J. Great Lakes Res. 19(4):660–664
Internat. Assoc. Great Lakes Res., 1993

Pre-1900 St. Clair River Flow Regime

Frank H. Quinn, Jan A. Derecki, and Cynthia E. Sellinger

Great Lakes Environmental Research Laboratory, NOAA
Ann Arbor, Michigan 48105

Abstract. *The St. Clair River is the outlet channel for Lakes Michigan and Huron to the lower Great Lakes. The river's hydraulic characteristics naturally regulate Lakes Michigan-Huron's water levels by controlling the amount of water that flows out of the lakes. Accurate determinations of the outflows are necessary, in conjunction with the St. Marys River flows and lake level data, to determine the water supplies to Lakes Michigan-Huron. The hydraulic regime of the river has been changed many times since the mid-1800s primarily due to dredging for deeper draft navigation and sand and gravel mining. In addition there have also been minor effects due to shipwrecks at the head of the river. For water resource studies of the Great Lakes system it would be highly desirable to determine Lakes Michigan-Huron's water supplies for the period 1860-1900. Additional water supply values would extend the available period of study by 40 years or approximately 45 percent. This period is also particularly important as it contains extreme high water supplies that led to record Lakes Michigan-Huron water levels. This study comprised an analysis of the existing discharge and dredging data for the 1860-1902 period to determine if discharge equations could be developed with sufficient accuracy to compute monthly St. Clair River flows. The analysis demonstrated that it is not possible to quantify St. Clair River flows prior to 1900, thus limiting the period available for determining Lakes Michigan-Huron water supplies to this century. The study also confirmed the previously determined 0.18 m lowering of Lakes Michigan-Huron between 1900 and present due to channel dredging in the upper river.*

Index Words: *St. Clair River, channel flow, stage-discharge relations.*

INTRODUCTION

The St. Clair River, Figure 1, is the outlet channel for Lakes Michigan and Huron to the lower Great Lakes. The river's hydraulic characteristics naturally regulate Lakes Michigan-Huron's water levels by controlling the amount of water that flows out of the lake. Accurate determinations of the outflows are necessary, in conjunction with inflows from the St. Marys River and lake level data, to determine water supplies to Lakes Michigan-Huron. For water resource studies of the Great Lakes system it would be highly desirable to determine Lakes Michigan-Huron water supplies for the period 1860-1900. This would extend the available period of study by 40 years or approximately 45 percent. This period is also particularly important as it contains the extreme high water supplies that led to the record Lakes Michigan-Huron water levels of 1886. Existing discharge and dredging data for the 1860-1902 period were analyzed to determine if discharge equations could be developed with sufficient accuracy to compute monthly St. Clair River flows.

ST. CLAIR RIVER CHANNEL REGIMES

Changes in the hydraulic capacity and flow regimes of the St. Clair River occurred as early as 1856 (Brunk 1968). These early changes were mostly due to commercial excavation of gravels (Horton and Grunsky 1927). Figure 2 illustrates the cumulative volume of gravel excavation with time. Plateaus, depicted in this figure, are indicative of distinct flow regimes.

Other major dredging in the upper St. Clair River was undertaken between 1908 and 1925 (Derecki 1985). In 1909 private parties removed 191,000 cubic meters of sand and gravel from the St. Clair River channel in the vicinity of the rapids (Horton and Grunsky 1927). Following this commercial

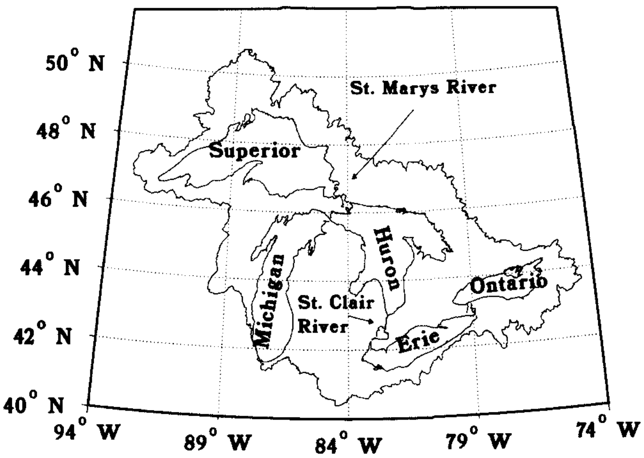

FIG. 1. Great Lakes basin map.

