NOAA Technical Memorandum ERL GLERL-24

UPPER ST. LAWRENCE RIVER HYDRAULIC TRANSIENT MODEL

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Ann Arbor, Michigan
October 1978
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CONTENTS

Abstract 1
1. INTRODUCTION 1
2. COMPUTER REQUIREMENTS 2
3. MODEL DESCRIPTION 2
4. MATHEMATICAL THEORY 4
5. MODEL CALIBRATION 12
6. HYDRAULIC EFFECT OF ICE COVER 14
7. THE HANGING DAM 22
8. MODEL STRUCTURE
9. MODEL INITIALIZATION 28
10. REFERENCES 30

Appendix A. MODEL INPUT SUMMARY
Appendix B. EXAMPLE PROBLEMS 37
Appendix C. PROGRAM LISTING 80
FIGURES

1. St. Lawrence River conceptualized transient model. 3
2. Definition sketch. 6
3. Time-space grid for implicit solution. 6
4. Comparison of stage vs. \((Q/\sqrt{P})^{1/2}\) for prototype and model. 15
5. Determination of composite roughness in ice-covered channel. 20
6. Sensitivity of river profile to ice thickness and ice roughness. 21
7. Sensitivity of fall to ice-cover roughness with 12-inch ice cover. 23
8. The hanging dam. 24
9. Flow-Chart. 28

APPENDIX FIGURES

Page

B.1. River profiles for example problems a, b, and c. 65
B.2. Simulation of river profile for the period 7-10 August 1977. 79
TABLES

1. Manning's roughness values.
2. Calibrated Manning's roughness coefficients.
3. Water level simulation error during ice-cover conditions.
The Great Lakes Environmental Research Laboratory (GLERL) has developed hydrologic response models for simulation studies on precipitation augmentation, ice retardation, system diversions, and connecting channel changes. For example, hydraulic transient models developed for use on the Detroit and St. Clair Rivers have been used to compute channel flow.

The most recent addition to this series of models, a hydraulic transient model of the upper St. Lawrence River, is designed to simulate river profiles and flows on the St. Lawrence River from Lake Ontario to the Moses-Saunders powerhouse near Massena, N.Y. It is capable of simulation on varying time increments and includes flow under ice-covered, as well as open-water conditions. This paper describes the mathematical model, its development, calibration, verification, and typical applications.

1. INTRODUCTION

As the outlet from Lake Ontario, the St. Lawrence River conveys water from the Great Lakes Basin to the Atlantic Ocean. It varies from 0.25 to 2 miles in width, averages near 30 feet in depth, and normally discharges between 180 and 320 thousand cubic feet of water per second. Approximately 90 miles downstream of Lake Ontario the river flow is regulated by the Moses-Saunders Power Dam, which was built during the development of the St. Lawrence Seaway in 1959.

Operation of the power dam is governed by the water level in Lake Ontario in accordance with Regulation Plan 1958-D. Regulation of the river is of vital concern to many interests of national and international power, navigation, recreation, industrial, and domestic users. Although regulation of the river occurs on a weekly basis, the river flows and water levels are monitored and adjusted on an hourly and daily basis to meet power demands or navigational requirements. During winter ice forms on the river, resulting in a suspension of navigation and reduced power generation for approximately 15 weeks of the year.

GLERL Contribution No. 181.
The international reach of the river between Lake Ontario and the Moses-Saunders Power Dam has been simulated by a hydraulic transient model. Development of the model, designed to simulate river profiles and flows during open-water and partially or totally ice-covered conditions, was undertaken at the request of the U.S. Army Corps of Engineers, Detroit District. The purpose was to provide a useful tool in water resources management. The Corps of Engineers needs such a model to evaluate water surface changes due to channel dredging, changing ice covers, and the effect of extending the navigation season on the St. Lawrence River.

2. COMPUTER REQUIREMENTS

The St. Lawrence River hydraulic transient model is a digital model relying on the simultaneous solution of the mass continuity and momentum equations to determine discharge and stage at various points along the river from Lake Ontario to the Moses-Saunders Power Dam. The program was developed on a CDC 6600 computer with a FORTRAN IV language compiler. An implicit solution procedure used in the program requires a banded matrix solution subroutine. Subroutine LEQT1B (1), developed by International Mathematical and Statistical Libraries, Inc., was used during development of the model. However, any subroutine capable of solving the linear equation

\[ CX = D \]

may be used in its place.

The model requires a core storage of 58 k (octal) on a CDC 6600 machine. Central processing time is a function of the number of time increments used in the model run. Estimated computer costs are $3 for initialization of the model and $.20 for each time step of solution required. Manpower requirements are limited to defining the set of circumstances to be examined by the model.

3. MODEL DESCRIPTION

The area of the St. Lawrence River simulated by the model extends from Lake Ontario to the Moses-Saunders Power Dam near Massena, N.Y. The configuration in the model consists of 30 reaches interrelated by 21 intersection or "nodal" points as shown in Figure 1. Each reach is assumed prismatic with its own physical characteristics of length, width, wetted area, wetted perimeter, and bed roughness. The nodal points describe the river configuration by specifying the sequence of reaches and the logic of the flow pattern. For example, at a node
number 9, the flow leaving reach 13 is an incoming flow to the node. Likewise, the water flowing into reach 14 is an outgoing flow. The flow and stage at the downstream end of reach 13 can then be equated to the flow and stage at the upstream end of reach 14 from the equations of continuity and energy. Information describing the nodal points is maintained in a separate array. The technique of maintaining an array to describe the flow pattern was employed because of the need for a generalized model during development to allow a changing definition of the channels and a changing emphasis on points of information.

The model is capable of simulating a river profile under partial or total ice cover, as well as open water conditions. When ice is included on a reach of the river, the model decreases the hydraulic radius for that reach and the area is constricted by an amount 0.9 times the ice thickness (the specific gravity of ice is assumed to be 0.9). In addition, the Manning's roughness coefficient is adjusted by the composite roughness formula developed by Belokon-Sabaneev (Sabaneev, 1948). Any ice configuration may be input into the model by specifying the ice thickness and roughness coefficient of the ice cover. Each reach is considered either open or completely ice covered depending on whether or not the ice thickness is zero.

The history of the river has shown ice jams to form in the Galop and Ogden Island reaches of the river. These ice jams, called hanging dams, severely restrict river flows and power generation downstream. The model provides for simulation of hanging dams (up to a maximum of three), if desired, in addition to the ice cover on the river.

Input to the model consists of the initial stage and flow conditions along the river, the respective channel roughness coefficients, ice-cover roughness coefficients, and ice thickness for all the reaches. Generally, a complete set of initial stage and flow conditions is not available. In this case, initial conditions are set at zero discharge and a level pool at the elevation of Lake Ontario. An initial discharge is then simulated and a steady state profile is achieved corresponding to the desired discharge to be simulated. All input and output data are in the English system of units.

A net total supply (NTS) hydrograph or water level hydrograph is allowable input as upstream boundary conditions. Downstream boundary conditions include a discharge or water level hydrograph at the power house. Sample computer runs and a program listing are given in Appendices B and C.
4. MATHEMATICAL THEORY

The unsteady one-dimensional equations of continuity and momentum have been adapted by numerous authors (e.g., Wylie and Streeter, 1978). In the St. Lawrence model, the equations take the form

\begin{equation}
\frac{\partial Q}{\partial A} + A_t = 0 \tag{1}
\end{equation}

\begin{equation}
\frac{\partial Q}{\partial A} + \frac{Q^2}{2A} A_x + g \frac{\partial H}{\partial x} + \frac{g n^2 Q A_x}{2.208 A^2 g/3} + \frac{Q_t}{p} T = 0 \tag{2}
\end{equation}

where

- \( Q \) = mean discharge in a reach,
- \( A \) = mean area in a reach,
- \( R \) = mean hydraulic radius, and
- \( A_x \) = the partial derivative of the area \( A \) with respect to distance \( x \),
- \( H_x \) = the partial derivative of the water surface elevation \( H \) with respect to distance \( x \),
- \( Q_x \) = the partial derivative of the flow \( Q \) with respect to distance \( x \),
- \( A_t \) = the partial derivative of \( A \) with respect to \( t \) (time),
- \( Q_t \) = the partial derivative of \( Q \) with respect to \( t \) (time),
- \( n \) = the Manning's roughness coefficient,
- \( g \) = force of gravity,
- \( T_x \) = wind stress \( (T_x = C_d p_a V_w^2) \),
- \( T \) = channel top width,
- \( p \) = density of water (assumed at 10°F),
- \( C_d \) = drag coefficient \( (C_d = 0.0013) \),
- \( p_a \) = density of air, and
- \( V_w \) = wind speed along the channel.

Equations (1) and (2) are evaluated over the time-space domain to find the variation in unknown conditions of stage and flow at the upstream and downstream end points of each reach as shown in Figures 2 and 3.
Because each end of each reach is uniquely defined, equations (1) and (2) are expressed in terms of four unknown quantities of flow Q and stage H. That is, 30 reaches implies 60 points, each of which has an unknown H and Q. Using finite difference methods, one can evaluate equations (1) and (2) at point \( m \) as follows:

\[
\frac{\partial(Q_d^p - Q_u^p)}{\partial x} + (1 - \varepsilon)(Q_d - Q_u) = 0
\]

\[
\frac{2Q}{A} \left[ \frac{\partial(H_d^p - H_d)}{\partial x} + \frac{\partial(H_u^p - H_u)}{\partial x} \right] = 0
\]

\[
+(1 - \varepsilon) \left[ T_d(H_d^p - Z_d) - T_u(H_u^p - Z_u) \right] - \frac{gA}{2} \frac{Q_d^p + Q_u^p - (Q_d + Q_u)}{2At}
\]

\[
= 0
\]
Figure 2. Definition sketch.

Figure 3. Time-space grid for implicit solution.
normally large with respect to the incremental area $T(H - Z)$. Therefore, substitution of a mean top width $T = T = T$ can be made without affecting the $A$ term in the momentum equation. Equation (4) can then be simplified to

$$\frac{2Q}{\Delta x} \left[ \Theta \left( T_d^P - Q_u^P \right) + (1 - \Theta) (Q_d - Q_u) \right] + \frac{Q^2}{2A^2 \Delta x}$$

$$= x \left[ \Theta \left( (H_d^P - Z_d) - (H_u^P - Z_d) \right) + (1 - \Theta) \left( (H_d - Z_d) - (H_u - Z_u) \right) + A_{bd} - A_{bu} \right] + \Theta \left( (H_d^P - H_u^P) \right)$$

$$+ (1 - \Theta) \left( H_d - H_u \right) + \frac{2 \Delta T}{2.208} \frac{2(Q_d^P + Q_u^P)}{A}$$

$$+ \frac{Q_d^P + Q_u^P - (Q_d^P + Q_u^P)}{2 \Delta T} - \frac{T_x T}{R} = 0$$

(5)

where

$$\bar{Q} = 0.5 \left[ \Theta (Q_d^P + Q_u^P) + (1 - \Theta) (Q_d + Q_u) \right]$$

$$\Theta = \Delta t_m/\Delta t$$, and

$$\bar{A} = 0.5 \left[ \Theta (A_d^P + A_u^P) + (1 - \Theta) (Q_d + Q_u) \right]$$.

