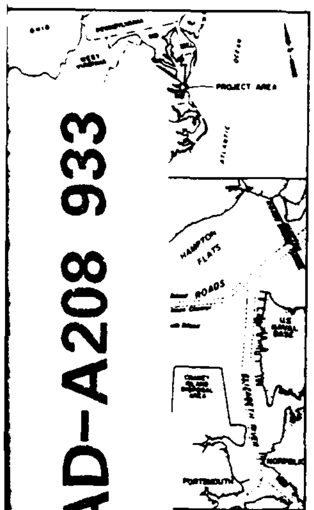
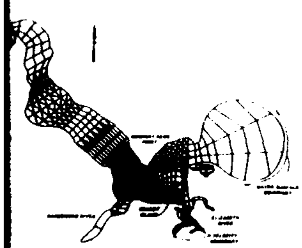
US Army Corps
of Engineers





HYDRAULICS LABORATORY

TECHNICAL REPORT HL-89-12

NEWPORT NEWS CHANNEL DEEPENING STUDY, VIRGINIA

Numerical Model Investigation

by

Hsin-Chi J. Lin, William D. Martin

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39181-0631

June 1989

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Norfolk District Corps of Engineers
Norfolk, Virginia 23510-1096

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report HL-89-12	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION USAEWES Hydraulics Laboratory 6b. OFFICE SYMBOL (If applicable) CEWES-HE-E	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) PO Box 631 Vicksburg, MS 39181-0631	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Norfolk District Corps of Engineers 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) 803 Front Street Norfolk, VA 23510-1096	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

Newport News Channel Deepening Study, Virginia; Numerical Model Investigation

12. PERSONAL AUTHOR(S)
Lin, Hsin-Chi J.; Martin, William D.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final report	FROM ______ TO ______	June 1989	60

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	SUB-GROUP	Estuarine circulation	James River
			Hydrodynamic	Lower James River
			I-664 James River Bridge-Tunnel	Numerical modeling

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report presents results from the numerical model investigation whose primary objective was to evaluate general changes in circulation, currents, and sedimentation associated with the overdeepening of the Newport News Channel. An additional objective of the study was to assess the effects of the overdeepening on the reported estuarine circulation cell (flow convergence) off Hampton Flats and Newport News Point. Three alternative plans of overdeepening, 57, 64, and 70 ft, were evaluated.

This numerical model investigation used the TABS-2 finite element numerical models RMA-2V for hydrodynamic analysis and STUDH for sediment transport computation with a modified version of an existing numerical mesh (expansion plan B) of the Lower James River.

(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL	22b TELEPHONE (Include Area Code) / 22c. OFFICE SYMBOL

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

19. ABSTRACT (Continued).

Results from the numerical hydrodynamic modeling indicated no velocity increases in the Willoughby Bay area. The maximum velocity change identified in the Hampton Flats area was less than 0.1 fps during the maximum flood tide. The maximum velocity change in the channel was 0.2 fps. No circulation changes were identified in the base-to-plan comparison of velocity vector plots. Additionally, no change in tidal phasing or water-surface elevation was detected. The formation and location of the two-dimensional circulation cell off Newport News Point were unaffected by any of the plans.

Results from the sedimentation modeling showed that a maximum decrease in shoaling in the Hampton Flats area was about 7 percent, a maximum increase in shoaling in the Newport News Channel was less than 1 percent, and a maximum increase in shoaling in the Willoughby Bay areas was about 6 percent. The various deepening plans resulted in a redistribution of sediments with a net loss over the Hampton Flats area and a net increase in the Willoughby Bay area. The channel will experience a slow rate of shoaling due to the overdeepening. However, all changes in sedimentation were small in absolute volumes.

The reported frontal effect off Newport News Point is a three-dimensional density current-driven phenomenon and cannot be quantified within the two-dimensional analysis. However, no evidence was generated by this study that would indicate that the channel overdeepening will affect the front formation or propagation.

PREFACE

In December 1988, the Norfolk District Corps of Engineers requested that the US Army Engineer Waterways Experiment Station (WES) conduct an investigation to assess general changes in circulation, currents, and sedimentation associated with three proposed overdeepening plans for the Newport News Channel between the I-664 Bridge-Tunnel crossing and the Hampton Roads Bridge-Tunnel crossing.

The study was conducted by personnel of the Hydraulics Laboratory, WES, under the general direction of Messrs. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory; R. A. Sager, Assistant Chief of the Hydraulics Laboratory; W. H. McAnally, Jr., Chief of the Estuaries Division; and W. D. Martin, Chief of the Estuarine Engineering Branch. The study was conducted by Dr. Hsin-Chi J. Lin, with technical consultation supplied by Messrs. S. B. Heltzel and M. A. Granat, all of the Estuarine Engineering Branch. This report was prepared by Mr. Martin and Dr. Lin and edited by Mrs. Marsha C. Gay of the Information Technology Laboratory, WES.

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

CONTENTS

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:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres
pounds (force)-second per foot per foot	47.88026	pascals-second

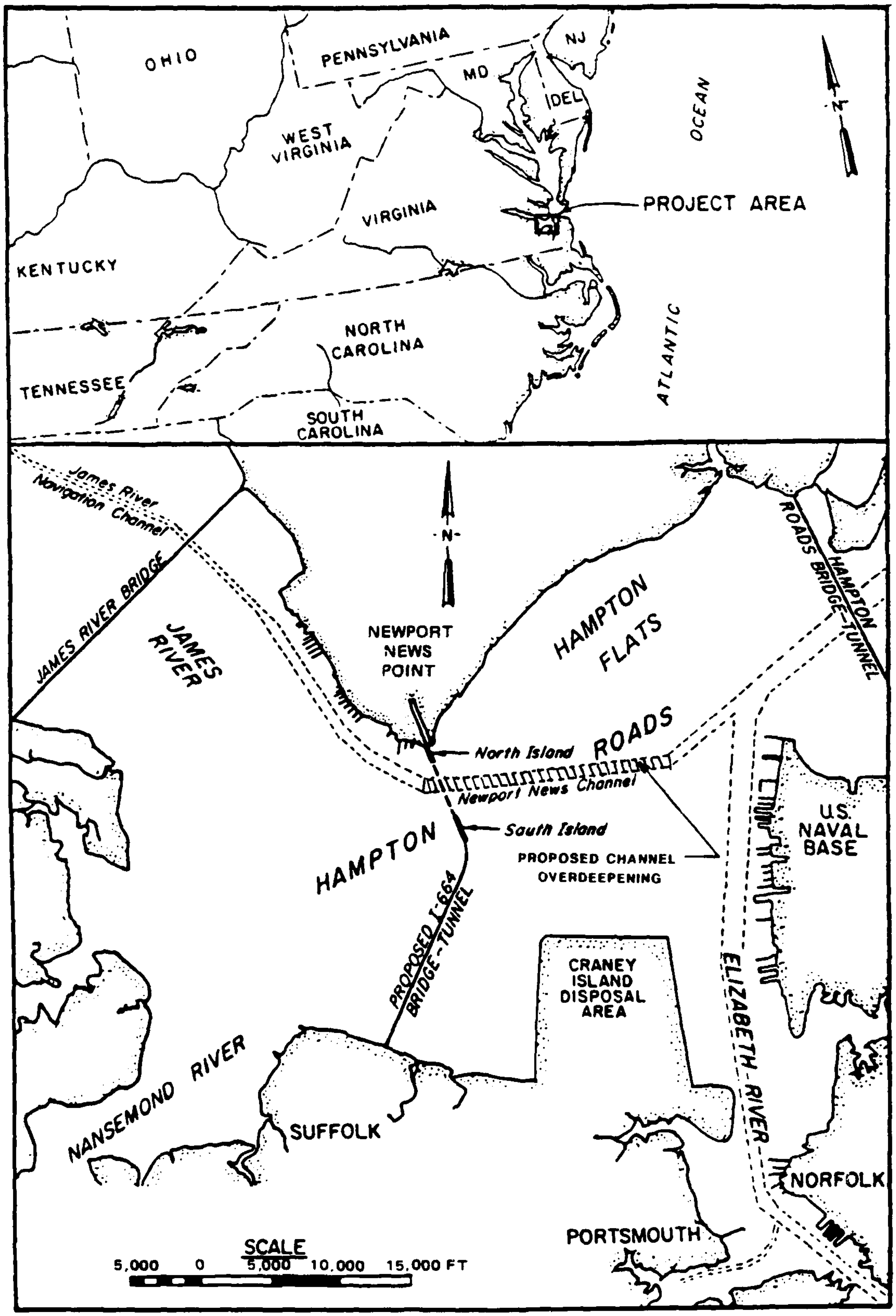


Figure 1. Project location

NEWPORT NEWS CHANNEL DEEPENING STUDY, VIRGINIA

Numerical Model Investigation

PART I: INTRODUCTION

Background

1. The deepening of the Newport News Channel from 45 to 55 ft* was studied by the US Army Engineer Waterways Experiment Station (WES) as a portion of the Norfolk Harbor and Channels deepening study (Richards and Morton 1983). That study was conducted on the Chesapeake Bay physical model located on Kent Island in Matapeake, MD.

2. The effects on sedimentation of this deepening were also investigated by WES using the hybrid modeling approach. This approach combined the physical model results with a numerical analysis using the WES TABS-2 system of numerical models (Berger et al. 1985).

3. Other WES studies in this area evaluated the effects of the I-664 Bridge-Tunnel crossing (Heltzel 1988) and the enlargement of the Craney Island disposal area (Heltzel and Granat 1988 and Bottin 1984).

4. To expand the Craney Island facility, a levee is to be constructed using expansion Plan B (Heltzel and Granat 1988). The Norfolk District Corps of Engineers wished to investigate obtaining the material to construct the levee by overdeepening the Newport News Channel between the I-664 crossing and the Hampton Roads Bridge-Tunnel crossing (Figure 1) from the current depth of 55 ft. Three alternative depths of 57, 64, and 70 ft were evaluated.

Purpose

5. The objective of this study was to use available numerical models to evaluate general changes in circulation, currents, and sedimentation associated with the overdeepening of the Newport News Channel. Additionally, the effects of the overdeepening on the reported estuarine circulation cell (flow

---

* A table of factors for converting non-SI units of measurement to SI (metric) units of measurement is found on page 3.

convergence) off Hampton Flats and Newport News Point was to be assessed.

Scope

6. The numerical modeling was designed to evaluate relative changes in hydrodynamics and sedimentation adjacent to the study area. The sedimentation comparisons focused on two areas adjacent to the Newport News Channel and the deepened portion of the channel. The cff-channel areas were designated A and B and were the same as those reported by Heltzel and Granat (1988). These zones are shown in Figure 2. In these relatively low velocity areas, the sediment study focused on changes in cohesive sediment transport. The channel comparisons were made in an area of relatively high velocities and focused on noncohesive sediment transport.

7. The circulation cell off Newport News Point and Hampton Flats was addressed by comparing study results with previously compiled data on the phenomenon (Heltzel and Granat 1988).

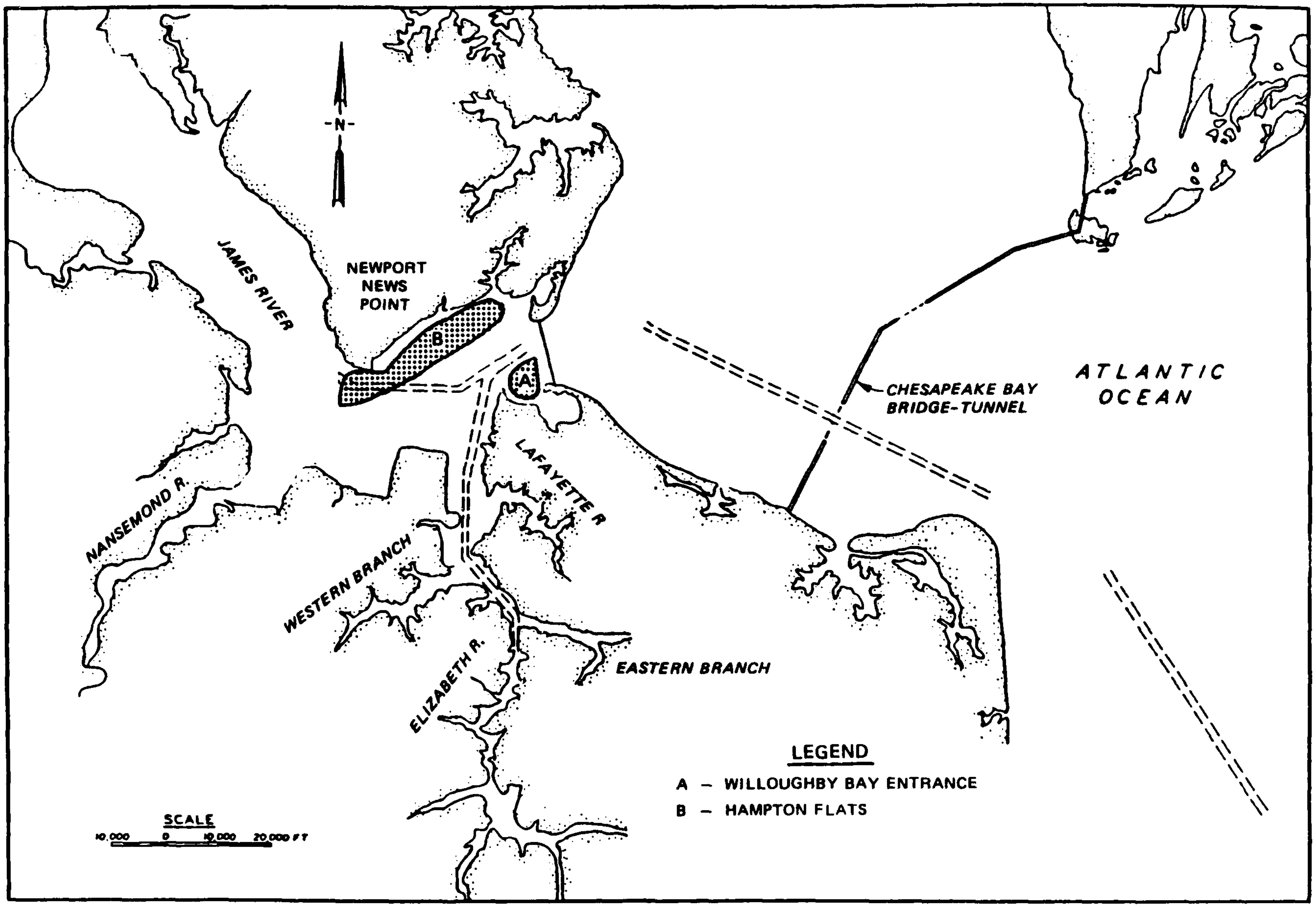


Figure 2. Critical sedimentation zones of interest

PART II: NUMERICAL MODELING APPROACH

The Numerical Models

8. The Corps numerical modeling system, Open-Channel Flow and Sedimentation, TABS-2 (Thomas and McAnally 1985), was used in this investigation. The two primary finite element numerical codes used were A Two-Dimensional Model for Free Surface Flows (RMA-2V) and Sediment Transport in Unsteady Two-Dimensional Flows, Horizontal Plane (STUDH). Both computer codes employ the finite element method to solve the depth-integrated governing equations. A description of RMA-2V and STUDH appears in Appendix A.

Newport News Channel Computational Meshes

9. The computational mesh used in this study was a modified version of the mesh used in the Lower James River circulation study (Heltzel and Granat 1988). The following modifications were included:

- a. The manner in which the I-664 North and South islands were represented in the model was revised. They were previously represented by elements with increased roughness coefficients. For this study, they were modeled as solid structures with slip flow boundaries.
- b. The new small boat harbor at Newport News Point was added to the mesh.
- c. The mesh resolution was increased in the vicinity of the North and South islands and in the Hampton Flats area.
- d. Additional resolution was added to allow for the modeling of the overdeepened Newport News Channel.

The limits of the overdeepened reach are shown in Figure 1. An easement extending 500 ft on either side of the I-664 tunnel crossing was not overdeepened.

10. The revised mesh, shown in Figure 3, contains 2,672 nodes and 933 elements. This mesh incorporated as base conditions those tested as expansion Plan B for Craney Island in the Lower James River circulation study (Heltzel and Granat 1988) with the exception of the addition of the small boat harbor adjacent to the island north of the I-664 crossing. A detail of the Craney Island expansion configuration incorporated in the mesh is shown in Figure 4.

