Derecki
88 ✓

LAKES MICHIGAN-HURON OUTFLOWS
ST. CLAIR AND DETROIT RIVERS
1900-1986

BY THE
COORDINATING COMMITTEE
ON
GREAT LAKES BASIC HYDRAULIC AND HYDROLOGIC DATA

OCTOBER 1988

SECTION 5

METHOD USED BY THE GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY (NOAA) FOR DETERMINATION OF FLOWS (1979-86)

5.1 Unsteady Flow Models. Basic flow computations for 1979-86 were made with numerical flow models developed to simulate unsteady flow rates in the rivers. These models can be operated at hourly or daily time intervals, giving flows tabulated for daily or monthly periods, respectively. The models are based on complete partial differential equations of continuity and motion, expressed in terms of flow Q and stage Z above a fixed datum as follows:

$$\frac{\partial Z}{\partial t} + \frac{1}{T}\frac{\partial Q}{\partial x} = 0 \qquad (1)$$

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

where x = the positive flow direction of discharge

t = time

A = channel cross-sectional area

T = top width

g = acceleration due to gravity

R = hydraulic radius

n = Manning's roughness coefficient

∂ = partial derivative function

$//$ = absolute value

Equations (1) and (2) were placed in finite difference form at point M in the implicit computation network (see Figure 11) to yield, respectively,

$$\frac{Zu' + Zd' - Zu - Zd}{2\Delta t} - \frac{\theta\ (Qd' - Qu') + (1-\theta)\ (Qd - Qu)}{T\Delta X} = 0 \qquad (3)$$

$$\frac{Qu' + Qd' - Qu - Qd}{2\ \bar{A}\Delta t} - \frac{\bar{Q}T\ (Zu' + Zd' - Zu - Zd)}{\bar{A}^2\Delta t} +$$

$$(g - \frac{\bar{Q}^2 T}{\bar{A}^3}) \cdot \frac{\theta\ [(Zd' - Zu') + (1-\theta)\ (Zd - Zu)]}{\Delta X} +$$

$$\frac{gn^2\ \bar{Q}/\bar{Q}/}{2.208\ \ \bar{A}^2\ \bar{R}^{4/3}} = 0 \qquad (4)$$

where u and d indicate upstream and downstream locations for a distance increment Δx, a prime indicates new values at these locations, after time increment Δt, and overbar indicates mean, such that

$$\theta = \frac{\Delta t'}{\Delta t} \qquad (5)$$

$$\bar{Q} = 0.5\ [\theta\ (Qu' + Qd') + (1-\theta)\ (Qu + Qd)\ ] \qquad (6)$$

$$\bar{A} = 0.5\ [\theta\ (Au' + Ad') + (1-\theta)\ (Au + Ad)\ ] \qquad (7)$$

Solution of equations (3) and (4) by the implicit method forms the basis of the numerical models. A stable solution for these equations is provided by the weighting coefficient θ, which was selected empirically by Quinn and Wylie[17] to be 0.75. Application of the equations at selected cross-sections for predetermined river reaches produces a set of nonlinear equations that are solved simultaneously with linear approximations by the Newton-Raphson numerical iteration procedure. The predetermined river reaches are bounded by water level gauges, which serve as the model's boundary conditions. These are simply imposed physical limits with known water level conditions, which are needed for the solution of individual model versions that correspond to preselected river reaches. Descriptions of the initial St. Clair and Detroit River models, including calibration, sensitivity analysis, program listings, and output samples, are given by Quinn and Hagman[16]. These initial models have been revised; the modified St. Clair River models are described by Derecki and Kelley[2], and the Detroit River models by Quinn.[14,15]

5.2 Current Meter Flows. Flows in the St. Clair and Detroit Rivers determined by either stage-fall-discharge equations or by unsteady flow numerical models are calibrated from periodic discharge measurements taken over the years during the open-water season. Consequently, these computed flows are reasonably accurate during ice-free periods, but may contain large errors during those winter months having an extensive ice cover. The winter flow discrepancies are usually produced by heavy ice accumulation and ice jamming, primarily taking place in the lower St. Clair River, where an extensive river delta retards the passage of ice flows. To collect winter flow information in the rivers, an in-place current meter measurement program was started in the St. Clair River, with continuous measurements beginning in November 1983. Initial instrumentation consisted of two electromagnetic (EM) current meters (Marsh-McBirney, Inc., Model 585) deployed in the upper river at Port Huron, about 165 and 225 ft from the U.S. shore, in an average water depth of about 45 ft. This instrumentation placement was duplicated on the Detroit River in August 1984, with the meters deployed in the upper river near the Fort Wayne water level gauge, about 200 and 300 ft from the U.S. shore, in an average water depth of about 40 ft. In November 1984, the St. Clair River metering station was augmented with one acoustic Doppler current profiler (ADCP) meter (RD Instruments, Model 1200 RDDR), which provided averaged vertical velocities for approximately 1 m (3.3 ft) consecutive depth segments throughout the water column.