Several values of $\Theta$ in the range of $0.5 < \Theta < 1.0$ were examined. It was determined that $\Theta = 0.75$ provided a rapid convergence to a stable solution. At each of the 21 junction points shown in Figure 1, the equations of steady continuity are applied, giving

$$\Sigma Q_u^P - \Sigma Q_d^P = 0$$

(6)
and,

\[ H_u^p = H_d^p = 0 \quad (7) \]

where \( Q^p \), \( H^p \) and \( Q^d \), \( H^d \) correspond to the flow and stage at the entering (upstream) and leaving (downstream) reaches of each junction. Lake Ontario and the power dam reservoir pool are included in the model by the use of the reservoir storage routing equation.

\[ \frac{AS}{At} = (I - O) \quad (8) \]

where

\[ \frac{AS}{At} = \text{the time rate of change in storage}, \]
[= I \text{ = the mean inflow over the time period, and}]
[= O \text{ = the mean outflow over the time period.}]

For a reservoir with a large surface area \((A_0)\), such as Lake Ontario or the reservoir pool, the change in storage can be approximated by:

\[ \frac{AS}{At} = A_0 \frac{AH}{At} \quad (9) \]

Substituting into equation (8) and rearranging yields

\[ F_u = \frac{NTS_1 + NTS_2}{2} - \frac{Q^p}{2} + \frac{Q^d}{2} \frac{A_0 (H^p - H)}{At} = 0 \quad (10) \]

\[ F_d = \frac{Q_{fb}^p + Q_{fb}^d}{2} - \frac{Q_{ph}^p + Q_{ph}^d}{2} \frac{A_{fb} (H^p - H)}{At} = 0 \quad (11) \]

where

\[ NTS = \text{the net total supply of water to Lake Ontario (including precipitation, runoff, evaporation, and Niagara River and Welland Canal inflows);} \]
[= Q = \text{the flow from Lake Ontario;}]
[= A_0 = \text{the surface area of Lake Ontario,} \text{ km}^2 \text{;}]
\[ H = \text{the respective water surface elevation at Lake Ontario or the reservoir pool}; \]
\[ Q_{fb} = \text{the river flow entering the reservoir pool}; \]
\[ Q_{ph} = \text{the discharge through the powerhouse}; \]
\[ A_{fb} = \text{the surface area of the powerhouse reservoir pool, km}^2. \]

The superscript \( p \) indicates the solution at time increment \( t + \Delta t \). Equations (10) and (11) complete the equation set for the model. Equations (3), (5), (6), and (7) are applied to each of the 30 reaches and 21 nodal points in the model. These equations, along with equations (10) and (11), form a matrix of 120 equations and 122 unknowns. Either the net total supply (NTS) or the water level at Kingston, and either the discharge through the powerhouse \( Q_{ph} \) or the water level at the powerhouse are specified as functions of time, leaving 120 equations and 120 unknowns.

The non-linear nature of the equation matrix requires application of an iterative solution technique. A Newton-Raphson algorithm with projected approximations is used in the model. The Newton-Raphson procedure can be defined by equations of the form

\[ F_i + \sum_{j=iu}^{id} \frac{\partial F_i}{\partial H_j} \Delta H_j + \sum_{j=iu}^{id} \frac{\partial F_i}{\partial Q_j} \Delta Q_j = 0, \tag{12} \]

where \( iu \) and \( id \) represent the upstream and downstream points, respectively, of each reach \( i \) \((i = 1 \text{ to } 30)\). The partial derivatives \( \frac{\partial F_i}{\partial H_j} \) and \( \frac{\partial F_i}{\partial Q_j} \) are evaluated with finite difference techniques and the partial derivatives of continuity for the \( i \)-th reach \((i = 1 \text{ to } 30)\) are expressed as

\[ \frac{\partial F_{c1}}{\partial H_{iu}} = \frac{\partial F_{c1}}{\partial H_{id}} = \frac{T}{2\Delta t} \tag{13} \]

\[ \frac{\partial F_{c1}}{\partial Q_{iu}} = -\frac{Q}{L} \tag{14} \]

\[ \frac{\partial F_{c1}}{\partial Q_{id}} = \frac{Q}{L} \tag{15} \]
The partial derivatives of the momentum equation are approximated as

\[
\frac{\partial F_{m1}}{\partial H_{1u}} = -\frac{2Q}{A} \frac{\partial Q}{\partial x} \frac{\partial T}{\partial x} + \frac{Q^2}{A} \frac{\partial T}{\partial x} + \frac{Q^2}{A^2} \frac{\partial T}{\partial x} + \frac{Q}{A} \frac{\partial T}{\partial x} + \frac{4Q}{A} \frac{\partial T}{\partial x}
\]

\[
- \frac{gA}{\Delta X} \frac{\partial T}{\partial x} + gH_{2k-1} \left(\frac{7/3}{A} \frac{\partial Q^2}{A} \frac{\partial Q}{A} \frac{\partial T}{A} \frac{\partial T}{A}\right) + \frac{A^2}{A^2} \frac{\partial T}{\partial x}
\]

\[
+ \frac{A^2}{A^2} \frac{\partial T}{\partial x} + \frac{A^2}{A^2} \frac{\partial T}{\partial x}
\]

(16)

\[
\frac{\partial F_{m1}}{\partial H_{1d}} = \frac{\partial F_{m1}}{\partial H_{1u}} + \frac{2gA}{\Delta X}
\]

(17)

\[
\frac{\partial F_{m1}}{\partial Q_{1u}} = \frac{\partial F_{m1}}{\partial Q_{1u}} + \frac{2gA}{\Delta X} \frac{\partial T}{\partial x} + \frac{1/2\Delta t}{\Delta X}
\]

(18)

\[
\frac{\partial F_{m1}}{\partial Q_{1d}} \left(\frac{\partial F_{m1}}{\partial Q_{1u}} \frac{\partial T}{\partial x} + \frac{4Q}{A} \frac{\partial T}{\partial x}ight)
\]

(19)

For each nodal point \(j\) (\(j = 1\) to \(21\)) the partial derivatives of equations (6) and (7) are

\[
\frac{\partial F_{m1}}{\partial H_{2k}} = 1
\]

(20)

where

\(2k\) is the downstream point of the incoming reach \(k\).

\[
\frac{\partial F_{m1}}{\partial H_{2k-1}} = -1
\]

(21)
where

$2k-1$ is the upstream point of the outgoing reach $k$.

$$\sum_{n=1}^{IN} \frac{\partial F}{\partial Q_{2k}} = 1 \quad (22)$$

where

$IN$ = the number of reaches flowing into the node.

$$\sum_{n=1}^{OUT} \frac{\partial F}{\partial Q_{2k-1}} = -1 \quad (23)$$

where

$OUT$ = the number of reaches flowing out of the node.

Partial derivatives of the boundary condition at Lake Ontario, equation (10), become

$$\frac{\partial F_u}{\partial H_1} = \frac{\partial F_d}{\partial H_2} = \frac{A_o}{A_t} \quad (24)$$

$$\frac{\partial F_u}{\partial Q_1} = -\frac{1}{2} \quad (25)$$

$$\frac{\partial F_u}{\partial Q_2} = -\frac{1}{2} \quad (26)$$

Finally, the partial derivatives of the downstream boundary at the powerhouse are
The partial derivatives equations (13) through (28) form the Jacobian matrix \( C \) in the model. Equations (3), (4), (5), (7), (8), (10), and (11) form the functional vector \( D \) in the model.

Although there are 120 equations to be solved simultaneously, each equation will be a function of no more than 4 unknowns \( \{ P^d, H, d, Q\} \). Assigning the proper row number to each of the equations involved results in a banded matrix with all the array elements outside the band equal to zero. Assignment of row numbers to the equations is accomplished by the nodal descriptive array \( B \) in the model. The number of incoming reaches to each node will determine the number of continuity and energy equations \((6) \) and \((7)\) to be evaluated before the reach equations of continuity and momentum \((4) \) and \((5)\) can be evaluated. The advantage to this technique is the savings in core storage (about 60 percent) and CPU time (about 80 percent) obtained by using a banded matrix solution routine as opposed to a standard Gaussian elimination routine on a square matrix.

5. MODEL CALIBRATION

Model calibration consisted of determining the bed roughness coefficient in each reach. An estimate of the roughness coefficients between two water level gages can be obtained from the adaptation of the equation (2) to steady, uniform flow. Setting \( Q = Q_t = 0 \) yields

\[
\frac{8\eta}{2 208 \sqrt[4]{\frac{x}{2}}} + gA\frac{Q^2}{2A^2} = 0
\]

(29)

Solving for \( n \) yields

\[
n = \frac{1,4486 \sqrt{AR2/3}}{Q} \left( \frac{\frac{Q^2A}{gA^3} + Hx}{Hx} \right)^{1/2}
\]

(30)
Initial estimates of bed roughness coefficients were made by applying equation (30) to recorded stage and discharge data as described by Quinn and Hagman (1977).

Recorded stage data at Cape Vincent, N.Y.; Clayton, N.Y.; Kingston, Ont.; Alexandria Bay, N.Y.; Ogdensburg, N.Y.; Canada, Iroquois Dam, Morrisburg, Ont.; and Long Sault Dam were used to calibrate the segments of river between each gage. Each segment contained more than one reach as conceptualized by the model. The A and R terms of equation (16) were estimated by weighted averaging of several representative cross sections for each reach within each segment. Cross sections were computed by the U.S. Army Corps of Engineers, Detroit District, from navigation charts at 1:30,000 and weighted according to the length of each equivalent reach. The time periods examined were selected such that a quasi-steady state existed along the river, allowing Q to be assumed equal to the recorded discharge at the powerhouse. Flows used ranged from 248 TCFS to 330 TCFS. Typical values of roughness coefficients obtained for each segment of the river are shown in Table 1. To complete calibration of the model, individual reach roughness coefficients were adjusted to reflect proper flow distribution around islands as determined by the U.S. Army Corps of Engineers (1976, 1977).

<table>
<thead>
<tr>
<th>Segment of River</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kingston to Clayton</td>
<td>0.022</td>
</tr>
<tr>
<td>Clayton to Alexandria Bay</td>
<td>0.042</td>
</tr>
<tr>
<td>Alexandria Bay to Ogdensburg</td>
<td>0.033</td>
</tr>
<tr>
<td>Ogdensburg to Cardinal</td>
<td>0.035</td>
</tr>
<tr>
<td>Cardinal to Iroquois Dam</td>
<td>0.027</td>
</tr>
<tr>
<td>Iroquois Dam to Morrisburg</td>
<td>0.034</td>
</tr>
<tr>
<td>Morrisburg to Long Sault</td>
<td>0.039</td>
</tr>
</tbody>
</table>
Model calibration was verified by using the model to simulate recorded river profiles for flows ranging from 260 TCFS to 350 TCFS. Errors in river stage were less than 0.2 ft for the cases tested.

