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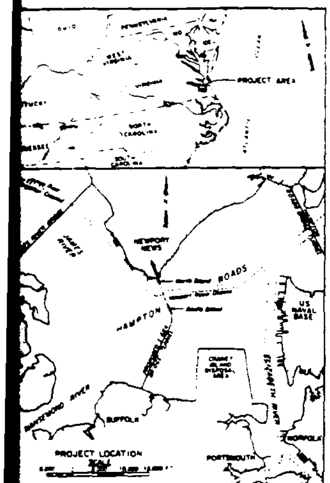

I-664 BRIDGE-TUNNEL STUDY, VIRGINIA SEDIMENTATION AND CIRCULATION INVESTIGATION

by

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This report presents results from physical and numerical model tests on the effects of the proposed I-664 James River Bridge-Tunnel complex on (a) sedimentation in the federally maintained channels (Newport News, Norfolk Harbor, and Elizabeth River); (b) general sedimentation in the lower James River; (c) changes in overall flushing characteristics; and (d) changes in current velocities and flushing near the Craney Island disposal site.

The navigation channel sedimentation was evaluated using the TABS-2 finite element numerical models RMA-2V for hydrodynamics and STUDH for sedimentation with an existing numerical mesh of the Elizabeth River and lower James River areas. For the general sedimentation investigation, a new numerical mesh was created and the same numerical models, RMA-2V and STUDH, were used. Data for the flushing and currents evaluation were provided by the Virginia Institute of Marine Science.

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Results from the physical model tests indicate circulation changes will be localized with minimal effects on the general circulation of the lower James River.

Results from the numerical sedimentation modeling indicate that sedimentation will be generally unchanged or reduced except on either side of the north island where increases can be expected. The areas experiencing unchanged or slightly reduced sedimentation rates include the oyster grounds, the Elizabeth River and Norfolk Harbor Channels, and the Newport News Channel.

PREFACE

In August 1983, the US Army Engineer Waterways Experiment Station (WES) was requested by the Norfolk District Corps of Engineers to conduct an investigation of the possible sedimentation changes in the federally maintained channels, general sedimentation in the lower James River, and changes in flushing near Craney Island caused by the proposed I-664 Bridge-Tunnel complex. This study was funded by the Federal Highway Administration and the Virginia Department of Highways and Transportation.

The study was conducted from August 1983 to August 1984 by personnel of the Hydraulics Laboratory, WES, under the general direction of Messrs. H. B. Simmons and F. A. Herrmann, Jr., former and present Chiefs of the Hydraulics Laboratory, respectively; R. A. Sager, Chief of the Estuaries Division; E. C. McNair, Chief of the Sedimentation Branch; and R. A. Boland, Chief of the Hydrodynamics Branch. The project was conducted by Messrs. S. B. Heltzel, M. J. Trawle, and R. F. Athow, Estuaries Division. Mr. Heltzel prepared this report. Mr. D. Stewart, Estuaries Division, also participated in this study. This report was edited by Information Technology Laboratory personnel Mrs. Beth Burris and Mrs. Marsha Gay with Mrs. Chris Habeeb coordinating the final layout.

Mr. J. R. Melchor, Norfolk District Corps of Engineers, made valuable contributions to this project.

Col Dwayne G, Lee, EN, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

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
acres	0.4047	hectares
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
miles (US nautical)	1.852	kilometres
miles (US statute)	1.609344	kilometres
square miles (US statute)	2.589998	square kilometres

I-664 BRIDGE-TUNNEL STUDY, VIRGINIA
SEDIMENTATION AND CIRCULATION INVESTIGATION

PART I: INTRODUCTION

The James River Estuary

Background

1. The James River is a narrow, funnel-shaped, shallow estuary with a mean low-water average depth of 12.1 ft.* Riverbed channels have an average depth of 32.8 ft. Some channel scour holes exceed 98.4 ft in depth. At Hampton Roads, where the James River becomes wider as the Elizabeth and Nansemond Rivers enter the estuary, the harbor deepens to about 59 ft with a channel dredged at its mouth. Figure 1 details the bathymetry of the James River estuary.

2. The James River, a partially mixed estuary of the Chesapeake Bay estuary system, drains the geological provinces of the Blue Ridge, the Piedmont, and the Coastal Plain of Virginia. The three major tributaries entering the James River are the north branch of the James River, with a drainage area of 6,757 square miles; the Appomattox River, which enters the James River at Hopewell, VA, with a drainage area of 1,344 square miles; and the Chickahominy River, which enters the James River along Hog Island, with a drainage area of 248 square miles (Nichols 1972). Minor tributaries include the Pagan, the Nansemond, the Elizabeth, and the Warwick Rivers. The three major tributaries have gaging stations and have recorded the following average discharges: the North James River, 7,098 cfs; the Appomattox River, 1,095 cfs; and the Chickahominy River, 247 cfs (Nichols 1972). Minor tributaries have not been gaged and are assumed to have comparatively low discharges.

Circulation**

3. During a mean tide, tidal currents vary from -1.15 to +1.48 fps from Newport News to Jamestown. Tidal currents reach their peak 3 hr after slack.

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

** Summarized from Nichols (1972).

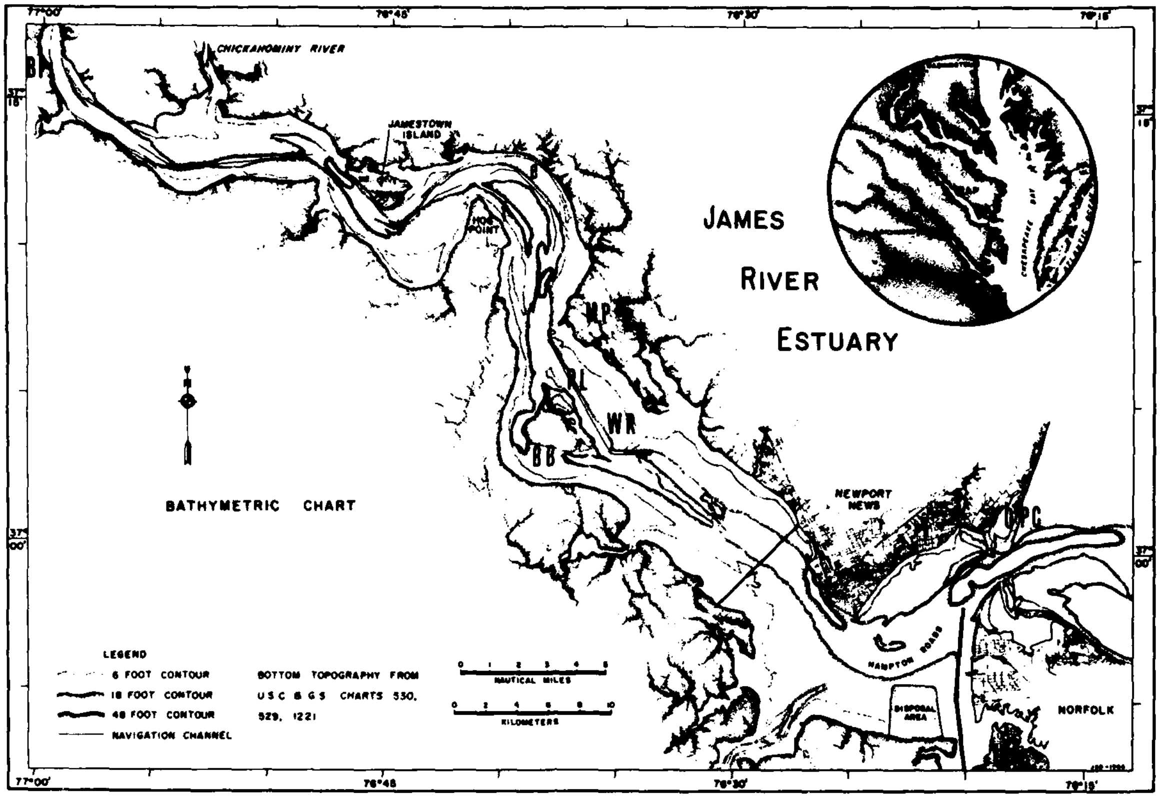


Figure 1. Bathymetric chart of the James River estuary, based on US Coast and Geodetic Survey charts 400 and 529. BP is Brandon Point; RL, Rocklanding Shoal Channel; WR, Wreck Shoal; BB, Burwell Bay; MP, Mulberry Point; OPC, Old Point Comfort; RAP, Rappahannock River; e, ebb channel; f, flood channel (Nichols 1972) (Originally published by the Geological Society of America as "Sediments of the James River Estuary, Virginia," by Maynard M. Nichols, in Environmental Framework of Coastal Plain Estuaries, Geological Society of America Memoir 133, pp 169-212)

There is a density circulation in the James River that is potentially important in transporting sediment up the estuary.

4. Salinity varies with distance downstream from 0 ppt at Richmond, VA, to 24 ppt at the mouth. High river inflow produces the greatest stratification in the upper estuary. The limit of saltwater intrusion varies from Hog Island, 24 miles above the mouth, during high river discharge to a location approximately 54 miles above the mouth during low discharge in the summer and fall.

5. The seasonal variations in river inflow change the estuary from moderately stratified to well mixed. At low river inflow, tidal mixing reduces stratification, producing a vertically homogeneous estuary. Figure 2 shows the distribution of surface salinity averaged over one to two tidal cycles or at slack water.

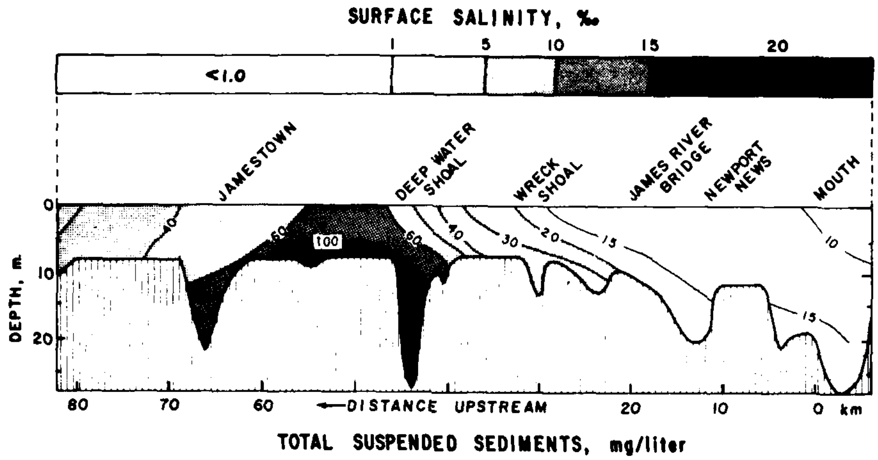


Figure 2. Distribution of total suspended sediment concentrations and surface salinity along the estuary channel, based on average values over one to two tidal cycles between 31 miles and the mouth, and on slack-water concentrations between 31 and 50 miles above mouth, 11-20 March 1965 (Nichols 1972) (Originally published by the Geological Society of America as "Sediments of the James River Estuary, Virginia," by Maynard M. Nichols, in Environmental Framework of Coastal Plain Estuaries, Geological Society of America Memoir 133, pp 169-212)

Sediment characteristics and distribution

6. Suspended sediment concentrations increase from an average of about 30 mg/ℓ above Jamestown to more than 100 mg/ℓ at the limit of saltwater intrusion (Deep Water Shoal). Concentrations decrease to 12 mg/ℓ at the mouth. Although concentrations vary during the tidal cycle, this overall pattern persists. Measured concentrations are low compared with other east coast estuaries. Figure 2 shows the distribution of total suspended sediment concentration averaged over one to two tidal cycles or at slack water.

7. The turbidity maximum is located at the upstream limit of salinity intrusion. This maximum persists most of the year, being most pronounced in the spring when river inflow is high and weak in the fall when inflow is low. Nichols (1972) reports the following: "Located close to or slightly upstream of the 0.5 ppt isohaline, the maximum shifts upstream with landward penetration of salt water from spring to fall. This trend indicates that the position and intensity of the maximum may be partly controlled by the inner limit of salt water and in turn by the magnitude of river inflow."

8. Nichols (1972) also states: "It is evident that about 20 percent of the suspended load remains in suspension at slack water, whereas the greater part is alternately suspended and settled out. These changes are not symmetrical about slack water or maximum current. Concentrations near the surface are slightly higher at the end of ebb than at the end of flood, a trend ascribed to shifting of the longitudinal concentration gradient." Figure 3 shows patterns of deposition and erosion in the James River estuary.

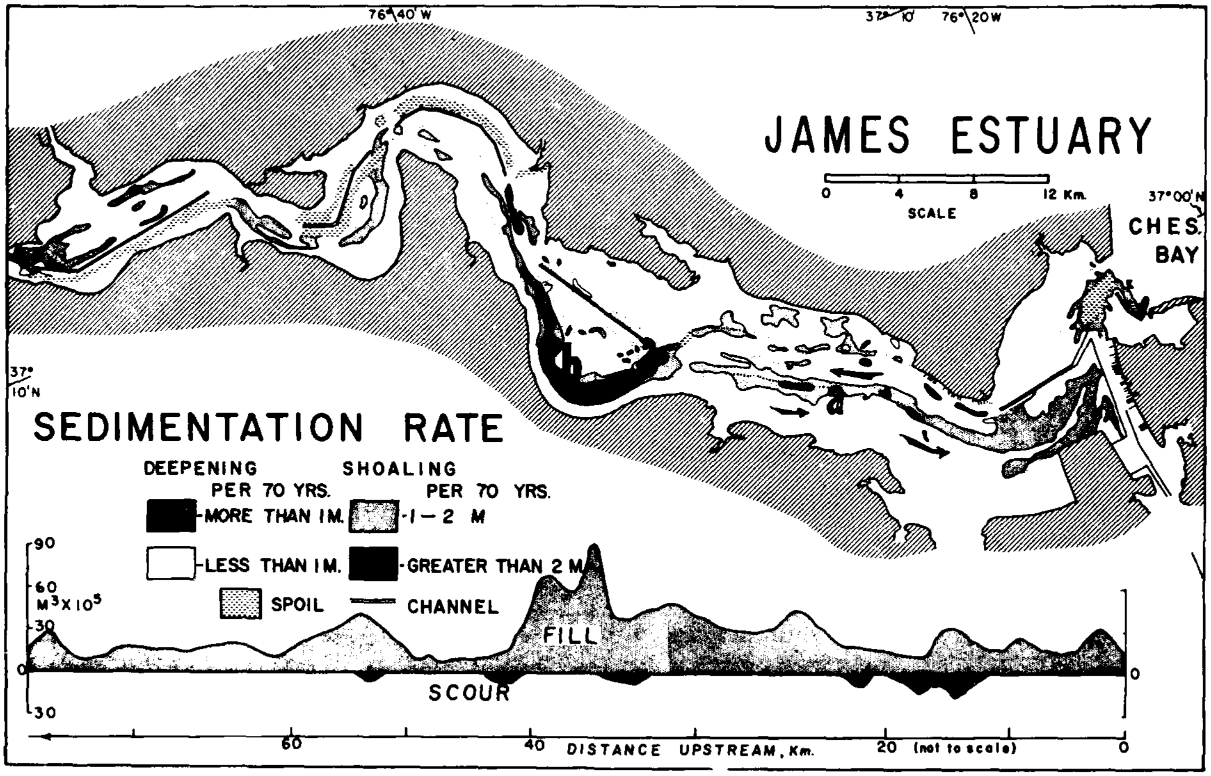


Figure 3. Patterns of deposition and erosion in James River estuary determined from depth changes over a 70-year period. Prominent zone of deposition (a) in the lower estuary; Burwell Bay (b), the main site of deposition. Dotted line is a 13-ft depth contour. Arrows represent direction of net flow along bottom (Nichols 1972) (Originally published by the Geological Society of America as "Sediments of the James River Estuary, Virginia," by Maynard M. Nichols, in Environmental Framework of Coastal Plain Estuaries, Geological Society of America Memoir 133, pp 169-212)

Scope

9. The navigation channel sedimentation was to be studied using the Elizabeth River/lower James River numerical mesh developed for the Norfolk

Harbor and channels deepening study (Berger et al. 1985). A new mesh was developed for the general sedimentation study. Data for the circulation study were provided by the Virginia Institute of Marine Science (VIMS) (Fang et al. 1972) from a 1972 VIMS study of the proposed bridge-tunnel crossing conducted with the James River physical model at the US Army Engineer Waterways Experiment Station (WES).

Proposed Bridge-Tunnel Complex

10. The proposed I-664 Bridge-Tunnel complex consists of (a) two man-made islands, (b) a tunnel section connecting the two islands, and (c) a bridge portion connecting the south island and the south shore. Figure 4 shows the location of the bridge-tunnel complex.

Purpose

11. The purpose of this study was to determine the effects of the proposed I-664 James River Bridge-Tunnel complex on (a) sedimentation in the federally maintained channels (Newport News, Norfolk Harbor, and Elizabeth River), (b) general sedimentation in the lower James River (specifically those regions containing oyster and clamming beds), (c) changes in overall flushing characteristics, and (d) changes in current velocities and flushing near the Craney Island disposal site. Items (a) and (b) were to be numerical model studies and items (c) and (d) were to be desk studies.

12. Tests involving the impact of the proposed I-664 Bridge-Tunnel complex on wave conditions in the Newport News Small-Boat Harbor were investigated at WES and are reported in Bottin (1984).