Use of these current meters for continuous measurement of flows in the St. Clair and Detroit Rivers was described by Derecki and Quinn.[5] Periodically, the EM meters gave sharply reduced velocity readings, approaching zero at times, due to frazil ice coating (in winter) or weed accumulation around the sensors (mainly in summer and fall). There were about a half dozen frazil ice episodes occurring on each river per winter, causing short-term (hours or days) data gaps. The weed problem was considered the most serious as it caused long periods (weeks or months) of measured velocity data to be either questionable or erroneous. Frazil ice episodes were easily discernible in the records, presenting no problems in making data corrections. However, weeds have a tendency to build up gradually and the effects are more subtle and difficult to ascertain. With periodic meter inspection and cleaning of sensors by divers, the weed problem was generally manageable in the relatively clean upper St. Clair River, but could not be effectively controlled in the Detroit River which has much heavier weed growth. The St. Clair River ADCP meter was unaffected by frazil ice and weeds, which eliminated most of the data gaps. The quality of data from this meter was also better than the other meters during periods unaffected by frazil ice and weeds, as described by Derecki and Quinn.[5]

Flow estimates from the current meter measurements were obtained by computing daily model-to-meter velocity ratios (eliminating ice affected winter periods) and then multiplying velocities from the meters by the averaged ratios to obtain average river velocities. These velocities were, in turn, multiplied by corresponding cross-sectional areas to produce quantitative river flows.

5.3 <u>Transfer Factors.</u> Monthly hydrologic transfer factors pertaining to Lake St. Clair, for 1979-86, were developed to enable comparison between the St. Clair and Detroit River monthly flows. These transfer factors represent the hydrologic water balance for Lake St. Clair. Ignoring the ground water flux at the lake, which is assumed to be negligible, the transfer factor T is defined by the equation,

$$T = P + R - E - S \tag{8}$$

where P = over-lake precipitation

R = drainage basin runoff

E = lake surface evaporation

S = change in lake storage

The above input parameters were determined independently from available data. The procedure is documented by Quinn.[12] Applying the transfer factor to the Lake St. Clair hydrologic balance yields the flow comparison equation,

$$Q_{SC} + T = Q_D \tag{9}$$

where Q_{SC} = inflow into lake from the St. Clair River

Q_D = outflow from lake into Detroit River.

5.4 <u>St. Clair River Open-Water Flows.</u> Several operational St. Clair River models, based on the one-dimensional equations for continuity and motion described earlier, were developed. These models span the upper portion of the river from Port Huron to the city of St. Clair. Six U.S. water level gauges, located along this river reach, supply data for the models, with three or more gauges included in each model assessment. The extreme gauges (downstream and upstream) form the model's boundary conditions and are used as forcing functions to compute the river profiles and dependent flows. The in-between, or centrally located gauge data (one or more gauges), are included for checking the accuracy of derived flows by comparing computed and measured water levels at the gauges. Each model produces three flow values, corresponding to both the extreme gauges and also the middle water level gauge, to indicate possible flow variations along the employed river reaches due to local inflow. Because of small lateral inflow, differences between these flows are generally insignificant.

The following six model reaches, defined by the above method, are available for the St. Clair River:

1. Ft. Gratiot - Mouth of Black River - Dry Dock (FG-MBR-DD).
2. Dunn Paper - Mouth of Black River - Dry Dock (DP-MBR-DD).
3. Mouth of Black River - Dry Dock - St. Clair (MBR-DD-SC).
4. Ft. Gratiot - Mouth of Black River - St. Clair (FG-MBR-SC).
5. Ft. Gratiot - Dry Dock - St. Clair (FG-DD-SC).
6. Ft. Gratiot - Dunn Paper - Mouth of Black River (FG-DP-MBR).

