PHASE I MODEL STUDY RESULTS, COPELAND CUT REACH, ST. LAWRENCE RIVER

Numerical Model Investigation

by

R. E. Heath

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

November 1989
Final Report

Approved For Public Release; Distribution Unlimited

Prepared for US Army Engineer District, Buffalo
Buffalo, New York 14207-3199
### Abstract

Crosscurrents in the Copeland Cut Reach of the Wiley–Dondero Canal make navigation difficult during periods of high flow with accompanying low water levels. The problem area is located in Lake St. Lawrence approximately 3 miles west of Eisenhower Lock. A TABS-2 numerical model reproducing a portion of Lake St. Lawrence from Wilson Hill–Ault Islands downstream to Eisenhower Lock, Long Sault Spillway Dam, and Moses–Sanders Power Dam was used to investigate current patterns in the problem area and the distribution of flows through the system. The model was used to evaluate plans for reducing the magnitude of the crosscurrents by altering the distribution of flows through the system. The results of this investigation showed that significant reductions in crosscurrent magnitude could be achieved by closure of a river channel downstream of the problem area. A physical model study has been proposed to refine these plans. The numerical model will be used to generate boundary conditions for the physical model.
The Phase I TABS-2 model study of the Copeland Cut Reach on the St. Lawrence River documented by this report was performed for the US Army Engineer District, Buffalo.

The study was conducted in the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) during the period May 1987 to September 1987 under the direction of Mr. F. A. Herrmann, Chief of the Hydraulics Laboratory, and M. B. Boyd, Chief of the Waterways Division (WD). Mr. M. J. Trawle, Math Modeling Group Leader, WD, and Mr. W. A. Thomas, WD, provided general guidance and review. The project engineer and author of this report was Mr. Ronald E. Heath, Math Modeling Group. Lead technician for the study was Ms. Brenda L. Martin, Math Modeling Group. Mrs. Peggy Hoffman and Mrs. Dinah N. McComas, Math Modeling Group, assisted with development of the finite element mesh and preparation of report figures, respectively. Mr. Trawle assisted in report preparation.

Acting Commander and Director of WES during the preparation of this report was LTC Jack R. Stephens, EN. Technical Director was Dr. Robert W. Whalin.
CONTENTS

<table>
<thead>
<tr>
<th>PART I: INTRODUCTION</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Background</td>
<td>4</td>
</tr>
<tr>
<td>Objective</td>
<td>4</td>
</tr>
<tr>
<td>Approach</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PART II: THE NUMERICAL MODEL</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Description</td>
<td>6</td>
</tr>
<tr>
<td>Model Adjustment</td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PART III: TEST PROGRAM AND RESULTS</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan Formulation</td>
<td>8</td>
</tr>
<tr>
<td>Test Results</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PART IV: SUMMARY AND CONCLUSIONS</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary</td>
<td>11</td>
</tr>
<tr>
<td>Conclusions</td>
<td>11</td>
</tr>
</tbody>
</table>

FIGURES 1-24
CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<table>
<thead>
<tr>
<th>Multiply</th>
<th>By</th>
<th>To Obtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>cubic feet</td>
<td>0.02831685</td>
<td>cubic metres</td>
</tr>
<tr>
<td>degrees (angle)</td>
<td>0.01745329</td>
<td>radians</td>
</tr>
<tr>
<td>feet</td>
<td>0.3048</td>
<td>metres</td>
</tr>
</tbody>
</table>
PHASE I MODEL STUDY RESULTS, COPELAND CUT REACH,  
ST. LAWRENCE RIVER 
Numerical Model Investigation

PART I: INTRODUCTION

Background

1. Periods of high flow with accompanying low water levels in the St. Lawrence River result in difficult navigation conditions in the Copeland Cut Reach of the International Rapids Section just upstream from Eisenhower Lock (Figure 1). These difficulties are created by relatively high channel velocities and by the fact that these currents cross the navigation channel at an angle of about 30 deg.* Field measurements made in 1986 using drogues** at a river flow of 340,000 cfs document these flow conditions (Figure 2).