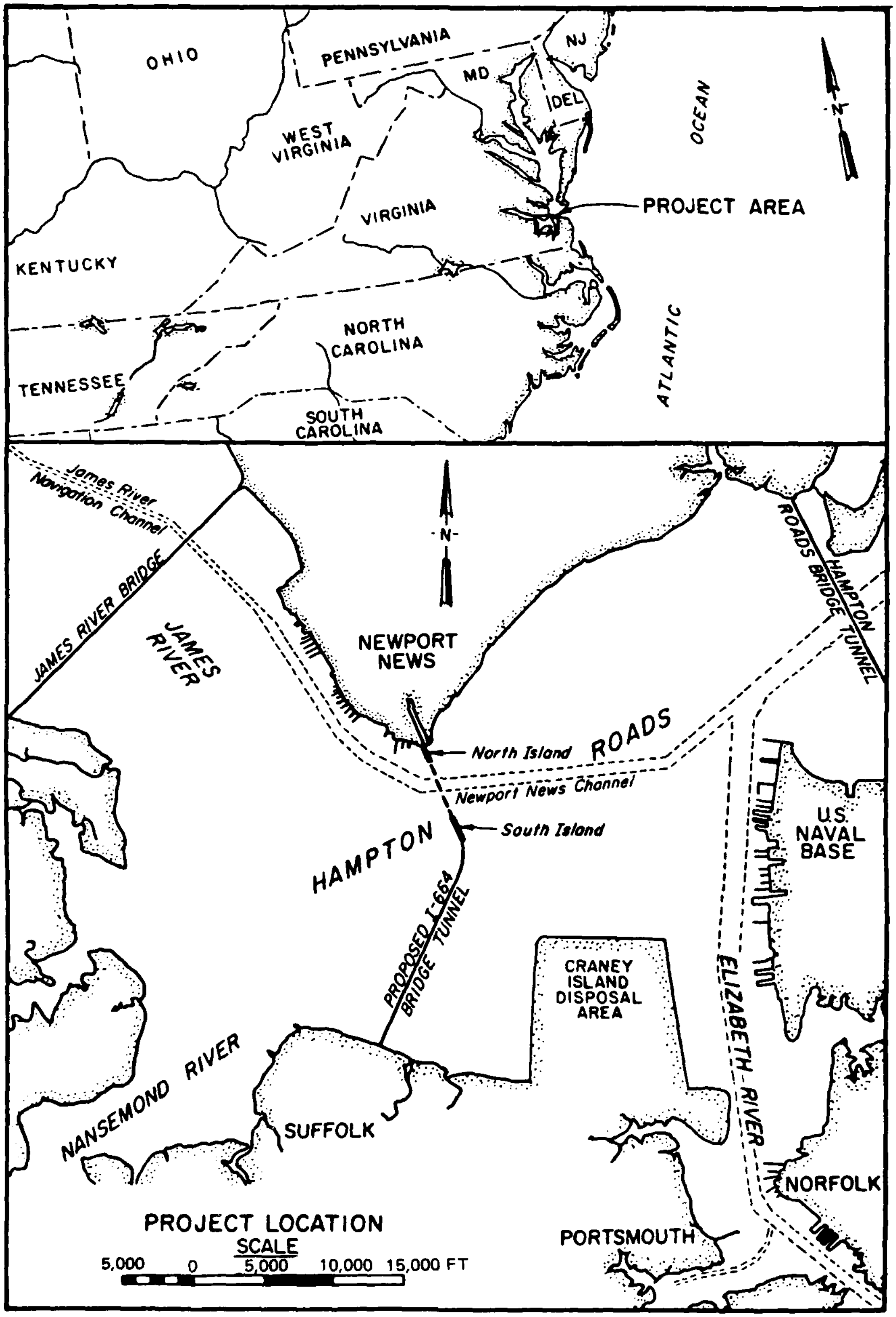


Figure 4. I-664 crossing of Hampton Roads

PART II: THE MODELS

James River Physical Model

13. The 1972 VIMS study (Fang et al. 1972) was conducted in the existing James River model, which reproduces the entire James River estuary, a portion of lower Chesapeake Bay, and about 200 square miles of the Atlantic Ocean as shown in Figure 5. The tidal portions of all major tributary streams were reproduced, including the Elizabeth, Nansemond, Pagan, Warwick, Chickahominy, and Appomattox Rivers. The model is about 550 ft long and 130 ft wide at the widest point.

14. Since gravitational forces are predominant in tidal flows, it can be determined that the model and prototype Froude numbers F must be equal. Therefore

$$\frac{V_m^2}{g_m L_m} = \frac{V_p^2}{g_p L_p} \tag{1}$$

where

$V^2/(gL)$ = Froude number
V = velocity of flow
g = acceleration of gravity
L = length dimension
m,p = subscripts indicating model and prototype, respectively

Geometric scales of the model are 1:1,000 horizontally and 1:100 vertically, reflecting a geometric distortion ratio of 10:1. These dimensions and Froude model laws defined the following model-to-prototype ratios:

Characteristic	Scale Relations Model:Prototype
Time	1:100
Velocity	1:10
Volume	1:100,000,000
Discharge	1:1,000,000

The model-to-prototype ratio for salinity is 1:1.

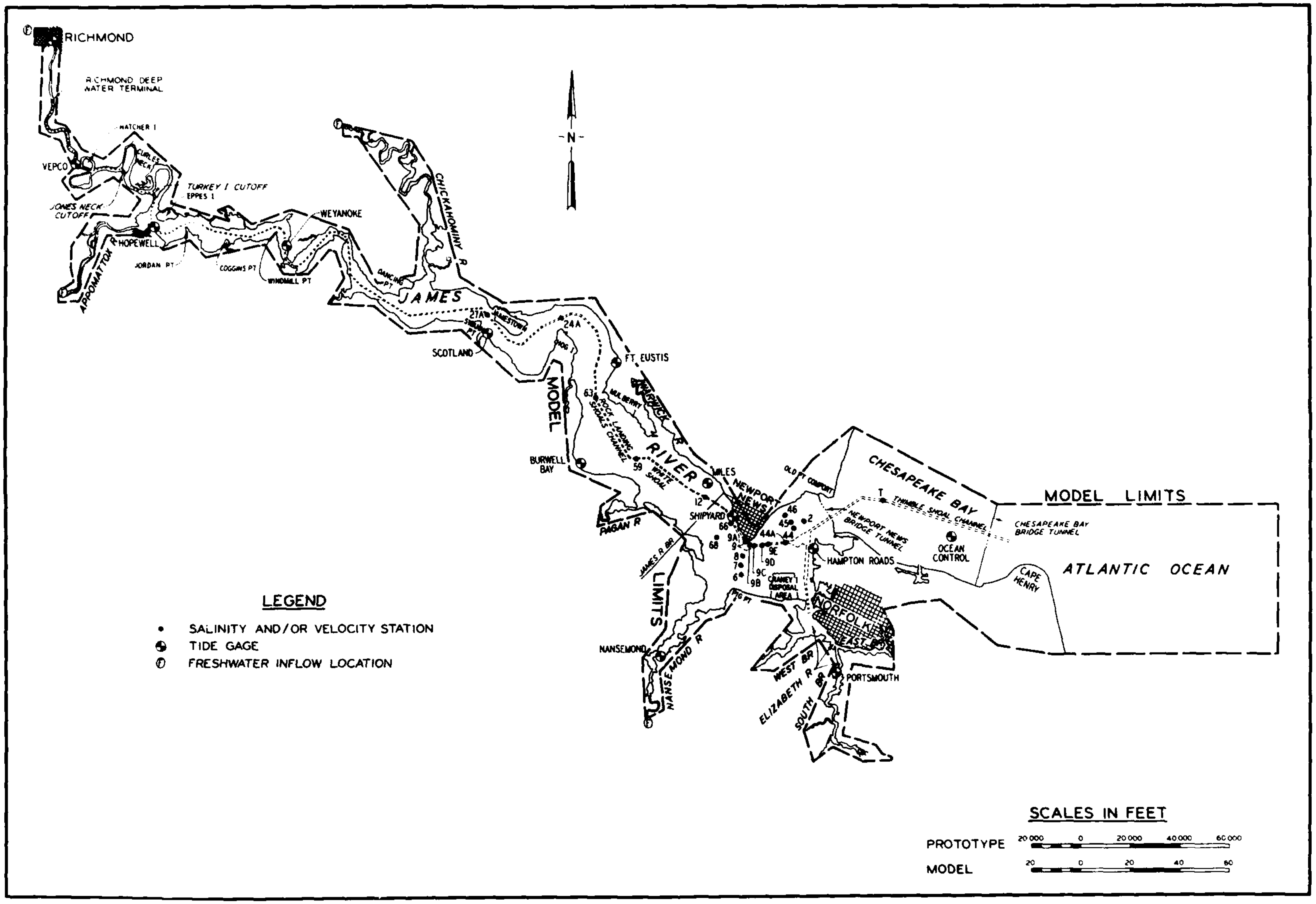


Figure 5. James River physical model limits

Chesapeake Bay Physical Model

15. The physical model of Chesapeake Bay is located on Kent Island in Matapeake, MD. It is an 8.6-acre, fixed-bed model. The area reproduced in the model extends from approximately 30 miles offshore in the Atlantic Ocean to the heads of tide for all tributaries emptying into the Chesapeake. The entire length of the Chesapeake and Delaware (C&D) Canal and a portion of Delaware Bay are also modeled. Overbank geometry is reproduced to the +20-ft contour. Model limits are shown in Figure 6.

16. The model-to-prototype scale ratios are the same for this model as for the model of the James River.

The Numerical Models

17. The finite element hydrodynamic model RMA-2V was used in both the navigation channel sedimentation study and the general sedimentation study. The finite element transport model STUDH, operating in a noncohesive sediment mode, was used in the navigation channel sedimentation study to evaluate changes in shoaling in the federally maintained channels. The cohesive sediment mode was used in the navigation channel sedimentation study to evaluate changes in shoaling in the Elizabeth River and in the general sedimentation study. RMA-2V and STUDH are components of the TABS-2 numerical modeling system, the following description of which was taken from McAnally et al. (1983) and Thomas and McAnally (1985).

Finite element mesh generation

18. The finite element models RMA-2V and STUDH require that a representation of the area to be studied be put in a digital form. This representation is in the form of a set of computational points that have been located with respect to a reference system. These computational points, called nodes, are assigned sequential numbers and bed elevations. The nodes are connected to one another by lines that create either triangular or quadrilateral elements. The nodes midway between corners are called midside nodes.

The hydrodynamic model, RMA-2V

19. The hydrodynamic model, RMA-2V, solves the depth-integrated equations of fluid mass and momentum conservation in two horizontal directions. The present model, an improvement of an earlier version, RMA-2 (Norton and

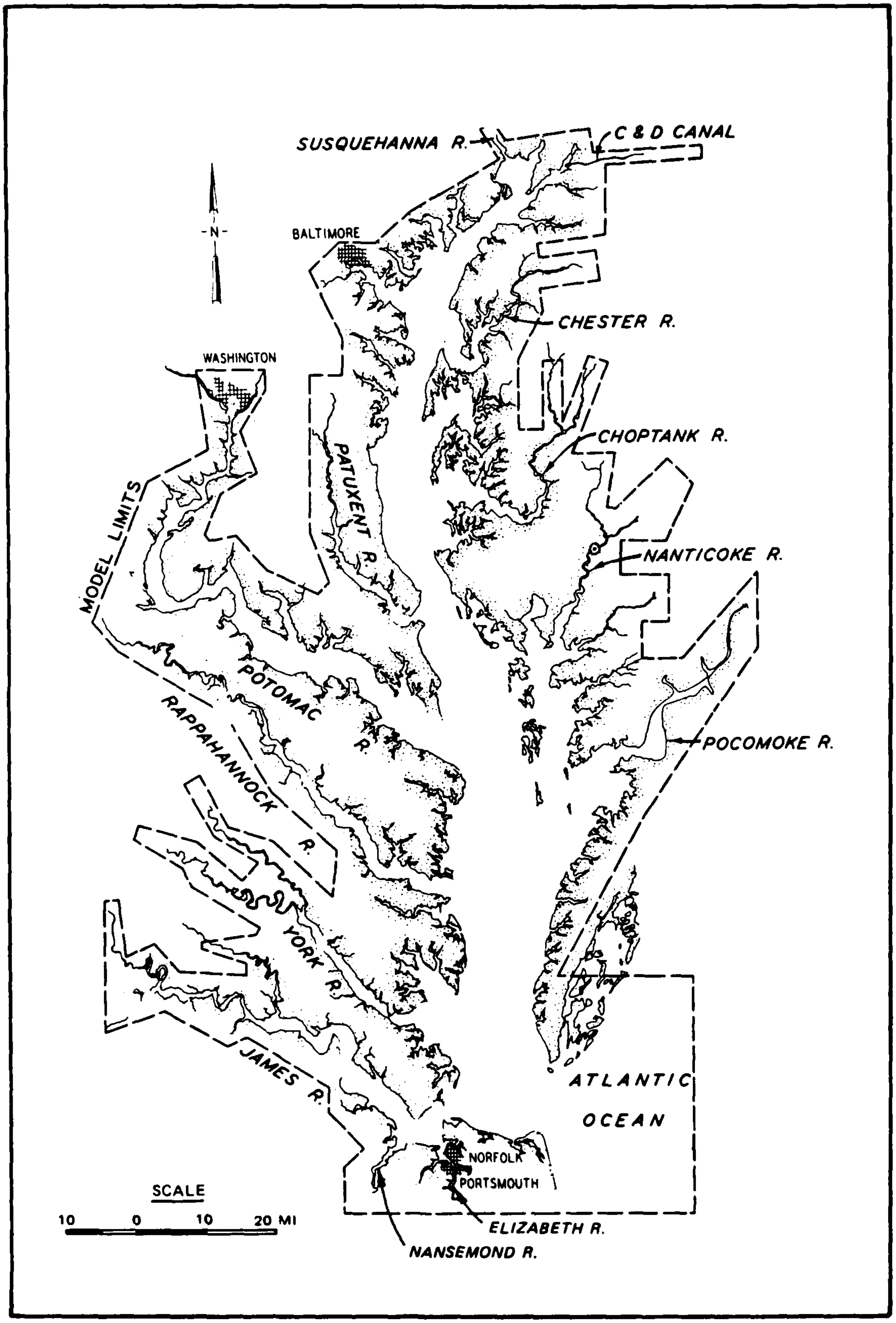


Figure 6. Chesapeake Bay physical model limits

King 1977), is formulated in terms of velocities and turbulent exchange coefficients.

20. The finite element method using the method of weighted residuals is used to solve the conservation of mass and momentum equations. Individual elements may be either quadrilaterals or triangles and may have curved (parabolic) sides. 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.

21. The finite element solution is fully implicit and a set of simultaneous equations is solved by Newton-Raphson iteration. The solution is achieved using a front-type matrix solver that assembles a portion of the matrix and solves that portion 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.

The sediment transport model, STUDH

22. Convection-diffusion equation. The sediment transport model, STUDH, solves the depth-integrated convection-diffusion equation in two horizontal dimensions for a single sediment constituent. The form of the solved equation is

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + w\frac{\partial C}{\partial z} = \frac{\partial}{\partial x}\left(D_x \frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial z}\left(D_z \frac{\partial C}{\partial z}\right) + \alpha_1 C + \alpha_2 \qquad (2)$$

where

C = concentration of sediment, kg/m^3

t = time, sec

u = flow velocity in x-direction, m/sec

x = primary flow direction, m

w = flow velocity in z-direction, m/sec

z = direction perpendicular to x, m

D_x = effective diffusion coefficient in x-direction, m^2/sec

D_z = effective diffusion coefficient in z-direction, m^2/sec

α_1 = coefficient for concentration-dependent source/sink term, 1/sec

α_2 = coefficient of source/sink term, $kg/m^3/sec$

23. Bed shear stress. The bed shear stress, τ_b, takes the form:

$$\tau_b = \rho u_*^2 \quad (3)$$

where

ρ = water density

u_* = shear velocity

24. Manning shear stress equation. The Manning form of the shear stress equation was used in this study:

$$u_* = \frac{un\left(g^{1/2}\right)}{CME\left(D^{1/6}\right)} \quad (4)$$

where

u = flow velocity

n = Manning's roughness coefficient

g = acceleration due to gravity

CME = coefficient of 1 for SI units and 1.486 for non-SI units

D = flow depth

25. Sand transport. This supply of sediment to and from the bed for noncohesive bed material (sand) is controlled by the transport potential of the flow and the availability of material in the bed. The bed source term is calculated by

$$S = \frac{Ceq - C}{t_c} \quad (5)$$

where

S = source term

Ceq = equilibrium concentration

t_c = characteristic time for effecting the transition

26. The value of Ceq can be determined from any of several transport relations. The sand version of STUDH uses the Ackers-White formula (1973), which performed satisfactorily in tests by WES and others (White, Milli, and Crabbe 1975; Swart 1976).