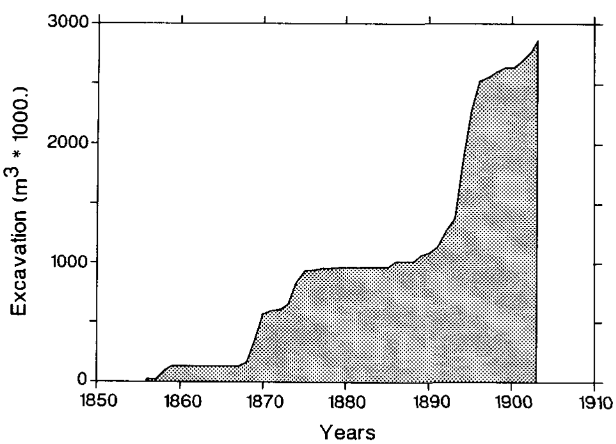

FIG. 2. St. Clair River excavation cumulatives (Brunk 1978).

dredging, the St. Clair River underwent two navigation improvements which consisted of uncompensated dredging for the 7.6 m (25 ft) and 8.2 m (27 ft) navigational channels completed in 1933 and 1962, respectively. In addition to the major changes, there have been minor changes in the river's regime due to shipwrecks at the head of the river. Derecki (1985) analyzed the effect of the post-1900 dredging on Lakes Michigan-Huron using the Great Lakes Environmental Research Laboratory's (GLERL) dynamic flow model for the St. Clair River. His results showed a post-1900 lowering of Lakes Michigan-Huron by 0.27 m (0.88 ft.) with 0.18 m (0.59 ft) of the lowering occurring due to alteration above the dry dock gage.

DEVELOPMENT OF DISCHARGE EQUATIONS

Development of stage-fall-discharge or stage-discharge equations for the 1860-1900 period requires discharge measurements and corresponding water level elevations. An inventory of historical data indicated that two sets of open water (non-ice conditions) flow measurements were undertaken on the upper St. Clair River during the period of interest. The first set consists of measurements taken in 1867 along several unspecified locations on the St. Clair River (Report of the Chief of Engineers 1868). These measurements had no corresponding water level data (Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data in press; Brunk 1968), and therefore, were not appropriate for this study. The second set of measurements was collected between 1899 and 1902. This set consisted of approximately 240 flow observations (Reports of the Chief of Engineers 1900, 1902, and 1903). Flows from this second set were measured at the Grand Trunk Western Railroad (GTR) section and corresponding water level readings at the GTR, Dry Dock, and St. Clair Flats gages (Fig. 3). Water levels recorded at these gages were referenced to the Mean Tide at New York (MTNY). Of these gages, only Dry Dock is in operation at the present time. Although these data would not precisely represent pre-1895 flow regimes they offer a better approximation of the pre-1900 channel than the present regime which is based upon coordinated flows for the period 1962 - present.

Like most sloping open channels with rough bottoms, the St. Clair River can be described with a

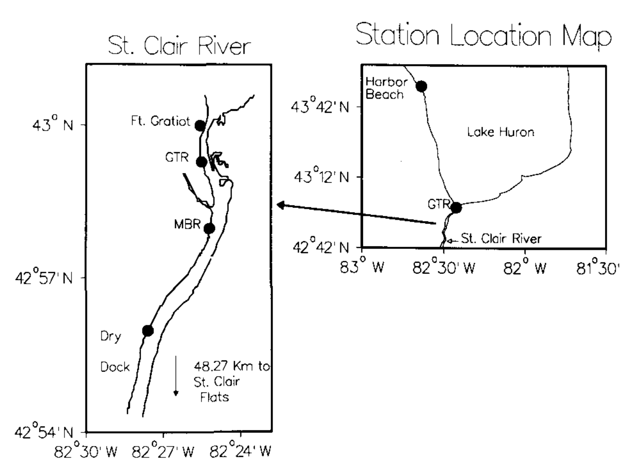

FIG. 3. Station location map.