Objective

2. The objective of this preliminary investigation (Phase 1 of a two-phase study plan) was to use a two-dimensional numerical model to explore the magnitude of system modification which might be required to produce satisfactory navigation conditions in the Copeland Cut Reach during high riverflow periods.

Approach

3. A two-phased model study was proposed by the US Army Engineer Waterways Experiment Station (WES) to analyze the crosscurrent problem and to

* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.
** US Army Engineer District, Detroit. 1987 (Mar). "Preliminary Results of Discharge Measurements, Flow Distributions, Drogue Surveys; St. Lawrence River, International Rapids Section," Detroit, MI.
evaluate plans to improve navigation conditions. In Phase 1, described in this report, a two-dimensional numerical model (TABS-2)* was used to compute flow distribution and depth-averaged velocities in Lake St. Lawrence for existing conditions and six plans which involved major structural changes to the channel network. At the writing of this report, the Phase 2 work has not been initiated. The proposed Phase 2 work will consist of a physical model of a shorter reach around Copeland Cut. A remotely controlled model ship will be used to refine system modifications needed to provide improved navigation conditions in the problem area.

Model Description

4. A finite element mesh containing 2115 elements (Figure 3) was developed to simulate flows through Lake St. Lawrence. Model limits (Figure 4) extended from Wilson Hill-Ault Islands on the upstream end to Eisenhower Lock, Long Sault Spillway Dam, and Moses-Sanders Power Dam on the downstream end. Bed elevations were digitized from hydrographic survey maps (dated 1985) prepared by the Canadian Hydrographic Survey.

Model Adjustment

5. A Manning's $n$ value of 0.046 for the reach from the Long Sault Spillway Dam to the Moses Sanders Power Dam and 0.04 for the upstream reaches was obtained from the Upper St. Lawrence River Hydraulic Transient Model operated by the US Army Engineer District, Detroit.* A Manning's $n$ value of 0.05 was assumed for shallow areas described as "scattered boulders" or "scattered stumps" on the survey maps. Turbulent diffusion coefficient for all elements was assumed to be 50 sec/ft/ft.

6. Preliminary results from a flow distribution survey conducted by the Detroit District from 13 October to 15 November 1986 are shown in Figure 5.** A comparison to model results obtained using the initial set of coefficients for an equivalent steady state discharge of 330,000 cfs is given in Figure 6. The computed flow distribution varied by less than 3 percent of the total inflow from the measured distribution. In most cases, the computed flow at a section fell within the range of flows measured in the field. The most significant difference between measured and computed flow distributions was at the location of Sections 4 and 5 where the computations indicated more flow than measured in the river channel (Section 5) and less flow than measured in the navigation channel. Adjustments to the turbulent diffusion coefficients

---


** US Army Engineer District, Detroit, op. cit.
did not cause significant changes in flow distribution; therefore, the initial value of 50 sec/ft/ft was used for all subsequent simulations. The computed flow distribution could be altered by using different roughness coefficients for natural and man-made channels and overbank areas; however, the available field data do not provide an adequate basis for making these adjustments. The Detroit District has initiated a program to collect stage data along the Wiley-Dondero Canal which could be used to make adjustments to roughness coefficients in the future. In any case, the agreement between computed and measured flows is considered completely adequate for comparative tests of the plans studied.
Plan Formulation

7. Ship motion in the problem area is a complex phenomenon which may be influenced by changes in channel depth and the presence of asymmetric banks as well as crosscurrents. In addition, the current pattern may have three-dimensional characteristics such as vertical variations in current direction and may vary during the passage of a ship. Given the complexity of this problem, plans which attempt to improve shiphandling with localized changes to the geometry of the problem area can not be properly evaluated using the Phase 1 numerical model. Such plans can be addressed during the proposed second phase of the study when ship motion will be simulated in a physical model.

