US Army Corps of Engineers
Waterways Experiment Station

Technical Report HL-90-2
September 1997

Red River Waterway, Lock and Dam No. 4

Report 2
Navigation Alignment Conditions

Hydraulic Model Investigation

by Howard E. Park

Prepared for U.S. Army Engineer District, Vicksburg

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U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Report 2 of a series

Prepared for U.S. Army Engineer District, Vicksburg
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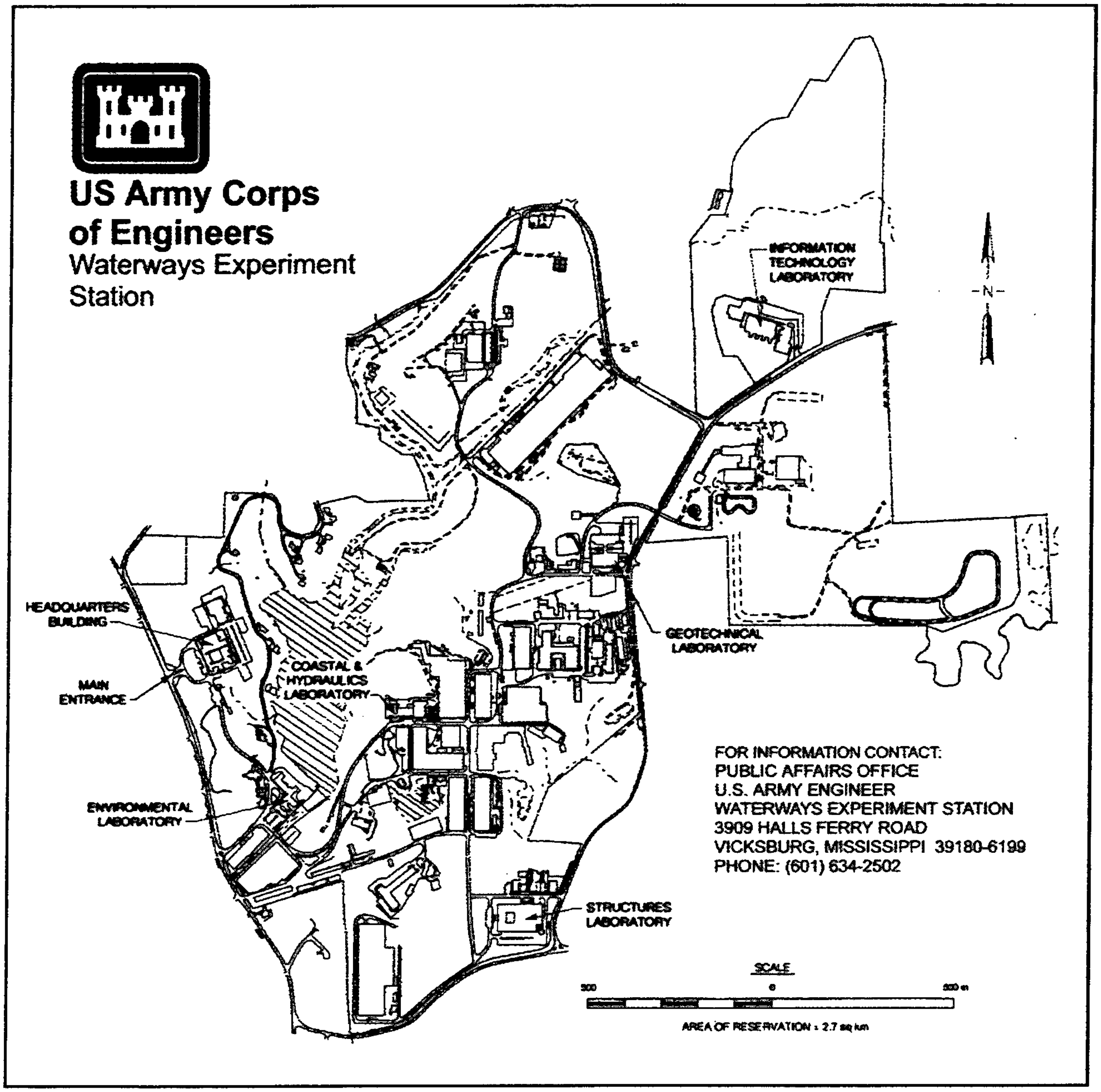

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Preface

The model investigation herein described was conducted for the U.S. Army Engineer District, Vicksburg, by personnel of the Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, during the period August 1984 to July 1991.

In addition to this fixed-bed navigation model study, two physical model studies and two numerical model studies were conducted at WES: a hydraulic movable-bed model study (Report 3); a hydraulic structures model study (Report 4); a numerical model sedimentation study of upstream and downstream approaches to Lock and Dam No. 4 (Report 5); and a numerical model sedimentation study of the Red River upstream and downstream of Lock and Dam No. 4 (Report 6). This is Report 2 of the series. Report 1, to be published later, will summarize all of the model studies.

During the course of the model study, representatives of Vicksburg District and U.S. Army Engineer Division, Lower Mississippi Valley, visited WES at different times to observe the model and discuss test results. The Vicksburg District was kept informed of the progress of the study through monthly progress reports and evaluation reports at the end of each test.

The model study was conducted under the general supervision of Messrs. F. A. Herrmann, Jr., Director of the Hydraulics Laboratory, and R. A. Sager, Assistant Director of the Hydraulics Laboratory; and under the direct supervision of Mr. M. B. Boyd, Chief of the Waterways Division, Hydraulics Laboratory; and Dr. L. L. Daggett, Chief of the Navigation Branch, Waterways Division. The principal investigator in immediate charge of the model was Mr. H. E. Park with the assistance of Mr. R. T. Wooley. Also assisting during the study were Messrs. E. Johnson, J. Sullivan, and M. Caldwell and Mmes. D. P. George and P. Birchett, all of the Navigation Branch. This report was prepared by Mr. Park.

At the time of publication of this report , Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

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

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
miles (US statute)	1.609347	kilometers

1 Introduction

Present Development Plan and Description of Prototype

As presently authorized, the Red River multipurpose project provides for the improvement of the Red River and its tributaries in Louisiana, Arkansas, Texas, and Oklahoma through coordinated developments for navigation, bank stabilization, flood control, recreation, fish and wildlife, and water quality control. The project consists of four distinct reaches: (a) Mississippi River to Shreveport, LA; (b) Shreveport to Daingerfield, TX, by Twelve Mile Bayou; (c) Shreveport to Index, AR; and (d) Index to Denison Dam, Texas. Only the first reach is pertinent to this report. Within the first reach, the plan provides for establishing a navigable channel, approximately 236 miles[1] long, 9 ft deep, with a minimum width of 200 ft, from the vicinity of Old River by means of a system of five locks and dams, which will furnish the required total lift of 141 ft, that connect with the Mississippi River through the Old River Lock and Dam (Figure 1).

The Red River flows easterly from the northwest portion of Texas along the border between Texas and Oklahoma through southwestern Arkansas into northwestern Louisiana then southeasterly to join the Old River and form the Atchafalaya River. Flow in the upper portion of the Red River is controlled by releases from Denison Dam, which is located on the Texas-Oklahoma state line. Flow from the Mississippi River through Old River Diversion Channel into the Atchafalaya River has considerable backwater effect on upstream stages including the lower Red River. A 75- by 1,200-ft lock at the mouth of Old River provides for navigation between the Mississippi, Red, and Atchafalaya Rivers.

Public Law 90-483, 90th Congress, approved 13 August 1968, authorized the construction of the Red River Waterway, Louisiana, Texas, Arkansas, and Oklahoma, Project, in accordance with the recommendations of the Chief of Engineers as contained in House Document No. 304, 90th Congress, 2nd

[1] A table of factors for converting non-SI units of measure to SI units is found on page vi.

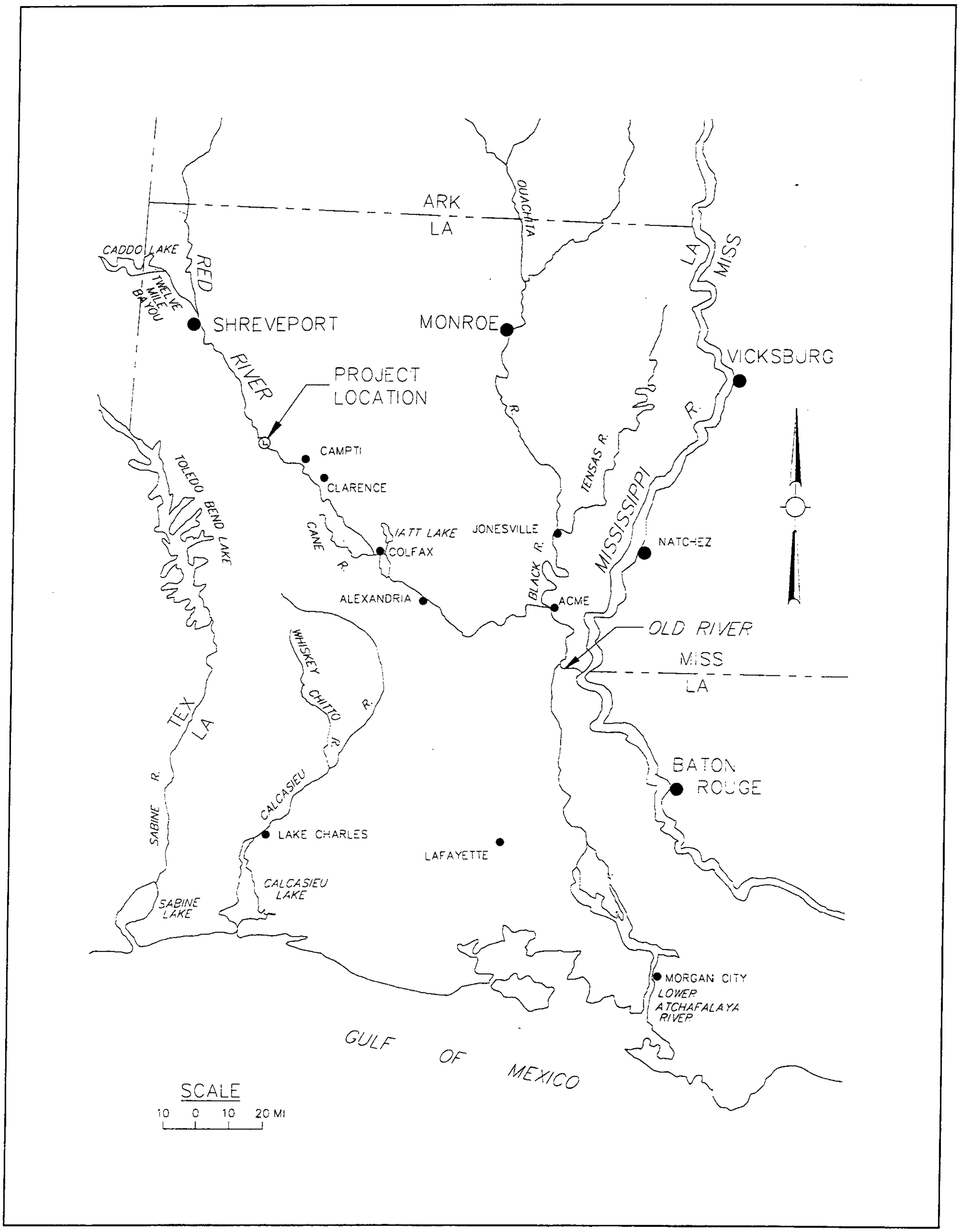

Figure 1. Location map

Session. The Appropriations Act of 1971, approved 7 October 1970, as Public Law 91-439, provides the authority to initiate preconstruction planning from the Mississippi River to Shreveport, LA, reach of the project.

Lock and Dam No. 4

Lock and Dam No. 4 is to be constructed in a cutoff canal approximately 169 postproject miles above the mouth of the Red River. The lock and dam will be the fourth navigation structure above the mouth of the Red River. The general design of Lock and Dam No. 4 consists of an 84-ft-wide by 785-ft-long navigation lock, a gated spillway containing five tainter gates 60 ft wide, and a hinged crest gate 100 ft wide. The structure will provide a normal upper pool at el 120[1] and a lift of 25 ft in the lock chamber from Pool 3 at el 95. The lock will be located on the left bank of the cutoff canal. The gated spillway is 69 ft riverward of the lock, and the adjacent hinged crest spillway is connected to the right bank of the cutoff wall.

Need for and Purpose of Model Study

The general design of Lock and Dam No. 4 was based on sound theoretical design practice and experience with similar structures. However, navigation conditions vary with location and flow characteristics both upstream and downstream of a structure, and an analytical study to determine the hydraulic effects that can reasonably be expected to result from a particular design is both difficult and inconclusive. Since Lock and Dam No. 4 was to be constructed in an excavated channel that was downstream of several bendways, whether man-made or the natural river channel, it was important that the realignment of the river channel provide satisfactory navigation conditions into and out of the proposed lock. Therefore, a model study was considered necessary to investigate conditions that could be expected with the proposed design and to develop modifications required that would ensure satisfactory navigation conditions. The specific purposes of the model study were

a. To determine the adequacy of the proposed design.

b. To develop modifications required to provide satisfactory navigation conditions for the proposed design.

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

2 The Model

Description

The model (Figure 2) reproduced about 3.5 miles of realigned Red River channel (between river miles 213.4 and 205.3[1]) and adjacent overbank area that would contain riverflows up to el 125.0. The model reproduced about 2.5 miles of river channel upstream of the lock and dam and about 1.0 mile downstream. The model was of the fixed bed type with the channel and overbank areas molded in brushed concrete to sheet metal templates. In some portions of the model where changes could be anticipated during the experiments, pea rock was used to facilitate those changes. The lock and dam were fabricated of sheet metal. The tainter gates were simulated with a simple sheet metal slide-type gate. The channel portion of the model was molded to a 1981 hydrographic survey and the overbanks were molded to a 1978 topographic survey. The model was constructed out of brushed concrete to provide a roughness factor (Manning's n) corresponding to the prototype channel roughness of about 0.035.

Scale Relations

The model was built to an undistorted linear scale ratio of 1:100, model to prototype, to obtain accurate reproduction of velocities, crosscurrents, and eddies that would affect navigation. Other scale relationships resulting from the linear ratio are listed in the following tabulation. Measurement of discharges, water-surface elevations, and current velocities can be transferred qualitatively from the model to the prototype equivalents using these scale relations.

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[1] River mile numbers refer to the nonrealigned Red River Waterway river miles.

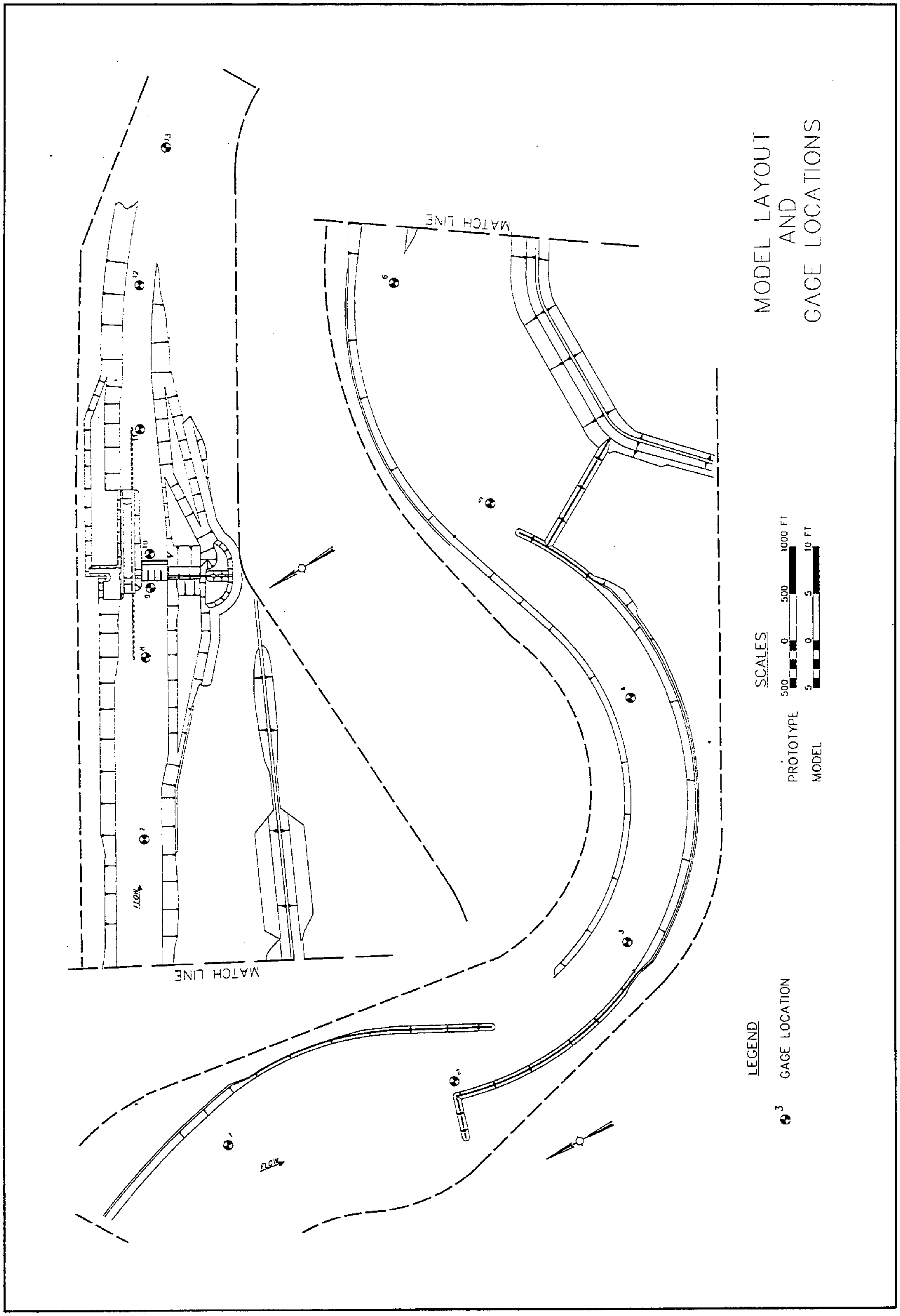


Figure 2. Model layout and gauge locations

Characteristic	Dimension[1]	Scale Relation Model:Prototype
Length	L_r	1 : 100
Area	$A_r = L_r^2$	1 : 10,000
Velocity	$V_r = L_r^{1/2}$	1 : 10
Time	$T_r = L_r^{1/2}$	1 : 10
Discharge	$Q_r = L_r^{5/2}$	1 : 100,000
Roughness (Manning's n)	$n_r = L_r^{1/6}$	1 : 2.15
[1]Dimensions are in terms of length *L*.		

Appurtenances

Water was supplied to the model by a 10-cfs pump operating in a recirculating system. The discharge was controlled and measured at the upper end of the model with a valve and a venturi meter, respectively. Water-surface elevations were measured with piezometer gages located at various places throughout the river channel (Figure 2) and connected to a centrally located gage pit. A tailgate was provided at the lower end of the model to control the tailwater elevation downstream of the dam, and the spillway gates were used to maintain the upper pool elevation during controlled riverflows.

Velocities and current directions were determined in the model using wooden cylinder floats weighted on one end to simulate the draft of a loaded barge using the waterway (9-ft prototype). A model towboat and tow were used to determine and demonstrate the effects of currents on tows entering and leaving the lock. The design tow used in the model study was 70 ft wide by 685 ft long loaded to a draft of 9.0 ft. The towboat was equipped with twin screws and was propelled by two small electric motors operated by a battery located in the tow; the rudders and speed of the tow were remote controlled. The towboat could be operated in forward or reverse with the power adjusted by a rheostat to a maximum speed comparable to that of the towboats expected to use the Red River Waterway. During experiments to evaluate navigation conditions, minimal power was applied to the model towboat engines to maintain steerage in the downbound direction and enough power to make headway in the upbound direction.

Model Adjustment

The proposed lock and dam plans were included in the initial model construction, which precluded adjustment of the model. An adjustment of the model to existing conditions was not considered necessary since the proposed improvements were considerably different from existing conditions. Although the model was not adjusted to the preproject existing conditions, model water-surface elevations were compared with the U.S. Army Engineer District, Vicksburg, HEC-2 water-surface elevations for postproject conditions and were found to be quite different. After experiments with Plans A and B were completed, the model was readjusted to the tailwater rating curve developed at the U.S. Army Engineer Waterways Experiment Station (WES).[1] The water-surface elevations obtained from the model using WES's HEC-2 results were considered acceptable.

[1] D. S. Mueller, D. M. Maggio, T. J. Pokrefke. (1992). "Red River Waterway, Lock and Dam No. 4; Report 3, sedimentation conditions; hydraulic model study," Technical Report HL-90-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, paragraph 15.

3 Experiments and Results

Experiment Procedures

Experiments on the model were concerned primarily with the study of flow patterns, measurement of velocities and water-surface elevations, and the effects of currents on the movement of the model tow. Navigation conditions were evaluated with both controlled and uncontrolled riverflows. With the controlled riverflows, the flow was distributed uniformly through all the dam gates. With the uncontrolled riverflows, the dam gates were in the fully open position.

The tailwater rating curve, shown in Figure 3, and the following representative flows were used for experimentation based on information received from the Vicksburg District:

a. A controlled riverflow of 20,000 cfs with normal upper pool elevation of 120.0 and tailwater elevation of 101.3.

b. A controlled riverflow of 60,000 cfs with normal upper pool elevation of 120.0 and tailwater elevation of 108.9.

c. A controlled riverflow of 80,000 cfs with normal upper pool elevation of 120.0 and tailwater elevation of 111.8.

d. A controlled riverflow of 100,000 cfs with normal upper pool elevation of 120.0 and tailwater elevation of 114.3.

e. The maximum navigable uncontrolled riverflow of 134,000 cfs with a tailwater elevation of 118.3.

The upper pool was controlled using model gauge 8, and the tailwater was controlled using model gauge 13. The controlled riverflow experiments were conducted by introducing the proper discharge, setting the tailwater for that discharge, and manipulating the dam gates until the proper upper pool elevation

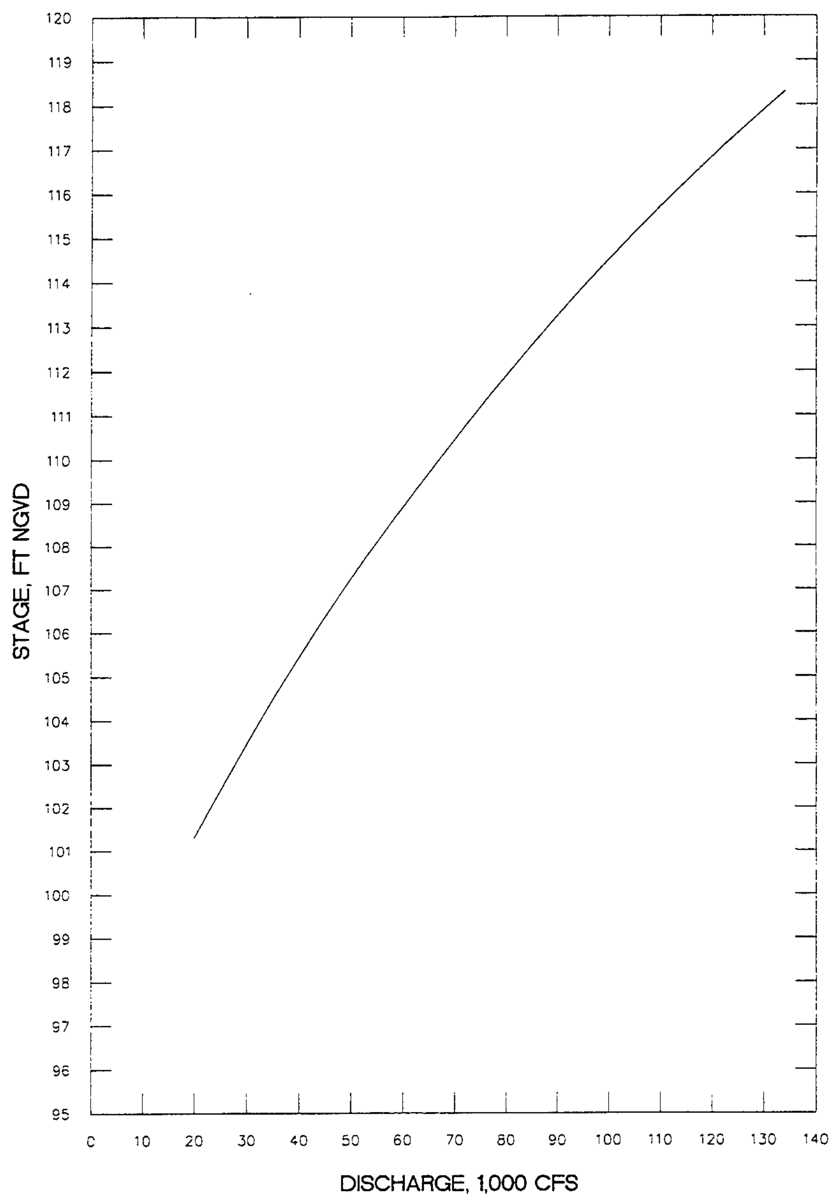


Figure 3. Original postproject tailwater rating curve

was obtained. Uncontrolled riverflows were reproduced by introducing the proper discharge, setting the dam gates to the fully open position, and manipulating the tailgate to obtain the proper tailwater elevation downstream of the dam. Before any data were recorded, all stages were allowed to stabilize. Current direction and velocities were obtained by plotting the paths of the floats with respect to the ranges established for that purpose, and velocities were measured by timing the travel of the floats over measured distances. In the plots of currents where eddies, crosscurrents, and highly turbulent areas existed, only the main trends are shown in the interest of clarity. Navigation conditions were obtained with the model tow by observing its behavior in the lock approaches and through the upper and lower reaches of the model and were recorded with time-lapse photography.

The original project design to be investigated in the model was designated as Plan A. Experimentation and evaluation were initiated with Plan A. During the investigation of Plan A, several changes to the original design were made. These changes included the realignment of revetments in the upper pool of the model and relocation and reorientation of the lock. Therefore, investigation of Plan A was suspended because of changes in the proposed design. The results of experiments using Plan A conditions are not included in this report.

Plan B

Description

Plan B, shown in Figures 4 and 5, included the following principal features:

a. A lock, a nonnavigable gated spillway, and a hinged crest spillway were located in the cutoff channel. The lock, located on the left descending bank of the cutoff channel, had a clear chamber dimension of 84 by 785 ft with the top of the lock walls at el 128.0, a 700-ft-long ported upper guard wall with top of the wall at el 128.0 and top of ports at el 109.0, and a 650-ft-long nonported lower guard wall with top of the wall at el 121.5.

b. The gated spillway, which was separated from the lock by 69 ft, contained four 60-ft-wide gate bays and five 8-ft-wide piers with the crest at el 86.0.

c. The hinged crest spillway adjoining the gated spillway contained three 100-ft-wide gate bays and four 10-ft-wide piers with crest at el 115.0. A closure extended from the right end of the hinged crest spillway across to the overbank area and the existing river channel in the upper reach.

d. The upper reach consisted of two reverse bends and a radial cutoff upstream of the entrance to the cutoff in which the lock was located. The bends and the cutoff were formed via trench-filled revetments and stone-filled dikes. The structure azimuth line (SAL) was at el 98.0 for the upper pool. Bull Revetment, at the uppermost limits of the study reach on the left bank, consisted of a trench fill with radius of 8,000 ft to

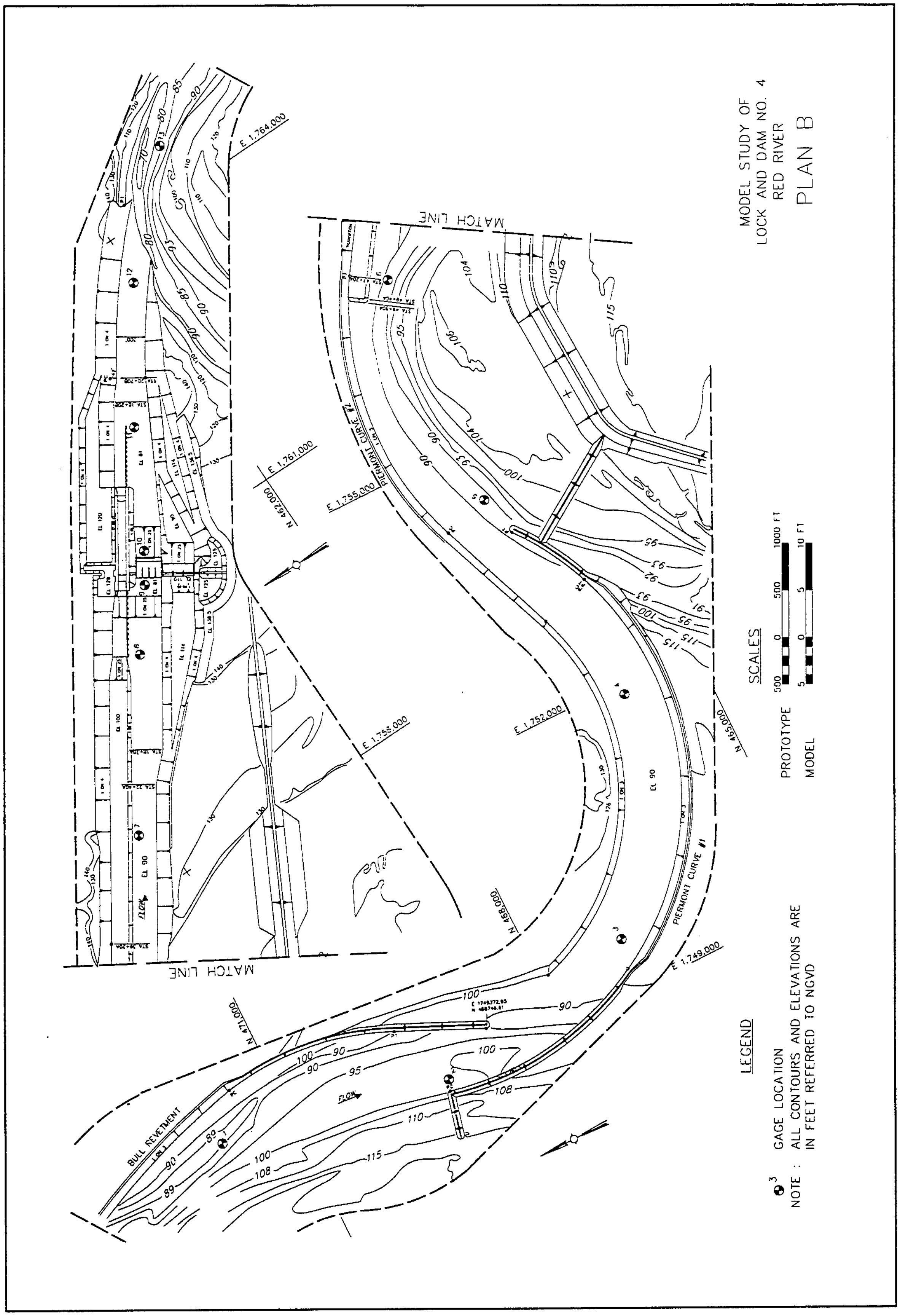


Figure 4. Plan B

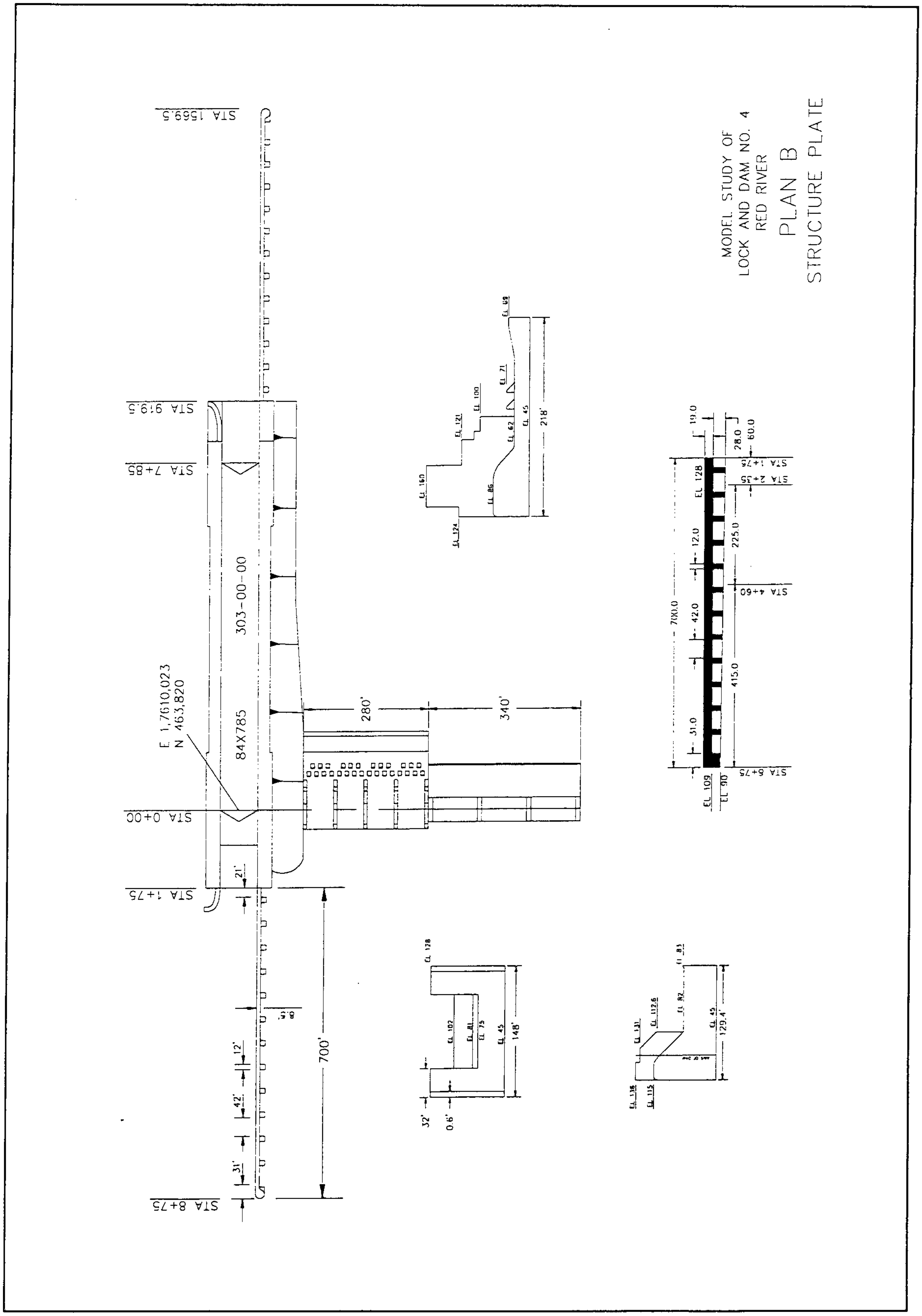


Figure 5. Plan B structure

SAL and stone fill with top el 125.0 and radius of 3,000 ft to SAL and extended tangentially out into the river channel.

e. Piermont cutoff with bottom el 90.0 and a width of 600 ft from the SAL's consisted of trench fill and stone fill formed by Piermont Revetment Curve 1 with radius of 3,150 ft to the SAL of the right bank with top el at 125.0.

f. Piermont kicker dike at the downstream end of Piermont cutoff had a radius of 3,000 ft to the SAL and top el 125.0.

g. Piermont Revetment Curve 2, upstream of the cutoff in which the lock was located, consisted of trench fill forming a 3,250-ft-radius bend to the SAL on the left bank.

h. The excavated channel bottom along the left bank in the upper approach to the lock was at el 100.0 and el 90.0 in the vicinity of the upper guard wall. The excavated channel upstream of the gated spillway in the cutoff was at el 90.0 and el 81.0 adjacent to the gated spillway. The excavated berm upstream of the hinged crest spillway was at el 114.0.

i. The excavated channel downstream of the gated spillway was at el 81.0 to its junction with the old river channel. The excavated channel in the lower lock approach had a bottom width of 300 ft at el 81.0, forming a bend of 7,425-ft radius to the SAL on the left bank. The SAL in the lower pool was at el 95.0. The channel downstream of the hinged crest spillway was excavated to el 90.0 with a berm at el 114.0 adjoining.