Stage-fall relationships were then computed from recorded data for the following sections of river: Kingston-Ogdensburg, Ogdensburg-Cardinal, Ogdensburg-Morrisburg, and Morrisburg-Long Sault Dam. Mean monthly values of fall ($F$), flow ($Q$), and the stage at the upstream gage were used to plot the relationship of stage versus the quantity ($Q/\sqrt{F}$) to the power of 1/2 for each of the four sections. Regression lines and correlation coefficients for recorded data were also determined. Simulated model output was then plotted for a series of conditions of flow and stage. As shown by Figure 4, the model compared well with the regression line in all segments of the river, with the Kingston-Ogdensburg segment showing the largest variation. This is due to the low fall over this region. A difference of 0.01 ft in fall will result in a substantial shift in the ($Q/\sqrt{F}$) axis. This sensitivity is also reflected in the low correlation and the scatter about the regression line.

Final bed roughness coefficients used in the model are tabulated in Table 2.

6. HYDRAULIC EFFECT OF ICE COVER

The St. Lawrence River is at least partially ice covered 3 months of the year. Simulation of the river operation during these winter months requires compensation for the drag effect of ice cover on the wetted perimeter and roughness of the channel. A review by Nezhikhovskiy (1964) compared the assumptions and limitations of several formulae for computing a composite channel roughness. Three of the methods presented; Pavlovskiy's (1931), Ivan-Sabaneev's (Sabaneev, 1948), and a mean weighted formulae; were considered for use in the St. Lawrence model.

Equation (30) is applicable to ice covered channels provided the wetted perimeter is adjusted for ice cover and the restriction in flow area due to ice thickness is known. Since 1963, the St. Lawrence Seaway Authority has taken periodic ice thickness measurements in the reach between the Cardinal and Iroquois Dam water level gages. The channel roughness was computed using equation (30) assuming a 0.90 specific gravity for ice and using recorded river stage at the Cardinal and Iroquois Dam water level gages. Channel roughness was computed for 49 periods of ice measurement between 1963 and 1975.

Using the Manning roughness coefficient of $n = 0.026$ calibrated for open water conditions, the ice-cover roughness was computed according to each of the three formulae. The ratio of composite roughness to Manning's roughness coefficient ($n/n$) was plotted against the ratio of the ice roughness to the Manning's roughness coefficient ($n_i/n$) from each of the three formulae (Fig. 5) in turn. A distribution of all the computed
Figure 4a. Comparison of stage vs. $(q/\sqrt{F})^{1/2}$ for prototype (+) and model (A) (Kingston, Ont., to Ogdensburg, N.Y.).
Figure 4b. Comparison of stage vs. \((q/\sqrt{P})^{1/2}\) for prototype (+) and model (\(\Delta\)) (Ogdensburg, N.Y., to Cardinal, Ont.).
Figure 4a. Comparison of stage vs. $(\frac{Q}{F})^{1/2}$ for prototype (+) and model (△) (Cardinal to Morrisburg, Ont.).
Figure 4d. Comparison of stage vs. \((Q/\sqrt{F})^{1/2}\) for prototype (+) and model (△) (Morrisburg to Long Sault, Ont.).
<table>
<thead>
<tr>
<th>Reach</th>
<th>n</th>
<th>Reach</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.028</td>
<td>16</td>
<td>0.033</td>
</tr>
<tr>
<td>2</td>
<td>0.023</td>
<td>17</td>
<td>0.033</td>
</tr>
<tr>
<td>3</td>
<td>0.028</td>
<td>18</td>
<td>0.038</td>
</tr>
<tr>
<td>4</td>
<td>0.037</td>
<td>19</td>
<td>0.026</td>
</tr>
<tr>
<td>5</td>
<td>0.025</td>
<td>20</td>
<td>0.031</td>
</tr>
<tr>
<td>6</td>
<td>0.032</td>
<td>21</td>
<td>0.026</td>
</tr>
<tr>
<td>7</td>
<td>0.040</td>
<td>22</td>
<td>0.033</td>
</tr>
<tr>
<td>8</td>
<td>0.038</td>
<td>23</td>
<td>0.033</td>
</tr>
<tr>
<td>9</td>
<td>0.033</td>
<td>24</td>
<td>0.040</td>
</tr>
<tr>
<td>10</td>
<td>0.035</td>
<td>25</td>
<td>0.040</td>
</tr>
<tr>
<td>11</td>
<td>0.035</td>
<td>26</td>
<td>0.040</td>
</tr>
<tr>
<td>12</td>
<td>0.036</td>
<td>27</td>
<td>0.040</td>
</tr>
<tr>
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<td>28</td>
<td>0.040</td>
</tr>
<tr>
<td>14</td>
<td>0.029</td>
<td>29</td>
<td>0.040</td>
</tr>
<tr>
<td>15</td>
<td>0.026</td>
<td>30</td>
<td>0.046</td>
</tr>
</tbody>
</table>
values of \( n/n_B \) was also plotted. The mean computed ratio \( n/n_B \) for these 49 periods was 0.86 and all but four of the values are above 0.7. Entering Figure 6 with the mean values of \( n/n_B \) of 0.86 indicates that any of the three formulae being examined would result in virtually the same ice roughness coefficient. Of the three formulae, only that of Belokon-Sabaneev, equation (31), considers a non-linear velocity distribution in the ice-covered channel. For this reason, it was incorporated into the model in the form

\[
n = 0.63 n_B \left( 1 + \left( \frac{n_I}{n_B} \right)^{1.5} \right)^{2/3}
\]

where

- \( n = \) composite channel roughness,
- \( n_B = \) Manning's roughness coefficient, and
- \( n_I = \) roughness of underside of ice cover.
**Figure 6a.** Sensitivity of river profile to ice thickness. (Flow = 245 thousand cubic feet per second.)

**Figure 6b.** Sensitivity of river profile to ice roughness. (Flow = 245 thousand cubic feet per second.)
Varying $n_r$ in the range $0.005 < n_r < 0.03$ resulted in duplicating river profiles recorded on the St. Lawrence River.

Required input to the model for computation of river profiles under ice cover conditions includes the ice roughness coefficient and ice thickness. Although adequate data on the characteristics of the St. Lawrence River ice cover is not readily available, the limited data combined with aerial photographs allowed the following assumptions:

a. The roughness of the underside of the ice cover has a normal range of $0.005 < n_r < 0.03$, with a mean value of $n_r = 0.014$ as determined through the use of equations (13) and (14).

b. Sheet ice at least 12-inches thick is experienced along the entire river, except for the area immediately downstream of the Prescott ice boom and Iroquois Dam, which remain ice free.

The river profile is sensitive to both input parameters as exhibited in Figure 6. While ice thickness may be the easier parameter to estimate, it is the least sensitive of the two. Success in simulating river profiles was achieved by assuming a uniform 12-inch layer of ice on the river and adjusting the roughness coefficients to attain the required profile.

Figure 7 represents the sensitivity of river stage to ice roughness. The discharges selected are typical of those experienced during winter. Entering the curves in Figure 7 with recorded conditions of stage and flow, a related ice roughness coefficient was obtained. Using this coefficient, the river profile over an entire winter could be simulated, until the ice cover changed during spring thawing. Table 3 lists the mean errors and error distribution obtained with a single ice roughness coefficient. A strong point of interest was that the ice roughness remains fairly stable over the winter (although it varies from season to season) and the changing fall is due primarily to fluctuating river flows.

7. THE HANGING DAM

Conditions of intermittent freezing and thawing of the ice cover and strong winds on the river have been known to cause portions of the ice cover to break free and flow downstream, where they are stopped by a solid sheet of ice cover. Unconsolidated ice forced under the solid cover causes an ice jam referred to as a hanging dam. Hanging dams occur most frequently around the areas of Ogden Island and Galop Island. Conditions under the dam include a severely restricted flow area and rougher Manning's coefficient. Simulation of a hanging dam (Fig. 8) is accomplished by considering the energy equation across the dam. If

$$Q_1 = Q_2 = Q_3 = Q_4$$
Figure 7a. Sensitivity of fall to ice-cover roughness with 12-inch ice cover (Lake Ontario to Ogdensburg, N.Y.).

Figure 7b. Sensitivity of fall to ice-cover roughness with 12-inch ice cover (Ogdensburg, N.Y., to Cardinal, Ont.).
Figure 7a. Sensitivity of fall to ice-cover roughness with 18-inch ice cover (Cardinal to Morrisburg, Ont.).

Figure 8. The hanging dam


<table>
<thead>
<tr>
<th>Year</th>
<th>Number of Events</th>
<th>Mean Difference (Computed- Recorded), Feet</th>
<th>Maximum Difference (Computed- Recorded), Feet</th>
<th>Number of Events Whose Difference Was in the Range</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>0-0.1 ft</td>
<td>0.1-0.2 ft</td>
<td>0.2-0.3 ft</td>
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<tr>
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<td>-0.5</td>
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<td>+0.15</td>
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<td>+0.29</td>
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<tr>
<td>1972</td>
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<td>+0.02</td>
<td>+0.32</td>
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<td>+0.03</td>
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<td>1976</td>
<td>5</td>
<td>+0.07</td>
<td>+0.29</td>
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</tr>
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</table>
and 

\[ V_2 = V_3 \]

then the energy equation between points (1) and (4) can be written as

\[ h_1 + \frac{V_1 V_1}{2g} = h_4 + \frac{V_4 V_4}{2g} + f_L + h_e + h_d, \quad (32) \]

where

- \( h_1 \) = the hydraulic gradient at section 1,
- \( h_4 \) = the hydraulic gradient at section 4,
- \( f_L \) = the friction loss through the dam,
- \( h_e \) = the entrance loss equal to 1.0 \( \frac{V_3^2 - V_1^2}{2g} \), and
- \( h_d \) = the exit loss equal to 0.5 \( \frac{V_3^2 - V_4^2}{2g} \).

The friction loss term can be related to the Manning's roughness coefficient by

\[ f_L = \frac{Q^2 n^2 L}{2.208 A^2 R_{avg}^{4/3}}. \]

Rewriting equation (32) yields

\[ h_1 + \frac{V_1 V_1}{2g} = h_4 + \frac{V_4 V_4}{2g} + \frac{Q^2 n^2 L}{2.208 A^2 R_{avg}^{4/3}} + 1.0 \frac{(V_2^2 - V_1^2)}{2g} \]

\[ + 0.5 \frac{(V_3^2 - V_4^2)}{2g}, \quad (33) \]

Since \( V_2 = V_3 \) and \( \frac{Q}{A} = V \), the equation reduces to

\[ h_1 + \frac{1.5 Q |q|}{2gA_1^2} = h_4 + \frac{1.5 Q |q|}{2gA_2^2} + \frac{Q |q| n^2 L}{2.208 A_2^2 R_{avg}^{4/3}} = 0. \quad (34) \]
The model assumes that the hanging dam occurs at the upstream end of the reach selected for study. Equation (7) at the particular nodal point involving the reach is then modified to include the energy losses created by the hanging dam represented by equation (34). Input required to simulate the effects of a hanging dam include the length of the dam, the ice thickness, and the anticipated roughness of the channel under the dam. Because the dam may be of substantial length, the length of the dam is subtracted from the reach length when solving equations (3), (4), and (5). It is assumed that the hanging dam will not occupy an entire reach length.

