US Army Corps
of Engineers
Hydrologic Engineering Center

Use of Two-Dimensional Flow Model to Quantify Aquatic Habitat

April 1985

TP-105

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
April 1985

2. REPORT TYPE
Technical Paper

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE
Use of Two-Dimensional Flow Model to Quantify Aquatic Habitat

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
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5d. PROJECT NUMBER

5e. TASK NUMBER

5F. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
Institute for Water Resources
Hydrologic Engineering Center (HEC)
609 Second Street
Davis, CA 95616-4687

8. PERFORMING ORGANIZATION REPORT NUMBER
TP-105

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/ MONITOR'S ACRONYM(S)

11. SPONSOR/ MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Presented at the American Society of Civil engineers Specialty Conference on computer Applications in Water Resources, Buffalo, NY, 10 -12 June 1985.

14. ABSTRACT

This paper describes the use of a numerical two-dimensional flow model to evaluate the impacts of potential hydropower retrofits on downstream flow distributions at Lock and Dam No. 8 on the upper Mississippi River. The model used (RMA-2) solves the complete Reynolds equations for two-dimensional free-surface flow in the horizontal plane using a finite element solution scheme. RMA-2 has been in continuing use and development at the Hydrologic Engineering Center and elsewhere for the past decade. although designed primarily for the simulation of hydraulic conditions, RMA-2 may be used in conjunction with related numerical models to simulate sediment transport and water quality. In this study, velocity distributions were evaluated with regard to environmental, navigational and small-boat safety considerations. Aquatic habitat was defined by depth, substrate type and current velocity. Habitat types were quantified by measuring the areas between calculated contours of velocity magnitude (isotachs) for existing and project conditions. The capability for computing and displaying isotachs for the depth-average velocity, velocity one foot from the bottom and near the water surface was developed for this study. The product of this study effort is an application of the RMA-2 model that allows prediction of structural aquatic habitat in hydraulically complex locations. Elements of the instream flow group methodology could be incorporated to provide detailed predictions of impacts of habitat quality.

Calibration of the numerical model to field measurements of velocity magnitude and direction is also described.

15. SUBJECT TERMS
numerical models, finite elements, computational hydraulics, aquatic habitat

16. SECURITY CLASSIFICATION OF:

a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
U	U	U	UU	18

19a. NAME OF RESPONSIBLE PERSON

19b. TELEPHONE NUMBER

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Use of a Two-Dimensional Flow Model to Quantify Aquatic Habitat

by
D. Michael Gee[1] and Daniel B. Wilcox[2]

Introduction

This paper describes the use of a numerical two-dimensional flow model to evaluate the impacts of potential hydropower retrofits on downstream flow distributions at Lock and Dam No. 8 (Fig. 1) on the upper Mississippi River. The model used (RMA-2 (6)) solves the complete Reynolds equations for two-dimensional free-surface flow in the horizontal plane using a finite element solution scheme. RMA-2 has been in continuing use and development at the Hydrologic Engineering Center and elsewhere for the past decade (2,3,4,5). Although designed primarily for the simulation of hydraulic conditions, RMA-2 may be used in conjunction with related numerical models to simulate sediment transport and water quality (5,7). In this study, velocity distributions were evaluated with regard to environmental, navigational and small-boat safety considerations. Aquatic habitat was defined by depth, substrate type and current velocity. Habitat types were quantified by measuring the areas between calculated contours of velocity magnitude (isotachs) for existing and project conditions. The capability for computing and displaying isotachs for the depth-average velocity, velocity one foot from the bottom and near the water surface was developed for this study. The product of this study effort is an application of the RMA-2 model that allows prediction of structural aquatic habitat in hydraulically complex locations. Elements of the instream flow group methodology (1) could be incorporated to provide detailed predictions of impacts to habitat quality.

Calibration of the numerical model to field measurements of velocity magnitude and direction is also described.