27. Clay transport. Deposition rates for clay beds were calculated with the equations of Krone (1962):

$$S = \begin{cases} \dfrac{-2V_s}{D} C \left(1 - \dfrac{\tau_b}{\tau_d}\right) & \text{for} \quad C < C_c \quad (6) \\ \\ \dfrac{-2V_k}{D} C^{5/3} \left(1 - \dfrac{\tau_b}{\tau_d}\right) & \text{for} \quad C > C_c \quad (7) \end{cases}$$

where

V_s = fall velocity of a single particle

τ_d = critical shear stress for deposition

C_c = critical concentration = 300 mg/ℓ

$V_k = V_s/C_c^{4/3}$

28. Erosion rates were computed by Ariathurai's equation (Ariathurai, MacArthur, and Krone 1977) for particle-by-particle erosion. The source term is computed by

$$S = \frac{P}{D} \left(\frac{\tau_b}{\tau_e} - 1\right) \quad (8)$$

where

P = erosion rate constant

τ_e = critical shear stress for particle erosion

29. STUDH is a descendent of the model SEDIMENT II (Ariathurai, MacArthur, and Krone 1977) developed under the direction of R. B. Krone at the University of California, Davis.

PART III: MODELING PROCEDURES

Circulation

30. The primary source of information for this portion of the study is the 1972 VIMS study (Fang et al. 1972) on the proposed bridge-tunnel crossing. The study was conducted in the James River hydraulic model at WES from 15 to 30 May 1972. The purpose of the hydraulic model study was to determine the effects of the proposed I-664 river crossing structures on the tides, currents, and distribution of salinity and sediments in the reach between Old Point Comfort and the existing James River Bridge. In addition to the existing (base) conditions, two basic configurations were considered. The first was the base configuration plus the new islands for the I-664 Hampton Roads Bridge-Tunnel crossing (Plan 1A) and the second James River Bridge crossing. The second configuration was identical with the first, but added a westward triangular extension of the Craney Island disposal area (Plan 1B).

Physical model operating conditions

31. Throughout the series of model tests, the freshwater inflow at Richmond, VA, was maintained at 7,500 cfs, which is the average yearly freshwater flow. The total freshwater inflow from the Appomattox, Chickahominy, and other tributaries was 2,000 cfs. The model was operated with a mean tide, and the tidal gage near Thimble Shoal was used as the control gage. The Chesapeake Bay salinity was maintained at 24.2 ppt. These particular boundary conditions correspond to a Condition 4 run in the Chesapeake Bay physical model for the Norfolk Harbor and channels deepening study (Richards and Morton 1983) and can be compared to those data.

Data collected

32. Table 1 summarizes what data were obtained by VIMS for the base and Plan 1A. These data included velocity and salinity measurements taken at surface (S), middepth (M), and bottom (B). Figures 7-10 show the locations of the stations sampled with the number of depths sampled. Locations of the tidal height stations are also shown. All data were collected half-hourly over a tidal cycle.

Data collection procedure

33. Tidal heights were measured for three tidal cycles at three tide gage stations: Hampton Roads, which is located in Norfolk at the Navy

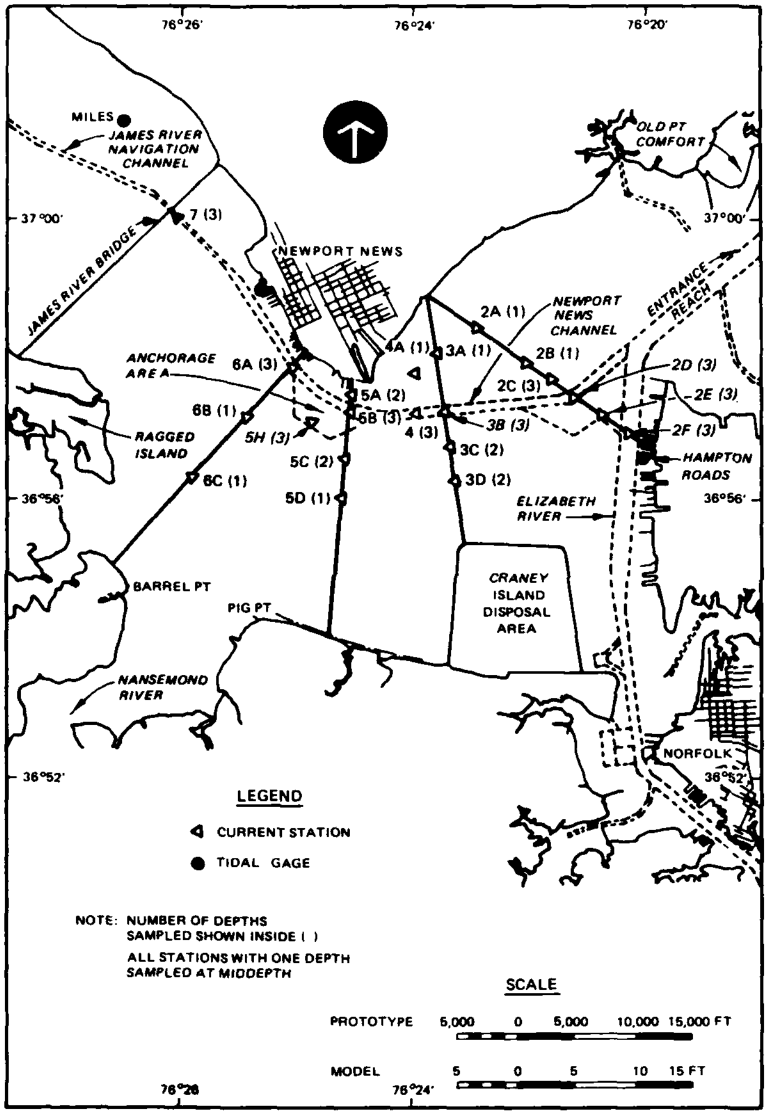


Figure 7. Current measuring station locations (base)

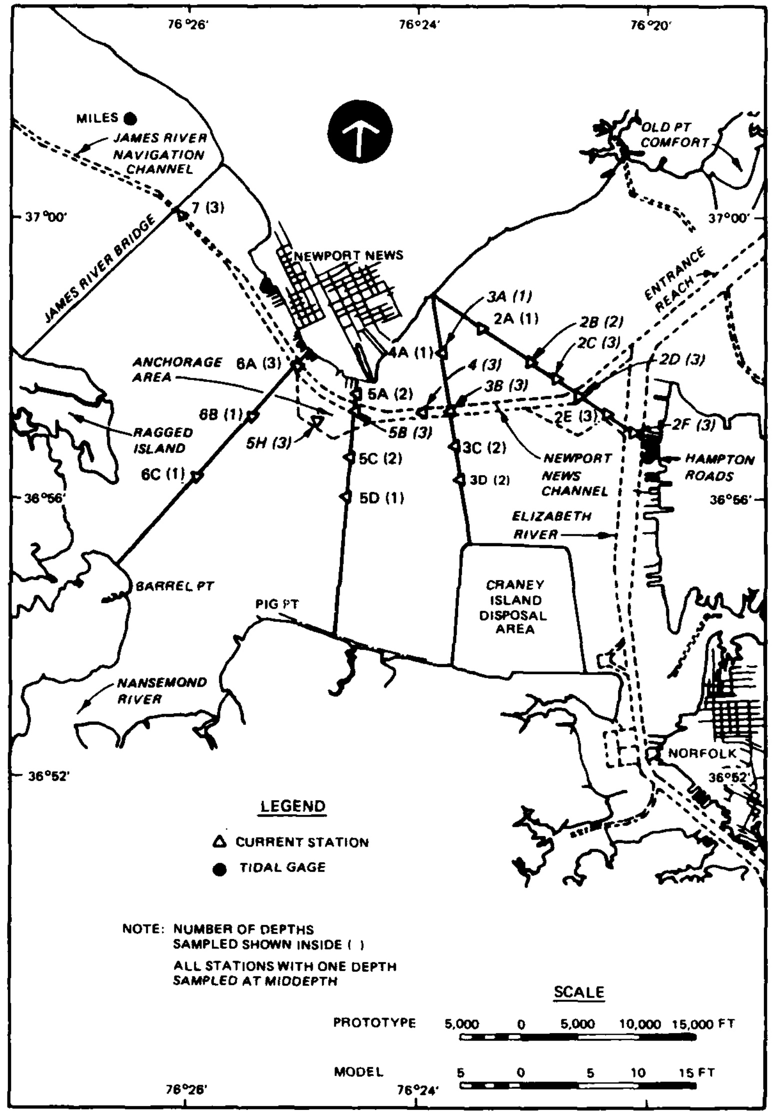


Figure 8. Current measuring station locations (Plan 1A)

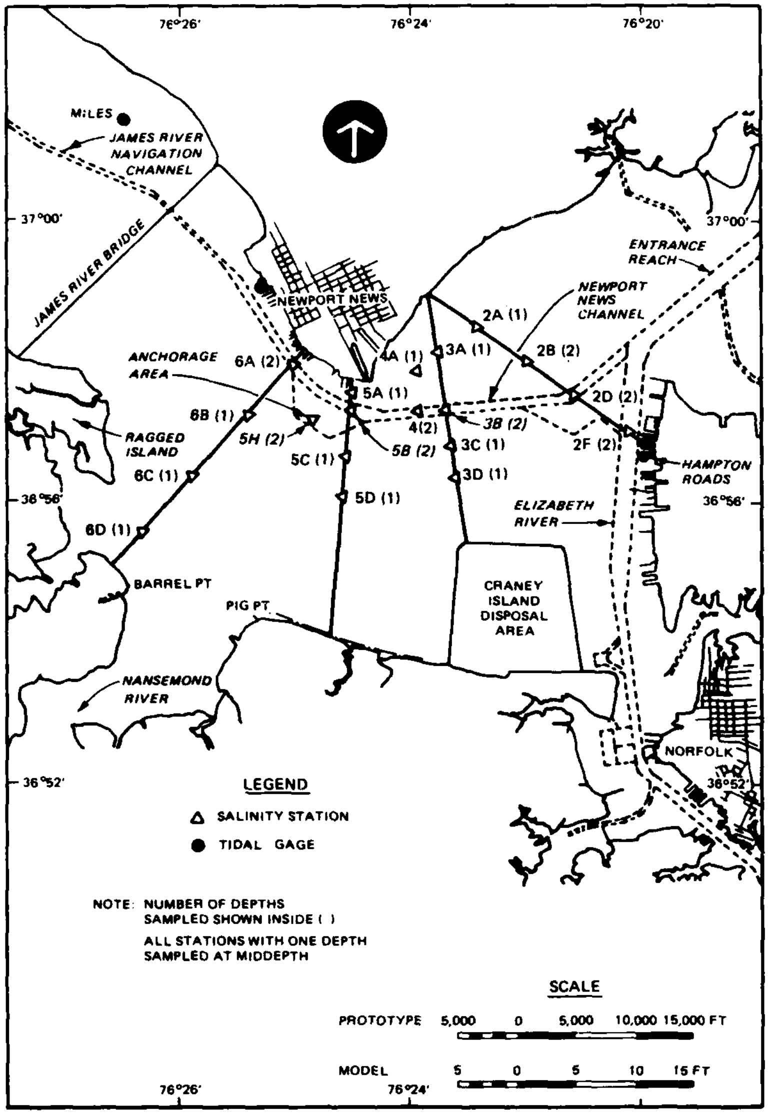


Figure 9. Salinity measuring station locations (base)

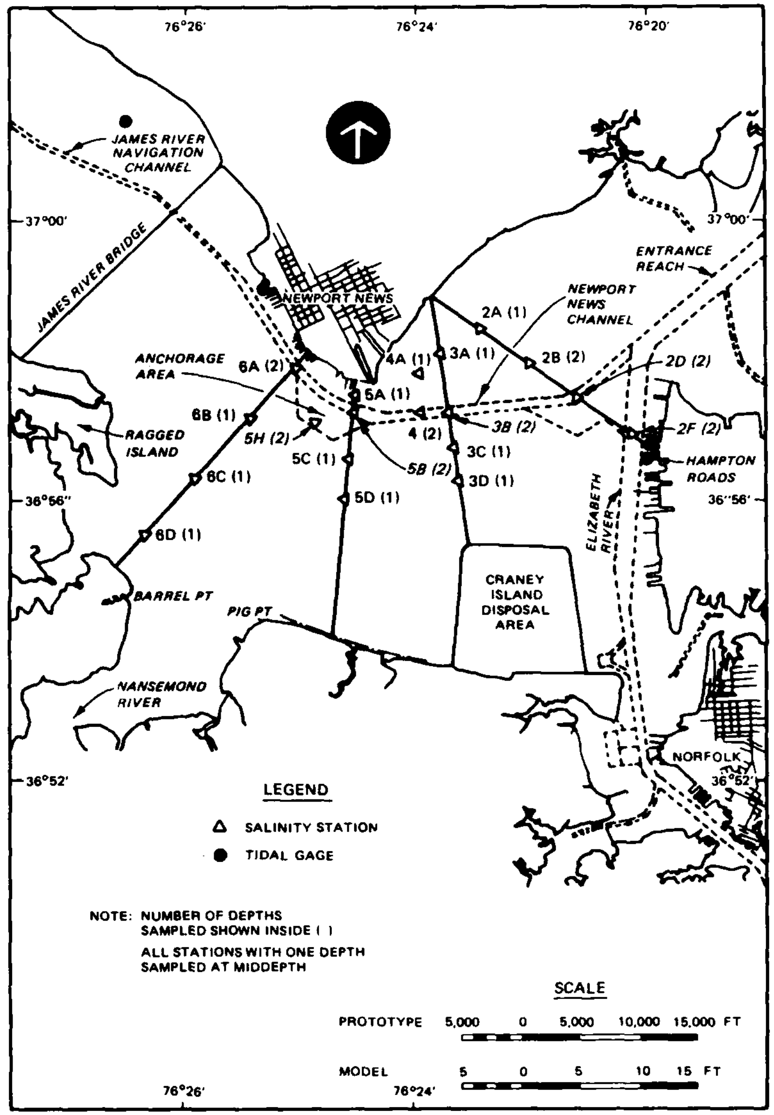


Figure 10. Salinity measuring station locations (Plan 1A)

Shipyard on the Elizabeth River; Newport News Shipbuilding and Dry Dock in Newport News; and Miles, which is located just upstream from the James River Bridge on the Newport News side of the channel.

34. In the VIMS study, a simple technique was devised to measure the current directions. Direction rosettes were placed on the model floor underneath the current meters and a piece of thread was attached to the rear of the meter bracket. The thread trailing behind the meter indicated the current direction. Fang et al. (1972) indicate that at most stations where the current direction did not vary widely and frequently, the direction reading could be accurate to ±15 deg.

35. Surface current photographs were also taken consisting of time exposures of confetti moving along the water surface. Actual current magnitudes can be measured from the photographs, which were taken hourly during the tidal cycle. Figure 11 shows the area over which the surface current photographs were taken.

Analysis of data

36. To analyze the surface current photographs, a sample grid (Figure 12) was established to allow for consistent reading of point values. This grid was then placed over each photograph, and the current magnitudes were determined for each location and compared with the base conditions (before the structures were included in the model).

37. At Range 3 (Figure 7), hourly discharge calculations were made to determine the changes in the tidal prism and residence time upstream of the range. Base and plan data at other stations were compared to the Range 3 data for an estimate of changes caused by the bridge.