8. MODEL STRUCTURE

The physical characteristics of the St. Lawrence River are described by two arrays in the model. Array R (30, 23) describes each of the 30 reaches in terms of length, top width, perimeter, bed roughness, and low water datum at each end of the reach. Elements R (N, 16-23) contain the computed discharge and stage at each end of each reach N (N = 1 to 30). Channel configuration is defined by array B (21, 9). This array provides the model with information required to define the sequence of flow from reach to reach. Array B is used to develop equations (6) and (7) in the model.

The use of arrays R and B provide a generalized model formulation. As a result, the user is not limited to examining the river in its existing state, but by appropriate substitution of the elements in R, can evaluate what will happen if changes are made. Modification of array B would allow the user to look at only a portion of the river or a different river configuration. While the model is generalized to allow the user to examine only a portion of the river, it requires a limited number of programming changes to accomplish this purpose. Figure 9 is the flow chart representing step by step logic in the model.

The model can be operated on hourly, daily, weekly, or monthly (assuming 1 month = 720 hr) time increments. Required input data include the initial stage and flow conditions in each reach, the initial stage at Lake Ontario, the NTS hydrograph into Lake Ontario, or the stage hydrograph at Kingston, and either the powerhouse discharge hydrograph or Long Sault Dam water level hydrograph. If conditions with ice are to be considered, the time variation of ice roughness and thickness must also be included. Sample input deck listings and corresponding output are given in Appendices A and B.
Figure 9. Flow chart.

9. MODEL INITIALIZATION

The complex configuration of the river, combined with the limited number of stage recorders, makes it difficult to estimate an initially accurate river profile with the model. Although this can be estimated if desired, the inaccuracies caused by the lack of recorded data cause the model to start with an inaccurate condition and thus to spend considerable time stabilizing to an accurate solution.

To overcome this drawback, the model can be initiated by assuming a level pool at the level of Lake Ontario along with entire length of the river and zero discharge at the powerhouse. A desired discharge then simulated with a monthly (720 hrs) time increment. The simulation continues until the simulated profile is steady. Ten iterations of monthly time increments are used in the model to reach the steady profile. After the steady profile has been achieved, the time increment is changed internally to that desired in operation of the model to examine its response to changing conditions at the boundaries.
RECOMMENDATIONS

It has been shown that the hydraulic transient model for the Upper St. Lawrence River provides an accurate simulation of water levels and flows. Because the model uses the full equations of mass continuity and momentum, the author believes the model to be a vast improvement over the stage-fall-discharge methods presently used.

There are many potential uses for the model relating to water resource studies, including analysis of both physical and operational changes in the river. The generalized nature of the model leaves room for future operational capabilities. Any improvements made to the model will be published in future reports.
10. REFERENCES


Appendix A. MODEL INPUT SUMMARY
ST LAURENCE RIVER HYDRAULIC TRANSIENT MODEL INPUT SUMMARY

Program input is divided into three groups:
- River configuration
- Initial conditions
- Time dependent data

Group 1: Model configuration

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<th>Card 2</th>
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<tr>
<td><strong>FORMAT</strong>(215)</td>
</tr>
<tr>
<td>NR = Number of reaches (usually 30)</td>
</tr>
<tr>
<td>NB = Number of nodal points (usually 21)</td>
</tr>
</tbody>
</table>

**Note:** A portion of the river may be examined by appropriately reducing NR and NB. Lake Ontario is always assumed to be the upstream boundary.

| Card 3 (and 4) |
| **FORMAT**(16F5.4) |
| R(N,13) = Manning's roughness coefficients for open water for each reach calibrated respectively to: |
| 028*023*025*037*025*032*040 |
| 038*033*035*035*035*029 |
| 025*033*033*038*025*031*026 |
| 033*033*048*046*046*046*040 |
| 040*044 |

**Note:** Second card is not necessary for NR less than 7. (True for all similar cases)
CARD 5 (AND 6)
FORMAT(5X,15F5.0)
R(N+14) = ICE THICKNESS IN EACH REACH

CARD 7 (AND 8)
FORMAT(16F5.4)
RI CN(N) = MANNINGS ICE ROUGHNESS IN EACH REACH

CARD 9
FORMAT(3F5.0,15,2F6.2,F10.0,S15)
DTT = TIME INCREMENT
TMAX = ENDING TIME
PSI = 1.75
KIT = NUMBER OF NEWTON-RAPHSON ITERATIONS ALLOWED.
8 IS A SAFE MAXIMUM SINCE THE MODEL USUALLY
SUCCEEDS IN 4
PL = INITIAL STAGE AT LAKE ONTARIO
PLON = INITIAL STAGE AT DOWNSTREAM RESERVOIR
AR = AREA OF LAKE ONTARIO IN SQUARE MILES (7340)
ITMIN = UNITS OF DTT 1-HR, 2-DAY, 3-WEEK, 4-MONTH
IPRTYF = 0-PRINT ALL COMPUTATIONS INCLUDING
INITIALIZATION
1=DO NOT PRINT COMPUTATIONS DURING
INITIALIZATION
2=PRINT ONLY FINAL DATA
ISICE = =0 ICE IS NOT INCLUDED IN THIS RUN
=1 ICE IS INCLUDED

CARD 13
FORMAT(F10.0,S15)
ARES = AREA OF DOWNSTREAM FOREBAY IN SQUARE MILES
(USUALLY 15)
NEXIT = REACH ENTERING FOREBAY (USUALLY 3)

CARD 11
FORMAT(2I5)
NUMJF = NUMBER OF REACHES FLOWING FROM UPSTREAM
RESERVOIR (USUALLY 2, ONE ON EACH SIDE OF
WOLFE ISLAND)
NHD = NUMBER OF HANGING DAMS, A MAXIMUM OF THREE
IS ALLOWED
CARD 12

FORMAT(6F10.4)

HANGING DAM DESCRIPTION

RN1 (I) = BOUNDARY NODE AT WHICH THE DAM OCCURS

THICK(I) = ICE THICKNESS IN FEET

RL (I) = LENGTH OF DAM IN FEET

RN(1) = MANNINGS ROUGHNESS UNDER DAM.

* NOTE: ONE CARD FOR EACH DAM. OMIT IF NHD = 0

************************************************************

GROUP 2

INITIAL CONDITIONS

CARD 1

FORMAT(5X,F19.6)

DISO - INITIAL DISCHARGE AT POWERHOUSE (USUALLY 0)

CARD 2

FORMAT(5X,F13.0)

NTSO - INITIAL NET TOTAL SUPPLY (USUALLY 0)

CARD 3 (AND 4)

FORMAT(5X,15F5.2)

R(N,16) = INITIAL UPSTREAM STAGE FOR EACH REACH (USUALLY = HL)

CARD 5 (AND 6)

FORMAT(5X,15F5.2)

R(N,17) = INITIAL DOWNSTREAM STAGE AT EACH REACH (USUALLY = HL)

CARD 7 (THRU 11)

FORMAT(5X,7F10.3,F5X)

R(N,18) = INITIAL FLOWS IN EACH REACH (USUALLY 0)
GROUP 3

TIME DEPENDENT DATA

CARD A (AND 2)

FORMAT(5X,15F5.0)

RICHTK(N) = ICE THICKNESS FOR EACH REACH

* NOTE: ONLY REQUIRED IF ISICE=1

CARD 3 (AND 4)

FORMAT(16F5.4)

RICE(N) = ICE ROUGHNESS IN EACH REACH

* NOTE: ONLY REQUIRED IF ISICE=1

CARD 5

FORMAT(10X,2F16.5,3F5.2,15)

DIS = DISCHARGE AT POWERHOUSE

NTS = NET TOTAL SUPPLY AT LAKE

STAGE = CONTROLLING STAGE AT DOWNSTREAM RESERVOIR.

IF STAGE DOES NOT EQUAL 0 , DIS IS COMputed RATHER THAN INPUT. FIRST VALUE MUST = 0.

HKING = CONTROLLING STAGE AT KINGSTON. IF HKING DOES NOT EQUAL 0, THERE IS NO NEED TO INCLUDE NTS.

WIND = WIND SPEED IN MPH. WIND IS + IN DIRECTION OF FLOW AND - IF OPPOSITE FLOW.

NHDC = CHANGES TO BE MADE IN HANGING DAM.

IF NHDC .GT. 0, CARD 12 SHOULD BE REPEATED USING NEW INFORMATION.

* RFPEAT 3 SEQUENCE FOR EACH TIME INTERVAL *
Appendix B. EXAMPLE PROBLEMS
a. The Simple Drawdown

The most basic use of the model is to solve for a steady state profile given a level of Lake Ontario and a powerhouse discharge. The model initially starts as a level pool at the elevation specified (244.00 for this case). Using the initial discharge (280 TCFS) as a forcing function, the model iterates through 11 steps until a steady profile is achieved. In conditions of very high flow, a small fluctuation of 0.01 or 0.02 may be exhibited near Lake St. Lawrence. However, eleven time steps were found to provide ample time for convergence.
### AUGUST 1978

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ST LAWRENCE RIVER HYDRAULIC TRANSIENT MODEL

DEVELOPED BY
GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY
ANN ARBOR, MICHIGAN

July 1976

Includes:
Open Water Only

PRINT OPTION 0
ALL INTERMEDIATE CALCULATIONS ARE PRINTED OUT.

PERIOD: NONE TO NONE
PURPOSE: SIMPLE DRAWDOWN

GEOGRAPHICAL KEY TO REACH NUMBERS

1. Kingston
2. Cape Vincent
3. North of Wolfe Island
4. North of Howe Island
5. South of Howe Island
7. South of Grindstone Island
8. North of Grindstone Island
10. South of Wellsley Island
11. North of Wellsley Island
12. South of Wellsley Island
13. South of Granadier Island
14. Hell Cott Point
15. Brockville
16. Ogdensburg
17. North of Gallop Island
18. South of Gallop Island
19. Cardinal
20. Troilott
21. North of Ogdens Island
22. Madonna
23. South of Ogdens Island
24. Morrisburg
25. North of Croil Island
26. South of Croil Island
28. North of Long Sault Island
29. South of Long Sault Island
30. Long Sault Dam
<table>
<thead>
<tr>
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**DATA FOR ST. LAWRENCE MODEL**

**JULY 1976**

- **NUMBER OF REACHES**: 30
- **TIME INCREMENT**: 1.50 HRS
- **ENDING TIME**: 1.50 HRS
- **AREA OF LACONANDA**: 280x1250 ft.
- **NUMBER OF NEWTON-RAPHSON ITERATIONS**: 8
- **OUTPUT OPTION**: 0

**INITIAL DISCHARGE**: 0.0 CFS
**INITIAL NET TOTAL SUPPLY**: 0.0 CFS

**NODAL POINT INFORMATION**
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**PRINTOUT OF CHANNEL CHARACTERISTICS ARRAY FOR REACHES 1 TO 10**