For more specific details of the revetments, cutoffs, and bendways, see Table 1.

Results

Results shown in Table 2 indicate that the drop in water level across the dam (gauges 9 and 10) ranged from 18.0 ft with a flow of 20,000 cfs to 0.5 ft with 134,000 cfs (maximum navigable). The total drop in water level from the bullnose of the upstream guard wall to the bullnose of the downstream guard wall (gauges 8 and 11) ranged from 18.6 ft with a flow of 20,000 cfs to 3.1 ft with a flow of 134,000 cfs. The slope in water surface in the upper pool (gauges 1 to 9) ranged from 0.1 ft/mile to 1.0 ft/mile with controlled riverflows up through 100,000 cfs and 0.8 to 1.6 ft/mile in the lower pool (gauges 10 to 13). The slope in water surface (gauges 1 to 13) with the 134,000-cfs flow (uncontrolled riverflow, maximum navigable) was 1.7 ft/mile.

Current direction and velocity data, shown in Plates 1-5, indicate a concentration of flow through the constriction formed by the convergence of the stone-fill dikes at the upstream entrance to Piermont cutoff (Photo 1). The maximum current velocity through this reach ranged from 2.6 to 12.1 fps with riverflows of 20,000 cfs and 134,000 cfs, respectively. Current direction and velocity data indicate that the flow tended to be more concentrated toward and along the right descending bank of the bendway. The average velocity of the current about midway through the bendway ranged from 1.7 to 7.0 fps with riverflows of 20,000 and 134,000 cfs, respectively. As the flow exited Piermont cutoff, the flow remained concentrated along the right descending bank. The maximum velocity of the current in this area ranged in magnitude from 2.4 to 12.3 fps with riverflows of 20,000 and 134,000 cfs, respectively. A large clockwise eddy formed on the right bank downstream of Piermont cutoff with upstream velocity of the current ranging in magnitude from less than 0.5 to 2.8 fps with riverflows of 20,000 and 134,000 cfs, respectively.

As flow entered the cutoff in which the lock was located (Photo 2), the flow was generally parallel to the left bank and the maximum current velocity in the upper approach to the lock ranged from 2.1 to 10.8 fps with riverflows of 20,000 and 134,000 cfs, respectively. In the immediate vicinity of the upstream guard wall, the flow began to move from the left bank across the upper lock approach with the maximum current velocity ranging from 1.8 to 6.9 fps with riverflows of 20,000 and 134,000 cfs, respectively. With all representative riverflows evaluated in this study, a counterclockwise eddy was observed landward of the upstream guard wall with upstream velocities ranging from less than 0.5 fps to 2.6 fps.

Currents downstream of the dam were directed toward the left descending bank, across the lower lock approach, where the flow then crossed the main channel toward the right bank in the direction of the old river channel (Photo 3). The maximum current velocity across the lower lock approach downstream of the lower guard wall ranged from 5.5 to 10.1 fps with riverflows of 20,000 and 80,000 cfs, respectively. A counterclockwise eddy was observed in the lower lock approach with upstream velocities ranging from 1.0 to 5.2 fps with riverflows of 20,000 and 80,000 cfs, respectively. The maximum current velocities recorded in the lower pool generally occurred in the vicinity of the lower guard wall with maximum velocities ranging from 6.1 to 14.9 fps with riverflows of 20,000 and 134,000 cfs, respectively. The velocity of the currents across the lower lock approach and the size of the eddy decreased in magnitude somewhat with riverflows above 80,000 cfs due to the increase in flow area.

Navigation conditions were evaluated for three distinct reaches in the study area as follows:

a. Tows entering and leaving Piermont cutoff.

b. Tows entering and leaving the upper lock approach.

c. Tows entering and leaving the lower lock approach.

With some riverflows, navigation conditions were considered very difficult or hazardous for downbound tows entering Piermont cutoff due to the configuration of stone-fill dikes on the left and right banks of the navigation channel. Tows entering the bendway were required to make a sharp left turn around the stone-fill dike on the left bank of the channel to enter the bendway, thereby exposing the stern to very strong currents directed toward the right bank. With a riverflow of 20,000 cfs, navigation conditions for downbound tows entering the bendway were considered satisfactory. As the riverflow increased to 60,000 cfs, navigation conditions were considered marginal, due to minimal clearance between the stern of the tow and the right bank of the bendway. With a riverflow of 60,000 cfs, the tow could be confined against the right bank of the bendway and difficulties would exist for the tows trying to exit the bendway (Photo 4). With riverflows above 60,000 cfs, navigation conditions were unsatisfactory for downbound tows driving the bendway. Downbound tows driving the bendway were often grounded on the right bank at some point in the bend. To navigate the bendway safely, a flanking maneuver was required to achieve proper alignment entering the bend (Photo 5). The flanking maneuver allowed the towboat to position the head of the tow toward the inside of the bend away from the stronger currents on the outside of the bend. Once positioned properly, downbound tows could drive Piermont cutoff.

There was no indication of any major difficulties for downbound tows navigating past the constriction at the downstream end of the bendway provided a proper alignment was achieved entering the bendway. It should be noted that downbound tows could experience difficulties if confined against the right bank while navigating through the bendway.

No major difficulties were indicated for upbound tows navigating through the bendway, but it should be noted that considerable maneuvering was required to move through the constriction at the upstream entrance to Piermont cutoff because of the alignment of currents through this reach (Photo 6).

Navigation conditions for downbound tows approaching and entering the lock were considered satisfactory with all riverflows. It should be noted that although the alignment of the current was generally parallel to the left bank and no appreciable outdraft was present, velocity of the currents in the upper approach to the lock were high. Downbound tows could be aligned with the lock four to five tow lengths upstream of the upper guard wall, and provided sufficient power could be maintained, could satisfactorily enter the lock (Photo 7).

Navigation conditions were satisfactory for upbound tows leaving the lock with all riverflows used (Photo 8).

Downbound tows leaving the lower lock approach were adversely affected by the limited maneuvering area available in the lower lock approach, the configuration of the left bank just downstream of the guard wall, and the flow moving across the lower lock approach. Downbound tows leaving the lower lock approach had a strong tendency to be moved toward and against the left bank just downstream of the guard wall with all riverflows used (Photo 9).

There was no indication of any major difficulties for upbound tows entering the lower lock approach (Photo 10). With riverflows above 60,000 cfs, a considerable amount of maneuvering was required to enter the lock due to the direction and magnitude of the currents in the lower lock approach.

Plan C

Description

Plan C (Figures 6 and 7) was developed to improve the navigation conditions through Piermont cutoff and in the lower lock approach. This plan also included several alignment changes in the upper lock approach due to reorientation of the lock, thereby changing the approach channels. This plan is considerably different from Plan B and includes the following principal features:

a. The downstream end of Bull Revetment was removed, and four rock spur dikes with top el 125.0 were placed along the left bank upstream of the entrance to Piermont cutoff to reduce the concentration of flow toward the right bank of the cutoff. See Table 3 for description of spur dikes.

b. The stone-fill kicker at the downstream end of Piermont cutoff was replaced with a reverse kicker.

c. The trench-fill revetment, Piermont Curve 2, just upstream of the lock canal was increased to a radius of 4,350 ft.

d. Two spur dikes, 209.70R and 209.90R, were placed just upstream of the lock canal and extended from the closure levee into the river channel. Each dike was sloped on the stream ends from el 120.0 to el 125.0 for 500 ft. Both dikes then extended to the closure levee with a top el 125.0. See Table 3 for description of dikes.

e. The berm along the left bank of the upper lock approach with top el 100.0 was shortened 770 ft to sta 41+70A.

f. The intersection of the center line of the lock and the axis of the dam was relocated to State Plane Coordinates N 463,829 and E 1,761,007. The azimuth of the lock was changed to 301°48'47" to avoid a cemetery on the left bank upstream of the structure.

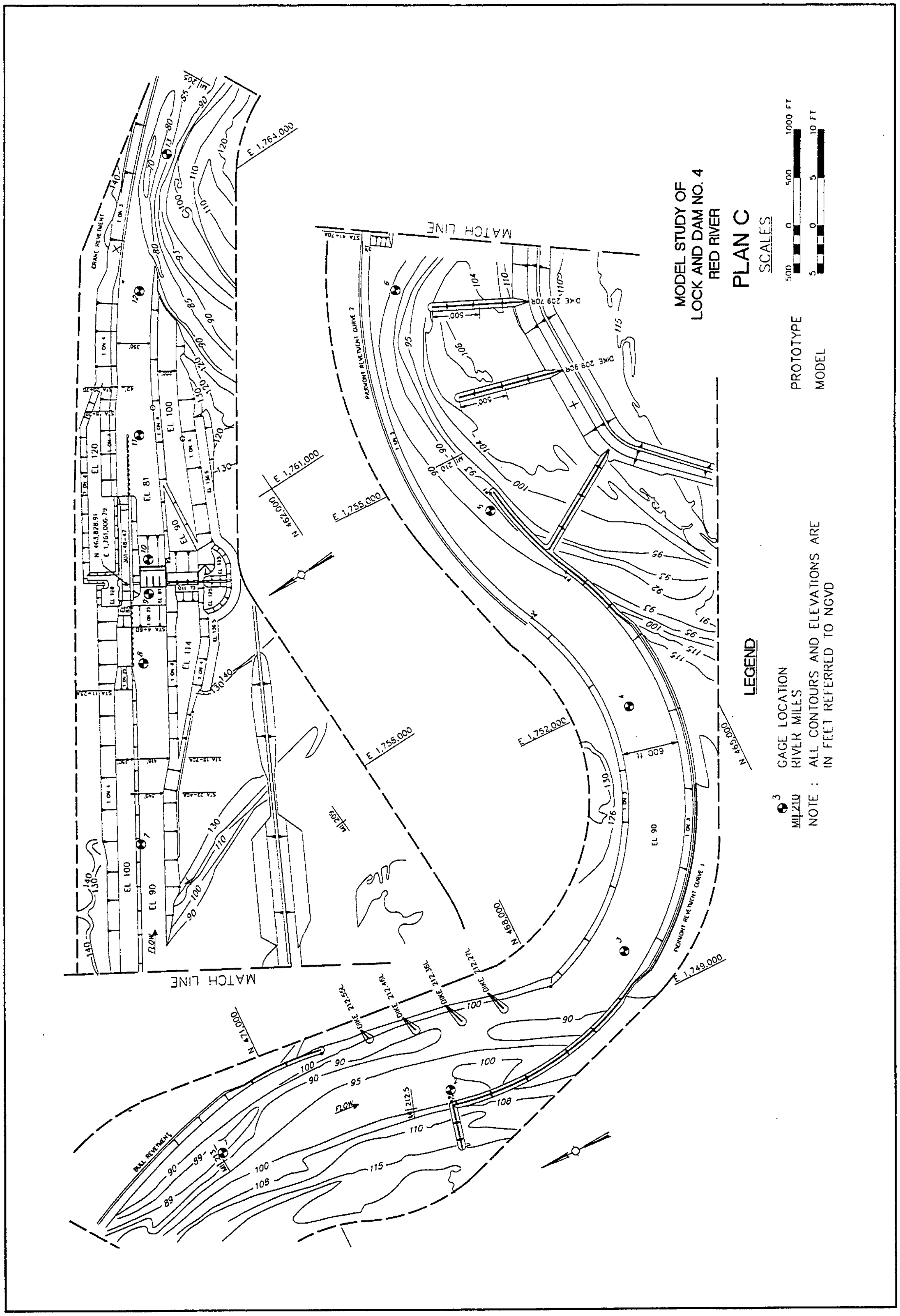


Figure 6. Plan C

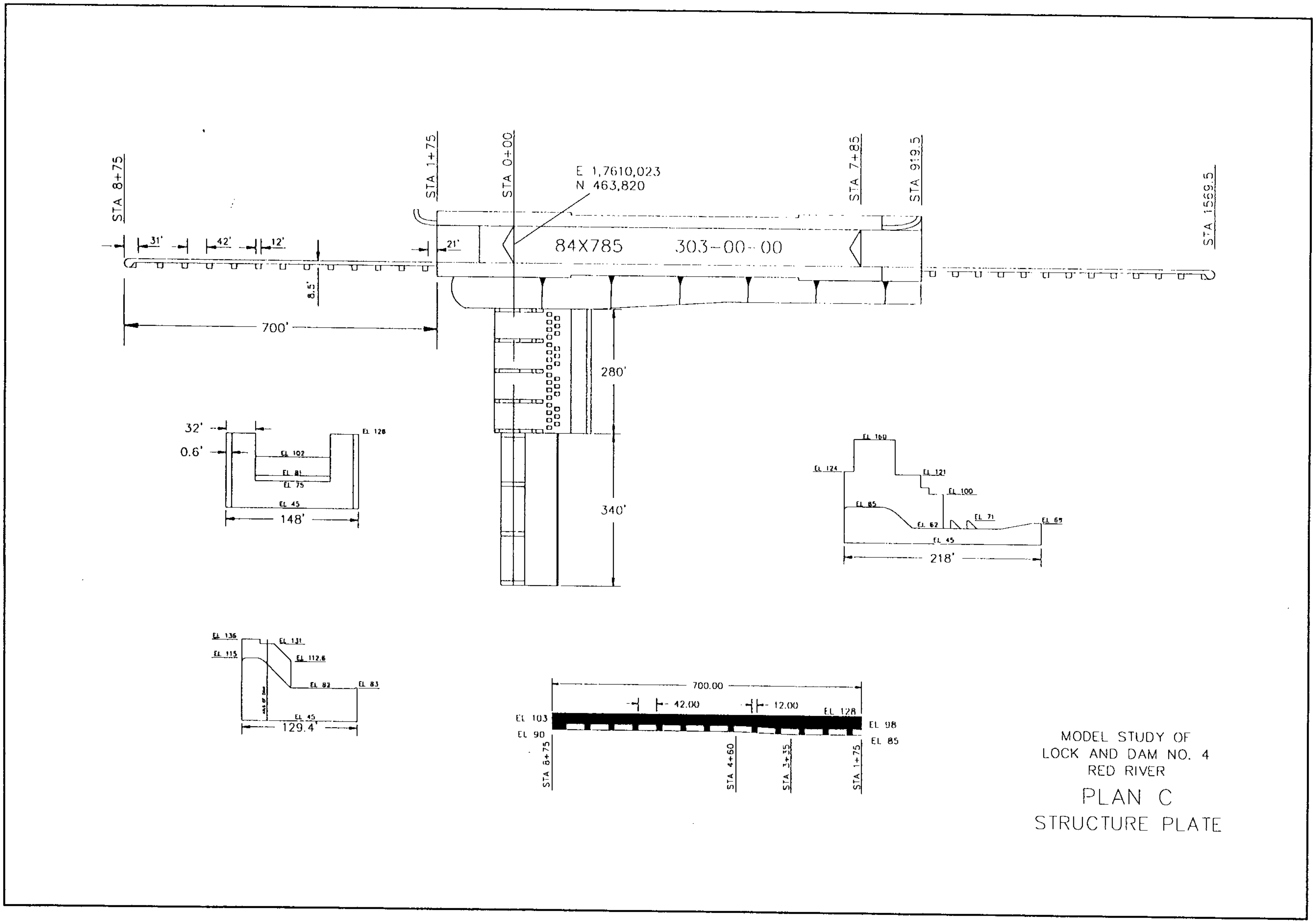


Figure 7. Plan C structure

g. The top of the ports in the upstream guard wall varied from el 103 at the upstream end of the wall to el 98 near the lock so a port opening of 13 ft would be maintained for the entire length of the guard wall (Figure 7).

h. The downstream approach channel was widened 50 ft to a channel with a bottom width of 350 ft.

i. A berm with top el 100.0 was placed along the right bank downstream of the hinge crest spillway to provide additional flow area. This berm was 200 ft wide and extended downstream to its junction with the old river channel.

For more specific details about the dikes and bends, see Tables 3 and 4.

Results

As directed by the Vicksburg District, the postproject tailwater rating curve was changed to adhere to the HEC-2 rating curve developed at WES (Figure 8). This rating curve was lower than that used in Plans A and B. The differences in the rating curves (gauge 13) ranged from 0.5 to 0.3 ft with riverflows of 20,000 and 134,000 cfs, respectively. The results, as shown in Table 5, indicate some changes in stages and slopes throughout the study reach when compared with those for Plan B and in particular with riverflows of 100,000 cfs and above. The total drop in water surface across the structure (gauges 8 and 11) ranged from 19.1 to 2.2 ft with riverflows of 20,000 and 134,000 cfs, respectively. The increase in total drop in water surface across the structure is attributed to two changes: lowering of the post-project tailwater rating curve and an increase in flow area in the lower lock approach. The slope in water surface in the upper pool (gauges 1-9) ranged from 0.1 to 1.1 ft/mile with controlled riverflows of 20,000 and 100,000 cfs, respectively. With the controlled riverflows, there were some changes in water-surface elevations, but in particular with a riverflow of 100,000 cfs. The replacement of the downstream end of Bull Revetment with four spur dikes reduced the ponding effect at gauge 1 by lowering the stages when compared with Plan B conditions. The addition of the two spur dikes downstream of Piermont cutoff increased water-surface elevations with all controlled riverflows. A significant increase was observed with a riverflow of 100,000 cfs. The increase in stage is attributed to the restriction of the flow area in this reach by the spur dikes. The slopes in water surface in the lower pool (gauges 10-13) were significantly reduced and ranged from 0.6 to 0.5 ft/mile with controlled riverflows of 20,000 and 100,000 cfs, respectively. The decrease in water-surface slope in the lower pool is attributed to the increase in flow area. With uncontrolled riverflow of 134,000 cfs, a very significant reduction in stage throughout the study reach was observed. Although stages were reduced, only a slight decrease in water-surface slope (gauges 1-13) to 1.5 ft/mile was noted.

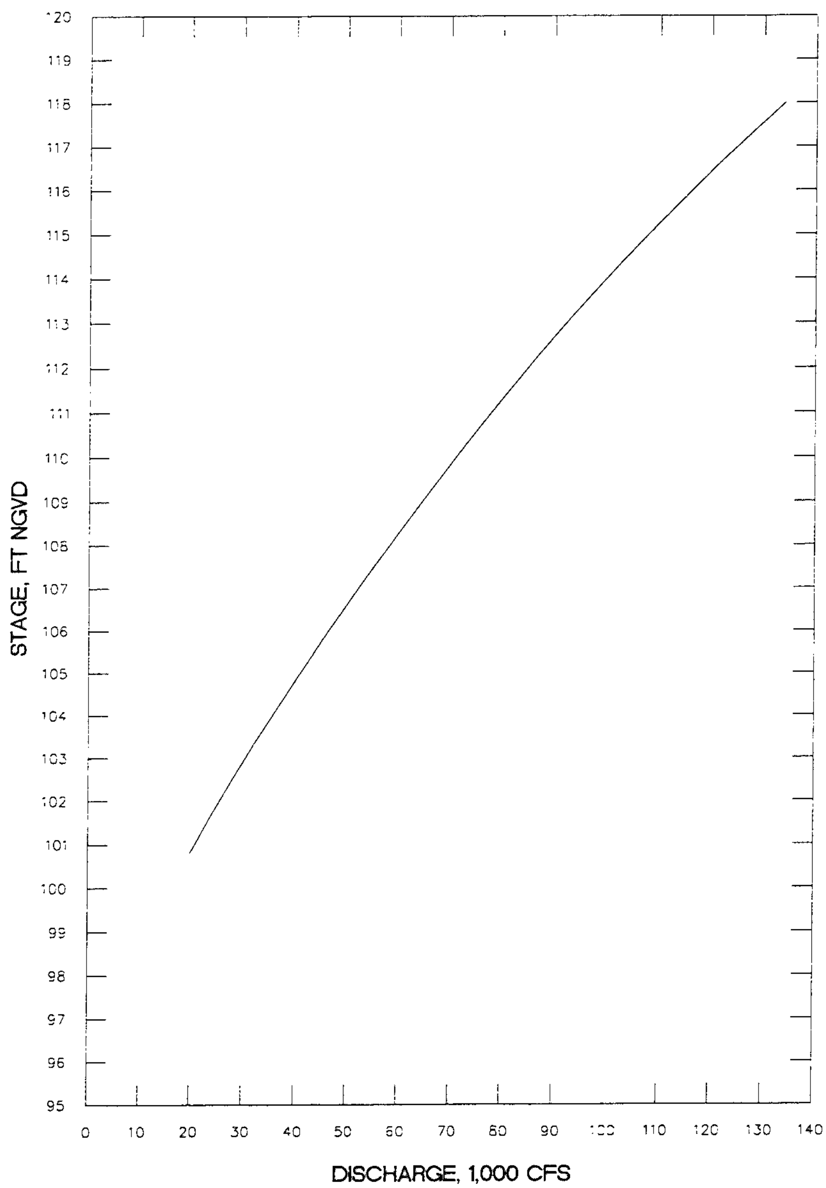


Figure 8. Revised postproject tailwater rating curve

Current direction and velocity data are shown in Plates 6-10. These data indicate that removing the stone-fill kicker at the upstream entrance to Piermont cutoff and placing four spur dikes on the left bank reduced the velocities at the entrance to the cutoff. The maximum velocity of the current ranged from 2.1

to 9.1 fps with riverflows of 20,000 and 134,000 cfs, respectively. In this reach, a reduction in the maximum velocity of the current of about 2.0 fps was observed when compared to Plan B. There was very little difference in current alignment and velocities through the cutoff. The flow appears to be more uniformly distributed at the upstream entrance to the cutoff; however, the flow was still concentrated toward and along the right descending bank of the bendway (Photo 11).

The velocity of the current at the downstream end of the cutoff was reduced compared with those of Plan B. The maximum velocity of the current ranged from 2.1 to 9.4 fps with riverflows of 20,000 and 134,000 cfs, respectively. The addition of the two spur dikes extending from the closure levee provided a more uniform flow pattern along Piermont Curve 2 and into the lock canal.

The current in the upper approach to the lock was generally parallel to the left bank, but in the vicinity of the upper guard wall, a fairly strong crosscurrent was observed. Current velocities in the upper approach ranged from about 2.2 to 10.5 fps with riverflows of 20,000 and 134,000 cfs, respectively. Current velocities in the immediate vicinity of the guard wall ranged from 1.4 to 7.2 fps with riverflows of 20,000 and 134,000 cfs. As observed with Plan B conditions, a large counterclockwise eddy was observed landward of the upper guard wall with upstream current velocities ranging from less than 0.5 fps to 3.3 fps with riverflows of 20,000 and 100,000 cfs.

Current direction and velocity data indicate that widening the berm on the right descending bank and increasing the bottom width of the downstream exit channel provided smoother flow patterns and reduced current velocities in the lower lock approach. Current velocities in the lower lock approach along the left bank ranged from about 3.0 to 5.4 fps with riverflows of 20,000 and 134,000 cfs, respectively. As the riverflow increased, the size and magnitude of the eddy in the lower lock approach increased. The maximum upstream velocity of the eddy ranged from about 1.0 to 2.9 fps with riverflows of 20,000 and 134,000 cfs, respectively. Maximum current velocities in the lower pool generally occurred along the toe of the berm on the right bank in the vicinity of the lower guard wall and ranged from about 6.3 fps with a riverflow of 20,000 cfs to 13.1 fps with a riverflow of 134,000 cfs.

Navigation conditions were evaluated for three distinct reaches in the study area as follows:

a. For tows entering and leaving Piermont cutoff.

b. For tows entering and leaving the upper lock approach.

c. For tows entering and leaving the lower lock approach.

Navigation conditions for downbound tows entering the Piermont cutoff were satisfactory for riverflows up to 60,000 cfs provided sufficient power could be maintained. With riverflows of 80,000 cfs and above, downbound tows were required to use a flanking maneuver to satisfactorily enter the Piermont cutoff. With riverflows of 60,000 cfs and below, downbound tows could drive past the spur dikes on the left bank upstream of the cutoff, align with, and navigate through the Piermont cutoff with no significant difficulties (Photo 12). However, it should be noted that any error in judgment entering the cutoff could result in the tow being grounded on the right bank of the bend. With riverflows of 80,000 cfs and above, downbound tows were required to flank past the spur dikes on the left bank upstream of the cutoff, position the head of the tow to the inside of the bend, and drive through the cutoff (Photo 13). Downbound tows experienced no significant difficulties exiting the cutoff with all riverflows, provided proper alignment was achieved entering and through the cutoff.

Navigation conditions for upbound tows navigating Piermont cutoff were satisfactory with all riverflows. However, it should be noted that some maneuvering was required at the upstream entrance of the cutoff (Photo 14).

Downbound tows exiting Piermont cutoff experienced some difficulties at the upstream entrance to the lock canal with all flows. However, conditions were not considered to be hazardous or unsatisfactory as long as sufficient power could be maintained. Once inside the lock canal, downbound tows could be aligned with the lock chamber about two to three tow lengths upstream of the guard wall. With a riverflow of 20,000 cfs, a slight outdraft was observed upstream of the guard wall. As the riverflow increased, the outdraft was more noticeable. With a riverflow of 20,000 cfs, downbound tows could align with the lock chamber, reverse engines, reduce speed, and enter the lock chamber with no significant difficulties. However, as the riverflow increased to 60,000 cfs and above, downbound tows entering the upper lock approach would require a considerable amount of maneuvering to enter the lock chamber due to a more pronounced outdraft. Provided sufficient power could be maintained, downbound tows could enter the lock chamber with all riverflows, but not without a considerable amount of maneuvering.

Navigation conditions for upbound tows leaving the upper lock approach were satisfactory with all flows. Upbound tows could rotate the head of the tow off the guard wall, align with the currents, and proceed upstream with no significant difficulties. The outdraft that was observed did not appear to have any significant adverse impacts on upbound traffic.

Navigation conditions for downbound tows leaving the lower lock approach were improved compared with those observed with Plan B due to an overall reduction in current magnitudes in the lower pool. However, the configuration of the left bank near and downstream of the lock had adverse impacts on downbound traffic. Downbound tows leaving the lower lock approach had a strong tendency to be moved toward and against the left bank just downstream of the guard wall with all flows.

There was no indication of any major difficulties for upbound tows entering the lower lock approach with all riverflows. However, the eddy and the flow across the lower lock approach required tows to perform additional maneuvering to enter the lock.

The navigation difficulties that were observed with this plan led to the development of the next two plans: Plan C-1, which addressed issues in the lower lock approach; and Plan C-2, which addressed issues in the upper lock approach.

Plan C-1

Description

Plan C-1 is shown in Figure 9 and Photo 15. Plan C-1 is the same as Plan C with the following exceptions. Plan C-1 was a result of efforts to improve navigation conditions in the lower lock approach. Results of experiments performed in the movable-bed model were also included in this plan, specifically, the addition of the wing dike off the downstream guard wall.

a. The left descending bank was realigned. In the vicinity of the downstream guard wall, the left bank was parallel to the guard wall to about sta 22+19. From sta 22+19, the left bank was a radial curve of radius 8,160 ft to SAL with PC at State Plane Coordinate N 462,773 and E 1,762,963 and the PT at State Plane Coordinate N 462,276 and E 1,763,652 and ties to the Crane Revetment. The center of the curve was located at State Plane Coordinate N 455,918 and E 1,758,536.

b. A 225-ft-long wing dike was added, flared riverward about 15 deg from the center line of the lock, off the downstream guard wall with top el 97.0.

Results

Water-surface elevations, shown in Table 6, indicate an increase in water-surface elevations of about 0.2 to 0.3 ft. The increases in water-surface elevations were observed primarily at model gauges 10 and 11 compared to those of Plan C. The increase in water-surface elevation was more than likely caused by the wing dike off the end of the downstream guard wall causing a "backwater" type effect in that area. Model gauge 12 indicated no significant change in water-surface elevations compared with that for Plan C.