Navigation Channel Sedimentation

Grid evolution

38. The numerical model mesh to study the navigation channel sedimentation was a modified version of the mesh used to study Elizabeth River shoaling for the Norfolk Harbor and channels deepening study (Berger et al. 1985). The Elizabeth River mesh contained 1,496 computational nodes and 407 elements. This mesh was revised to include a representation of the I-664 Bridge-Tunnel complex. Details for the alignment of the bridge/tunnel used in this mesh were provided by the Virginia Department of Transportation. This alignment

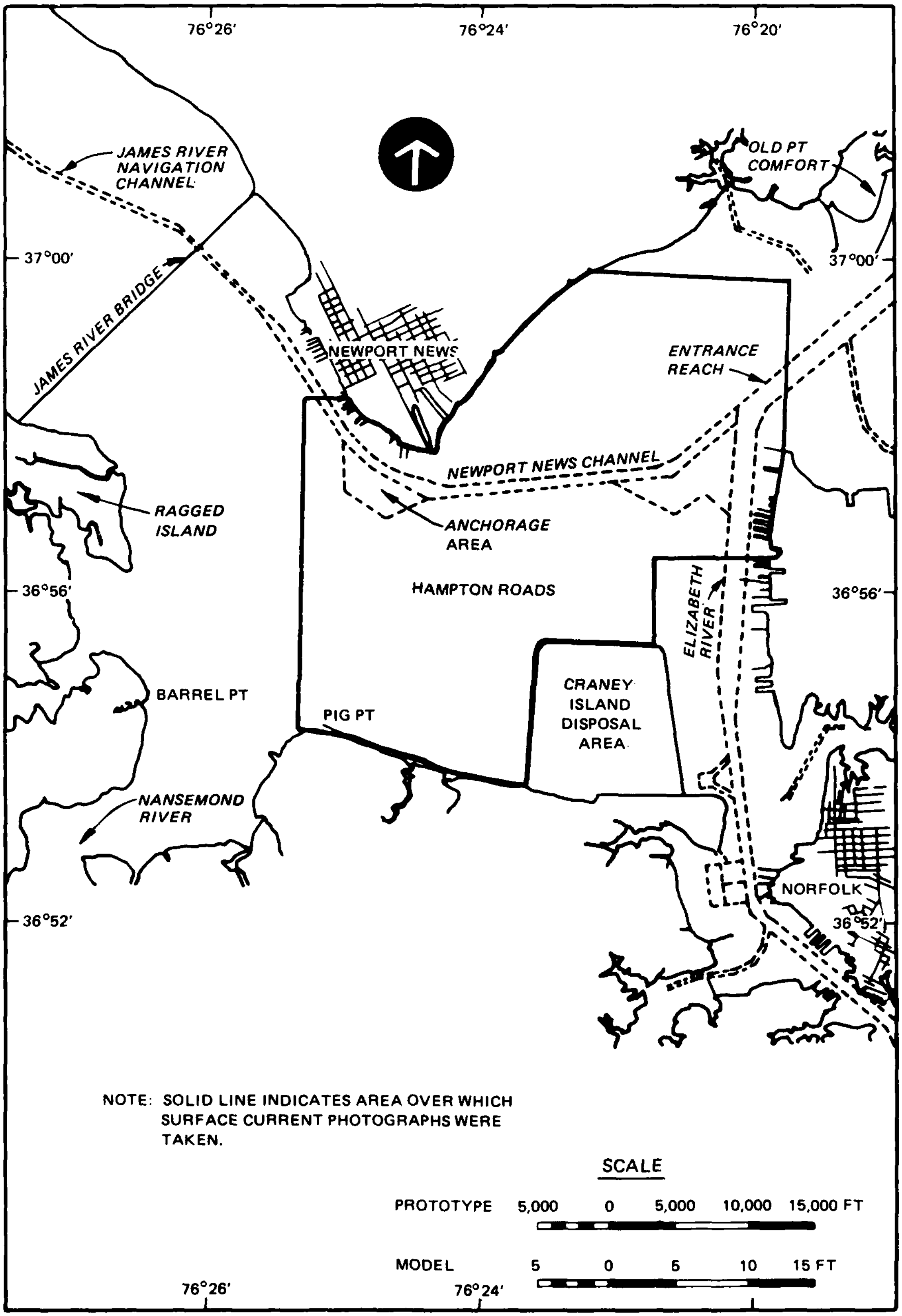


Figure 11. Surface current photograph coverage

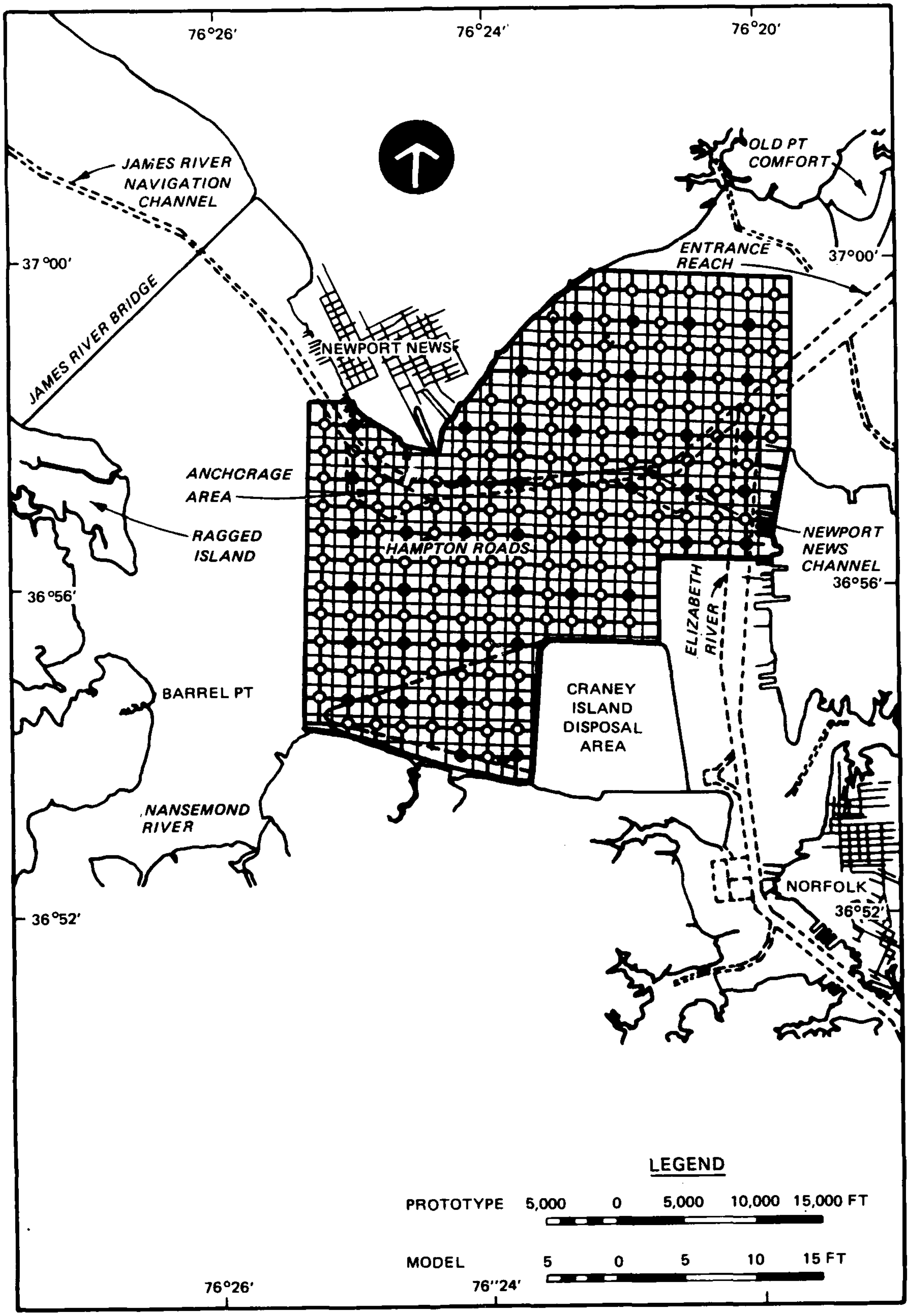


Figure 12. Surface current photograph comparison grid, 48 locations

was similar to Plan 1A but not identical to it. The revised mesh contained 1,582 computational nodes and 436 elements. Figure 13 is the numerical model mesh used in this portion of the study.

Hydrodynamic modeling procedures

39. The hydrodynamic base condition runs developed for the mesh used to study Elizabeth River shoaling for the Norfolk Harbor and channels deepening study (Berger et al. 1985) were used as the base conditions to study sedimentation in the navigation channels. To simulate the I-664 Bridge and islands, the friction coefficient was adjusted for those elements that represented the islands and bridge. This change caused the two islands to block the flow of water and the bridge to restrict the flow of water. Numerical model parameters established for the original mesh at other locations were not changed. Therefore it was not necessary to reverify this mesh.

40. The hydrodynamic plan condition runs were then made using the modified grid. The four sets of boundary conditions established for the hydrodynamic base condition runs (see paragraphs 51-53) were used for the plan runs.

Sedimentation modeling procedures

41. Cohesive. To determine the effects of the I-664 Bridge-Tunnel complex on the shoaling in the Elizabeth River and Norfolk Harbor Channels, the sediment model was used with cohesive sediment calculations. Since the base condition had been run for the Norfolk Harbor and channels deepening study (Berger et al. 1985), those results were used directly. For the plan runs, the hydrodynamic results for the revised mesh were used. The various model parameters established during adjustment of the sediment model used for the Norfolk Harbor and channels deepening study were used for these plan runs. This included sediment concentration boundary conditions. Results from these runs were compared with the Norfolk Harbor and channels deepening study plan runs and the verification was found to be intact.

42. Noncohesive. To determine the effects of the I-664 Bridge-Tunnel complex on shoaling in the Newport News Channel, the sediment model was used with noncohesive sediment calculations. The sediment model was run with the four sets of base and plan hydrodynamic input.

43. The length of the sedimentation model time-step selected was 1,800 sec (0.5 hr). This was small enough to prevent advection of sediment completely through an element during one time-step. The computational mesh

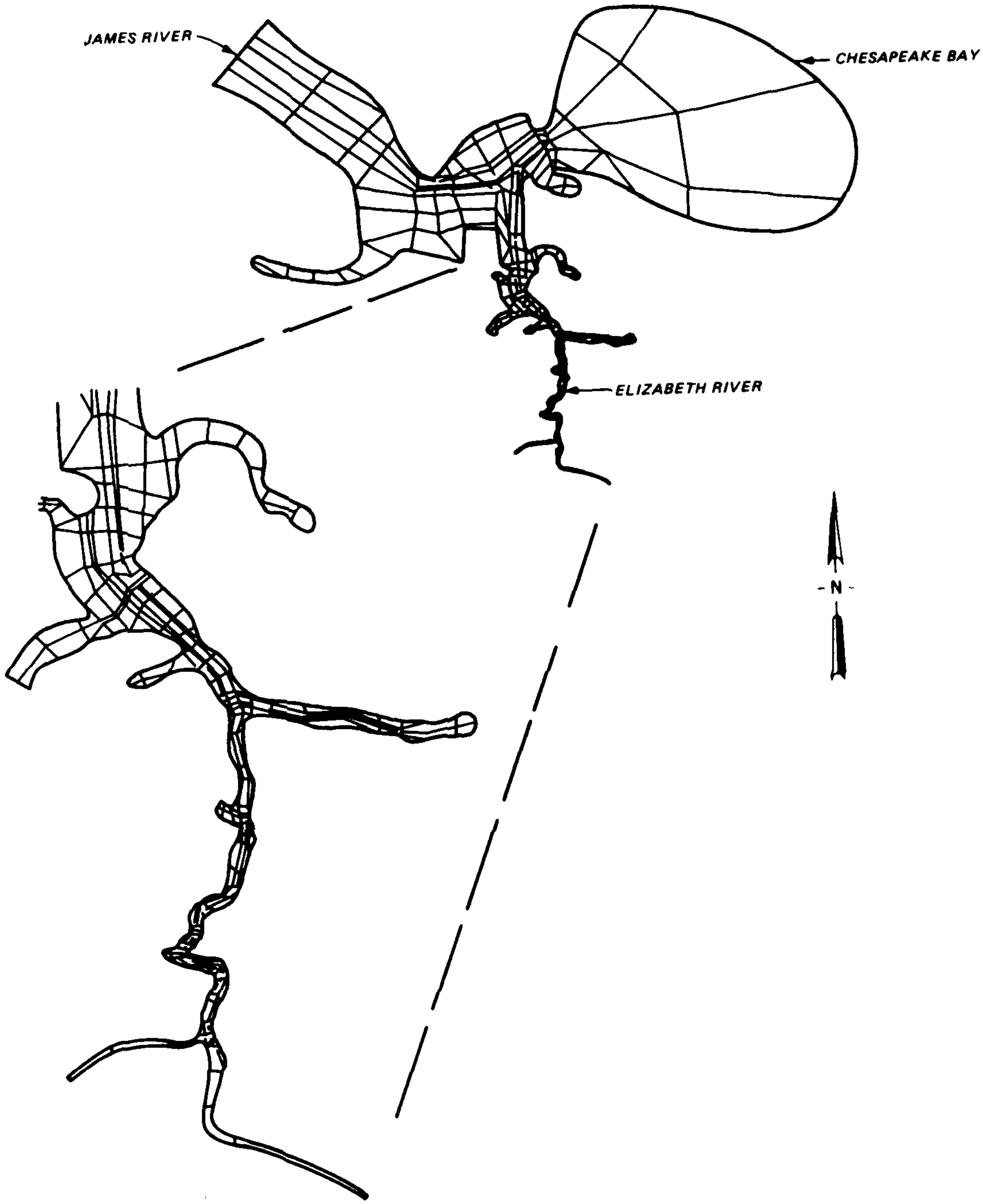


Figure 13. Channel sedimentation mesh

was identical with that of the hydrodynamic model. Other model parameters were generally as follows:

Parameter	Value
Crank-Nicholson implicitness factor	0.70
Manning's n roughness	0.017
Effective particle diameter for transport, mm	0.20
Effective settling velocity, m/sec	0.01
Boundary concentration, kg/m^3	0.008

44. This modeling effort was conducted assuming noncohesive sediment transport with the given effective particle diameter for transport as being coarse silt to very fine sand.

45. Analysis of prototype surveys during the period 1970-1977 indicated an average shoaling rate of about 0.04 ft/year in the Newport News Channel, i.e., a nearly stable channel. After minor adjustments, the noncohesive (sand) run of the numerical sediment model, STUDH, agreed well with the observed shoaling rate of about 0.04 ft/year.

46. Results from the four boundary condition runs were combined as described in Berger et al. (1985) and compared with the base. The sediment results from plans 1-4 were combined using the percentages in paragraph 66 and compared to the base results combined in the same way.

General Sedimentation

47. The lower James River contains valuable oyster beds that could be affected by the bridge-tunnel complex. Figure 14 shows the location of these oyster beds and clamming grounds. This figure is a composite of various location maps provided by the Norfolk District. The general sedimentation study was performed to specifically evaluate the sedimentation changes within the confines of the oyster beds and clamming grounds. Locations 4, 5, and 8 were not evaluated since these areas are not actively harvested.

Development of the numerical model mesh

48. The numerical model mesh was developed in two stages. The first mesh incorporated the general features of the study area. In the final mesh, the oyster grounds were resolved in greater detail and the bridge-tunnel was more accurately represented. The Nansemond River was crudely represented but did simulate the appropriate tidal prism volume. The final mesh contained

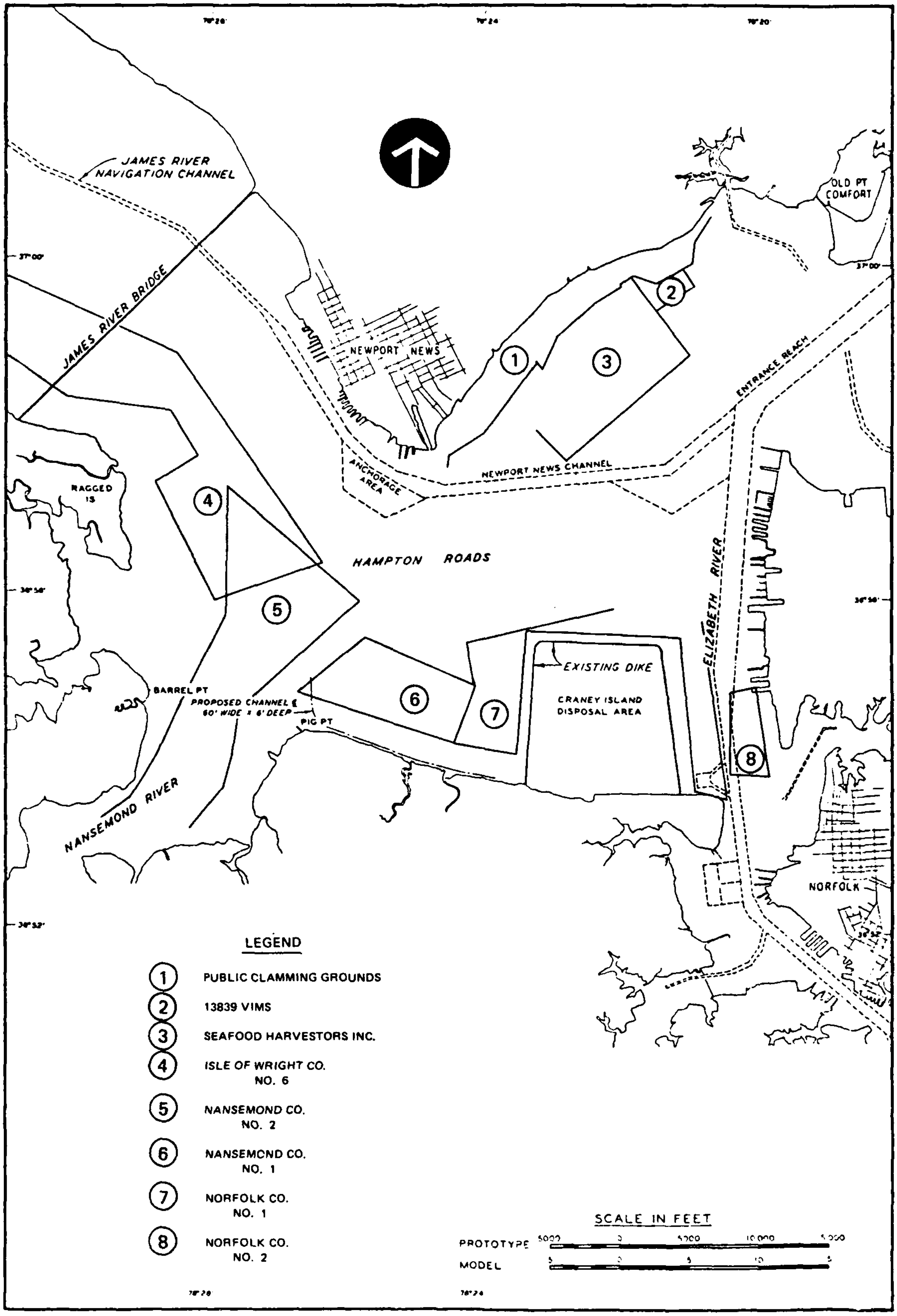


Figure 14. Oyster bed and clamming ground locations

1,493 nodes and 464 elements. Figure 15 shows the completed numerical mesh for this study.

49. Two National Ocean Survey (NOS) charts were used in the mesh development: 12222, Chesapeake Bay, Cape Charles to Norfolk Harbor, 23 January 1982; and 12248, James River, Newport News to Jamestown Island, 4 April 1981. These charts were also used to determine appropriate depths for each node. These depths were not always exact depths at nodes since some of the elements covered large variations in bathymetry. In these cases, a depth was chosen that provided the proper cross-sectional area.