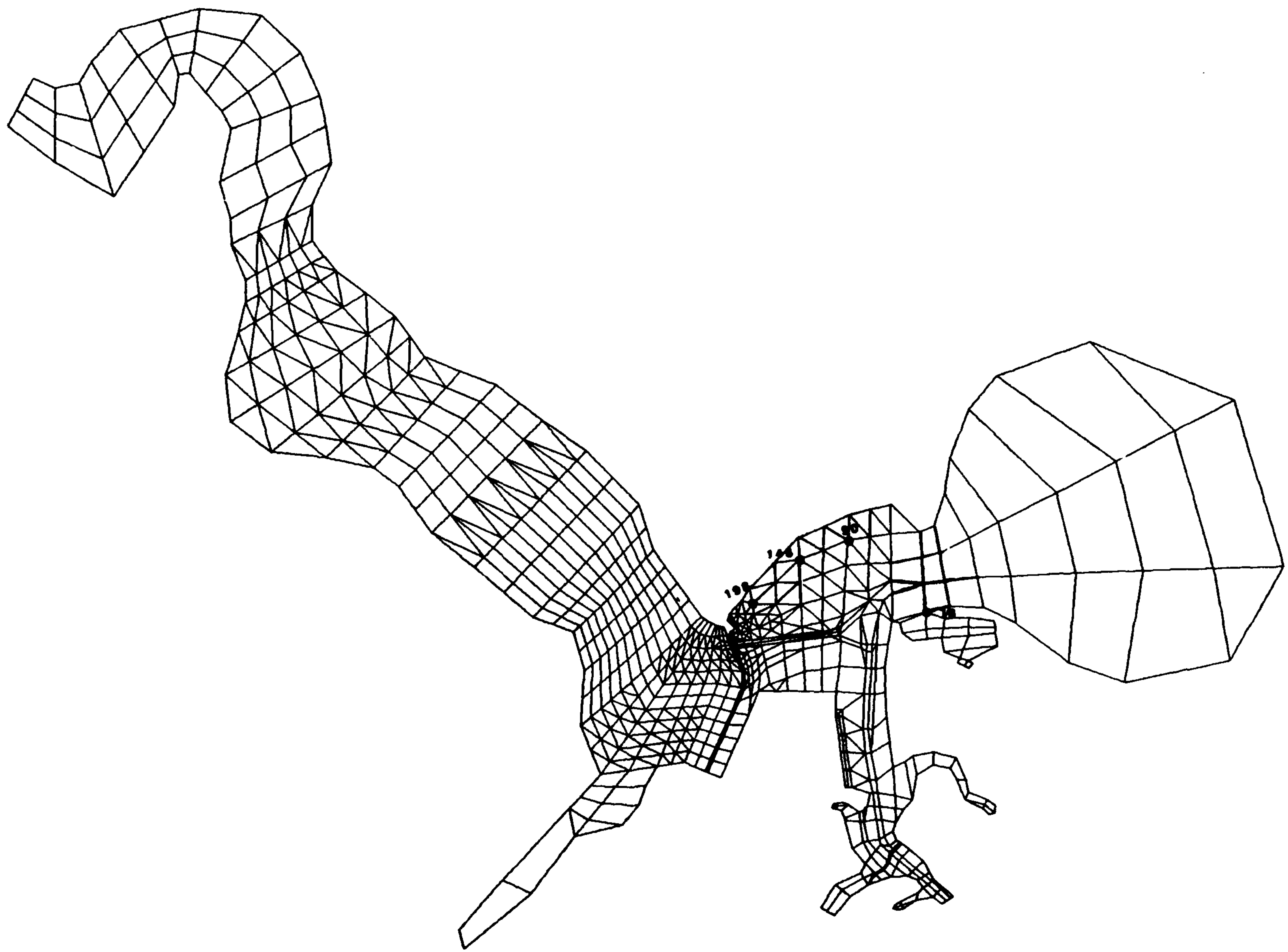
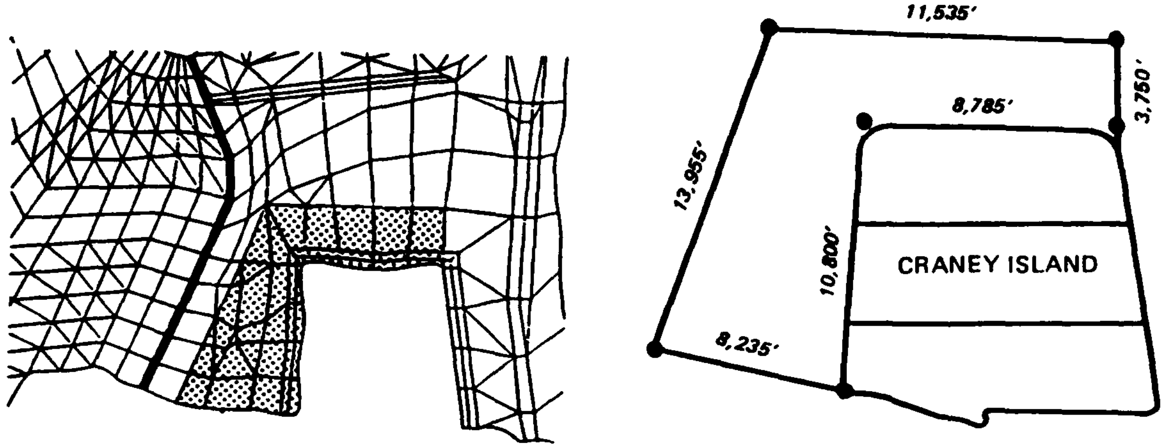


Figure 3. Numerical model mesh for Newport New Channel Deepening Study



a. Mesh schematization b. Dimensions

Figure 4. Craney Island expansion plan B used in Newport News Channel deepening study

Figure 5 shows a detail of the computational mesh in the vicinity of the I-664 bridge crossing and Hampton Flats.

Testing Conditions

11. Three plans for overdeepening the channel from 55 ft (Plan 0) were tested, representing depths of 57 ft (Plan 1), 64 ft (Plan 2), and 70 ft (Plan 3).

12. Boundary conditions were identical to those used in the Lower James River circulation study (Heltzel and Granat 1988). These were developed from physical model data collected in the Chesapeake Bay physical model and used in the Norfolk Harbor and Channels deepening study (Richards and Morton 1983). The lower or bay boundary of the model was represented by water-surface elevation data. The mean range tide (2.5 ft at Old Point Comfort) was used. Depth-averaged velocity data represented the inflows of the Elizabeth and Upper James rivers. The long-term average James River discharge of 8,900 cfs and Elizabeth River discharge of 300 cfs were used.

13. In general, the hydrodynamic and sediment coefficients and modeling procedures used in the Lower James River circulation study were used in this study with the exception of the eddy viscosity coefficients, which were relaxed to a value of 50 lb-sec/ft/ft in the vicinity of Newport News Point to reproduce the circulation cells indicated by physical model results. The Plan B expansion scheme from the Lower James study was reactivated and tested

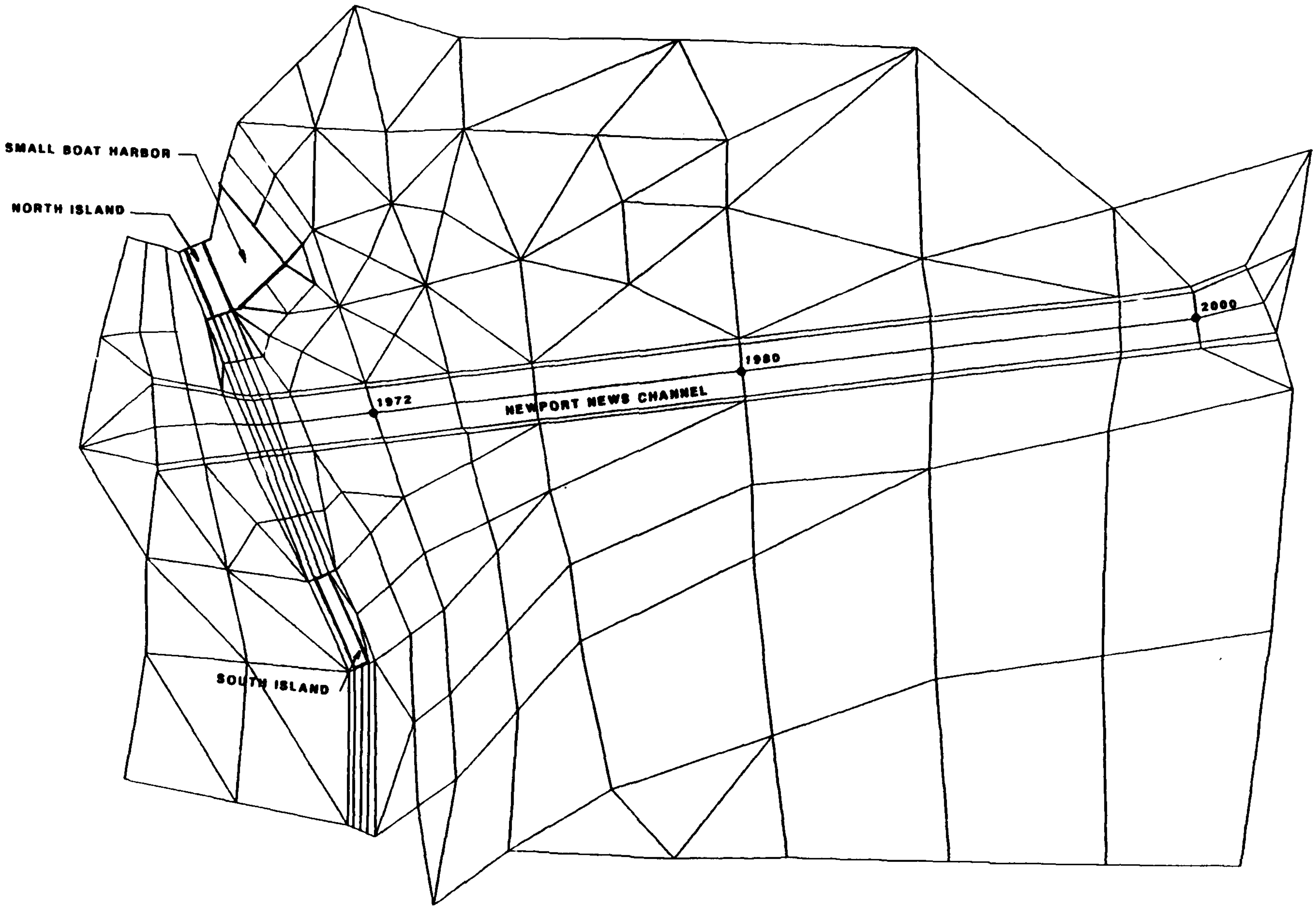


Figure 5. Numerical model mesh, vicinity of Hampton Flats

to ensure that the model was yielding consistent results. Once the mesh modifications were incorporated, a similar check indicated a slight change in the magnitude of the Plan B results from those previously reported (Heltzel and Granat 1988). Maximum differences were 0.1 fps or less in areas A and B and 0.3 fps in the main channel. Therefore, the results reported herein are not directly comparable to the previous study for small changes.

PART III: MODELING RESULTS AND DISCUSSION

Hydrodynamic Results

14. The channel overdeepening resulted in no discernible change in the two-dimensional circulation patterns in the Lower James River. The addition of the small boat harbor and the increased mesh resolution resulted in a more clearly defined eddy over the Hampton Flats off Newport News Point than that previously reported (Heltzel and Granat 1988) during the period around slack before flood (hours 15, 16, and 17). Detailed vector plots for hours 15, 16, 17, and 18 for each plan are shown in Plates 1-16.

15. Figures 3 and 5 show the location of seven nodes that were used for comparison of the three deepening plans. Differences in the magnitudes of the maximum ebb and flood velocities for the base and the three plans were compared, and the results are summarized in Table 1. Node 18 is located in the center of the Willoughby Bay area of interest. Nodes 90, 146, and 198 are located in the Hampton Flats area. Nodes 1972, 1980, and 2000 are located in the Newport News Channel proper.

16. As can be seen in Table 1, there was no difference in the velocity magnitudes for any of the plans tested in the Willoughby Bay area. Plans 1 and 2 had virtually no effect on the velocities in the Hampton Flats area. Plan 3 showed a slight but measurable decrease in velocities of the flats, the maximum decrease being less than 0.1 fps at node 198. Velocities in the Newport News channel were uniformly reduced, as would be expected, by the channel overdeepening. The maximum reduction in ebb velocity was 0.2 fps at node 1972. The maximum decrease in flood velocity was 0.1 fps at node 1972.

17. Plates 17 and 18 illustrate the time-history plots of the ebb and flood velocities for the selected nodes comparing Plan 0 (55-ft depth) with Plan 1 (57-ft depth). It can be seen that these plots are virtually identical. Plates 19 and 20 illustrate the same comparison for Plan 0 and Plan 2 (64-ft depth). Only slight reductions in the ebb and flood velocities were noted for nodes 1972 and 2000, both of which are located in the channel proper. Plates 21 and 22 illustrate the comparison for Plan 0 and Plan 3 (70-ft depth). Again, little discernible change in velocities is observed outside the channel area, while slight reductions were observed at nodes 1972, 1980, and 2000 in the channel.

18. Water-surface elevations were also compared for the base and three plan deepenings. These time-histories were identical for each comparison, indicating no effect on water-surface elevations or phasing of the tide. These plots are, therefore, not included in this report.

Sediment Results

19. The approach to analyzing the sediment results consisted of qualitative comparisons between the base (Plan 0) and the three deepening plans. The procedure followed and parameters selected duplicated those used in the I-664 Bridge-Tunnel study (Heltzel 1988).

20. The areas with relatively low velocity that were of interest in Willoughby Bay and Hampton Flats were analyzed using cohesive sediment modeling techniques. The higher velocity areas in the channel proper were analyzed using noncohesive sediment modeling techniques.

21. The sediment analysis was limited to three areas, area A (see Figure 2) in Willoughby Bay, area B in Hampton Flats, and the overdeepened portion of the Newport News Channel. For reporting purposes, the predicted shoaling volume for each element in the zone of interest was combined to produce a cumulative rate for each area. The plan rate was then divided by the base (Plan 0) rate to produce a shoaling index, which could then be used as a basis for comparison between the plans. The results of this comparison are summarized in the following tabulation. Plans 1 and 2 showed a slight increase in shoaling in the Willoughby Bay area. Plan 3 indicated a 6 percent increase in shoaling. All plans showed a decrease in shoaling in the Hampton Flats area, with the maximum decrease being 7 percent. The Newport News Channel showed very slight increases in the shoaling rate, the increases amounting to less than 1 percent.

	Shoaling Index*		
Area	Plan 1	Plan 2	Plan 3
A	1.01	1.03	1.06
B	0.93	0.94	0.95
Newport News Channel	1.00+	1.00+	1.00+

* 1.00+ indicates amount less than 1 percent.

22. The deepening will cause a redistribution of concentrations of cohesive sediments that will account for generally decreased shoaling in the Hampton Flats area and increased shoaling in the Willoughby Bay area. It should be pointed out that the increases are reported as percentages and represent relatively small absolute increases in shoaling. Reduced velocities in the channel proper and a small but definite tendency to shoal will result in a gradual filling of the overdeepened areas and an eventual return to base conditions.

PART IV: ESTUARINE CIRCULATION AND FLOW CONVERGENCE: HAMPTON FLATS AND NEWPORT NEWS POINT

23. A previous WES report (Heltzel and Granat 1988) summarized the information available regarding the estuarine circulation and flow convergence observed off Newport News Point and the Hampton Flats. This summary included information from previous model studies, both physical and numerical (Brogdon and Bobb 1967,* Heltzel 1988), data collected by the Virginia Institute for Marine Sciences (VIMS) (Byrne et al. 1987), and WES field data collected in 1986.

24. The potential impacts to the reported frontal system, a three-dimensional phenomenon, cannot be quantified with information from either past or present studies. However, inferences can be drawn from the present two-dimensional study.

25. Based on the hydrodynamic results, there will be no discernible changes in two-dimensional circulation patterns in the area off Newport News Point or over the Hampton Flats due to the channel overdeepening. Velocity magnitudes will decrease by such a small amount that the impacts of this change should also be negligible. The tide phasing and elevations were also unaffected by the deepening.

---

* N. J. Brogdon, Jr., and W. H. Bobb. 1967. "Effects of Proposed Waterfront Developments at Newport News Point on Tides, Currents, Salinities, and Shoaling," Draft Report, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

PART V: CONCLUSIONS

26. Comparisons of base and channel velocities for overdeepening plans indicate no velocity increases in the Willoughby Bay area. The maximum velocity change identified in the Hampton Flats area was a less than 0.1-fps decrease in the maximum flood tide velocity. Velocities in the channel proper decreased a maximum of 0.2 fps.

27. No circulation changes were identified in base-to-plan comparisons of vector plots. Additionally, no change in tidal phasing or water-surface elevations was detected.

28. Qualitatively, the various deepening plans resulted in a redistribution of cohesive sediments with a net loss over the Hampton Flats area and a net increase in the Willoughby Bay area. The channel will experience a slow rate of shoaling due to the overdeepening. However, all changes in sedimentation were small in absolute volumes.

29. The formation and location of the two-dimensional circulation cell off Newport News Point were unaffected by any of the plans addressed.

30. The reported frontal effect off Newport News Point is a three-dimensional density current-driven phenomenon and cannot be quantified within the scope of this two-dimensional analysis. However, no evidence was generated by this study that would indicate that the channel overdeepening will affect the frontal formation or propagation.

REFERENCES

Berger, R. C., Jr., Heltzel, S. B., Athow, R. F., Jr., Richards, D. R., and Trawle, M. J. 1985 (Mar). "Norfolk Harbor and Channels Deepening Study; Sedimentation Investigation; Chesapeake Bay Hydraulic Model Investigation," Technical Report HL-83-13, Report 2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Bottin, Robert R., Jr. 1984 (Oct). "Impact of I-664 Bridge-Tunnel Project on Wave Conditions at Newport News Harbor, Virginia; Hydraulic Model Investigation," Technical Report CERC-84-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Byrne, R. J., Kuo, A. Y., Mann, R. L., Brubaker, J. M., Ruzecki, E. P., Hyer, P. V., Diaz, R. J., and Posenau, J. H. 1987 (Feb). "New Port Island, An Evaluation of Potential Impacts on Marine Resources of the Lower James River and Hampton Roads," Special Report in Applied Marine Science and Ocean Engineering No. 283, Virginia Institute of Marine Science, Gloucester Point, VA.