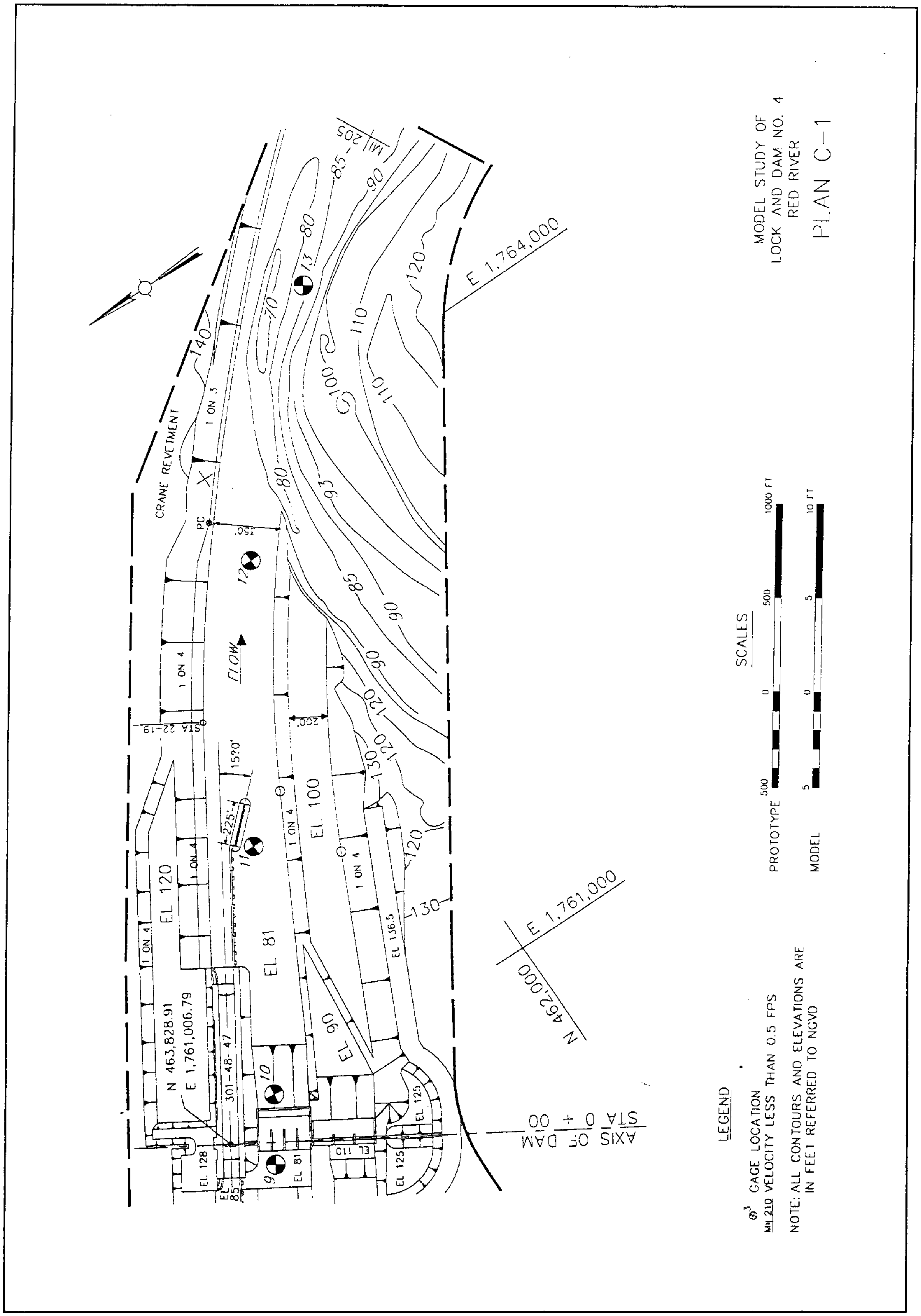


Figure 9. Plan C-1

Current direction and velocity data are shown in Plates 11-15. These data indicate an overall increase in current magnitudes in the exit channel compared with Plan C. The wing dike off the downstream guard wall increased the upstream intensity of the eddy (Photo 16) in the lower lock approach by as much as 1.0 fps compared with conditions for Plan C. Current magnitudes in the exit channel appear to have increased by about 20 percent compared with those for Plan C.

Navigation conditions for downbound tows leaving the lower lock approach were satisfactory with all riverflows. Realigning the left bank near and downstream of the lower guard wall increased the maneuvering area compared with that of Plan C. The wing dike off the downstream guard wall did have some negative impacts on navigation due to the flow patterns that it created in the lower lock approach. Downbound tows could push out of the lower lock approach, take a set toward midchannel, and proceed downstream without any major difficulties (Photo 17). However, as the riverflow increased, downbound tows were observed to encroach on the left bank more than with the lower riverflows.

Navigation conditions for upbound tows entering the lower lock approach were satisfactory with all riverflows. Upbound tows could move upstream along the left descending bank, align with, and land on the guard wall with no significant difficulties (Photo 18).

It should be noted that the wing dike off the lower guard wall was designed primarily for diversion of sediment out of the lower lock approach. The wing dike was observed to have created some negative impacts on tow traffic moving into and out of the lower lock approach. Navigation conditions in the lower lock approach would probably improve if the wing dike were removed.

Plan C-2

Description

Plan C-2 is shown in Figure 10 and Photo 19. Plan C-2 was a result of efforts to improve navigation conditions in the upper lock approach. Plan C-2 is the same as Plan C-1 with one exception: the berm in the upper lock approach along the left descending bank with Plan C was removed.

Results

Water-surface elevations, shown in Table 7, indicated no significant changes compared with those for Plan C-1.

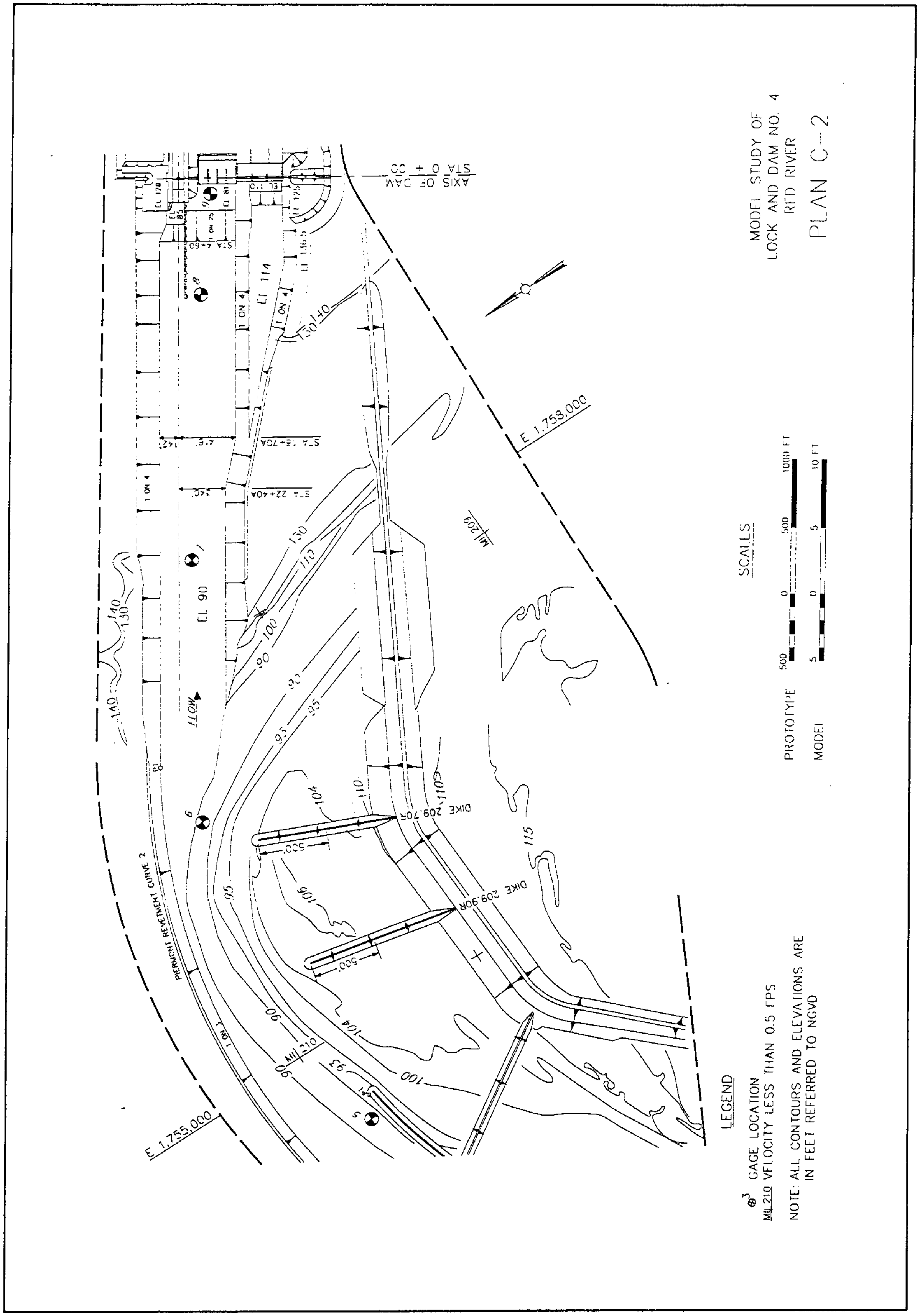


Figure 10. Plan C-2

Current direction and velocity data are shown in Plates 16-20. Surface current patterns are shown in Photo 20. These data indicate that removing the berm provided a more uniform flow distribution in the upper lock approach compared with that of Plan C. However, current magnitudes in the upper lock approach did not significantly change compared with those of Plan C. Current patterns in the upper lock approach were generally parallel to the left bank in the upstream portion of the lock canal, and in the vicinity of the upstream guard wall a fairly strong crosscurrent was observed with all riverflows. The maximum current magnitudes in the upper lock approach ranged from about 2.1 fps with a riverflow of 20,000 cfs to about 10.3 fps with a riverflow of 134,000 cfs. The maximum current magnitude in the vicinity of the upper guard wall ranged from about 1.5 to 7.6 fps with riverflows of 20,000 and 134,000 cfs, respectively. A counterclockwise eddy was observed landward of the upper guard wall with all riverflows. The maximum upstream current magnitude recorded was 1.2 fps with a riverflow of 134,000 cfs.

Navigation conditions for downbound tows entering the upper lock approach were satisfactory with all riverflows as long as sufficient power could be maintained. Downbound tows could align with the lock chamber about three to four tow lengths upstream of the guard wall, reverse engines, reduce speed, and enter the lock chamber with no significant difficulties (Photo 21). However, it should be noted that the crosscurrents at the upstream end of the guard wall did require downbound tows to perform some additional maneuvering to enter the lock chamber. The maneuvering required was observed to increase as the riverflow increased. With riverflows of 100,000 cfs and above, it should be noted that the tendency for flow to increase through the guard wall became more noticeable.

Navigation conditions were satisfactory for upbound tows leaving the upper lock approach with all riverflows. Upbound tows could push out of the lock chamber, rotate the head of the tow off the guard wall, align with the flow, and proceed upstream with no significant difficulties (Photo 22). The crosscurrent near the upstream end of the guard wall did not appear to have any significant effects on upbound traffic.

Plan D

Plans D, D-1, and D-2 were a result of design changes to the gated dam. Plans B through C-2 were performed with four tainter gates and 300 ft of hinge crest dam, and Plans D through D-2 were performed with five tainter gates and 100 ft of hinged crest gate.

Description

Plan D, shown in Figures 11 and 12 and Photos 23-25, consists of the following principal features:

a. Bull Revetment, located on the left descending bank of the channel, was realigned on a radius of 5,115 ft to SAL and top elevation of 125.0. The downstream end of Bull Revetment was submerged. The submerged portion had a top elevation of 106.0 and was about 667 ft long with radius of 5,115 ft to SAL.

b. Piermont cutoff was the same as in Plans B through C-2.

c. Downstream of Piermont cutoff, four dikes with top elevation of 125.0 were placed along the right descending bank, and along the left descending bank was a revetment referred to as Piermont Revetment Curve 2. The four dikes along the right bank extended from the closure levee into the river channel. Information on these dikes is given in Table 8.

d. The upper approach channel to the lock with bottom el 90.0 was 639.0 ft wide. A berm 108 ft wide with top el 122.0 was placed along the right bank in the upper lock approach canal. Three mooring cells were placed in the upper lock approach along the left bank.

e. A lock 84 ft wide by 785 ft long with the top of lock at el 128.0. A ported upper guard wall 700 ft long with 13-ft port height along the entire length of the wall. A nonported downstream guard wall 650 ft long.

f. A gated spillway with five tainter gates each with a gate bay 60 ft wide and crest el 85.0. The gated spillway was separated from the lock by 69 ft.

g. A hinged crest 100 ft long with crest el 113.0 was located adjacent to the tainter gate portion of the dam.

h. The lower lock approach was a minimum of 350 ft wide with bottom el 81.0. A berm 200 ft wide with top el of 100.0 was placed along the right descending bank. Three mooring cells were placed in the lower lock approach along the left bank.

i. The left bank in the lower lock approach was tied to Crane Revetment as shown. Crane Revetment is located along the left bank with radius of curvature of 12,022.5 ft to SAL.

j. A wing dike off the lower guard wall.

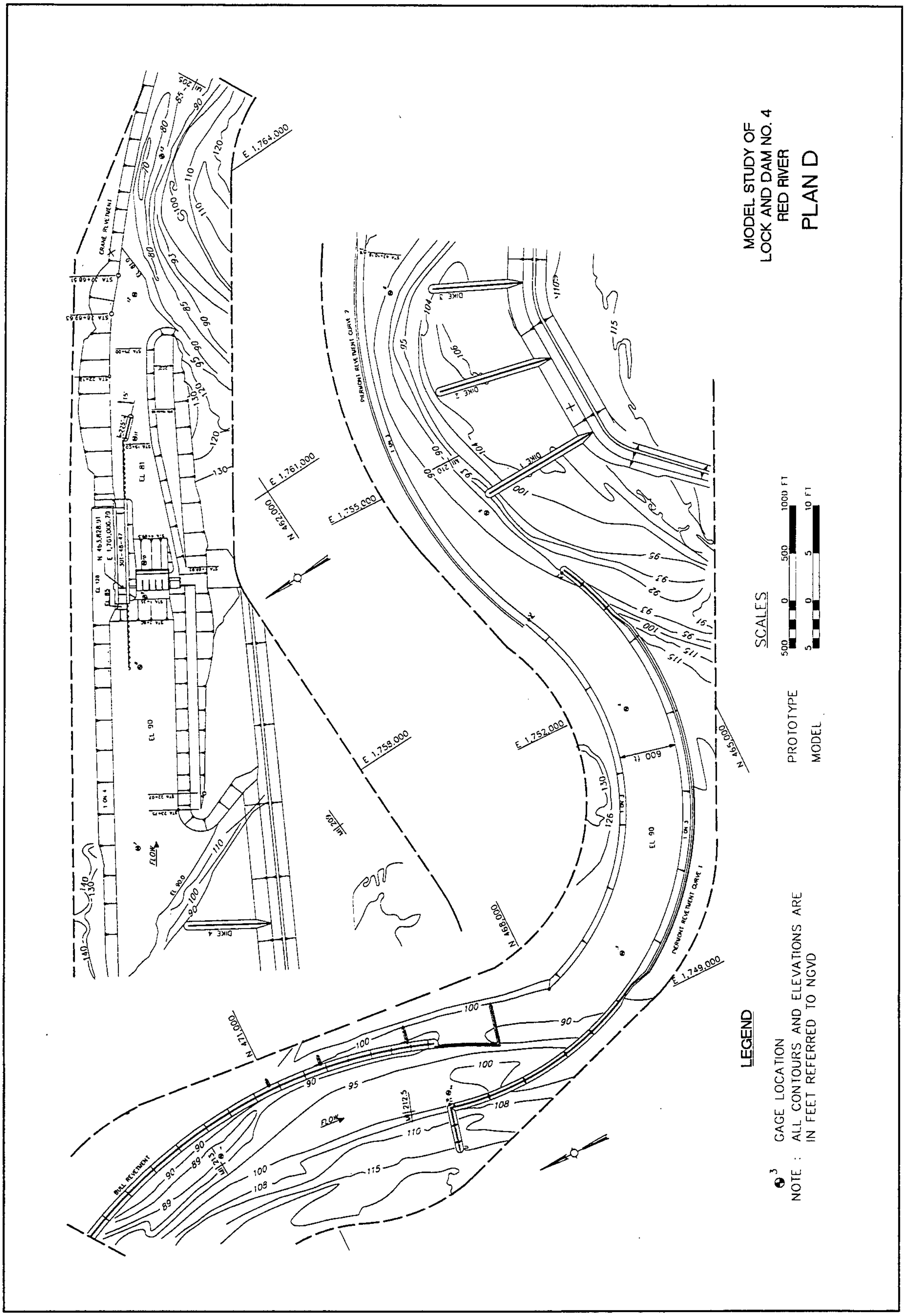


Figure 11. Plan D

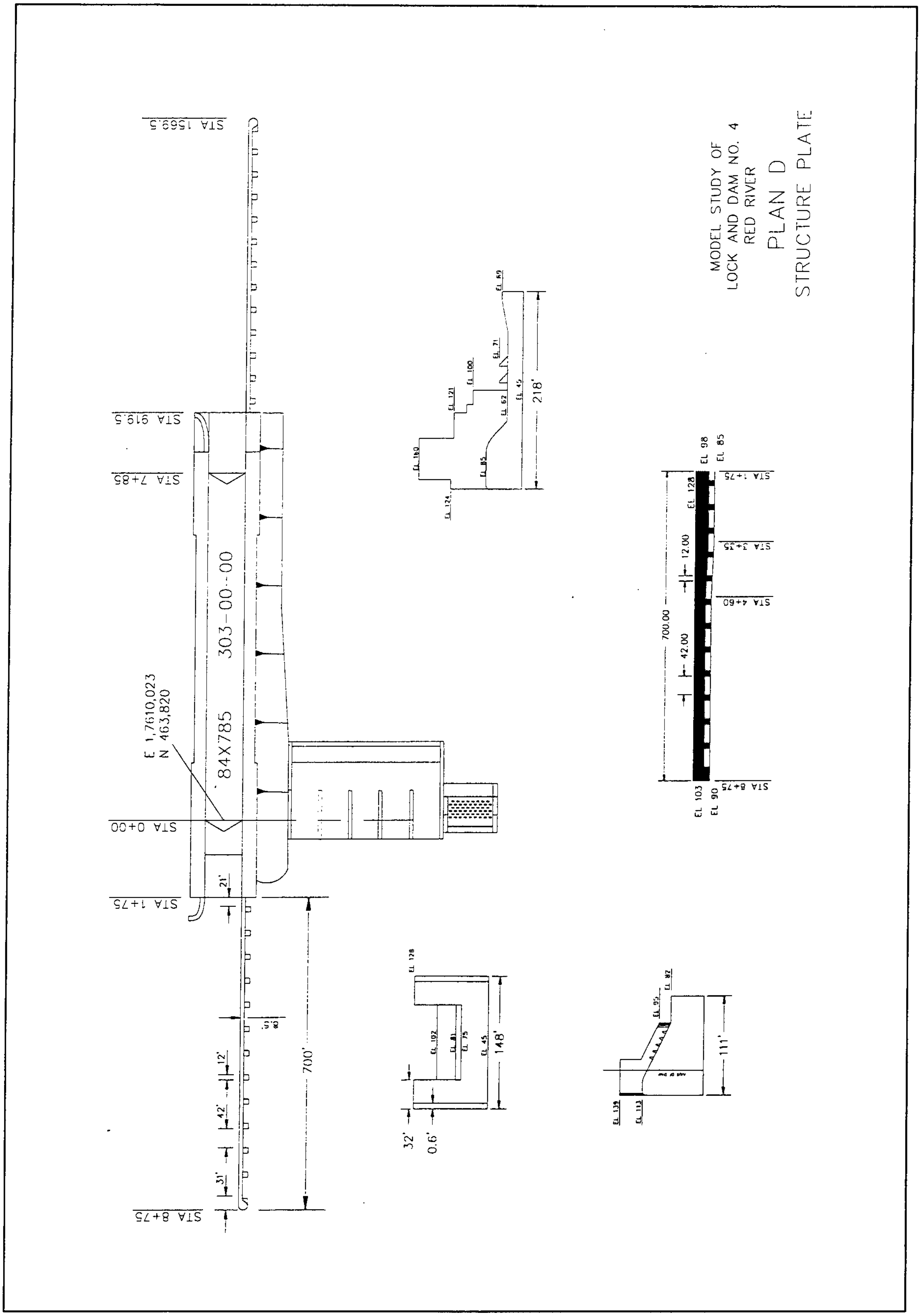


Figure 12. Plan D structure

Results

Water-surface elevations are shown in Table 9. The drop in water surface measured between model gauges 1 and 2 ranged from 0.1 ft with a riverflow of 20,000 cfs to 1.2 ft with a riverflow of 134,000 cfs. This translates into a slope in water surface between model gauges 1 and 2 of about 0.2 to 2.4 ft/mile with riverflows of 20,000 and 134,000 cfs, respectively. With controlled riverflows, the slope in water-surface elevation in the upper pool, model gauges 2 to 9, ranged from about 0.1 to 0.7 ft/mile with riverflows of 20,000 and 100,000 cfs, respectively. With open river flow conditions, a riverflow of 134,000 cfs, the slope in water surface was about 1.1 ft/mile (model gauges 2-13).

Current direction and velocity data are shown in Plates 21-25, and surface current patterns are shown in Photo 26. Current patterns were generally parallel to Bull Revetment and the left bank, and current velocities recorded in this area ranged from about 1.5 fps with a riverflow of 20,000 cfs to a little above 6.0 fps with a riverflow of 134,000 cfs. Where the downstream end of Bull Revetment and right bank converge, the velocity of the flow increased. The maximum current velocity in this area ranged from about 2.3 fps with a riverflow of 20,000 cfs to about 10.4 fps with a riverflow of 134,000 cfs. The water surface over the submerged portion of Bull Revetment was very turbulent. The convergence of Bull Revetment and Piermont Revetment concentrated the flow toward and along the right bank of Piermont cutoff. The maximum current velocity recorded through Piermont Revetment Curve 1 ranged from about 2.0 fps with a riverflow of 20,000 cfs to 9.1 fps with a riverflow of 134,000 cfs and occurred along the right bank of the bendway.

Current direction and velocity data indicate that flow crossed from the right bank of Piermont Revetment Curve and was concentrated toward the outside of Piermont Revetment Curve 2 at the lock approach. The maximum current velocity recorded in this area ranged from about 2.1 fps with a riverflow of 20,000 cfs to about 11 fps with a riverflow of 134,000 cfs. The maximum current velocity recorded in the upper lock approach just downstream of Piermont Revetment Curve 2 ranged from about 1.5 to 8.5 fps with riverflows of 20,000 and 134,000 cfs, respectively. The maximum current velocity recorded in the immediate vicinity of the upper guard wall ranged from 1.3 to 6.0 fps with riverflows of 20,000 and 134,000 cfs, respectively. A counterclockwise eddy, as shown in Photo 27, was observed landward of the upper guard wall with all flows. The maximum upstream current velocity recorded was about 1.2 fps with a riverflow of 100,000 cfs.

Current direction and velocity data indicate that flow is directed across the lower lock approach (Photo 28). The maximum current velocity recorded moving across the lower lock approach ranged from about 4.2 to 9.1 fps with riverflows of 20,000 and 134,000 cfs, respectively. A large counterclockwise eddy was observed in the lower lock approach with all flows. The maximum upstream current velocity recorded ranged from about 1.3 fps with a riverflow of 20,000 cfs to 3.5 fps with a riverflow of 134,000 cfs.

Navigation conditions for downbound tows entering Piermont cutoff were difficult with all flows. With riverflows of 60,000 cfs and above, a flanking maneuver, as shown in Photo 29, was required to enter Piermont cutoff. The flanking maneuver was considered very difficult due to the high- velocity currents moving across the submerged portion of Bull Revetment. These currents tended to move the tow over the dike very strongly and toward the left bank (Photo 30). Downbound tows that approached Piermont cutoff more midchannel (Photo 29) were not affected as much by the currents moving over the dike. Downbound tows attempting to drive past Bull Revetment, shown in Photo 31, and into Piermont cutoff had a strong tendency to be moved toward or grounded on the right bank.

Navigation conditions were also difficult for upbound tows in this reach of the model. The high-velocity currents moving across the dike and the currents deflected off the right bank revetment tended to move upbound tows from midchannel toward Bull Revetment (Photo 32). Upbound tows leaving Piermont cutoff and moving upstream over the submerged portion of Bull Revetment experienced a very strong tendency to be moved toward or into Bull Revetment. An underpowered tow could experience serious navigation difficulty in this reach of the study.

Navigation conditions were satisfactory for downbound tows entering the upper lock approach with all riverflows provided proper alignment was achieved exiting Piermont cutoff. Downbound tows could navigate past Piermont Revetment Curve 2 with no significant difficulties as long as sufficient power could be maintained. Downbound tows could align with the lock chamber about four tow lengths upstream of the guard wall, reverse engines, reduce speed, and come to rest on the guard wall with no significant difficulties (Photo 33). There did not appear to be an excessive amount of flow through the guard wall ports that would pull the tow toward or against the wall with excessive force. The mooring dolphins in the upper lock approach reduce the effective approach width for downbound tows to enter the upper lock approach, are an obstacle that tows have to avoid, and could be hit by downbound tows.

Navigation conditions for upbound tows leaving the upper lock approach were satisfactory with all riverflows. Upbound tows could move up the guard wall, rotate the head of the tow off the wall, and move upstream with no significant difficulties (Photo 34). Upbound tows experienced no significant difficulties moving past the dike field along the right descending bank.

Navigation conditions were unsatisfactory for downbound tows leaving the lower lock approach with all flows. Downbound tows leaving the lock were pushed toward or into the left bank by the flow moving across the lower lock approach (Photo 35). The mooring dolphins located about 1,000 ft downstream of the guard wall on the left bank were very likely to be hit by downbound tows with all riverflows.

Navigation conditions were difficult for upbound tows entering the lower lock approach (Photo 36) due to the intensity of the eddy in the lower lock approach. The eddy caused upbound tows to perform additional maneuvering to enter the lower lock approach.

Plan D-1

Description

Plan D-1, shown in Figure 13, is the same as Plan D with two exceptions:

a. The wing dike extending downstream from the bullnose of the downstream guard wall was removed.

b. The mooring cells in the lower lock approach were removed.

Note that the wing dike was originally included in Plan C-1 based on movable-bed and navigation model experiments. The results of these experiments reflect the impacts on navigation only and do not include the impacts of removing the wing dike on maintaining the channel in the lower lock approach.

Results

Current direction and velocity data, shown in Plates 26-28, indicate removing the wing dike slightly decreased velocities of the current along the left bank and midchannel and increased the velocities of the currents on the berm along the right bank. Removing the wing dike significantly changed the flow pattern. The currents generally became parallel to the right bank, and the angle of the flow moving across the lower lock approach was reduced compared with that of Plan D.

Water-surface elevations are shown in Table 10. There was no significant change in water-surface elevations from those of Plan D.

Navigation conditions for downbound tows were improved when compared with those of Plan D. The angle of the currents moving across the lower lock approach was reduced; therefore, the tendency for tows to be pushed onto the left bank decreased. Downbound tows could move out of the protection of the guard wall, take a set toward midchannel, and proceed downstream. Even with this plan, the bend downstream of the lower lock approach required downbound tows to take a set toward right bank to overcome currents in the bend.

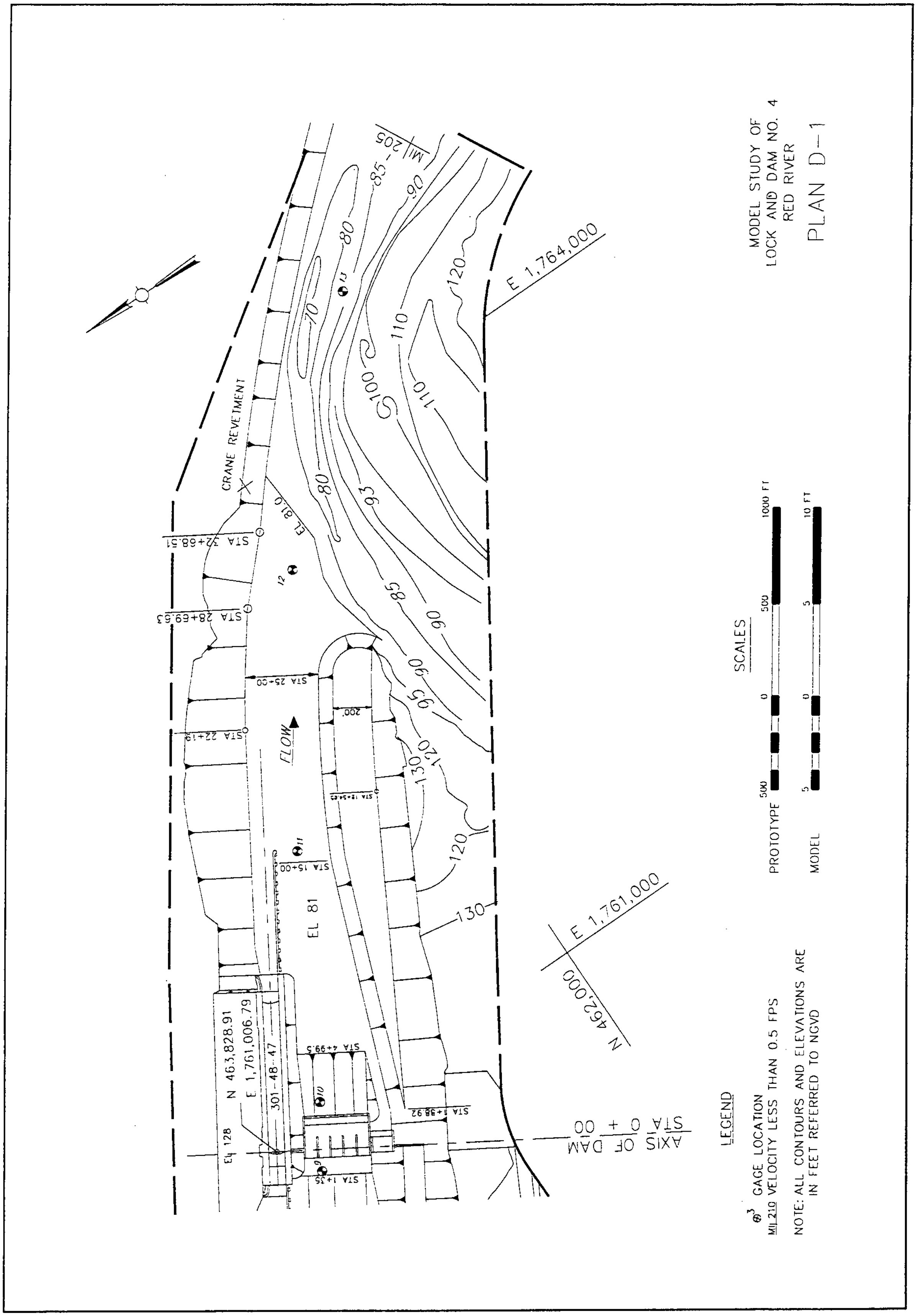


Figure 13. Plan D-1

Navigation conditions for upbound tows entering the lower lock approach were improved compared with those of Plan D, especially with the higher riverflows. With a riverflow of 134,000 cfs, the intensity of the eddy in the lower lock approach was reduced; therefore, the maneuvering required for upbound tows to enter the lower lock approach was reduced.

Plan D-2

Description

Plan D-2, shown in Figure 14 and Photo 37, was the same as Plan D-1 with one exception. The width of the downstream overflow berm with top el 100 on the right bank was reduced to 100 ft wide, thus widening the channel. The transition from the fifth gate bay was revised to accommodate this change. The lower lock approach has a minimum width of 450 ft with bottom el 81.0.