50. The coordinates of all nodes were based on the Virginia State Grid System. The grid is located on the NOS charts.

Development of boundary data

51. The boundary control data for this model were developed from data collected in the Chesapeake Bay physical model for the Norfolk Harbor and channels deepening study (Richards and Morton 1983). There were four test conditions in the physical model:

Condition	Discharge, cfs	Tidal Range, ft
1	200,000	4.8
2	200,000	3.0
3	70,000	4.8
4	70,000	3.0

52. The discharges shown in the preceding tabulation were the total high (200,000 cfs) and average (70,000 cfs) freshwater discharges into Chesapeake Bay from all tributaries. The tidal range was measured at the Atlantic Ocean physical model control gage for spring (4.8 ft) and neap (3.0 ft).

53. During the high flow, the discharge from the James River was 25,363 cfs and during the average flow, it was 8,877 cfs.

54. Figure 16 (tide stations) and Figure 17 (velocity stations) show the locations where physical model data were collected for the four test conditions. Each location is described by a range designator and a station number. The physical model data were also used to verify the numerical model predictions.

55. The boundary conditions needed were velocity data at the upstream

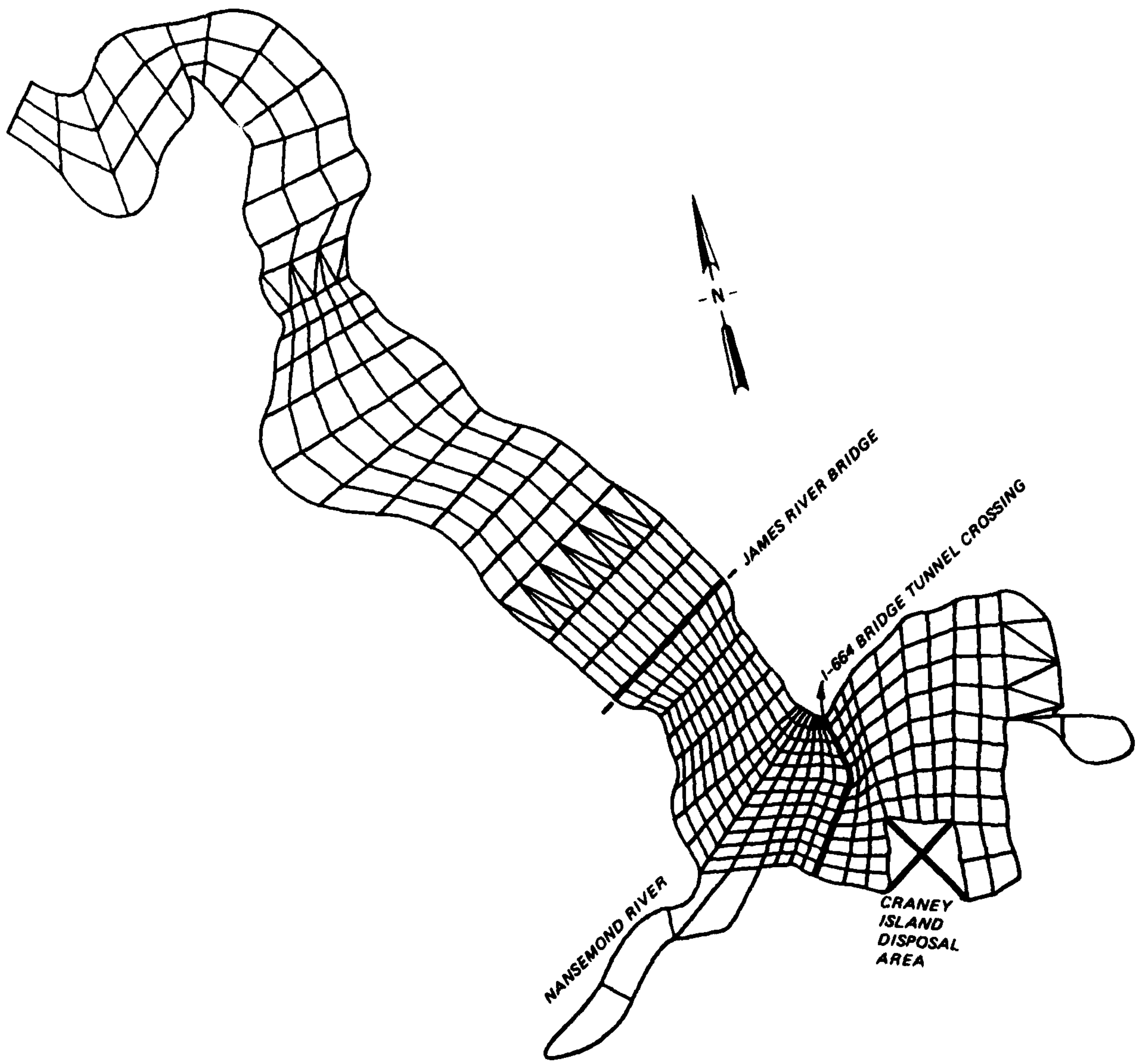


Figure 15. General sedimentation mesh

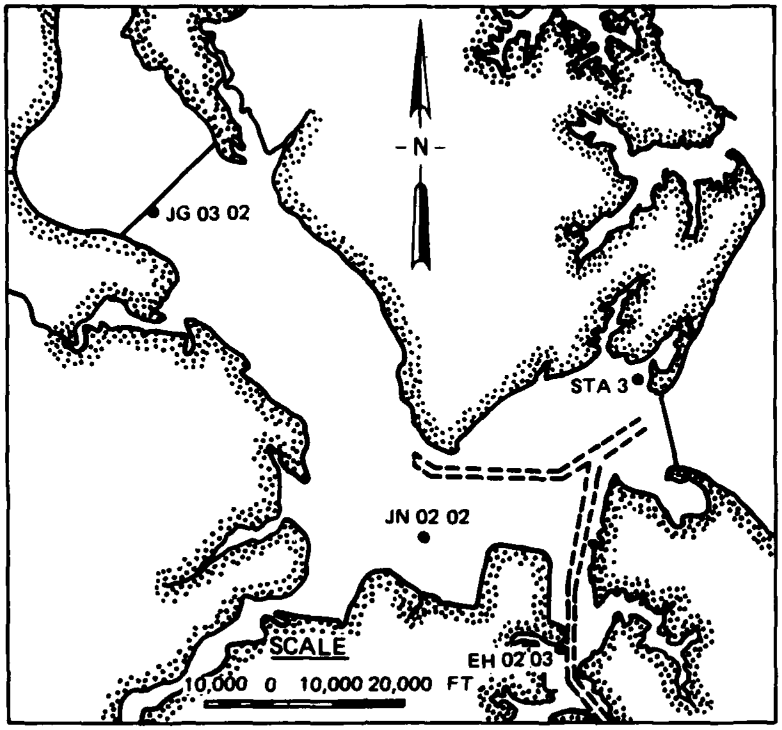


Figure 16. Steady-state manual tide station locations

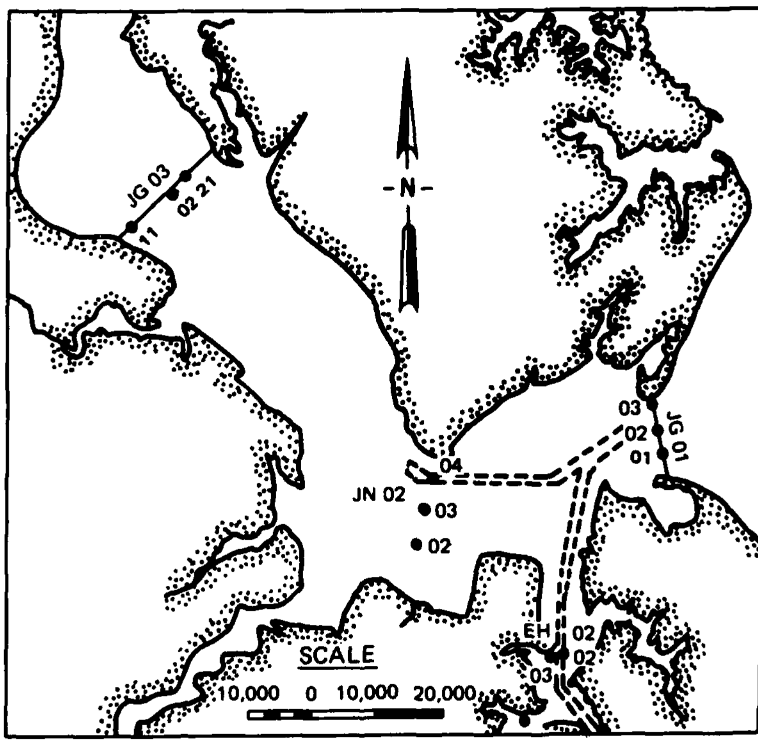


Figure 17. Steady-state velocity stations

boundary and in the entrance to the Elizabeth River and surface elevation data for the James River entrance. The velocity data had to be depth-integrated before they could be used as boundary data. These physical model data provided dynamic updates hourly (0-24) for the numerical model.

Comparison of hydrodynamic model results

56. Data from three physical model stations were compared with the numerical model results. Velocity data were collected at all three stations and tidal data at one station. These comparisons were needed to ensure that the numerical model was calculating an accurate representation of the vertically averaged currents and tidal elevations. Plates 1-4 compare the physical and numerical model results for the four conditions using data from stations shown in Figures 16 and 17.

57. The comparisons confirm the numerical model's ability to produce proper currents and surface elevations. The comparisons also indicate that the phasing of the tides during both conditions is excellent. The magnitude of velocity also shows very good agreement. Results confirm the validity of depths selected and the Manning's n values chosen. These comparisons also confirm the decision not to include a salinity component to this study although prototype data furnished by Nichols (1972) showed a longitudinal salinity gradient. If a salinity component had been included in this modeling effort, results would not have been significantly improved.

Hydrodynamic plan conditions

58. To simulate the proposed bridge plan, only a few changes in roughness were needed in those areas that represent the bridge and islands. This change caused the two islands to block the flow of water and the bridge to restrict the flow of water. The boundary conditions remained the same for the plan tests.

Sediment transport modeling

59. The modeling of sediment transport began once the hydrodynamic simulations were considered reasonable. The computational mesh was identical with that of the hydrodynamic model.

60. The following model parameters were established during verification:

Parameter	Value
Time-step length, sec	1,800 (0.5 hr)
Crank-Nicholson implicitness factor	0.70

Parameter	Value
Manning's n roughness	0.017
Critical shear stress for deposition, N/m^2	0.02
Critical shear stress for erosion, N/m^2	
Top layer	0.02
Second layer	0.06
Particle erosion constant, $kg/m^2/sec$	0.0012
Effective settling velocity, James River, m/sec	0.0008
Dry weight of deposit, kg/m^2	500

The following sediment concentration boundary conditions were established:

	High Freshwater Inflow, kg/m^3	Mean Freshwater Inflow, kg/m^3
James River (upstream)*	0.050	0.035
James River (downstream)**	0.10	0.010

* Values based on Onishi and Wise (1978).
** Values based on Nichols (1972).

61. The sediment transport model parameters were adjusted until reasonable average shoaling rates were calculated with the concentration within a reasonable range. The information in Nichols (1972) was used to determine an average shoaling rate in the area of interest.

62. In general Nichols (1972) found the sedimentation rates in the study area (excluding the navigation channel) to be less than 0.07 ft/year. After minor adjustments, the cohesive (clay) run of the numerical sediment model, STUDH, agreed well with this observed shoaling rate.

63. The sediment model was run in the extrapolation mode. This allowed the model to follow a sequence of a tidal cycle run, then extrapolation and another tidal cycle. This sequence continued until the bed had stabilized and the model was shoaling at a rate equivalent to the observed representative shoaling rate.

64. It was reasonable to assume this representative shoaling value for the entire area of study since Hampton Roads is an area of low shoaling and no additional detailed data were available. Comparisons were made at selected stations within the actual area of interest. These comparisons confirmed the

ability of the sediment model to adequately calculate the shoaling in this area with adequate sediment concentrations.

65. Once the sediment model was considered to be properly adjusted, all four base and plan sets of boundary conditions were run. A shoaling index (plan elemental shoaling volume divided by base elemental shoaling volume) was used to quantify the changes associated with the bridge-tunnel complex.

Combining individual events

66. In order to combine the shoaling indices for each testing condition, as described in paragraph 51, into one yearly index, the duration of each condition was expressed as percent of a year:

Condition	Tide	Discharge		Duration percent
1	Spring	High		1.6
2	Neap	High		8.4
3	Spring	Mean		14.4
4	Neap	Mean		75.6
			Total	100.0

The detailed discussion of the calculations made in establishing these percentages is given in Berger *et al.* (1985).

PART IV: RESULTS

Circulation

Physical model data

67. The analysis of the physical model data (Fang et al. 1972) indicated there would be no significant changes in water levels or currents from the I-664 crossing. Tidal elevations showed very little change. The average variation in the tidal range of 2.5 ft was 0.1 ft. There were very subtle changes (less than 0.5 ppt) in the overall salinity structure in the Hampton Roads area near Craney Island. The current regime was altered around Newport News Point. The maximum velocities on both ebb and flood were increased about 0.75 fps due to the constriction.

Surface current photographs

68. Analysis of the surface current photographs and the physical model velocity data isolated those areas most affected by the bridge-tunnel complex. In general, the complex reduced the cross-sectional area, causing velocities to increase. In the navigation channel, changes in velocity were noted. The north island completely blocked the nearshore flow and eddies developed both upstream and downstream of the island. Strong currents developed on the front face of the north island. Currents around the south island increased at the north and south ends of the south island and near the east and west edges. Along the bridge, velocities increased.

Navigation Channel Sedimentation

Numerical model hydrodynamic results

69. The hydrodynamic model, RMA-2V, was run for base (existing) and plan (proposed I-664 Bridge-Tunnel complex installed) with the four test conditions. Tables 2 and 3 show the maximum ebb and flood depth-averaged currents, respectively. Locations of these nodes are shown in Figure 18.

70. Boundary condition 1 had the largest impact on navigation channel circulation of the four boundary conditions tested. Maximum ebb velocity increased to about 0.5 fps and maximum flood about 0.3 fps at node 169, located in the channel between the tunnel islands. At node 137, upstream of the plan, the maximum ebb velocity increased about 0.1 fps and the maximum flood about

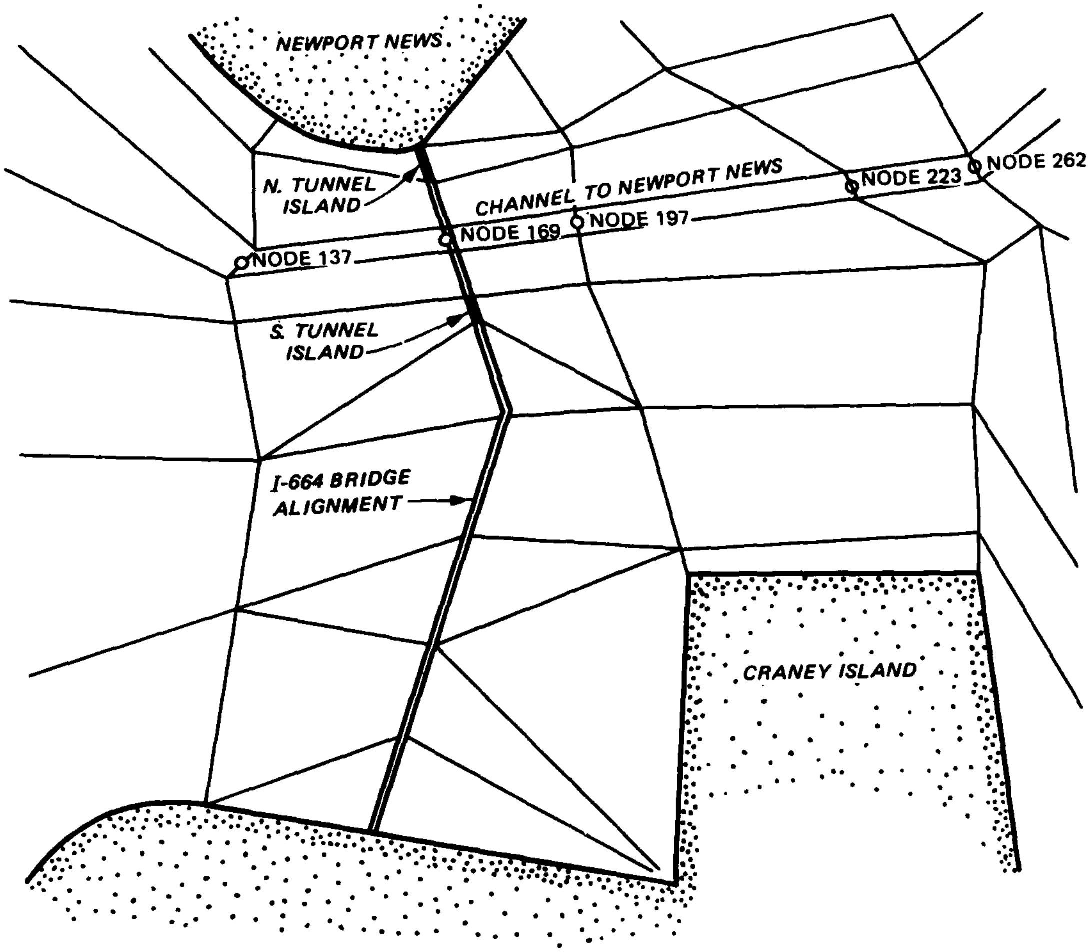


Figure 18. Location of channel sedimentation nodes

0.6 fps. At node 197, downstream of the plan, maximum ebb velocity increased about 0.6 fps and the maximum flood decreased about 0.1 fps. Farther downstream from the plan there was no noticeable difference in the ebb/flood velocity.