**PRINTOUT OF CHANNEL CHARACTERISTICS ARRAY FOR REACHES 11 TO 20**

**LENGTH**

**DEPTH**

**WIDTH**

**SLOPE**

**Siltation**

**Erosion**

**Pollution**

**Nutrients**

**Temperature**

**Dissolved Oxygen**

**pH**

**Salinity**

**Chlorophyll**

**Chlorophyll a**

**Chlorophyll b**

**Chlorophyll c**

**Chlorophyll d**

**Chlorophyll e**

**Chlorophyll f**

**Chlorophyll g**

**Chlorophyll h**

**Chlorophyll i**

**Chlorophyll j**

**Chlorophyll k**

**Chlorophyll l**

**Chlorophyll m**

**Chlorophyll n**

**Chlorophyll o**

**Chlorophyll p**

**Chlorophyll q**

**Chlorophyll r**

**Chlorophyll s**

**Chlorophyll t**

**Chlorophyll u**

**Chlorophyll v**

**Chlorophyll w**

**Chlorophyll x**

**Chlorophyll y**

**Chlorophyll z**

**Chlorophyll a**

**Chlorophyll b**

**Chlorophyll c**

**Chlorophyll d**

**Chlorophyll e**

**Chlorophyll f**

**Chlorophyll g**

**Chlorophyll h**

**Chlorophyll i**

**Chlorophyll j**

**Chlorophyll k**

**Chlorophyll l**

**Chlorophyll m**

**Chlorophyll n**

**Chlorophyll o**

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**PRINTOUT OF CHANNEL CHARACTERISTICS ARRAY FOR REACHES 21 TO 30**
### TIME IN HRS = 0.00 LAKE ONTARIO = 244.98 LAKE ST LAWRENCE = 239.72

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**DISCHARGE AT P.N.= 280000; NTS= 280000.**

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**DISCHARGE AT P.N.= 280000; NTS= 280000.**

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**TIME IN HRS**

- **Lake Ontario**: 244.98
- **Lake St. Lawrence**: 239.78
TIME IN HRS = 5.00 LAKE ONTARIO = 244.98 LAKE ST LAWRENCE = 239.76

REACH 1  2  3  4  5  6  7  8  9  10
STAGE 244.98 245.97 246.97 247.97 248.96 249.96 250.96 251.96 252.96 253.96
FLOW 122571 157665 117216 5995 117216 -20572 178255 181649 43886 107195

REACH 11  12  13  14  15  16  17  18  19  20
STAGE 244.91 245.92 246.93 247.93 248.93 249.93 249.93 249.93 249.93 249.93
FLOW 142759 137190 279995 279995 279995 279995 279995 279995 279995 279995

REACH 21  22  23  24  25  26  27  28  29  30
STAGE 241.95 242.95 243.95 244.95 245.95 246.95 247.95 248.95 249.95 250.95
FLOW 155057 124906 126097 279995 101559 176892 101532 201361 78579 279995

DISCHARGE AT P.W. = 260000  NTS= 260000

CAPE VINCENT  244.97
HUNSTON  245.92
LONGBAY DAM  239.92

TIME IN HRS = 5.80 LAKE ONTARIO = 244.98 LAKE ST LAWRENCE = 239.76

REACH 1  2  3  4  5  6  7  8  9  10
STAGE 244.98 245.97 246.97 247.97 248.96 249.96 250.96 251.96 252.96 253.96
FLOW 122571 157665 117216 5995 117216 -20572 178255 181649 43886 107195

REACH 11  12  13  14  15  16  17  18  19  20
STAGE 244.91 245.92 246.93 247.93 248.93 249.93 249.93 249.93 249.93 249.93
FLOW 142759 137190 279995 279995 279995 279995 279995 279995 279995 279995

REACH 21  22  23  24  25  26  27  28  29  30
STAGE 241.95 242.95 243.95 244.95 245.95 246.95 247.95 248.95 249.95 250.95
FLOW 155057 124906 126097 279995 101559 176892 101532 201361 78579 279995

DISCHARGE AT P.W. = 260000  NTS= 260000

CAPE VINCENT  244.97
HUNSTON  245.92
LONGBAY DAM  239.92
--- TIME IN HRS = 8.88 LAKE ONTARIO = 244.46 LAKE ST LAWRENCE = 239.68 ---

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DISCHARGE AT P.H.: 280000. NTS: 280000.

--- TIME IN HRS = 8.88 LAKE ONTARIO = 244.46 LAKE ST LAWRENCE = 239.68 ---

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DISCHARGE AT P.H.: 280000. NTS: 280000.

--- COMPLETED DT ---
b. The Simple \textit{Drawdown} Under Ice Conditions

The next basic problem to be solved with the model is similar to problem 1 with the addition of an ice cover. In the example problem, a 12-inch uniform ice cover with a Manning's roughness coefficient of $N = 0.02$ is used. The difference in input can be noted on cards 5, 6, 7, and 8 of the input deck listing. Intermediate results are not shown.
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<tr>
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| U.S. | 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 |
| U.S. | 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 |
| D.S. | 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 |
| D.S. | 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 2450 |

| 1 | 1 | 12 12 | 12 12 | 12 12 | 12 12 | 12 12 | 12 12 |
| 0260 0200 0280 0210 0200 0280 0200 0200 0200 0200 0200 0200 0200 0200 0200 0200 |
| 28 28 |
Output

ST LAWRENCE RIVER HYDRAULIC TRANSIENT MODEL

DEVELOPED BY

GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY
ANN ARBOR, MICHIGAN
JULY 1978

ICE CONDITIONS

HISTORY: NONE TO NONE

PURPOSE: SIMPLE DRAWDOWN

INCLUDES:

PER 100:

ICE CONDITIONS

GEOPHYSICAL KEY TO REACH NUMBERS

1. KENSTON
2. CAPE VINCENT
3. NORTH OF WOLFE ISLAND
4. NORTH OF NOKE ISLAND
5. SOUTH OF NOKE ISLAND
6. FLOW BETWEEN WOLFE IS. AND GRINDSTONE IS.
7. SOUTH OF GRINDSTONE ISLAND
8. NORTH OF GRINDSTONE ISLAND
9. FLOW BETWEEN GRINDSTONE IS. AND WELLSEY IS.
10. SOUTH OF WELLSEY ISLAND
11. NORTH OF WELLSEY ISLAND
12. SOUTH OF WELLSEY ISLAND
13. SOUTH OF GRENADIER ISLAND
14. HILLFEST POINT
15. ROUGHLEY
16. GEORGETOWN
17. NORTH OF GALOP ISLAND
18. SOUTH OF GALOP ISLAND
19. RAINFORD
20. TRINITY
21. NORTH OF OGDEN ISLAND
22. MADDINGTON
23. SOUTH OF OGDEN ISLAND
24. MONTEBBEG
25. NORTH OF ERIE ISLAND
26. SOUTH OF ERIE ISLAND
27. FLOW BETWEEN ERIE IS. AND LONG SAULT IS.
28. NORTH OF LONG SAULT ISLAND
29. SOUTH OF LONG SAULT ISLAND
30. LONG SAULT DAM
**Reaches Information**

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<th>Number of Reaches</th>
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<tr>
<td>Time Increment</td>
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<tr>
<td>Ending Time</td>
<td>1.0 hours</td>
</tr>
<tr>
<td>Area of Lake Entering Forebay</td>
<td>200,000 sq ft</td>
</tr>
<tr>
<td>Area of Downstream Forebay</td>
<td>210,000 sq ft</td>
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<tr>
<td>Number of Reaches Flowing from Upstream</td>
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</tbody>
</table>

**Ice and Hanging Dam Information**

**Ice Is Included**

**Hanging Dam Is Included**

| Number of Hanging Dams | 1 |
| Boundary or Node | 12 - R - R |
| Reach | 17 - R - R |
| Thickness | 8.51 ft |
| Length | 150 ft |
| Manning's Roughness | 0.30 ft |

**Initial Discharge** | 0 cfs |

**Initial Net Total Supply** | 0 cfs |

**Nodal Point Information**

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### PRINTOUT OF CHANNEL CHARACTERISTICS ARRAY FOR REACHES 1 TO 10

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### PRINTOUT OF CHANNEL CHARACTERISTICS ARRAY FOR REACHES 11 TO 20

|-----------|----------|----------|----------|----------|-----------|-----------|----------|----------|-----------|-----------|-----------|-----------|----------|----------|-----------|----------|----------|----------|----------|----------|

---

**Note:** The table columns represent different data points for each reach, including U.S. and D.S. positions, areas, percent, and other metrics typically used in geomorphology and river engineering studies.
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LENGTH 17500.0000 17500.0000 17500.0000 17500.0000 17500.0000 17500.0000 17500.0000 17500.0000 17500.0000 17500.0000

ICE THK 12.0000 12.0000 12.0000 12.0000 12.0000 12.0000 12.0000 12.0000 12.0000 12.0000


U.S. D. 245.0000 245.0000 245.0000 245.0000 245.0000 245.0000 245.0000 245.0000 245.0000 245.0000


U.S. Q 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

U.S. G.P 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000

LONGSAULT DAM 23.98

------------------------ TIME IN HRS = 0.00 LAKE ONTARIO = 245.01 LAKE ST LAWRENCE = 253.85------------------------

REACH 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

STAGE 245.02 245.03 245.04 245.05 245.06 245.07 245.08 245.09 245.10 245.11 245.12 245.13 245.14 245.15 245.16 245.17 245.18 245.19 245.20

FLOW 125440 125285 125130 124975 124820 124665 124510 124355 124200 124045 123890 123735 123580 123425 123270 123115 122960 122805 122650

REACH 21 22 23 24 25 26 27 28 29 30

STAGE 257.34 257.35 257.36 257.37 257.38 257.39 257.40 257.41 257.42 257.43 257.44 257.45 257.46 257.47 257.48 257.49 257.50 257.51 257.52 257.53 257.54

FLOW 151129 150974 150829 150684 150539 150394 150249 150104 149959 149814 149669 149524 149379 149234 149089 148944 148800 148655 148510 148366 148221 148076

DISCHARGE AT P.W.M 28000.00 28000.00 28000.00

COMPUTED MT

CAPE VINCENT 245.01

KINGSTON 245.01

GODERIS 245.17

CARLISLE 239.96

TRURO 238.38

TAMPA 239.88

WATTING 237.34

MORRIS 235.96

LONGSAULT DAM 233.92
c. The Hanging Dam

The situation from problem 2 is modified by including an ice dam with a length of 320 ft and a depth of 8.5 ft in the reach on the north side of Galop Island (reach 17). The difference in data sets is noted in cards 11 and 12 of the input deck.