Project Description:

Lock and Dam No. 8 is located on the upper Mississippi River 679.2 river miles (1094 km) above the mouth of the Ohio River, 23.3 miles (37.5km) below Lock and Dam No. 7, and 31.3 river miles

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Presented at the American Society of Civil Engineers Specialty Conference on Computer Applications in Water Resources, Buffalo, NY, 10-12 June 1985.

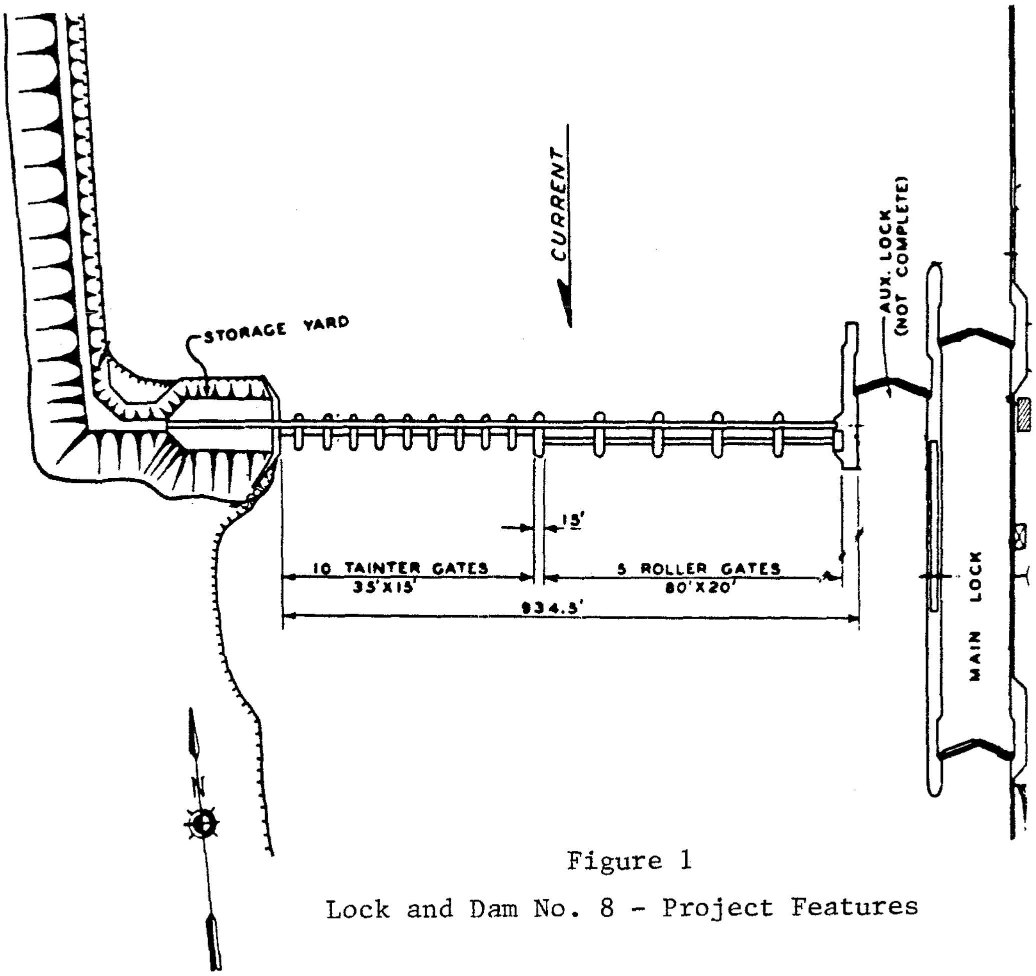

Figure 1

Lock and Dam No. 8 - Project Features

(50.4km) above Lock and Dam No. 9. The lock is on the left bank, or Wisconsin side of the river 0.3 miles (0.5 km) below the village of Genoa, Wisconsin, which is on State Highway No. 35, 17 miles (27 km) south of the City of La Crosse, Wisconsin.

The main lock is 110 feet (33.6 m) wide and 600 feet (182 m) long, and the upper gate bay of an auxiliary lock is provided in the event it becomes necessary to add another lock in the future. From the river wall of the auxiliary lock, a movable dam section consisting of five roller gates, 20 feet (6.1 m) x 80 feet (24.4 m), and 10 tainter gates, 15 feet (4.6 m) x 35 feet (10.7 m), extends across the main channel to the right bank of the river.

