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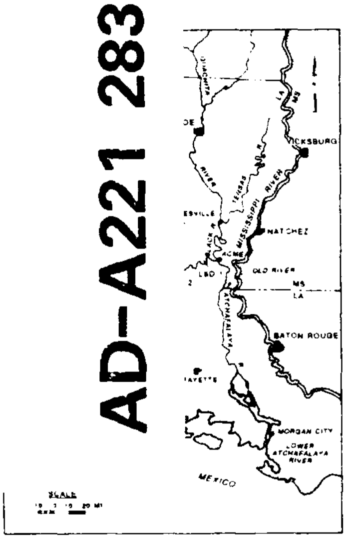

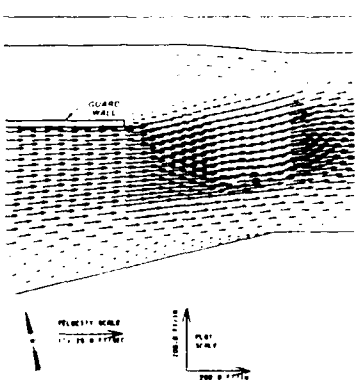

HYDRAULICS LABORATORY

RED RIVER WATERWAY, LOCK AND DAM NO. 4

Report 5

SEDIMENTATION IN LOCK APPROACHES

TABS-2 Numerical Model Investigation

by

Ronald R. Copeland, Ronald E. Heath, William A. Thomas

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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A two-dimensional numerical model, TABS-2, was used to predict fine sediment deposition in the lock approach channels upstream and downstream from proposed Lock and Dam No. 4 on the Red River Waterway, Louisiana. The numerical model was used to evaluate alternative designs. Fine sediment deposition with the proposed design at Lock and Dam No. 4 was compared to fine sediment deposition at existing locks and dams downstream.

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PREFACE

The numerical model investigation of the Red River upstream and downstream from Lock and Dam No. 4, reported herein, was conducted at the US Army Engineer Waterways Experiment Station (WES) at the request of the US Army Engineer District, Vicksburg (LMK). In addition to this numerical model study, an additional numerical model study and three physical model studies of Lock and Dam No. 4 were conducted at WES. The additional numerical model study (Report 6) addressed patterns of flow and sedimentation in the main river channel. The physical model studies included a fixed-bed navigation study (Report 2); a movable-bed sedimentation study (Report 3); and a hydraulic structures model study (Report 4). This is Report 5 of the series. Report 1, to be published later, will summarize all of the model studies.

The investigation was conducted during the period September 1987 to July 1988 by personnel of the Hydraulics Laboratory at WES under the direction of Mr. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory, Mr. M. B. Boyd, Chief of the Waterways Division, and Mr. M. J. Trawle, Chief of the Math Modeling Group. Mr. W. A. Thomas, Waterways Division, was the Hydraulics Laboratory coordinator for Red River studies and provided general guidance and review. The Project Engineers and authors of this report were Mr. R. R. Copeland and Mr. R. E. Heath, Math Modeling Group. Technical assistance was provided by Ms. Brenda L. Martin and Mrs. Peggy Hoffman, also of the Math Modeling Group. This report was edited by Mrs. Marsha C. Gay, Information Technology Laboratory, WES.

During the course of this study, close working contact was maintained with Mr. Terry Smith of the Engineering Division, LMK, who served as the coordinating engineer for LMK, providing required data and technical assistance. During this investigation, many representatives from LMK and WES engineering staffs attended several meetings at WES and LMK to discuss progress of this investigation and others related to the Red River Waterway.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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LIST OF FIGURES

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
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds-second (force) per square foot	47.88026	pascals-second
square feet	0.09290304	square metres

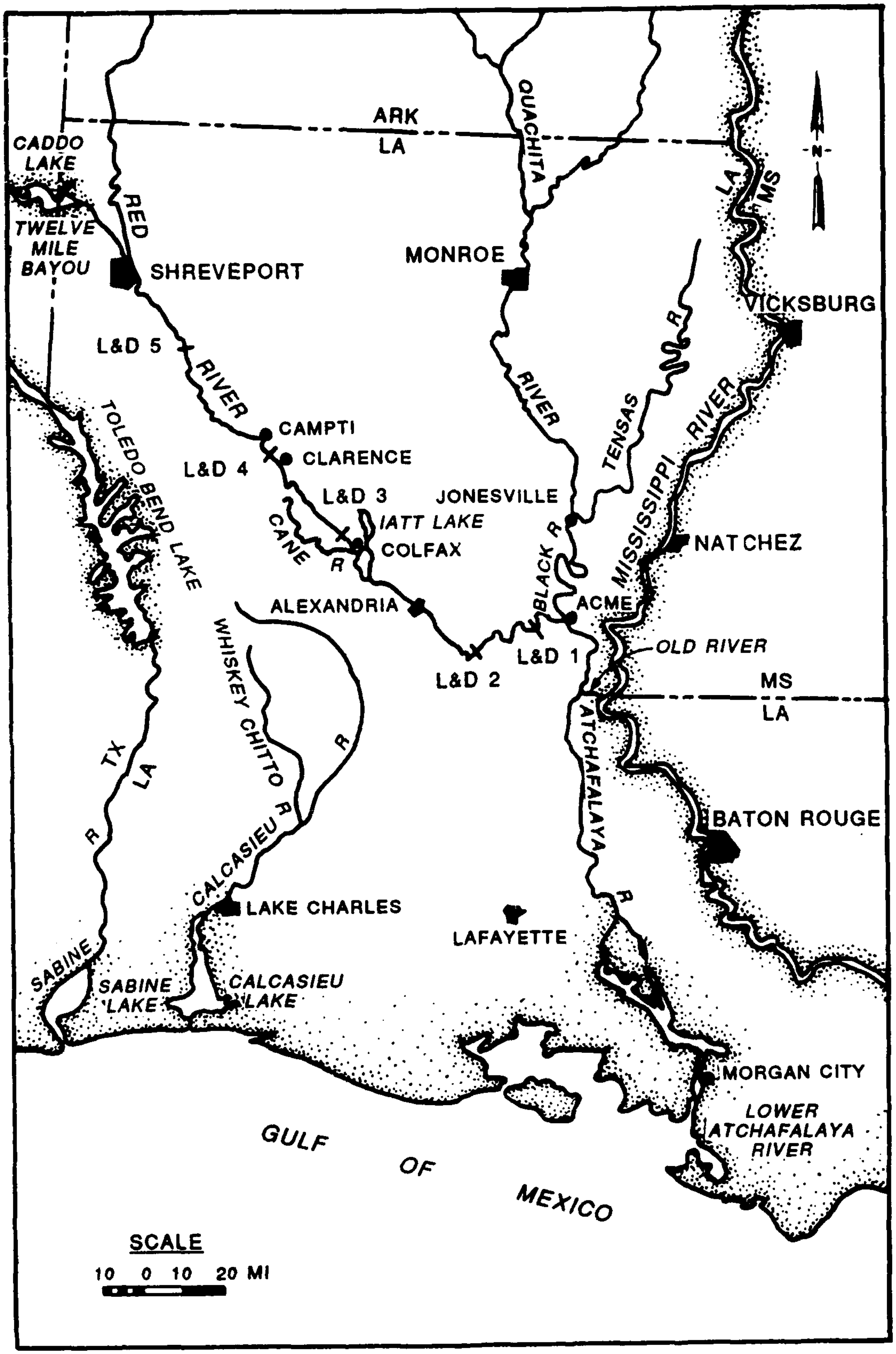

Figure 1. Location map

RED RIVER WATERWAY, LOCK AND DAM NO. 4

SEDIMENTATION IN LOCK APPROACHES

TABS-2 Numerical Model Investigation

PART I: INTRODUCTION

The Prototype

1. The Red River Waterway Project will provide a navigation route from the Mississippi River at its junction with Old River via the Old and Red rivers to Shreveport, LA. The project will provide a channel 236 miles* long, 9 ft deep, and 200 ft wide, and will include a system of five locks and dams to control water levels. The existing river will be realigned as necessary to develop an efficient channel, and bank stabilization and training works will be constructed to hold the newly developed channel in position.

2. Lock and Dam No. 4 is located in a river cutoff between river miles 206 and 209 about 71 miles downstream from Shreveport, LA (Figure 1). It consists of a single lock on the left descending side of the cutoff with an adjacent gated spillway and overflow weir. The lock is 84 ft wide with 685 ft of usable length. Upstream and downstream miter gate sill elevations are 95.0** and 77.0, respectively. The lock chamber floor is el 75.0. The gated spillway contains four tainter gates, 60 ft wide by 36 ft high, with a sill el of 85.0, and an overflow weir with three 100-ft-long hinged gates. The overflow weir crest is at el 115.0, and the top of the hinged gate in its fully raised (closed) position is at el 122.0. Upstream and downstream project features are shown in Figure 2.

3. The main channel upstream from the structure has a 325-ft-wide base width with 1V:4H side slopes and a design invert el of 90.0. The left descending bank has a 200-ft-wide berm at el 100.0. The upstream lock approach channel is separated from the spillway entrance channel by a 700-ft-long ported guard wall. The wall was designed to limit the outdraft conditions

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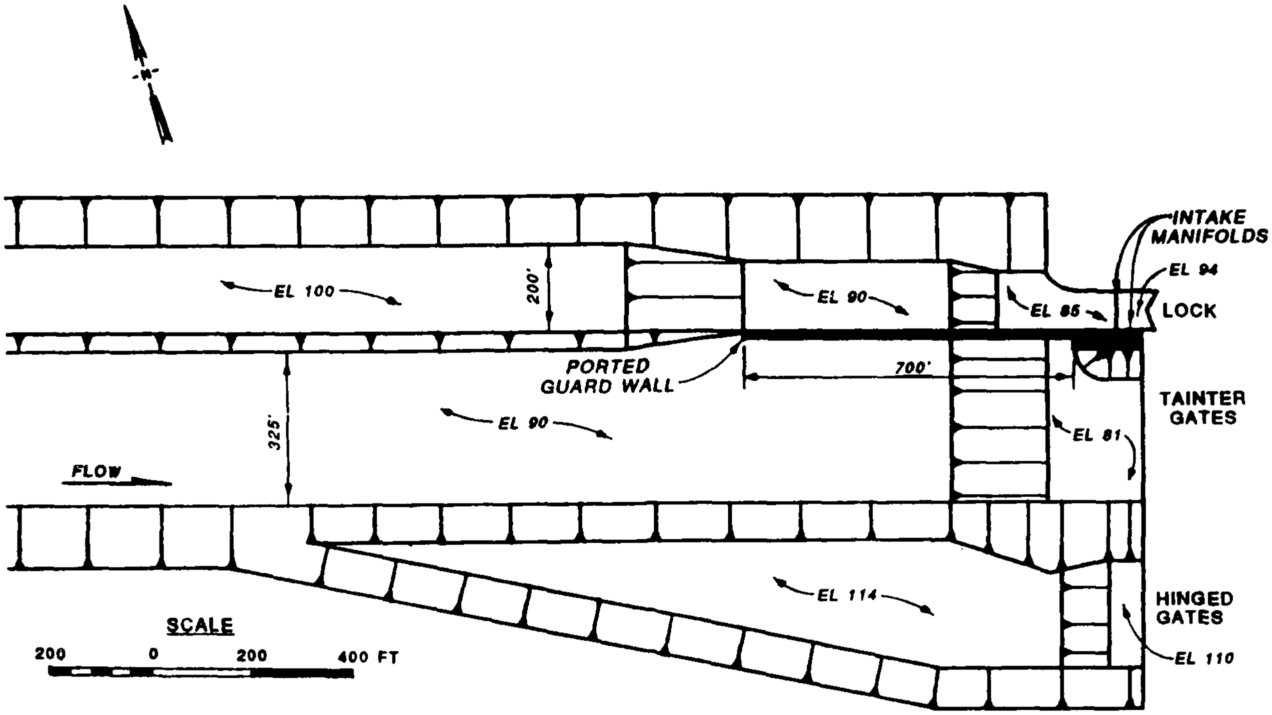
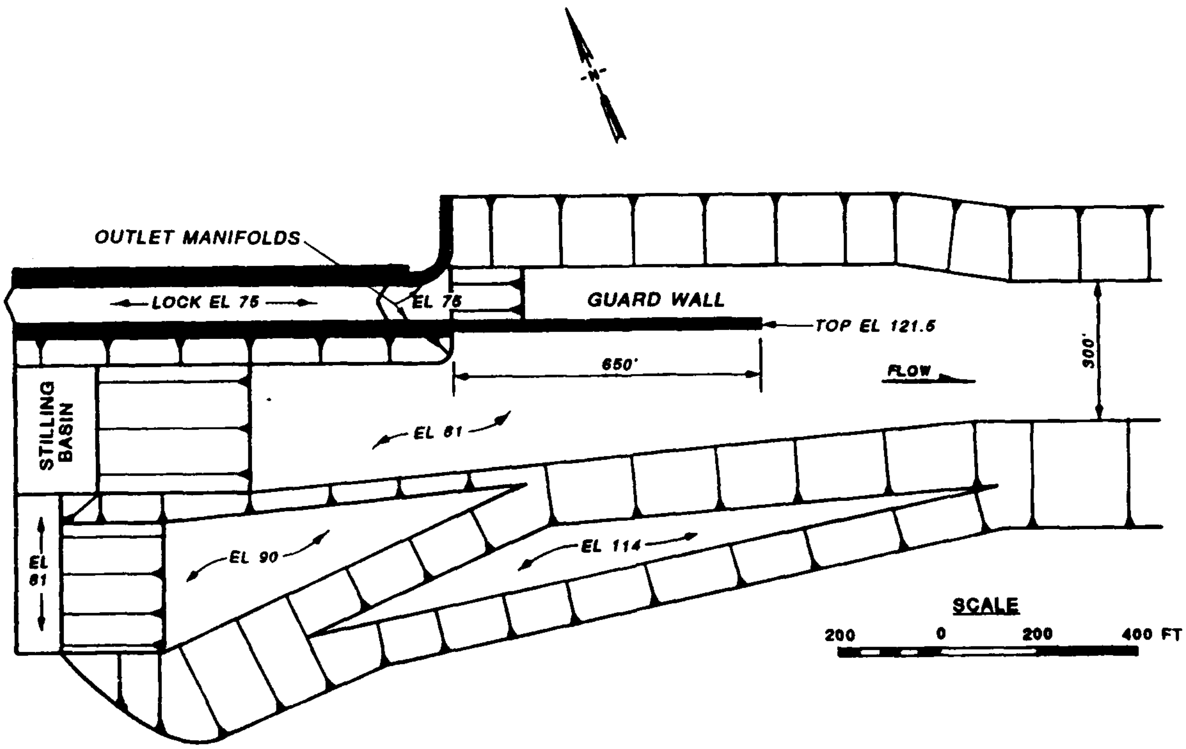
* A table of factors for converting non-SI units of measurement to SI (metric) units of measurement is presented on page 3.