Heltzel, S. B. 1988 (Sep). "I-664 Bridge-Tunnel Study, Virginia, Sedimentation and Circulation Investigation," Technical Report HL-88-25, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Heltzel, S. B., and Granat, M. A. 1988 (Apr). "Lower James River Circulation Study, Virginia, Evaluation of Craney Island Enlargement Alternatives," Technical Report HL-88-8, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Richards, D. R., and Morton, M. R. 1983 (Jun). "Norfolk Harbor and Channels Deepening Study; Physical Model Results; Chesapeake Bay Hydraulic Model Investigation," Technical Report HL-83-13, Report 1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Thomas, W. A., and McAnally, W. H., Jr. 1985 (Jul). "User's Manual for the Generalized Computer Program System; Open-Channel Flow and Sedimentation, TABS-2; Main Text and Appendices A through O," Instruction Report HL-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

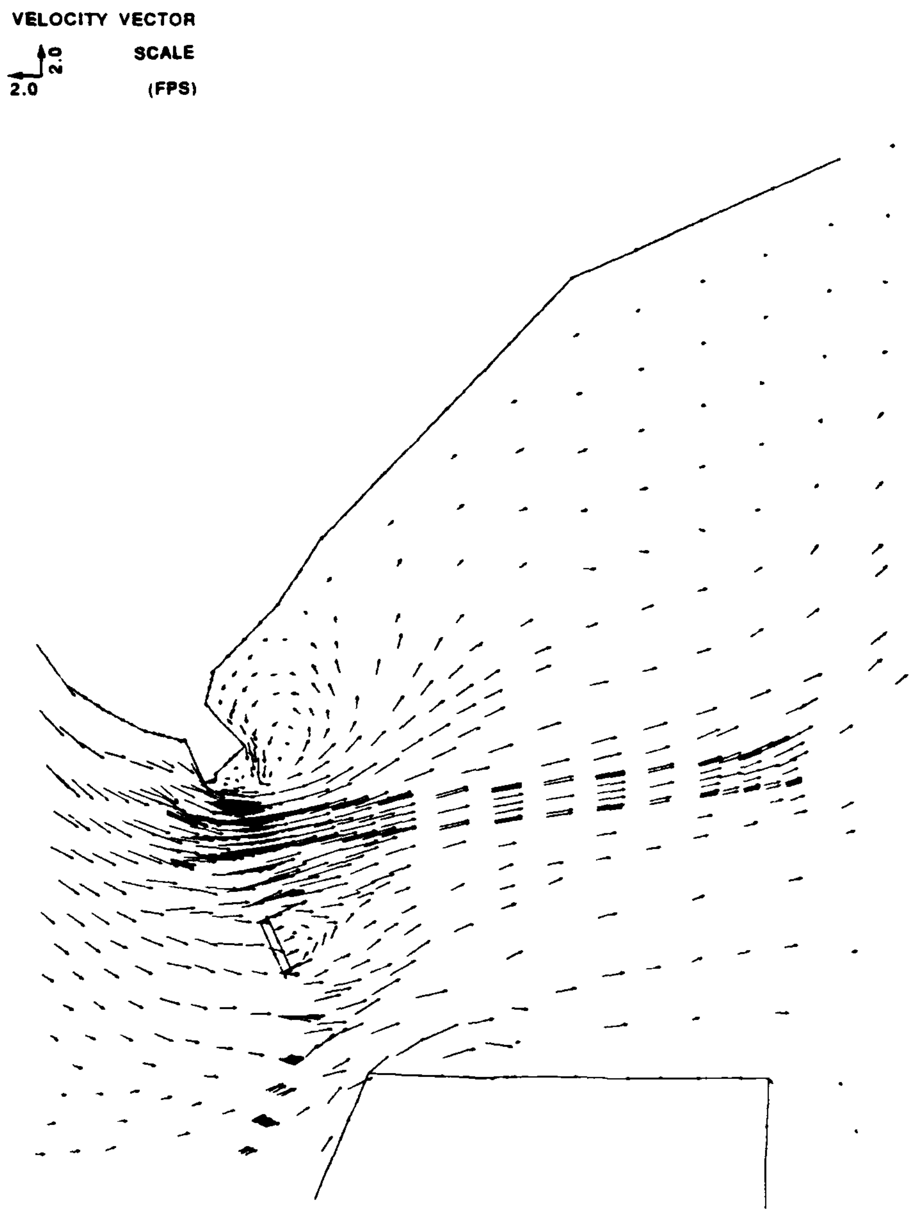
Table 1

Maximum Velocity Changes at Selected Nodes, fps

(Plan Minus Base)

Area	Node No.	Plan 0 Velocity		Change, Plan Minus Base					
				Plan 1		Plan 2		Plan 3	
		Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood
Willoughby Bay (area A)	18	0.77	0.75	0.0	0.0	0.0	0.0	0.0	0.0
Hampton Flats (area B)	90	0.58	0.62	0.0	0.0	0.0	T+	0.0	T+
	146	0.64	0.60	0.0	0.0	0.0	0.0	0.0	0.0
	198	0.83	0.85	0.0	0.0	T-	T-	T-	T-
Newport News Channel	1972	2.53	1.94	-0.1	T-	-0.1	-0.1	-0.2	-0.1
	1980	1.80	1.58	0.0	0.0	T-	T-	T-	T-
	2000	1.20	1.07	0.0	T-	T-	T-	T-	-0.1

Note: Velocities rounded to nearest 0.1 fps.
T+ or T- indicates values less than 0.1 fps.



DEEPENING PLAN 0
(55-FT DEPTH)
EXPANSION PLAN B
HOUR 15

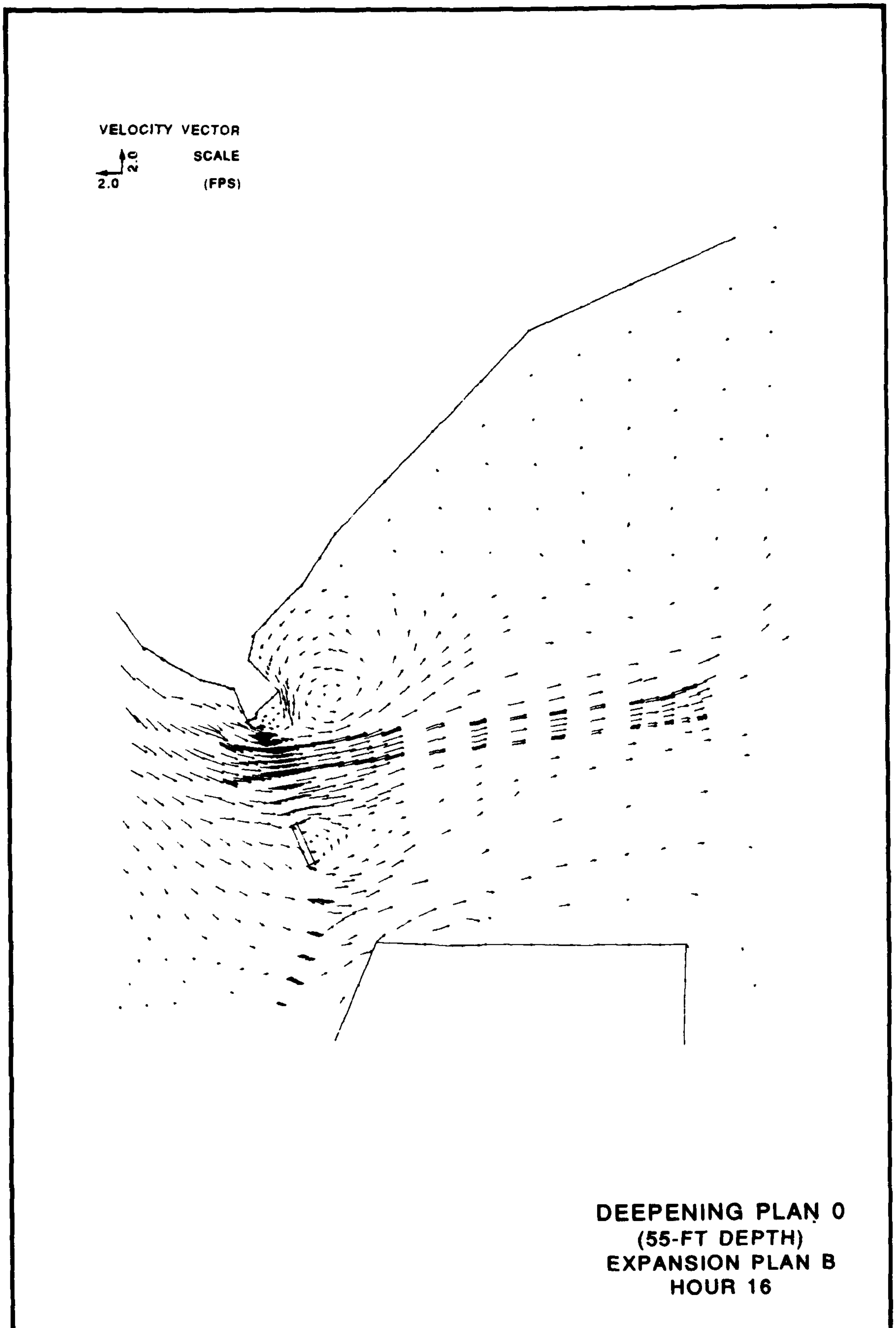
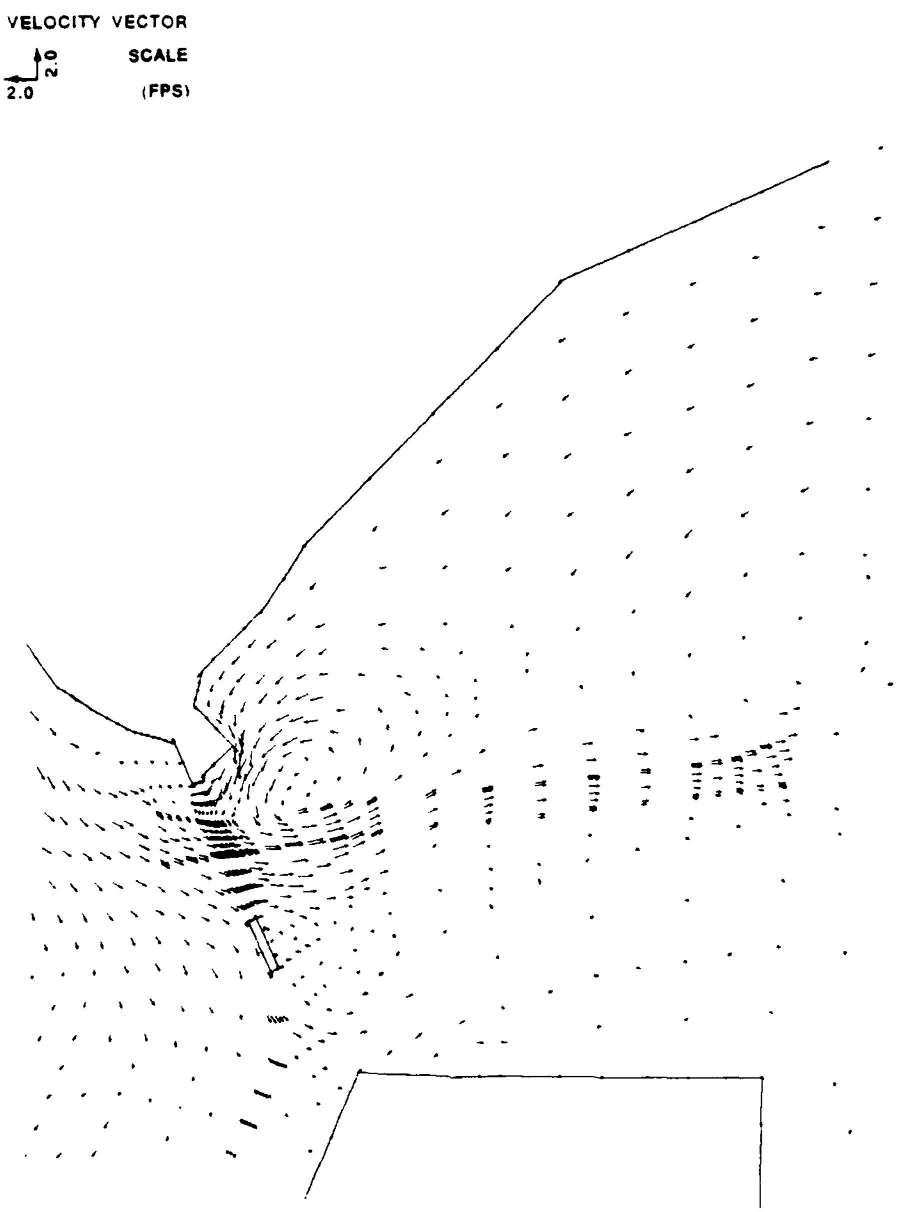
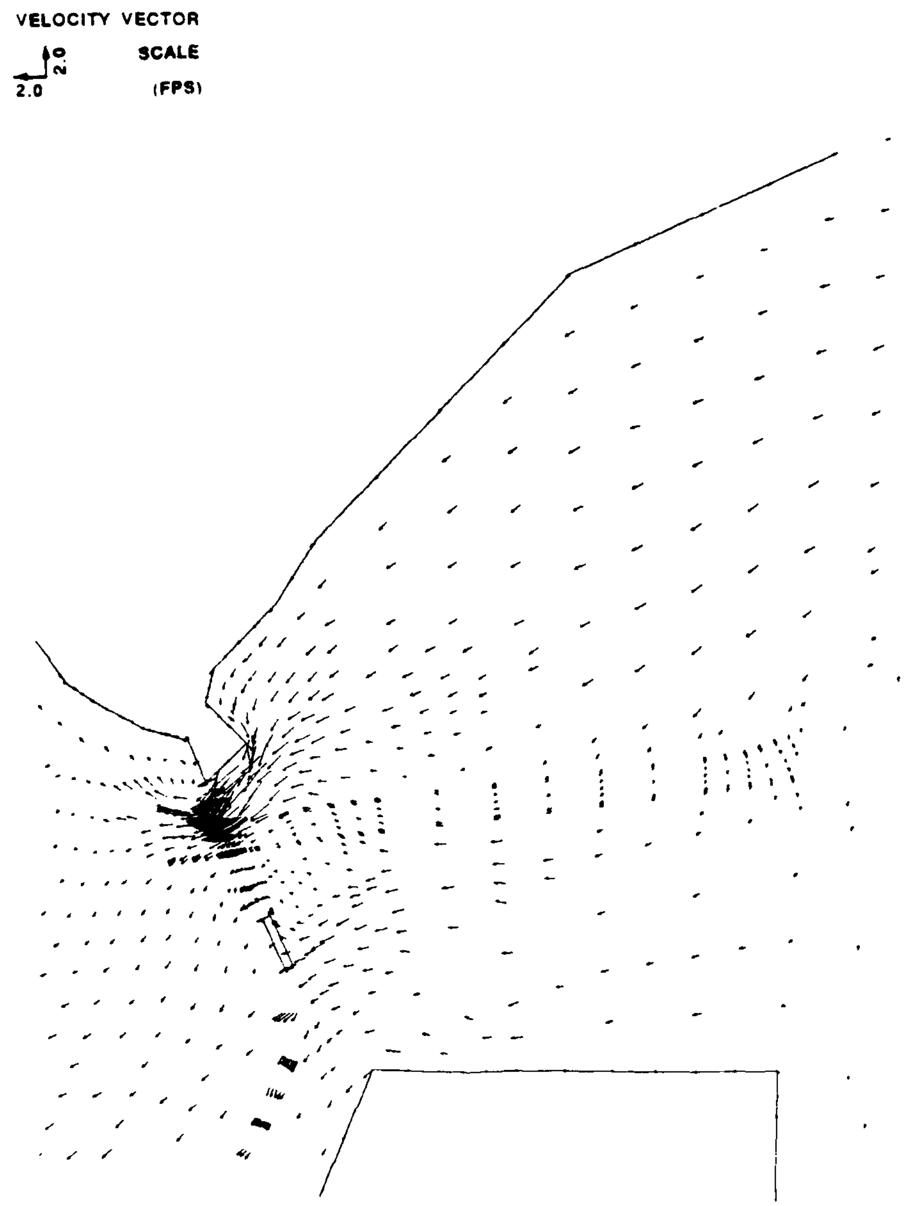

