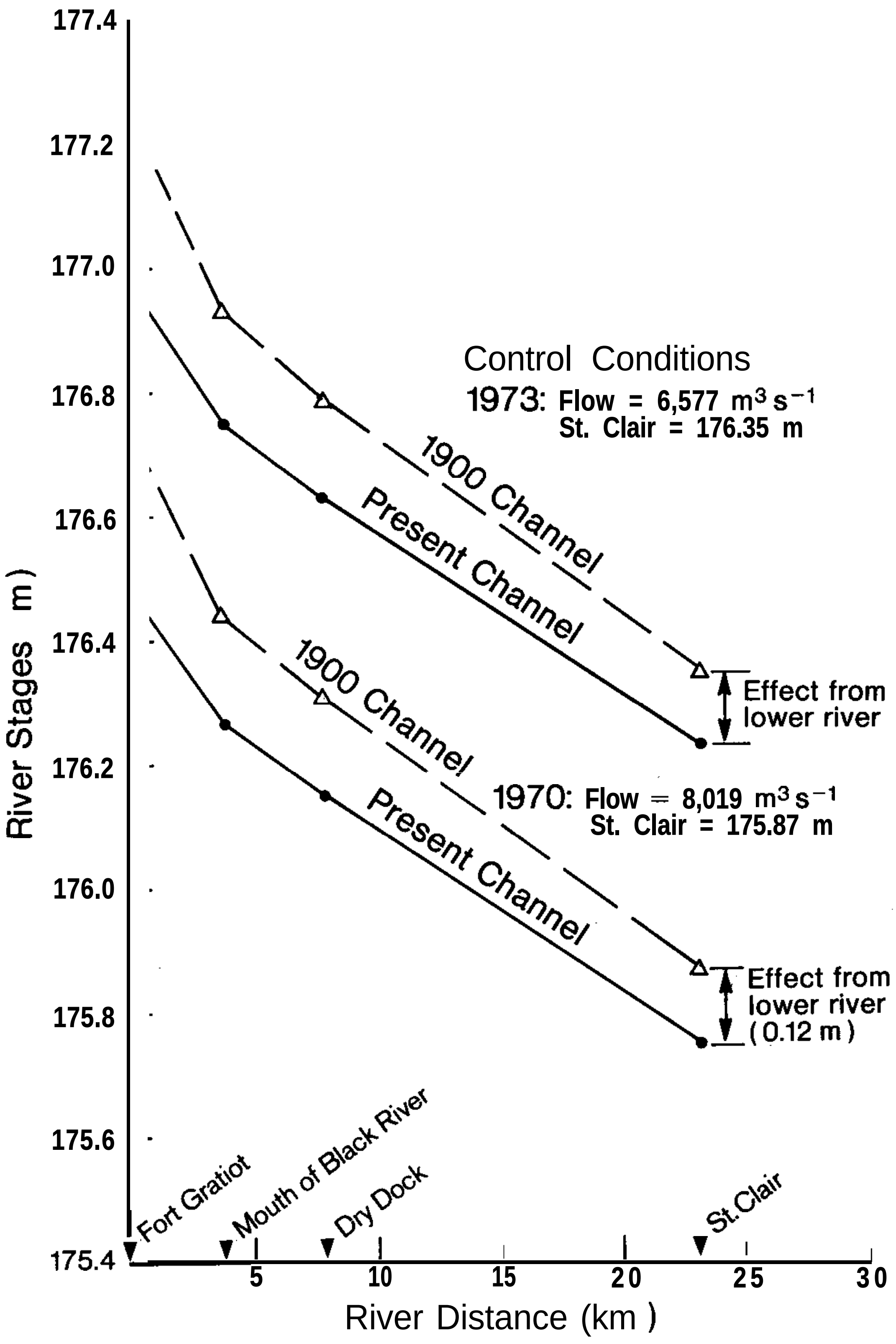

FIGURE 7.--Upper St. Clair River water surface profile for present and 1900 channel conditions.

m. This depth superimposed on the combined area of Lakes Michigan and Huron represents a permanent water loss of 32 km^3, which is more than nine times greater than the volume of Lake St. Clair.

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