Figure B.1 is a pictorial representation of the river profiles obtained from example problems a, b, and c.
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ST. LAURENCE RIVER HYDRAULIC TRANSIENT MODEL

DEVELOPED BY
GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY
ANN ARBOR, MICHIGAN
JULY 1978

INCLUSES:
ICE CONDITIONS
HANGING DAM

PERIOD:
PURPOSE: SIMPLE DRAWDOWN

GEOPHICAL KEY TO REACH NUMBERS

1. KINGSTON
2. CRYSTAL VILLAGE
3. NORTH OF WOLFE ISLAND
4. NORTH OF WOLFE ISLAND
5. SOUTH OF WOLFE ISLAND
6. FLOW BETWEEN WOLFE IS. AND GRINDSTONE IS.
7. SOUTH OF GRINDSTONE ISLAND
8. NORTH OF GRINDSTONE ISLAND
9. FLOW BETWEEN GRINDSTONE IS. AND WELLSLEY IS.
10. SOUTH OF WELLSLEY ISLAND
11. NORTH OF WELLSLEY ISLAND
12. SOUTH OF WELLSLEY ISLAND
13. SOUTH OF GREENE STONE ISLAND
14. WELLSLEY POINT
15. ROCKVILLE
16. GLOUSTER
17. NORTH OF GALLOP ISLAND
18. SOUTH OF GALLOP ISLAND
19. CARDELL
20. KINNOCK
21. NORTH OF OSIL ISLAND
22. WARTON
23. SOUTH OF OSIL ISLAND
24. MARSEILLES
25. NORTH OF CROIL ISLAND
26. SOUTH OF CROIL ISLAND
27. FLOW BETWEEN CROIL IS. AND LONG SAULT IS.
28. NORTH OF LONG SAULT ISLAND
29. SOUTH OF LONG SAULT ISLAND
30. LONG SAULT DAM
### DATA FOR ST LAWRENCE MODEL

**JULY 1978**

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Ice is included

---

**Initial discharge**

- 0.0 CFs

**Initial net total supply**

- 8.0 CFs

### Nodal Point Information

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**PRINTOUT OF CHANNEL CHARACTERISTICS ARRAY FOR REACHES 1 TO 10**

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**PRINTOUT OF CHANNEL CHARACTERISTICS ARRAY FOR REACHES 11 TO 20**
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Figure B.1. River profiles for example problems a, b, and c.


d. The Unsteady Condition

The advantage to using a flood routing model or transient model over a backwater model is its capability to examine a time varying condition on the river. The period 7 through 10 August 1977 is examined using recorded hourly values of the stage at Kingston and the powerhouse discharge.

The primary difference between problem d. and problem a. is the addition of a flow hydrograph and water level hydrograph for each of 96 hourly periods.

Two cases are examined. The first uses the flow hydrograph at the power dam as a downstream control to determine river profiles. The second uses the stage at the Moses-Saunders Power Dam as a downstream control to derive a flow hydrograph (Fig. B.2).
ST LAWRENCE RIVER HYDRAULIC TRANSIENT MODEL

DEVELOPED BY
GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY
ANN ARBOR, MICHIGAN

NO INTERMEDIATE CALCULATIONS ARE PRINTED OUT.

PERIOD: AUGUST 7, 1977 TO AUGUST 10, 1977
PURPOSE: 96 HOUR RUN

GEOPHYSICAL KEY TO REACH NUMBERS

1. KINSONT
2. CAPE VINCENT
3. NORTH OF WOLFE ISLAND
4. NORTH OF HOWE ISLAND
5. SOUTH OF HOWE ISLAND
6. FLOW BETWEEN WOLFE IS. AND GRINSTONE IS.
7. SOUTH OF GRINSTONE ISLAND
8. NORTH OF GRINSTONE ISLAND
9. FLOW BETWEEN GRINSTONE IS. AND WELLSLEY IS.
10. SOUTH OF WELLSLEY ISLAND
11. NORTH OF WELLSLEY ISLAND
12. SOUTH OF WELLSLEY ISLAND
13. SOUTH OF GRENADIER ISLAND
14. WELLCREEST POINT
15. ROSEVILLE
16. OGDENSBURG
17. NORTH OF BALD ISLAND
18. SOUTH OF BALD ISLAND
19. ONTARIO
20. LINCOLN
21. NORTH OF ODEN ISLAND
22. WESTPORT
23. SOUTH OF OGDEN ISLAND
24. MERRITTSHUR
25. NORTH OF CROLL ISLAND
26. SOUTH OF CROLL ISLAND
27. FLOW BETWEEN CROLL IS. AND LONG SAULT IS.
28. NORTH OF LONG SAULT ISLAND
29. SOUTH OF LONG SAULT ISLAND
30. LONG SAULT DAM
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Figure B.2. Simulation of river profile for the period 7-10 August 1977.
LOAD 'BOUNDARY NODES INTO ARRAY B

DO 9 I=1,NB
  DO 9 J=1,9
    M=(I-1)*9+J
    B(I,J)=E(M)
  9

DOWNSTREAM BOUNDARY AND REACH NUMBER

READ(5,907) ARES,NEXIT
  ARE$=ARES+2.78784E7

READ NUMBER OF REACHES AT UPSTREAM BOUNDARY
A MAXIMUM OF TWO IS ALLOWED
AND NUMBER OF HANGING DAMS

IC=1
  READ(5,902) NUMUP,NHD

READ HANGING DAM INFORMATION, BOUNDARY REACH, THICKNESS OF ICE, LENGTH AND ICE ROUGHNESS

IF(NHD=0) GO TO 113
  DO 114 I=1,NHD
    READ(5,910) BOUND(I),RN1(I),THICK(I),RL(I),RN(I)
    N3=RN1(I)
  114
  R(N3,12)=R(N3,12)-RL(I)
  GO TO(112,492),IC
  CONTINUE

IC=2
  READ(5,905) DISO
  READ(5,905) NTSO.

READ IN INITIAL STAGES FOR UPSTREAM AND DOWNSTREAM ENDS OF EACH REACH.

READ(5,904) (R(N+16),N=1,NR)
  READ(5,904) (R(N+17),N=1,NR)

READ IN INITIAL DISCHARGE IN EACH REACH (USUALLY 0)

READ(5,905) (R(N+18),N=1,NR)

READ IN FIRST TIME DEPENDENT DATA

IF(ISICE.EQ.0) GO TO 148
  READ(5,936) (RICTHK(I),I=1,NR).
  READ(5,938) (RICTK(I),I=1,NR)
  148 READ(5,939) DIS,NTS,STAGE,HKING,WIND
DO 15 N=1, NR
R(N*16)=R(N*17)
R(N*18)=R(N*18)
R(N*19)=R(N*19)
R(N*20)=R(N*20)
R(N*21)=R(N*21)
R(N*22)=R(N*22)
R(N*23)=R(N*23)
15 CONTINUE

WRITE OUT INPUT DATA

WRITE(6,7601) IDATER
WRITE(6,7602) NR,DDT,TWOD(ITIMINT),NB, TMAX, TWOD(ITIMINT)
1*PSI, ARARES, KIT, NUMUP, IPRTYP, NEXIT
IF(ISICE.EQ.0) GO TO 6340
WRITE(6,7603)
IF(NHD.EQ.6) GO TO 6340
WRITE(6,7604) NHD, ROUND, RN, THICK, RL, RN
6340 WRITE(6,7605) DISO, NTSO
WRITE(6,7606)
DO 11 I=1, NR
11 WRITE(6,7607) (E(I,J), J=1, 9)
WRITE(6,7608)
DO 779 I=1, 9
N2=N1+9
WRITE(6,7609) N1, N2
DO 777 I=1, 23
777 WRITE(6,776) ICHAR(I), (R(N,I), N=N1, N2)
779 CONTINUE
TOLH = .JuGO+32.2+NR
INITIAL Q*S: ALL SET

Nou SET TOLERANCES

TOLQ=10**8
K=1
T=0

WRITE TITLE PAGE

WRITE(6,7600)
WRITE(6,7620)
WRITE(6,7621)
IYGX=IPRTYP+1
WRITE(6,7622) IPRTYP, IPKIT(ICYG), IDATER
IF(ISICE.EQ.0) GO TO 6290
WRITE(6,7610) (INCON(I), I=1, 2)
IF(NHD.EQ.6) GO TO 6291
WRITE(6,7610) (INCON(I), I=3, 4)
GO TO 6231
6290 WRITE(6,7611) (INCON(I), I=5, 6)
6291 WRITE(6,7623) IDATE, IPURF
READ IN PERMANENT CHANNEL CHARACTERISTICS, BASE PERIMETERS.

READ (5,902) Nr,Nh
READ (5,908) (R(I,10),I=1,NR)
READ (5,906) (R(I,11),I=1,NR)
READ (5,908) (RIECE(J),J=1,NR)

READ PROGRAM DATA (TIME INTERVAL, MAXTIME, PSI, ITERATIONS, AREA OF UPSTREAM RESERVOIR, TIME INTERVAL (1=HR, 2=DAY, 3=WEEK, 4=MONTH), ... PRINT FORMAT AND ISICE)

READ (5,903) DTT, TMAX, PSI, KIT, HL, HLDN, AR, ITIMINT, IPRTYP, ISICE
FACTOR=3600.
NCOND=TMAX/DTT+.9999
DT=720*FACTOR
TCAL=25920000.
AR=AR*2.78784E7
PSI1=1-Ps1

COMPUTE CHANNEL PERIMETER, TOP WIDTH AND LENGTH

DO 10 I=1,NR
R(I,15)=R(I,13)
ZETA=0.
IF(R(I,14)*6T>0.) ZETA=1.
R(I,6)=R(I,6)+1000.
R(I,7)=R(I,7)+1000.
R(I,12)=R(I,12)+100.
R(I,8)=R(I,8)+200.
R(I,9)=R(I,9)+200.
R(I,10)=2.*R(I,6)+R(I,4)+R(I,4)*(1.+ZETA)
R(I,11)=2.*R(I,7)+R(I,5)+R(I,5)*(1.+ZETA)
CPERU(I)=R(I,10)
CPERD(I)=R(I,11)
10 CONTINUE

85
WRITE(6,97621)
WRITE(6,97625)
WRITE(6,97626)
WRITE(6,97600)
DIS2=DIS0
NTS2=NTS0-3*NTS
DELH=(HLDN-STAGE)/11.
DO 4 J=1,NR
IF(R(J,14)*ST0.R(J1,13)=R(J,15)*0.63*(1+(RICE(J)/R(J,15))
**1.5)**6.67
4 CR1(J)=R(J,13)
IF(IPRTYP.EQ.2) GO TO 30
WRITE(6,9912) (R(J,13),J=1,TV
IF(ISICE.EQ.0) GO TO 30
WRITE(6,9914) (RICE(J),J=1,TV
30 TH=T/FAC
IF(IPRTYP.EQ.0.AND.T.TCAL) GO TO 40
WRITE INTERMEDIATE CALCULATIONS
N2=0
IF(TH.GT.TMAX) TH=0.
WRITE(6,9918) TWORD(TIMINT),TH,HL,HLDN
IF(IPRTYP.EQ.2) GO TO 45
DO 31 I=1,5
N1=N2+1
N2=N1+1
WRITE(6,9919) (R(N1),N=N1,N2),R(N1),N=N1,N2),R(N1),N=N1,N2),R(N1),N=N1,N2)
31 CONTINUE
WRITE(6,561) DIS2,NTS2
WRITE(6,560) DIS1,NTS1,NTS2=NTS
IF(STAGE.EQ.0.) GO TO 39
DIS2=DIS
GO TO 43
39 HLDN-HLDN-DELH
GO TO 43
41 CONTINUE
NR2=2+NR
OUT(1)=TH
DO 417 IOA=2,NR2,2
IOP=I0A/2
OUT(I0A)=R(I0B+18)/1000.
OUT(I0A+1)=R(I0B+16)