Hydropower installations were being considered by the Corps of Engineers for the storage yard at the west abutment or in the auxiliary lock location. In addition to the Corps plans, privately funded installation of floating powerplants, "hydrobarges", is being considered for some of the roller gate bays.

Network Development:

A key component of the successful application of RMA-2 is the development of a well designed finite element network that accurately represents flow boundaries, bottom topography, inflow and outflow locations, and contains enough detail to resolve flow patterns of interest. A study area was selected extending from the downstream face of the dam downstream approximately 2.2 miles (3.5 km). The downstream boundary was set at approximately river mile 677 (km 1090). This location was judged to be sufficiently far downstream from the dam that differing flow distributions at the structure, representing the different project configurations, would not affect the water surface elevation (assumed horizontal) at the boundary.

Bathymetry for the study reach was provided at 1:2400 map scale with a 5 ft. (1.5 m) contour interval. A finite element network was constructed to define the study area with adequate detail at the dam face to distinguish releases from individual spillway bays. Several wing dams and training structures within the study reach are reflected in the network as well as a large island in the lower half of the reach (Fig. 2). Curved-sided elements were used along lateral flow boundaries to allow for smooth tangential flows at the sides (slip flow boundary conditions). The network was revised somewhat during calibration. The final network consisted of 375 elements and 1,189 nodes. Both triangular and quadrilateral elements were used.

Boundary Conditions:

Boundary condition selection was straightforward for this study. Releases from the spillway bays and/or powerplants were described as flows. The downstream boundary condition was a specified water surface elevation, assumed horizontal across the river. That elevation was varied, depending upon the flow magnitude, based upon information provided by the St. Paul District. Lateral boundaries were generally "slip" conditions which allow flow parallel to the boundary. In some cases where sharp corners exist on the boundary a zero velocity was specified (stagnation point boundary condition). All simulations assumed steady flow, although RMA-2 can readily be used to simulate unsteady flow problems as well.

Calibration:

An essential ingredient to any modeling effort, be it physical or numerical, is calibration of various model parameters or coefficients such that model results acceptably reproduce prototype observations. The parameters available for calibration of RMA-2 are bottom roughness and turbulent exchange coefficients. Calibration strategy typically consists of estimation of bottom roughness values (based upon knowledge of bed material) followed by adjustment to reproduce prototype head loss within the study reach. Turbulent exchange coefficients are then adjusted to reproduce details of prototype velocity distributions. Thus, it is desirable to have prototype measurements of velocity (magnitude and direction).

Velocity measurements were obtained at ten transects in the study reach. Coverage was very good consisting of up to five point measurements at each of up to ten locations across each transect. This calibration data set was obtained during the period 15-16 August 1984 at a river flow of 25,400 cfs (711 m^3/sec) using a

