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METHOD USED BY GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY (U.S.) TO COMPUTE FLOWS*

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Background. Flows in the St. Clair and Detroit Rivers are coordinated by the River Flow Subcommittee to avoid deviations in official flow records,as derived and published by agencies in the United States and Canada. This flow coordination is performed by representatives from the Corps of Engineers, Detroit District, and the NOAA, Great Lakes Environmental Research Laboratory, for the United States and the Inland Waters Directorate, Environment Canada, Ontario Region, for Canada.

Unsteady Flow Models. Basic flow computations for 1959-85 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:

$$\frac{dZ}{dt} + \frac{1}{T}\frac{dQ}{dX} = 0 \qquad (1)$$

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$$\frac{1}{A}\frac{dQ}{dt} - \frac{2QT}{A^2}\frac{dZ}{dt} + \left(g - \frac{Q^2T}{A^3}\right)\frac{dZ}{dX} + \frac{gn^2Q/Q/}{2.208\ A^2R^{4/3}} = 0 \qquad (2)$$

where X = discharge in the positive flow direction

t = time

A = channel cross-sectional area

T = top width of the channel at the water surface

g = acceleration due to gravity

R = hydraulic radius

n = Manning's roughness coefficient

d = partial derivative function

// = absolute value.

Equations (1) and (2) were placed in finite difference form at point M in an X-t grid (see Figure 10) to yield respectively,

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

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

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

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

where a prime indicates <u>location</u> and overbars indicate <u>mean</u>, 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 (1972) 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. 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 (1977). These initial models have been revised; the modified St. Clair River models are described by Derecki and Kelley (1981), and the Detroit River models by Quinn (1980a, 1980b).

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 normally reasonably accurate during ice-free periods, but may contain large errors during winter months with extensive ice cover. The winter flow discrepancies are produced by heavy ice accumulation and ice jamming, primarily in the lower St. Clair River, where an extensive river delta retards the passage of ice flows. To provide information on winter flow variability in the rivers, a current meter flow 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 was duplicated on the Detroit River in August 1984, with the meters deployed in the upper river at Fort Wayne, 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 meter station was augmented with one acoustic Doppler current profiler (ADCP) meter (RD Instruments, Model 1200 RDDR), which provides averaged vertical velocities for approximately 1 m (3.3 ft) consecutive depth segments throughout the water column.

Use of these current meters for continuous measurements of flows in the St. Clair and Detroit Rivers is described by Derecki and Quinn (1986c). 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 on each river per winter, causing short-term (hours or days) data gaps due to bad data. The weed problem was more serious because for long periods (weeks or months) measured velocity data could be either questionable or erroneous. Frazil ice episodes were obvious in the records, presenting no problems in data correction. However, except for occasional sudden surges, weeds build up gradually and the effects were more 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 with much heavier weed transport. Also, the St. Clair River ADCP meter was unaffected by frazil ice and weeds, which eliminated data gaps due to bad or questionable measured data. The quality of data from the ADCP meter was also better during periods unaffected by frazil ice and weeds, as described by Derecki (1986).

Flow estimates from the current meter measurements were obtained by computing daily model-to-meter velocity ratios (eliminating winter periods in which ice affected model results) and then multiplying velocities from the meters by the averaged ratios to obtain average river velocities based on meter measurements. These velocities were, in turn, multiplied by corresponding cross-section areas to produce river flows. Except for occasional mechanical/electronic problems with EM meters on both rivers, this procedure generally worked satisfactorily on the St. Clair River, but largely failed to provide usable data on the Detroit River. To correct this problem, the ADCP meter will be deployed in the Detroit River for the 1986-87 season.

Transfer Factors. Monthly hydrologic transfer factors pertaining to Lake St. Clair for 1959-85 were developed to enable comparison between the St. Clair and Detroit Rivers' monthly flows. This transfer factor represents 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 (1976). 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.

St. Clair River -- Open-Water Flows. 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 its outflow at Port Huron to the city of St. Clair. Six U.S. water level gauges located along this reach supplied data for the models, with three or more gauges per model. The extreme gauges (lowest and highest) are used as forcing functions to compute the river profile and dependent flows. The in-between or centrally located (middle) gauge data (one or more gauges) are included for checking flow values by comparing computed and measured water levels. Each model provides three sets of flows corresponding to the computed river profile, indicated by the extreme and middle water level records of the employed gauges. Because of small lateral inflow, differences between these flows are generally insignificant.

The following six models, 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 river flows were determined by selecting appropriate values (normally average) from three models, usually the first three. Two models for the Ft. Gratiot - St. Clair reach of the river (nos. 4 and 5) were used only if needed. The last model (no. 6) at the head of the river was used only during winter months with ice problems. This model usually represents the last open-water reach, but is apparently too short to give dependable open-water flows (large fluctuations). Toward the end of the flow coordination period (1983-85), flow estimates obtained from the current meter measurements were given heavy emphasis in the selection of river flows, in comparison with normal model results.