71. In general, downstream at node 197, the change in ebb velocity was larger than that in the flood velocity. Upstream at node 137, the pattern was reversed with the flood velocity increasing more than the ebb velocity. In the plan center line, node 169, the ebb/flood changes were close in magnitude.

Numerical model sedimentation results

72. Thus, it can be seen that velocities increased in the constriction and in the jet formed by the constriction, but the impact on currents away from the bridge was negligible. Analysis of the results indicated that the Newport News Channel will remain basically stable with an overall shoaling

rate of about 0.01 ft/year, which represents a reduction from the base condition of 0.04 ft/year. This shoaling reduction was expected since the hydrodynamic numerical results indicated an average increase in flood velocities of 0.3 fps and 0.4 fps in ebb velocities.

73. The STUDH cohesive sediment results from the mesh including the I-664 Bridge-Tunnel complex were very carefully compared with the Norfolk Harbor and channels deepening study plan runs, and no change was noted in the Norfolk Harbor and Elizabeth River Channels.

General Sedimentation

Numerical model hydrodynamic results

74. Plates 5-12 are vector plots of the vertically averaged velocities computed at the computation locations in the area of interest (entire computational mesh shown in Figure 15). These plots show maximum ebb (hour 15) and flood (hour 21) velocities for the four base and plan conditions that represent various combinations of tide ranges (spring and neap) and discharge conditions (high and mean).

75. The bridge caused maximum velocities to increase downstream on ebb and upstream on flood. These increases were small and would have a minor impact on circulation. Between the two islands, both upstream and downstream velocities were increased. This effect diminished as the flow moved toward Craney Island. Directly in front of Craney Island, the flow reestablished itself and was essentially unchanged from the base test.

Numerical model sedimentation results

76. Figure 19 shows the yearly simulated computed shoaling indices for selected elements. These elements were selected to evaluate sedimentation changes within the confines of the oyster beds.

77. The sedimentation on oyster bed locations 6 and 7 (Figure 14), located on either side of the proposed bridge, remained unchanged or decreased slightly. This was as expected since velocities were slightly increased in these areas.

78. Sedimentation remained unchanged on oyster beds 2 and 3 (Figure 14). This area is effectively out of the influence of the I-664 Bridge-Tunnel complex.

79. Sedimentation did not change in the majority of the public clamming

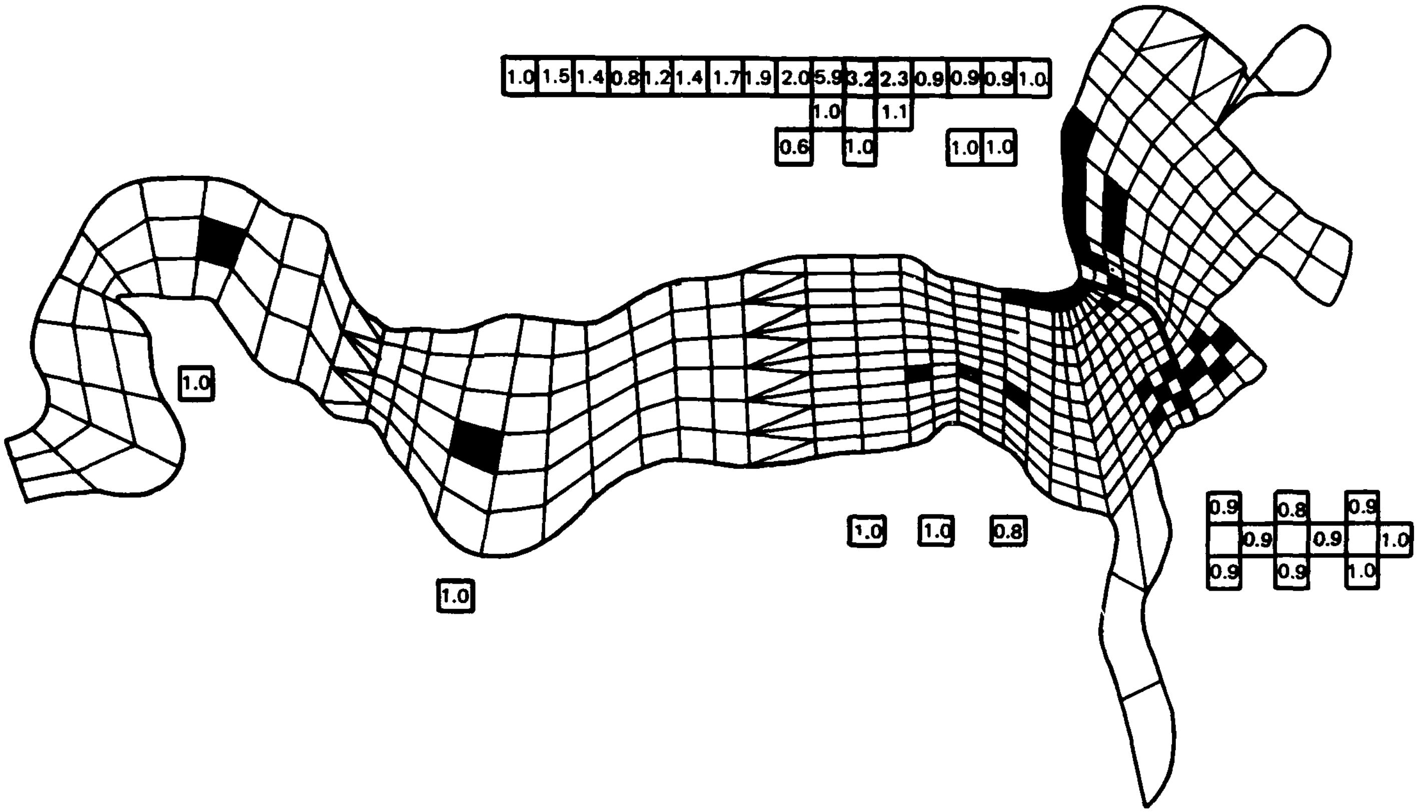


Figure 19. Yearly simulated shoaling indices

grounds (shown as Area 1 in Figure 14). However, sedimentation increased near the north island as a result of nearshore circulation blocked by the island and generation of an eddy. This eddy could be moving sediment into this area. The prototype sedimentation in this area is relatively minor, and the increases caused by the north island would probably be local.

41

PART V: CONCLUSIONS

80. The TABS-2 model of the lower James River accurately reproduced currents and surface elevations. The phasing of the tides was excellent and the magnitude of velocity also showed very good agreement. It can be expected to provide reliable guidance for hydrodynamic and sedimentation impacts of proposed construction.

81. The model test results showed that the I-664 Bridge-Tunnel had the following effects:

- a. Circulation changes and resulting flushing changes were localized with minimal effects on the general circulation of the lower James River.
- b. Sedimentation was generally unchanged or reduced except on either side of the north island where increases will be expected. The areas experiencing unchanged or slightly reduced sedimentation rates included the oyster grounds, the Elizabeth River and Norfolk Harbor Channels, and the Newport News Channel.

REFERENCES

Ackers, P., and White, W. R. 1973 (Nov). "Sediment Transport: New Approach and Analysis," Journal, Hydraulics Division, American Society of Civil Engineers, Vol 99, No. HY11, pp 2041-2060.

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

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," 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.

Fang, C. S., Neilson, B. J., Kuo, A. Y., Byrne, R. J., Welch, C. S. 1972 (Aug). "Physical and Geological Studies at the Proposed Bridge Tunnel Crossing of Hampton Roads near Craney Island," Special Report in Applied Marine Science and Ocean Engineering, Number 24, Virginia Institute of Marine Science, Gloucester Point, VA.

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

McAnally, W. H., Jr., Brogdon, N. J., Jr., Letter, J. V., Jr., Stewart, J. P., and Thomas, W. A. 1983 (Sep). "Columbia River Estuary Hybrid Model Studies; Verification of Hybrid Modeling of the Columbia River Mouth," Technical Report HL-83-16, Report 1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Nichols, M. M. 1972. "Sediments of the James River Estuary, Virginia," Environmental Framework of Coastal Plain Estuaries, Bruce W. Nelson, ed., Geological Society of America Memoir 133, Boulder, CO, pp 169-212.

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

Onishi, Y., and Wise, S. E. 1978 (Sep). "Mathematical Simulation of Transport of Sediment and Kepone in the James River Estuary," PNL-2731/UC-11, Pacific Northwest Laboratory operated for the US Department of Energy by Battelle Memorial Institute, Columbus, OH.

Richards, D. R., and Morton, M. R. 1983 (June). "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.

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

Thomas, William A., and McAnally, William H., Jr. 1985 (Jul). "User's Manual for the Generalized Computer Program System: Open-Channel Flow and Sedimentation, TABS-2," 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 Interior 119 (Vols 1 and 2), Hydraulic Research Station, Wallingford, England.

Table 1

Velocity and Salinity Data Collected

During Circulation Study by VIMS

Station	Depth	Base Velocity	Base Salinity	Plan 1A Velocity	Plan 1A Salinity
2A	S				
	M	*	*	*	*
	B				
2B	S	*	*	*	*
	M				
	B		*	*	*
2C	S	*		*	
	M	*		*	
	B	*		*	
2D	S	*	*	*	*
	M	*	*	*	*
	B	*	*	*	*
2E	S	*		*	
	M	*		*	
	B	*		*	
2F	S	*	*	*	*
	M	*		*	
	B	*	*	*	*
3A	S				
	M	*	*	*	*
	B				
3B	S	*	*	*	*
	M	*		*	
	B	*	*	*	*
3C	S	*		*	
	M				*
	B	*		*	
3D	S	*		*	
	M		*		*
	B	*		*	
4	S	*	*	*	*
	M	*		*	
	B	*	*	*	*

(Continued)

* Indicates data collected at this location.

Table 1 (Concluded)

Station	Depth	Base Velocity	Base Salinity	Plan 1A Velocity	Plan 1A Salinity
4A	S				
	M	*	*	*	*
	B				
5A	S	*		*	
	M		*		*
	B	*		*	
5B	S	*	*	*	*
	M	*		*	
	B	*	*	*	*
5C	S	*		*	
	M		*		*
	B	*		*	
5D	S				
	M	*	*	*	*
	B				
5H	S	*	*	*	*
	M	*		*	
	B	*	*	*	*
6A	S	*	*	*	*
	M	*		*	
	B	*	*	*	*
6B	S				
	M	*	*	*	*
	B				
6C	S				
	M	*	*	*	*
	B				
6D	S				
	M		*		*
	B				
7	S	*		*	
	M	*	*	*	*
	B	*		*	

* Indicates data collected at this location.

Table 2

Maximum Ebb Velocities

Test Conditions

	High Discharge, fps				Mean Discharge, fps			
	Spring Tide		Neap Tide		Spring Tide		Neap Tide	
Node	Base 1	Plan 1	Base 2	Plan 2	Base 3	Plan 3	Base 4	Plan 4
137	1.94	2.04	1.04	1.09	2.17	2.28	1.57	1.63
169	2.27	2.79	1.12	1.51	2.50	3.03	1.67	2.11
197	2.68	3.32	1.37	1.77	2.88	3.57	2.00	2.49
223	1.80	1.82	0.98	0.99	2.01	2.09	1.39	1.27
262	1.75	1.70	0.93	0.96	1.88	1.80	1.22	1.20

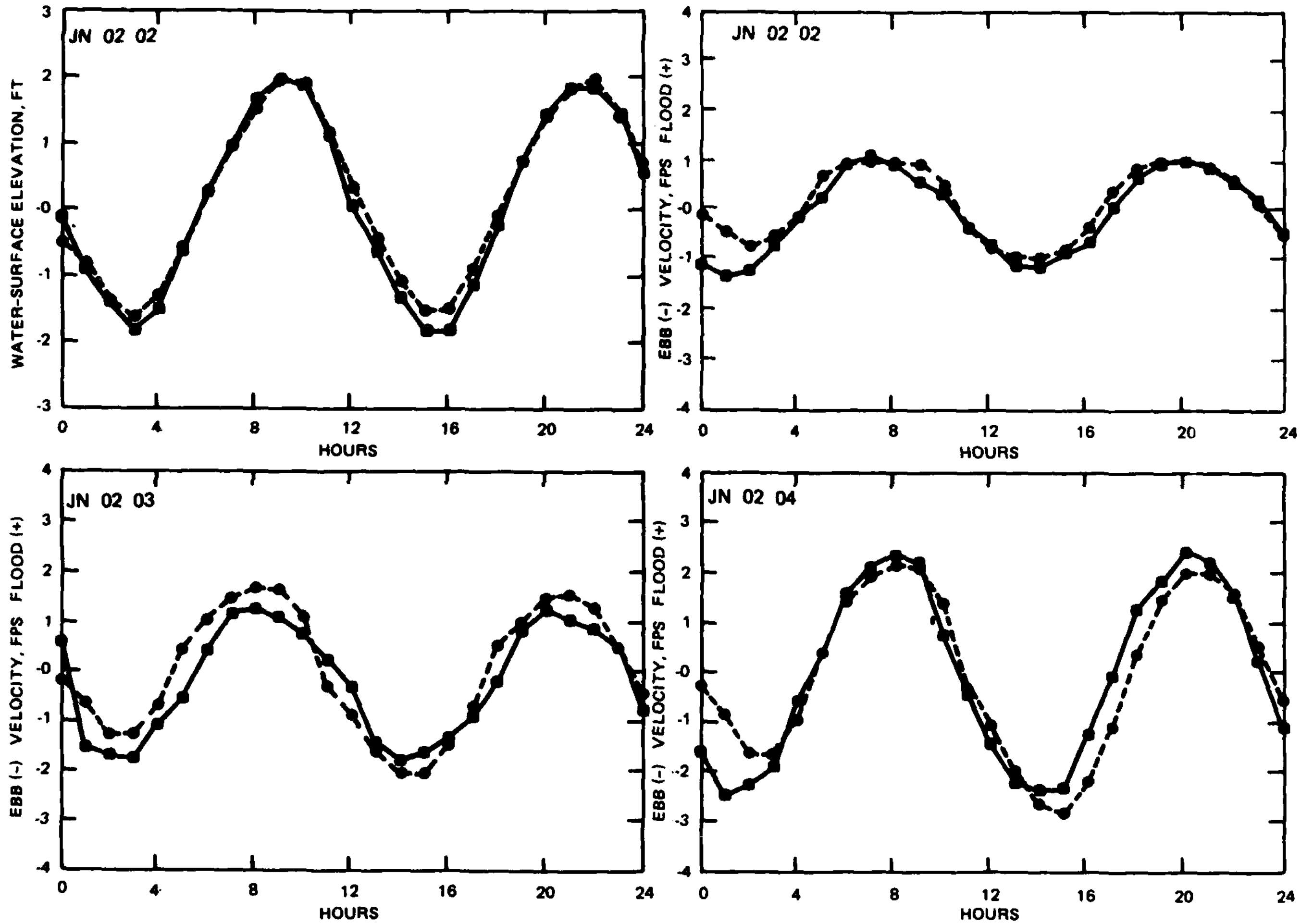
Table 3

Maximum Flood Velocities

Test Conditions

	High Discharge, fps				Mean Discharge, fps			
	Spring Tide		Neap Tide		Spring Tide		Neap Tide	
Node	Base 1	Plan 1	Base 2	Plan 2	Base 3	Plan 3	Base 4	Plan 4
137	1.51	2.09	1.03	1.50	1.47	2.17	1.23	1.70
169	2.40	2.74	1.61	1.90	2.27	2.65	1.85	2.16
197	1.90	1.78	1.30	1.28	1.75	1.73	1.46	1.39
223	1.50	1.44	1.20	1.18	1.59	1.57	1.13	1.09
262	0.97	0.92	0.85	0.81	1.19	1.16	0.73	0.70