** All elevations (el) and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).



a. Upstream



Downstream

Figure 2. Project features

caused by the dam spillway flows and provide a point for tows to align their approach and await lockage. The intake manifolds for the lock filling system are located in a 175-ft-long extension of the lock walls between the downstream end of the guard wall and the upper miter gates. Each manifold has six ports, each 7.5 ft wide by 10 ft high, with inverts at el 85.0, which is equal to the channel invert. Intake velocities will be about 7.6 fps.

4. The exit channel downstream from the structure has a 300-ft-wide base width with 1V:4H side slopes and a design invert el of 81.0. The invert decreases to el 75.0 at the lower miter gates. A 650-ft-long, nonported guard wall separates the downstream lock approach channel from the spillway exit channel. The top of the guard wall is set at el 121.5, which is 2 ft above the tailwater for the 10-year-frequency flow of 134,000 cfs. The guard wall is attached to the lock wall, which extends 125 ft downstream from the lower miter gate. The outlet manifolds are located in the lock sidewalls immediately downstream from the lower miter gate recesses. Each manifold has eight 4.5-ft-wide by 7-ft-high ports with an invert el of 73.0, which is 2 ft below the channel invert. Normal lock operations are expected to flush sediment out of the exit ports.

5. Lock and Dam No. 4 is designed to maintain a normal pool el of 120.0 and to pass the 100-year-frequency project flood of 227,400 cfs. The minimum downstream tailwater is el 95.0, which is the normal pool elevation maintained at Lock and Dam No. 3.

Purpose and Scope of the Model Study

6. Lock and Dam No. 1 on the Red River was opened in the fall of 1984. Deposition of fine sediment in the upstream and downstream lock approach channels was much greater than anticipated. Dredging was required at the entrance to the upstream approach channel and throughout the downstream approach channel. Sediment deposition at the downstream miter gate was severe enough to prevent operations. The lock chamber eventually had to be dewatered to clean out the deposited sediment and repair the miter gates. Two-dimensional numerical model studies were employed by the US Army Engineer District (USAED), Vicksburg, and the US Army Engineer Waterways Experiment Station (WES) to address the fine sediment problem at Lock and Dam No. 1 (Little 1985, Copeland and Thomas 1988). As a result of these studies, design modifications were

recommended and constructed at Lock and Dam No. 1. After 3 years of operations these modifications appear to have significantly reduced the fine sediment problems in the lock approach channels (Copeland, Combs, Little 1989). Using the same two-dimensional numerical approach as was employed at Lock and Dam No. 1, the model study of Lock and Dam No. 4 was conducted to identify sedimentation problems at that site and develop appropriate remedial measures.

7. Upstream and downstream numerical models were developed. The downstream model simulated the river for about 0.7 mile downstream from the dam to the end of the excavated channel. The upstream model also modeled the area between the dam and the natural river, which was about 0.8 mile. These models were used to evaluate fine sediment deposition in the lock approach channels and near the miter gates. Results of the numerical modeling of fine sediment deposition were coordinated with other WES studies to achieve a recommended design that adequately satisfied the needs of navigation, bed-load sediment transport, and considerations related to the hydraulic structure itself.

PART II: THE MODEL

Description

8. The two-dimensional numerical model study was conducted using the TABS-2 modeling system (Thomas and McAnally 1985). This system provides two-dimensional solutions to open-channel flow and sediment problems using finite element techniques. It consists of more than 40 computer programs to perform modeling and related tasks. A two-dimensional depth-averaged hydrodynamic numerical model, RMA-2V, was used to generate current patterns. RMA-2V employs a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. The turbulent exchange coefficients in these equations are treated as input parameters in the numerical model. Friction is calculated using Manning's equation. Current patterns from RMA-2V are coupled with the sediment properties of the river and used as input to a two-dimensional sedimentation model, STUDH. STUDH solves the convection-diffusion equation with bed source and sink terms. Sediment diffusion coefficients in these equations are unknowns and must be adjusted in the numerical model. The Ackers-White equation (Ackers and White 1973) is used to calculate a sediment transport potential from which the actual transport is calculated based on availability of sediment in the bed. The other programs in the system perform digitizing, mesh generation, data management, graphical display, output analysis, and model interfacing tasks. Although TABS-2 may be used to model unsteady flow, only steady-state conditions were simulated in this study. Input data requirements for the hydrodynamic model, RMA-2V, include channel geometry, Manning's roughness coefficients, turbulent exchange coefficients, and boundary flow conditions. The sediment model, STUDH, requires hydraulic parameters from RMA-2V, sediment characteristics, inflow concentrations, and sediment diffusion coefficients. Sediment is represented by a single grain size. Due to the uncertainty related to the turbulent exchange and diffusion coefficients in the two models, prototype and/or physical model data for adjustment purposes are highly desirable.

Finite Element Network

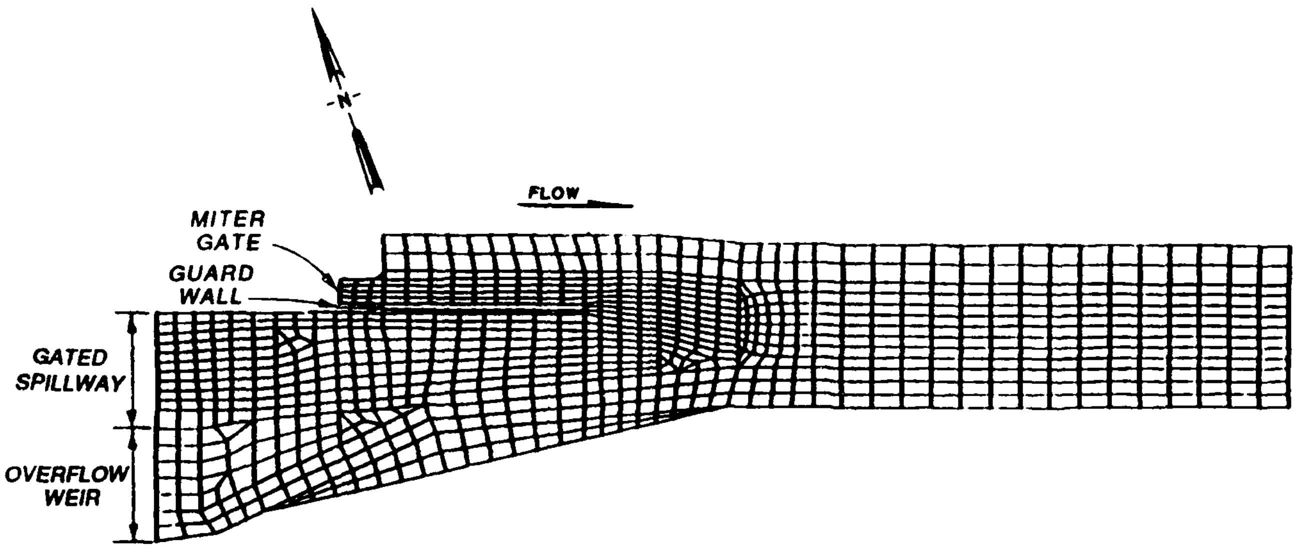
9. Finite element networks were developed to simulate about 0.7 mile of

the Red River downstream from Lock and Dam No. 4 (Figure 3a) and 0.8 mile upstream (Figure 3b). The downstream network contained 834 elements and included lock approach and spillway exit channels and the excavated exit channel to the natural river. The upstream network contained 1,039 elements and included the lock and spillway approach channels, the overflow weir, and the ported guard wall. Conveyance through the ported guard wall was simulated in a depth-averaged sense by treating the wall as a weir, adjusting the crest elevation to achieve the correct flow area, and increasing Manning's roughness coefficients to account for pier losses. Increased grid resolution behind the guard wall was added to allow the model to reproduce eddies. Initial bed elevations for both models were obtained from the Vicksburg District and represent conditions prior to opening of the structure. Slip boundaries were specified for most of the grid perimeter, allowing velocities to be calculated at these locations. This eliminated the need for fine grid resolution adjacent to the boundary where the lateral velocity gradient is steep. Some of the boundary nodes were specified as "stagnation points," i.e., locations of zero velocity. These specifications are generally located in corners of the grid or along boundaries that have negligible flow velocities and are employed to ease calculation of slope for slip boundaries. Tailwater was assigned at the downstream boundary of each grid and inflow distribution specified at the upstream boundary. Grid boundary specifications are shown in Figure 4.

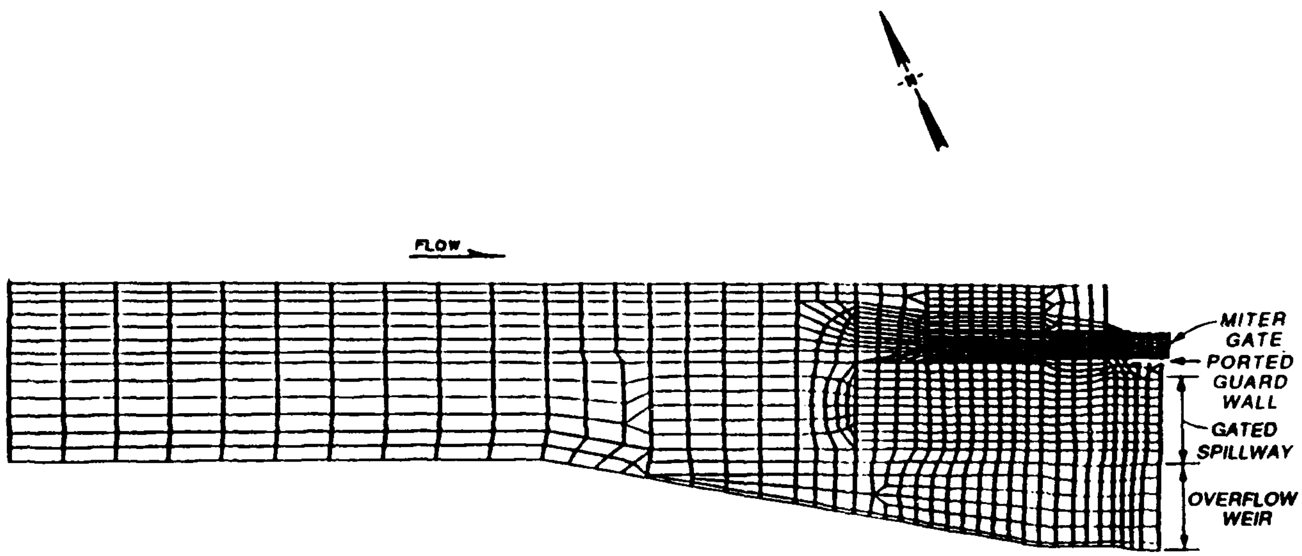
Hydrodynamic Boundary Conditions

10. Steady-state discharges of 90,000 and 145,000 cfs were modeled in this study. Spillway tainter gates carry the total flow at a discharge of 90,000 cfs. At 145,000 cfs, the flow is divided between the spillway tainter gates and the overflow weir, with 116,000 cfs passing through the tainter gates and 29,000 cfs over the overflow weir (USAED, Vicksburg, 1987).

11. Lateral flow distribution across the upstream boundary of the upstream model was taken from results of the far-field numerical model study of Lock and Dam No. 4 (Schneider, in preparation). Pool elevations for the upstream model were taken from results of the 1:40-scale physical model study of Lock and Dam No. 4 (Leech, in preparation), which was used to determine losses through the lock and dam. Pool elevations were determined at the upstream end of the ported guard wall to minimize the influence of drawdown at the spillway