8. A reduction in the magnitude of crossflow may be required to improve navigation conditions in the problem area. Six plans were developed to redistribute flow in the system and tested in the Phase 1 numerical model. Five plans tested the response of the system to closure of the river channel at various locations to the south and east of Long Sault Island. The sixth plan tested the response to excavation of a shallow area to the south of East Croil Island. These plans were designed to maximize system response and highlight any potential adverse impacts. The Phase I tests are intended to demonstrate whether or not significant crossflow reductions can be achieved by reasonable structural modifications. Once the impacts of these crossflow reductions on ship handling have been determined in Phase 2 of the study, these plans can be scaled down to provide a less severe redistribution of flow.

Test Results

Base test

9. An inflow of 340,000 cfs, the maximum navigable flow, was selected for comparison of alternatives. Based on historical records of project operation, an outflow of 7,500 cfs was specified along the southern half of the Long Sault Spillway Dam, and the rest of the flow was discharged at the Moses-Sanders Power Dam. The water surface at the Moses-Sanders Power Dam was
held at 238.7 ft.* The computed flow distribution, water surface, and current pattern for existing conditions are shown in Figures 7-9, respectively.

Plan 1

10. Plan 1 was the closure of the river channel on the east side of Long Sault Island approximately 10,000 ft downstream of the problem area in the Wiley-Dondero Canal. The computed flow distribution and water surface for Plan 1 are shown in Figures 10 and 11. Plan 1 caused a 60 percent reduction in flow through the problem area (Sections 4 and 5) and reduced maximum, depth-averaged velocities from 3.0 fps to 1.2 fps (Figure 12). The water-surface differential at the closure was 0.5 ft, and current speeds in the shallow areas to the east of the closure increased from less than 2 fps to 3 fps. The diversion of additional flow through Section 3 caused only a 5 percent increase in current speeds to the south of East Croil Island.

Plan 2

11. Plan 2 was the closure of the river channel on the east side of Long Sault Island approximately 5,000 ft downstream of the problem area. Plan 2 caused a 40 percent reduction in flow through Sections 4 and 5 (Figure 13) and reduced maximum, depth-averaged velocities in the problem area to 1.2 fps. However, Plan 2 created potentially adverse currents in the Wiley-Dondero Canal downstream from Section 7 where 2 to 3 fps outdrafts occurred along the north side of the channel (Figure 14).

Plan 3

12. Plan 3 was the closure of the river channel on the southeast side of Long Sault Island approximately 1,000 ft downstream of the problem area. Plan 3 caused a 20 percent reduction in flow through Sections 4 and 5 (Figure 15) and reduced maximum, depth-averaged velocities in the problem area to 2.2 fps. However, Plan 3 forced the combined outflow through the Wiley-Dondero Canal generating 4.5 fps currents in the vicinity of Section 6 and creating strong eddies and outdrafts along the navigation channel downstream from that section as shown in Figure 16.

Plan 4

13. Plan 4 was the closure of the river channel immediately to the south of the Wiley-Dondero Canal at Section 5. Plan 4 caused a 30 percent

* All elevations (el) cited herein are in feet referred to the International Great Lakes Datum (IGLD).
reduction in flow through the problem area; however, it also doubled the flow through Section 4 (Figure 17). The water-surface differential at the closure was 0.3 ft (Figure 18). The diversion of flow through Section 4 driven by this relatively large head differential produced 4-fps currents in the navigation channel upstream from Section 4 and 2.2-fps outdrafts along the north side of the channel downstream from Section 4 as shown in Figure 19. A partial closure at Section 5 would reduce the magnitude of these adverse currents; however, the reduction in flow through the problem area would still be less than that achieved with Plan 1.

**Plan 5**

14. Plan 5 was tested to determine the distribution of flow around the Croil Islands for a complete closure of the channels to the east of Long Sault Island. As compared with the base test, the flow at Section 1 increased by less than 10 percent while the flow at Section 3 increased by nearly 60 percent (Figure 20). This test indicated that diversion of additional flows through Section 1 without increasing the total energy loss through the system would require enlargement of the channels to the west and north of the Croil Islands.