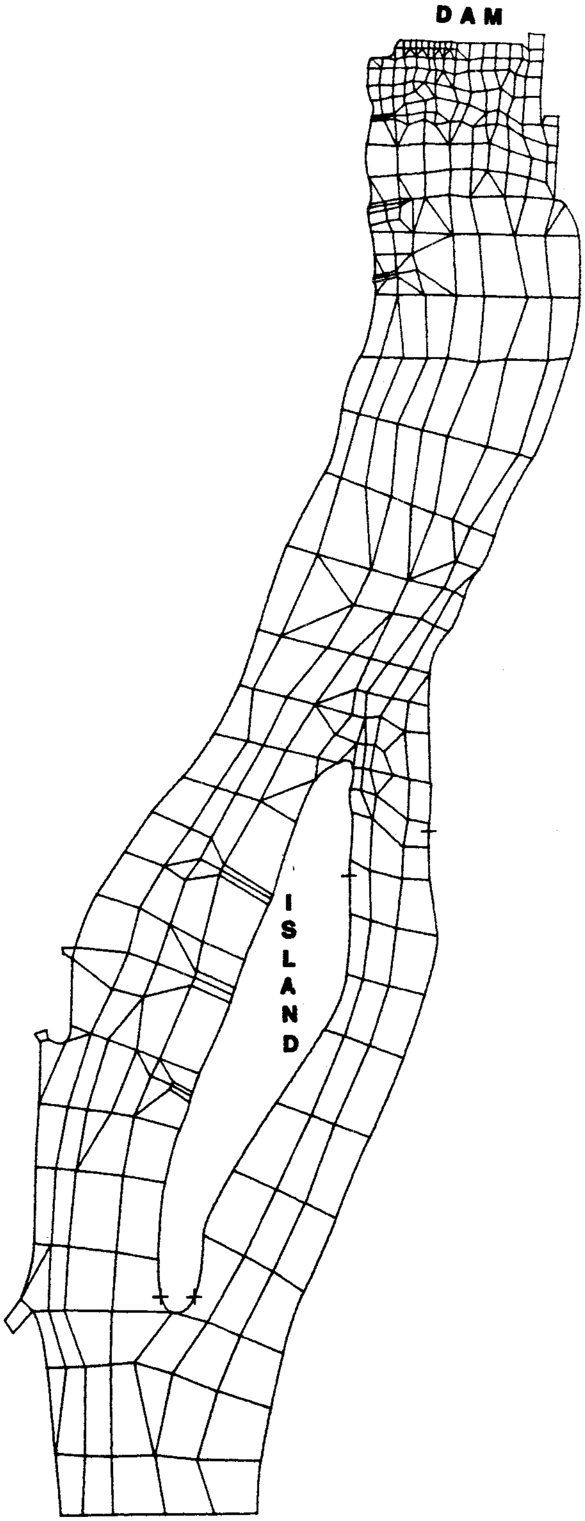

Figure 2

Finite Element Network - Flow is from Top to Bottom

Price Meter. Although the Price meter only yields directional information for near-surface measurements, these directions were assumed to apply to the entire water column at each point.

Based upon these velocity measurements, roughness coefficients were adjusted to match the flow distribution around the island indicated by the data; approximately 65% to the west, 35% to the east. Additionally, the transverse velocity distributions at certain transects were not symmetric, with lower velocities on the right (west) side than on the left. This did not appear to be entirely due to the presence of the right bank wing dams, therefore, the bottom roughness was increased along the right side of the channel from the wing dams to about the head of the island to reproduce the skewed velocity distributions (see Figure 3). Roughness used, in terms of Manning n-values, varied from 0.030 to 0.060.

The turbulent exchange coefficients were set at 25 pound-second/feet^2 (120 kg-sec/m^2) for small elements and 50 pound-second/feet^2 (240 kg-sec/m^2) for all others. This set of coefficients and network yielded well-behaved numerical solutions that generally converged in four iterations. Internal continuity checks, an indicator of network adequacy, were generally within ± 5%.

Calibration of a numerical two-dimensional flow model such as RMA-2 is a judgmental process. That is, no objective, or statistical, measures of error between measured and simulated velocities or water surface elevations are used. In this study, plots of velocity vectors (observed and simulated) were examined visually. Coefficients were then adjusted until, in the judgment of the modeler, an acceptable balance was achieved between reproduction of the measurements and physically realistic coefficient values. Some network modifications were made. Additional detail was added in some areas to better reproduce observed velocity gradients. A portion of the simulated and measured flow fields is shown in Figure 3.

Production Simulations:

All project (i.e., hydropower) simulations were made in conjunction with a corresponding existing (i.e., no hydropower) condition simulation. Thus, project impacts are defined as differences between project and existing conditions. Approximately 25 different conditions were analyzed.

Results of the numerical simulations were presented in the following formats for further analysis:

1. Plots of velocity vectors approximately one foot (0.3 m) above the bottom.
2. Plots of velocity vectors near the water surface.
3. Plots of velocity vectors of vertically averaged velocity (the model output).