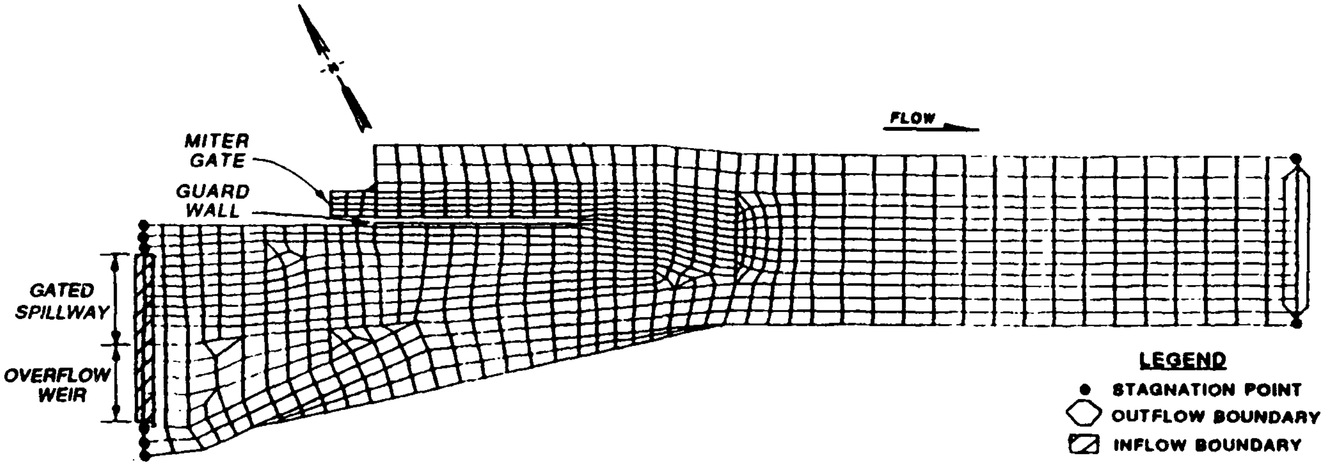


a. Downstream

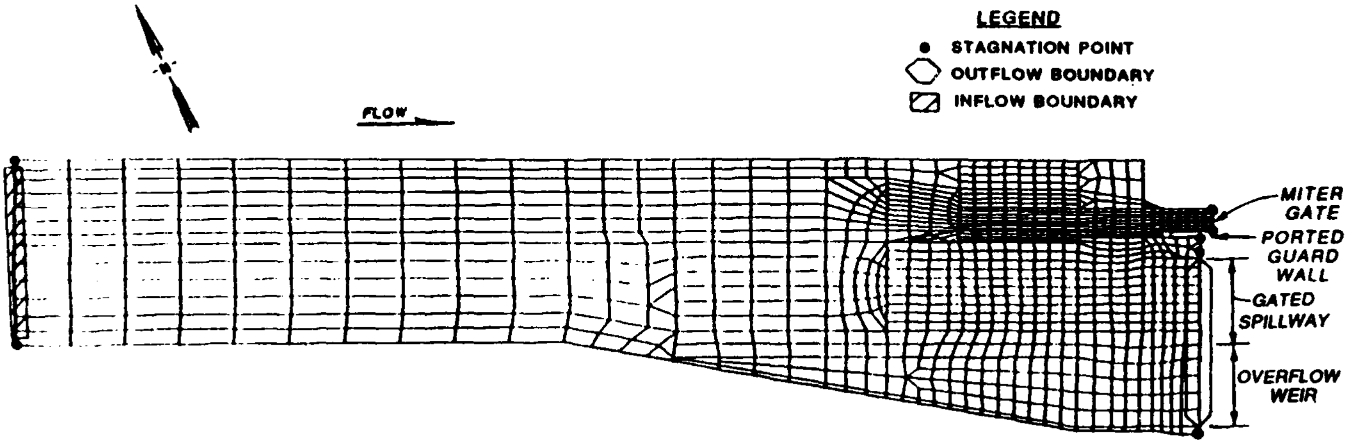


b. Upstream

Figure 3. Finite element grid



a. Downstream



b. Upstream

Figure 4. Boundary specifications

gates. Pool elevations of 120.0 and 124.6 were used for flows of 90,000 and 145,000 cfs, respectively.

12. Calculated flow distribution at the downstream boundary of the upstream model was used as the boundary condition for the downstream model. Tailwater elevations were based on the published tailwater rating curve at Lock and Dam No. 4 (USAED, Vicksburg, 1987). The tailwater elevation was taken to occur 200 ft downstream from the end of the guard wall, midchannel between the extension of the guard wall and the right-bank toe. Trial tailwaters were applied at the downstream boundary of the numerical model until the published tailwaters were calculated at the designated location. Published tailwaters were at el 114.3 and 120.8 for flows of 90,000 and 145,000 cfs, respectively. At the model boundary, starting water-surface elevations were 0.5 ft lower.

Roughness Coefficients

13. Manning's roughness coefficients were assigned to each element. The roughness coefficient for elements on the channel bottom with a sand bed was set at 0.017. This value was used by the Vicksburg District in their study upstream of Lock and Dam No. 1 (Little 1985) and is based on grain size and water-surface elevation adjustments to their numerical model. Riprap placed on the channel bottom and side slopes and on dikes had a D_{50} that varied between 10 and 40 in. The Limerinos equation (Limerinos 1970), which includes relative roughness as a variable, was used to calculate roughness coefficients for the different features through a range of depth:

$$n = \frac{0.0926R^{0.1667}}{1.16 + 2.0 \log (R/D_{84})} \qquad (1)$$

where

n = Manning's roughness coefficient

R = hydraulic radius

D_{84} = particle size of which 84 percent of the bed is finer

Average depths were used to calculate a roughness coefficient on side slopes. Calculated values were adjusted slightly to account for additional losses due to disturbance of the hydrostatic velocity distribution. These adjustments were made based on comparisons to measured data from physical model studies at John H. Overton Lock and Dam (Lock and Dam No. 2) (Comes, Copeland, and Thomas 1989) and Lock and Dam No. 3, and prototype measurements at Locks and Dams Nos. 1 and 2. The following roughness coefficients were assigned in the numerical model:

Feature	Assigned Value
Sand bottom	0.017
Riprap bottom	0.040
Riprap side slope	0.045
Boundary elements	0.055
Riprap berm	0.045
Upstream guard wall (submerged weir)	0.060
Submerged dikes (downstream, at guard wall)	0.060

These values are compatible with those used in previous work at locks and dams on the Red River.

Turbulent Exchange Coefficients

14. Momentum exchanges due to velocity gradients are approximated in RMA-2V by multiplying a turbulent exchange coefficient times the second derivative of the velocity with respect to the x- and y-directions. Limited guidance is available for selection of these coefficients. Previous studies of Red River locks and dams (Little 1985, Copeland and Thomas 1988, Comes, Copeland, and Thomas 1989) have verified values for these coefficients using measured data from physical models and the prototype. Sensitivity studies conducted in these previous studies indicated that a coefficient of 25 lb-sec/sq ft was satisfactory. For this study, the element aspect ratios remained approximately the same and the turbulent exchange coefficients of 25 lb-sec/sq ft were selected.

Bed Material

15. The TABS-2 system analyzes sediment movement using a representative grain size. This technique works well with fairly uniform bed material. Unfortunately, bed material size will vary considerably around the structure

as well as laterally across the channel. Since the complex variation of bed material size cannot be accounted for in the numerical model, a representative size must be selected for the area of primary interest. For this study, measured data from Lock and Dam No. 1 were applied at Lock and Dam No. 4 because Lock and Dam No. 4 was not in operation and data from the site were not available. Previous one-dimensional numerical model work (Copeland and Thomas 1988) demonstrated the reasonableness of this application by showing that the variation in average bed material gradation in the Red River downstream from Shreveport is very slight. Bed samples from deposits in the upstream and downstream lock approach channels at Lock and Dam No. 1 had D_{50}'s between 0.07 and 0.04 mm. Based on these samples, the Vicksburg District chose an average grain size of 0.07 mm for their upstream numerical model study. Differences between this measurement and subsequent measurements upstream and downstream from Lock and Dam No. 1 were deemed insufficient to forsake consistency, and an average grain size of 0.07 mm was adopted for numerical simulations of deposition in the lock approach channels for all lock and dam studies on the Red River.

Sediment Concentration

16. The sediment inflow concentration for the numerical model is a function of the representative grain size used in the study. Only the portion of the total sediment load that contributes to bed changes in the primary area of interest should be included. Using the bed material gradation in the upstream lock approach channel at Lock and Dam No. 1 with a median diameter of 0.07 mm, it was determined that only very coarse silt and very fine sand (0.031-0.125 mm) would be considered in determining sediment inflow.

17. Sediment inflow concentrations for the numerical model were determined from analysis of measured sediment data at Shreveport. Total sediment concentrations were measured between 1977 and 1986. Only the data taken in 1977 had size-class distributions in the silt range. The 1977 data were used to develop a relationship between the total measured load and the percentage of very fine sand and coarse silt. This relationship was applied to the 9-year data base to obtain a sediment inflow curve for the size class between 0.031-0.125 mm. These data had to be extrapolated for discharges greater than 100,000 cfs. Measured data at Alexandria, LA, were used to establish the

validity of the extrapolation. Regression curves of total concentration at Alexandria (1971-79) and Shreveport (1977-86) were parallel; Shreveport concentrations were slightly higher. These data are compared in Figure 5. The concentration rating curve used in this study is shown in Figure 6. From the rating curve it was determined that the concentration of material able to be deposited was 1,100 mg/ℓ at 90,000 cfs and 1,800 mg/ℓ at 145,000 cfs.

Sediment Diffusion Coefficients

18. The same sediment diffusion coefficients used in the previous numerical model studies of locks and dams on the Red River (Copeland and Thomas 1988; Little 1985; Comes, Copeland, and Thomas 1989) were used in these studies. Sensitivity studies conducted as part of those studies indicated that calculated deposition was not sensitive to the sediment diffusion coefficient in areas where flow is moving generally in a downstream direction and conveyance is the primary driving force affecting sediment movement. However, in essentially dead-water areas, such as in front of the lock miter gates, deposition is primarily a function of diffusion and the sediment diffusion coefficients are critical. Reproduction of hydrographic survey data from the upstream and downstream lock approach channels at Lock and Dam No. 1 were used to determine the appropriate coefficients for these models.

19. Measured deposition in the downstream lock approach channel at Lock and Dam No. 1 between October 1984 and May 1985 was compared to calculated deposition using sediment diffusion coefficients of 2 m^2/sec (Figure 7). This simulation was especially good for the first 500 ft downstream from the lock gate. For the next 1,000 ft, the model predicted about 75 percent of the measured deposition.

20. Measured deposition in the upstream lock approach channel at Lock and Dam No. 1 between 4 December 1985 and 17 December 1985 was compared to calculated deposition using sediment diffusion coefficients of 0.5, 2.0, and 25.0 m^2/sec. The primary function of the sediment diffusion coefficients is to move fine sediments into the dead-water zones. The prototype measurements indicated that the material moved approximately 500 ft into the dead-water zone. Sediment diffusion coefficients of 0.5, 2.0, and 25.0 m^2/sec moved material 50, 600, and 1,200 ft, respectively, into the dead-water zone.