VELOCITY VECTOR
SCALE
(FPS)
2.0
2.0
DEEPENING PLAN 0
(55-FT DEPTH)
EXPANSION PLAN B
HOUR 16

PLATE 2

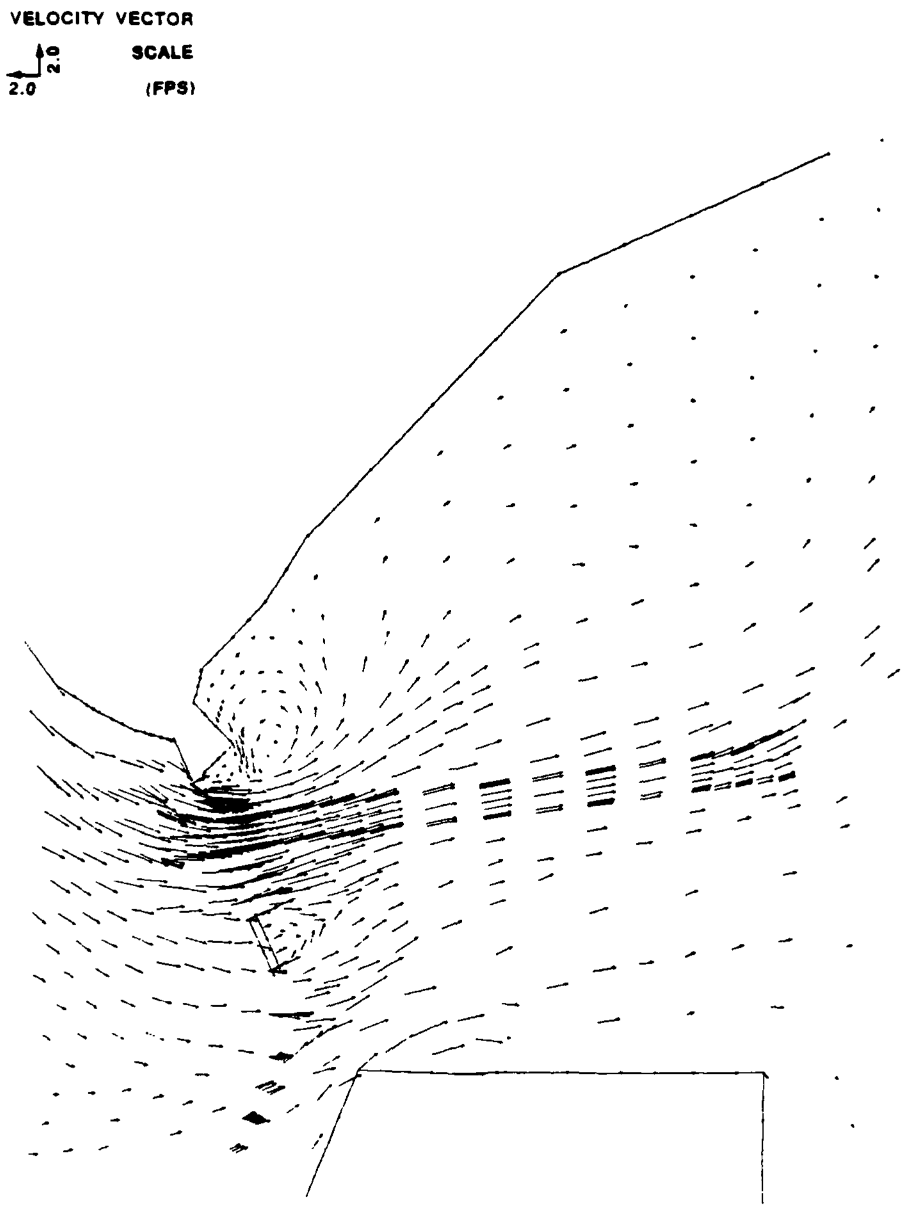


DEEPENING PLAN 0
(55-FT DEPTH)
EXPANSION PLAN B
HOUR 17

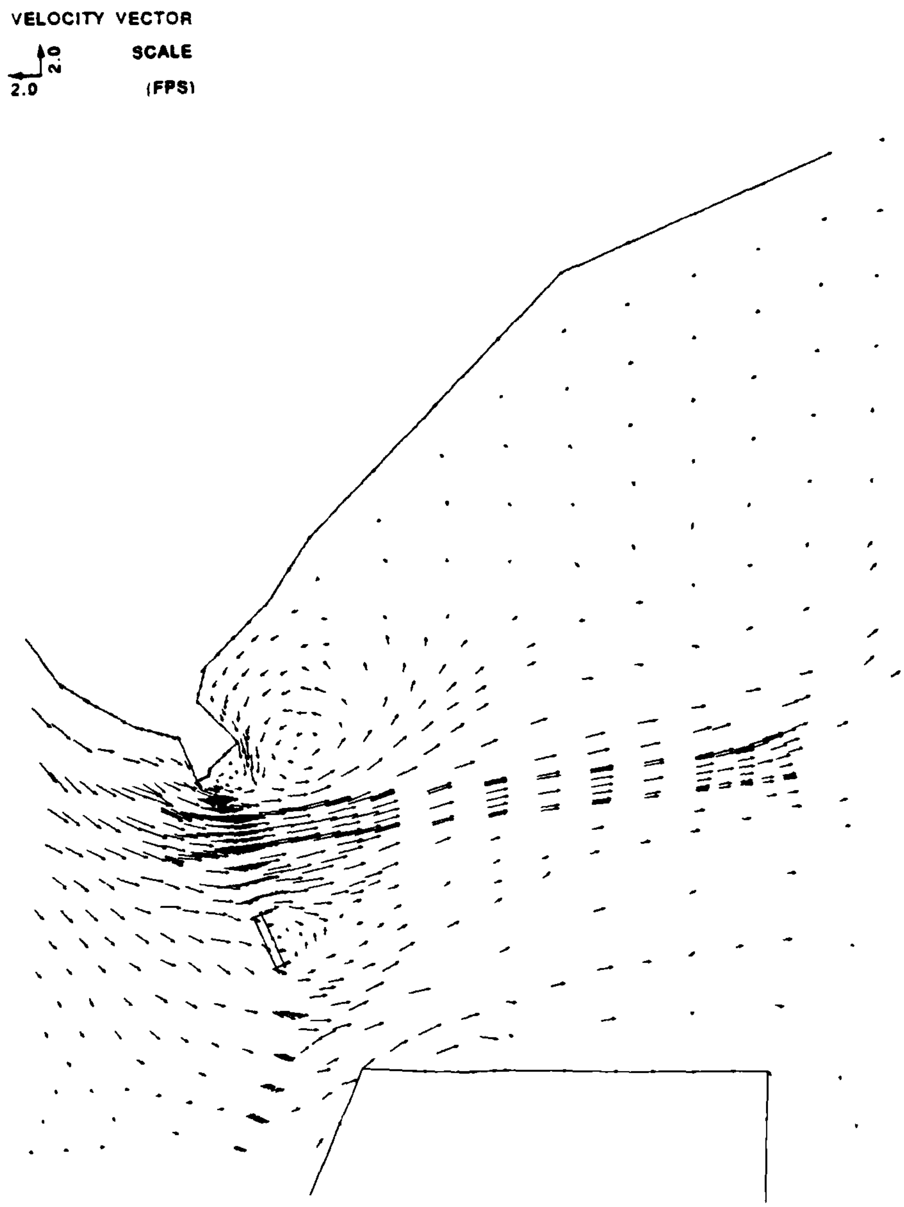


DEEPENING PLAN 0
(55-FT DEPTH)
EXPANSION PLAN B
HOUR 18

PLATE 4

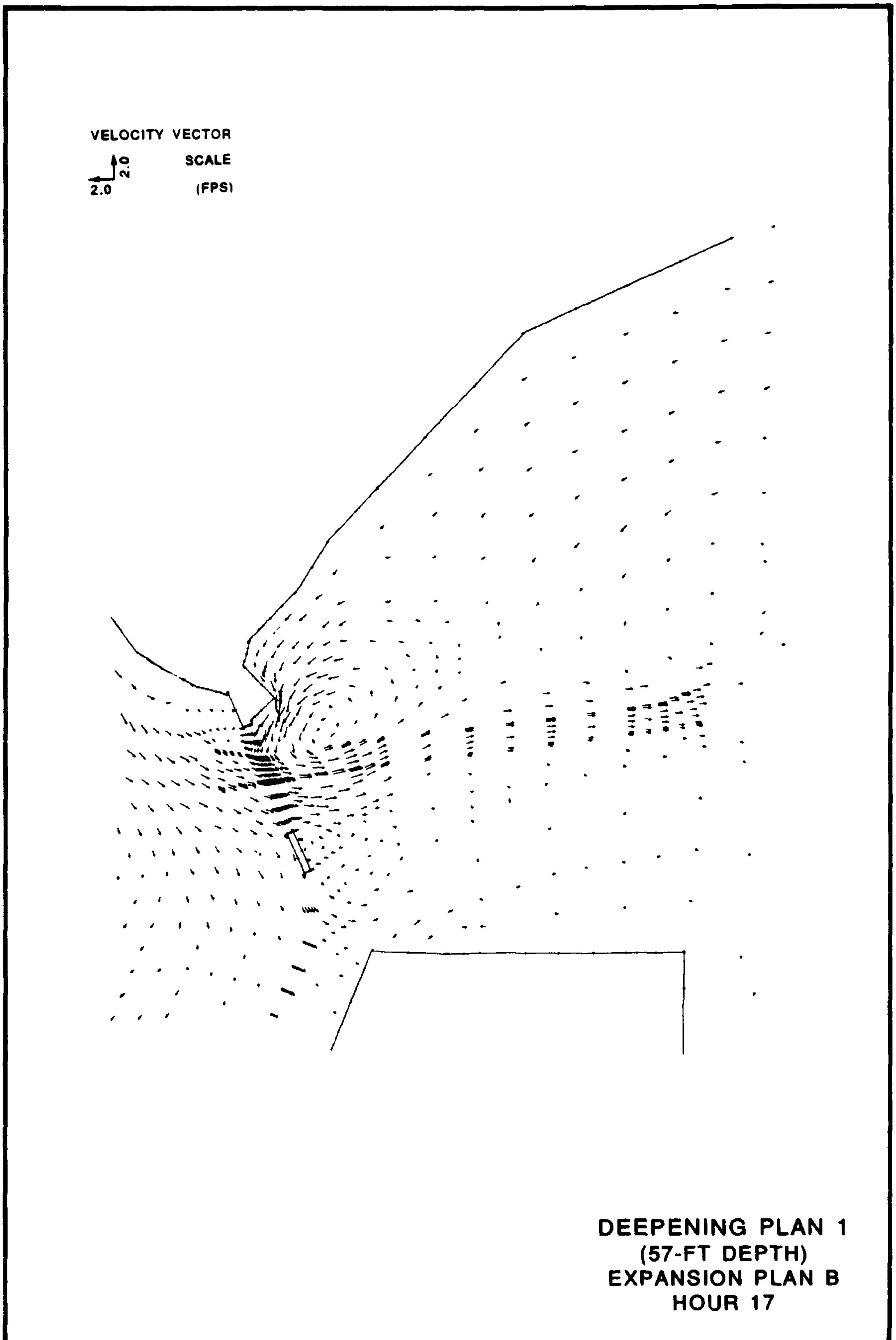


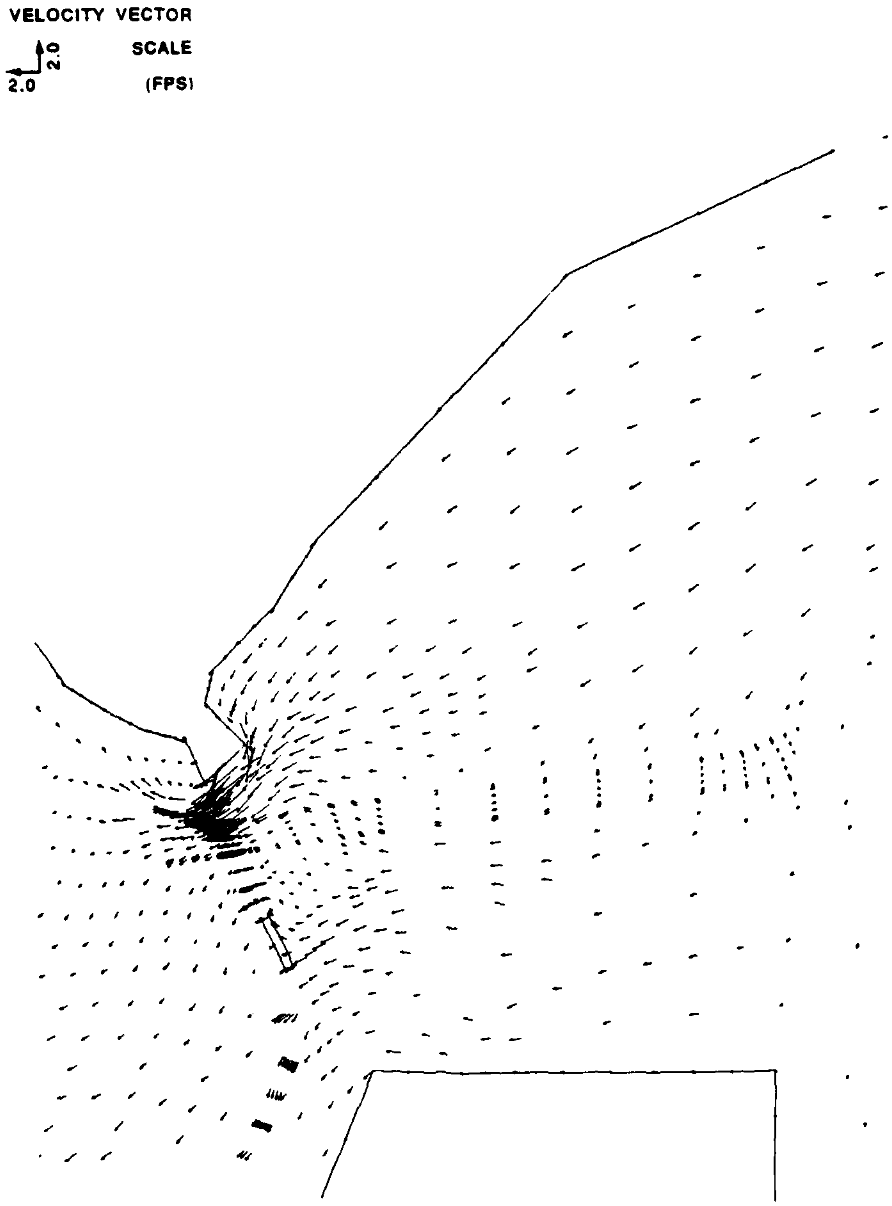
DEEPENING PLAN 1
(57-FT DEPTH)
EXPANSION PLAN B
HOUR 15