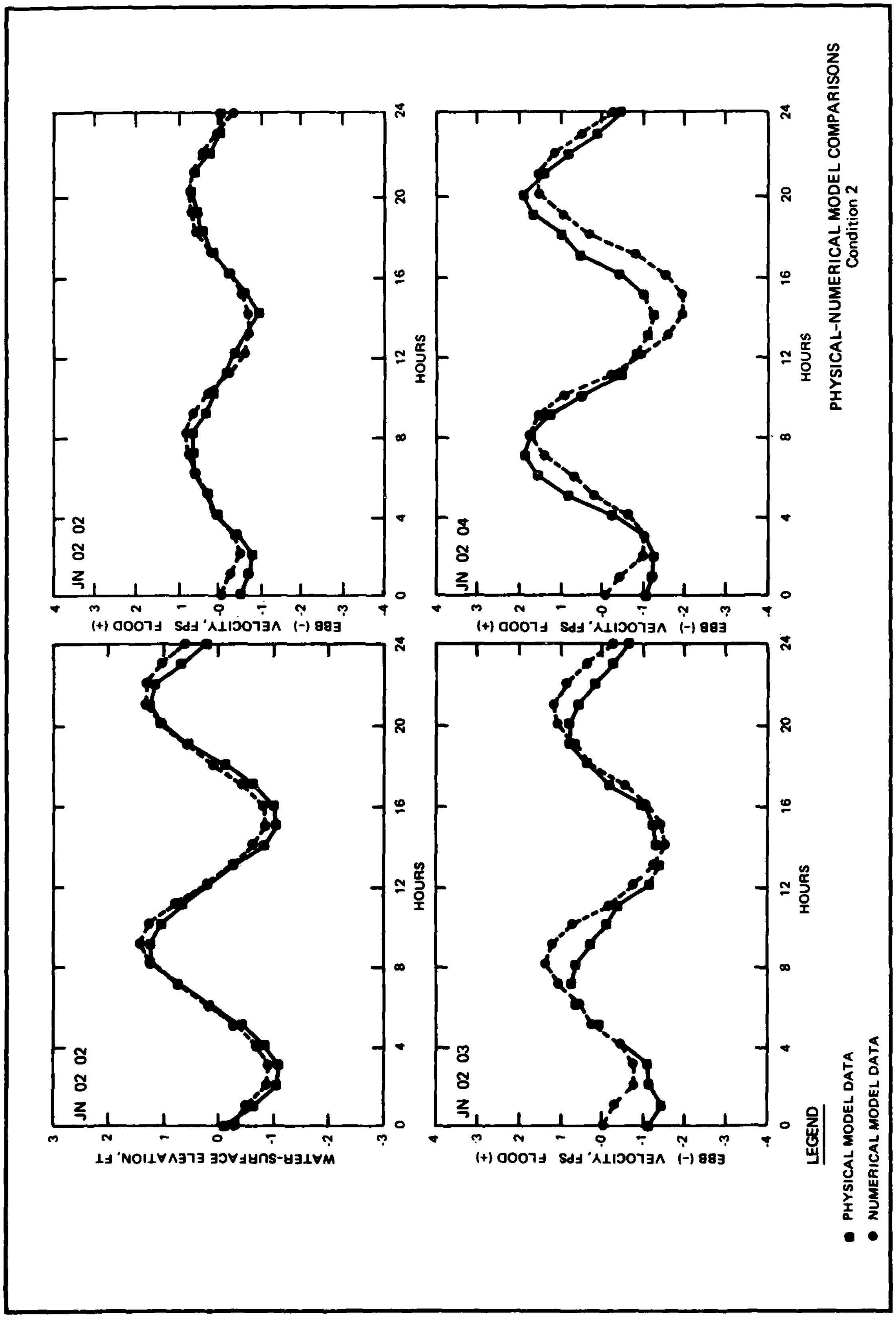
NOTE: Base 1 indicates the base configuration with boundary condition 1; Plan 1 indicates the bridge/tunnel configuration with boundary condition 1; etc.



LEGEND

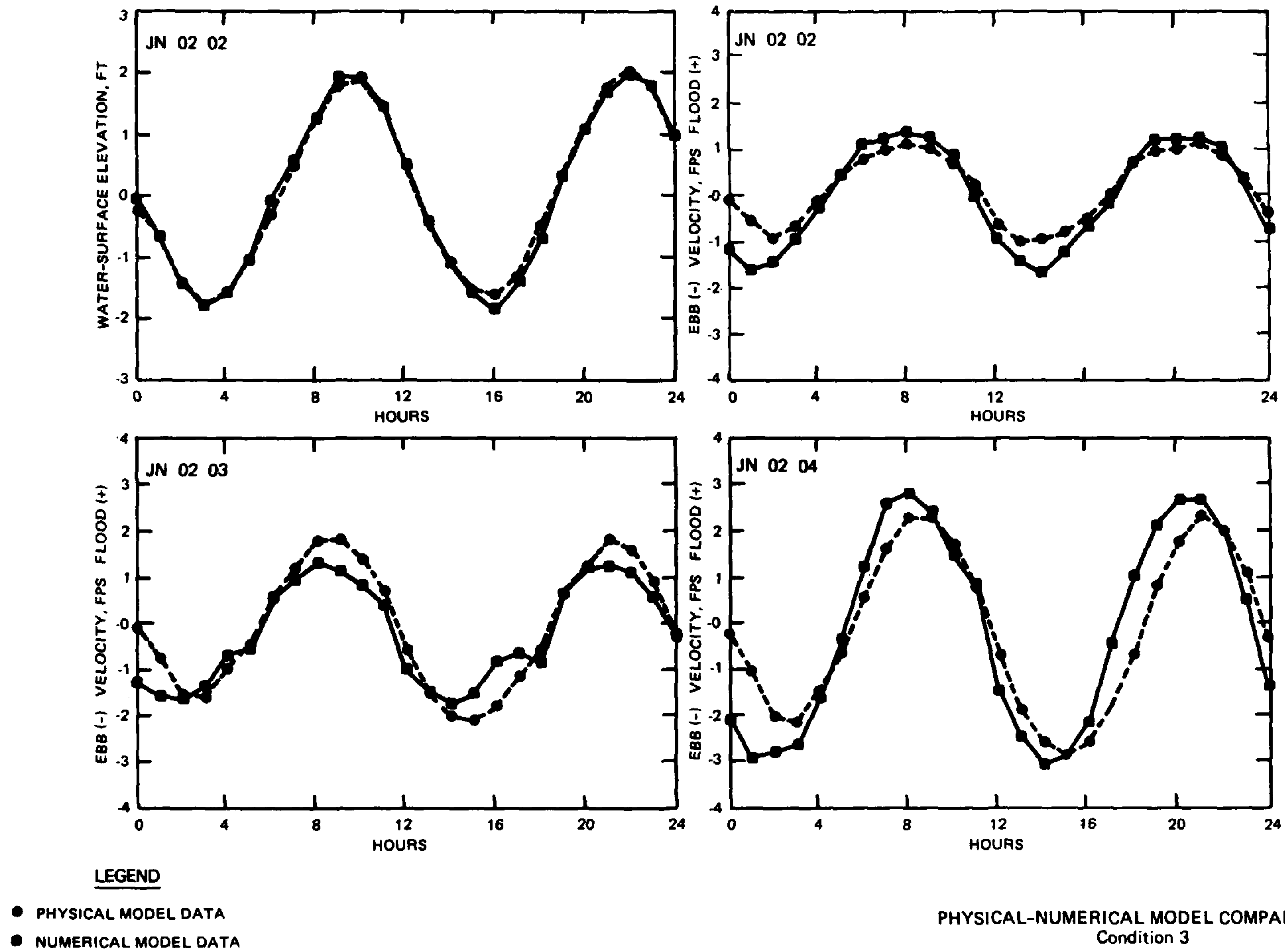
● PHYSICAL MODEL DATA
● NUMERICAL MODEL DATA

PHYSICAL-NUMERICAL MODEL COMPARISONS
Condition 1



PHYSICAL-NUMERICAL MODEL COMPARISONS
Condition 2

PLATE 2



PHYSICAL-NUMERICAL MODEL COMPARISONS
Condition 3

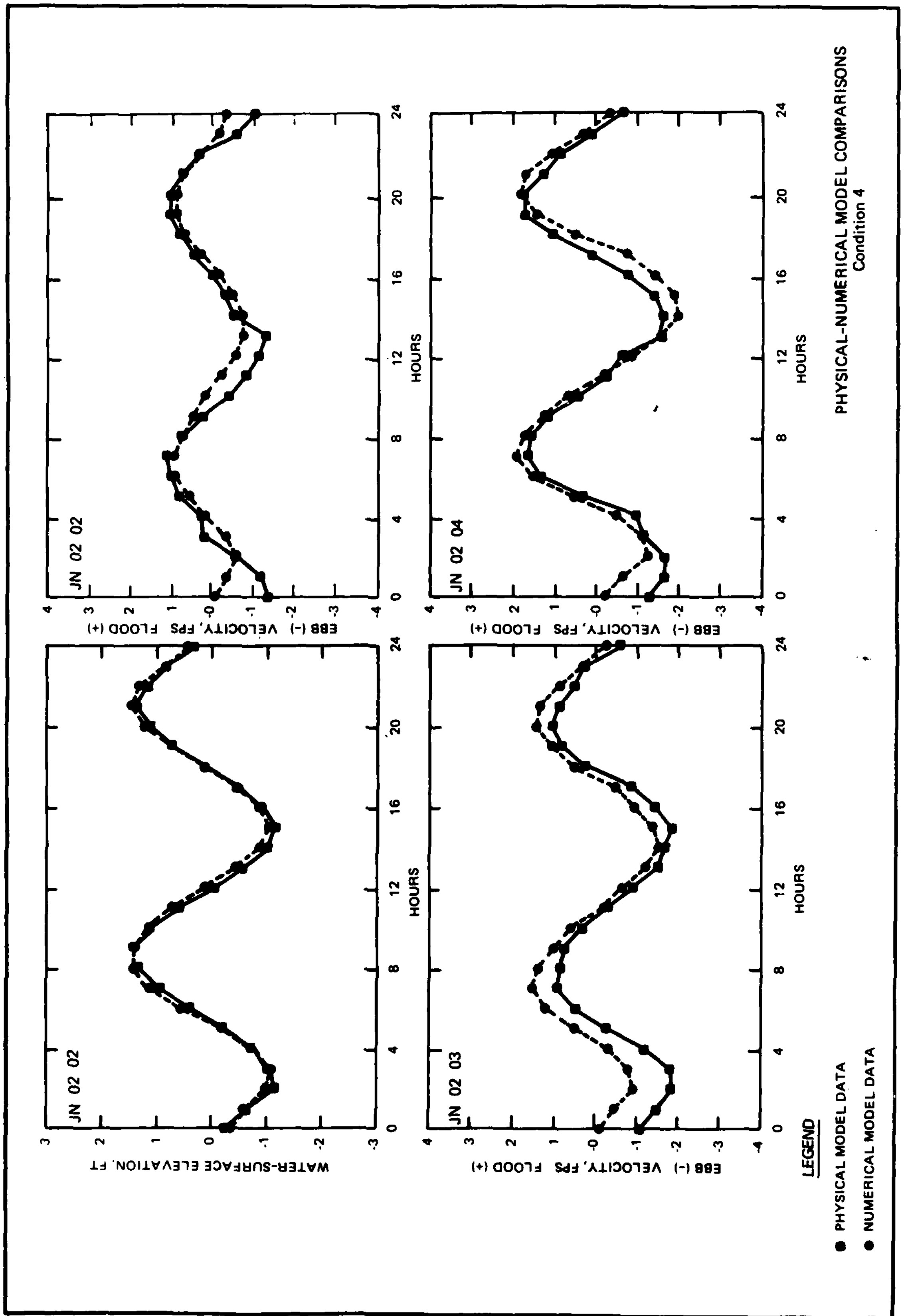
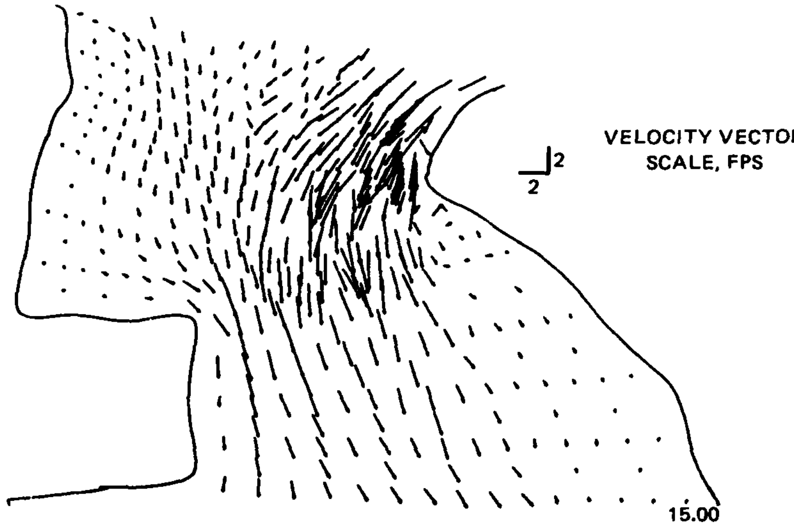
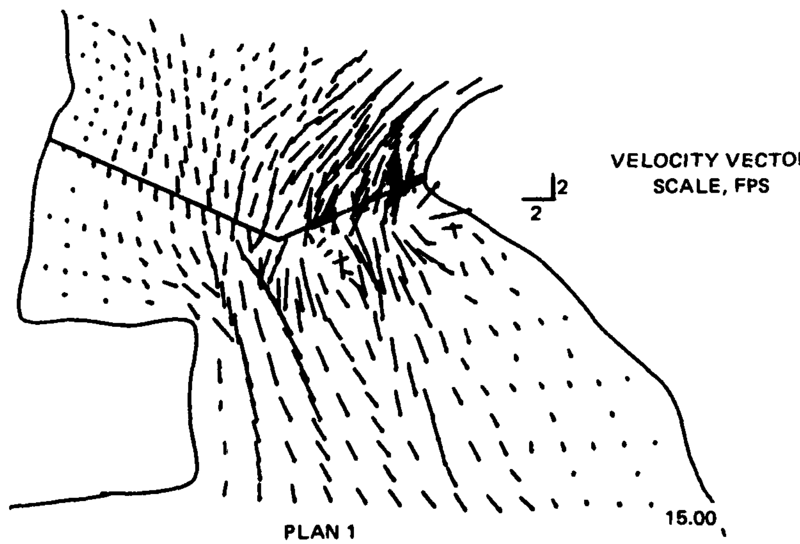

PHYSICAL-NUMERICAL MODEL COMPARISONS
Condition 4
JN 02 02
JN 02 02
JN 02 03
JN 02 04
WATER-SURFACE ELEVATION, FT
EBB (-) VELOCITY, FPS FLOOD (+)
HOURS
LEGEND
PHYSICAL MODEL DATA
NUMERICAL MODEL DATA