21. The Lock and Dam No. 1 upstream and downstream numerical models

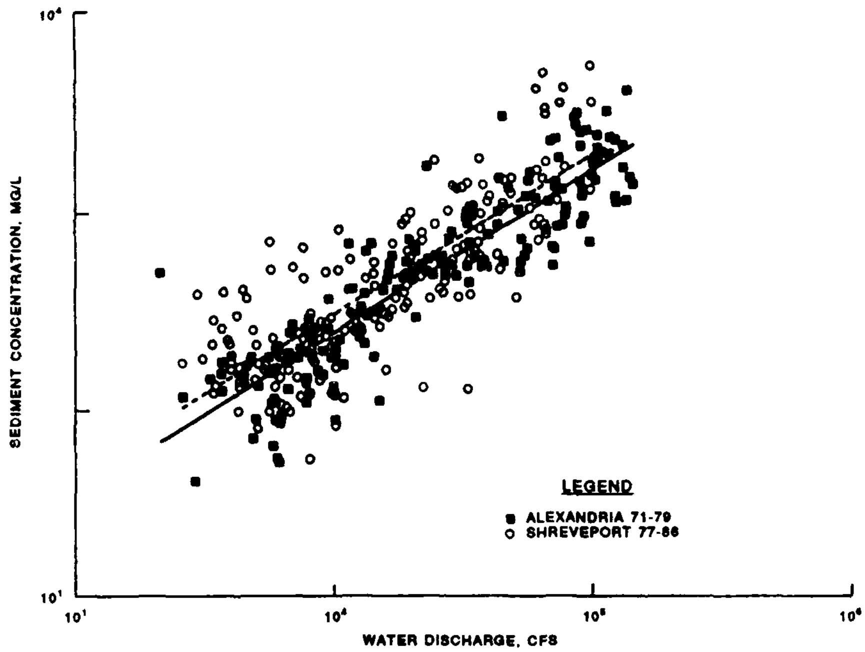


Figure 5. Total measured suspended sediment

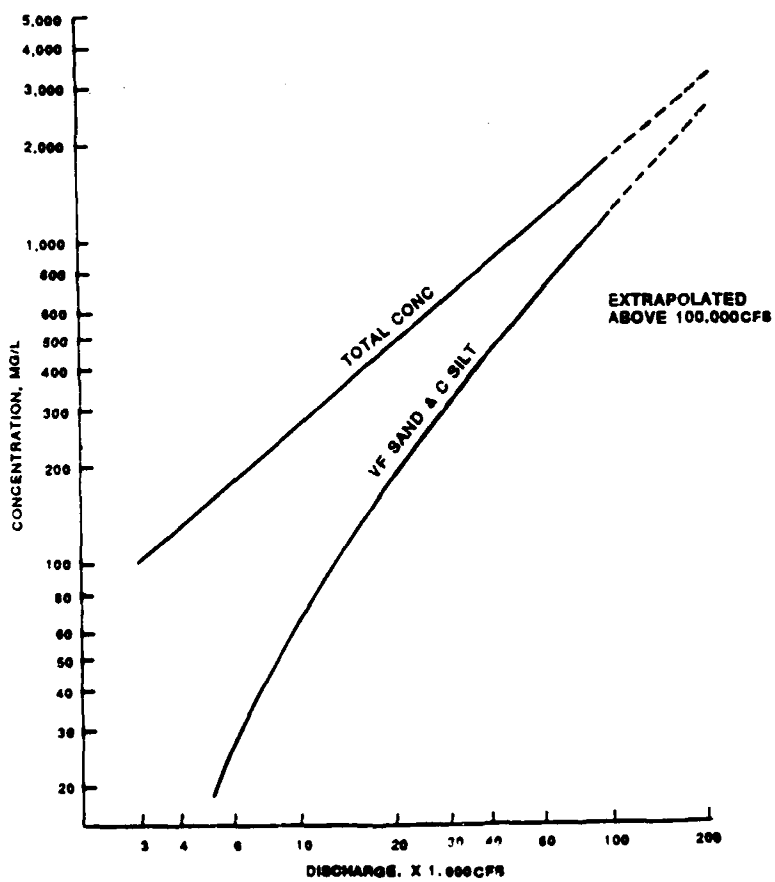


Figure 6. Sediment inflow rating curve

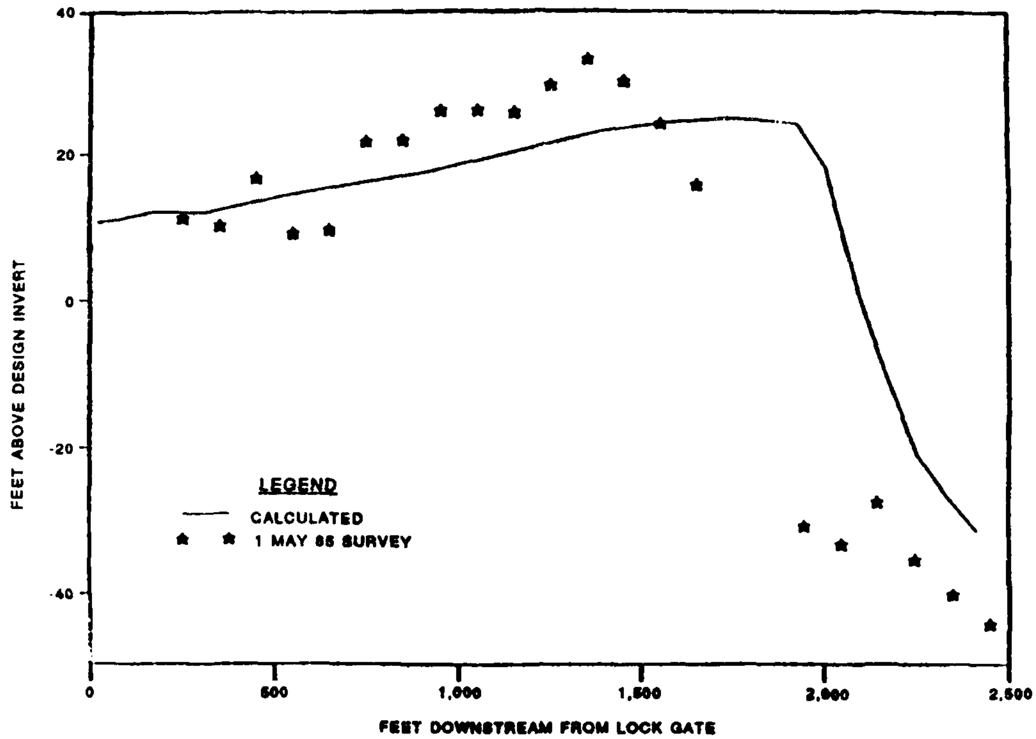


Figure 7. Model adjustment at Lock and Dam No. 1

were deemed to have successfully reproduced the prototype data in the primary area of interest using a sediment diffusion coefficient of 2.0 m^2/sec. This value was adopted for the Lock and Dam No. 4 studies because hydraulic conditions and model grid resolution were similar.

PART III: MODEL RESULTS

Original Downstream Design

22. Velocity and sediment deposition patterns for 10-day simulations with steady-state discharges of 90,000 and 145,000 cfs were calculated for the original design. Velocity patterns in the vicinity of the downstream lock approach channel are shown in Plates 1 and 2. At both flow rates, a counterclockwise eddy developed in the lock approach channel downstream from the unsubmerged guard wall that separates the lock approach and spillway exit channels. Calculations indicated maximum velocities in the exit channel between 6 and 8 fps at 90,000 cfs and between 8 and 10 fps at 145,000 cfs. These velocities will scour the channel unless riprap protection is provided. This conclusion was confirmed by physical model studies at WES (Mueller, in preparation). These hydrodynamic results were used to calculate sediment deposition in the lock approach channel. At 90,000 cfs, about 0.8 ft of material was deposited at the lock miter gate during the 10-day simulation, with the maximum deposition, about 4.8 ft, occurring about 950 ft downstream of the miter gate. At 145,000 cfs, more than twice as much material was deposited, about 2.7 ft at the miter gate and 9.2 ft 950 ft downstream of the miter gate (Figure 8). Deposition contour plots are shown in Plates 3 and 4.

23. Qualitative assessment of deposition in the downstream lock approach channel was made by comparing calculated deposition at Lock and Dam No. 4 with calculated deposition at Lock and Dam No. 1 with conditions similar to the 1985 situation. A discharge of 90,000 cfs and sediment concentration of 670 mg/ℓ were simulated at Lock and Dam No. 4 for a 10-day period. These were characteristic values for peak flow conditions at Lock and Dam No. 1 during the October 1984 to May 1985 period when 11 ft of material deposited at the downstream miter gate (Copeland and Thomas 1988). Calculated deposition in the downstream lock approach channels is shown in Figure 9. This figure also shows the calculated deposition at Lock and Dam No. 4 for a concentration of 1,100 mg/ℓ, which is representative of the expected conditions at that site. It can be concluded from this analysis that the depth of deposition immediately in front of the downstream miter gate at Lock and Dam No. 4 would be about 38 percent of what occurred at Lock and Dam No. 1 in 1985, or about 4.2 ft (38 percent of 11 ft) for a similar hydrological event.

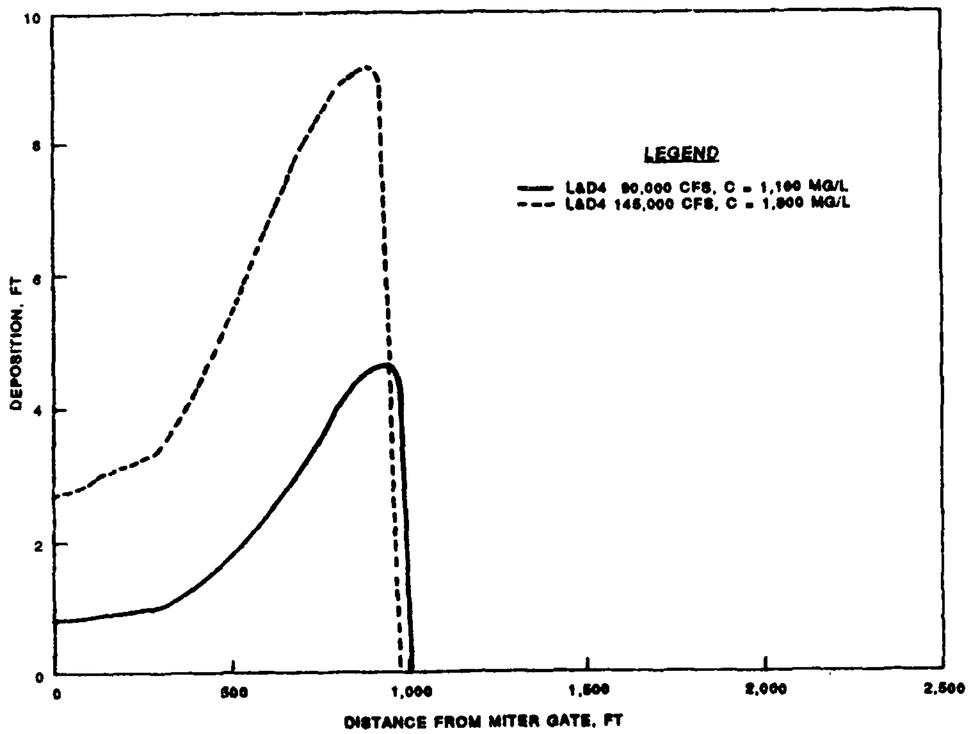


Figure 8. Profile of deposition in downstream lock approach channel, 10-day simulation

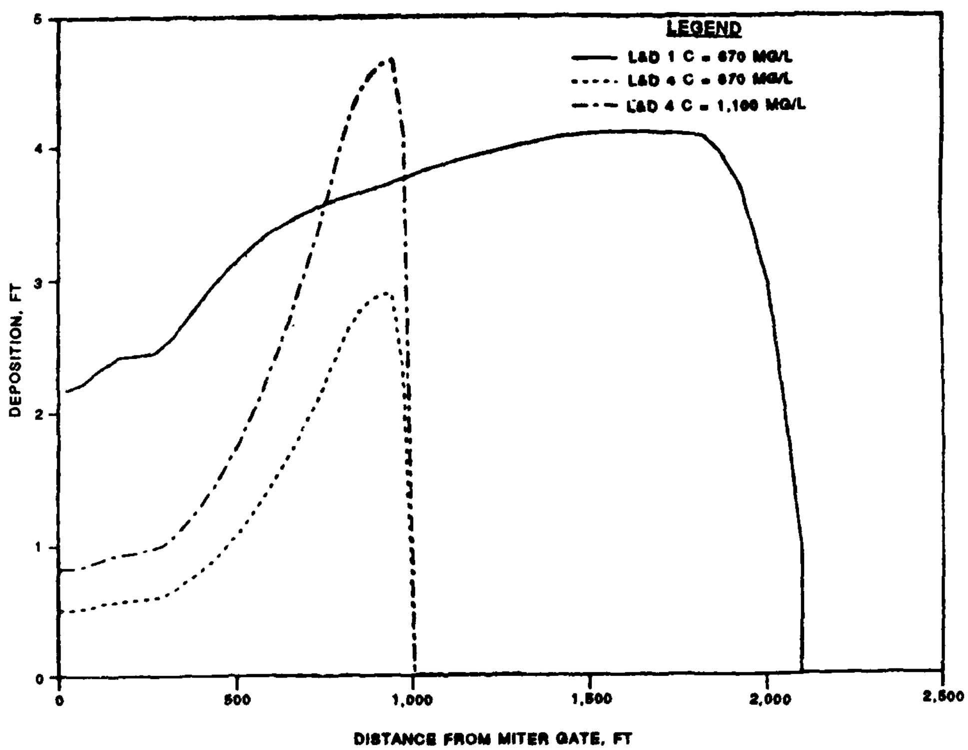


Figure 9. Comparison of deposition profiles for downstream lock approach channel, Locks and Dams Nos. 1 and 4, 10-day simulation at 90,000-cfs discharge

Alternative Downstream Designs

24. The effect of increasing the exit channel base width at Lock and Dam No. 4 from 300 to 400 ft was tested. Fine sediment deposition in the lock approach channel was calculated using discharges of 90,000 and 145,000 cfs for 10-day durations. Deposition contour plots are shown in Plates 5 and 6. These plots show a slight increase of fine sediment deposition in the lock approach channel. Deposition profiles are compared in Figure 10. The extent

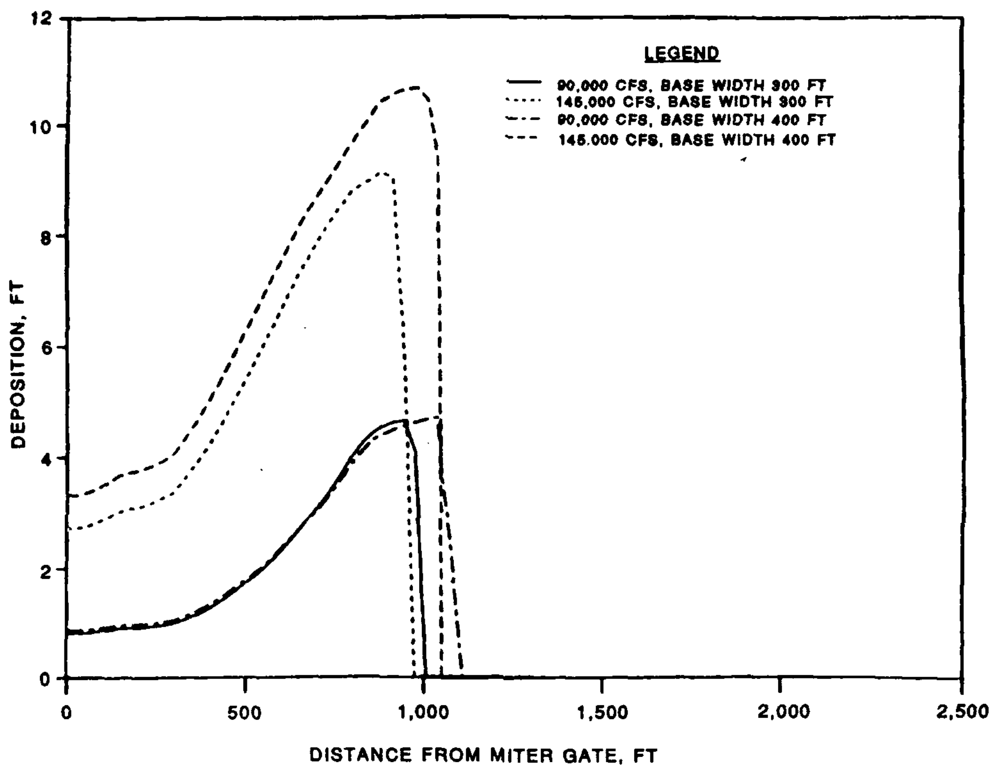


Figure 10. Profile of deposition in downstream lock approach channel, 10-day simulation, effect of 400-ft base width in exit channel

of deposition increases slightly due to redistribution of the flow toward the right descending bank. Flow patterns for 90,000 and 145,000 cfs are presented in Plates 7 and 8, respectively. These plots show that flow patterns are essentially unchanged due to the channel widening. The deposition in front of the miter gates for the 10-day simulation is shown in the following tabulation:

Base Width, ft	Deposition, ft	
	90,000 cfs	145,000 cfs
300	0.8	2.7
400	0.9	3.4

25. The numerical model was used to evaluate the effect of geometry changes in the downstream exit channel that resulted from movable-bed physical model studies at WES (Mueller, in preparation). The finite element grid was revised to simulate an adjustment to the left descending bank alignment, an increase in channel base width to 350 ft, a 100-ft-wide berm on the right descending bank, and a submerged deflector dike that extended from the end of the guard wall. Figures 11 and 12 show a comparison with previous calculations using the original design, which had a 300-ft base width without a berm or dike. The revised design had no significant effect on deposition at 90,000 cfs. However, at 145,000 cfs, a 12 percent increase in fine sediment deposition was calculated at the miter gate. As an independent feature, the submerged dike reduced deposition at the miter gate by 0.3 ft, as shown in the following tabulation:

Adjustment	Deposition, ft	
	90,000 cfs	145,000 cfs
300-ft base width	0.8	2.7
350-ft base width with berm	0.8	3.3
350-ft base width with berm & submerged deflector dike	0.8	3.0

Upstream Design

26. Velocity and sediment deposition patterns for 10-day simulations with steady-state discharges of 90,000 and 145,000 cfs were calculated for the upstream design. Velocity patterns in the vicinity of the lock approach channel are shown in Plates 9 and 10. For both flow rates, flow through the ported guard wall was concentrated at the downstream ports. This result is consistent with previous model study results at Locks and Dams Nos. 2 (Comes, Copeland, and Thomas 1989) and 3 (Comes and Copeland, in preparation), and with prototype observation at Lock and Dam No. 2. At 90,000 cfs, about 4.1 ft of material deposited at the lock miter gate during the 10-day simulation. At