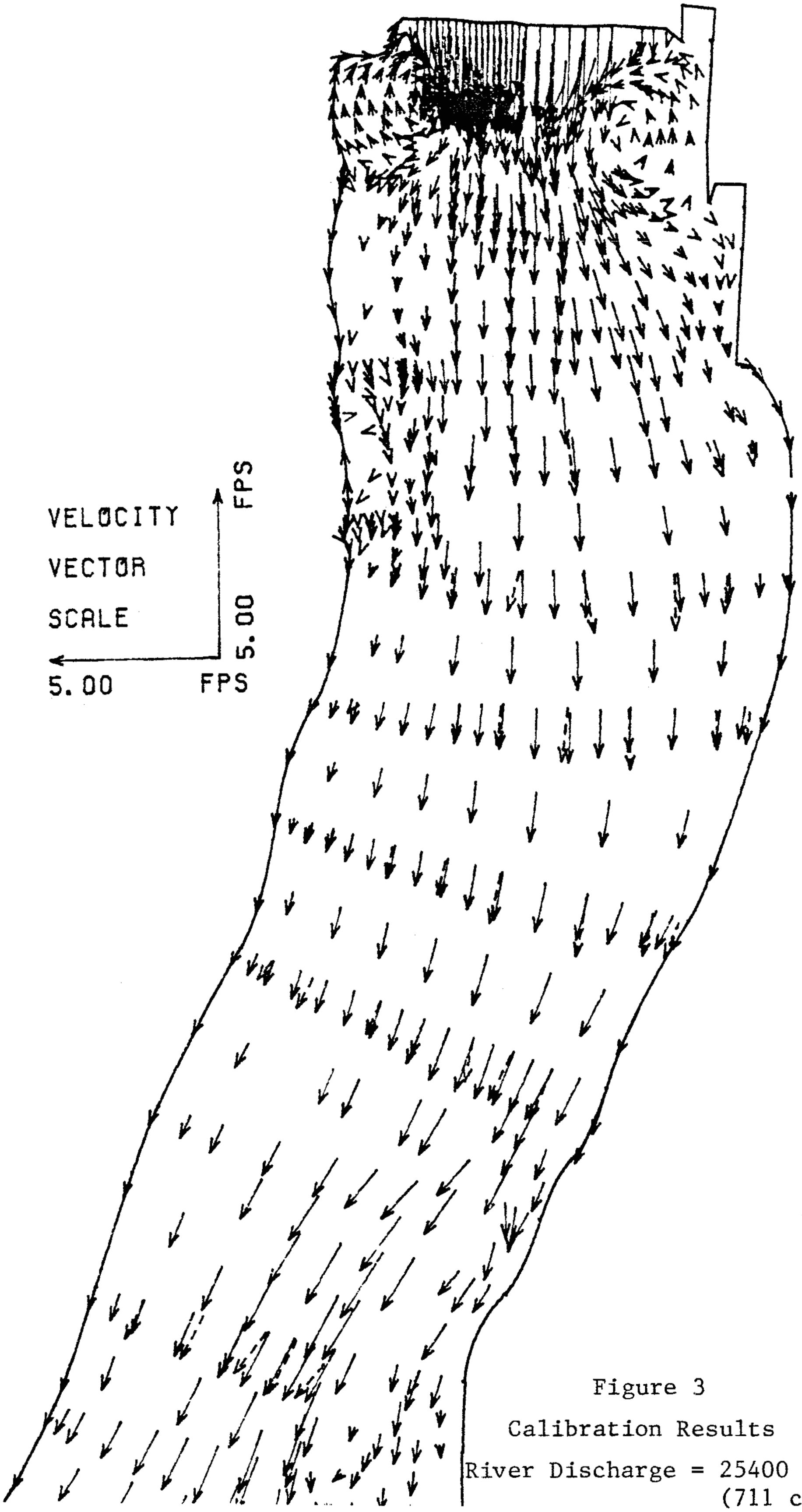

Figure 3

Calibration Results

River Discharge = 25400 cfs
(711 cms)

Dashed vectors are measurements

4. Isotachs (i.e., contours of equal velocity magnitude) one foot (0.3 m) above the bottom.

5. Isotachs near the surface.

6. Pathline plots depicting paths taken by particles traveling at the vertically-averaged velocity released at various points.