CONTINUE
NR2=NR2+3
OUT(NR2-1)=DIS/1000.
OUT(NR2)=HLDN

WRITE OUTPUT TO FILE TAPE7

WRITE(7,418) (OUT(I),I=1,NO2)
DIS1=DIS2
FACTOR=TMULT(ITINIT)
DT=DT*FACTOR
T=T-TCAL*1.1+DT
TCAL=0.
K=K+1

READ IN TIME DEPENDENT DATA

IF(ISICE.EQ.0) GO TO 487
484 IRIC=IRIC+1
READ(S,906) (RICTHK(IRIC),I=1,NO)
IF(EOF(S)) 120,486
486 READ(S,908) (RICTHK(I),I=1,NO)
487 READ(S,539) DIS,NTS,STAGE,HKING,WIND,NHDC
IF(EOF(S)) 120,481
481 IF(NHDC.GT.0) GO TO 113
482 IF(ISICE.EQ.0) GO TO 49
483 J=1
484 R(J,15)=RICTHK(J)
CR2=R(J,15)*CR2+PSI1*CR1(J)
R(J,13)=PSI1*CR2+PSI1*CR1(J)
CR1(J)=CR2
ZETA=0.
IF(R(J,14).GT.0.&&.RICTHK(J).LE.0.) GO TO 52
IF(R(J,14).LE.0.&&.RICTHK(J).GE.0.) GO TO 53
GO TO 54
52 ZETA=1.
IF(IPRTYP.EQ.2) GO TO 54
WRITE(6,561) J
GO TO 54
53 ZETA=-1.0
IF(IPRTYP.EQ.2) GO TO 54
WRITE(6,57) J
54 CPERU(J)=R(J,10)
CPERD(J)=R(J,11)
R(J,10)=R(J,10)+ZETA*R(J,4)
R(J,11)=R(J,11)+ZETA*R(J,5)
IF(IPRTYP.EQ.2) GO TO 48
IF ZETA.NE.3.) WRITE(6,58) R(J+10),R(J+11)
48 CONTINUE
   IF(IPRTYP.EQ.2) GO TO 49
   WRITE(6,912) (R(J+13)+J=1,NR)
   WRITE(6,913) (R(J+14)+J=1,NR)
   WRITE(6,914) (RICE(J),J=1,NR)
   WRITE(6,915) (PER(J),J=1,NR)
49 CONTINUE
NTS1=NTS2
NTS2=NTS
IF(STAGE.NE.?) GO TO 42
DIS2=DIS
GOT O 43
4 2 HDN=STAGE
43 CONTINUE
   TAUX=6.77 E-6*WIND*ABS(WIND)
   DO 100 K=1,KIT
     DO 45 I=1,J122
     DO 45 J=1,J131
45 C(I,J)=0.0
     DO 46 I=1,J122
     DO 46 J=1,J131
46 C(I,J)=0.
4 5 DI(I)=0.
   UPSTREAM BOUNDARY CDND AT KINGSTON AND. PSEUDOREACH ABOVE CAFE
   VINCENT. REACH=1=KINGSTON, REACH F.2 IS PSEUDO REACH
   QOUT=0.0
   QPOUT=0.0
   DO 44 N=1,NUMUP
   QOUT=QOUT+R(N+18)
   QPOUT=QPOUT+R(N+22)
   DO 47 N=1,NUMUP
   AP=(R(N+20)-R(N+8))*R(N+4)+R(N+6)-0.075*R(N+14)*R(N+4)
   AAP(N)=AP
44 CONTINUE
   N1=1
   N2H=2*R(N+2)-1
   N2H=N2H+16-41
   N2Q=N2H+1
   AP=R(N+22)*R(N+22)*R(N+4)/(32.2*AAP(1)+AAP(1)+AAP(1))
   C1=1.
   IF(R(N+22).LT.0.1) C1=0.
   THETA=AR/DT
   IF(HKING.NE.0) GO TO 252
   C1=1.*THETA*(R(N+20)-(32.2*AAP(1)+AAP(1)+AAP(1))
5 0 C1=1.*THETA*(R(N+20)+(32.2*AAP(1)+AAP(1)+AAP(1))
   D(1)=THETA*(R(N+20)+R(N+22)+R(N+22)/(4.4*AAP(1)+AAP(1))
   THETA=(1./NTS+NTS2)*TCI*(QPOUT+QOUT)*0.5
   GO TO 249
252 C1(N+20)=1.
   C1(N+20)=0.
   D(1)=R(N+20)-HKING
249 CONTINUE
N2H=N2H+16=N1
N3H=R(P,3)/2-1
N3H=N3H+16=N1
N2O=N2H+1
N3O=N3H+1
C(N1+N2H)=R(P,4)/(2*DT)
C(N1+N3H)=R(P,5)/(2*DT)
C(N1+N2O)=PSI/R(P,12)
C(N1+N3O)=PSI/R(P,12)

**MOMENTUM EQUATION**

N1=N1+1
N2H=N2H+1
N3H=N3H+1
N2O=N2O+1
N3O=N3O+1
TWOQA=2*QDIS(P)/AREAR
SF2=32.2*R(P,13)*R(P,13)/(2*208*(AREAR+2*333))
PERR=1.333

SF=QDIS(P)*ABS(QDIS(P))*SF2
DQX=(DQP+DG)/R(P,12)
DAX=(DQP+DQ)/R(P,12)
C(N1,N2H)=TWOQA/(AREAR)*DQX+PSI*R(P,4)*2/5
1+TWOQA**2/(2*AREAR)*DAX+PSI*R(P,4)/2
2*TWOQA=TWOQA/4+PSI*R(P,4)*R(P,12)
3-32.2*AREAR*PSI/R(P,12)+32.2*(DHP+DH)/R(P,12)
4+PSI*R(P,4)/2-2*333*SF/(AREAR)*PSI*R(P,4)/2
5+1.333*SF/(PERR)*PSI

DN=PSI*R(P,4)/2
(C(N1,N3H)=TWOQA/(AREAR)+DQX+DN*TWOQA*2/(2*AREAR)*DAX
1+DN=TWOQA*DQX+DN/(2*(R(P,12))+32.2*AREAR*PSI/R(P,12)
+32.2*(DHP+DH)/R(P,12)+DN=2*333*SF+DN/(AREAR)
+1.333*SF+PSI/(PERR)

C(N1,N3O)=DQX+PSI/(AREAR)+TWOQA*R(P,12)-TWOQA*DAX*PSI
1+5/(AREAR)+SF2+ABS(QDIS(P))*PSI • 11(DT+2)
C(N1,N2O)=C(N1,N3O)-2*TWOQA*PSI/R(P,12)
1-TAU=X*R(P,4)/1.94
60 CONTINUE

REACH EQUATIONS OF MOMENTUM AND CONTINUITY OF RATED. NO NEED NODAL CONDITIONS OF STEADY STATE CONTINUITY AND ENERGY

IF (N*EQ*N4) GO TO 65
IF(NHD*EQ*J)GO TO 116
IFLAG=0
DO 115 J=1,NHD
NBON=BOUND(J)
115 IF(N*EQ*NBON) IFLAG=J
116 CONTINUE
\[ N1 = N1 + 1 \]
\[ IN = B(N+2) \]
\[ IOUT = B(N+3) \]

**CONTINUITY'**

- **FLOWOUT** = 0.0
- **FLOWIN** = 0.0
- DO 61 I = 1, IN
  - **IPT** = B(N*3 + I)
  - **FLOWIN** = FLOWIN + R(IP, 23)
  - **IPT** = R(IP, 3)
  - **IQIN** = 2 * IPT
  - **IQIN** = IQIN + I6 - N1
  - C(N1, IQIN) = 1.0
- DO 62 I = 1, IOUT
  - **IP** = B(N*3 + IN + I)
  - **FLOWOUT** = FLOWOUT + R(IP, 22)
  - **IP** = R(IP, 2)
  - **IQOUT** = 2 * IP
  - **IQOUT** = IQOUT + I6 - N1
  - C(N1, IQOUT) = 0.0
  - D(N1) = FLOWIN - FLOWOUT

**ENERGY EQUATION**

- **IPT** = B(N*4)
- **IFIN** = R(IP, 3) * 2 - 1
- **ITOT** = IN + IOUT + 1
- DO 63 IJC = 1, ITOT
  - **N1** = N1 + 1
  - **IHIN** = IFIN + I6 - N1
  - **LN** = 4 + IJC
  - **IP** = B(N*LN)
  - IF (IJC.GE.IN) GO TO 64
  - **IHOUT** = R(IP, 3) * 2 - 1
  - **IHOUT** = IHOUT + I6 - N1
  - C(N1, IHIN) = 1.0
  - C(N1, IHOUT) = -1.0
  - D(N1) = R(IP, 21) - R(IP, 21)
  - GO TO 63
- CONTINUE
  - **IHOUT** = R(IP, 2) * 2 - 1
  - **IHOUT** = IHOUT + I6 - N1
  - C(N1, IHIN) = 1.0
  - C(N1, IHOUT) = -1.0
  - D(N1) = R(IP, 21) - R(IP, 20)
  - J = IFLAG
  - IF (J.EQ.0) GO TO 117
  - N3 = RN1(J)
  - IF (IP .NE. N3) GO TO 117
  - DIA = R(IP, 21) + R(IP, 6)/R(IP, 4) - (R(IP, 8) + THICK(J))
  - A = DIA * R(IP, 4)
A1 = R(IPT*21) - R(IPT*7) * R(IPT*5) + R(IPT*7)
COEF = 0.23 + RN(J) * RN(J) * RL(J) / (6.376 * DIA**1.333)
DH = COEF * R(IPT*22) * ABS(R(IPT*22)) / (A*A) - R(IPT*23) * ABS(R(IPT*23)) / 1.4293 * A1 * A1
IF (IPRTYP.'1'GOTO 63)
WRITE(6,4002)
WRITE(6,4003) DIA + COEF * DH
IF(IPRTYP.'1'GOTO 63)
IHOUT = IHOUT + 1
C(NIHIN) = C(NIHIN) - ABS(R(IPT*23)) / (2.47 * A1 * A1)
IHIN = IHIN + IHOUT
D(N1) = D(N1) - DH
117 CONTINUE
IF(N.NE.14) GO TO 63
FALL = 0.1 + 0.1 * (R(20.20) - E39.) - (R(420.22) - 2800.30) + 0.000001 - 0.19
IF (FALL.GE.0.) GO TO 63
C(NIHOUT) = C(NIHOUT) + 0.14
D(N1) = D(N1) + FALL
63 CONTINUE
65 CONTINUE