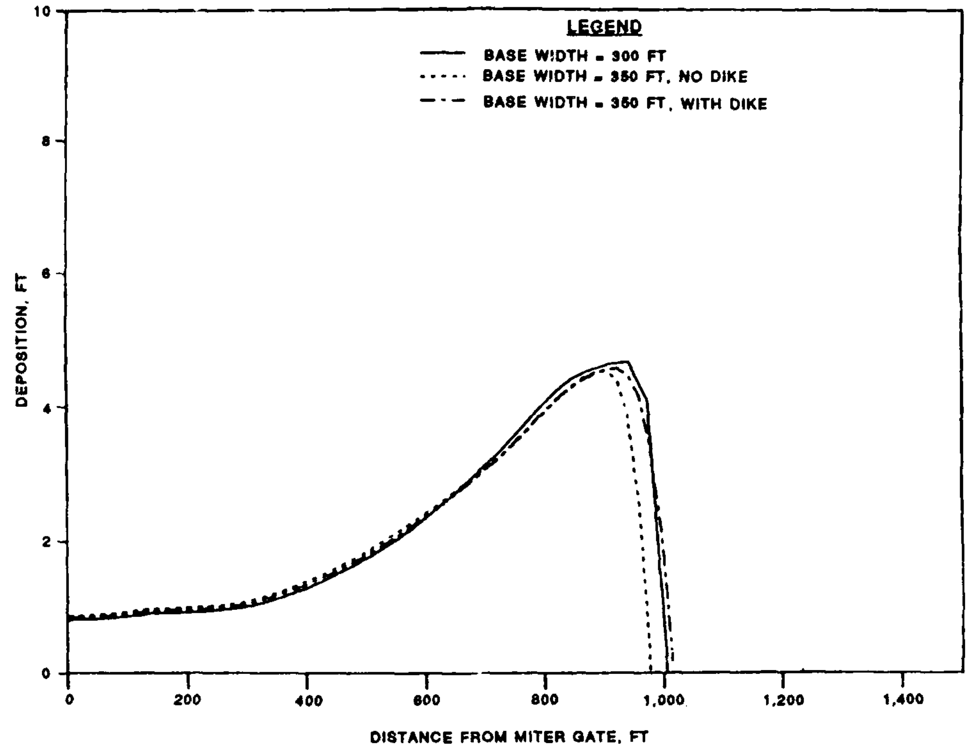


Figure 11. Profile of deposition in downstream lock approach channel, 10-day simulation, effect of 350-ft base width in exit channel at 90,000-cfs discharge and 1,100-mg/ℓ concentration

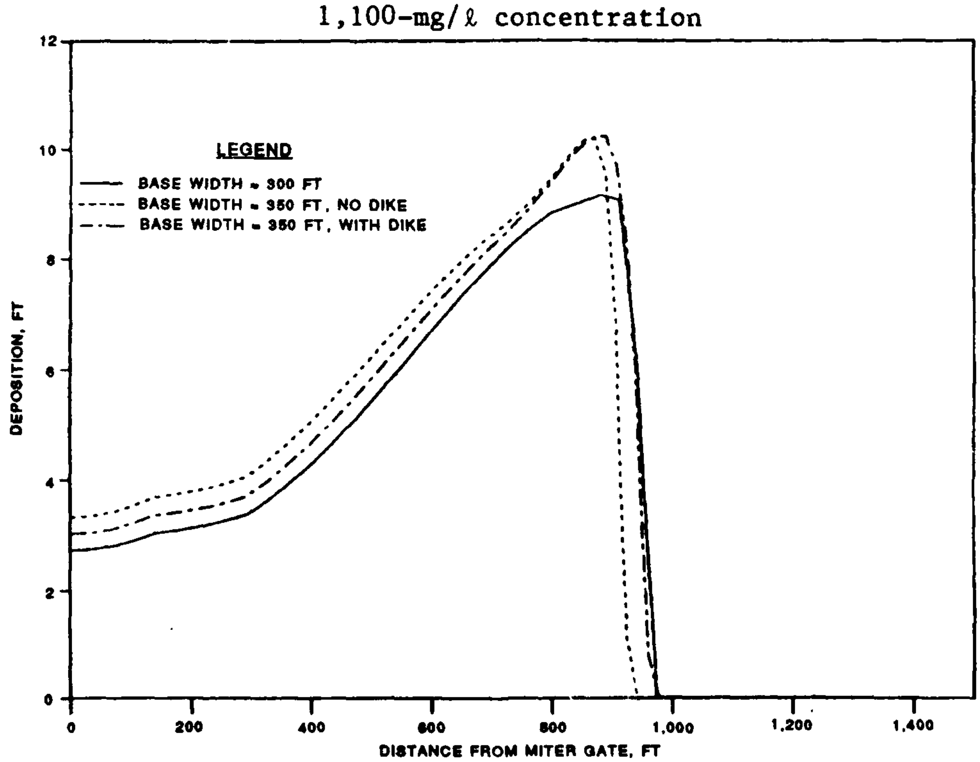


Figure 12. Profile of deposition in downstream lock approach channel, 10-day simulation, effect of 350-ft base width in exit channel at 145,000-cfs discharge and 1,800-mg/ℓ concentration

145,000 cfs, about 9.1 ft of fine material was deposited. Deposition contour plots are shown in Plates 11 and 12.

27. Methods to reduce the sediment deposition against the upstream miter gates were studied extensively with the numerical model at Lock and Dam No. 2 (Comes, Copeland, and Thomas 1989). These included approach channel geometry changes, upstream dikes, reducing openings in the ported guard wall, and extending the guard wall. Studies of reduced openings in the ported guard wall are continuing in an attempt to find an effective solution compatible with navigation requirements. Mechanical sediment removal methods may be required at the upstream miter gate.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

28. The two-dimensional numerical model study demonstrated that there will be significant suspended sediment deposition problems in front of the miter gates at Lock and Dam No. 4 with the proposed design. Deposition at the miter gate in the downstream lock approach channel would be about 38 percent of that experienced at Lock and Dam No. 1 in 1985 or about 4.2 ft for a similar hydrologic event. With a depth of 2.0 ft between the gate sill and the channel invert, some dredging or other mechanical removal technique will be necessary to ensure opening and closing of the gates. Deposition of fine sediment near the upstream miter gates will be much more severe at Lock and Dam No. 4 than was experienced at Lock and Dam No. 1. It will be similar to problems experienced at Lock and Dam No. 2. The ported guard wall brings large quantities of sediment-laden flow close to the lock gates. In order to maintain miter gate operations, mechanical removal of material will be necessary.

29. Increasing the base width of the exit channel and adding a berm on the right descending bank were tested with the numerical model. These geometry adjustments resulted in a slight increase in fine sediment deposition in the downstream lock approach channel.

30. A submerged deflector dike at the end of the downstream guard wall was found to have no significant effect on deposition of fines in the lock approach channel at a discharge of 90,000 cfs. At 145,000 cfs a slight reduction (about 9 percent) in deposition of fines was calculated.

31. The exit channel downstream from Lock and Dam No. 4 should be riprapped all the way to the existing river channel. This conclusion is based on results from both the numerical model study and physical model studies at WES.

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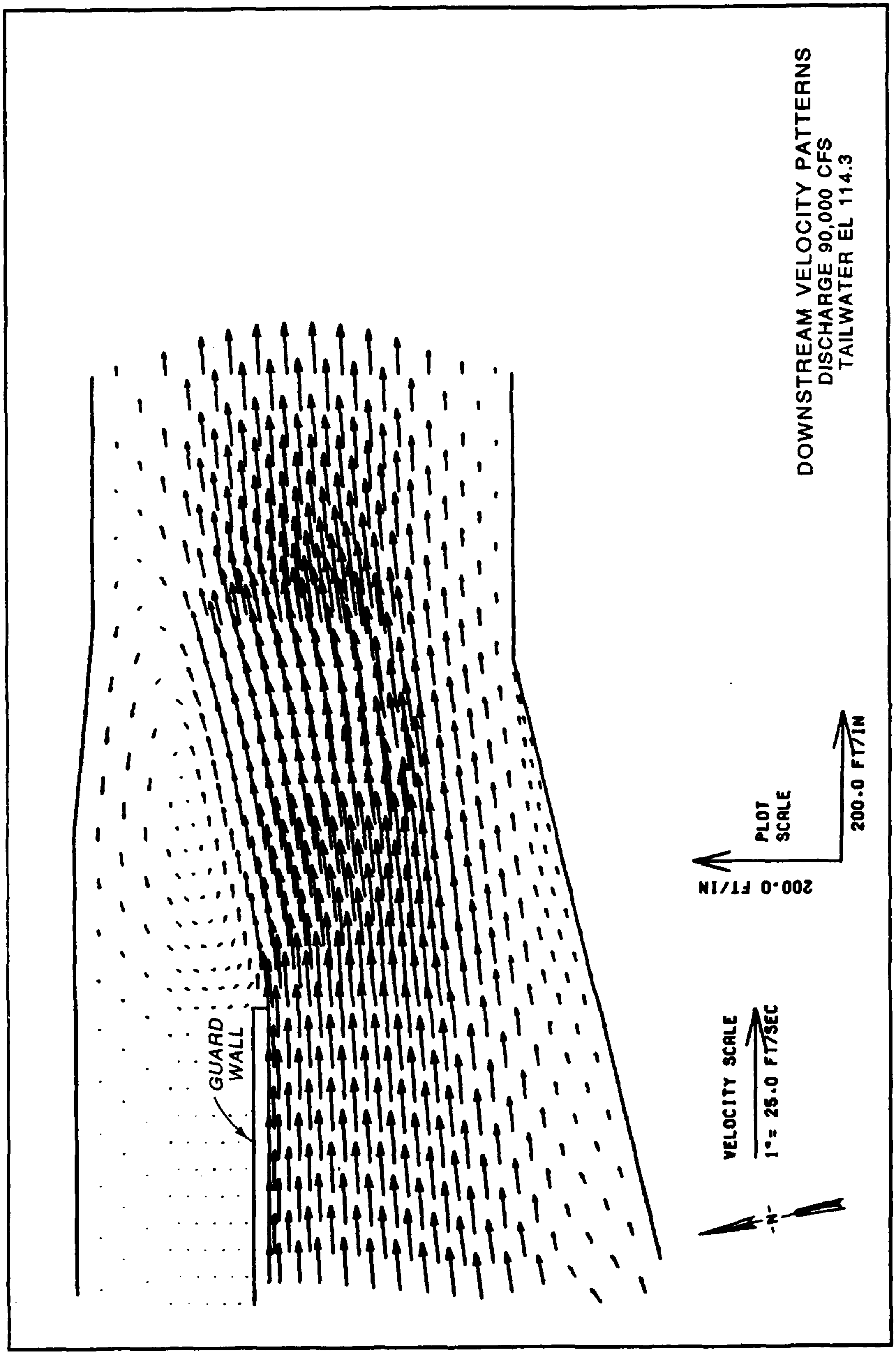
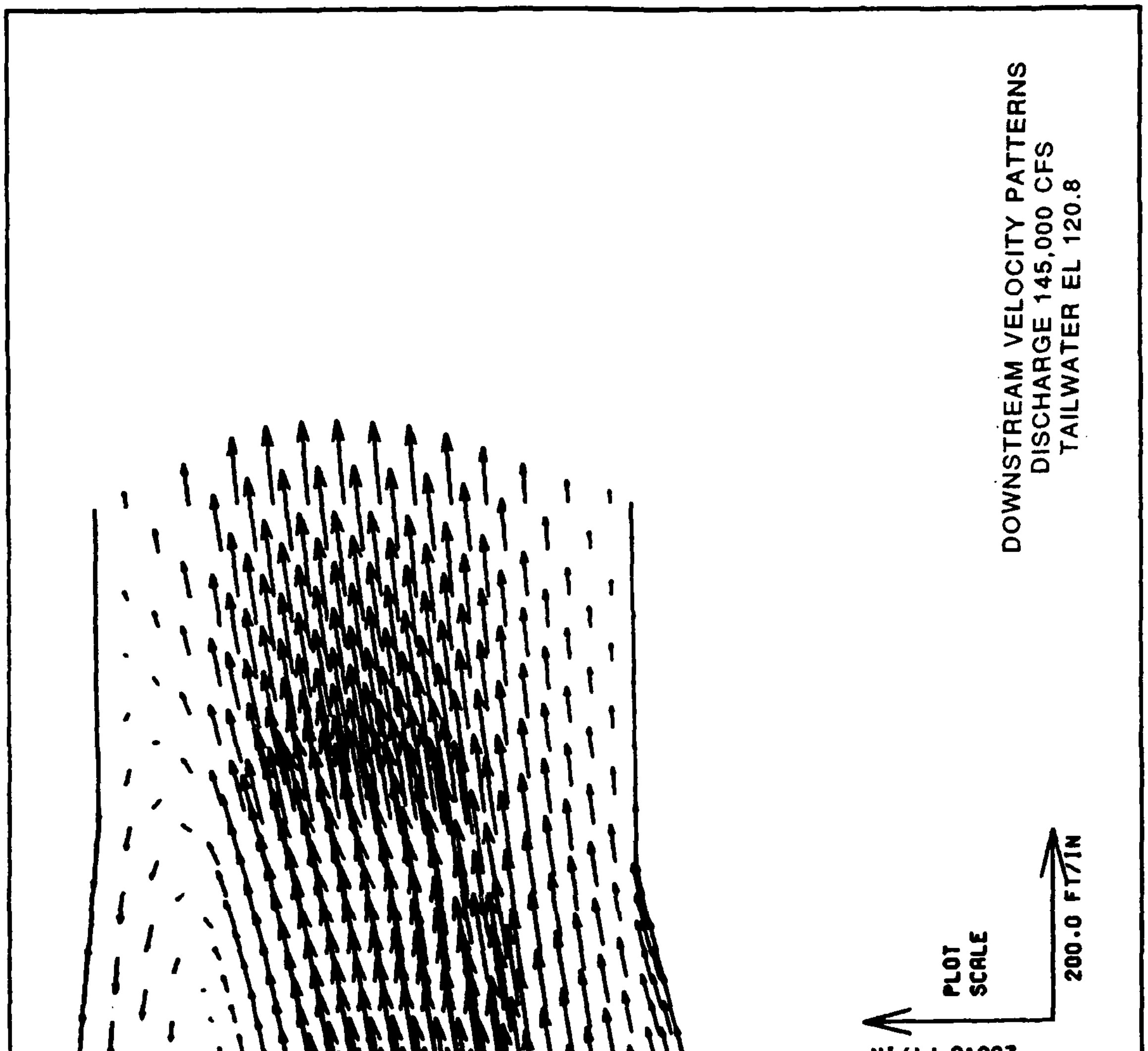
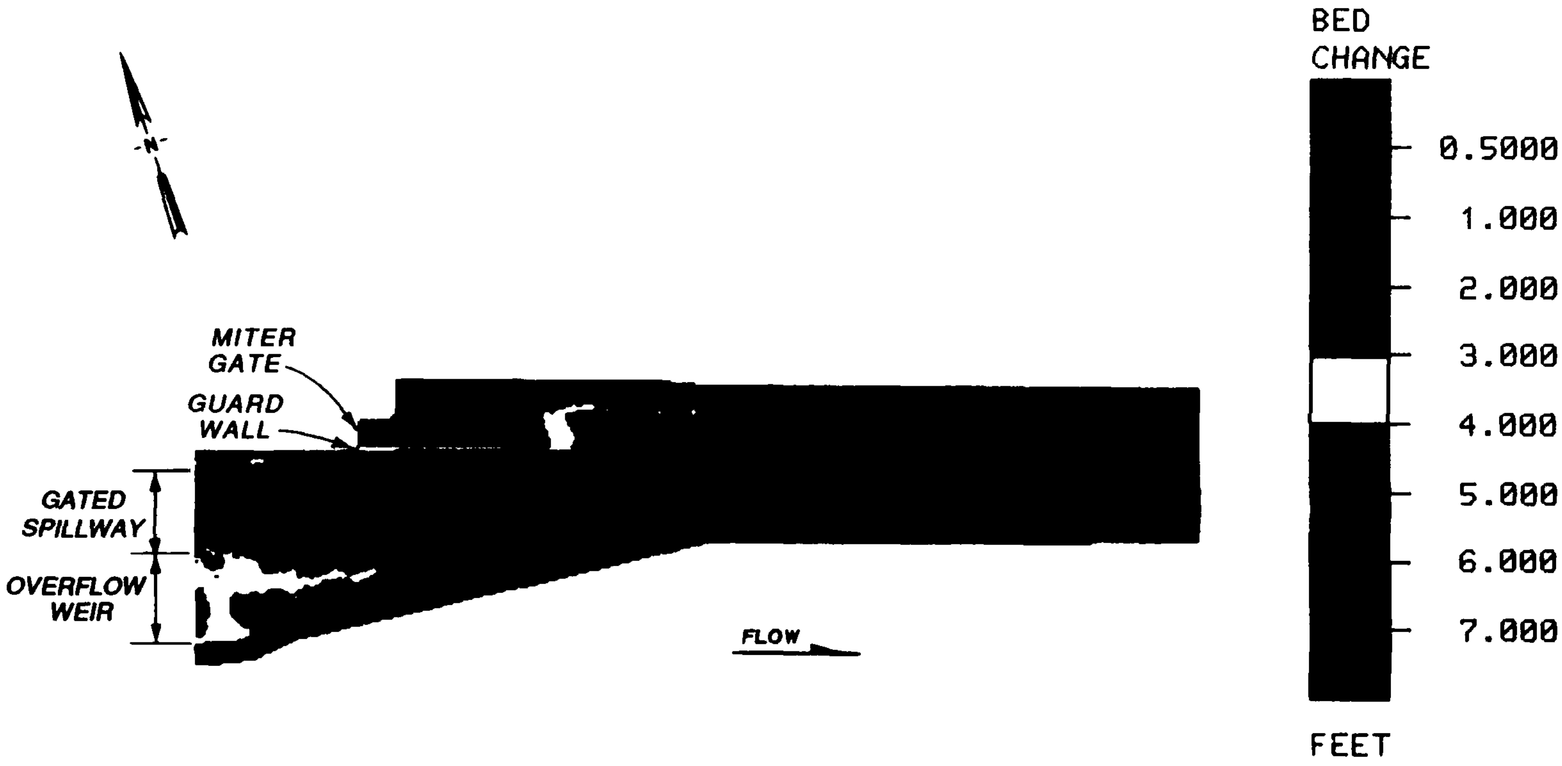