stage-fall-discharge equation (requiring two water level gages for flow estimates) as well as a single rating equation (requiring one water level gage for flow estimates). The stage-fall-discharge equation accounts for a sloping bottom by approximating Manning's roughness coefficient (Quinn 1964). Development of stage-fall-discharge and stage-discharge equations for the upper and lower river also requires data from the Harbor Beach (Sand Beach) gage, the Dry Dock gage, and the St. Clair Flats gage on the International Great Lakes Datum of 1955 (IGLD 1955). This requires both estimation of the Harbor Beach and St. Clair Shores water levels during the period of measurement and conversion of all water level data from the MTNY reference to the IGLD(1955) datum. It should be noted that Great Lakes datums have been computed every 20 to 30 years to adjust for isostatic rebound (Clark and Persoage 1970).

Harbor Beach water levels during the time of measurements were estimated by water level transfer from the GTR gage. In this case, the water level transfer was combined with the datum adjustment as monthly mean water level data were available for the period 1899-1902 for Harbor Beach on IGLD(1955) and for GTR on MTNY reference (Table 1).

TABLE 1. Harbor Beach water level transfer.

Year	Month	Harbor Beach[1] IGLD 1955 (m)	Grand Trunk Railroad[2] MTNY Reference (m)
1899	June	176.50	176.66
	July	176.79	176.74
	August	176.56	176.73
	September	176.50	176.67
1900	June	176.35	176.52
	July	176.43	176.59
	August	176.45	176.61
	September	176.48	176.61
1901	June	176.53	176.64
	July	176.58	176.70
	August	176.59	176.73
	September	176.52	176.66
1902	June	176.40	176.54
	July	176.48	176.64
	August	176.51	176.66
	September	176.41	176.57
Overall Average		176.49	176.64

[1]National Ocean Service (1990)
[2]Report of the Chief of Engineers (1903)

The combined datum correction and water level transfer factor of -0.15 m was obtained by taking the difference between the overall averages in Table 1 thus:

$$HB = GTR - 0.15 \quad (1)$$

where:

HB is the Harbor Beach water level on IGLD(1955), and
GTR is the water level at Grand Trunk Western gage on MTNY reference.

Equation 1 was applied to GTR gage readings to compute corresponding Harbor Beach water levels on IGLD(1955) for the 1899-1902 flow measurements. The square root of the flow measurements were plotted versus the Harbor Beach levels as shown in Figure 4. Also shown with these plotted measured values in Figure 4 is a stage-discharge relationship that was developed by least-squares regression. These results are compared with a stage-discharge equation for the present regime derived from the coordinated monthly mean St. Clair River flows (Coordinating Committee 1988).

As shown, the present discharge equation adequately represents the present channel regime which has existed since the completion of the 8.2 m (27 ft) navigation channel dredging. Figure 4, however, indicates potential problems with the 1899-1902 measured set. These measurements show a very wide spread, approximately 30 percent changes in flow, with little corresponding changes in Harbor Beach stage. In addition, many of the

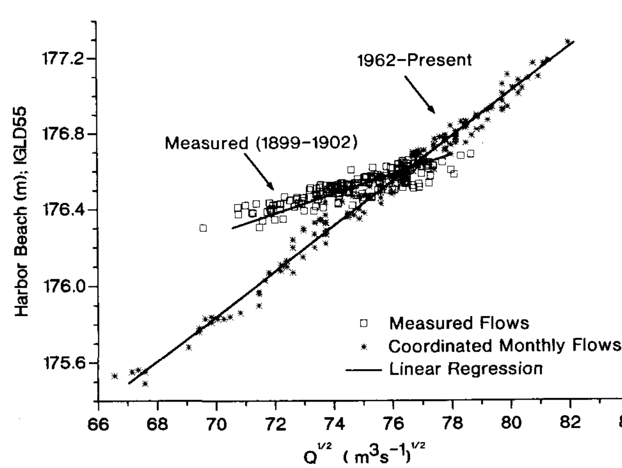

FIG. 4. St. Clair River stage-discharge relationship; Q = discharge.

measurements show higher flows, for a less efficient channel, than the present regime. This is not hydraulically possible. Two prior analyses (Brunk 1961, 1968; Report of the Chief of Engineers 1902) also found the 1899-1902 measurements to be too large. Brunk estimated the measurement set to be about 8% (425 m^3s^{-1}) too large. Fisk (Report of the Chief of Engineers 1902), also found: (1) 21 discharges measured between May and June of 1899 to be too large; (2) four discharges measured before 25 June 1900 to be too large; and (3) most of the discharges measured before 15 June 1901 to also be too large. Based upon the preceding analysis there is insufficient data of adequate quality to allow the computation of St. Clair River flows prior to 1900. Furthermore, since the 1899-1902 measurement set formed the basis for published St. Clair River monthly flows for the period 1860-1899 (Report of the Chief of Engineers 1902), this published data set should not be used.