Results

Current direction and velocity data are shown in Plates 29-33, and surface current patterns are shown in Photo 38. Current direction and velocity data indicate a 5 to 10 percent reduction in the velocity of the current in the excavated channel. The flow was more evenly distributed across the excavated channel than with Plan D-1. The intensity of the eddy in the lower lock approach was also reduced. The maximum current velocity recorded across the lower lock approach was about 5.0 fps with a riverflow of 100,000 cfs. The maximum upstream current velocity in the eddy in the lower lock approach was about 2.0 fps with a riverflow of 100,000 cfs.

Water-surface elevations are shown in Table 11. There were no significant changes in water-surface elevations from those of Plan D-1.

Navigation conditions were satisfactory and improved compared with those of Plan D-1 for downbound tows leaving the lower lock approach with all flows. Improvement was due to an overall reduction in velocities in the lower lock approach channel. Downbound tows could push out of the protection of the guard wall, take a set toward midchannel, and proceed downstream with no significant difficulties (Photo 39). Since the lower lock approach was in a slight bend, downbound tows were required to drive away from the left bank to keep from being grounded. There was a tendency for downbound tows to be moved toward the left bank.

Navigation conditions were satisfactory for upbound tows entering the lower lock approach with all flows (Photo 40). However, some maneuvering was required for upbound tows to align with and enter the lock chamber due to the eddy in the lower lock approach.

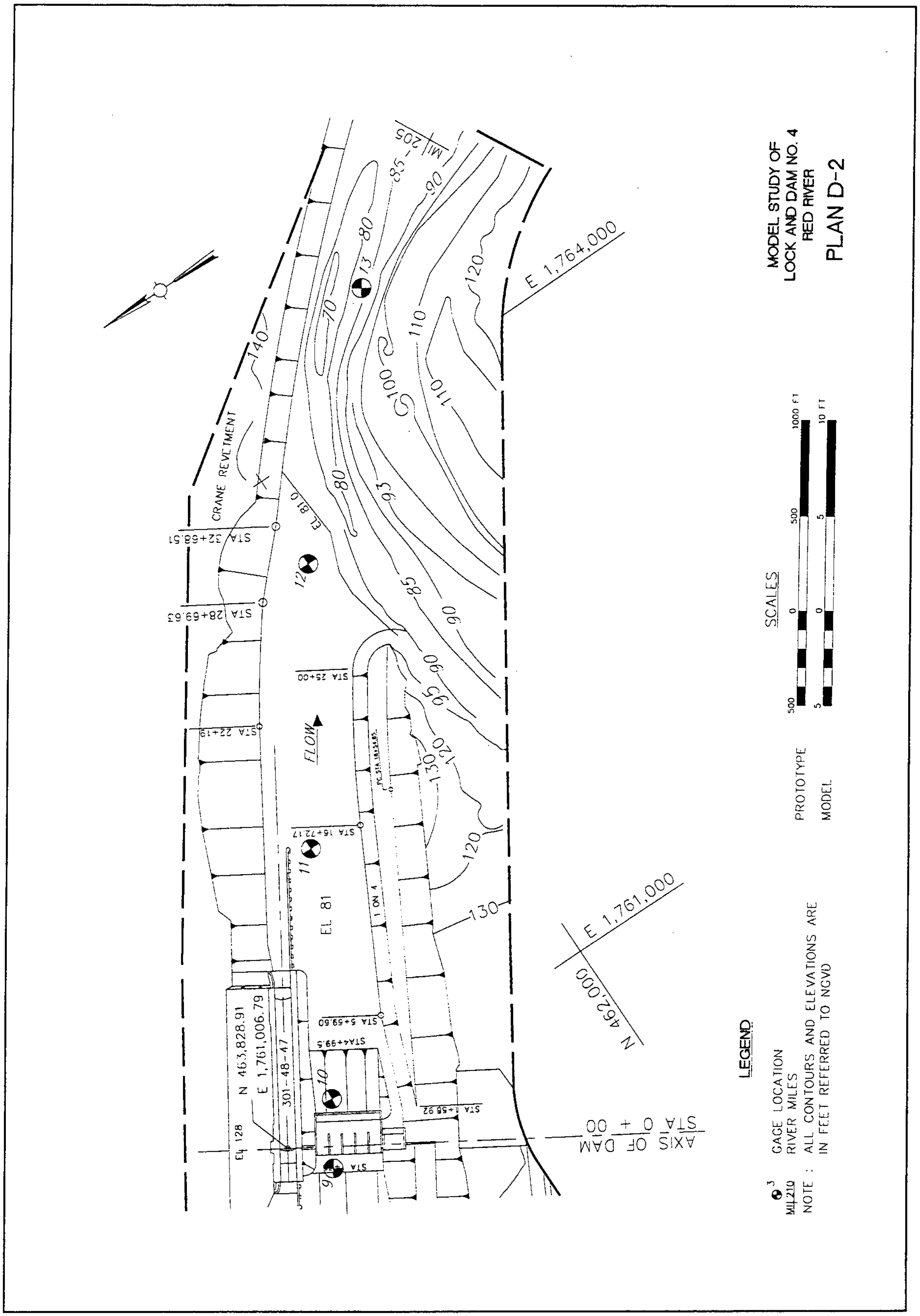


Figure 14. Plan D-2

4 Discussion of Results and Conclusions

Limitations of Model Results

The analysis of the results of this investigation is based on the study of the effects of various plans and modifications on current direction, current magnitudes, water-surface elevations, and the effects of the resulting currents on the behavior of the model tow and towboat. In evaluating results, it should be considered that small changes in current magnitude or direction are not necessarily changes induced by a modification to a plan, since several floats introduced at the same point in the model may travel at a slightly different speed and direction because of pulsating currents and eddies. Current direction and velocity data shown in the plates were obtained with floats submerged to the depth of a loaded barge (9-ft prototype) and are indicative of the currents that would affect the model tow and towboat behavior.

The small scale of the model made it difficult to measure water-surface elevations within an accuracy greater than ± 0.1 ft or to accurately reproduce the hydraulic characteristics of the prototype structures. The model was of the fixed-bed type and was not designed to address the movement of sediment in the prototype; therefore, changes in channel bed and banks that might occur due to changes in flow patterns or structures could not be determined in the model.

Summary of Results and Conclusions

The investigation produced the following results and conclusions.

Plan B

Navigation conditions for Plan B were very difficult and hazardous for downbound tows entering Piermont cutoff with riverflows above

20,000 cfs. With riverflows of 60,000 cfs and above, a flanking maneuver was required past Bull Revetment to achieve proper alignment to enter the Piermont cutoff. Attempting to drive past Bull Revetment and into the cutoff often resulted in the tow grounding on the right bank of the bend.

Navigation conditions for upbound tows leaving Piermont cutoff were satisfactory with all riverflows provided sufficient power could be maintained. It should be noted that current magnitudes at the upstream entrances to Piermont cutoff were high and could require tows to perform additional maneuvering.

Navigation conditions were satisfactory for upbound and downbound tows entering and leaving the upper lock approach with all riverflows provided sufficient power could be maintained.

Navigation conditions for downbound tows leaving the lower lock approach were difficult due to limited maneuvering area, the configuration of the left bank in the lower lock approach, and the flow moving across the lower lock approach. Downbound tows experienced a strong tendency to be moved toward and against the left descending bank with all riverflows.

Navigation conditions for upbound tows entering the lower lock approach were satisfactory with all riverflows. However, as the riverflow increased to 60,000 cfs and above, additional maneuvering was required to enter the lower lock approach due to the direction and magnitude of currents across the lower lock approach.

Plan C

The placement of the four spur dikes at the upstream entrance to Piermont cutoff reduced current magnitudes entering the cutoff in some instances by as much as 2.0 fps and more uniformly aligned currents entering the bendway. The addition of the four spur dikes improved navigation conditions entering the bendway compared with those of Plan B.

Navigation conditions for downbound tows entering Piermont cutoff were satisfactory for riverflows up to 60,000 cfs provided sufficient power could be maintained. With riverflows of 80,000 cfs and above, a flanking maneuver would be required for downbound tows to enter the cutoff. It should be noted that any error in judgment while attempting to drive into the cutoff could result in tows being grounded at some point in the bend.

Navigation conditions for downbound tows leaving Piermont cutoff were satisfactory with all riverflows provided proper alignment was achieved entering the bend.

Navigation conditions for upbound tows leaving the Piermont cutoff were satisfactory with all riverflows provided sufficient power could be maintained.

Navigation conditions for downbound tows entering the upper lock approach were not ideal with riverflows of 60,000 cfs and above. An outdraft was observed at the upstream end of the upper guard wall with all riverflows and became increasingly worse as the discharge increased. With a riverflow of 20,000 cfs, downbound tows could enter the upper lock approach with no significant difficulty. With riverflows of 60,000 cfs and above, additional maneuvering and power would be required for downbound tows to enter the upper lock approach.

Navigation conditions for upbound tows leaving the upper lock approach were satisfactory with all riverflows. The outdraft upstream of the guard wall did not appear to cause any significant difficulties for upbound traffic.

Navigation conditions for downbound tows leaving the lower lock approach were improved compared with those of Plan B due to an overall reduction in current magnitudes. However, the configuration of the left bank in the lower lock approach adversely impacted downbound tows. Downbound tows had a strong tendency to be pushed by the flow toward the left bank.

Navigation conditions for upbound tows entering the lower lock approach were satisfactory with all riverflows. However, the eddy and flow across the lower lock approach did require tows to perform some additional maneuvering.

Plan C-1

This plan evolved from the need to improve navigation conditions for downbound tows leaving the lower lock approach. Navigation conditions for downbound tows leaving the lower lock approach were satisfactory with all riverflows. Realigning the left bank downstream of the lower guard wall increased the maneuvering area in the lower lock approach compared to that of Plan C. Downbound tows could push out of the lower lock approach, take a set toward midchannel, and proceed downstream with no significant difficulties. However, as the riverflow increased, downbound tows were observed to encroach on the left bank.

Navigation conditions for upbound tows entering the lower lock approach were satisfactory with all riverflows.

Plan C-2

This plan evolved as a result of navigation conditions observed with Plan C. Navigation conditions for downbound and upbound tows entering and leaving the upper lock approach were satisfactory for all riverflows as long as sufficient power could be maintained. With riverflows of 100,000 cfs and above, a noticeable draw of flow through the guard wall was observed.

Plan D

Navigation conditions were very difficult for downbound tows to enter Piermont cutoff. A flanking maneuver was required with riverflows of 60,000 cfs and above. Downbound tows attempting to drive past Bull Revetment and into Piermont cutoff experienced a very strong tendency to be grounded on the right bank of the cutoff.

Navigation conditions were difficult for upbound tows leaving Piermont cutoff. Upbound tows experienced a tendency to be moved toward Bull Revetment. Underpowered upbound and downbound tows could experience serious navigation difficulties in this reach of the river.

Navigation conditions were satisfactory for downbound tows entering the upper lock approach with all flows provided sufficient power could be maintained. Downbound tows could align with the lock about four tow lengths upstream of the lock and enter the lock with no significant difficulties.

Navigation conditions were satisfactory for upbound tows leaving the upper lock approach with all flows. Upbound tows could rotate the head off the guard wall and proceed upstream with no significant difficulties.

Navigation conditions for downbound tows leaving the lower lock approach were not satisfactory. Downbound tows were pushed toward the left descending bank by flow moving across the lower lock approach and were likely to hit the mooring dolphins located on the left bank downstream of the lower guard wall.

Navigation conditions were difficult for upbound tows entering the lower lock approach. The intensity of the eddy in the lower lock approach created additional maneuvering for upbound tows.

Plan D-1

Navigation conditions for downbound tows leaving the lower lock approach were improved compared to those of Plan D.

Navigation conditions were improved for upbound tows entering the lower lock approach compared to those of Plan D. This is particularly true for the higher riverflows.

Plan D-2

Navigation conditions were satisfactory for downbound tows leaving the lower lock approach. However, downbound tows had to drive away from the left bank to overcome the currents moving toward the left bank of the bendway.

Navigation conditions were satisfactory for upbound tows entering the lower lock approach. Some maneuvering was required for upbound tows to align with and enter the lock chamber.

The results of experiments with Plan D-1 and Plan D-2 suggest that the wing dike off the downstream guard wall should be removed and that the downstream approach channel should be widened. It should also be noted that these recommendations address the impacts of these changes only on navigation and do not include any effects, positive or adverse, on sedimentation.

Table 1
Curve Information, Plan B

Curve Name	State Plane Center of	Radius ft	State Plane PC	State Plane PT
Bull 1 (Left Bank)	N 469,706 E 1,742,217	8,000	— —	N 471,470 E 1,750,020
Bull 2 (Left Bank)	N 470,919 E 1,747,071	3,000	N 471,470 E 1,750,020	N 469,630 E 1,749,780
Bull 2 (Kicker)	N/A	N/A	N 469,630 E 1,749,780	N 468,747 E 1,749,373
Piermont 1 (Right Bank)	N 468,645 E 1,752,020	3,150	N 469,381 E 1,748,957	N 465,711 E 1,753,166
Piermont 1 (Left Bank)	N 468,645 E 1,752,020	2,550	N 467,910 E 1,749,578	N 466,270 E 1,752,947
Piermont 1 (Kicker)	N 468,498 E 1,752,057	3,000	N 465,711 E 1,753,166	N 466,175 E 1,753,955
Piermont 2 (Left Bank)	N 463,750 E 1,755,430	3,250	N 466,777 E 1,754,248	N 466,517 E 1,757,135
Exit Channel (Left Bank)	N 456,440 E 1,758,964	7,425	N 462,790 E 1,762,811	Old River Channel
Exit Channel (Right Bank)	N 456,440 E 1,758,964	6,989	N 462,417 E 1,762,574	Old River Channel

Note: Radii, PC's, and PT's are referred to structure azimuth line (SAL).
SAL = 98.0 for the upper pool; SAL = 95.0 for the lower pool

Table 2
Water-Surface Elevations, Plan B

Gauge No.	Discharge, cfs				
	20,000	60,000	80,000	100,000	134,000
1	120.2	121.2	121.7	122.5	125.4
2	120.2	120.9	121.3	121.9	124.6
3	120.2	120.6	120.9	121.4	123.8
4	120.1	120.6	120.9	121.3	123.7
5	120.1	120.4	120.5	120.7	122.7
6	120.1	120.3	120.4	120.6	122.6
7	120.0	120.2	120.1	120.1	121.8
8[1]	120.0	120.0	120.0	120.0	121.6
9	119.9	119.9	119.7	119.4	120.5
10	101.9	110.0	112.9	115.7	120.0
11	101.4	109.2	111.9	114.4	118.5
12	101.3	109.1	111.8	114.2	118.2
13[1]	101.3	108.9	111.8	114.3	118.3

Notes: All elevations are in feet referred to NGVD.
[1] Control gauge.

Table 3
Spur Dike Information, Plan C

Dike No.	State Plane (Stream End)	Azimuth	Length ft	Top El
212.55 L	N 469,877 E 1,749,942	69° 47' 00"	127	125
212.46 L	N 469,396 E 1,749,803	69° 47' 00"	190	125
212.36 L	N 468,915 E 1,749,665	69° 47' 00"	253	125
212.27 L	N 468,458 E 1,749,590	69° 47' 00"	240	125
209.90 R	N 466,059 E 1,755,609	191° 34' 00"	1,136	125/120
209.70 R	N 465,899 E 1,756,586	203° 05' 00"	1,028	125/120

Note: Dikes 209.90R and 209.70R are at el 125 on the bank end and then tapered from el 125 to el 120 on the stream end of the dike.

Table 4
Curve Information, Plan C

Curve Name	State Plane Center of	Radius ft	State Plane PC	State Plane PT
Bull 1 (Left Bank)	N 469,706 E 1,742,217	8,000	— —	N 471,470 E 1,750,020
Bull 2 (Left Bank)	N 470,919 E 1,747,071	3,000	N 471,470 E 1,750,020	N 470,399 E 1,750,026
Piermont 1 (Right Bank)	N 468,645 E 1,752,020	3,150	N 469,381 E 1,748,957	N 465,843 E 1,753,459
Piermont 1 (Left Bank)	N 468,645 E 1,752,020	2,550	N 467,910 E 1,749,578	N 466,377 E 1,753,186
Piermont 1 (Kicker)	N 462,504 E 1,755,163	3,750	N 465,843 E 1,753,459	N 466,203 E 1,754,553
Piermont 2 (Left Bank)	N 462,504 E 1,755,163	4,350	N 466,377 E 1,753,186	N 466,222 E 1,757,419
Exit Channel (Left Bank)	N 456,385 E 1,759,124	7,425	N 462,826 E 1,762,818	N 462,263 E 1,763,660
Exit Channel (Right Bank)	N 456,385 E 1,759,124	6,955	N 462,534 E 1,762,375	Old River Channel
Crane (Left Bank)	N 452,805 E 1,756,181	12,022.5	N 462,110 E 1,763,793	— —

Note: Radii, PC's, and PT's are referred to structure azimuth line (SAL).
SAL = 98.0 for the upper pool; SAL = 96.0 for the lower pool

Table 5
Water-Surface Elevations, Plan C

Gauge No.	Discharge, cfs				
	20,000	60,000	80,000	100,000	134,000
1	120.2	120.9	121.5	122.3	124.0
2	120.2	120.8	121.2	121.9	123.3
3	120.2	120.7	121.0	121.8	123.1
4	120.1	120.6	120.8	121.5	122.6
5	120.1	120.4	120.6	121.2	122.0
6	120.0	120.3	120.4	120.9	121.7
7	120.0	120.1	120.1	120.3	120.8
8[1]	120.0	120.0	120.0	120.0	120.4
9	119.9	119.9	119.5	119.4	118.8
10	101.3	108.9	111.8	114.4	118.2
11	100.9	108.6	111.4	114.1	118.2
12	100.9	108.5	111.4	114.1	118.1
13[1]	100.8	108.4	111.3	114.0	118.0

Notes: All elevations are in feet referred to NGVD.
[1] Control gauges.

Table 6
Water-Surface Elevations, Plan C-1

Gauge No.	Discharge, cfs				
	20,000	60,000	80,000	100,000	134,000
1	120.2	120.9	121.5	122.3	124.0
2	120.2	120.8	121.2	121.9	123.3
3	120.2	120.7	121.0	121.8	123.1
4	120.1	120.6	120.8	121.5	122.6
5	120.1	120.4	120.6	121.2	122.0
6	120.0	120.3	120.4	120.9	121.7
7	120.0	120.1	120.1	120.3	120.8
8[1]	120.0	120.0	120.0	120.0	120.0
9	119.9	119.9	119.5	119.4	118.8
10	101.4	109.1	112.1	114.7	118.5
11	101.1	108.8	111.7	114.4	118.3
12	100.9	108.6	111.5	114.1	118.1
13[1]	100.8	108.4	111.3	114.0	118.0

Notes: All elevations are in feet referred to NGVD.
[1] Control gauges.

Table 7
Water-Surface Elevations, Plan C-2

Gauge No.	Discharge, cfs				
	20,000	60,000	80,000	100,000	134,000
1	120.2	120.8	121.3	122.1	123.8
2	120.2	120.6	121.1	121.7	123.1
3	120.2	120.5	120.9	121.5	122.8
4	120.1	120.4	120.8	121.2	122.4
5	120.1	120.3	120.5	120.9	122.0
6	120.0	120.2	120.3	120.7	121.5
7	120.0	120.1	120.2	120.3	120.9
8[1]	120.0	120.0	120.0	120.0	120.5
9	119.4	119.8	119.4	119.3	118.7
10	101.4	109.1	112.0	114.7	118.3
11	101.1	108.8	111.6	114.3	118.2
12	100.8	108.5	111.4	114.1	118.0
13[1]	100.8	108.4	111.3	114.0	118.0

Notes: All elevations are in feet referred to NGVD.
[1]Control gauges.

Table 8
Dike Information, Plan D

Dike No.	State Plane (Stream End)	Azimuth	Length ft	Top El
1	N 466,163 E 1,754,562	175° 32' 47"	1265	125
2	N 466,164 E 1,755,755	189° 36' 02"	1225	125
3	N 465,758 E 1,756,756	202° 26' 38"	955	125
4	N 465,221 E 1,757,621	211° 48'' 47"	880	125

Note: The lengths given are approximate lengths.
Elevations are in feet referred to NGVD.

Table 9
Water-Surface Elevations, Plan D

Gauge No.	Discharge, cfs				
	20,000	60,000	80,000	100,000	134,000
1	120.2	120.7	121.4	121.9	123.2
2	120.1	120.4	120.8	121.2	122.0
3	120.1	120.3	120.7	121.0	121.8
4	120.1	120.3	120.6	120.8	121.3
5	120.0	120.2	120.4	120.6	121.0
6	120.0	120.0	120.2	120.3	120.4
7	120.0	120.0	120.2	120.2	120.2
8[1]	120.0	120.0	120.0	120.0	119.8
9	119.9	119.7	119.6	119.4	118.7
10	101.4	108.9	112.1	114.4	118.3
11	101.1	108.6	111.7	114.3	118.2
12	100.9	108.5	111.6	114.1	118.1
13[1]	100.8	108.4	111.3	114.0	118.0

Notes: All elevations are in feet referred to NGVD.
[1] Control gauges.

Table 10
Water-Surface Elevations, Plan D-1

Gauge No.	Discharge, cfs 60,000	80,000	134,000
1	120.8	121.4	123.2
2	120.6	121.0	122.0
3	120.5	120.8	121.7
4	120.4	120.6	121.2
5	120.3	120.5	120.9
6	120.2	120.2	120.1
7	120.2	120.2	120.1
8[1]	120.0	120.0	119.7
9	119.8	119.7	118.7
10	108.7	111.9	118.1
11	108.6	111.6	118.2
12	108.6	111.5	118.1
13[1]	108.4	111.3	118.0

Notes: All elevations are in feet referred to NGVD.
[1] Control gauges.

Table 11
Water-Surface Elevations, Plan D-2

Gauge No.	Discharge, cfs				
	20,000	60,000	80,000	100,000	134,000
1	120.2	120.8	121.4	122.0	123.2
2	120.1	120.6	120.9	121.4	122.0
3	120.1	120.4	120.7	121.2	121.8
4	120.1	120.3	120.5	120.9	121.3
5	120.1	120.3	120.5	120.6	121.0
6	120.0	120.1	120.2	120.3	120.4
7	120.0	120.1	120.2	120.2	120.2
8[1]	120.0	120.0	120.0	120.0	119.7
9	119.9	119.8	119.6	119.4	118.5
10	101.3	108.9	111.8	114.4	118.2
11	101.1	108.8	111.6	114.3	118.2
12	101.0	108.7	111.5	114.1	118.1
13[1]	100.8	108.4	111.3	114.0	118.0

Notes: All elevations are in feet referred to NGVD.
[1] Control gauges.

Photo 1. Plan B, looking upstream, discharge 60,000 cfs. Confetti showing surface current patterns entering and through Piermont cutoff

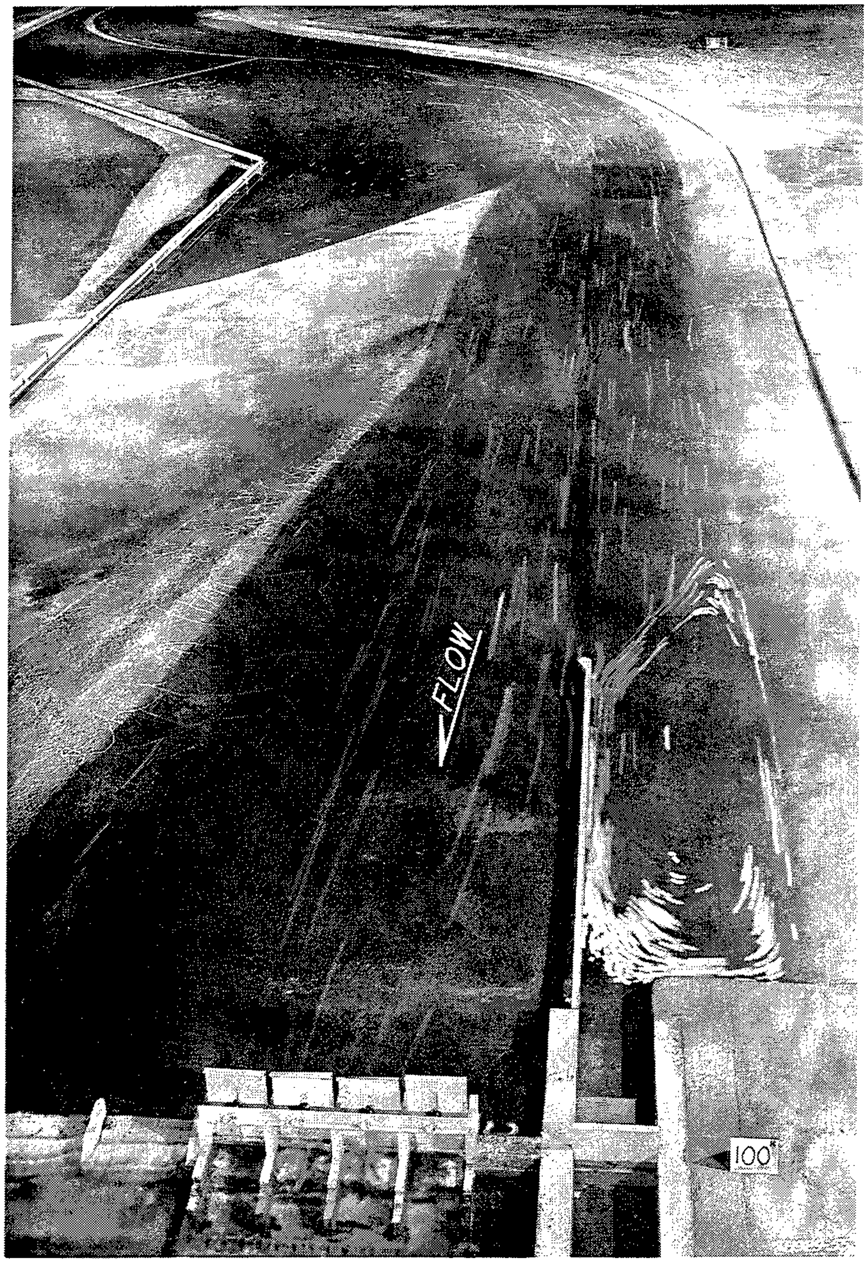


Photo 2. Plan B, looking upstream, discharge 100,000 cfs. Confetti showing surface current patterns in the upper lock approach

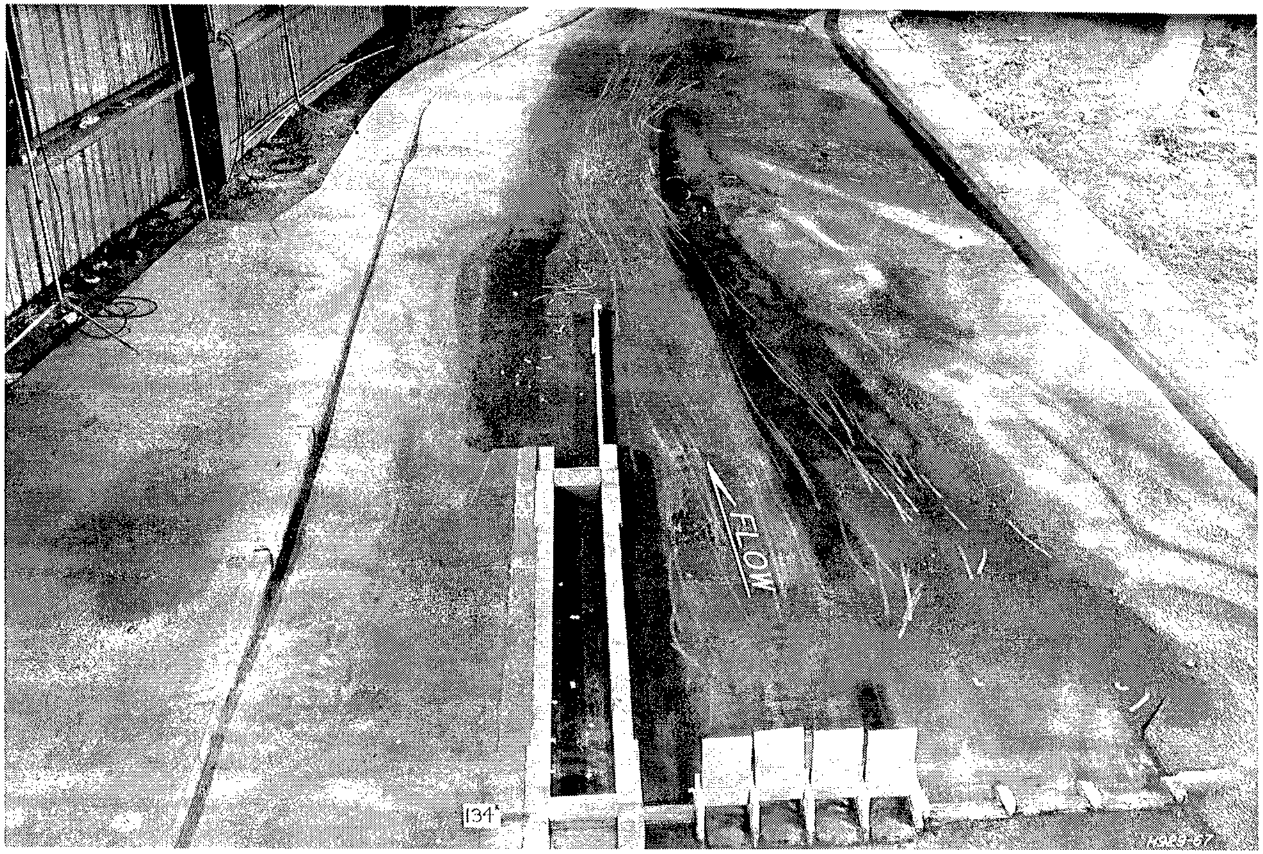


Photo 3. Plan B, looking downstream, discharge 134,000 cfs. Confetti showing surface current patterns in the lower lock approach

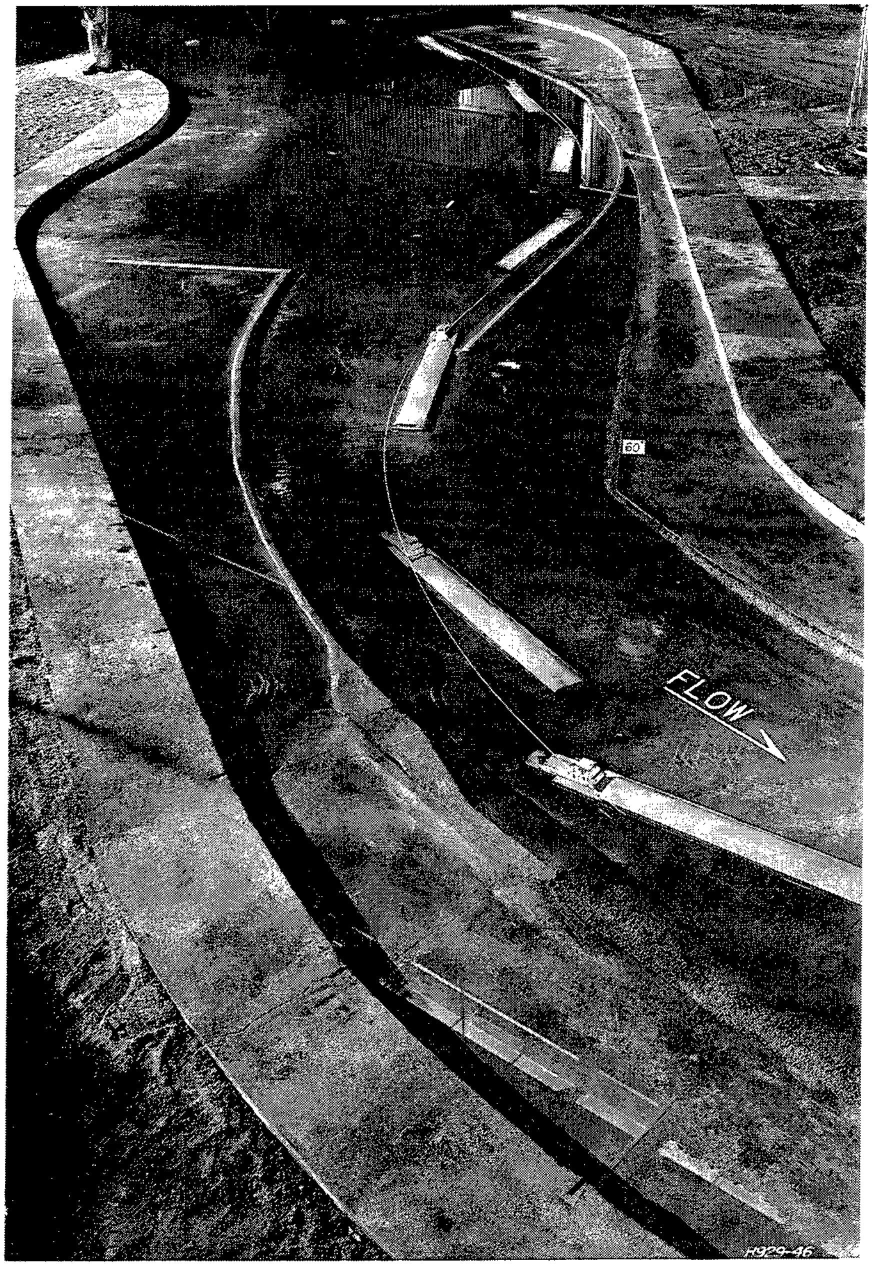


Photo 4. Plan B, looking upstream, discharge 60,000 cfs. Path of downbound tow entering Piermont cutoff. Note tendency for tow to be confined against right descending bank