<u>St. Clair River -- Winter Flows.</u> The three models used for open-water flows (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. The discrepancy between the models is due to ice retardation of flows, which occurs quite often, especially in the lower St. Clair River. Resolution of the ice retardation problem requires winter flow measurements; this was demonstrated by Derecki and Quinn (1986a, 1986b) for the record St. Clair River ice jam of April 1984.

Winter flows for the St. Clair River were determined by basically the same procedure used during open-water periods. However, computed flows were examined for possible ice effects, and flows indicating smallest discharge were normally used. During the last two winters, the main emphasis in the river flow selection was given to flows estimated from the current meter measurements, as opposed to normal model-simulated flows. Some consideration was also given to the transferred Detroit River flows, but the St. Clair River models produce flows that are normally assumed to be more representative of actual conditions. This assumption and the winter flow selection are based on minimum flow criteria established by the Regulation Subcommittee, International Great Lakes Levels Board (1969).

Detroit River -- Open-Water Flows. Two different unsteady flow models were developed for the Detroit River. One is the upper river model, which is similar to the St. Clair River models. The other is the total river model, which branches into two channels in the lower portion of the river to give separate flows around Grosse Ile. Operation of the models for both rivers is similar, except the total Detroit River model provides four additional flow values, corresponding to the upstream and downstream sections of the branching channels. Both model-simulated and transferred St. Clair River flows were used to select the Detroit River flows. Flow estimates available from the last two years of the current meter program were generally affected by weeds and instrument problems, and 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).

Detroit River -- Winter Flows. Both open-water 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 occured between computed flows for the two rivers, the recommended flows were based primarily on the transferred St. Clair River flows, under the minimum flow criteria mentioned previously (St. Clair River winter flows). Only partial current meter flow estimates were available for the last winter season and did not provide much help in the flow selection process.

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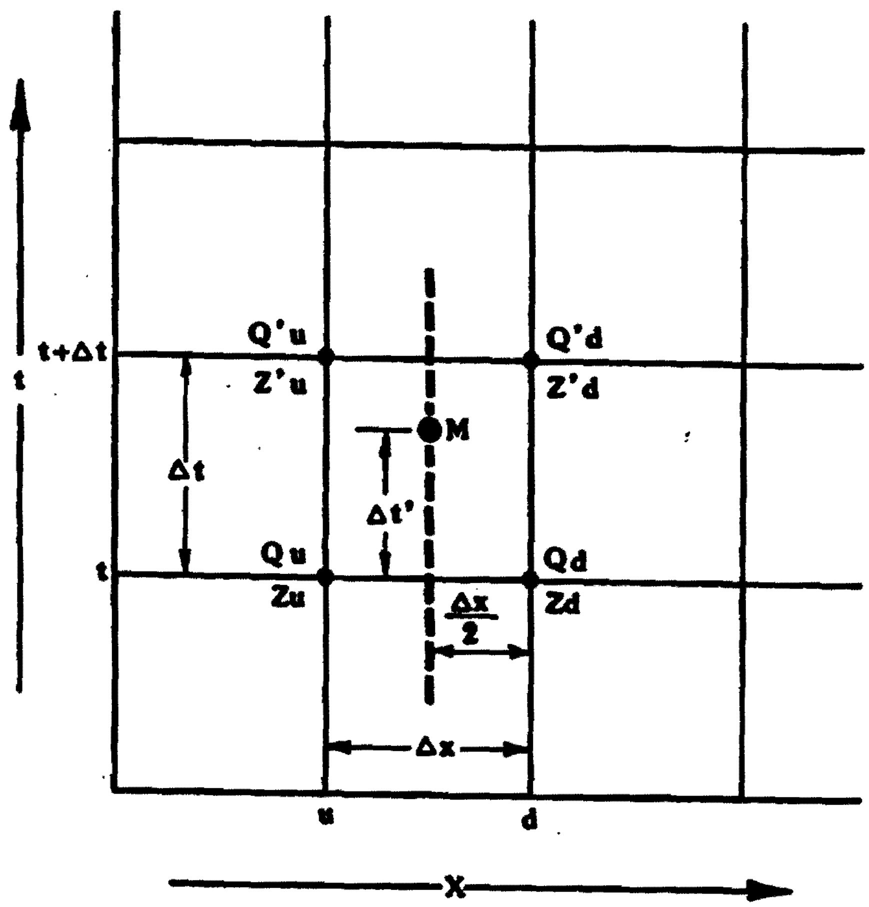
NOTE to RFS of CCGLBHHD: References in sequential alphabetic order, nos. 1-5 and 11-17, are cited in the GLERL revised text for the 1900-1985 period. Other references (also in alphabetic order), nos. 6-10, are from other sections of the original report for the 1900-1978 period.



X-t Grid for the Implicit Method

Figure 10