The open-water period flows were determined by selecting appropriate computed values (normally the average) from three models, usually the first three as shown above. Two models for the Ft. Gratiot - St. Clair reach of the river (nos. 4 and 5) were used only when required. The last model (no. 6), at the head of the river, was used only during those winter months experiencing ice problems. This model represents the portion of the river having the last open-water reach. Because it is so short (2 miles), it does not give dependable open-water flows (large fluctuations). Toward the end of the period (1983-86) being coordinated, flow estimates obtained from the current meter measurements were also used in the selection process for determining river flows. Model results were compared with the current meter derived flows and adjustments were made where appropriate (after consideration of those weed effects or other meter problems indicated on the data records).

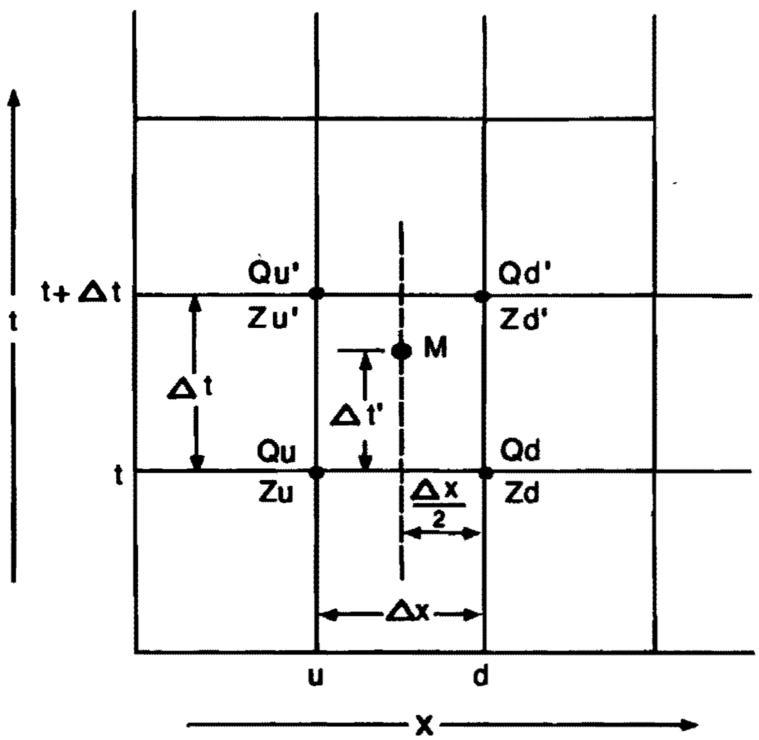
5.5 St. Clair River Winter Flows. Three models (nos. 1 to 3) plus the last model (no. 6) were generally used to compute winter flows. However, during winter, there is generally less agreement among St. Clair River models, and frequent discrepancies occur between the St. Clair River and Detroit River flows. This discrepancy between the models is due to ice retardation, which occurs quite often, especially in the lower St. Clair River. Complete resolution of the ice retardation problem would require winter flow measurements; this was demonstrated by Derecki and Quinn[3,4] for the record St. Clair River ice jam of April 1984.

Winter flows for the St. Clair River were determined by approximately the same procedure used during open-water periods. However, computed flows were examined for possible ice effects, and the flows indicating the least discharge were normally used. During the last three winters, considerable emphasis was given to flows estimated from the current meter measurements, in comparison with model-simulated flows. Some consideration was also given to flows determined by transferring Detroit River flows, but the St. Clair River models produce flows that are normally assumed to be more representative of actual conditions.

5.6 Detroit River Open-Water Flows. Two different unsteady flow models were developed for the Detroit River. One is the upper river model, which spans the river from Windmill Point to Wyandotte. The other is the total river model (Windmill Point to Fermi), which branches into two channels in the lower reach to give separate flows around Grosse Ile. Operation of both models is similar, except the total Detroit River model provided four additional flow values, corresponding to the upstream and downstream sections of the branching channels. Both model-simulated flows and transferred St. Clair River flows were used to make a final selection of the Detroit River flows. Flow estimates determined from the last three years of the current meter program were generally so affected by weeds and instrument problems, that they could not be used during most months. The three-gauge designations for the two models are as follows:

1. Windmill Pt. - Ft. Wayne - Wyandotte (WP-FW-WY).
2. Windmill Pt. - Wyandotte - Fermi (WP-WY-FE).

5.7 Detroit River Winter Flows. Both of the above models were used to compute winter flows, but the upper river model is considered more reliable, since it spans what is normally an ice-free reach. However, when discrepancies occurred between computed flows for the Detroit and St. Clair Rivers, the recommended Detroit River flows were based primarily on the transferred St. Clair River flows. Only partial current meter flow estimates were available for the last two winter seasons and did not provide much help in the flow selection process.