These plots are not reproduced herein in their entirety due to space limitations; examples of the above graphical displays are shown in Figures 4-6.

The velocities near the bottom and surface were estimated from the computed vertically-averaged velocity by fitting a classic logarithmic velocity profile at each point.

Interpretation of Results

Riverine habitat types, defined by substrate type, depth, and current velocity, vary in areal extent and distribution with river discharge. The location and extent of habitats in the tailwater of lock and dam 8 were quantified using the model simulations of current velocity at one foot above the bottom. Model results indicate that hydropower operation would affect the pattern of habitat types only within 2,000 feet (610 m) of the dam. The greatest net change in aquatic habitat between existing and with-project conditions would occur at the lowest river discharges. Model results indicate that hydropower operation would cause little disruption of habitat types and fish distribution during the high discharge period in spring when saugers, walleyes, and anglers congregate below the dam.

An analysis similar to that used to quantify aquatic habitat at lock and dam 8 could be used to evaluate effects of hydropower operation on navigation, by employing simulations of surface currents.

Conclusions

The application of RMA-2 described herein represents a new use of the model that had previously been used for hydraulic, water quality, and sediment transport studies. The importance of graphics post processors for interpretation of the results of two-dimensional flow simulations is highlighted in this study. The methods of extracting meaningful information from simulated flow fields illustrated herein should prove valuable for habitat evaluation in general.

Acknowledgements

This study was performed for and sponsored by the U.S. Army Corps of Engineer District, St. Paul. We wish to thank Tom McAloon of the St. Paul District for much of the data preparation and assistance with the numerical simulations. The opinions expressed herein are those of the authors and not necessarily those of the U.S. Army Corps of Engineers.