DEEPENING PLAN 1
(57-FT DEPTH)
EXPANSION PLAN B
HOUR 16

PLATE 6


VELOCITY VECTOR
SCALE
(FPS)
2.0
2.0
DEEPENING PLAN 1
(57-FT DEPTH)
EXPANSION PLAN B
HOUR 17



DEEPENING PLAN 1
(57-FT DEPTH)
EXPANSION PLAN B
HOUR 18

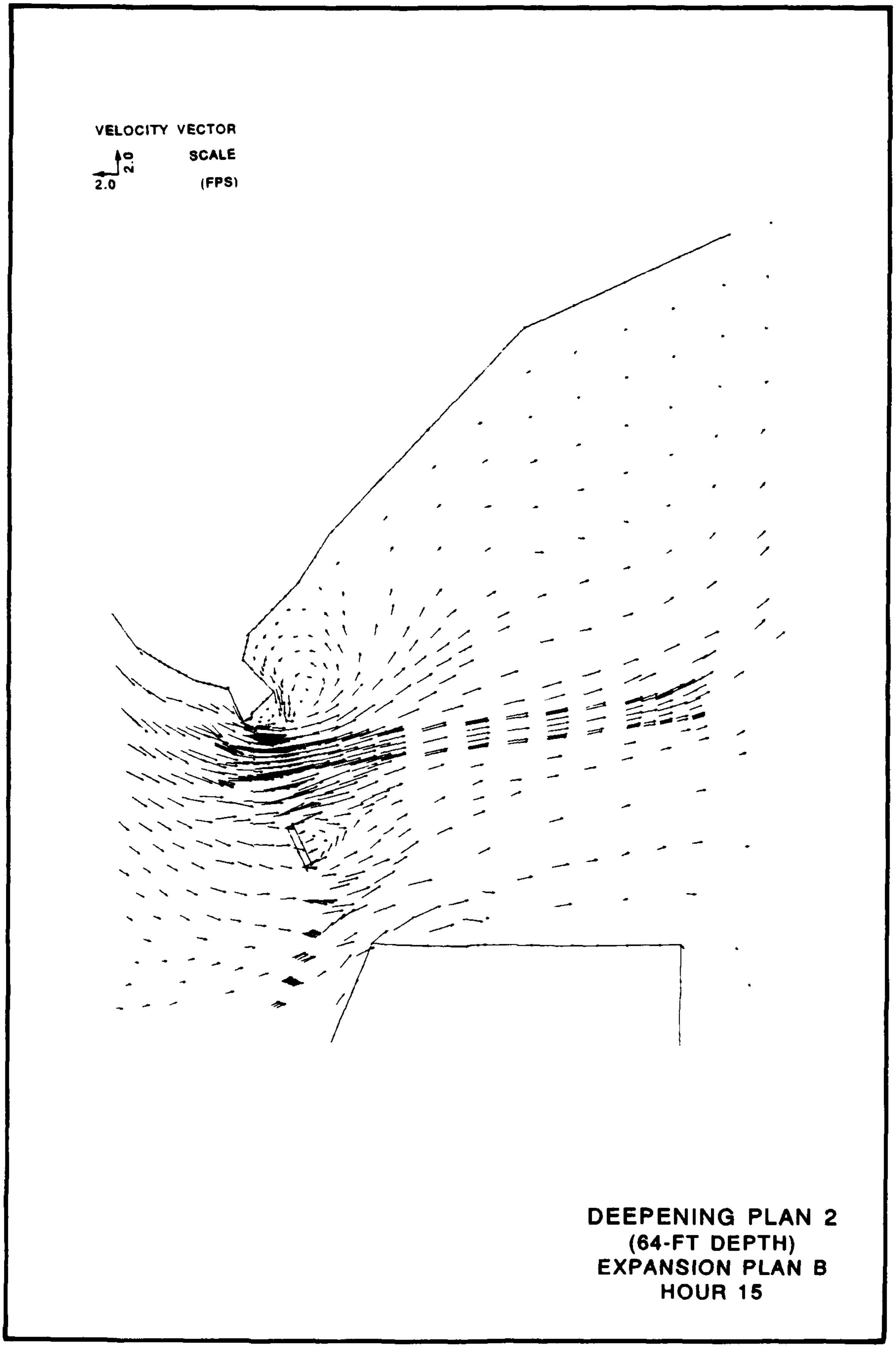

VELOCITY VECTOR
SCALE
(FPS)
2.0
2.0
DEEPENING PLAN 2
(64-FT DEPTH)
EXPANSION PLAN B
HOUR 15

PLATE 9

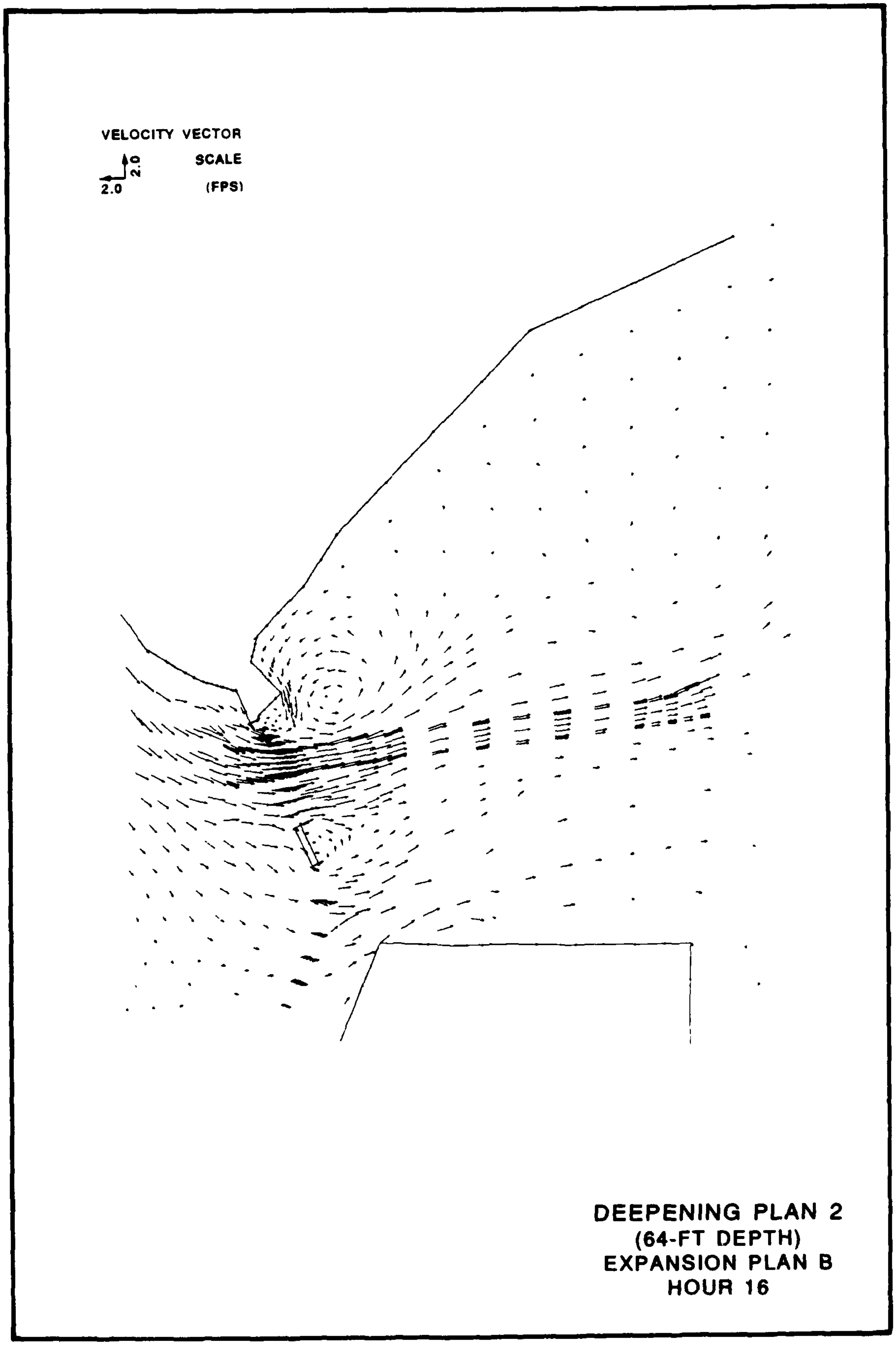
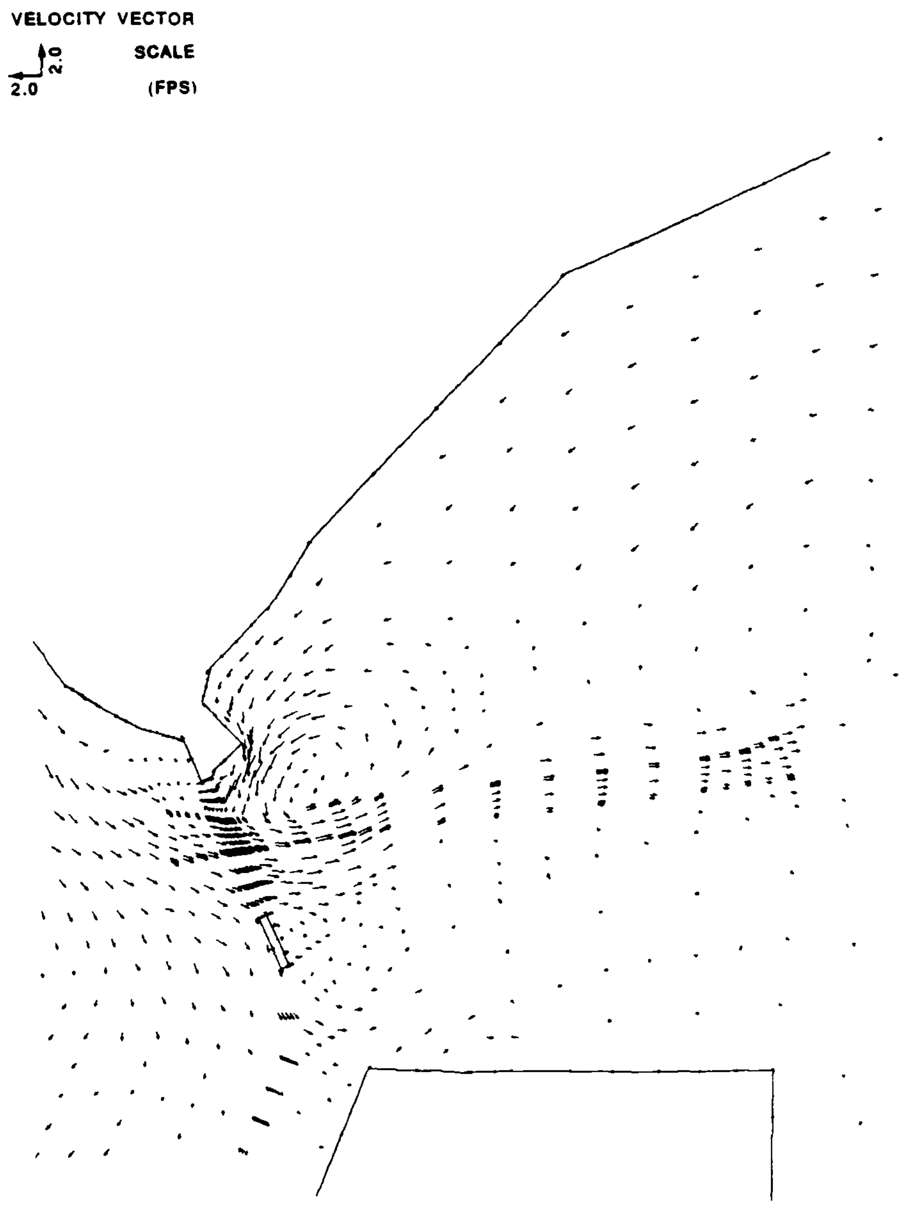

VELOCITY VECTOR
SCALE
(FPS)
2.0
2.0
DEEPENING PLAN 2
(64-FT DEPTH)
EXPANSION PLAN B
HOUR 16

PLATE 10



DEEPENING PLAN 2
(64-FT DEPTH)
EXPANSION PLAN B
HOUR 17

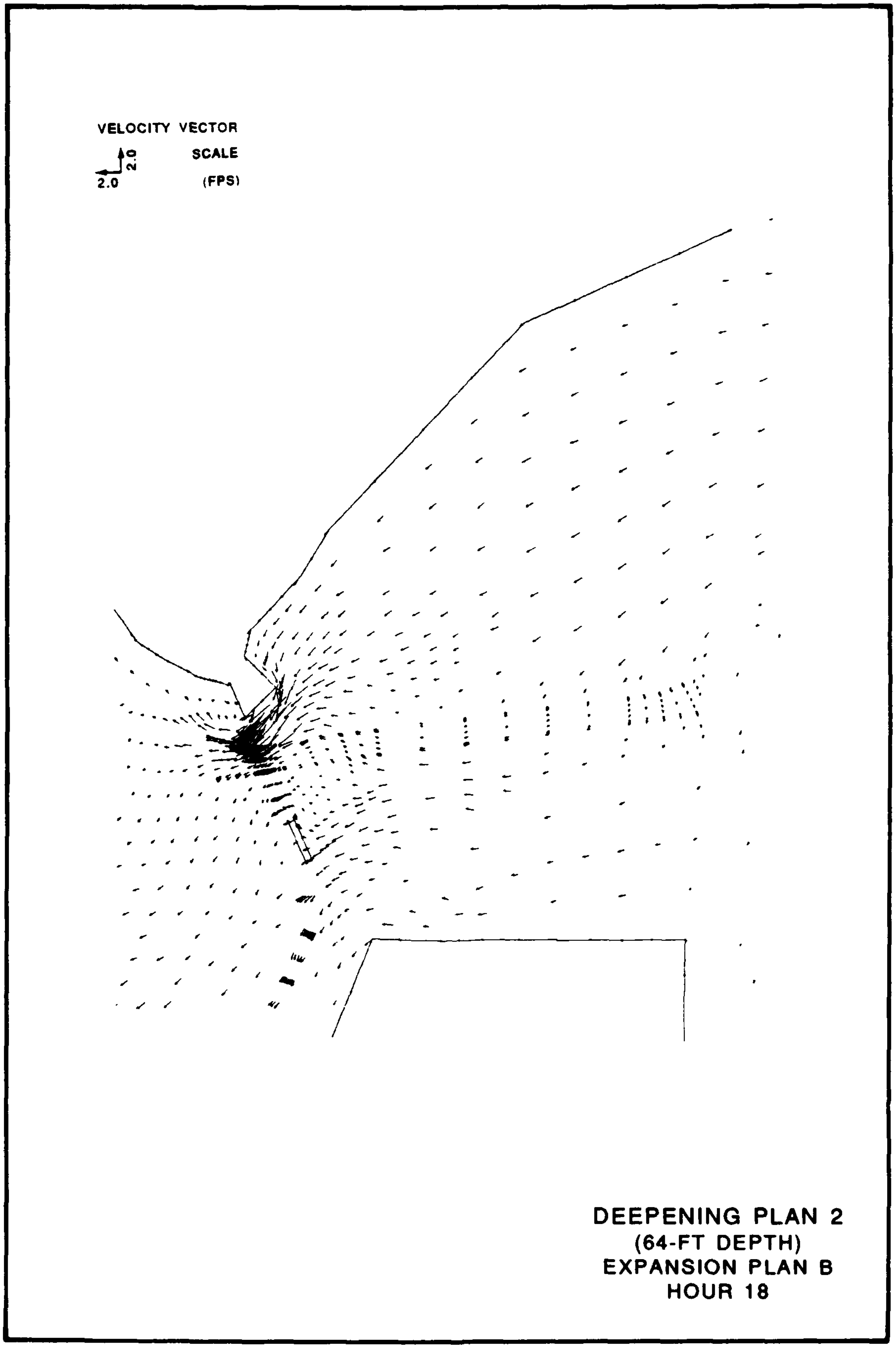
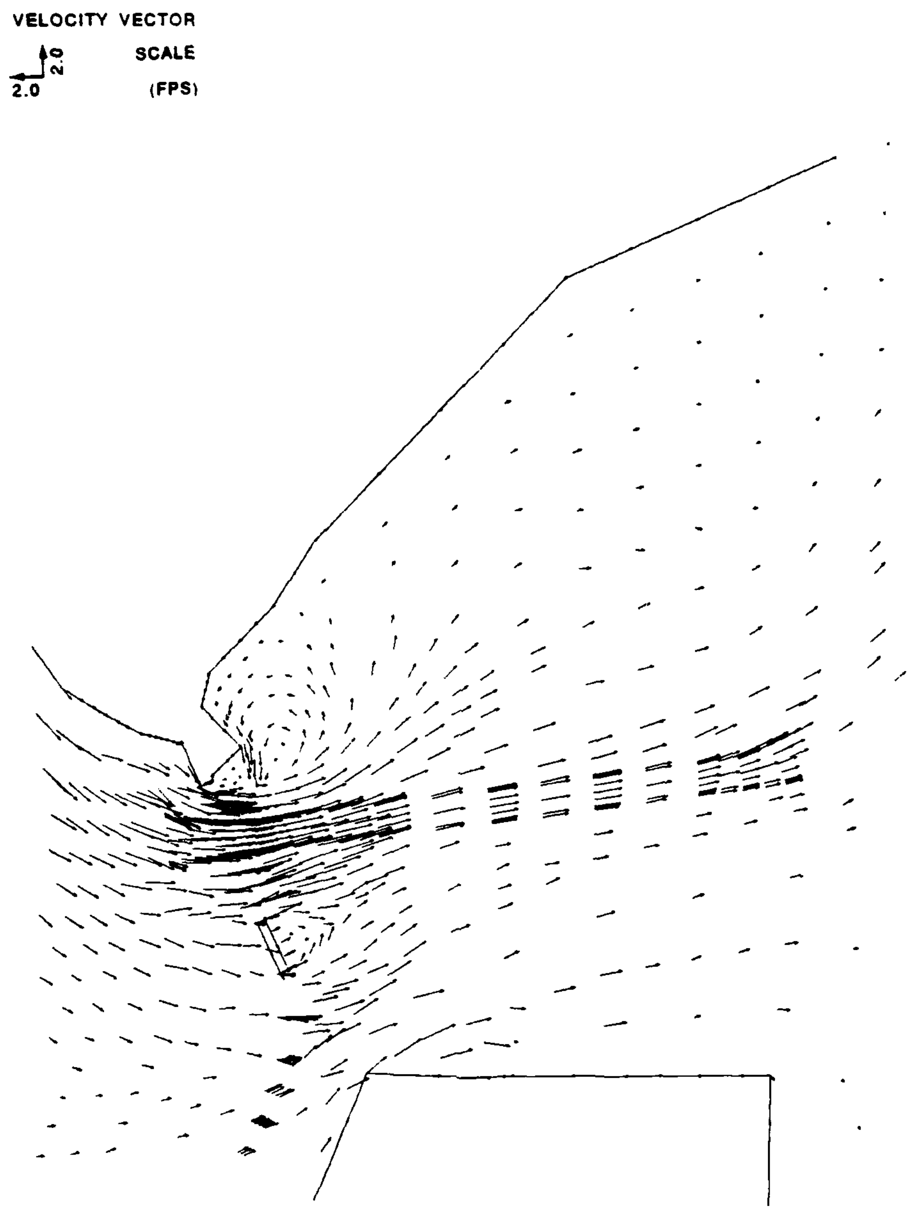
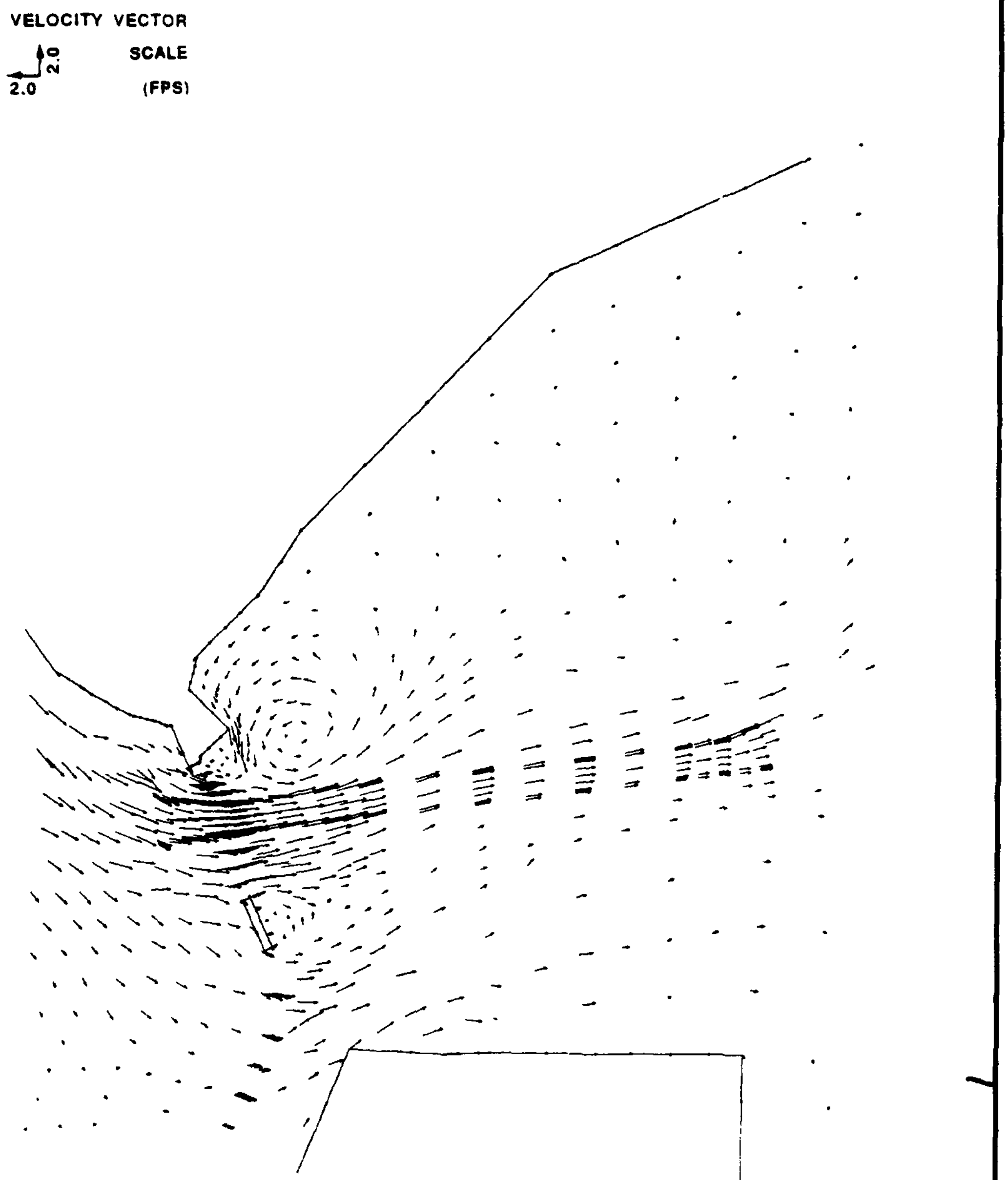