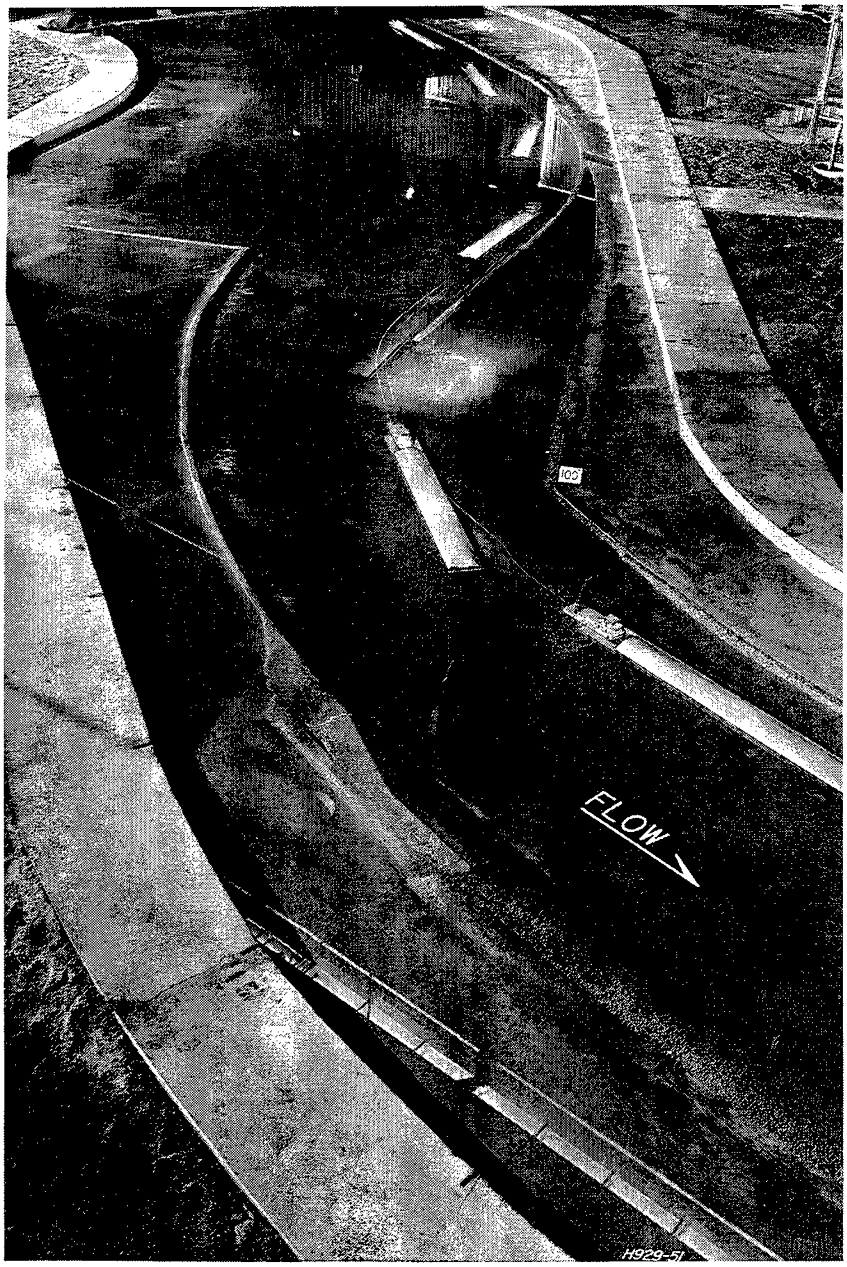


Photo 5. Plan B, looking upstream, discharge 100,000 cfs. Path of downbound tow flanking into Piermont cutoff

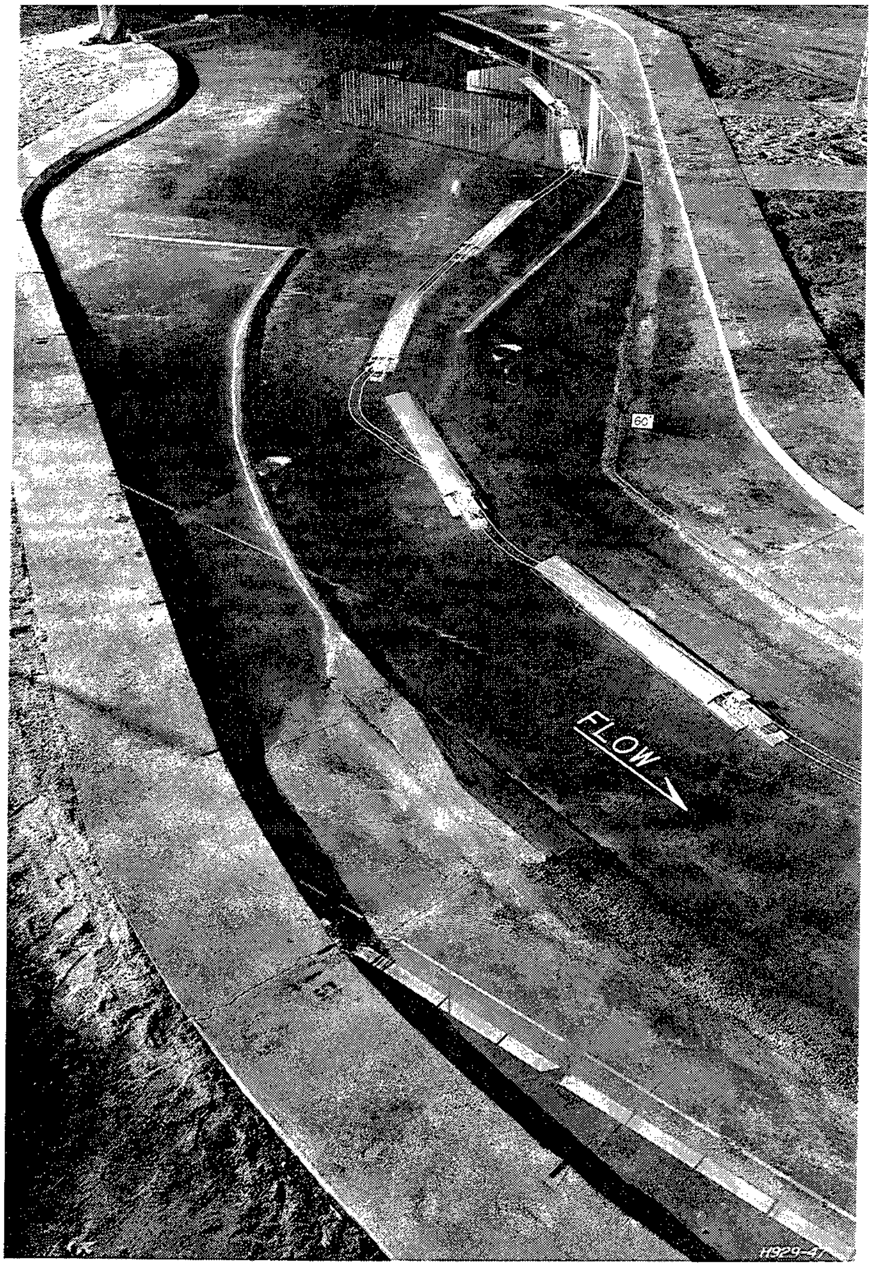


Photo 6. Plan B, looking upstream, discharge 60,000 cfs. Path of upbound tow leaving Piermont cutoff. Note maneuvering near end of Bull Revetment

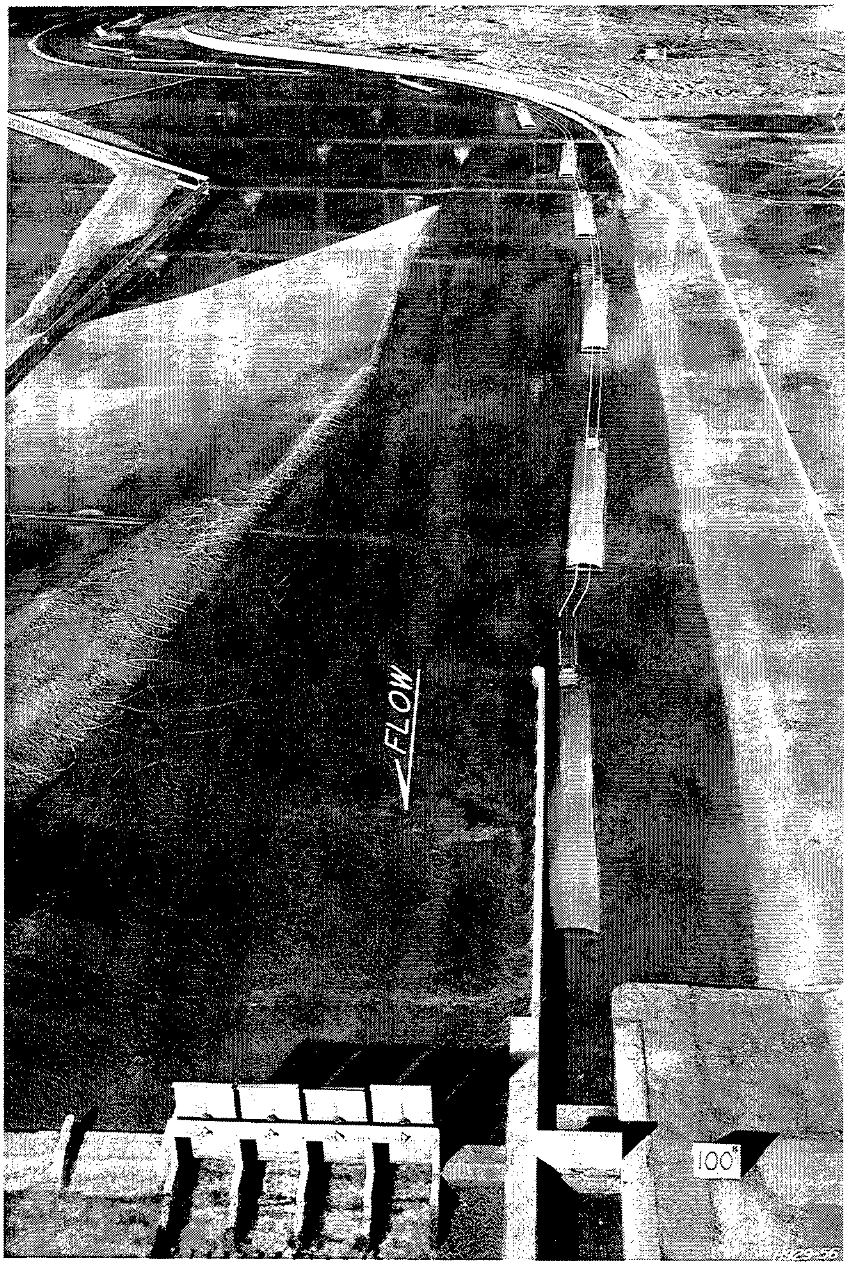


Photo 7. Plan B, looking upstream, discharge 100,000 cfs. Path of downbound tow entering the upper lock approach

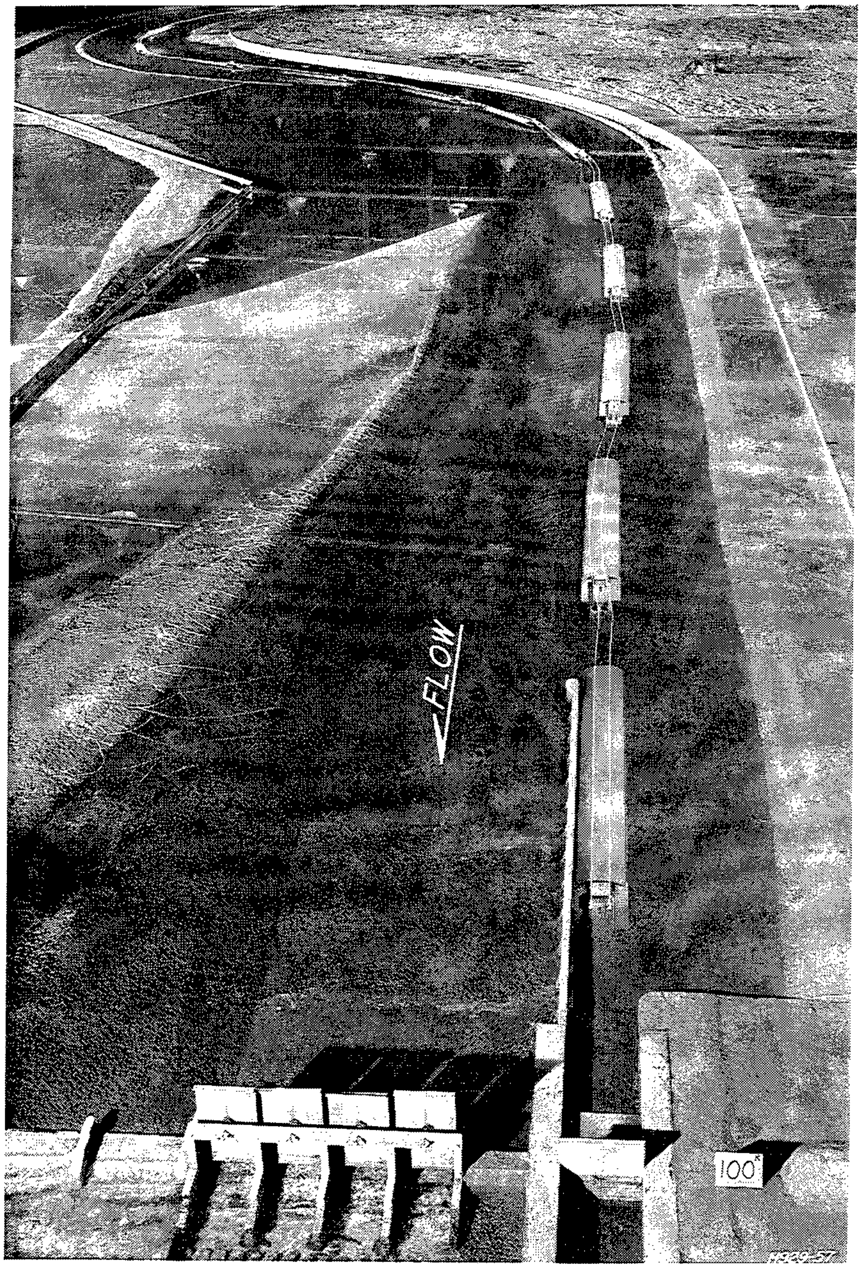


Photo 8. Plan B, looking upstream, discharge 100,000 cfs. Path of upbound tow leaving the upper lock approach.

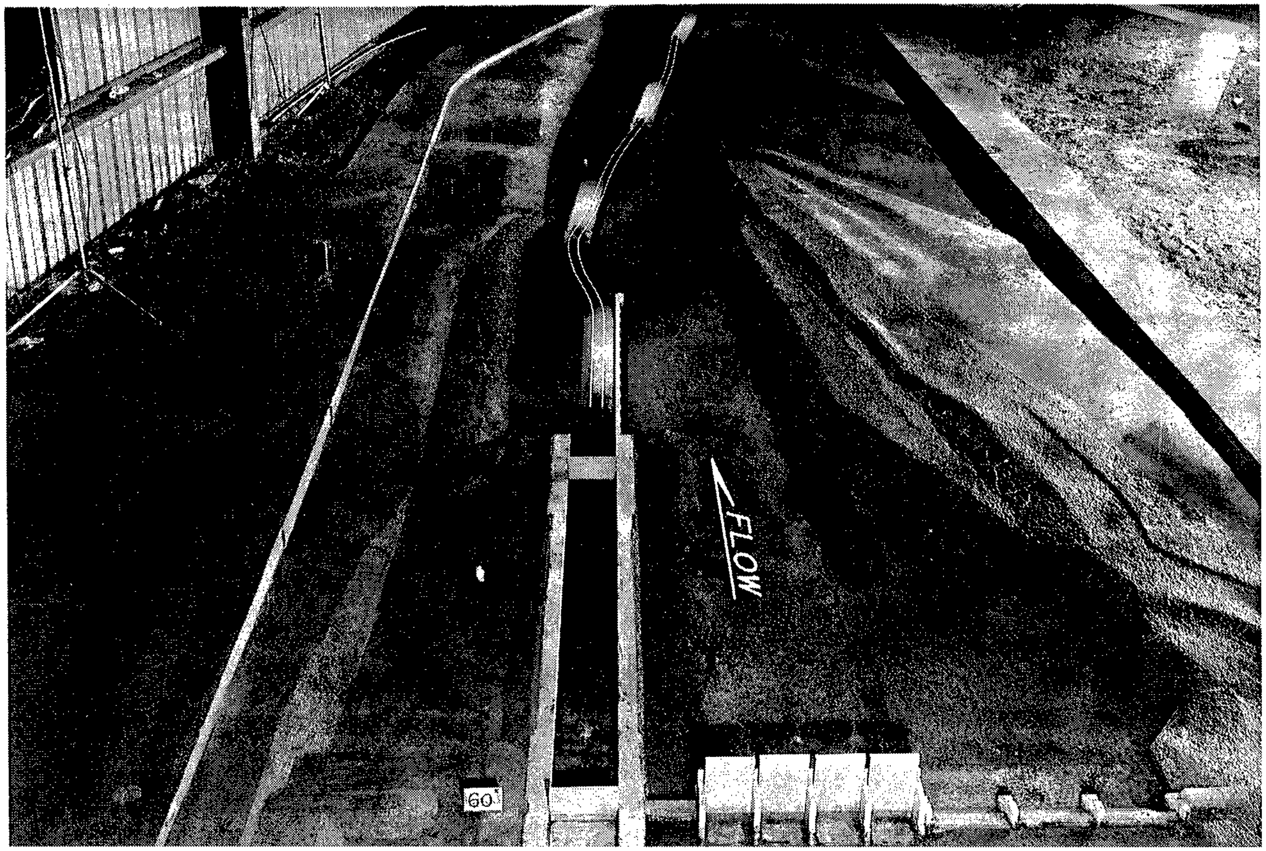


Photo 9. Plan B, looking downstream, discharge 60,000 cfs. Path of downbound tow leaving the lower lock approach. Note tendency for tow to be moved toward the left descending bank

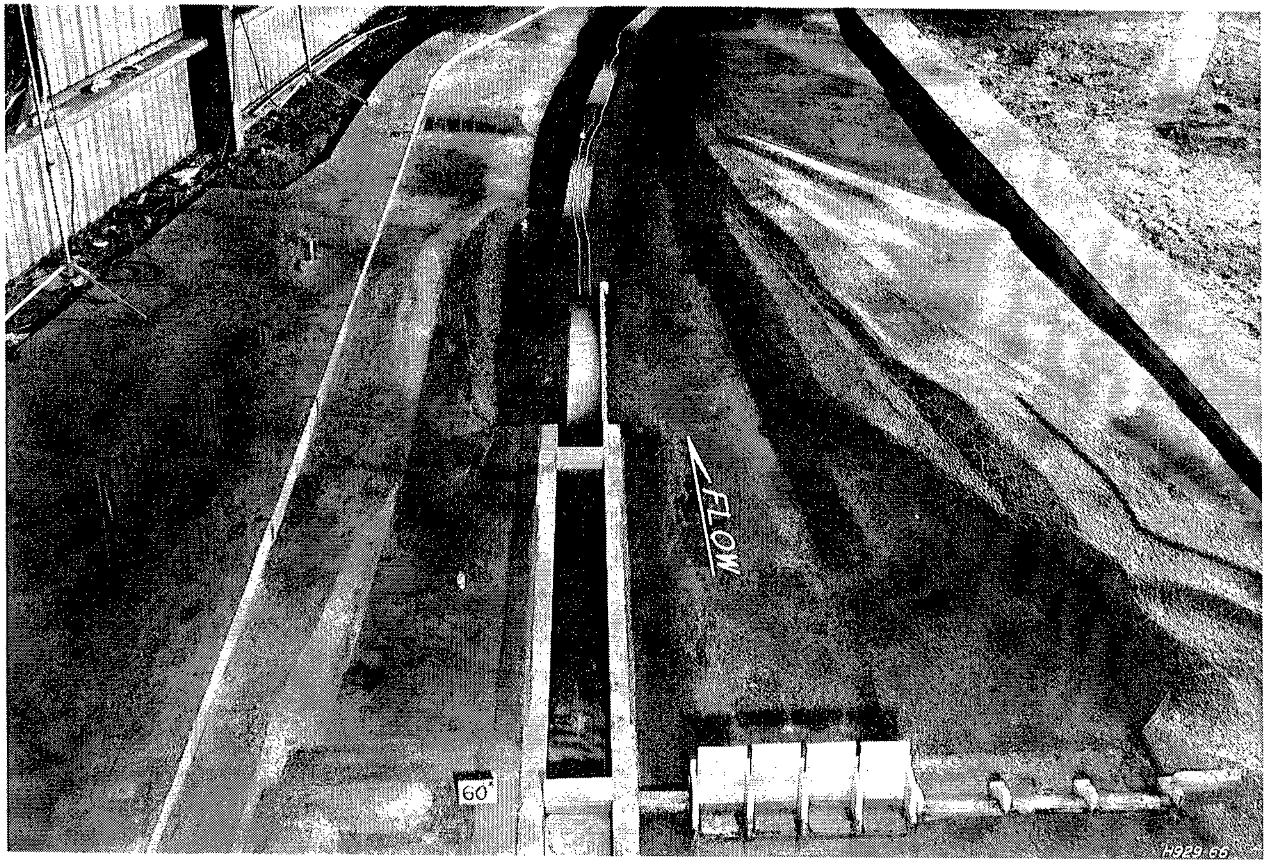


Photo 10. Plan B, looking downstream, discharge 60,000 cfs. Path of upbound tow entering the lower lock approach

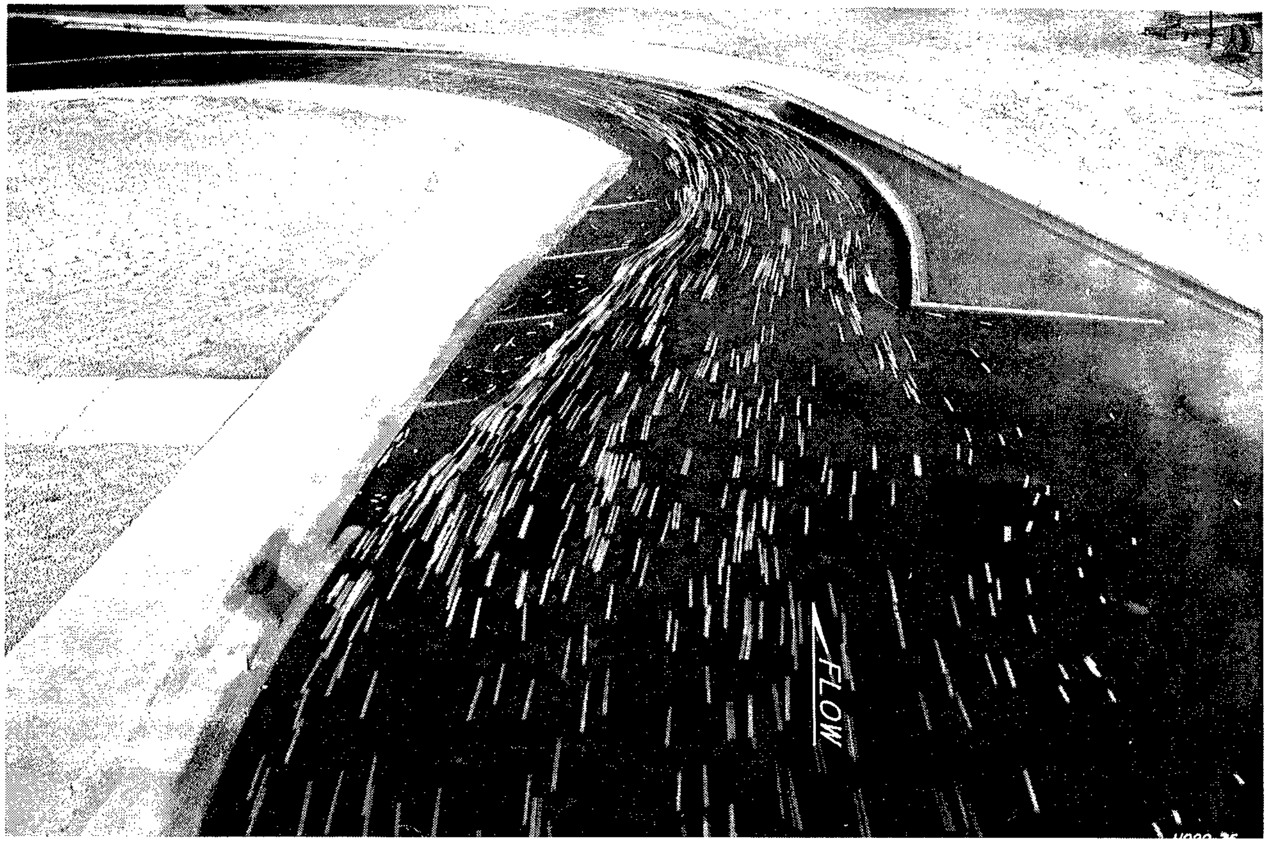


Photo 11. Plan C, looking downstream, discharge 80,000 cfs. Confetti showing surface current patterns entering and through Piermont cutoff

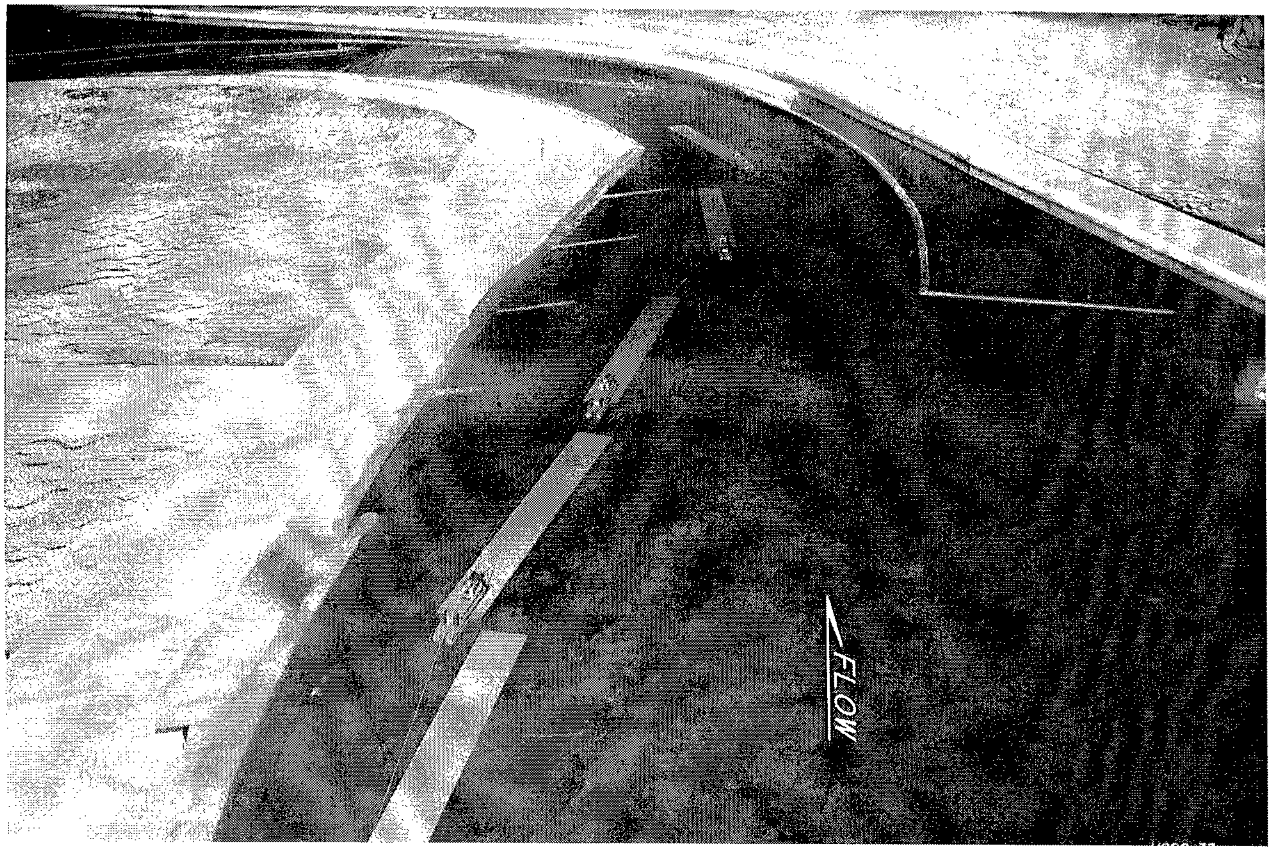


Photo 12. Plan C, looking downstream, discharge 60,000 cfs. Path of downbound tow driving past four spur dikes and into Piermont cutoff