DOWNSTREAM VELOCITY PATTERNS
DISCHARGE 90,000 CFS
TAILWATER EL 114.3
GUARD WALL
PLOT SCALE
200.0 FT/IN
200.0 FT/IN
VELOCITY SCALE
1"= 25.0 FT/SEC
N

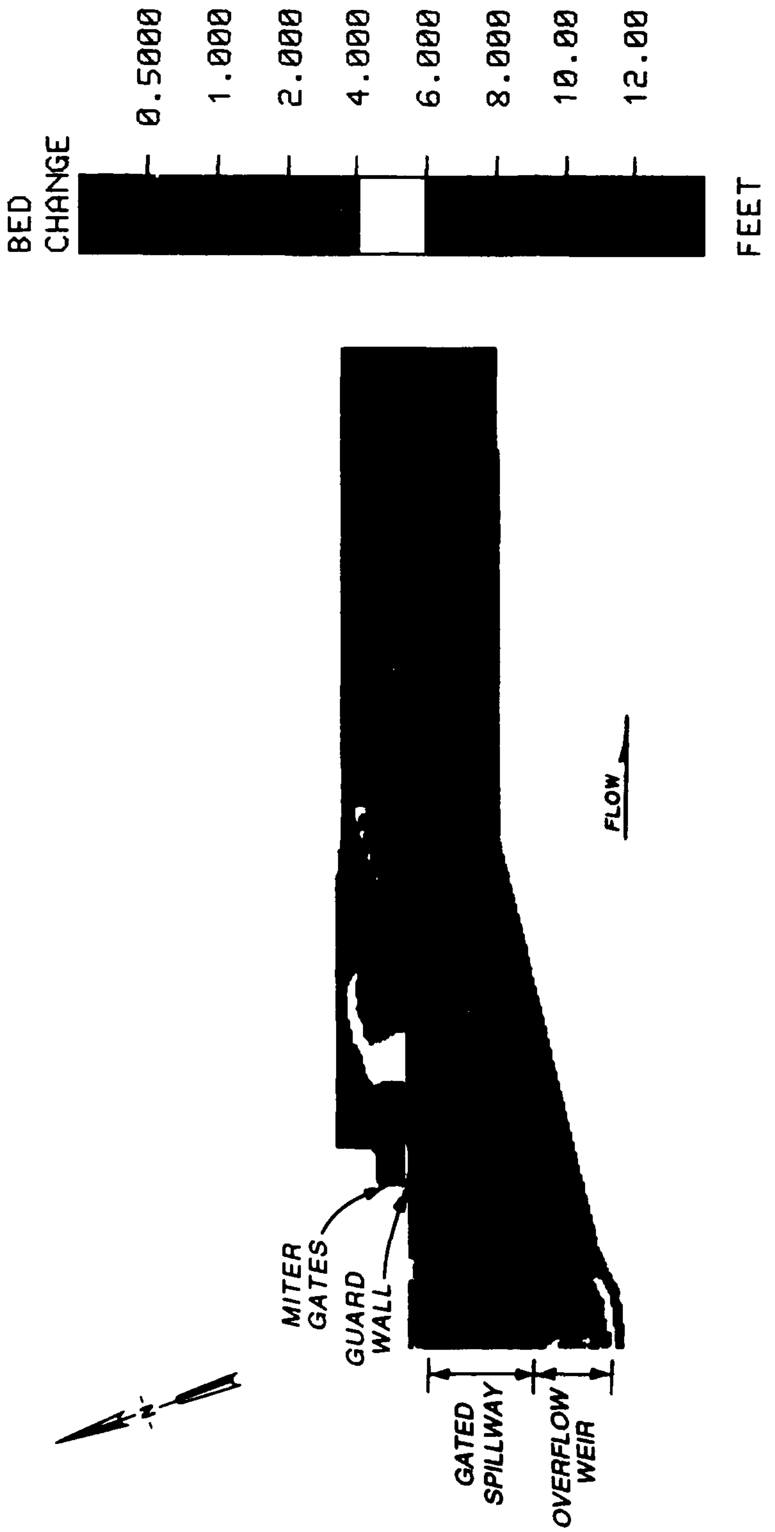
PLATE 1



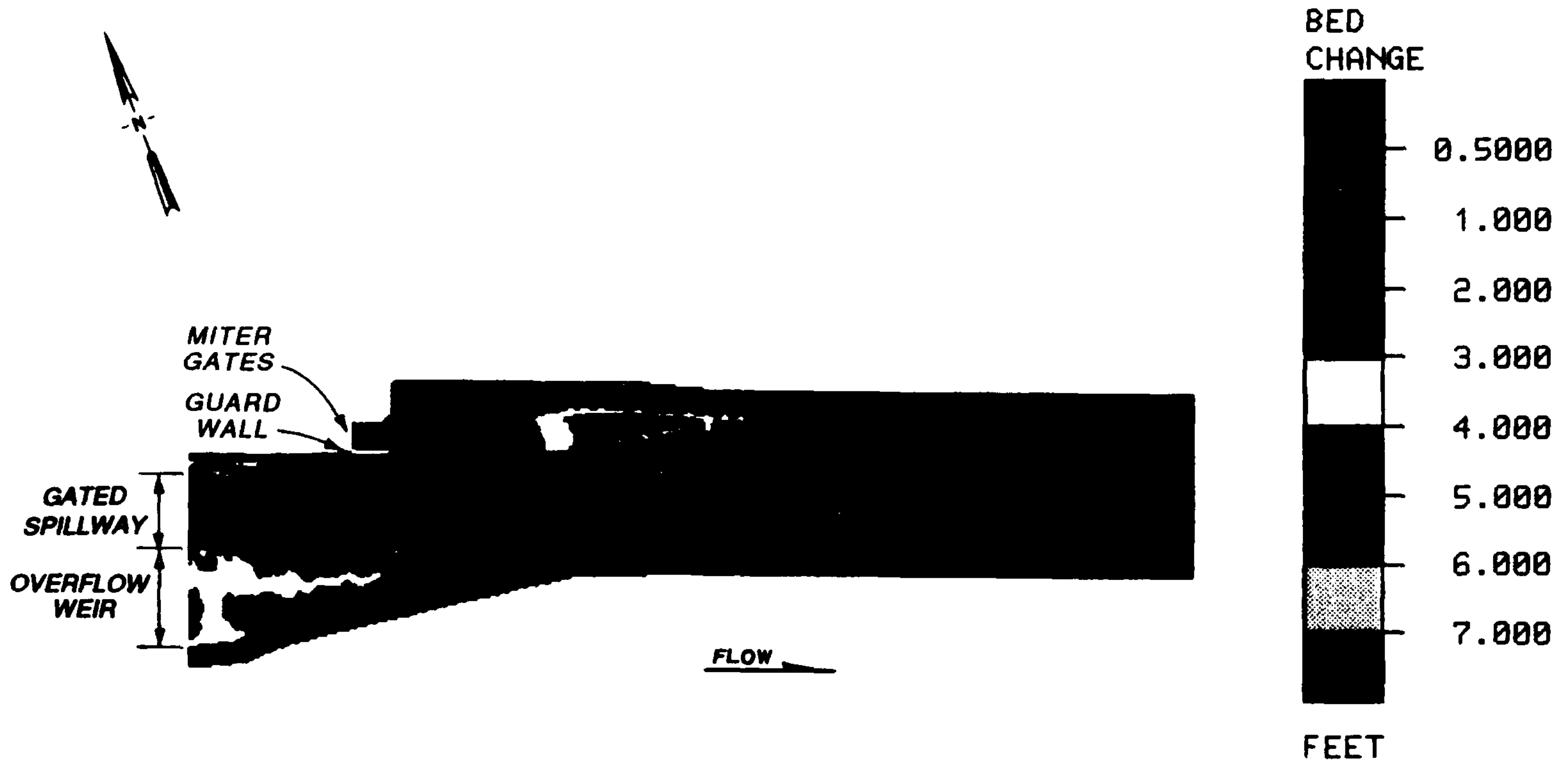
DOWNSTREAM VELOCITY PATTERNS
DISCHARGE 145,000 CFS
TAILWATER EL 120.8



DOWNSTREAM DEPOSITION CONTOURS
10-DAY SIMULATION
DISCHARGE 90,000 CFS
INFLOW CONCENTRATION 1,100 MG/L



DOWNSTREAM DEPOSITION CONTOURS
10-DAY SIMULATION
DISCHARGE 145,000 CFS
INFLOW CONCENTRATION 1,800 MG/L



DOWNSTREAM DEPOSITION CONTOURS
10-DAY SIMULATION
DISCHARGE 90,000 CFS
INFLOW CONCENTRATION 1,100 MG/L
400-FT BASE WIDTH

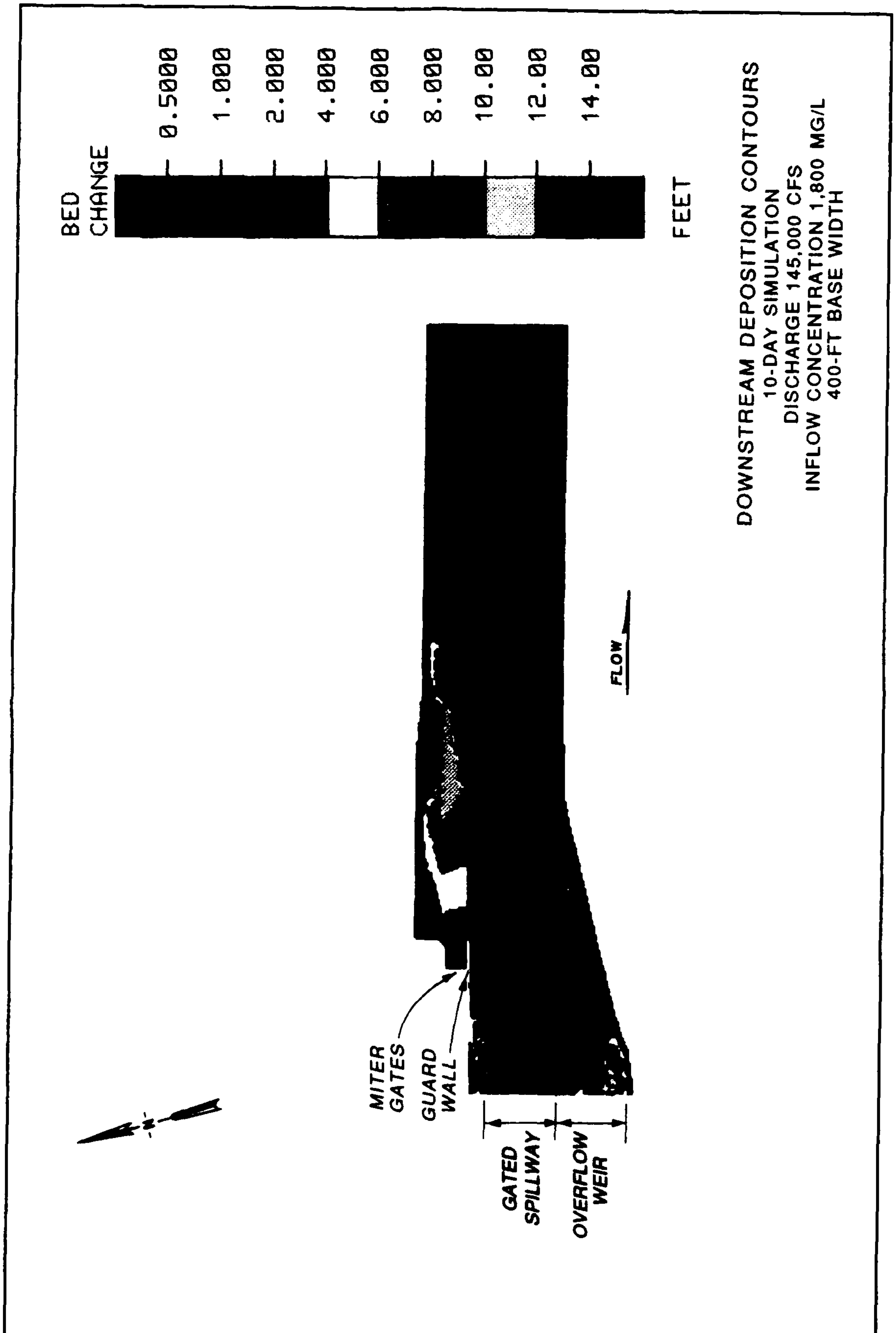
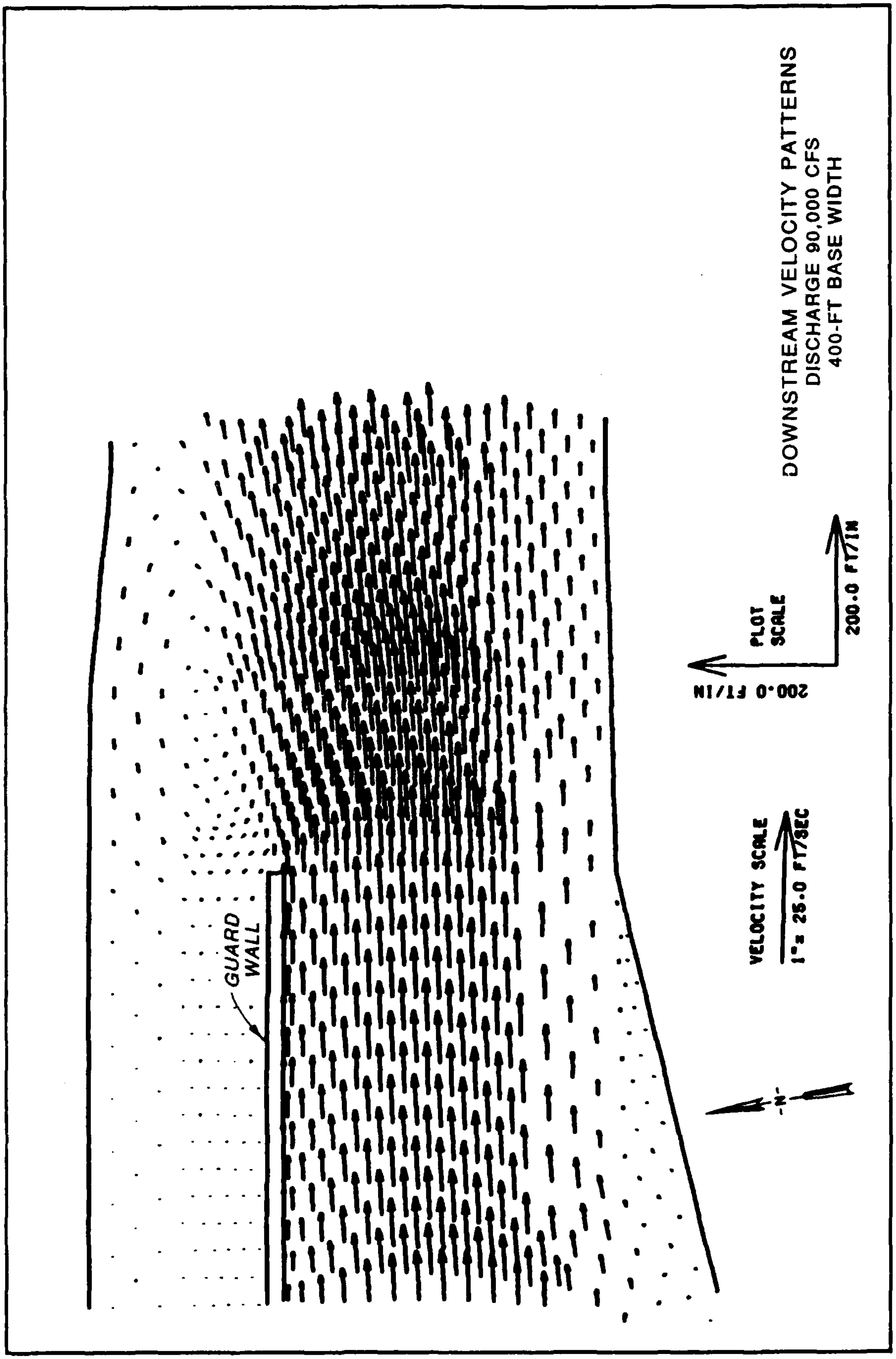

BED CHANGE
0.5000
1.000
2.000
4.000
6.000
8.000
10.00