VELOCITY VECTOR
SCALE
(FPS)
2.0
2.0
DEEPENING PLAN 2
(64-FT DEPTH)
EXPANSION PLAN B
HOUR 18

PLATE 12

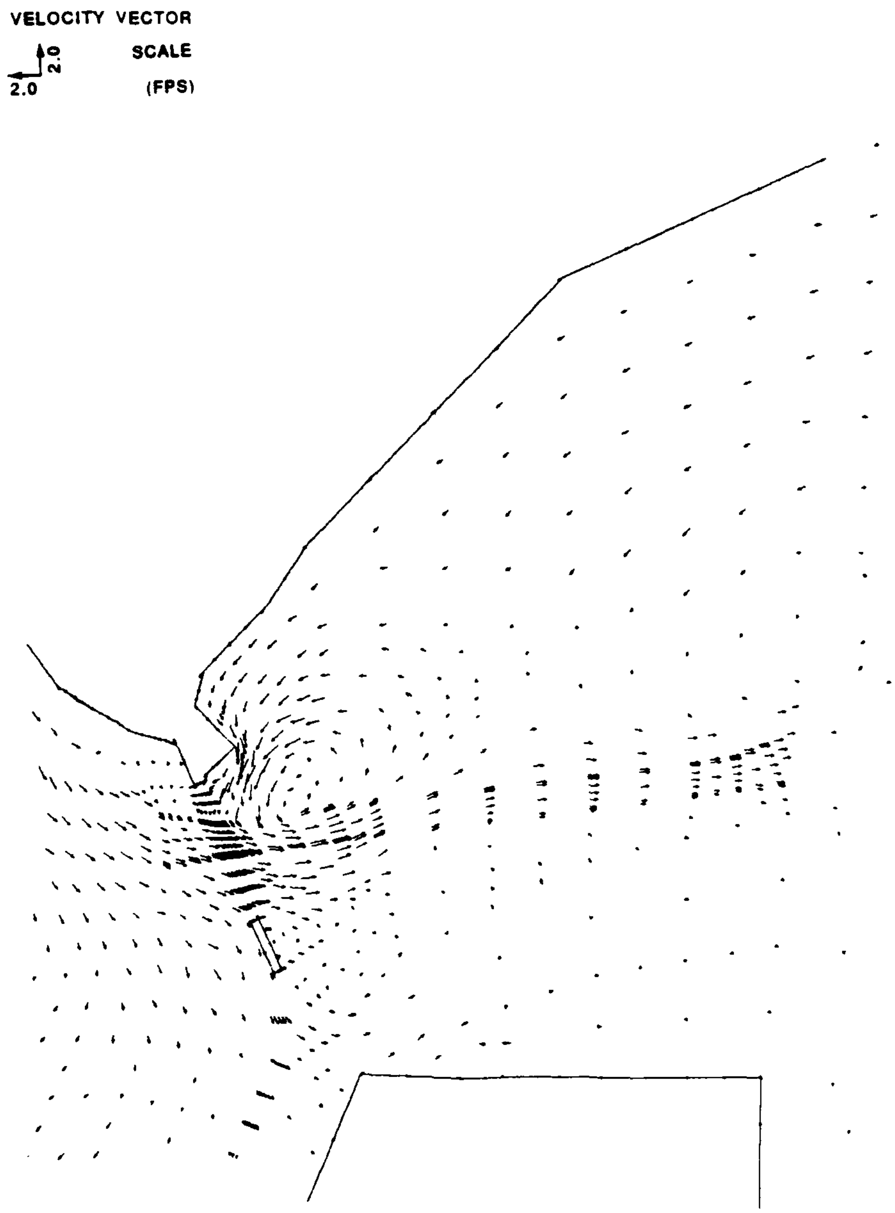


DEEPENING PLAN 3
(70-FT DEPTH)
EXPANSION PLAN B
HOUR 15

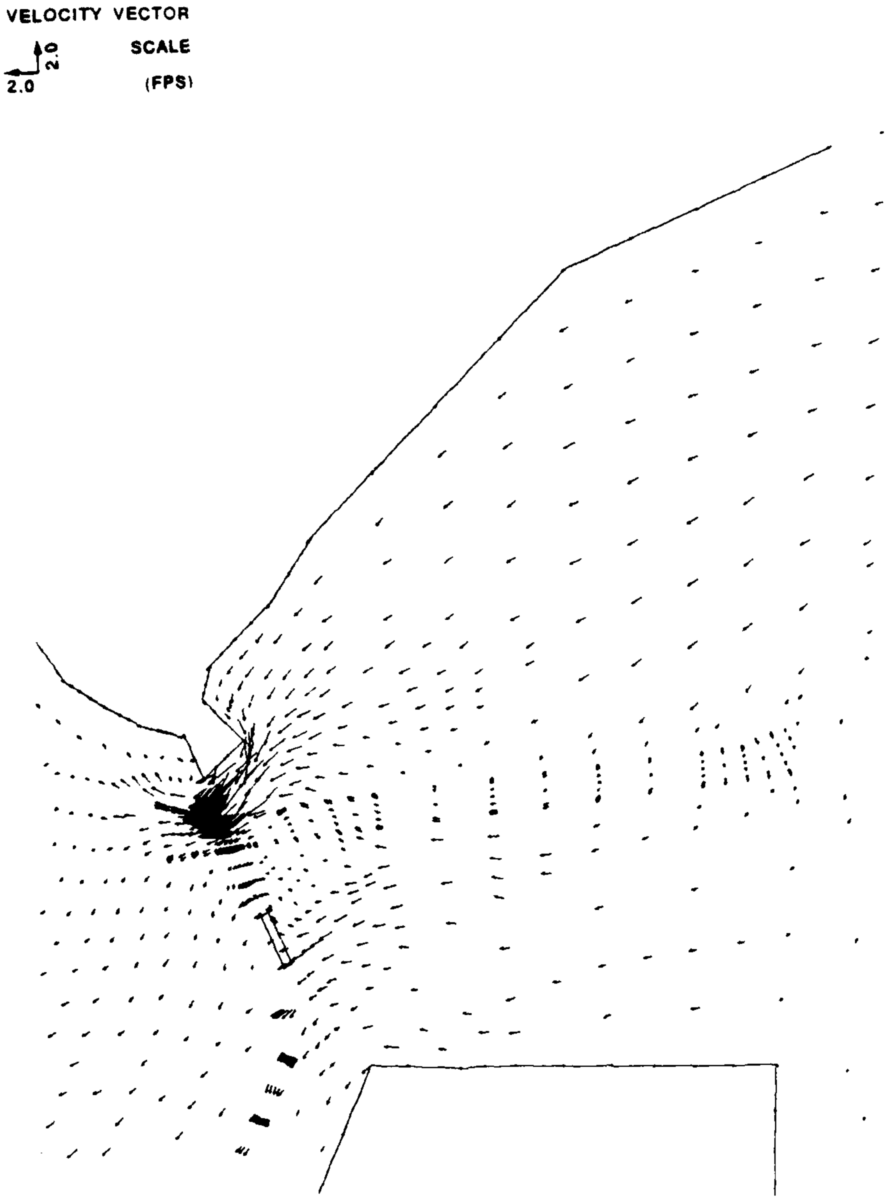


DEEPENING PLAN 3
(70-FT DEPTH)
EXPANSION PLAN B
HOUR 16

PLATE 14

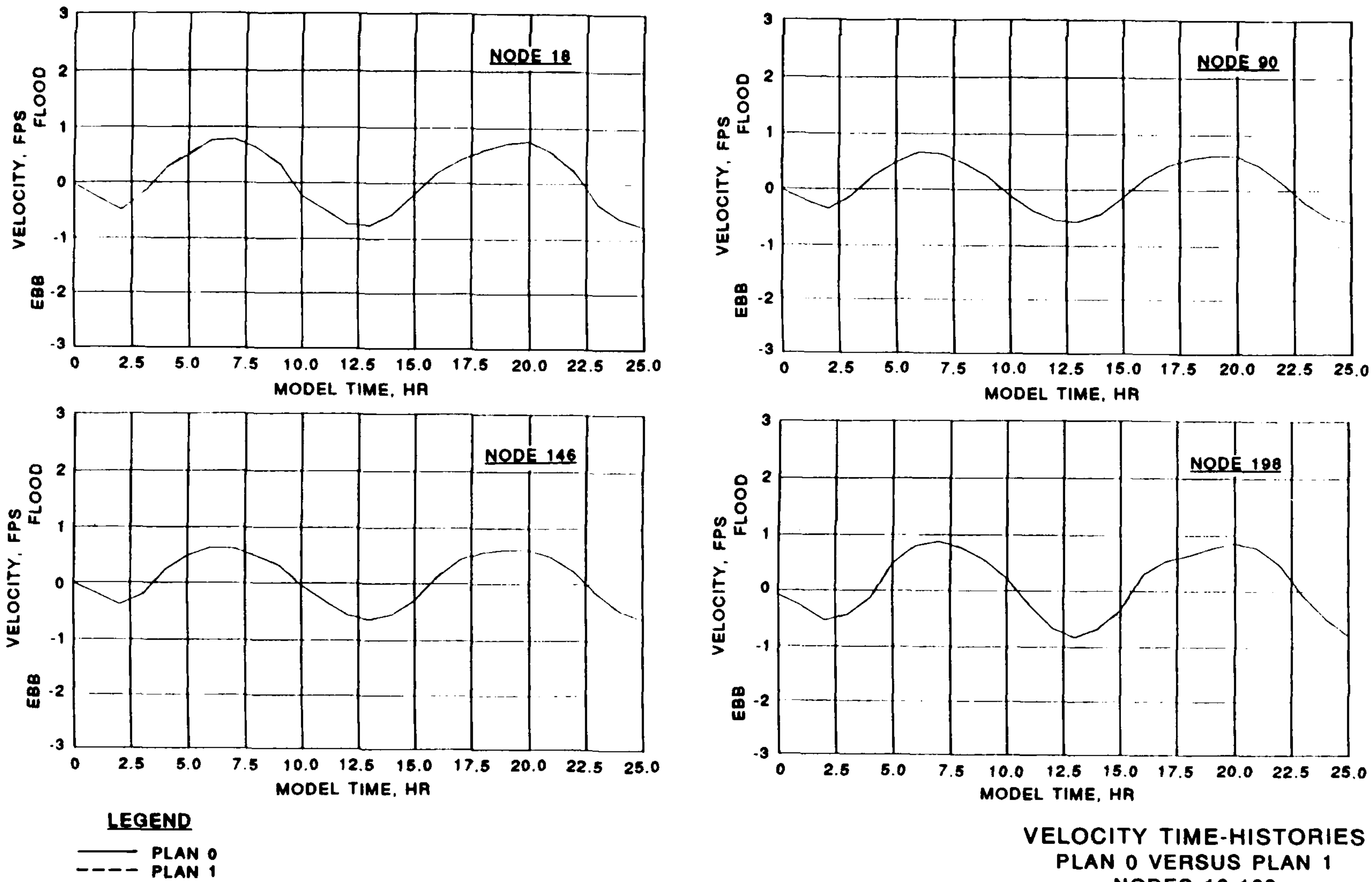


DEEPENING PLAN 3
(70-FT DEPTH)
EXPANSION PLAN B
HOUR 17

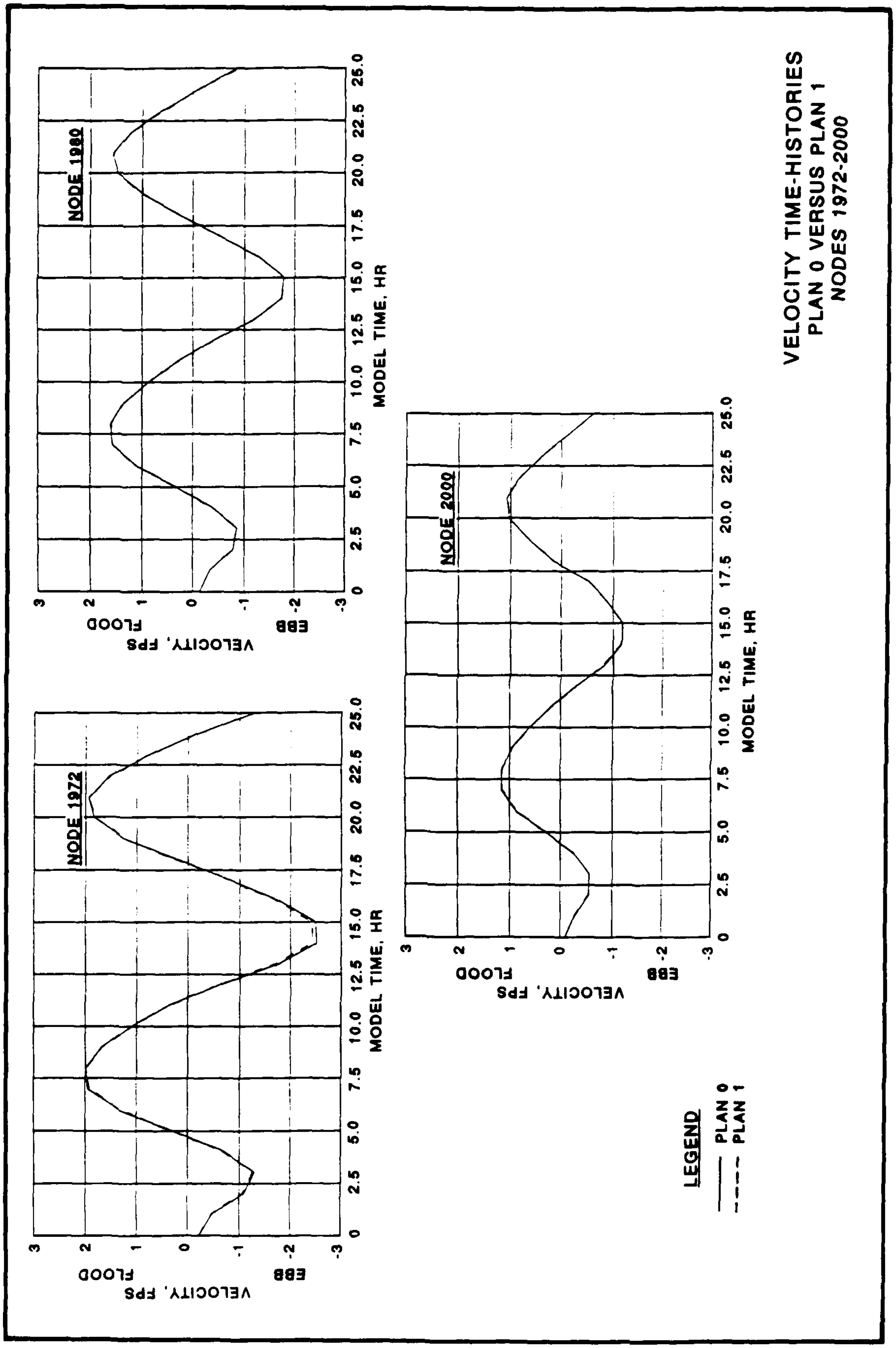


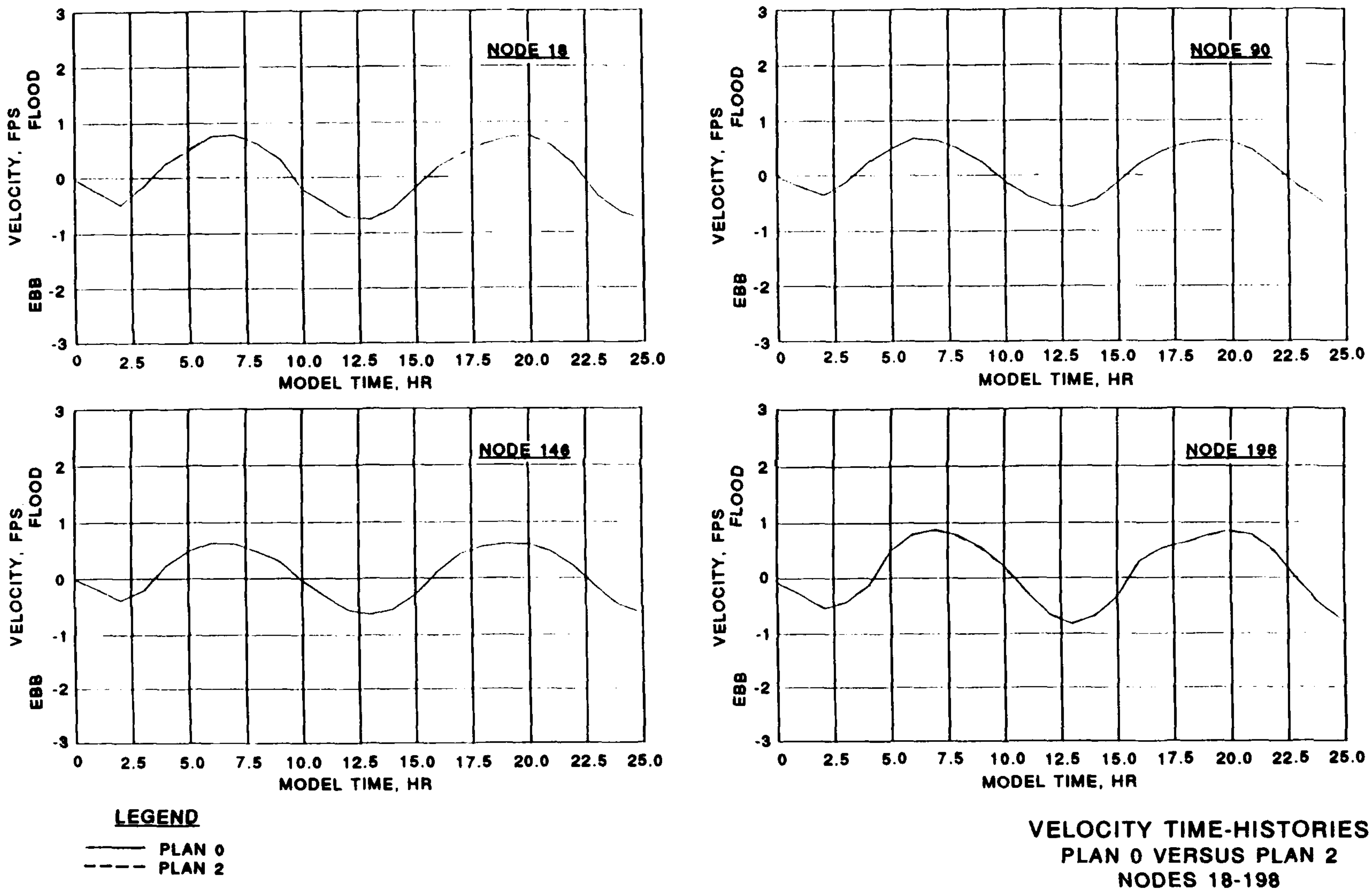
DEEPENING PLAN 3
(70-FT DEPTH)
EXPANSION PLAN B
HOUR 18