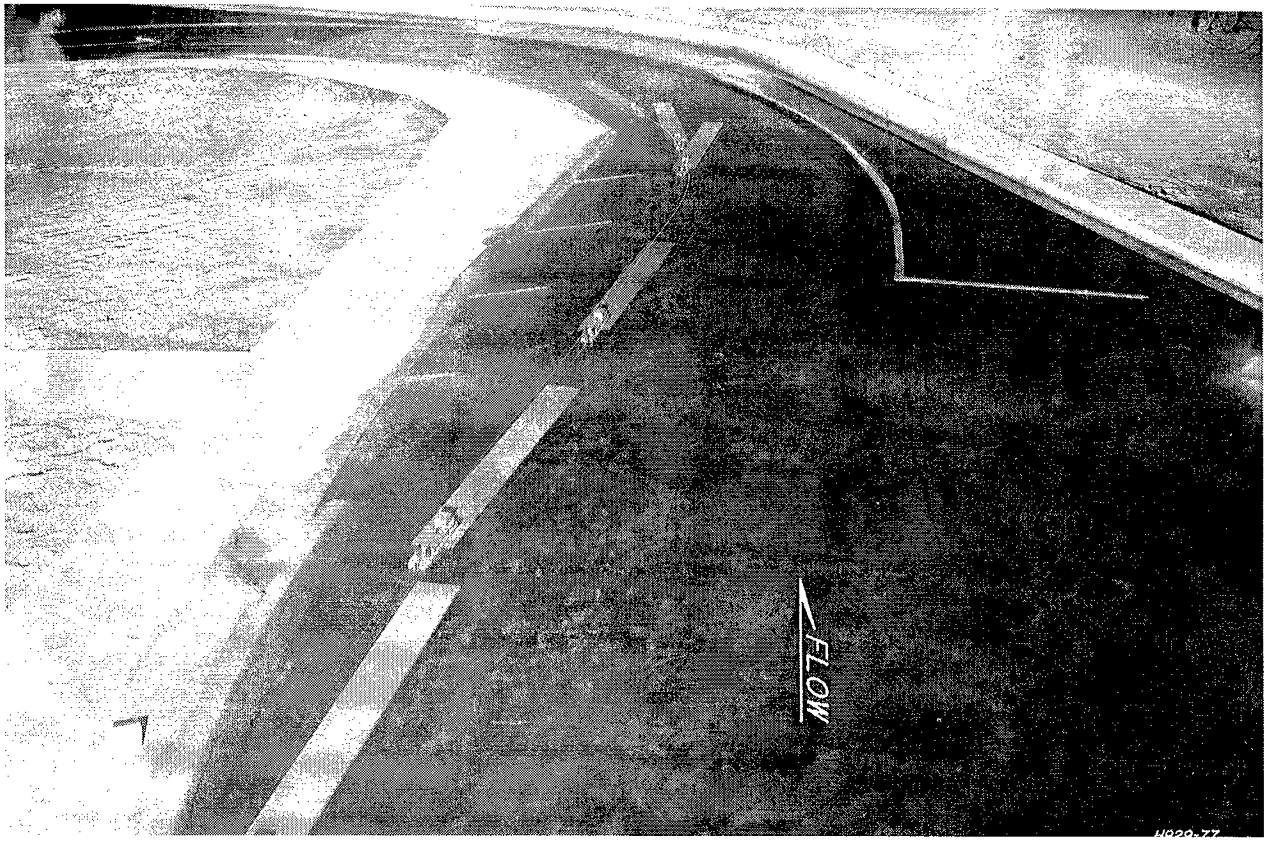


Photo 13. Plan C, looking downstream, discharge 80,000 cfs. Path of downbound tow flanking past four spur dikes and into Piermont cutoff. Note that tow is positioned to inside of bend

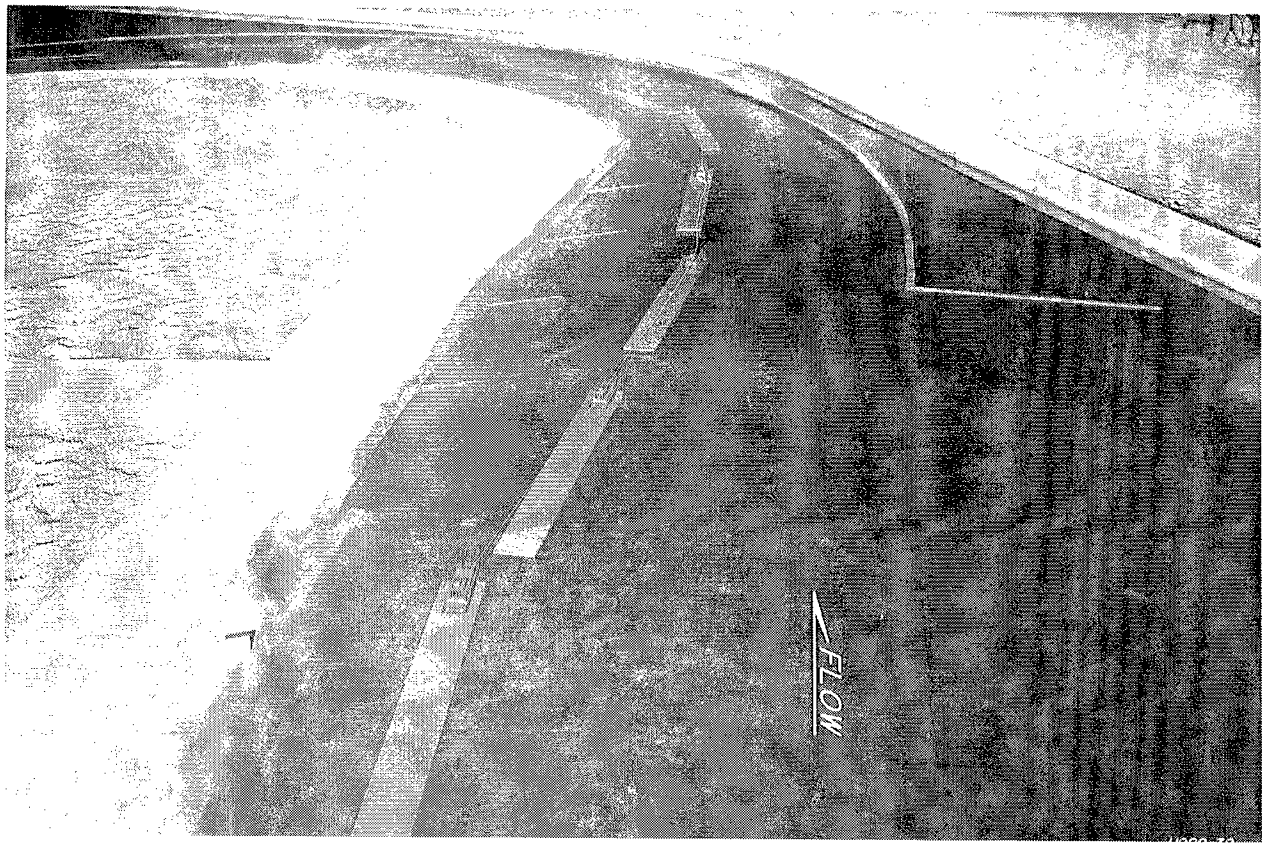


Photo 14. Plan C, looking downstream, discharge 80,000 cfs. Path of upbound tow leaving Piermont cutoff

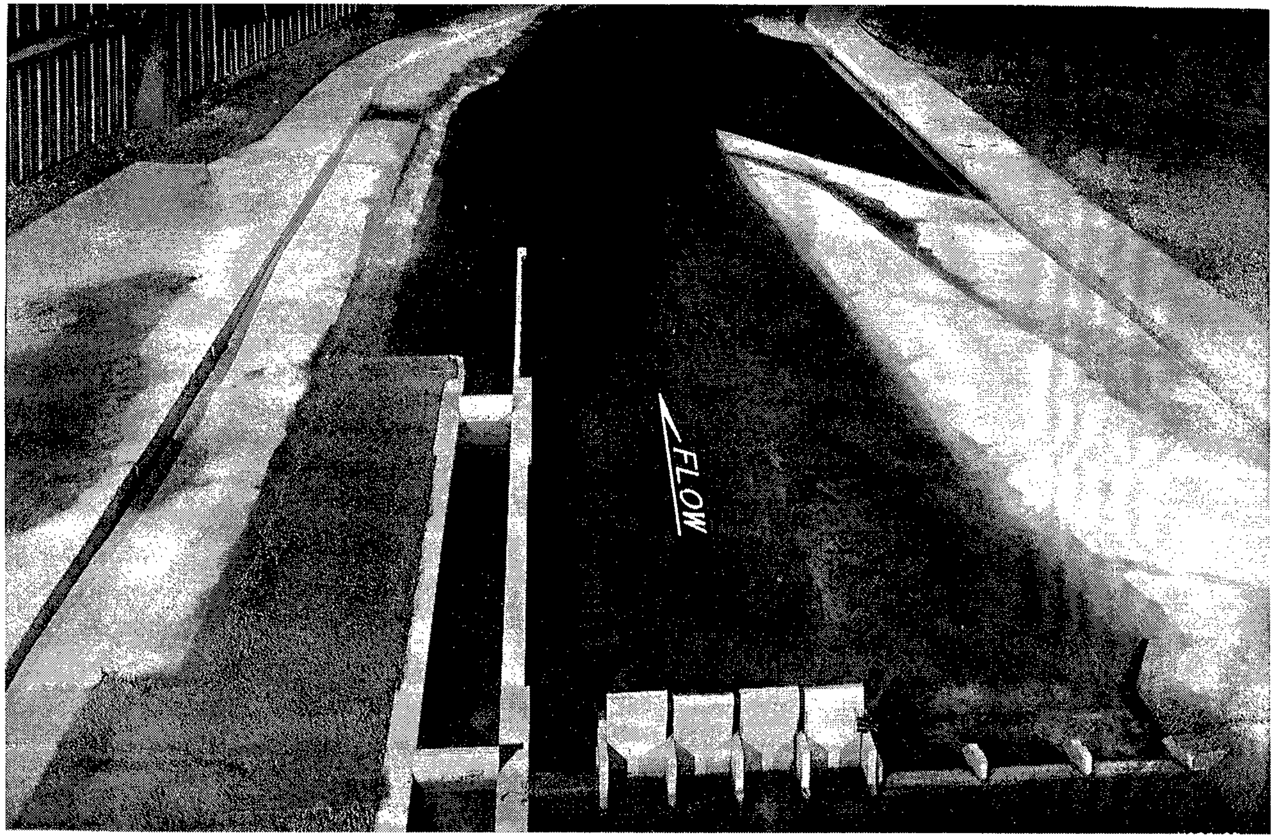


Photo 15. Plan C-1, looking downstream, showing lower lock approach

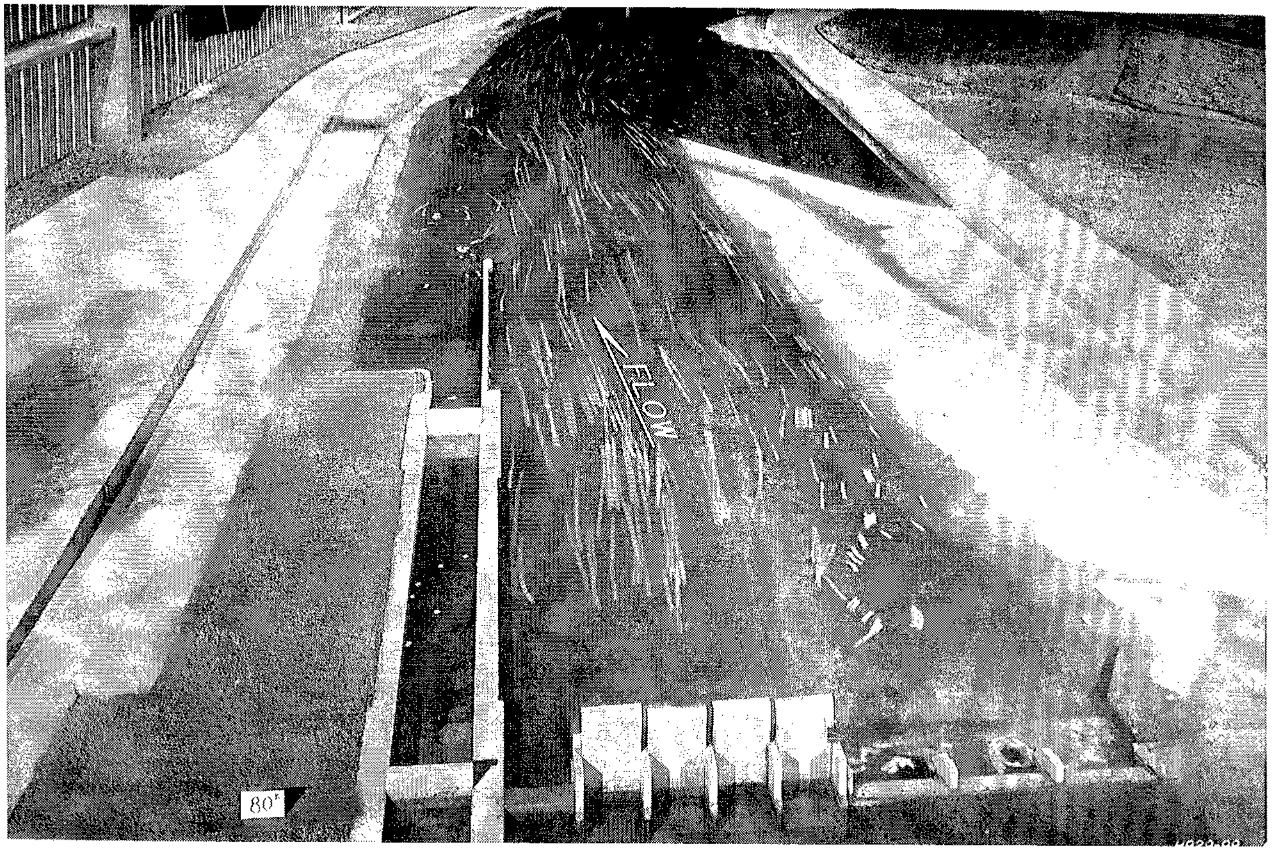


Photo 16. Plan C-1, looking downstream, discharge 80,000 cfs. Confetti showing surface current patterns in the lower lock approach. Note eddy downstream of guard wall

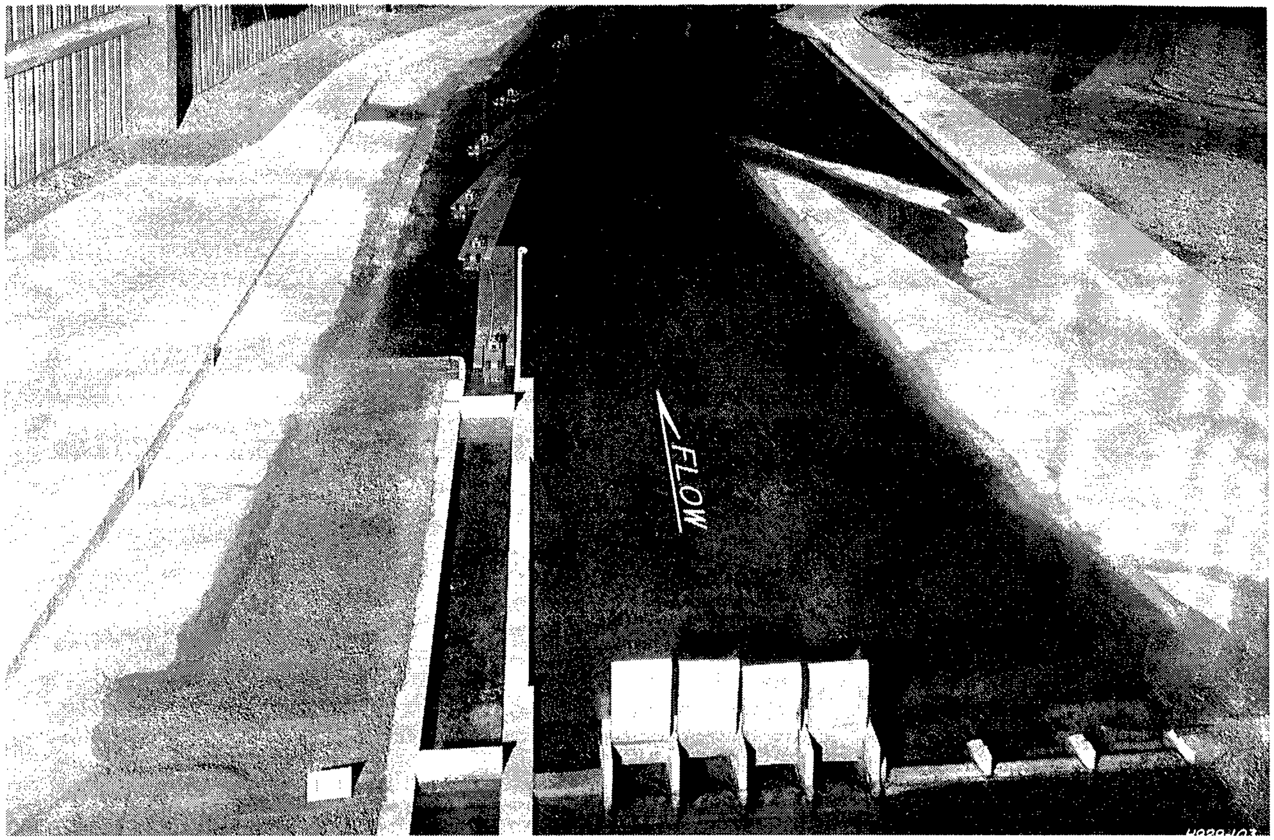


Photo 17. Plan C-1, looking downstream, discharge 134,000 cfs. Path of downbound tow leaving the lower lock approach

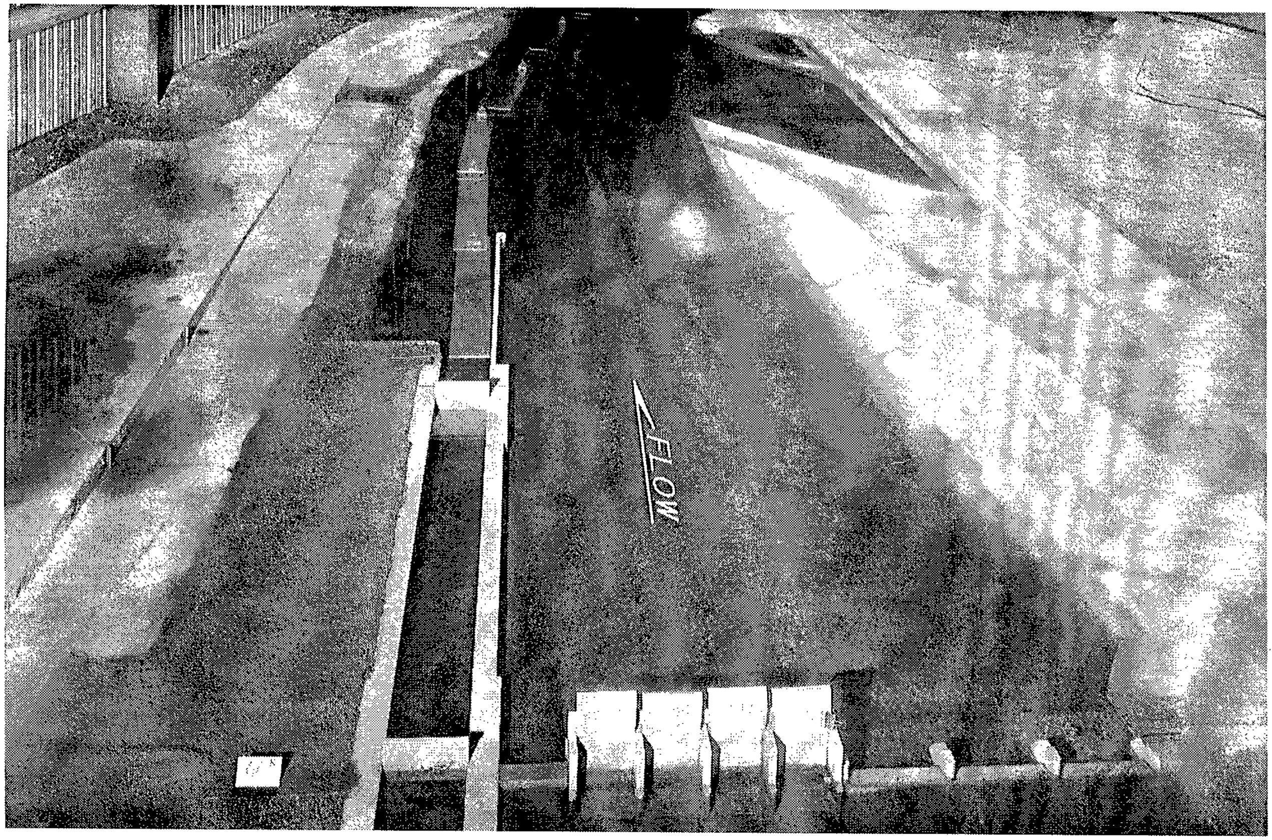


Photo 18. Plan C-1, looking downstream, discharge 60,000 cfs. Path of upbound tow entering the lower lock approach

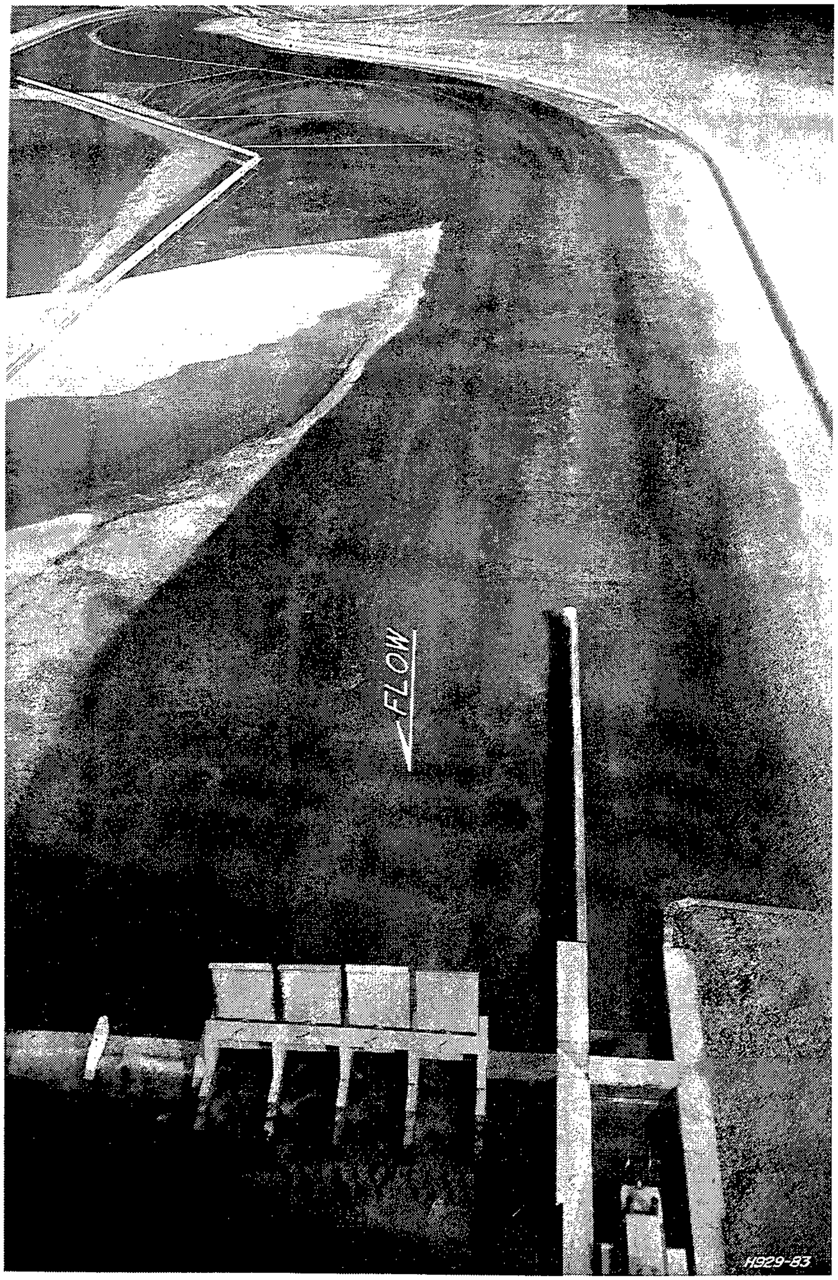


Photo 19. Plan C-2, looking upstream showing upper lock approach

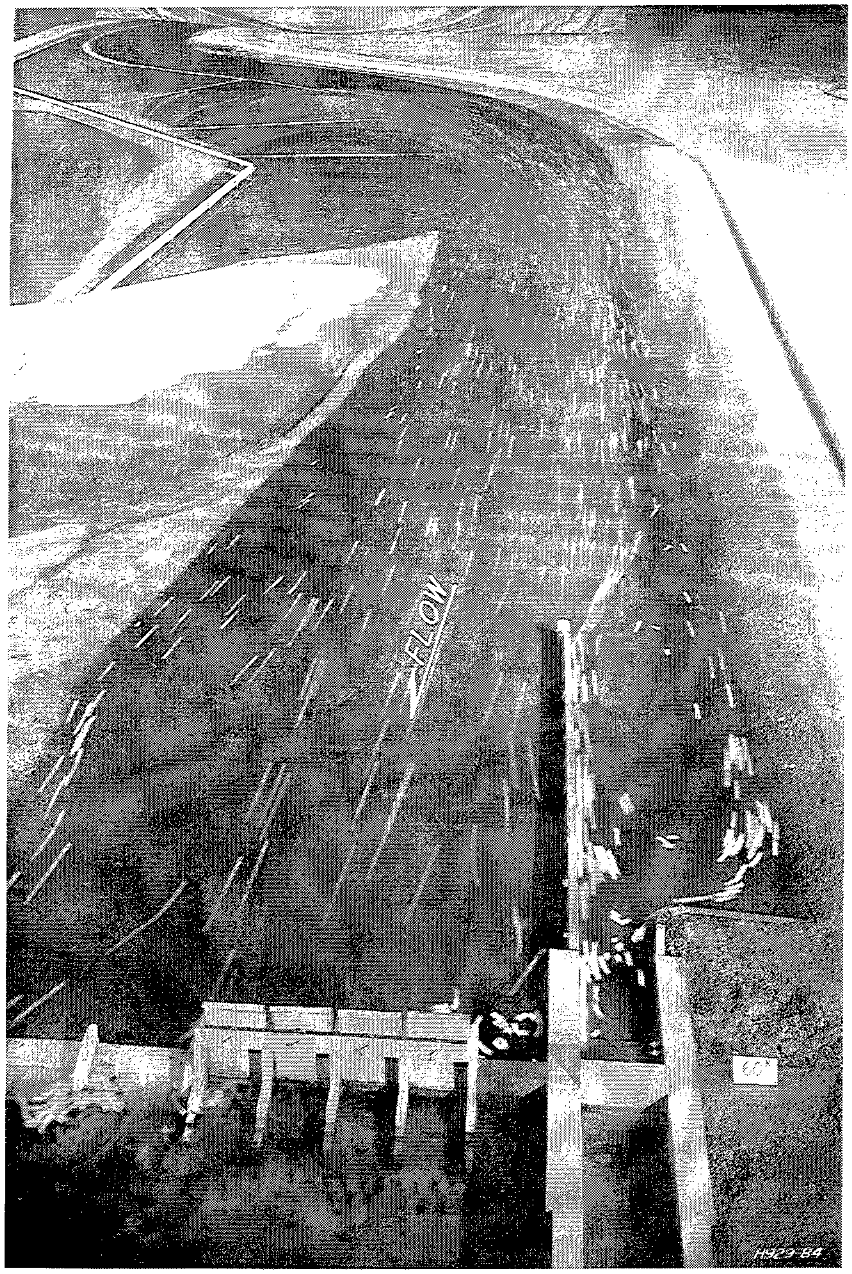


Photo 20. Plan C-2, looking upstream, discharge 60,000 cfs. Confetti showing surface current patterns. Note large eddy landward of guard wall

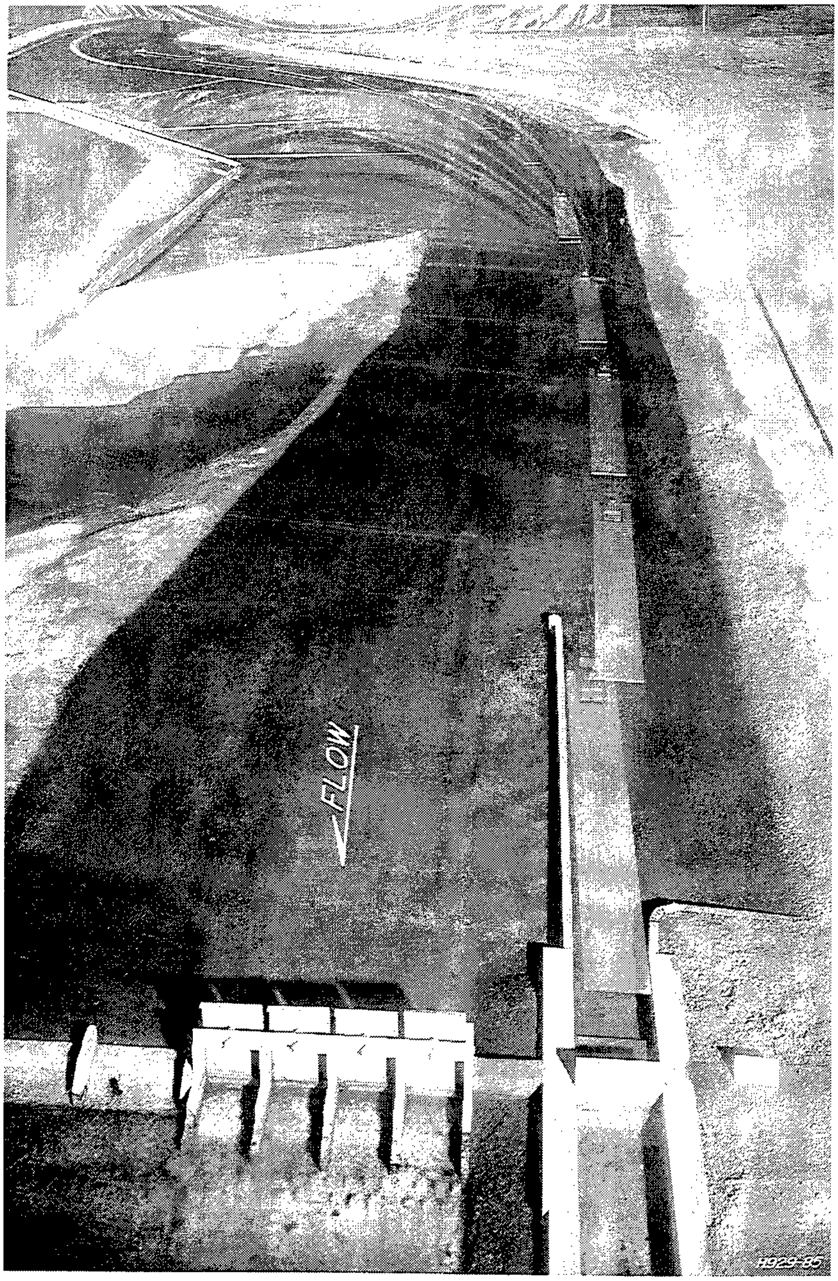


Photo 21. Plan C-2, looking upstream, discharge 60,000 cfs. Path of downbound tow entering the upper lock approach