PLATE 4

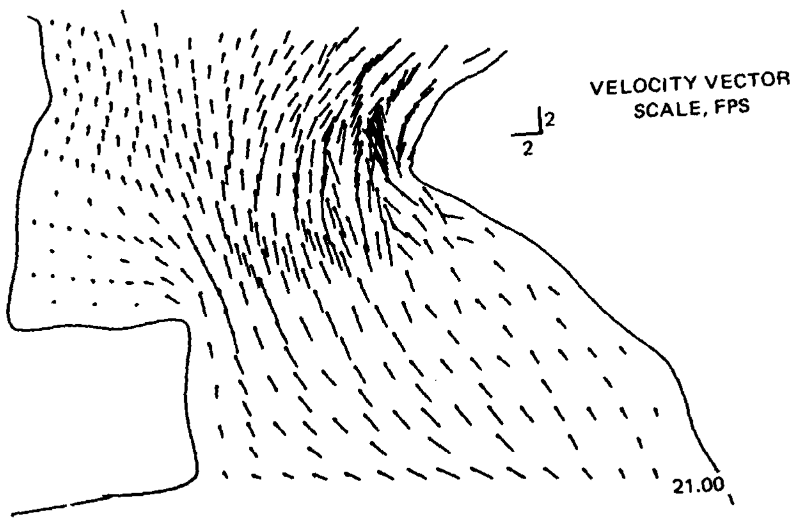


BASE 1

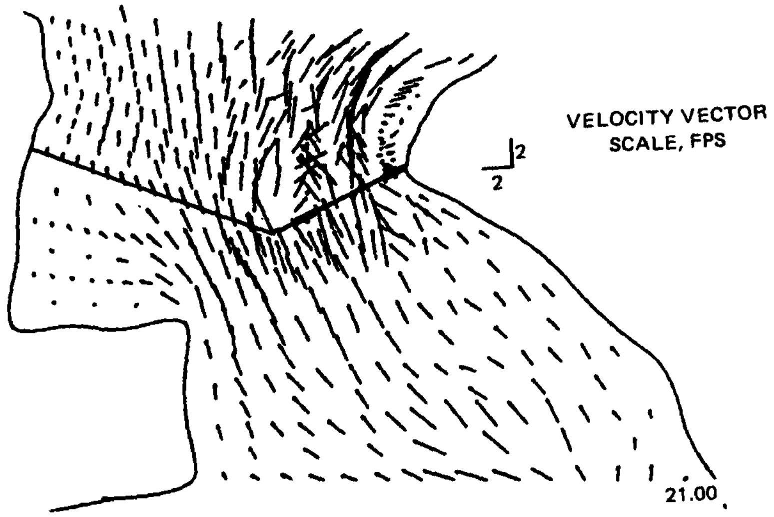


PLAN 1

VECTOR COMPARISONS
Base 1 to Plan 1
Maximum Ebb

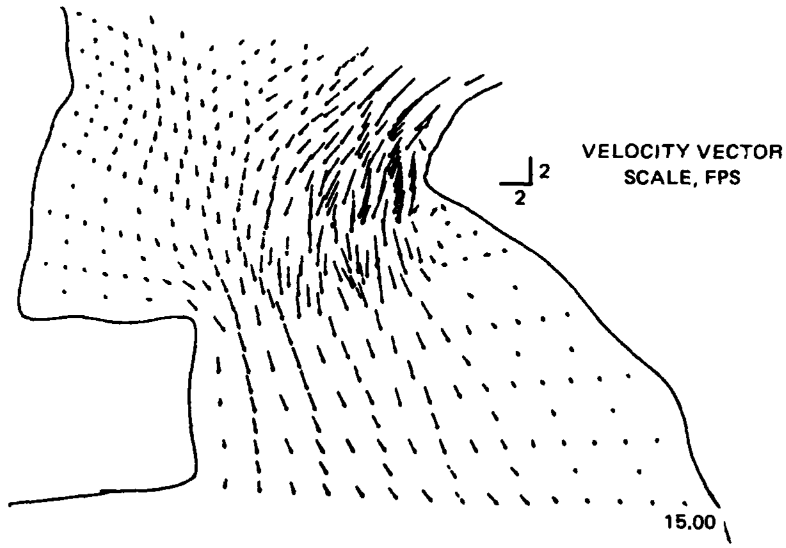


BASE 1

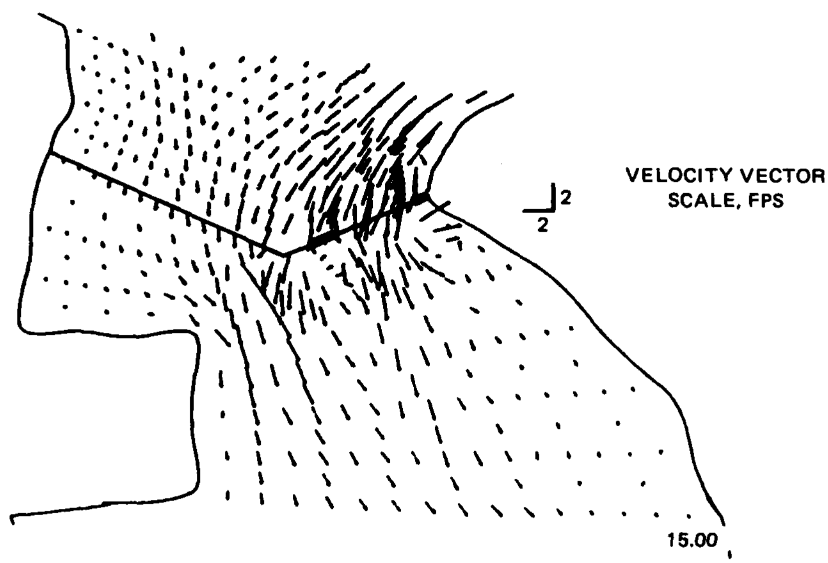


PLAN 1

VECTOR COMPARISONS
Base 1 to Plan 1
Maximum Flood

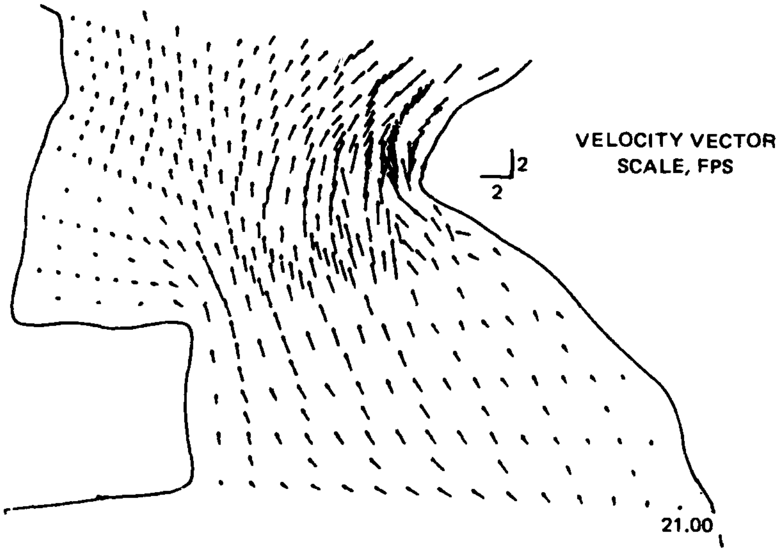


BASE 2

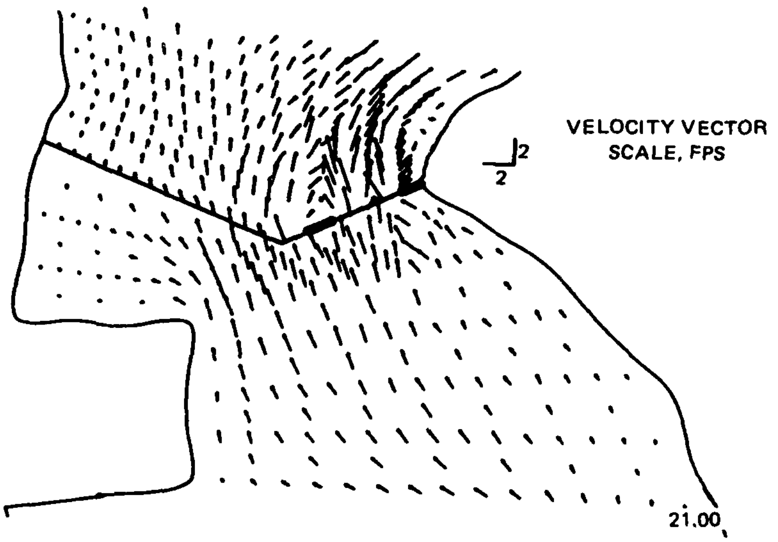


PLAN 2

VECTOR COMPARISONS
Base 2 to Plan 2
Maximum Ebb

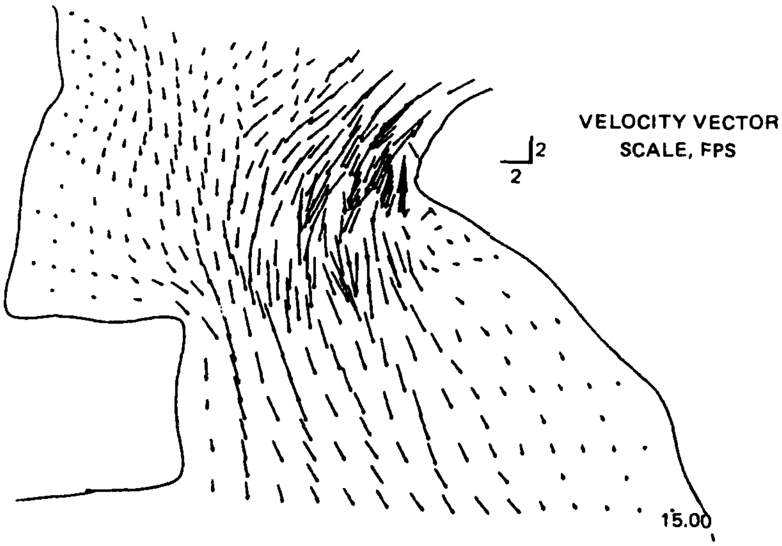


BASE 2

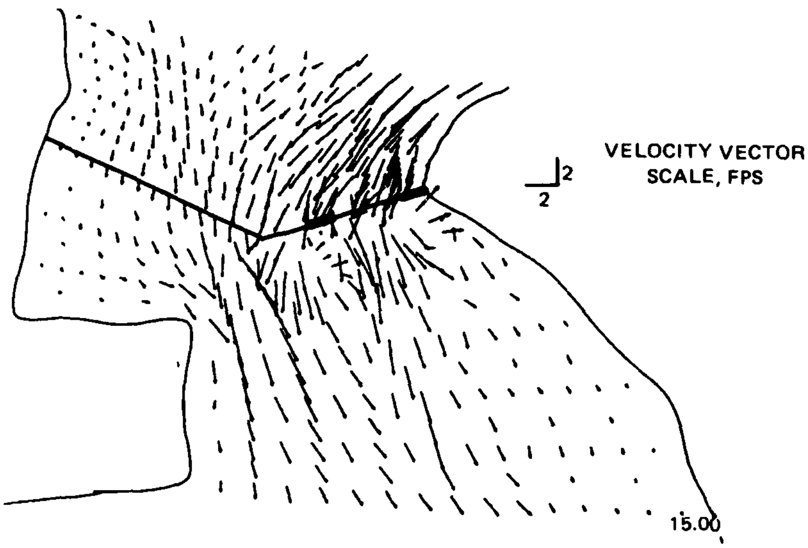


PLAN 2

VECTOR COMPARISONS
Base 2 to Plan 2
Maximum Flood

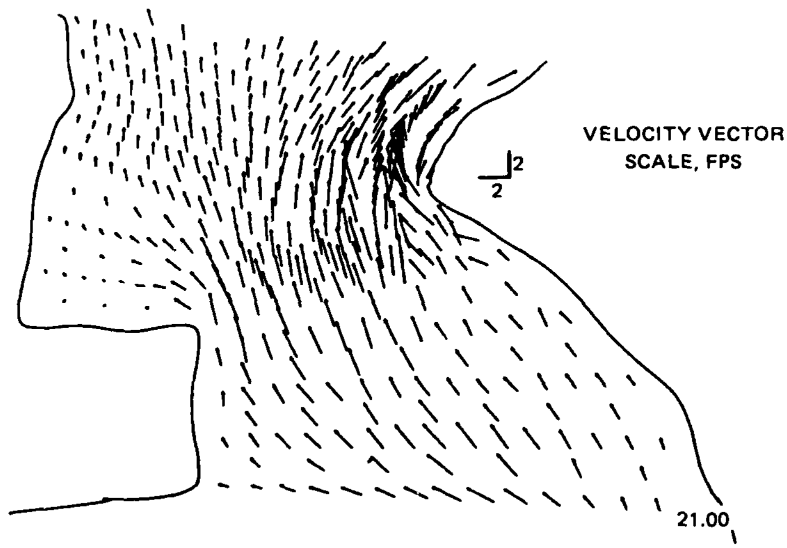


BASE 3

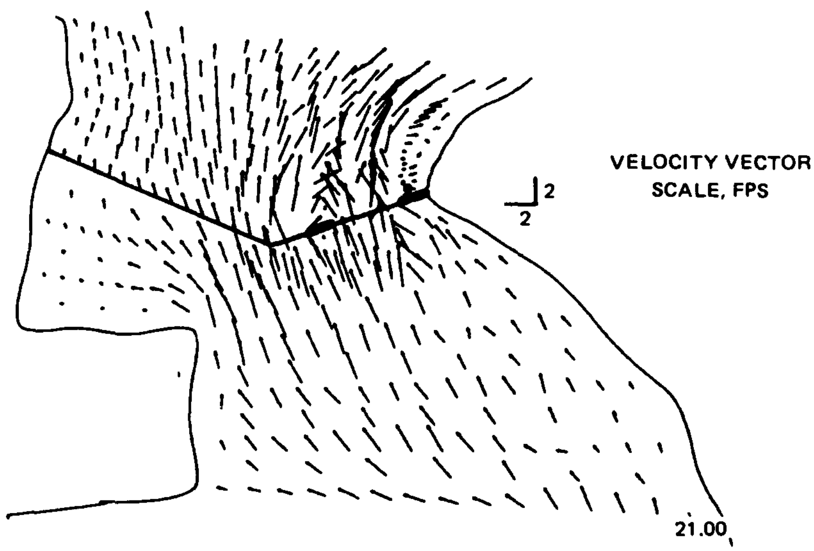


PLAN 3

VECTOR COMPARISONS
Base 3 to Plan 3
Maximum Ebb



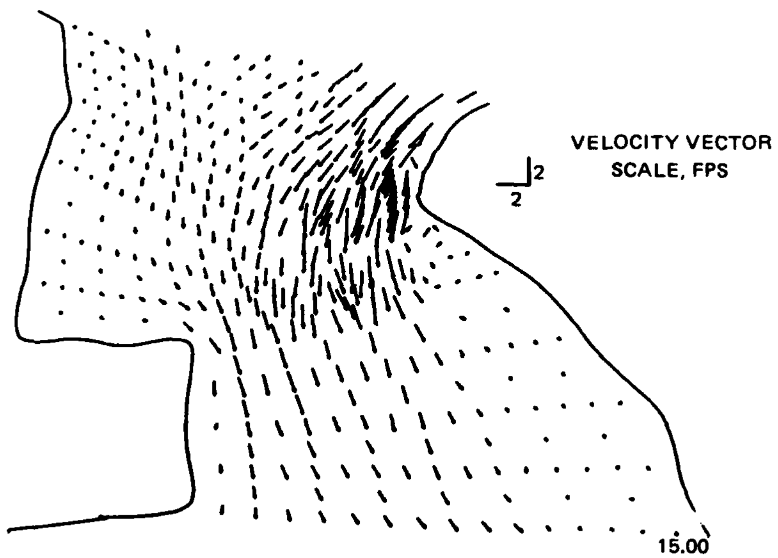
BASE 3



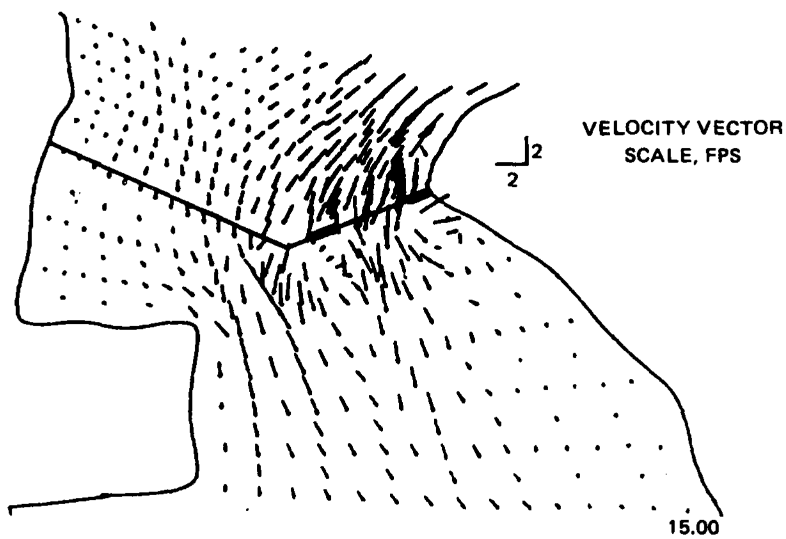
PLAN 3

VECTOR COMPARISONS
Base 3 to Plan 3
Maximum Flood

PLATE 10

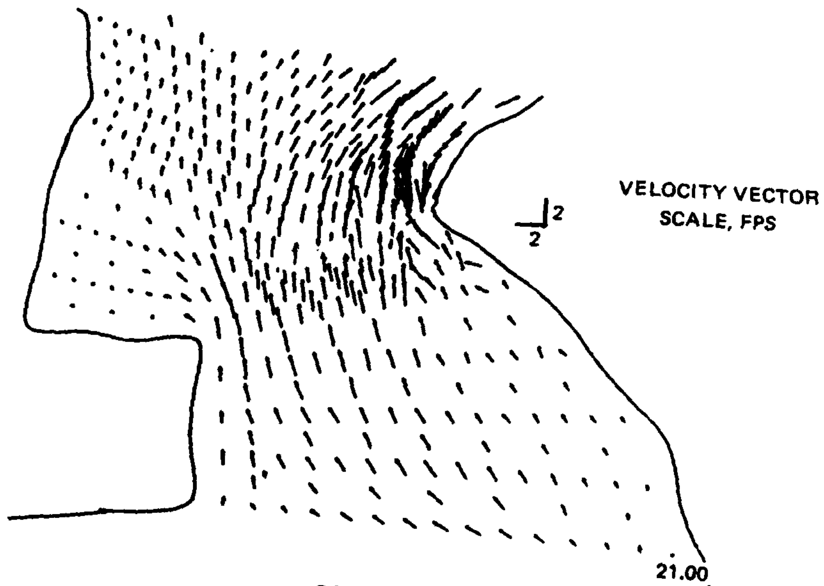


BASE 4

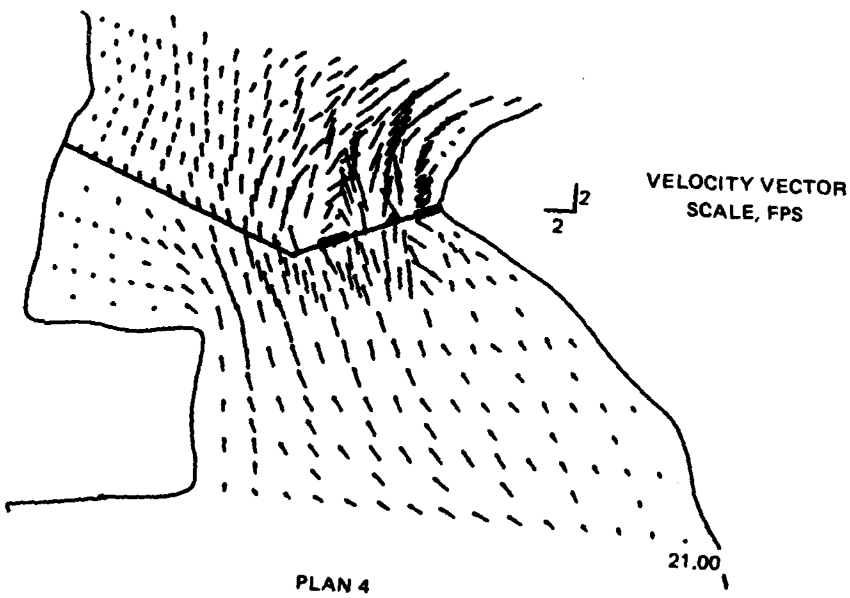


PLAN 4

VECTOR COMPARISONS
Base 4 to Plan 4
Maximum Ebb



BASE 4



PLAN 4

VECTOR COMPARISONS
Base 4 to Plan 4
Maximum Flood