Implicit Computation Network **Figure 11**

REFERENCES

1. Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data, 1982. Lakes Michigan-Huron Outflows, St. Clair and Detroit Rivers, 1900-1978. Detroit, MI and Cornwall, Ontario.

2. Derecki, J.A., and Kelley, R.N., 1981. Improved St. Clair River Dynamics Flow Models and Comparison Analysis. NOAA Technical Memorandum ERL GLERL-34, NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 36 pp.

3. Derecki, J.A., and F.H. Quinn, 1986a. Natural Regulation of the Great Lakes by Ice Jams: A Case Study. Proceedings, 4th Workshop on Hydraulics of River Ice, Service Hydraulique, Ecole Polytechnique de Montreal, Quebec, June 19-20, Vol. 1, pp. F4.1-F4.24.

4. Derecki, J.A., and F.H. Quinn, 1986b. The Record St. Clair River Ice Jam of 1984. Journal of Hydraulic Engineering, Vol. 112, No. 12, pp. 1182-1194 - December 1986.

5. Derecki, J.A., and F.H. Quinn, 1987. Use of Current Meters for Continuous Measurement of Flows in Large Rivers. Water Resources Research, Vol. 23, No. 9, pp. 1751-1756.

6. Franco, J.J. and Glover, J.E., 1972. Effects of Submerged Sills in the St. Clair River. WES Technical Report H-72-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

7. International Great Lakes Levels Board, 1973. Regulation of Great Lakes Water Levels. Report to the International Joint Commission, United States and Canada.

8. Korkigian, Ira M., 1963. "Channel Changes in the St. Clair River Since 1933." Journal of the Waterways and Harbors Division, Vol. 89, No. WW2, American Society of Civil Engineers N.Y., NY, May.

9. Lake Survey District, U.S. Army Corps of Engineers, 1965. Effects of Channel Changes in the St. Clair River. Archive No. 3-4236, Detroit, MI, October.

10. Moore, Sherman, 1933. A Study of the Hydraulics of the St. Clair River Prior to 1932. Unpublished report, Lake Survey District, Corps of Engineers, Archive No. 3-2692, Detroit, MI.

11. Moore, Sherman, 1946. Summaries of Detroit River Measurement. Unpublished report, Lake Survey District, Corps of Engineers, Archive No. 3-3083, Detroit, MI.

12. Quinn, F.H., 1976. Lake St. Clair Hydrologic Transfer Factors. NOAA Technical Memorandum ERL GLERL-10, NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 16 pp.

13. Quinn, F.H., 1979. Derivation and Calibration of Stage-Fall-Discharge Equations for the Great Lakes Connecting Channels. GLERL Open File Report, NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 7 pp.

14. Quinn, F.H., 1980a. Intercomparison Analysis of Detroit River Dynamic Flow Models. GLERL Open File Report, NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, MI., 11 pp.

15. Quinn, F.H., 1980b. "Note--Wind Stress Effects on Detroit River Discharges." Journal of Great Lakes Research, Vol. 6, No. 2, pp. 172-175.

16. Quinn, F.H., and Hagman, J.C., 1977. Detroit and St. Clair River Transient Models. NOAA Technical Memorandum ERL GLERL-14, NOAA Great Lakes Environmental Research Laboratory, Ann Arbor, MI., 45 pp.

17. Quinn, F.H., and Wylie, E.B., 1972. "Transient Analysis of the Detroit River by the Implied Method." Water Resources Research, Vol. 8, No. 6, pp. 1461-1469.

18. Subcommittee on Regulation, 1969. Report to International Great Lakes Levels Working Committee by Subcommittee on Regulation - St. Clair and Detroit River Flows. Detroit, MI and Cornwall, Ontario, March.

19. Thomas, R.J. 1979. Finite Difference Model for the Prediction of Transient Flows. Unpublished report, Detroit District, Corps of Engineers, Detroit, MI.