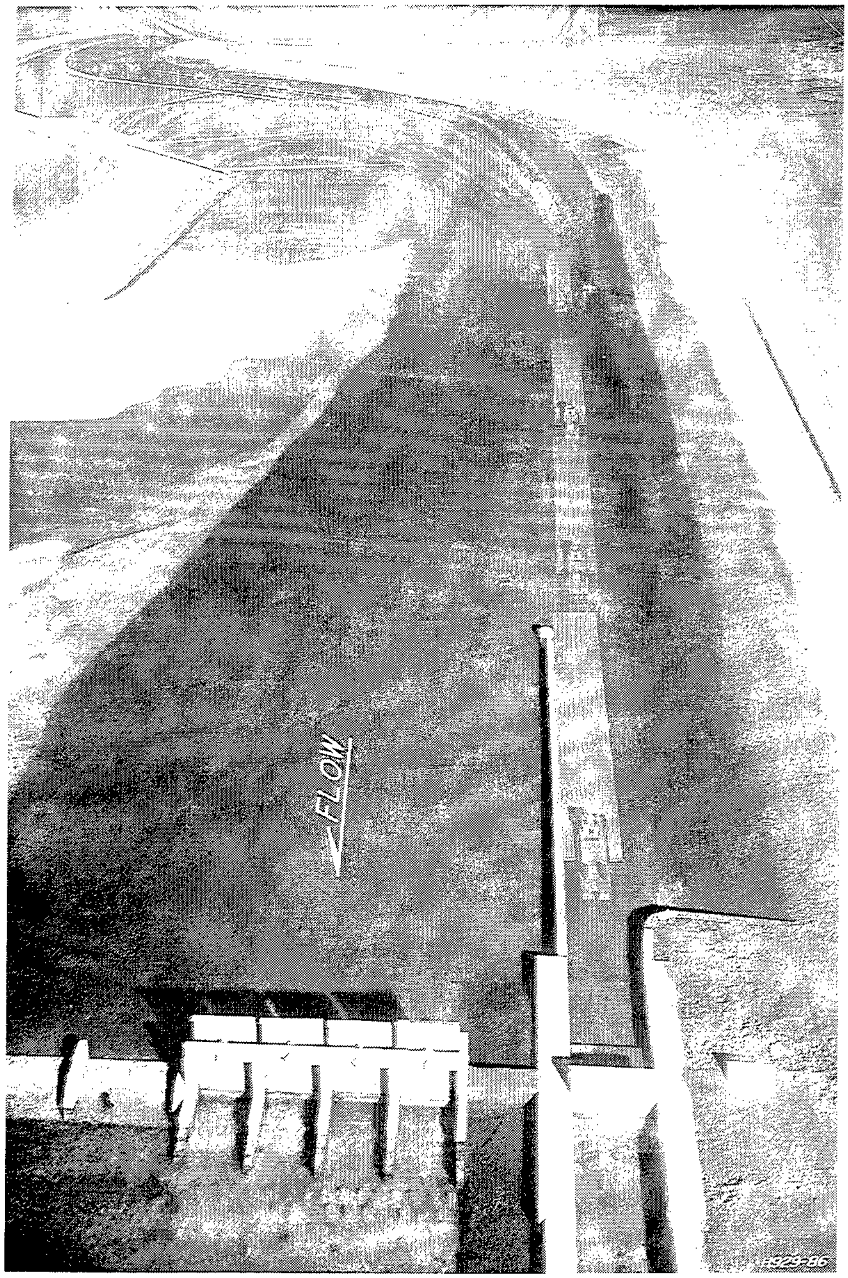


Photo 22. Plan C-2, looking upstream, discharge 60,000 cfs. Path of upbound tow leaving the upper lock approach

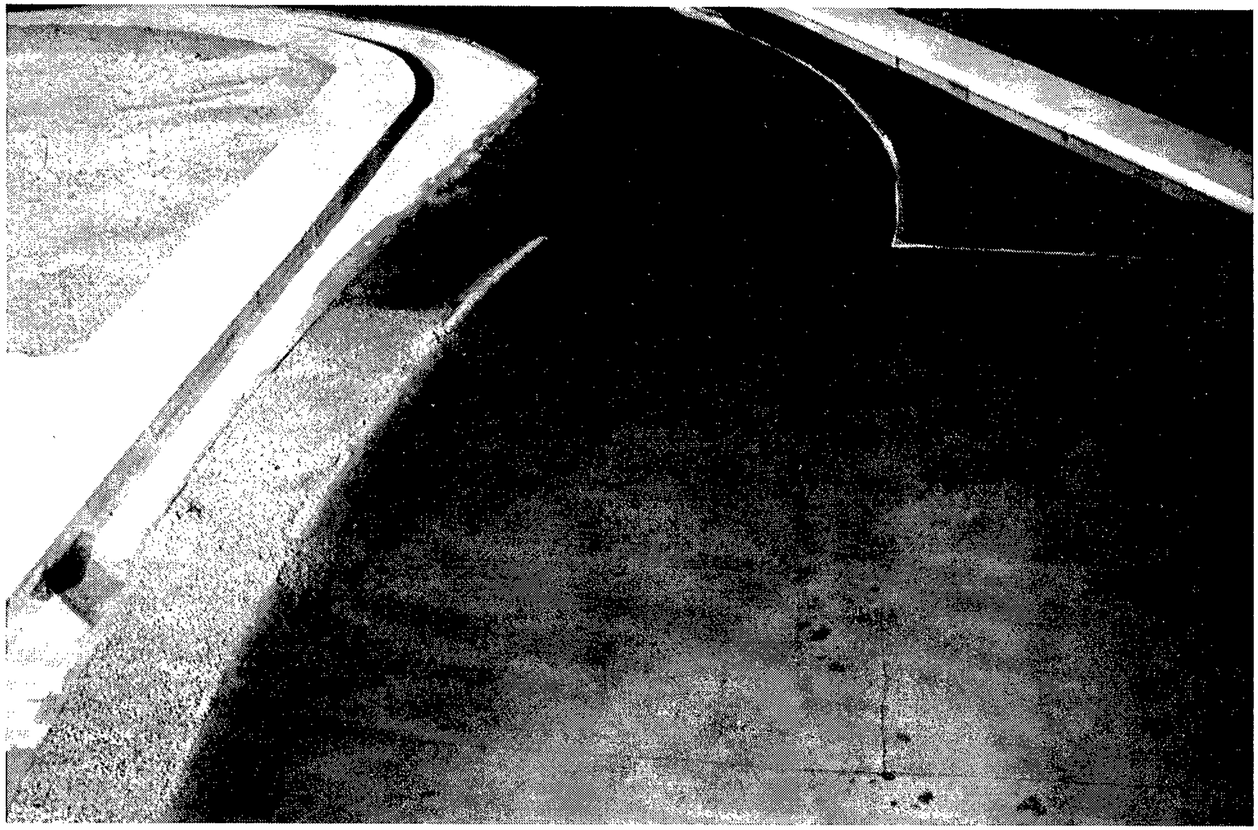


Photo 23. Plan D, looking downstream, showing Bull Revetment and the entrance to Piermont cutoff

Photo 24. Plan D, looking upstream, showing the upper lock approach

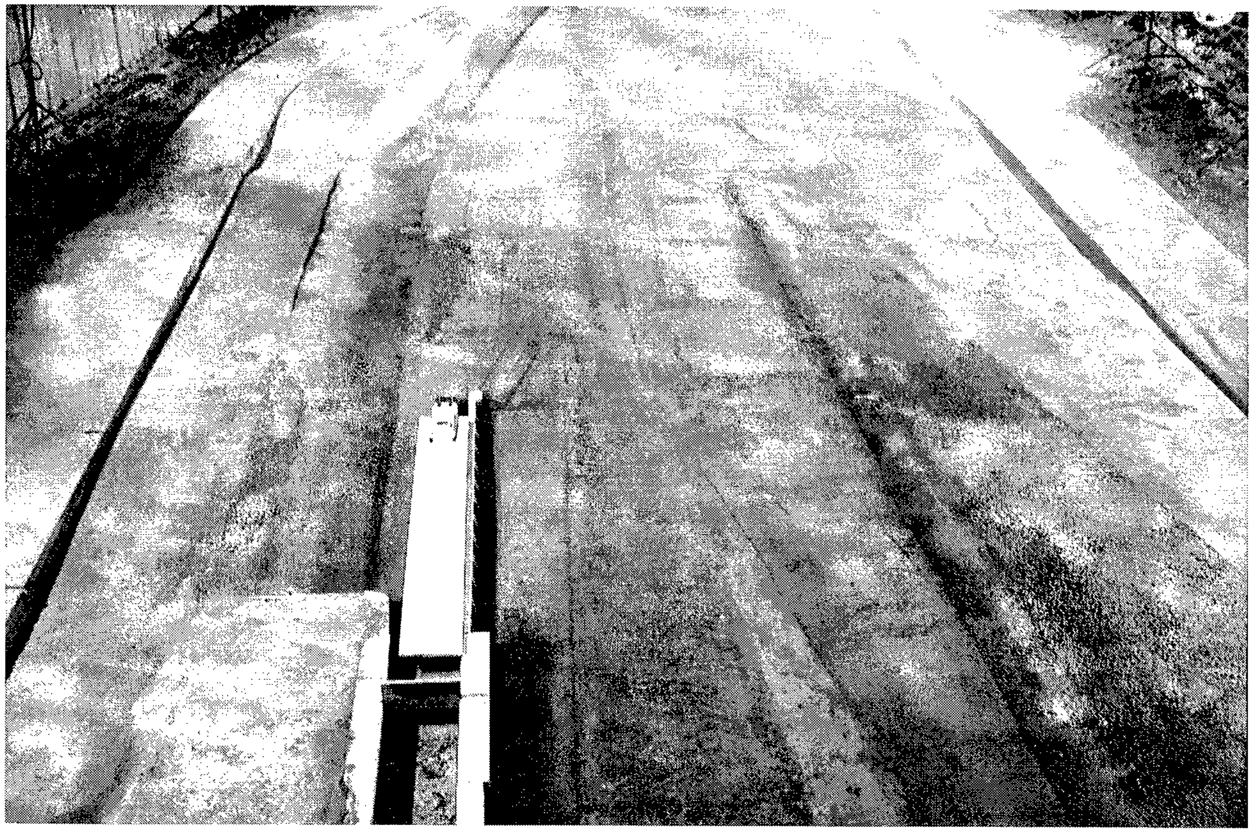


Photo 25. Plan D, looking downstream, showing the lower lock approach

Photo 26. Plan D, looking downstream, discharge 80,000 cfs. Confetti showing surface current patterns

Photo 27. Plan D, looking upstream, discharge 134,000 cfs. Confetti showing surface current patterns. Note large eddy landward of guard wall

Photo 28. Plan D, looking downstream, discharge 60,000 cfs. Confetti showing surface current patterns

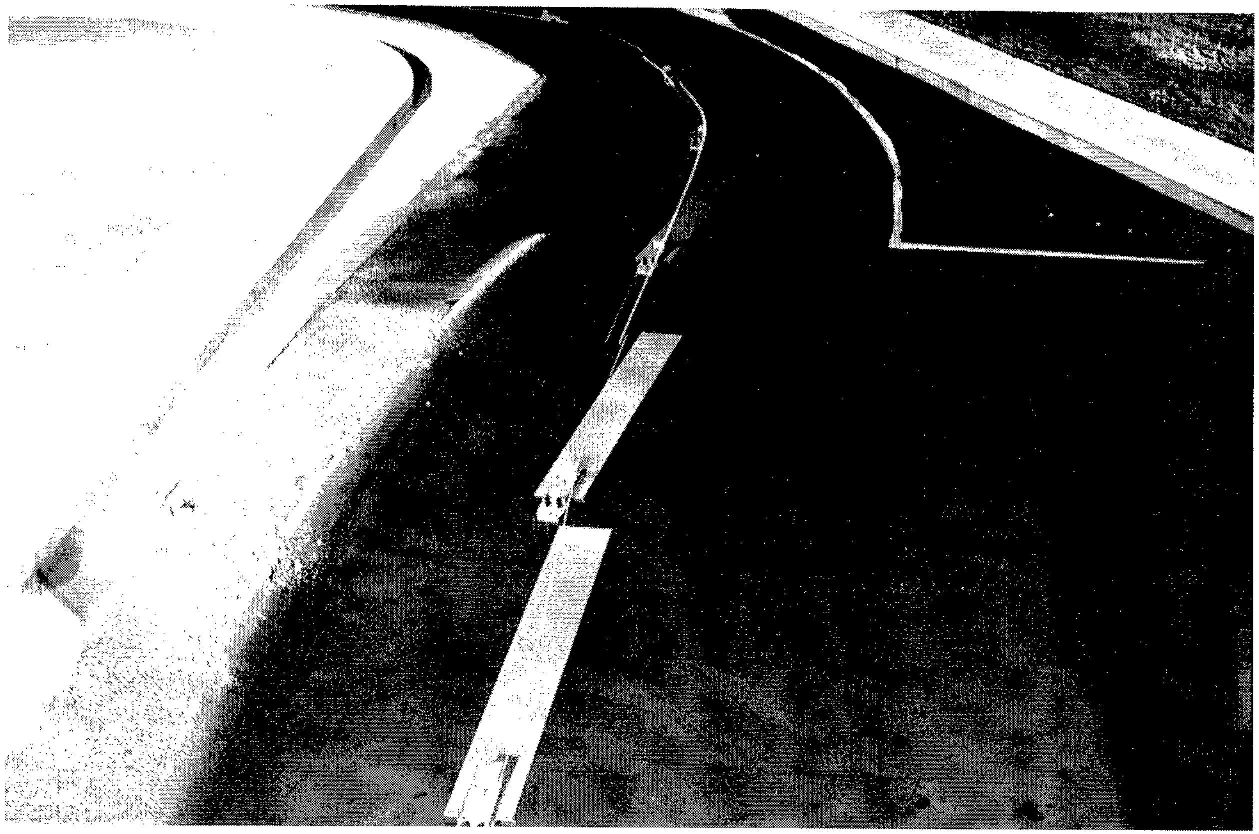


Photo 29. Plan D, looking downstream, discharge 60,000 cfs. Path of downbound tow flanking past Bull Revetment and into Piermont cutoff. Note tendency for currents to move tow toward submerged portion of Bull Revetment

Photo 30. Plan D, looking downstream, discharge 80,000 cfs. Path of downbound tow flanking past Bull Revetment and into Piermont cutoff. Note tendency for currents to move tow toward left bank in vicinity of Piermont cutoff

Photo 31. Plan D, looking downstream, discharge 60,000 cfs. Path of downbound tow driving past Bull Revetment. Note tendency for tow to be pushed toward or grounded on right bank

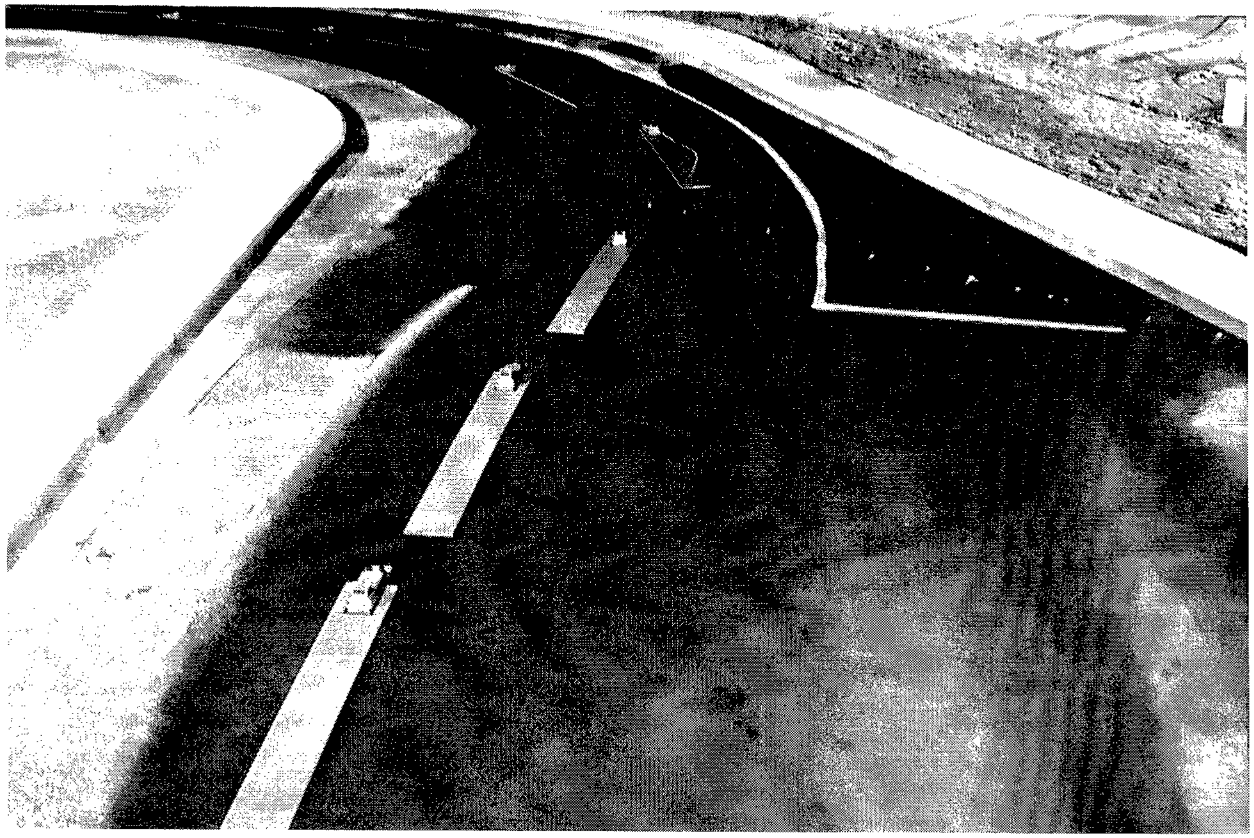


Photo 32. Plan D, looking downstream, discharge 80,000 cfs. Path of upbound tow leaving Piermont cutoff and moving past Bull Revetment. Note tendency for tow to be moved toward Bull Revetment

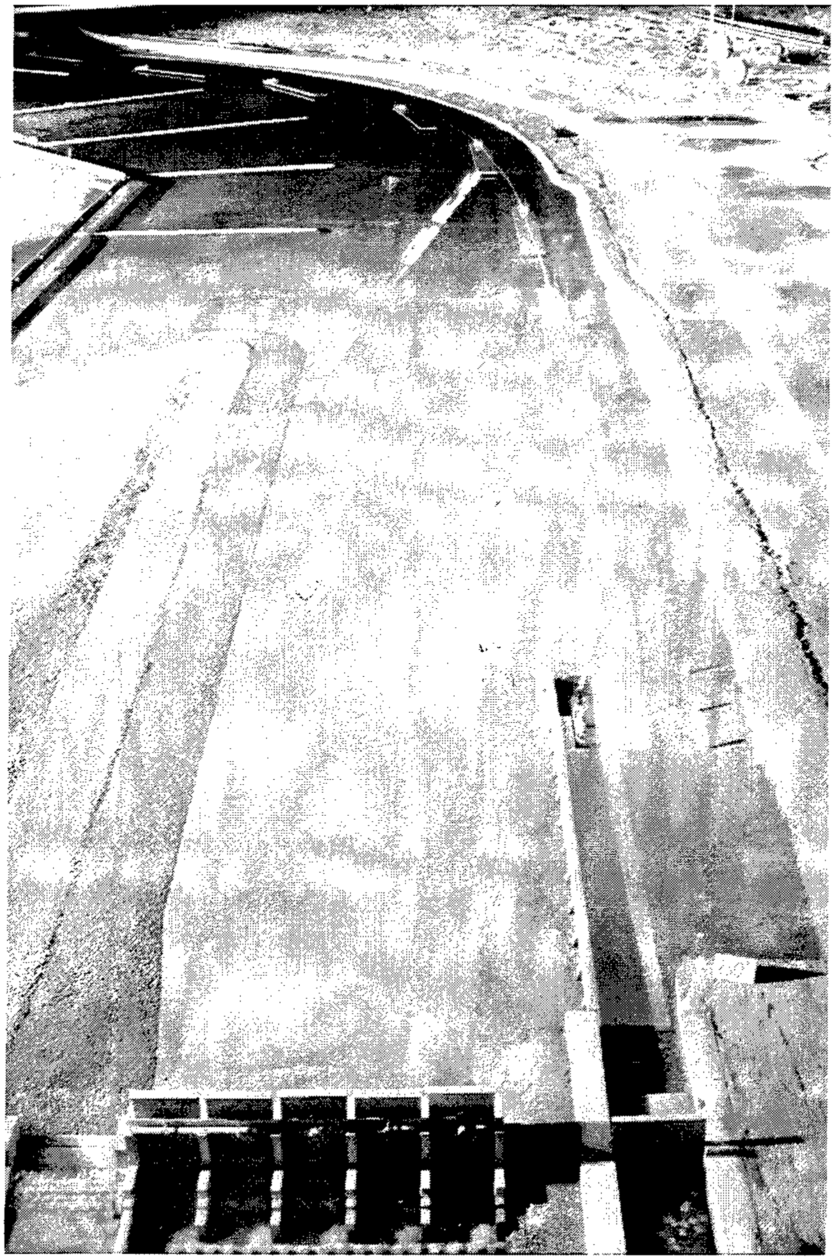


Photo 33. Plan D, looking upstream, discharge 80,000 cfs. Path of downbound tow entering the upper lock approach

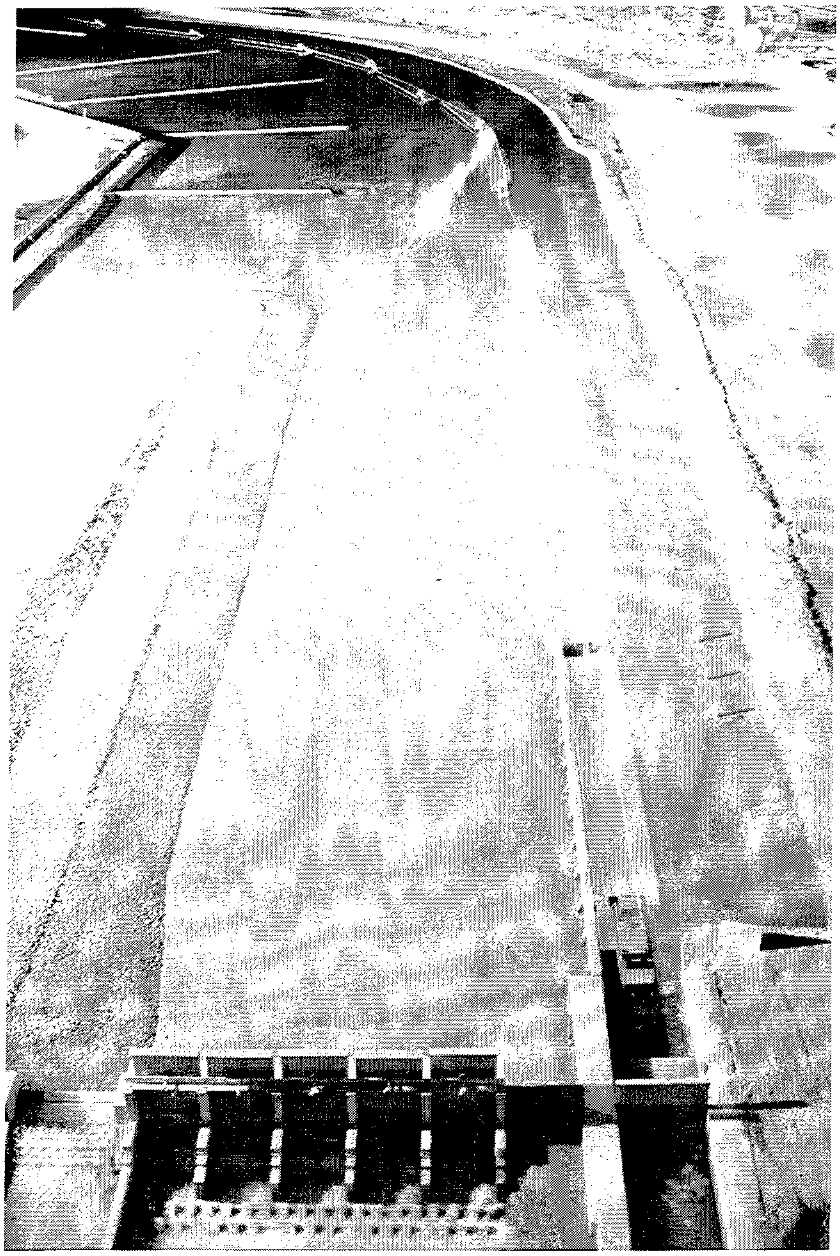


Photo 34. Plan D, looking upstream, discharge 80,000 cfs. Path of upbound tow leaving the upper lock approach

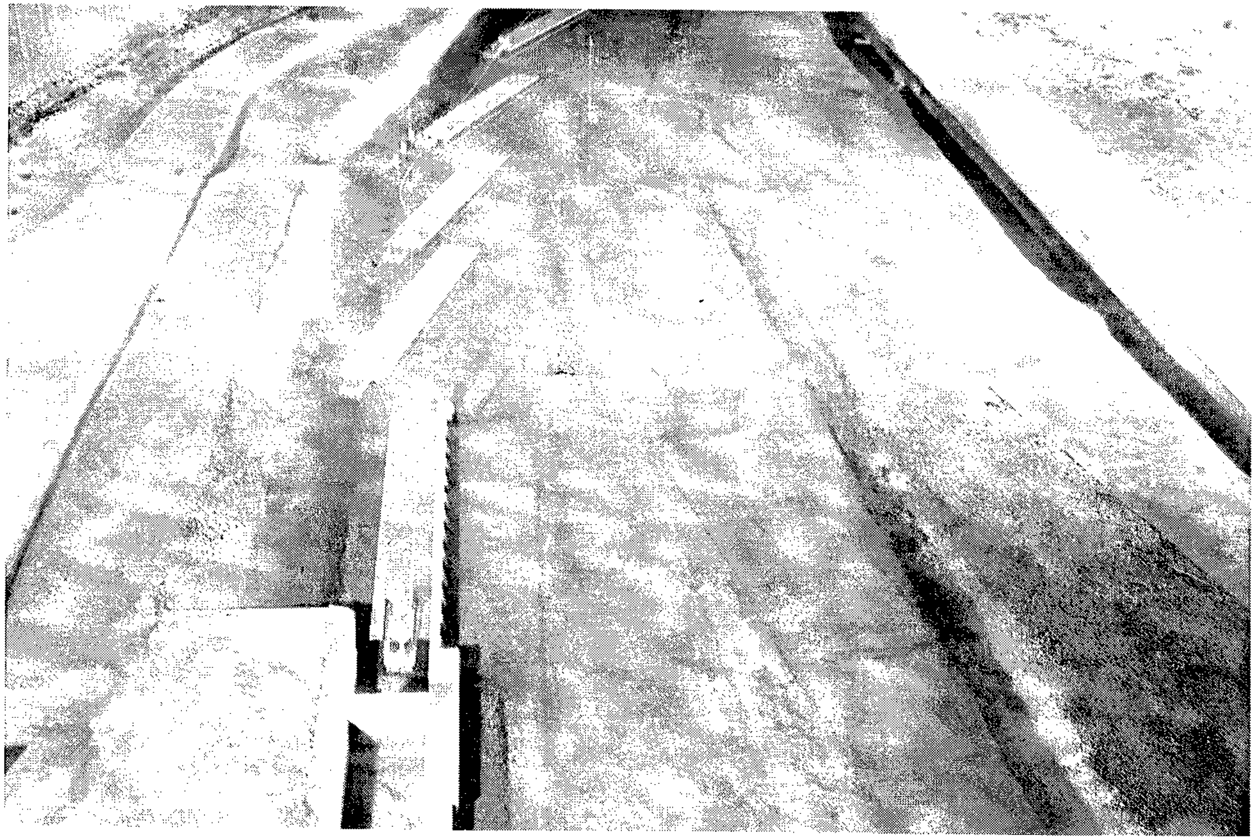


Photo 35. Plan D, looking downstream, discharge 80,000 cfs. Path of downbound tow leaving the lower lock approach. Note tendency for currents to move toward left bank and into mooring dolphins

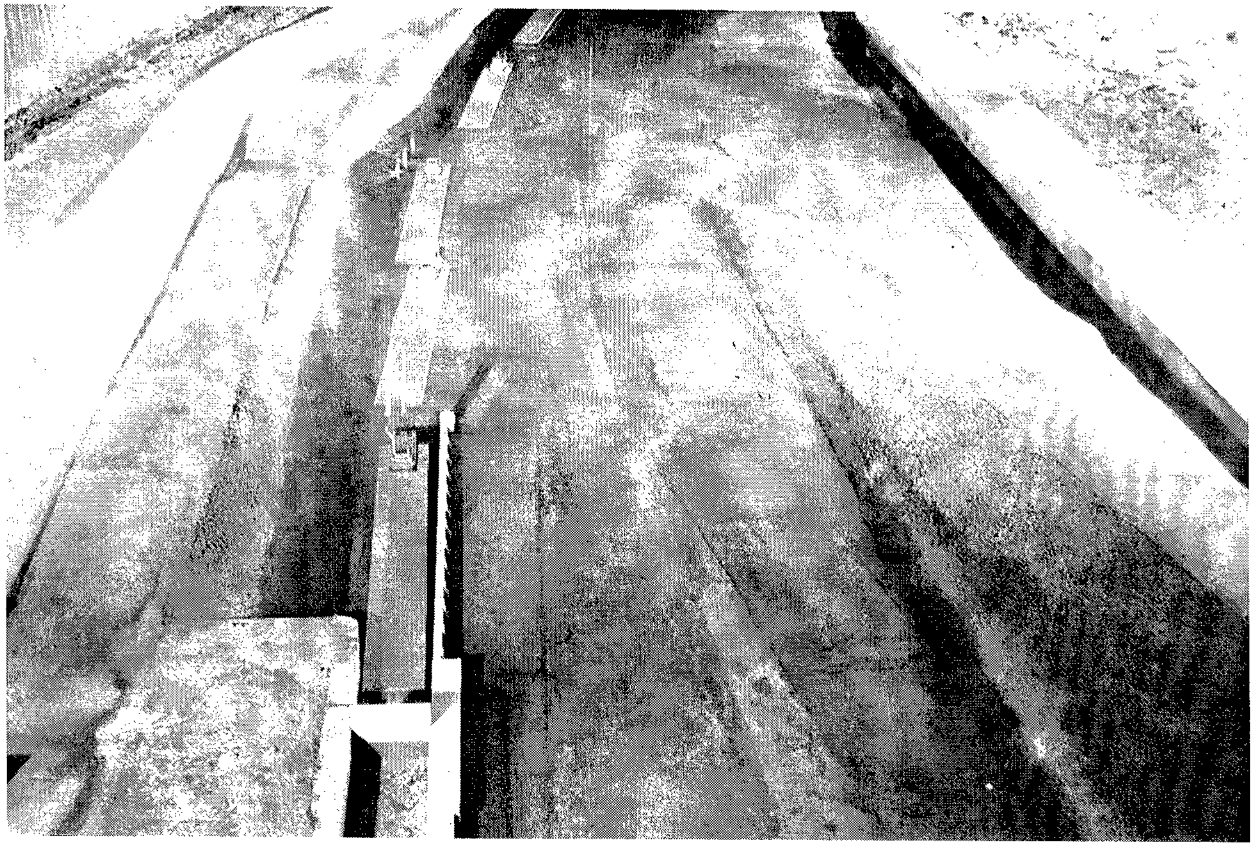


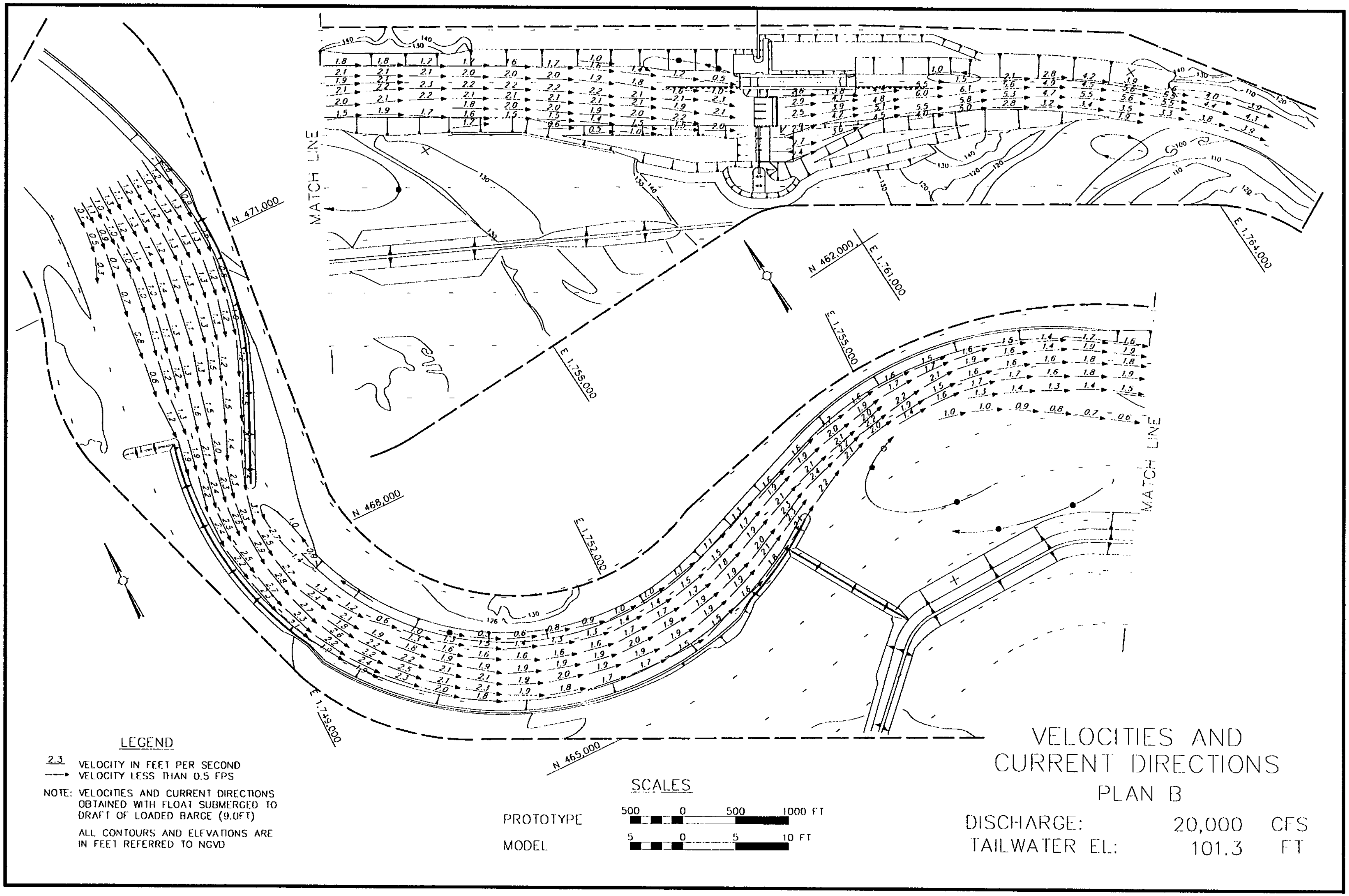
Photo 36. Plan D, looking downstream, discharge 60,000 cfs. Path of upbound tow entering the lower lock approach. Note clearance between tow and mooring dolphins