12.00
14.00
FEET
DOWNSTREAM DEPOSITION CONTOURS
10-DAY SIMULATION
DISCHARGE 145,000 CFS
INFLOW CONCENTRATION 1,800 MG/L
400-FT BASE WIDTH
FLOW
MITER GATES
GUARD WALL
GATED SPILLWAY
OVERFLOW WEIR
N

PLATE 6


DOWNSTREAM VELOCITY PATTERNS
DISCHARGE 90,000 CFS
400-FT BASE WIDTH
GUARD WALL
VELOCITY SCALE
1" = 25.0 FT/SEC
PLOT SCALE
200.0 FT/IN
200.0 FT/IN
N

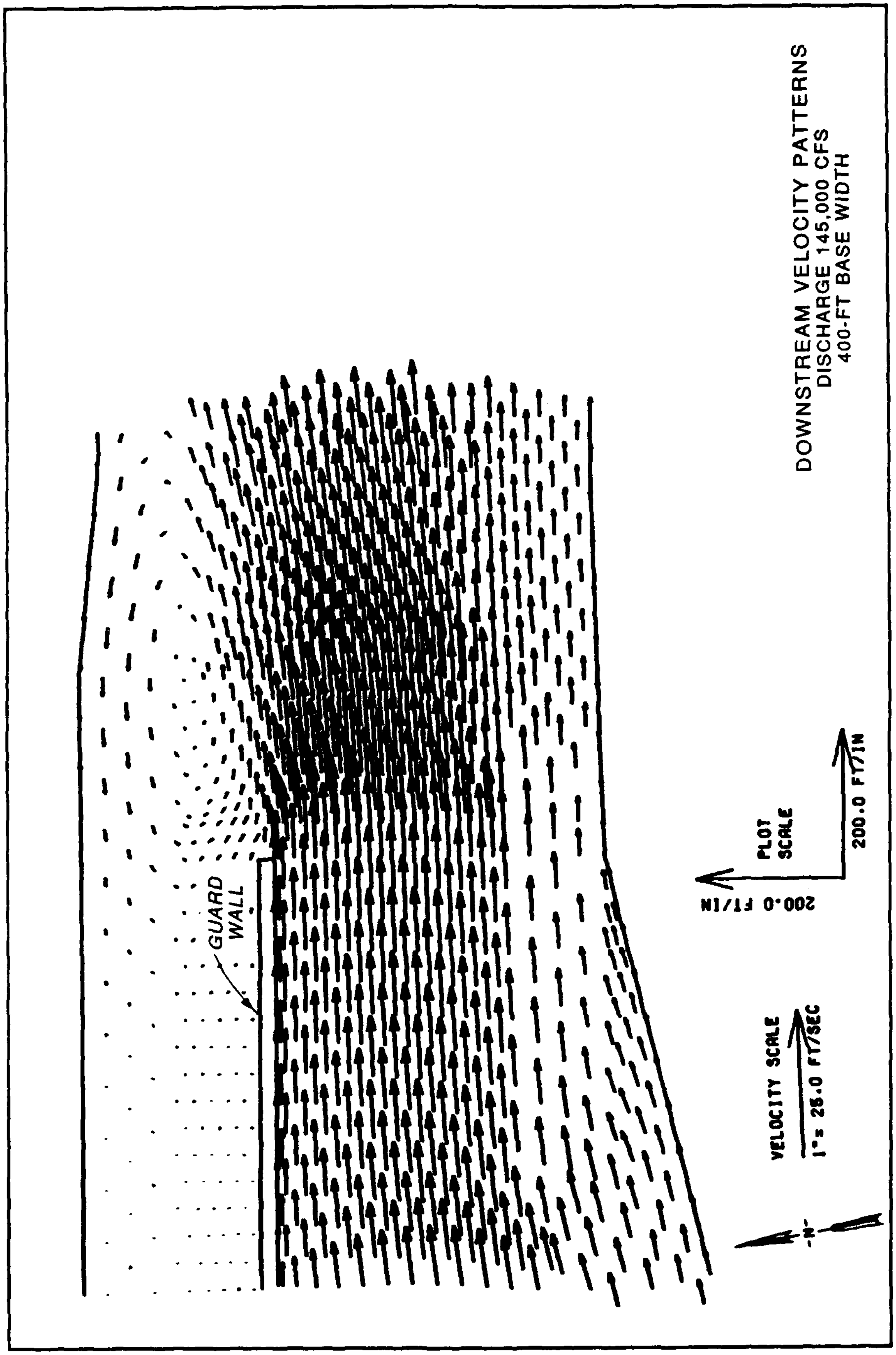

DOWNSTREAM VELOCITY PATTERNS
DISCHARGE 145,000 CFS
400-FT BASE WIDTH
GUARD WALL
PLOT SCALE
200.0 FT/IN
200.0 FT/IN
VELOCITY SCALE
1" = 25.0 FT/SEC
N

PLATE 8

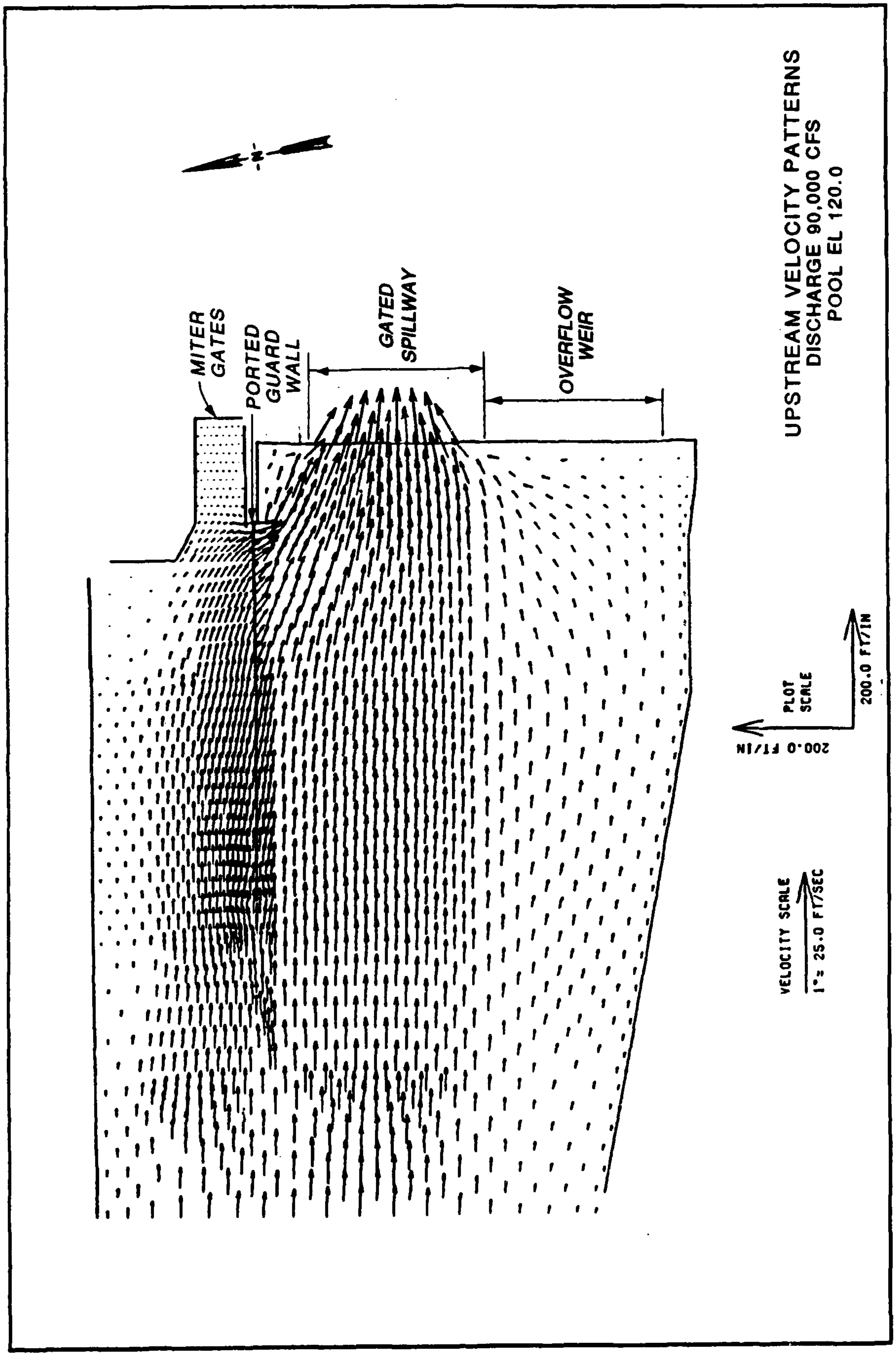

UPSTREAM VELOCITY PATTERNS
DISCHARGE 90,000 CFS
POOL EL 120.0
MITER GATES
PORTED GUARD WALL
GATED SPILLWAY
OVERFLOW WEIR
PLOT SCALE
200.0 FT/IN
200.0 FT/IN
VELOCITY SCALE
1" = 25.0 FT/SEC