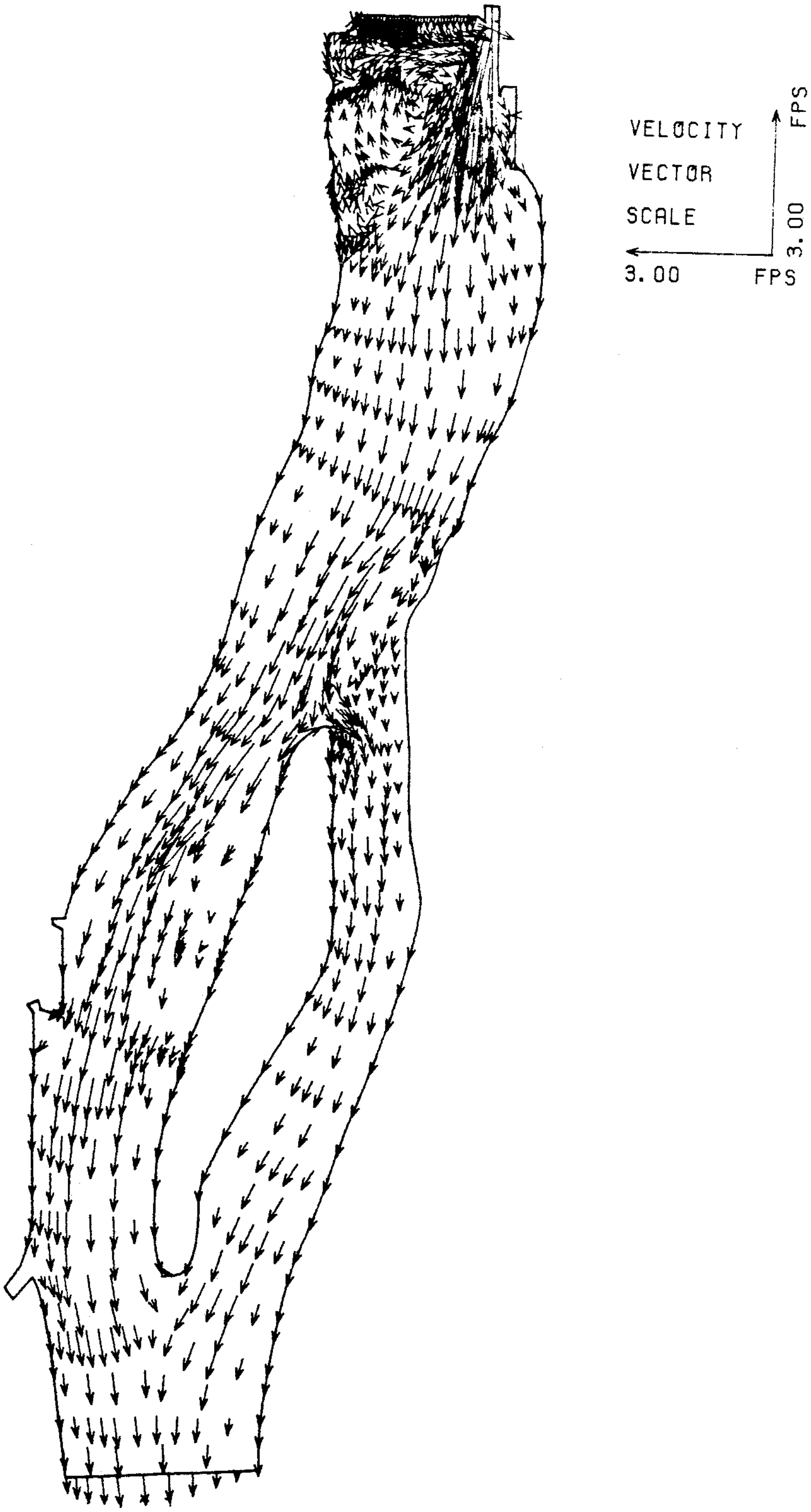

Figure 4 Example Vector Plot

Spillway Discharge = 3000 cfs (84 cms)
Powerplant Discharge = 7000 cfs (196 cms)
(located in auxiliary lock)