**Plan 6**

15. Plan 6 was the excavation of a shallow area to the south of East Croil Island to an elevation of 190 (Figure 21). Plan 6 did not affect the flow distribution in the problem area; however, it did alter the distribution of flows around the Croil Islands resulting in a 10 percent increase in the flow through Section 3 and a corresponding decrease in flow through Section 1. Plan 6 also caused a 10 percent reduction in current speeds in the vicinity of the excavation and produces a current alignment more favorable for navigation in that area as shown in Figure 22.
PART IV: SUMMARY AND CONCLUSIONS

Summary

16. The computed flow distributions for the base test and six plans are compared in Figures 23 and 24. Plan 1, consisting of closure of a river channel about 2 miles downstream of the problem area, produced the greatest reduction in flow through the problem area (Sections 4 and 5) with the only adverse impact on navigation being a small increase in current speeds to the south of East Croil Island. A partial closure or restriction of the channel at this location can be designed to produce the desired degree of flow reduction. Plan 6, consisting of excavation about 2 miles upstream of the problem area, did not affect conditions in the problem area; however, it did produce effects that would tend to counteract the adverse effects of Plan 1 including changes in the total energy loss through the system.

17. Plans 2-4, consisting of river channel closures at alternate locations, produced smaller reductions in flow through the problem area than Plan 1 and caused changes in the flow distribution in surrounding areas that might induce new navigation problems. Creating partial closures in these locations would reduce the adverse effects of these plans; however, the beneficial effect of reduced flow through the problem area would also be reduced.

Conclusions

18. The physical model study of ship motion proposed for Phase 2 of this study will provide a basis for determining the magnitude of flow reduction needed to ensure safe navigation conditions in the Copeland Cut Reach. The numerical model study results indicate that some variation of Plan 1 will be the most effective method of reducing the flow rate through the problem area. The Plan 1 structure lies outside the proposed limits of the physical model; therefore, the numerical model will be used to generate boundary condition settings for the physical model tests.

19. The physical model study using the model ship will permit evaluation of benefits from flow distribution changes and localized system modifications (channel depth, banklines, dikes, etc.). It will also ensure that possible impacts from three-dimensional currents and ship-current interactions in
the problem area are included in test results. This evaluation may result in
the development of less expensive alternatives for improving navigation
conditions.
Figure 1. Location map
Figure 2. Typical drogue survey results in problem area at maximum navigable flow (340,000 cfs) (from US Army Engineer District, Detroit, op. cit.)
Figure 3. Phase I numerical model, finite element mesh of Lake St. Lawrence
Figure 5. Measured flows as a percentage of total Lake St. Lawrence outflows during October-November 1986 survey. Average total outflow was 330,000 cfs
Figure 6. Comparison of computed, steady state flow distribution from model to October-November 1986 survey data for total flow of 330,000 cfs
Figure 7. Computed flow as a percentage of total Lake St. Lawrence inflow (340,000 cfs) for the base test.
Figure 8. Computed water-surface elevations for the base test.
Figure 9. Computed depth-averaged velocity field for the base test.
Figure 10. Computed flow as a percentage of total Lake St. Lawrence inflow for Plan 1
Figure 11. Computed water-surface elevations for Plan 1
Figure 12. Computed depth-averaged velocity field for Plan 1
Figure 13. Computed flow as a percentage of total Lake St. Lawrence inflow for Plan 2
Figure 14. Computed depth-averaged velocity field for Plan 2
Figure 15. Computed flow as a percentage of total Lake St. Lawrence inflow for Plan 3
Figure 16. Computed depth-averaged velocity field for Plan 3
Figure 17. Computed flow as a percentage of total Lake St. Lawrence inflow for Plan 4
Figure 18. Computed water-surface elevations for Plan 4.
Figure 19. Computed depth-averaged velocity field for Plan 4
Figure 20. Computed flow as a percentage of total Lake St. Lawrence inflow for Plan 5
Figure 21. Computed flow as a percentage of total Lake St. Lawrence inflow for Plan 6
Figure 22. Computed depth-averaged velocity field for Plan 6
FLOW DISTRIBUTION
340,000 CFS INFLOW

Figure 23. Comparison of computed flow distributions from the base test and Plans 1-3
Figure 24. Comparison of computed flow distributions from the base test and Plans 4–6.