PLATE 16

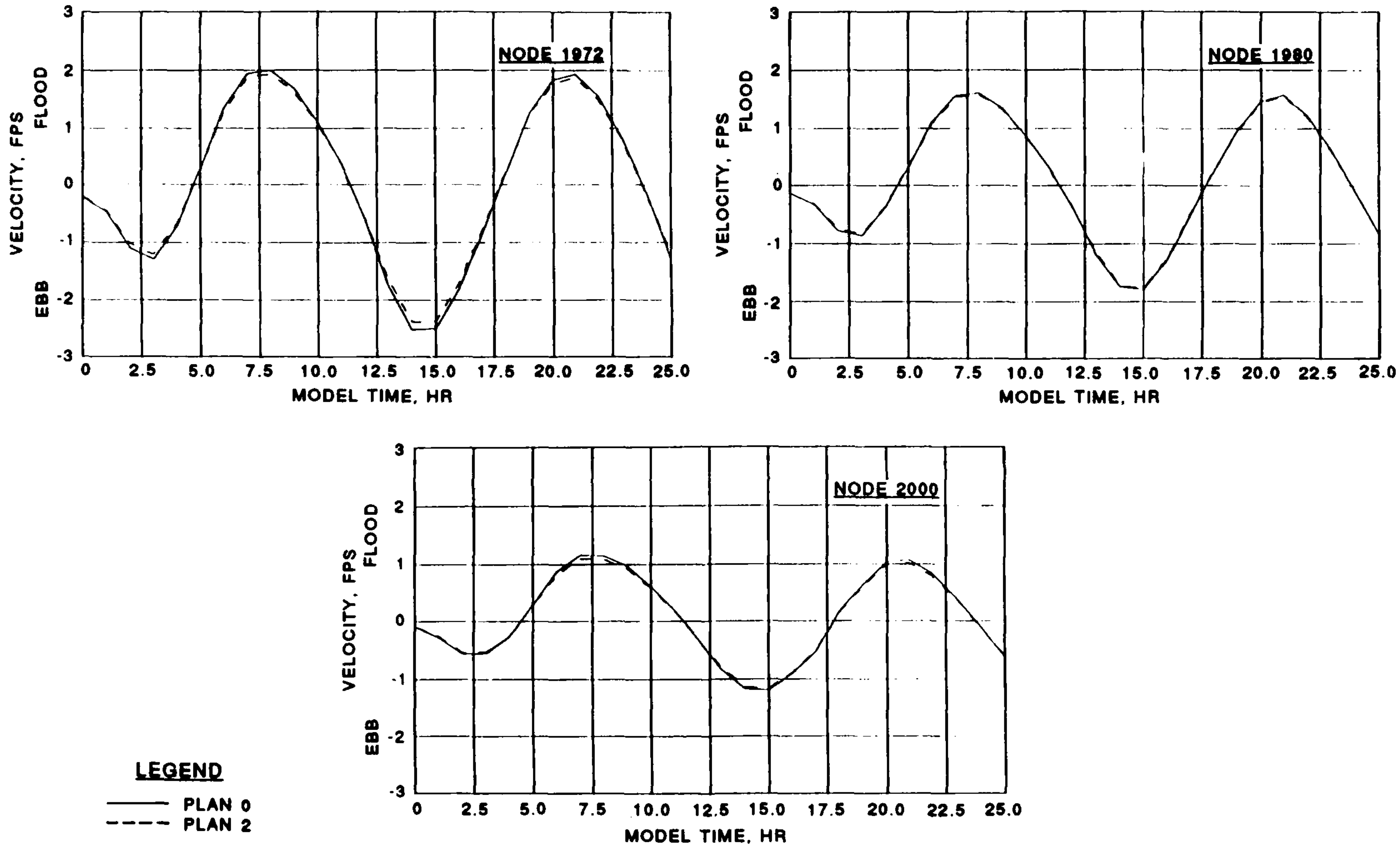


VELOCITY TIME-HISTORIES
PLAN 0 VERSUS PLAN 1
NODES 18-198

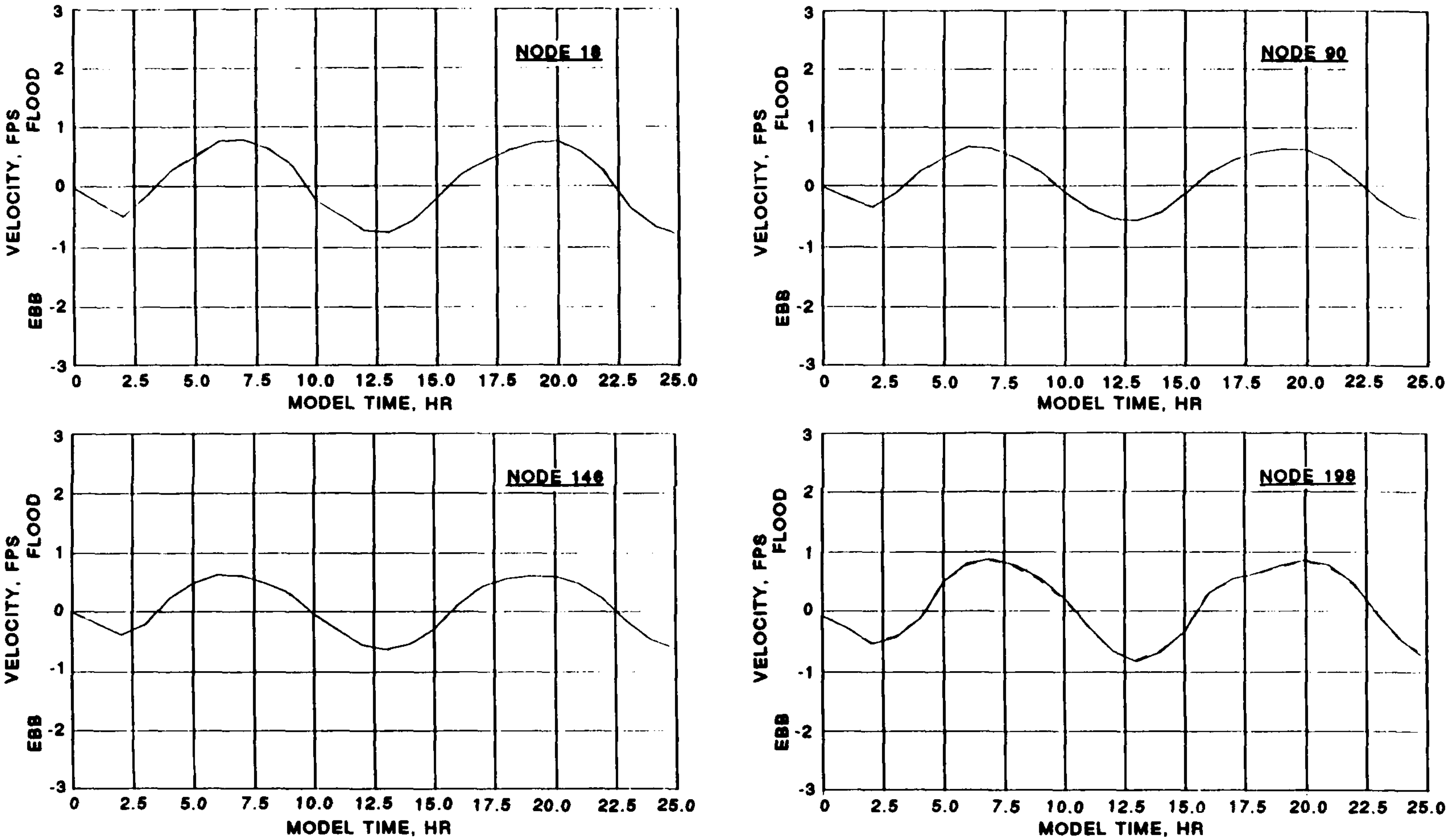

VELOCITY TIME-HISTORIES
PLAN 0 VERSUS PLAN 1
NODES 1972-2000
NODE 1972
NODE 1980
NODE 2000
VELOCITY, FPS
FLOOD
EBB
3
2
1
0
-1
-2
-3
MODEL TIME, HR
0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
22.5
25.0
LEGEND
PLAN 0
PLAN 1



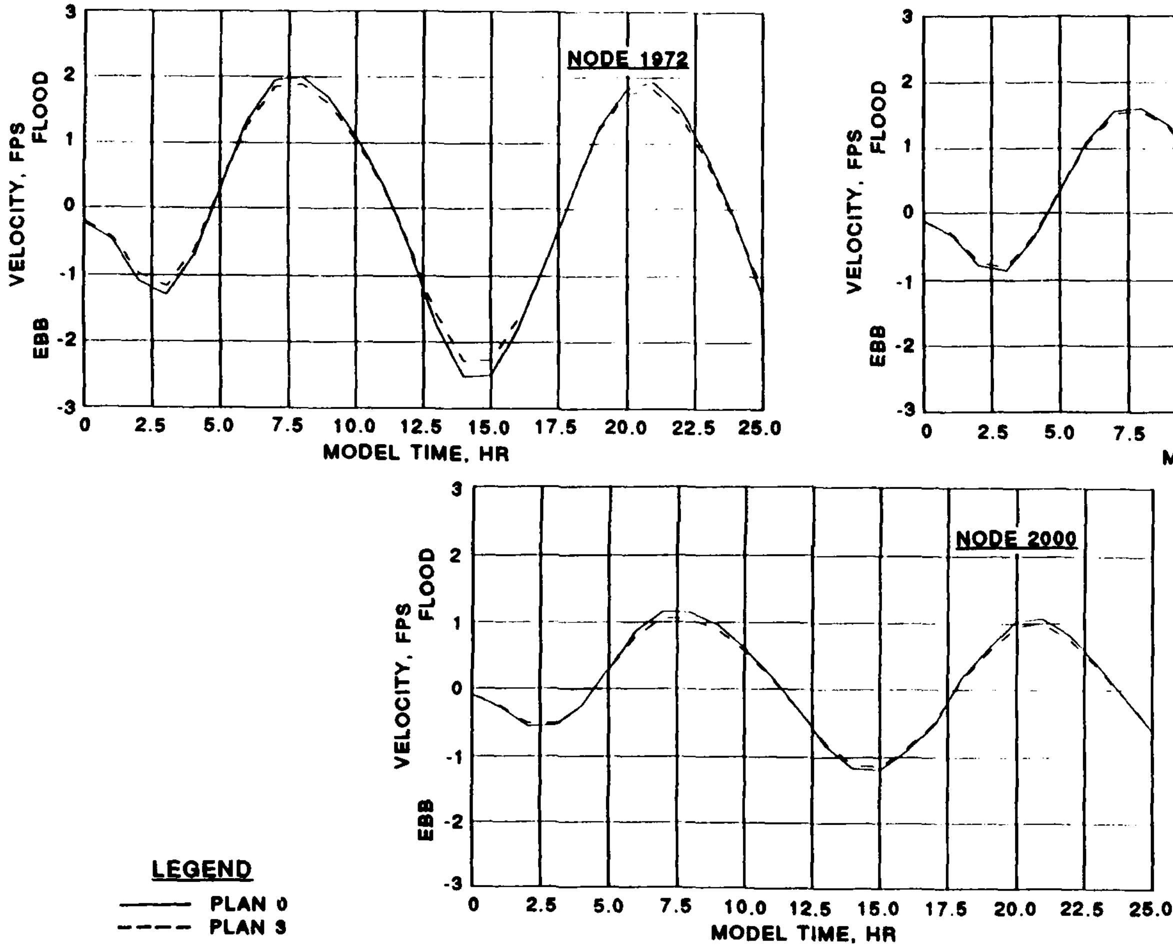
VELOCITY TIME-HISTORIES
PLAN 0 VERSUS PLAN 2
NODES 18-198



VELOCITY TIME-HISTORIES
PLAN 0 VERSUS PLAN 2
NODES 1972-2000



VELOCITY TIME-HISTORIES
PLAN 0 VERSUS PLAN 3
NODES 18-198



VELOCITY TIME-HISTORIES
PLAN 0 VERSUS PLAN 3
NODES 1972-2000

APPENDIX A: THE TABS-2 SYSTEM

1. TABS-2 is a collection of generalized computer programs and utility codes integrated into a numerical modeling system for studying two-dimensional hydrodynamics, sedimentation, and transport problems in rivers, reservoirs, bays, and estuaries. A schematic representation of the system is shown in Figure A1. It can be used either as a stand-alone solution technique or as a step in the hybrid modeling approach. The basic concept is to calculate water-surface elevations, current patterns, sediment erosion, transport and deposition, the resulting bed surface elevations, and the feedback to hydraulics. Existing and proposed geometry can be analyzed to determine the impact on sedimentation of project designs and to determine the impact of project designs on salinity and on the stream system. The system is described in detail by Thomas and McAnally (1985).

2. The three basic components of the system are as follows:

a. "A Two-Dimensional Model for Free Surface Flows," RMA-2V.

b. "Sediment Transport in Unsteady 2-Dimensional Flows, Horizontal Plane," STUDH.

c. "Two-Dimensional Finite Element Program for Water Quality," RMA-4.

3. RMA-2V is a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated with Manning's equation and eddy viscosity coefficients are used to define the turbulent losses. A velocity form of the basic equation is used with side boundaries treated as either slip or static. The model automatically recognizes dry elements and corrects the mesh accordingly. Boundary conditions may be water-surface elevations, velocities, or discharges and may occur inside the mesh as well as along the edges.

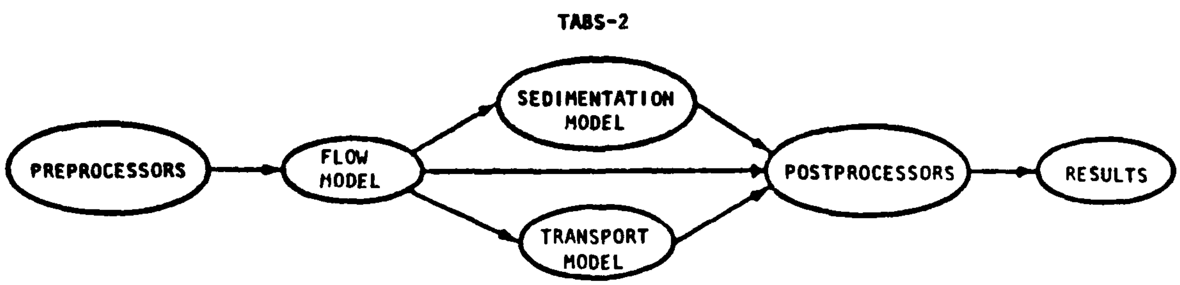


Figure A1. TABS-2 schematic

4. The sedimentation model, STUDH, solves the convection-diffusion equation with bed source terms. These terms are structured for either sand or cohesive sediments. The Ackers-White (1973) procedure is used to calculate a sediment transport potential for the sands from which the actual transport is calculated based on availability. Clay erosion is based on work by Parthen-iades (1962) and Ariathurai and the deposition of clay utilizes Krone's equations (Ariathurai, MacArthur, and Krone 1977). Deposited material forms layers, as shown in Figure A2, and bookkeeping allows up to 10 layers at each node for maintaining separate material types, deposit thickness, and age. The code uses the same mesh as RMA-2V.

5. Salinity calculations, RMA-4, are made with a form of the convective-diffusion equation which has general source-sink terms. Up to seven conservative substances or substances requiring a decay term can be routed. The code uses the same mesh as RMA-2V.

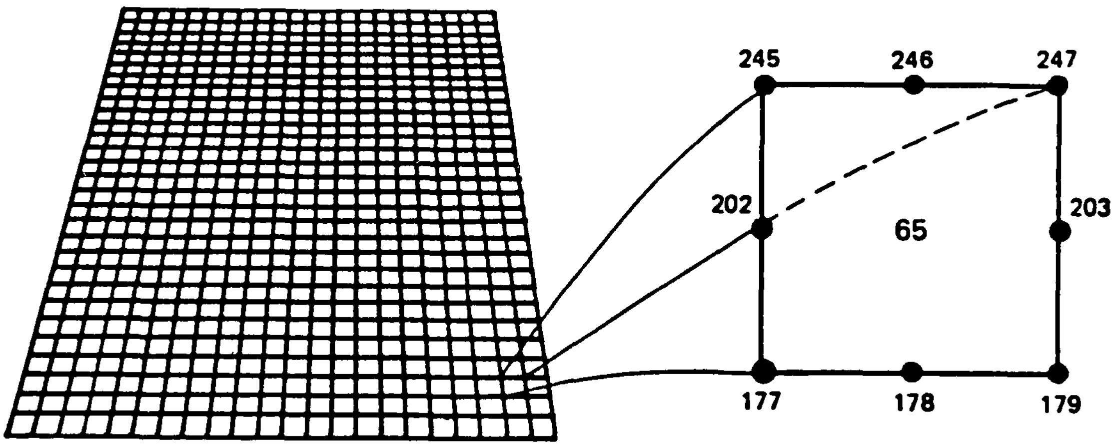
6. Each of these generalized computer codes can be used as a stand-alone program, but to facilitate the preparation of input data and to aid in analyzing results, a family of utility programs was developed for the following purposes:

- a. Digitizing
- b. Mesh generation
- c. Spatial data management
- d. Graphical output
- e. Output analysis
- f. File management
- g. Interfaces
- h. Job control language

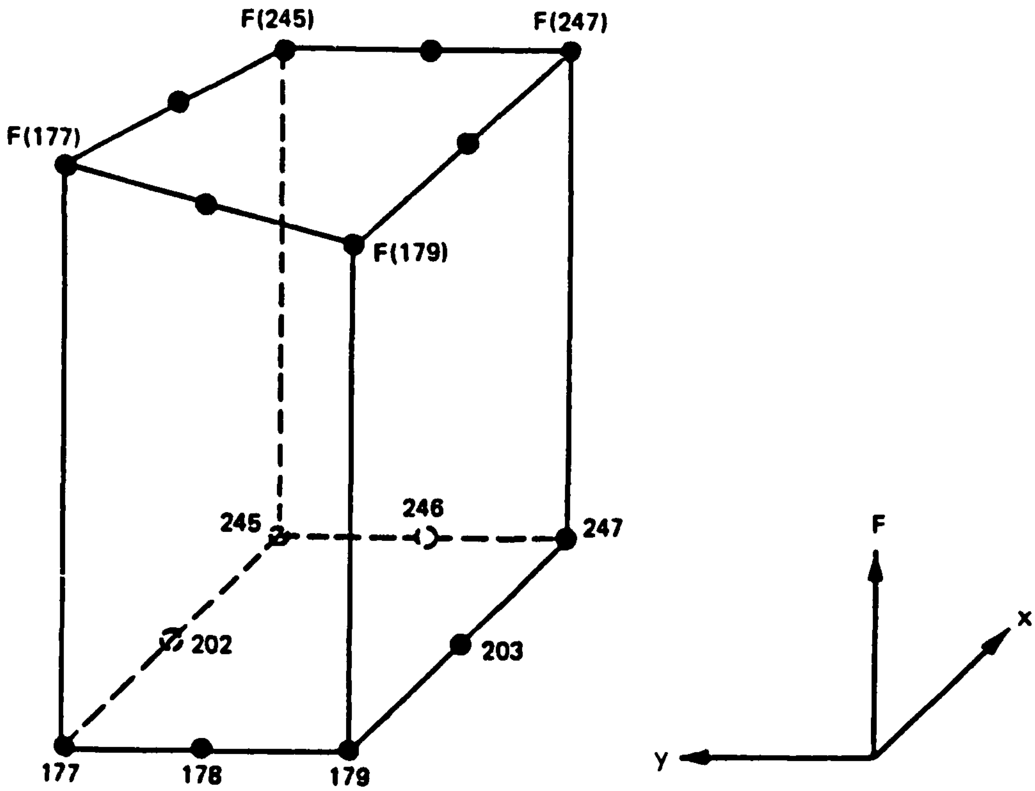
Finite Element Modeling

7. The TABS-2 numerical models used in this effort employ the finite element method to solve the governing equations. To help those who are unfamiliar with the method to better understand this report, a brief description of the method is given here.