CONDITIONS AT NODES COMPLETED. NOU D D W D N S T R E A M B O U N D A R Y
N1 = N1 + 1
LN = R(NEXIT,3)
N3H = 2 + LN - 1
N3H = N3H + 16 - N1
N3Q = N3H + 1
LN = NEXIT
IF (STAGE.GE.0.) GOTO 61
C(N1,N3H) = 1.
C(N1,N3Q) = 0.
D(N1) = R(LN,21) - HLQN
N1 = N1 + 1
C(N1,N3Q) = 0.5
N3Q = N3Q + 1
67 CONTINUE
THETA = ARC/SQRT
C(N1,N3Q) = THETA
C(N1,N3Q) = 3.3
D(N1) = THETA * (R(LN,21) - R(LN,17)) + (DIS1 + DIS2) * TC1 - (R(LN,23) + 1R(LN,19)) * 0.5
REVERSE SIGN OF EQUATION MATRIX
106 DO 66 N = 1,N1
66 D(N) = -D(N)
6 DO 66 N = 1,N1
6 D(N) = -D(N)
EQUATIONS ALL DONE

**SOLVE** MATRIX

\[
\text{IER=0}\\
\text{CALL LEQT1B(C*M1,15,15,122,0,1,122,0,8*BB,IER)}\\
\text{IF (IER.EQ.0) GO TO 70}\\
\text{WRITE}(6,909) IER*K6}\\
\]

70 SDH=0\\
SDQ=0\\
N3=4.*NR\\
CNR=1.*0\\
IF (K6.LT.3) CNR=1.5

UPDATE VALUES OF \( \text{HP} \) AND \( \text{QP} \) BASED ON DELTA SOLUTION VECTOR

\[
\text{DO 72 I=1,NR}\\
L=2*R(I*2)-1\\
M=2*R(I+3)-1\\
R(I+21)=R(I+21)+D(M)*CNR\\
R(I+20)=R(I+20)+D(L)*CNR\\
SDH=SDH+ABS(D(L))\\
L=L+1\\
M=M+1\\
R(I+22)=R(I+22)+D(L)*CNR\\
R(I+23)=R(I+23)+D(M)*CNR\\
\]

IF (STAGE.NE.1) M=M+1\\
IF (STAGE.NE.9.) DIS2=DIS2+D(M)

72 SDQ=SDQ+ABS(D(L))

ALL DOWNSTREAM HP AND HP REPLACE

\[
\text{IF(K6.EQ.KIT) WRITE(6,911) K6*SDH*SDQ}\\
\text{IF(SDH.LE.TOLH.AND.SDQ.LE.TDLQ) GO TO 105}\\
\]

100 CONTINUE

105 CONTINUE

\[
\text{DO 110 N=1,NR}\\
\text{HBUP=R(N*16)}\\
\text{HBDN=R(N*17)}\\
\text{R(N*16)=R(N*20)}\\
\text{R(N*17)=R(N+21)}\\
\text{R(N*21)=2*R(N+17)-HBDN)}\\
\text{R(N*20)=2*R(N*16)-HBUP)}\\
\text{QBUP=R(N*18)}\\
\text{QBDN=R(N*19)}\\
\text{R(N*18)=R(N*22)}\\
\text{R(N*19)=R(N*23)}\\
\text{R(N*22)=2*R(N*18)-QBUP)}\\
\]

110 CONTINUE

\[
\text{R(N*23)=2*R(N*19)-QBDN}\\
\text{ML=R(1*16)+R(1*18)-R(1*16)/(64.4*(R(1*4)+(R(1*16)-R(1*8)) + R(1*6)+10.075*R(1*14)+R(1*4))**2.)}\\
\text{HLDN=R(N*EXIT+17)}\\
\]

93
'GO TO 3
120 CONTINUE

FINAL OUTPUT

DO 3363 IOPUT=1,3
REWIND 7
IRE2=IOPUT+10
IRE1=IRE2-9
IF (NCOND.LT.141 GO TO 3290
WRITE(6,3418) (J,J=IRE1,IRE2)
GO TO 3291
3290 WRITE(6,3420) (J,J=IRE1,IRE2)
3291 WRITE(6,3419)
WRITE(6,3417) TWORD(INT=INT
3293 IF(IOPUT-2) 3251,3252,3253
3251 READ(7,1014) (OUT(I),I=1,21)
GO TO 3300
3252 READ(7,1015) (OUT(I),I=1,21)
GO TO 3310
3253 READ(7,1116) (OUT(I),I=1,21)
3300 IF (EOF(7)) 3363,3361
3301 WRITE(6,1017) (OUT(I),I=1,21)
GO TO 3293
3363,CONTINUE
121 CONTINUE
56 FORMAT(# ICE FORMED ON REACH *15)
57 FORMAT(# ICE MELTED ON REACH *15)
58 FORMAT(# PERIMETER CHANGES IN CHANNEL US, D. S. = # 2F10.0)
202 FORMAT(#A10)
418 FORMAT(F5.0,31(F5.0,F6.2))
560 FORMAT(1HO*2CH# COMPUTED H'T #, CAPE VINCENT #, 1 (4X,F6.2)/
                 KINGSTON  (4X,F6.2)/
                 GODENSBURG  (4X,F6.2)/
                 CARDINAL  (4X,F6.2)/
                 IRIGUOIS:  (4X,F6.2)/
                 B.H.  (4X,F6.2)/
                 IRIGUOIS T.U.  (7X,F6.2)/
                 YADDINGTON  (7X,F6.2)/
                 MORRISBURG  (7X,F6.2)/
                 LOS ALTOS  (7X,F6.2)/
561 FORMAT(# DISCHARGE AT P.H. = #F10.0 # NTS = #F10.0)
776 FORMAT(2X*35X#PRINTOUT OF CHANNEL CHARACTERISTICS ARRAY FOR REAC 1HERE *12# TO *12#)
902 FORMAT(2I5)
903 FORMAT(3F5.0*15F5.2*3I5)
904 FORMAT(5X*15F5.2)
905 FORMAT(5X*7F10.0*5X)
906 FORMAT(5X,15F5.0)
907 FORMAT(F10.0)
908 FORMAT(15F5.0)
909 FORMAT(# TROUBLE IN MATRIX AT E R=#,15#X1T=#,15#)
910 FORMAT(6F10.4)
911 FORMAT(# NUMBER OF ITERATIONS=#,15#S DH, SDG=#,2(1X,F8.2))
912 FORMAT(# ROUGHNESS FOR EACH REACH=#,2(1X,F15.6,0/))
913 FORMAT(# ICE THICKNESS FOR EACH REACH=#,2(1X,F15.6,0/))
914 FORMAT(# ICE ROUGHNESS FOR EACH REACH=#,2(1X,F15.6,0/))
915 FORMAT(# PERIMETER FOR EACH REACH=#,2(1X,F15.6,0/))
916 FORMAT(20(##F6.2)##TIME IN E N=#,##F6.2##LAKE E N T#N#T##F10 = =
917 FORMAT(##F6.2##LAKE ST LAURENCE##F6.2##20##
918 FORMAT(# REACH #,10(5X,15F5.0))
919 FORMAT(##STAGE##F10 = =##TIME##1N##F6.2##=
920 FORMAT(W##FL##2.4)
921 FORMAT(W##FL##2.4)
922 FORMAT(##TIME##223##FL##5.2##I5##3X,##TIME##223##FL##5.2##I5##
923 FORMAT(##TIME##223##FL##5.2##I5##3X,##TIME##223##FL##5.2##I5##
924 FORMAT(##TIME##223##FL##5.2##I5##3X,##TIME##223##FL##5.2##I5##
925 FORMAT(##TIME##223##FL##5.2##I5##3X,##TIME##223##FL##5.2##I5##
926 FORMAT(W##FL##2.4)
927 FORMAT(W##FL##2.4)
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ST LAURENCE RIVER HYDRAULIC TRANSIENT MODEL

13(#*#) 20X 10(#*#)

2ST LAURENCE RIVER HYDRAULIC TRANSIENT MODEL #, 10(#*#)

320X 13(#*#) 1X 15(#*#) 9X # PRINT OPTION # 12X 10(#*#) 50X##

410(#*#) 20X 13(#*#) 1X 15(#*#) 20X 10(#*#) 19X# DEVELOPED BY #

519X 10(#*#) 20X 13(#*#) 1X 13(#*#) 46# INTERMEDIATE 10(#*#)

6# GREAT LAKES ENVIRONMENTAL RESEARCH LABORATORY #

71C(#*#) 20X 13(#*#) 1X 13(#*#) CALCULATIONS ARE #, 10(#*#)

#16X# ANN ARBOR, MICHIGAN #, 15X 10(#*#) # INCLUDES: # 7Xq,

913(#*#) 1X 13(#*#) 4X # PRINTED CUT 4X 10(#*#) 15X 2A10,

115X 10(#*#) 320X13(#*#)

2623 FORMAT(1X 13(#*#) 20X 10(#*#) 5X 10(#*#) 20X 13(#*#) 1X,

113(#*#) 20X 10(#*#) # PERIOD: 2A10, TO 2A10 10(#*#) 20X

2X 13(#*#) 1X 13(#*#) 20X 10(#*#) 1X # PURPOSE: # 2410 10X*

310(#*#) 20X 13(#*#) 1X 13(#*#) 21X 10(#*#) 50X 10(#*#) 20X

413(#*#) 4225 FORMAT((51X#) GEOGRAPHICAL KEY TO REACH NUMBERS#51X 33(#*#)

1// 48X# 1------------- KINGSTON #/ 48X#

2#2Cape victor #/ 48X#

3#3 CAPE WOLFE ISLAND #/ 48X#

4#4 SOUTH OF HOWE ISLAND #/ 48X#

5#5 SOUTH OF HowE ISLAND #/ 48X#

6#6 FLOW BETWEEN WOLFE IS. AND GRINDSTONE IS. # / 48X#

7#7 SOUTH OF GRINDSTONE ISLAND #/ 48X#

8#8 NORTH OF GRINDSTONE ISLAND #/ 48X#

9#9 FLOW BETWEEN GRINDSTONE IS. AND WELLSLEY IS. #/ 47X#

1#10 SOUTH OF WELLSLEY ISLAND #/ 47X#

2#11 NORTH OF WELLSLEY ISLAND #/ 47X#

3#12 SOUTH OF GRINDSTONE ISLAND #/ 47X#

4#13 SOUTH OF GRENADIER ISLAND #/ 47X#

5#14 HILLCREST POINT #)

7626 FORMAT(47X# 15BROCKVILLE #/ 47X#

7#716 OGdenspurge #/ 47X#

8#817 NORT HER OF GALORE ISLAND #/ 47X#

9#918 SOUTH OF GALORE ISLAND #/ 47X#

1#19 CARDINALS #/ 47X#

2#20 IROQUIS #/ 47X#

3#31 NORTH OF FOGDEN ISLAND #/ 47X#

4#42 WADDINGTON #/ 47X#

5#52 SOUTH OF OGDEN ISLAND #/ 47X#

6#62 MORRISBURG #/ 47X#

7#72 SOUTH OF CROIL ISLAND #/ 47X#

8#826 SOUTH OF CROIL ISLAND #/ 47X#

9#927 FLOW BETWEEN CROIL IS. AND LONG SAULT IS. #/ 47X#

1#128 NORTH OF LONG SAULT ISLAND #/ 47X#

2#22 SOUTH OF LONG SAULT ISLAND #/ 47X#

3#330 LONG SAULT GAME #

STOP

END