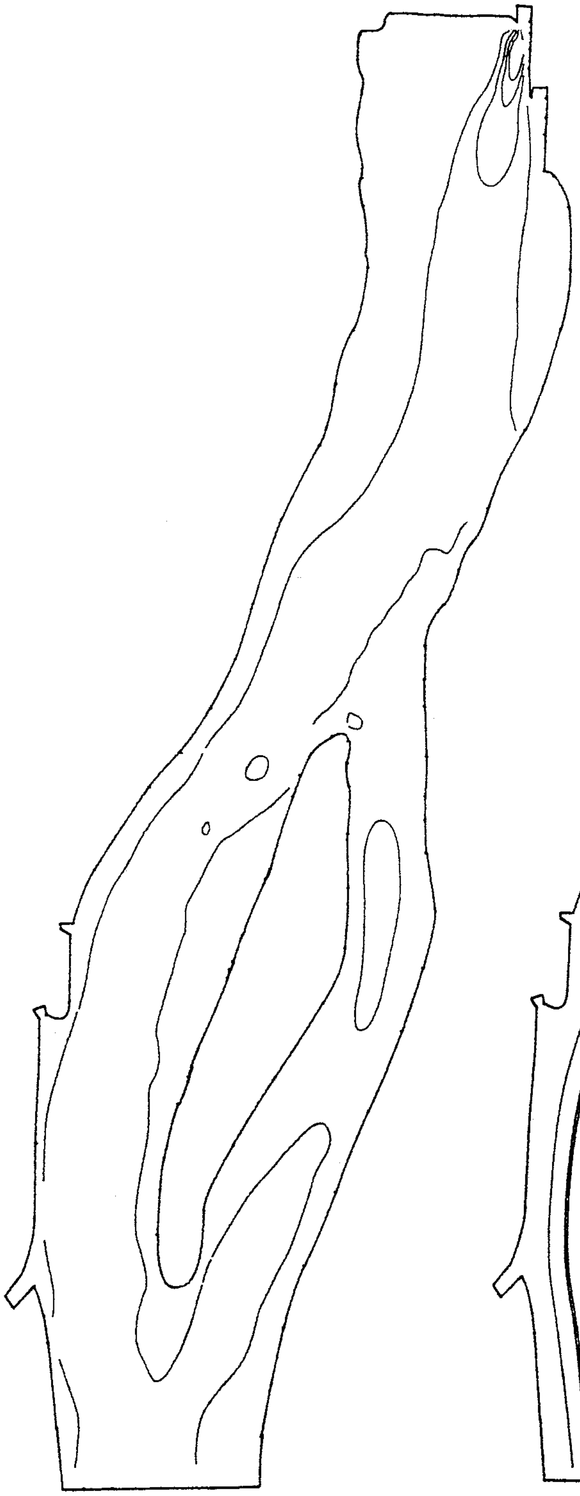

Figure 5
Example Isotach Plot

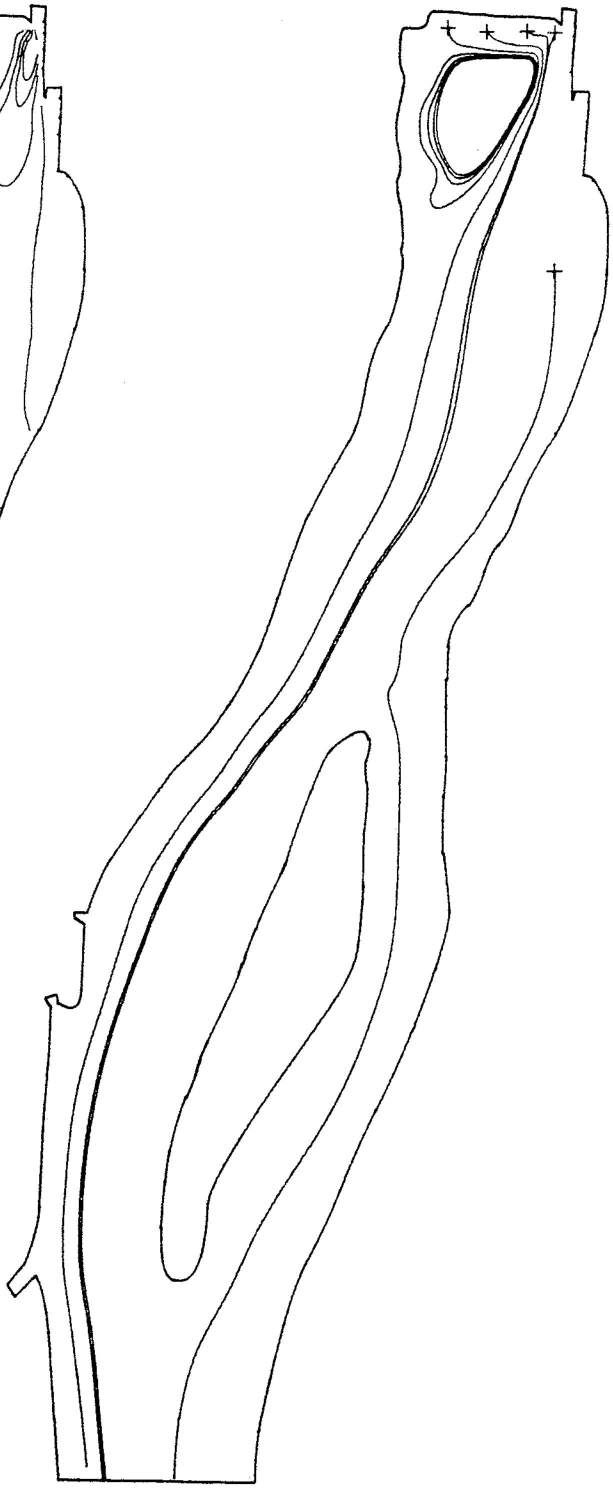

Figure 6
Example Pathline Plot

Spillway Discharge = 3000 cfs (84 cms)
Powerplant Discharge = 7000 cfs (196 cms)
(located in auxiliary lock)

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