Although these measured data cannot be used to compute accurate discharge values, they can be used to estimate the effect that dredging in the upper St. Clair River had on the post-1900 levels of Lakes Michigan-Huron. This is useful for water resource projects that may require compensation for the lowering during low lake level periods under climate variability or under global warming. The first step in the procedure to determine the dredging impact was to compute the intersection of the stage-discharge relationships depicted in Figure 5: a Dry Dock level (Dry Dock conversion to IGLD55 datum using MTNY -.38 m; personal communications with Jeff Oiler, National Ocean Service) of 175.97 m, and the corresponding discharge of 5,547.27 m^3s^{-1}.

The second step in the procedure was to develop stage-fall-discharge relationships above the Dry Dock gage using the original fall of the river on the MTNY reference (Equation 2), and the present fall of the river on the IGLD(1955) datum (Equation 3). These equations, along with the actual values are plotted in Figure 6.

$$Q_1 = 347.5316 \times (HB - 172.049)^2 \times (HB - DD)^{.5} \quad (2)$$

where:

Q_1 is the discharge for the measured data (1899-1902);

Q_2 is the discharge for the coordinated data (1962- present);

HB is the water level at the Harbor Beach gage;

DD is the water level at the Dry Dock gage.

The intersection values derived in the first step were substituted into Equation 2 which represents the intersection if no dredging had taken place, and Equation 3 which represents the present conditions. Solving for Harbor Beach gives 176.57 and 176.37 for Equations 2 and 3, respectively. The difference between the two Harbor Beach levels can be attributed to dredging in the upper St. Clair River and the subsequent lowering of Lakes Michigan-Huron's levels. This value of 0.2 m supports Derecki's 0.18 m (1985), and the International Great Lakes Levels Board's 0.18 m (1973).

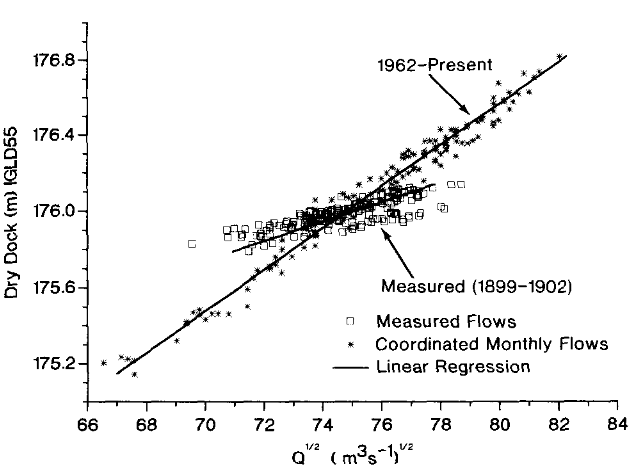

FIG. 5. St. Clair River stage-discharge relationship at the dry dock gage; Q = discharge.

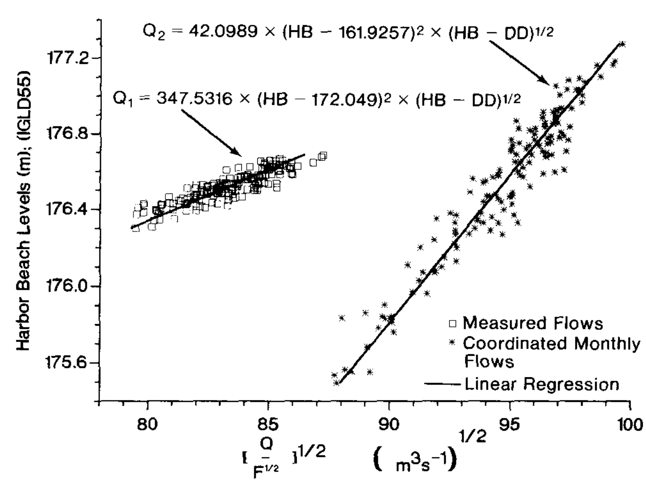

FIG. 6. St. Clair River stage-fall-discharge relationship for "HB − DD" reach; where F = HB − DD; Q = discharge.