PLATE 9

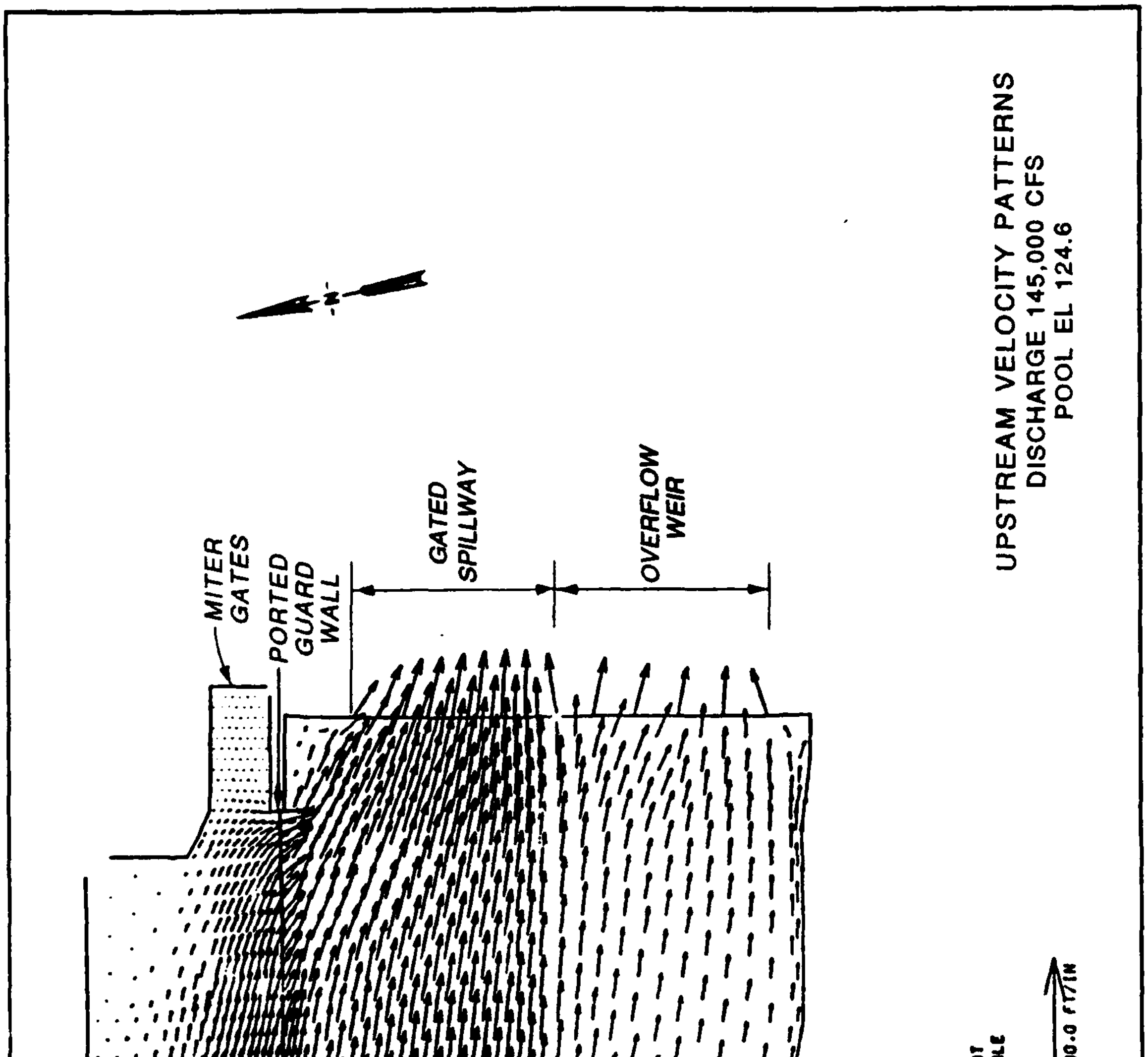
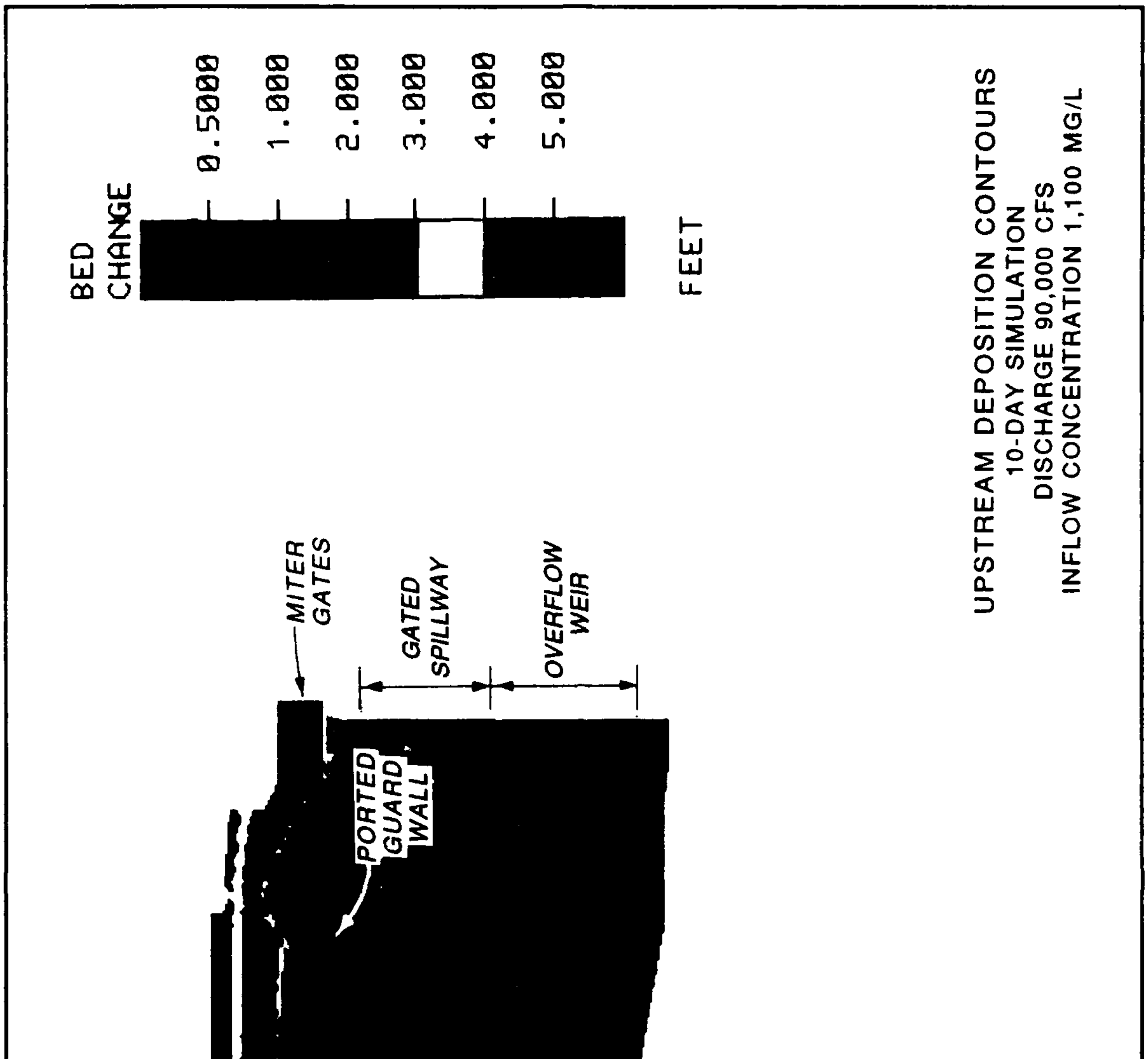
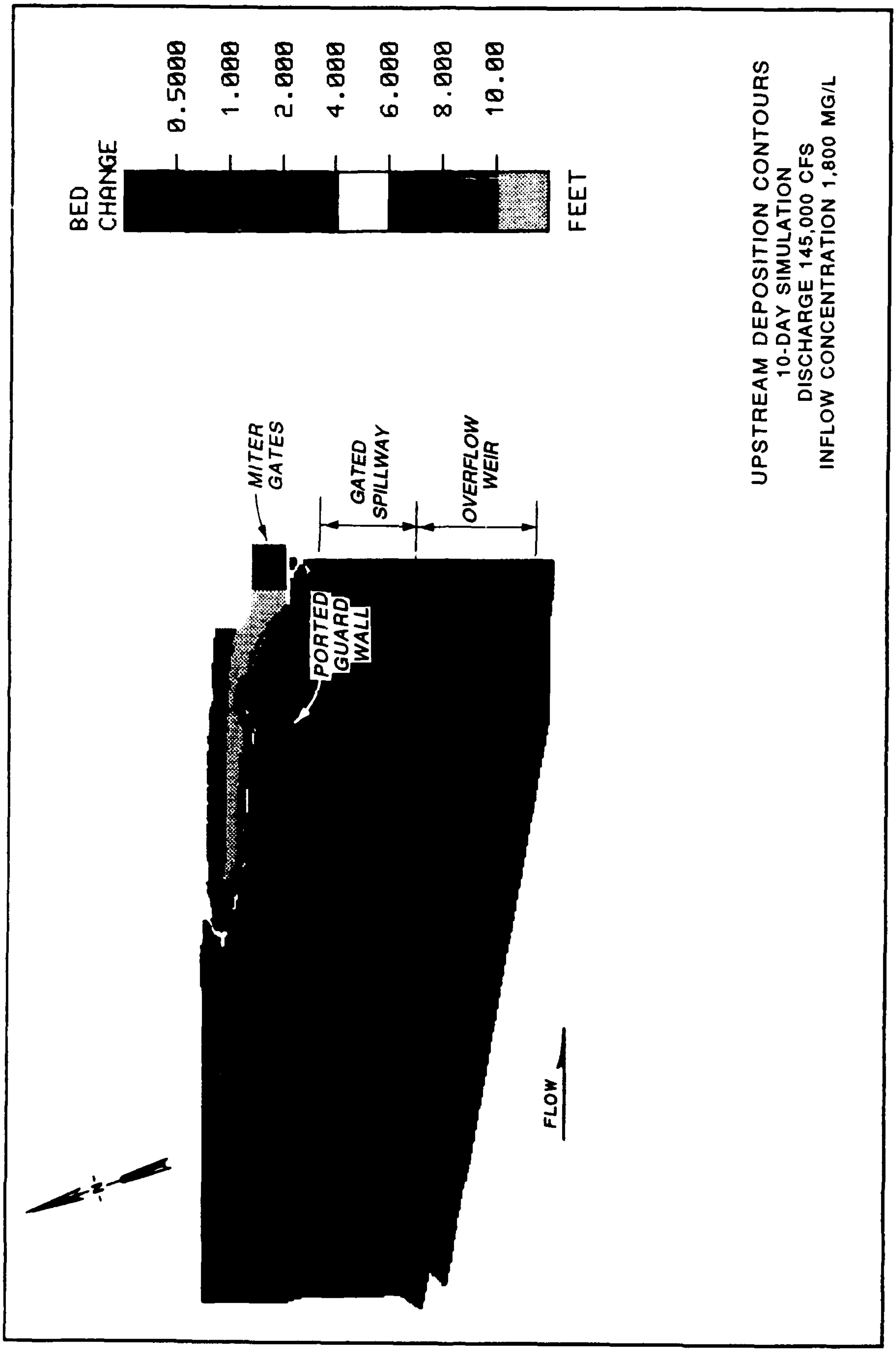

UPSTREAM VELOCITY PATTERNS
DISCHARGE 145,000 CFS
POOL EL 124.6
MITER GATES
PORTED GUARD WALL
GATED SPILLWAY
OVERFLOW WEIR
N
PLOT SCALE
200.0 FT/IN
200.0 FT/IN
VELOCITY SCALE
1" = 25.0 FT/SEC

PLATE 10


BED CHANGE
0.5000
1.000
2.000
3.000
4.000
5.000
FEET
MITER GATES
GATED SPILLWAY
OVERFLOW WEIR
PORTED GUARD WALL
FLOW
N
UPSTREAM DEPOSITION CONTOURS
10-DAY SIMULATION
DISCHARGE 90,000 CFS
INFLOW CONCENTRATION 1,100 MG/L



UPSTREAM DEPOSITION CONTOURS
10-DAY SIMULATION
DISCHARGE 145,000 CFS
INFLOW CONCENTRATION 1,800 MG/L