8. The finite element method approximates a solution to equations by dividing the area of interest into smaller subareas, which are called elements. The dependent variables (e.g., water-surface elevations and sediment



a. Eight nodes define each element



b. Linear interpolation function

Figure A2. Two-dimensional finite element mesh concentrations) are approximated over each element by continuous functions which interpolate in terms of unknown point (node) values of the variables. An error, defined as the deviation of the approximation solution from the correct solution, is minimized. Then, when boundary conditions are imposed, a set of solvable simultaneous equations is created. The solution is continuous over the area of interest.

9. In one-dimensional problems, elements are line segments. In two-dimensional problems, the elements are polygons, usually either triangles or quadrilaterals. Nodes are located on the edges of elements and occasionally inside the elements. The interpolating functions may be linear or higher order polynomials. Figure A2 illustrates a quadrilateral element with eight nodes and a linear solution surface where F is the interpolating function.

10. Most water resource applications of the finite element method use the Galerkin method of weighted residuals to minimize error. In this method the residual, the total error between the approximate and correct solutions, is weighted by a function that is identical with the interpolating function and then minimized. Minimization results in a set of simultaneous equations in terms of nodal values of the dependent variable (e.g. water-surface elevations or sediment concentration). The time portion of time-dependent problems can be solved by the finite element method, but it is generally more efficient to express derivatives with respect to time in finite difference form.

The Hydrodynamic Model, RMA-2V

Applications

11. This program is designed for far-field problems in which vertical accelerations are negligible and the velocity vectors at a node generally point in the same directions over the entire depth of the water column at any instant of time. It expects a homogeneous fluid with a free surface. Both steady and unsteady state problems can be analyzed. A surface wind stress can be imposed.

12. The program has been applied to calculate flow distribution around islands; flow at bridges having one or more relief openings, in contracting and expanding reaches, into and out of off-channel hydropower plants, at river junctions, and into and out of pumping plant channels; and general flow patterns in rivers, reservoirs, and estuaries.

Limitations

13. This program is not designed for near-field problems where flow-structure interactions (such as vortices, vibrations, or vertical accelerations) are of interest. Areas of vertically stratified flow are beyond this program's capability unless it is used in a hybrid modeling approach. It is two-dimensional in the horizontal plane, and zones where the bottom current is in a different direction from the surface current must be analyzed with considerable subjective judgement regarding long-term energy considerations. It is a free-surface calculation for subcritical flow problems.

Governing equations

14. The generalized computer program RMA-2V solves the depth-integrated equations of fluid mass and momentum conservation in two horizontal directions. The form of the solved equations is

$$h\frac{\partial u}{\partial t} + hu\frac{\partial u}{\partial x} + hv\frac{\partial u}{\partial y} - \frac{h}{\rho}\left(\varepsilon_{xx}\frac{\partial^2 u}{\partial x^2} + \varepsilon_{xy}\frac{\partial^2 u}{\partial y^2}\right) + gh\left(\frac{\partial a}{\partial x} + \frac{\partial h}{\partial x}\right)$$

$$+ \frac{gun^2}{\left(1.486h^{1/6}\right)^2}\left(u^2 + v^2\right)^{1/2} - \zeta V_a^2 \cos\psi - 2h\omega v \sin\phi = 0 \tag{A1}$$

$$h\frac{\partial v}{\partial t} + hv\frac{\partial v}{\partial x} + hv\frac{\partial v}{\partial y} - \frac{h}{\rho}\left(\varepsilon_{yx}\frac{\partial^2 v}{\partial x^2} + \varepsilon_{yy}\frac{\partial^2 v}{\partial y^2}\right) + gh\left(\frac{\partial a}{\partial y} + \frac{\partial h}{\partial y}\right)$$

$$+ \frac{gvn^2}{\left(1.486h^{1/6}\right)^2}\left(u^2 + v^2\right)^{1/2} - \zeta V_a^2 \sin\psi + 2\omega hu \sin\phi = 0 \tag{A2}$$

$$\frac{\partial h}{\partial t} + h\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) + u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} = 0 \tag{A3}$$

where

h = depth

u,v = velocities in the Cartesian directions

x,y,t = Cartesian coordinates and time

ρ = density

ε = eddy viscosity coefficient, for xx = normal direction on x-axis surface; yy = normal direction on y-axis surface; xy and yx = shear direction on each surface

g = acceleration due to gravity

a = elevation of bottom

n = Manning's n value

1.486 = conversion from SI (metric) to non-SI units

ζ = empirical wind shear coefficient

V_a = wind speed

ψ = wind direction

ω = rate of earth's angular rotation

ϕ = local latitude

15. Equations A1, A2, and A3 are solved by the finite element method using Galerkin weighted residuals. The elements may be either quadrilaterals or triangles and may have curved (parabolic) sides. The shape functions are quadratic for flow and linear for depth. Integration in space is performed by Gaussian integration. Derivatives in time are replaced by a nonlinear finite difference approximation. Variables are assumed to vary over each time interval in the form

$$f(t) = f(0) + at + bt^c \qquad t_0 \leq t < t \tag{A4}$$

which is differentiated with respect to time, and cast in finite difference form. Letters a , b , and c are constants. It has been found by experiment that the best value for c is 1.5 (Norton and King 1977).

16. The solution is fully implicit and the set of simultaneous equations is solved by Newton-Raphson iteration. The computer code executes the solution by means of a front-type solver that assembles a portion of the matrix and solves it before assembling the next portion of the matrix. The front solver's efficiency is largely independent of bandwidth and thus does not require as much care in formation of the computational mesh as do traditional solvers.

17. The code RMA-2V is based on the earlier version RMA-2 (Norton and King 1977) but differs from it in several ways. It is formulated in terms of velocity (v) instead of unit discharge (vh), which improves some aspects of the code's behavior; it permits drying and wetting of areas within the grid;

and it permits specification of turbulent exchange coefficients in directions other than along the x- and z-axes. For a more complete description, see Appendix F of Thomas and McAnally (1985).

The Sediment Transport Model, STUDH

Applications

18. STUDH can be applied to clay and/or sand bed sediments where flow velocities can be considered two-dimensional (i.e., the speed and direction can be satisfactorily represented as a depth-averaged velocity). It is useful for both deposition and erosion studies and, to a limited extent, for stream width studies. The program treats two categories of sediment: noncohesive, which is referred to as sand here, and cohesive, which is referred to as clay.

Limitations

19. Both clay and sand may be analyzed, but the model considers a single, effective grain size for each and treats each separately. Fall velocity must be prescribed along with the water-surface elevations, x-velocity, y-velocity, diffusion coefficients, bed density, critical shear stresses for erosion, erosion rate constants, and critical shear stress for deposition.

20. Many applications cannot use long simulation periods because of their computation cost. Study areas should be made as small as possible to avoid an excessive number of elements when dynamic runs are contemplated yet must be large enough to permit proper posing of boundary conditions. The same computation time interval must be satisfactory for both the transverse and longitudinal flow directions.

21. The program does not compute water-surface elevations or velocities; therefore these data must be provided. For complicated geometries, the numerical model for hydrodynamic computations, RMA-2V, is used.

Governing equations

22. The generalized computer program STUDH solves the depth-integrated convection-dispersion equation in two horizontal dimensions for a single sediment constituent. For a more complete description, see Appendix G of Thomas and McAnally (1985). The form of the solved equation is

$$\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = \frac{\partial}{\partial x}\left(D_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(D_y \frac{\partial C}{\partial y}\right) + \alpha_1 C + \alpha_2 = 0 \qquad \text{(A5)}$$

where

C = concentration of sediment

u = depth-integrated velocity in x-direction

v = depth-integrated velocity in y-direction

D_x = dispersion coefficient in x-direction

D_y = dispersion coefficient in y-direction

α_1 = coefficient of concentration-dependent source/sink term

α_2 = coefficient of source/sink term

23. The source/sink terms in Equation A5 are computed in routines that treat the interaction of the flow and the bed. Separate sections of the code handle computations for clay bed and sand bed problems.

Sand transport

24. The source/sink terms are evaluated by first computing a potential sand transport capacity for the specified flow conditions, comparing that capacity with the amount of sand actually being transported, and then eroding from or depositing to the bed at a rate that would approach the equilibrium value after sufficient elapsed time.

25. The potential sand transport capacity in the model is computed by the method of Ackers and White (1973), which uses a transport power (work rate) approach. It has been shown to provide superior results for transport under steady-flow conditions (White, Milli, and Crabbe 1975) and for combined waves and currents (Swart 1976). Flume tests at the US Army Engineer Waterways Experiment Station have shown that the concept is valid for transport by estuarine currents.

26. The total load transport function of Ackers and White is based upon a dimensionless grain size

$$D_{gr} = D \left[\frac{g(s-1)}{\nu^2} \right]^{1/3} \tag{A6}$$

where

D = sediment particle diameter

s = specific gravity of the sediment

ν = kinematic viscosity of the fluid

and a sediment mobility parameter

$$F_{gr} = \left[\frac{\tau^{n'} \tau'^{(1-n')}}{\rho g D(s - 1)} \right]^{1/2} \quad \text{(A7)}$$

where

τ = total boundary shear stress

n' = a coefficient expressing the relative importance of bed-load and suspended-load transport, given in Equation A9

τ' = boundary surface shear stress

The surface shear stress is that part of the total shear stress which is due to the rough surface of the bed only, i.e., not including that part due to bed forms and geometry. It therefore corresponds to that shear stress that the flow would exert on a plane bed.

27. The total sediment transport is expressed as an effective concentration

$$G_p = C\left(\frac{F_{gr}}{A} - 1\right)^m \frac{sD}{h} \left(\frac{\rho}{\tau} U\right)^{n'} \quad \text{(A8)}$$

where U is the average flow speed, and for $1 < D_{gr} \leq 60$

$$n' = 1.00 - 0.56 \log D_{gr} \quad \text{(A9)}$$

$$A = \frac{0.23}{\sqrt{D_{gr}}} + 0.14 \quad \text{(A10)}$$

$$\log C = 2.86 \log D_{gr} - (\log D_{gr})^2 - 3.53 \quad \text{(A11)}$$

$$m = \frac{9.66}{D_{gr}} + 1.34 \quad \text{(A12)}$$

For $D_{gr} < 60$

$$n' = 0.00 \quad \text{(A13)}$$

$$A = 0.17 \qquad (A14)$$

$$C = 0.025 \qquad (A15)$$

$$m = 1.5 \qquad (A16)$$

28. Equations A6-A16 result in a potential sediment concentration G_p. This value is the depth-averaged concentration of sediment that will occur if an equilibrium transport rate is reached with a nonlimited supply of sediment. The rate of sediment deposition (or erosion) is then computed as

$$R = \frac{G_p - C}{t_c} \qquad (A17)$$

where

C = present sediment concentration

t_c = time constant

For deposition, the time constant is

$$t_c = \text{larger of} \begin{cases} \Delta t \\ \text{or} \\ \dfrac{C_d h}{V_s} \end{cases} \qquad (A18)$$

and for erosion it is

$$t_c = \text{larger of} \begin{cases} \Delta t \\ \text{or} \\ \dfrac{C_e h}{U} \end{cases} \qquad (A19)$$

where

Δt = computational time-step

C_d = response time coefficient for deposition

V_s = sediment settling velocity

C_e = response time coefficient for erosion

The sand bed has a specified initial thickness which limits the amount of erosion to that thickness.

Cohesive sediments transport

29. Cohesive sediments (usually clays and some silts) are considered to be depositional if the bed shear stress exerted by the flow is less than a critical value τ_d. When that value occurs, the deposition rate is given by Krone's (1962) equation

$$S = \begin{cases} -\dfrac{2V_s}{h} C \left(1 - \dfrac{\tau}{\tau_d}\right) & \text{for } C < C_c \quad \text{(A20)} \\ \\ -\dfrac{2V_s}{hC_c^{4/3}} C^{5/3} \left(1 - \dfrac{\tau}{\tau_d}\right) & \text{for } C > C_c \quad \text{(A21)} \end{cases}$$

where

S = source term

V_s = fall velocity of a sediment particle

h = flow depth

C = sediment concentration in water column

τ = bed shear stress

τ_d = critical shear stress for deposition

C_c = critical concentration = 300 mg/ℓ

30. If the bed shear stress is greater than the critical value for particle erosion τ_e, material is removed from the bed. The source term is then computed by Ariathurai's (Ariathurai, MacArthur, and Krone 1977) adaptation of Partheniades' (1962) findings:

$$S = \frac{P}{h}\left(\frac{\tau}{\tau_e} - 1\right) \quad \text{for } \tau > \tau_e \tag{A22}$$

where P is the erosion rate constant, unless the shear stress is also greater than the critical value for mass erosion. When this value is exceeded, mass failure of a sediment layer occurs and

$$S = \frac{T_L P_L}{h \Delta t} \quad \text{for } \tau > \tau_s \tag{A23}$$

where

T_L = thickness of the failed layer

P_L = density of the failed layer

Δt = time interval over which failure occurs

τ_s = bulk shear strength of the layer

31. The cohesive sediment bed consists of 1 to 10 layers, each with a distinct density and erosion resistance. The layers consolidate with overburden and time.

Bed shear stress

32. Bed shear stresses are calculated from the flow speed according to one of four optional equations: the smooth-wall log velocity profile or Manning equation for flows alone; and a smooth bed or rippled bed equation for combined currents and wind waves. Shear stresses are calculated using the shear velocity concept where

$$\tau_b = \rho u_*^2 \tag{A24}$$

where

τ_b = bed shear stress

u_* = shear velocity

and the shear velocity is calculated by one of four methods:

a. Smooth-wall log velocity profiles

$$\frac{\bar{u}}{u_*} = 5.75 \log \left(3.32 \frac{u_* h}{\nu} \right) \tag{A25}$$

which is applicable to the lower 15 percent of the boundary layer when

$$\frac{u_* h}{\nu} > 30$$

where $\bar{u}$ is the mean flow velocity (resultant of u and v components)

b. The Manning shear stress equation

$$u_* = \frac{(\bar{u}n)\sqrt{g}}{CME\ (h)^{1/6}} \tag{A26}$$

where CME is a coefficient of 1 for SI (metric) units and 1.486 for non-SI units of measurement.

c. A Jonsson-type equation for surface shear stress (plane beds) caused by waves and currents

$$u_* = \sqrt{\frac{1}{2}\left(\frac{f_w u_{om} + f_c \bar{u}}{u_{om} + \bar{u}}\right)\left(\bar{u} + u_{om}\right)^2} \tag{A27}$$

where

f_w = shear stress coefficient for waves

u_{om} = maximum orbital velocity of waves

f_c = shear stress coefficient for currents

d. A Bijker-type equation for total shear stress caused by waves and current

$$u_* = \sqrt{\frac{1}{2} f_c \bar{u}^2 + \frac{1}{4} f_w u_{om}^2} \tag{A28}$$

Solution method

33. Equation A5 is solved by the finite element method using Galerkin weighted residuals. Like RMA-2V, which uses the same general solution technique, elements are quadrilateral and may have parabolic sides. Shape functions are quadratic. Integration in space is Gaussian. Time-stepping is

performed by a Crank-Nicholson approach with a weighting factor (θ) of 0.66. A front-type solver similar to that is RMA-2V is used to solve the simultaneous equations.

REFERENCES

Ackers, P., and White, W. R. 1973. (Nov). "Sediment Transport: New Approach and Analysis," Journal, Hydraulics Division, American Society of Civil Engineers, No. HY-11.

Ariathurai, R., MacArthur, R. D., and Krone, R. C. 1977 (Oct). "Mathematical Model of Estuarial Sediment Transport," Technical Report D-77-12, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Krone, R. B. 1962. "Flume Studies of Transport of Sediment in Estuarial Shoaling Processes," Final Report, Hydraulics Engineering Research Laboratory, University of California, Berkeley, CA.

Norton, W. R., and King, I. P. 1977 (Feb). "Operating Instructions for the Computer Program RMA-2V," Resource Management Associates, Lafayette, CA.

Partheniades, E. 1962. "A Study of Erosion and Deposition of Cohesive Soils in Salt Water," Ph.D. Dissertation, University of California, Berkeley, CA.

Swart, D. H. 1976 (Sep). "Coastal Sediment Transport, Computation of Longshore Transport," R968, Part 1, Delft Hydraulics Laboratory, The Netherlands.

Thomas, W. A., and McAnally, W. H., Jr. 1985 (Aug). "User's Manual for the Generalized Computer Program System; Open-Channel Flow and Sedimentation, TABS-2, Main Text and Appendices A through O," Instruction Report HL-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

White, W. R., Milli, H., and Crabbe, A. D. 1975. "Sediment Transport Theories: An Appraisal of Available Methods," Report Int 119, Vols 1 and 2, Hydraulics Research Station, Wallingford, England.