CONCLUSIONS

This study demonstrates that it is not possible to quantify the pre-1900 flow regime on the St. Clair River. It also supports the 0.20 m post-1900 lowering of Lakes Michigan-Huron water levels due to dredging in the upper St. Clair River. The continual progressive dredging in the river from the 1860s to present, coupled with the lack of reliable discharge measurements, prohibits the derivation of a pre-1900 stage-fall-discharge equation for the St. Clair River. Thus, it is impossible to accurately determine water supplies for the period prior to 1900. Therefore, the published monthly flows for the period 1860-1899 are in error and should not be used, and the period 1900-present is the appropriate base period for Great Lakes water resource studies.

ACKNOWLEDGMENTS

This paper is GLERL contribution no. 815, and has been sponsored under Phase II of the International Joint Commission Reference Level Study. The authors would like to thank editors Chuck Southam and Nanette Noorbakhsh for their significant editorial contributions.

REFERENCES

Brunk, I. W. 1961. Changes in the levels of Lakes Michigan and Huron. *Journal of Geophysical Research* 66:3329-3335.

_______. 1968. Evaluation of channel changes in St. Clair and Detroit Rivers. *Water Resources Research* 4:1335-1346.

Clark, R. H., and Persoage, N. P. 1970. Some implications of crustal movement in engineering planning. *Can. J. Earth Sciences* 7:628-633.

Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. 1988. Lakes Michigan-Huron outflows; St. Clair and Detroit River 1900-1986. Chicago, IL, and Cornwall, Ontario.

_______. (in-press). Hydraulic discharge measurements and regime changes on the Great Lakes connecting channels and the international section of the St. Lawrence River. Vol(s) 1 & 2.

Derecki, J. A. 1985. Effects of channel changes in the present century. *J. Great Lakes Res.* 11:201-207.

Horton, R. E., and Grunsky, C.E. 1927. *Hydrology of the Great Lakes.* Report of the Engineering Board of Review of the Sanitary District of Chicago on the Lake Lowering Controversy and a Program of Remedial Measures; Part III—Appendix II. Engineering Board of Review of the Sanitary District of Chicago, Chicago, IL.

IGLD. 1955. *Establishment of International Great Lakes Datum (1955).* Prepared by the Coordinating Committee on the Great Lakes in 1961. Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, Chicago, IL, and Cornwall, Ontario.

International Great Lakes Levels Board. 1973. *Regulation of Great Lakes water levels.* Report to the International Joint Commission, International Great Lakes Level Board, Ottawa, Ont. Chicago Ill., pp. 43-49.

International Joint Commission. 1976. *Further regulation of the Great Lakes.* IJC report to the governments of Canada and the United States, International Joint Commission, Windsor, Ontario. pp. 21-23.

National Ocean Service. 1990. *Great Lakes Water Levels.* U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 6001 Executive Blvd. Rockville, Maryland 20852.

Quinn, F.H. 1964. *Stage-fall discharge equations for the connecting channels of the Great Lakes.* Great Lakes Research Division, Pub. No. 11. The University of Michigan.

Report of the Chief of Engineers. 1868. *Annual report of the War Department for the fiscal year ended June 30, 1868.* Government Printing Office, Washington, D.C., pp. 500-506.

_______. 1900. *Annual report of the War Department for the fiscal year ended June 30, 1900.* Government Printing Office, Washington, D.C., pp. 5317-5402.

_______. 1902. *Annual report of the War Department for the fiscal year ended June 30, 1902.* Government Printing Office, Washington, D.C., pp. 2769- 2883.

_______. 1903. *Annual report of the War Department for the fiscal year ended June 30, 1903.* Government Printing Office, Washington, D.C., pp. 2617- 2883.

Submitted: 7 January 1993
Accepted: 30 August 1993