Photo 37. Plan D-2, looking downstream, showing the lower lock approach

Photo 38. Plan D-2, looking downstream, discharge 80,000 cfs. Confetti showing surface current patterns

Photo 39. Plan D-2, looking downstream, discharge 80,000 cfs. Path of downbound tow leaving the lower lock approach

Photo 40. Plan D-2, looking downstream, discharge 134,000 cfs. Path of upbound tow entering the lower lock approach



MATCH LINE
N 471,000
N 468,000
N 465,000
N 462,000
E 1,749,000
E 1,752,000
E 1,755,000
E 1,758,000
E 1,761,000
E 1,764,000
LEGEND
2.3 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FPS
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 500 0 500 1000 FT
MODEL 5 0 5 10 FT
VELOCITIES AND CURRENT DIRECTIONS
PLAN B
DISCHARGE: 20,000 CFS
TAILWATER EL: 101.3 FT

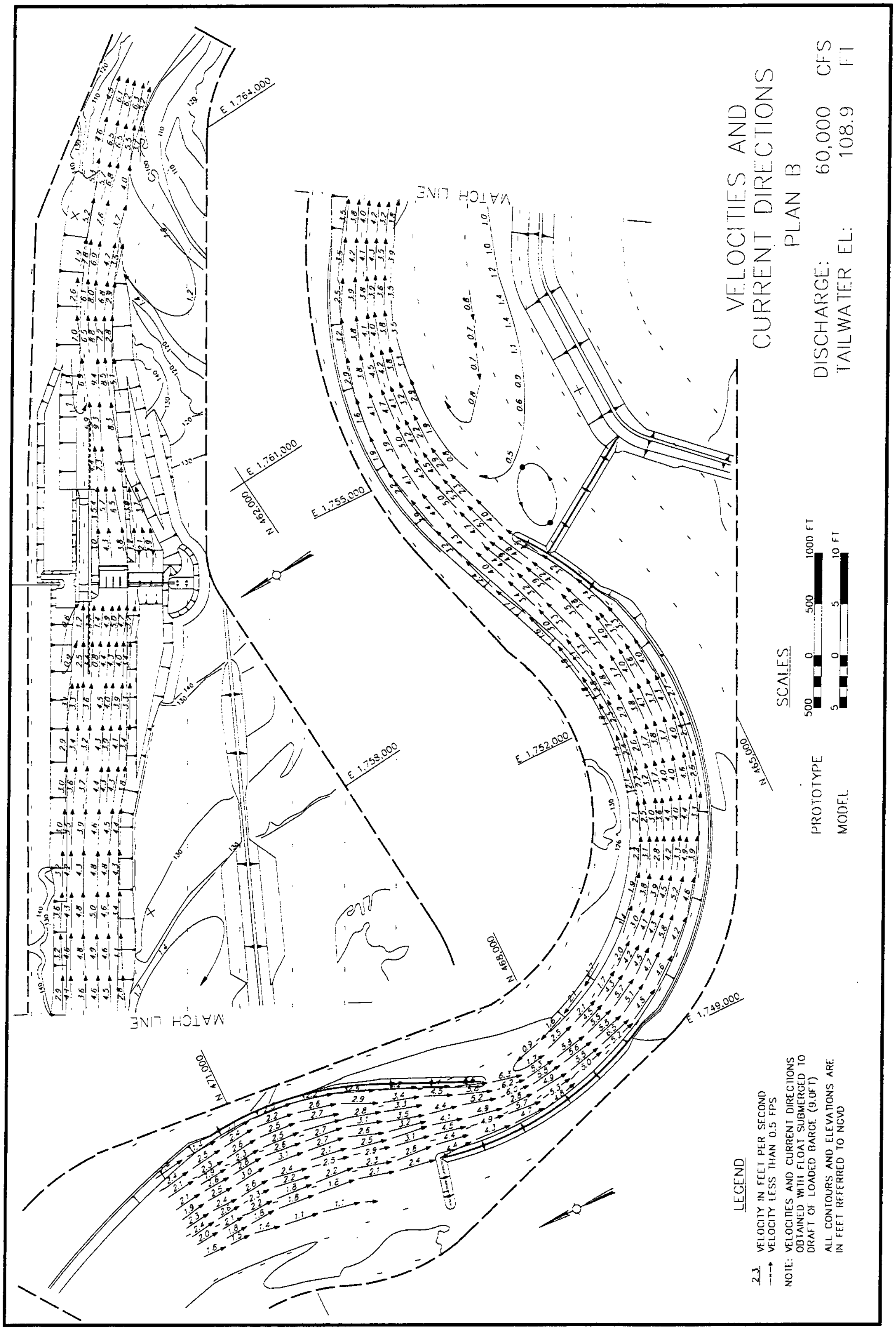

VELOCITIES AND CURRENT DIRECTIONS
PLAN B
DISCHARGE: 60,000 CFS
TAILWATER EL: 108.9 FT
SCALES
PROTOTYPE 500 0 500 1000 FT
MODEL 5 0 5 10 FT
LEGEND
2.3 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FPS
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
MATCH LINE
MATCH LINE
E 1,764,000
E 1,761,000
E 1,758,000
E 1,755,000
E 1,752,000
E 1,749,000
N 462,000
N 465,000
N 468,000
N 471,000

Plate 2

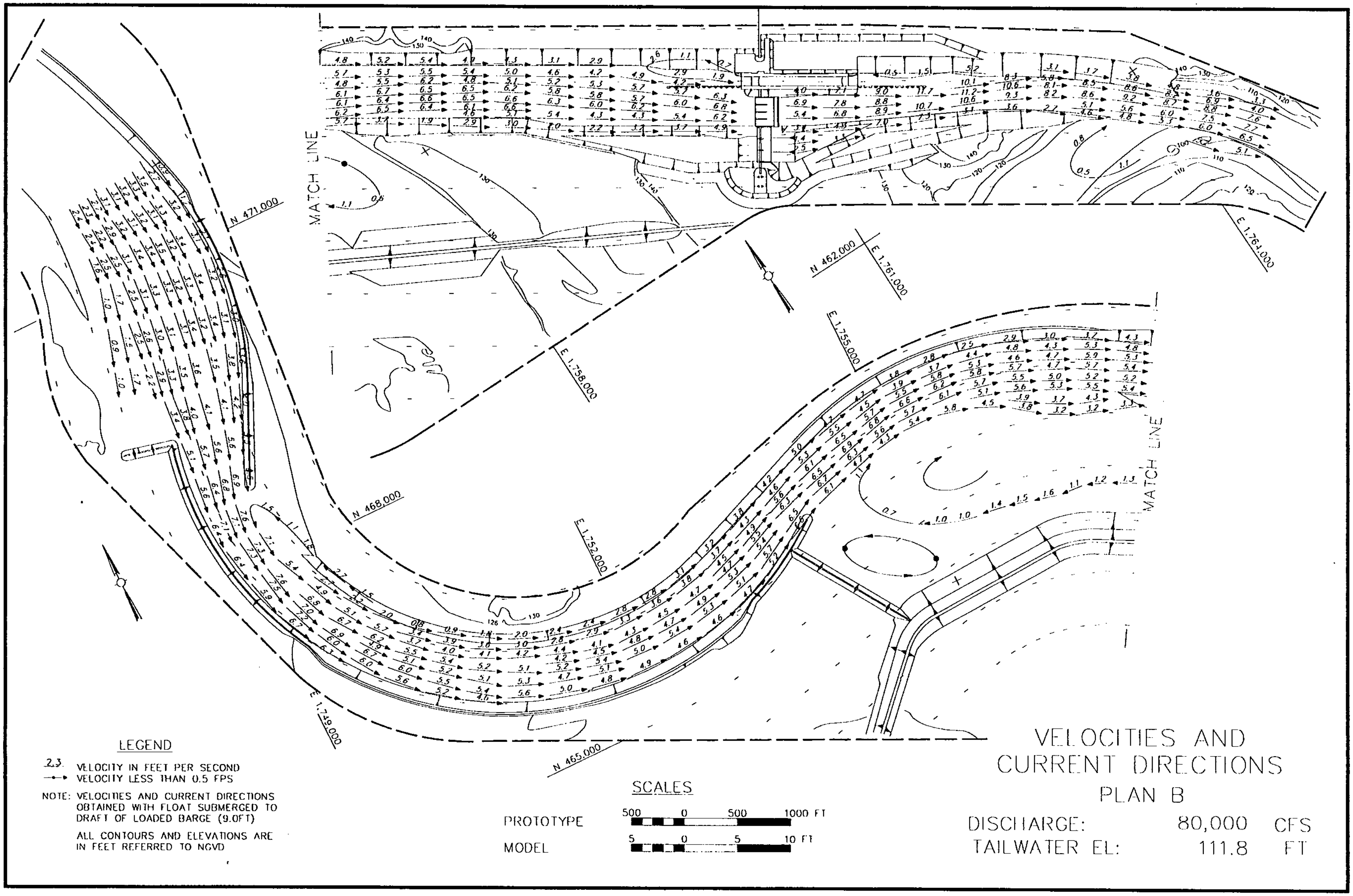

VELOCITIES AND CURRENT DIRECTIONS
PLAN B
DISCHARGE: 80,000 CFS
TAILWATER EL: 111.8 FT
LEGEND
2.3 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FPS
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 500 0 500 1000 FT
MODEL 5 0 5 10 FT
MATCH LINE
N 471,000
N 468,000
N 465,000
N 462,000
E 1,749,000
E 1,752,000
E 1,755,000
E 1,758,000
E 1,761,000
E 1,764,000

Plate 3

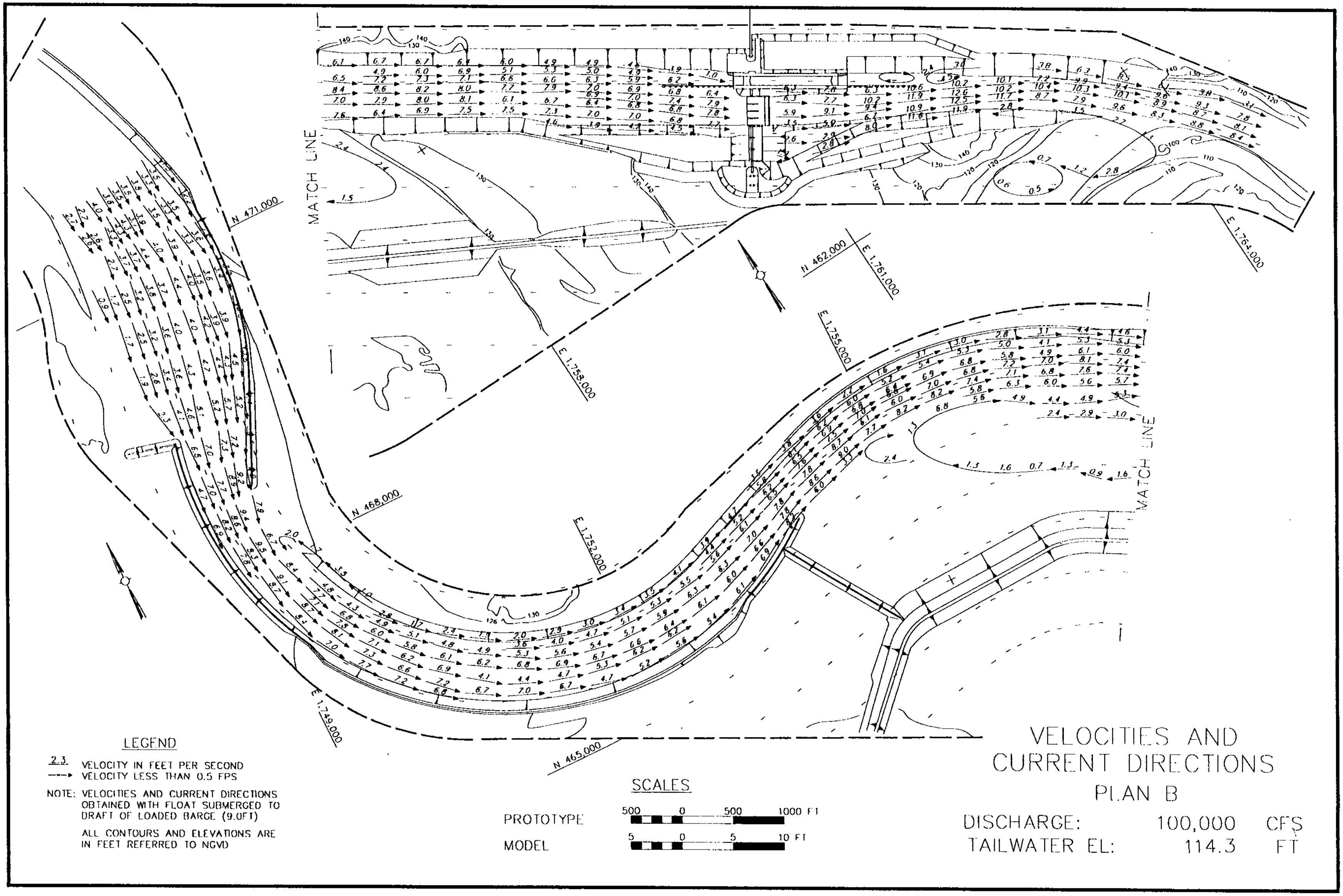

VELOCITIES AND
CURRENT DIRECTIONS
PLAN B
DISCHARGE: 100,000 CFS
TAILWATER EL: 114.3 FT
LEGEND
2.3 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FPS
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 500 0 500 1000 FT
MODEL 5 0 5 10 FT
MATCH LINE
MATCH LINE
N 471,000
N 468,000
N 465,000
N 462,000
E 1,749,000
E 1,752,000
E 1,755,000
E 1,758,000
E 1,761,000
E 1,764,000

Plate 4

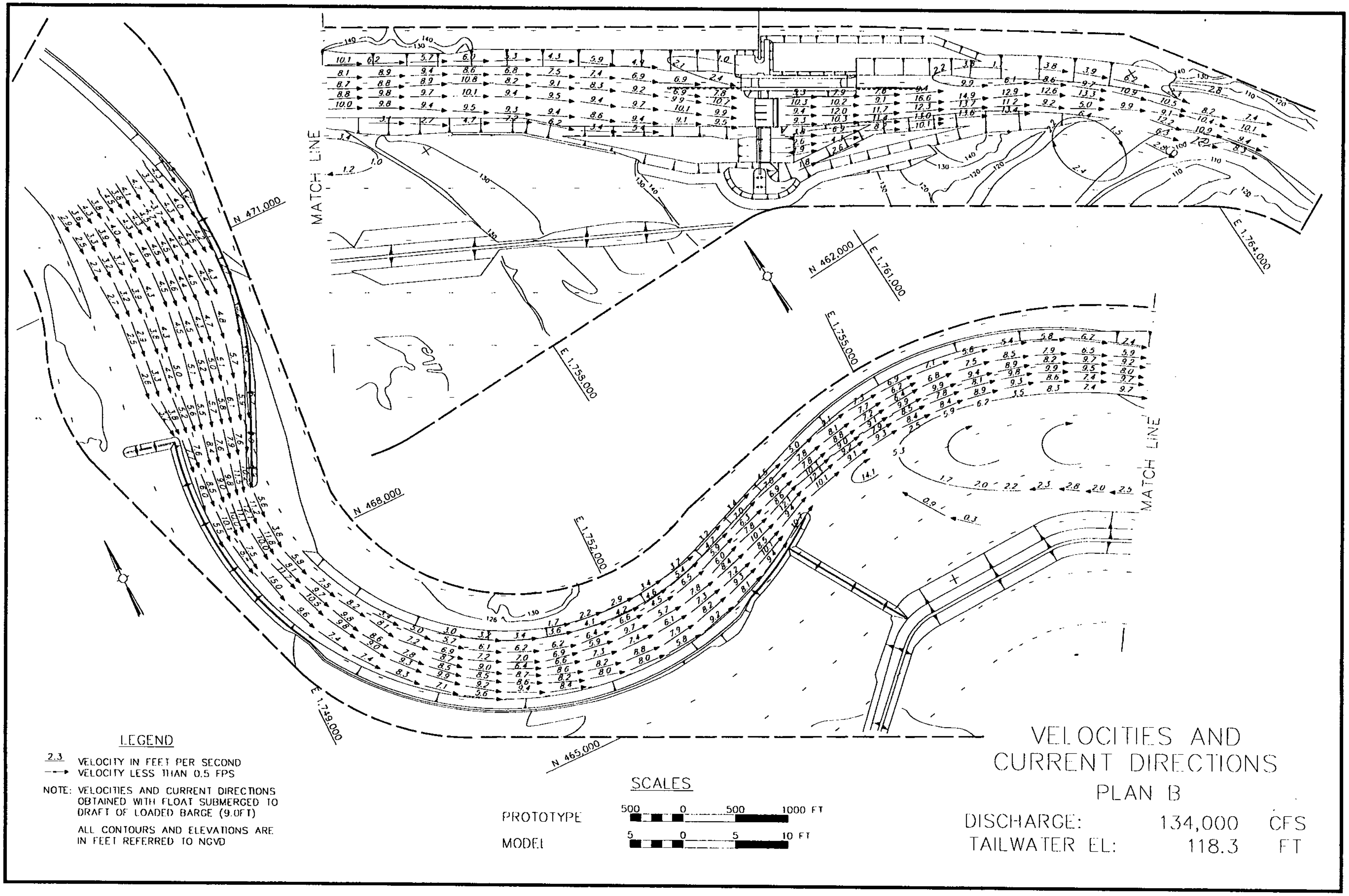

VELOCITIES AND
CURRENT DIRECTIONS
PLAN B
DISCHARGE: 134,000 CFS
TAILWATER EL: 118.3 FT
LEGEND
2.3 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FPS
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 500 0 500 1000 FT
MODEL 5 0 5 10 FT
MATCH LINE
MATCH LINE
N 471,000
N 468,000
N 465,000
N 462,000
E 1,749,000
E 1,752,000
E 1,755,000
E 1,758,000
E 1,761,000
E 1,764,000

Plate 5

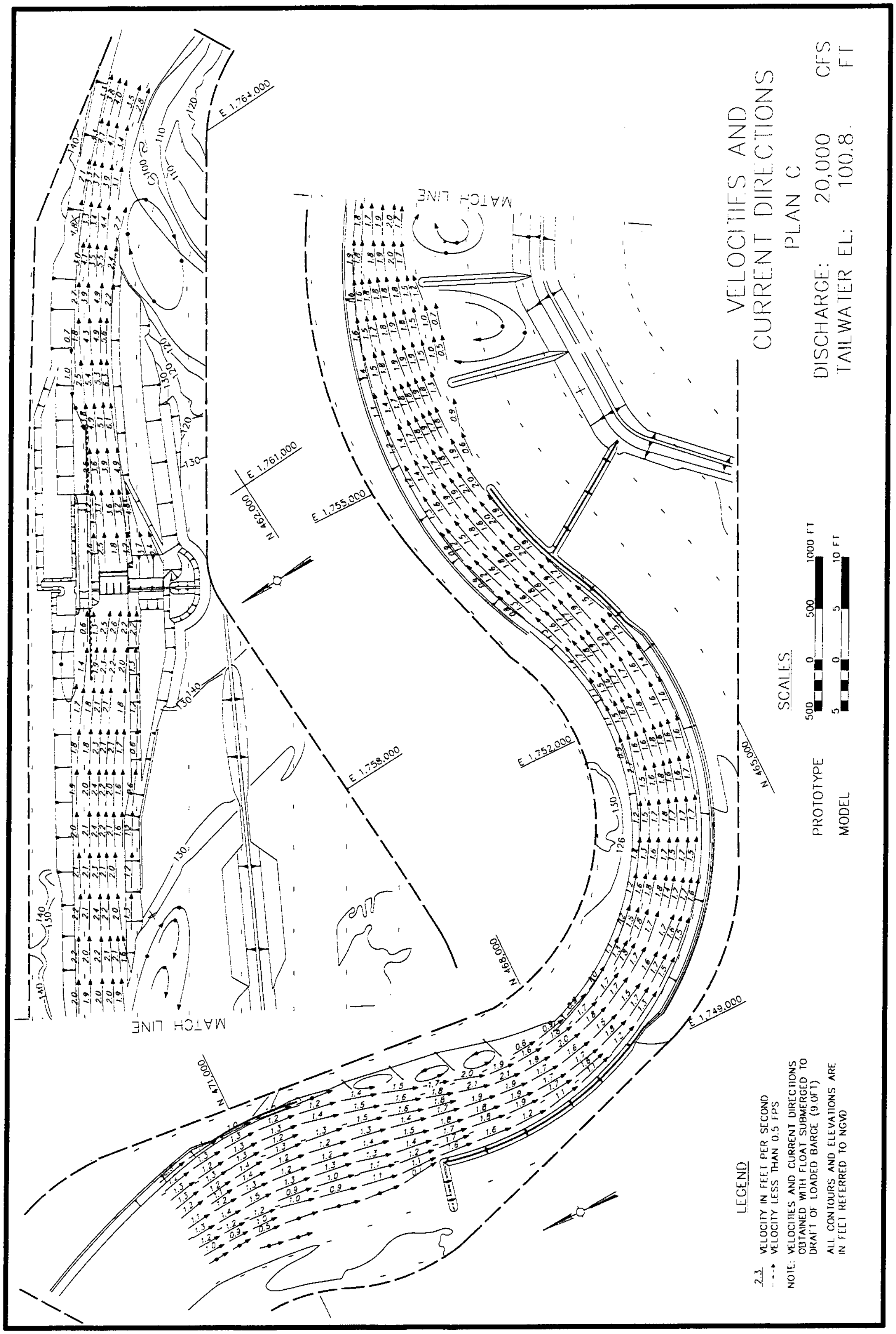

VELOCITIES AND
CURRENT DIRECTIONS
PLAN C
DISCHARGE: 20,000 CFS
TAILWATER EL: 100.8 FT
LEGEND
2.3 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FPS
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 500 0 500 1000 FT
MODEL 5 0 5 10 FT
MATCH LINE
MATCH LINE
E 1,764,000
E 1,761,000
E 1,758,000
E 1,755,000
E 1,752,000
E 1,749,000
N 462,000
N 465,000
N 468,000
N 471,000

Plate 6

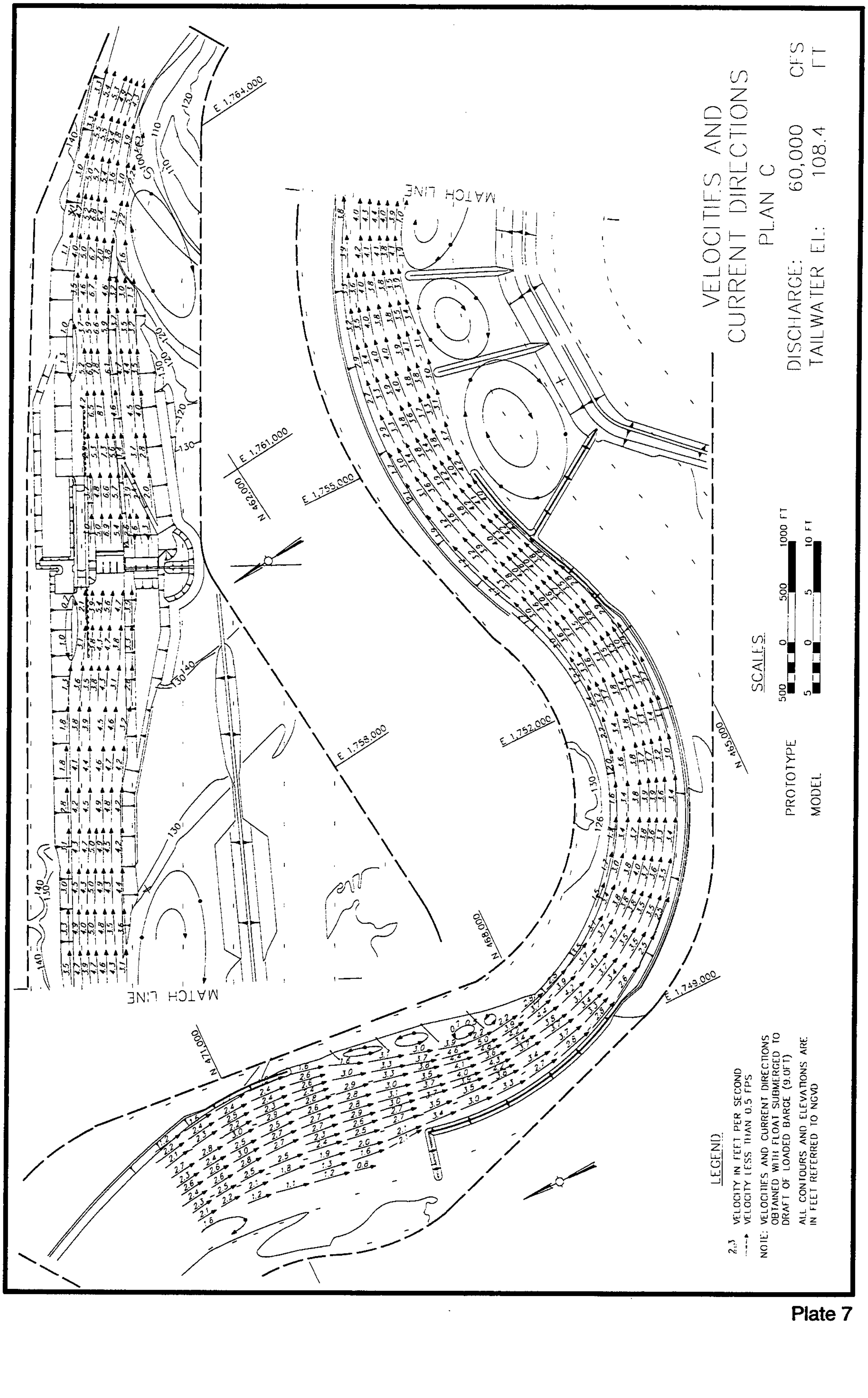

VELOCITIES AND
CURRENT DIRECTIONS
PLAN C
DISCHARGE: 60,000 CFS
TAILWATER EL: 108.4 FT
SCALES
PROTOTYPE 500 0 500 1000 FT
MODEL 5 0 5 10 FT
LEGEND
2.3 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FPS
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
MATCH LINE
MATCH LINE
E 1,764,000
E 1,761,000
E 1,758,000
E 1,755,000
E 1,752,000
E 1,749,000
N 462,000
N 465,000
N 468,000
N 471,000

Plate 7

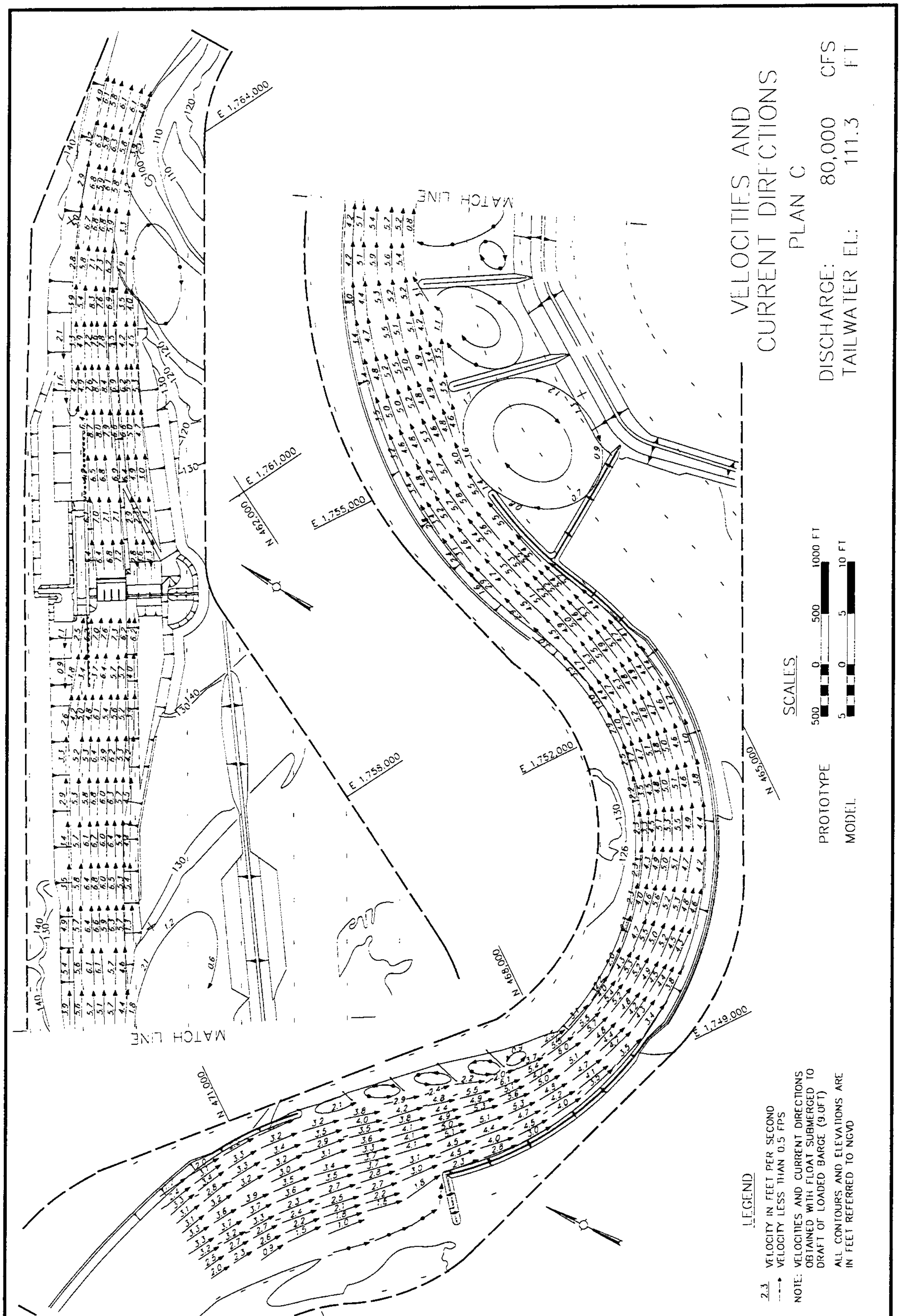
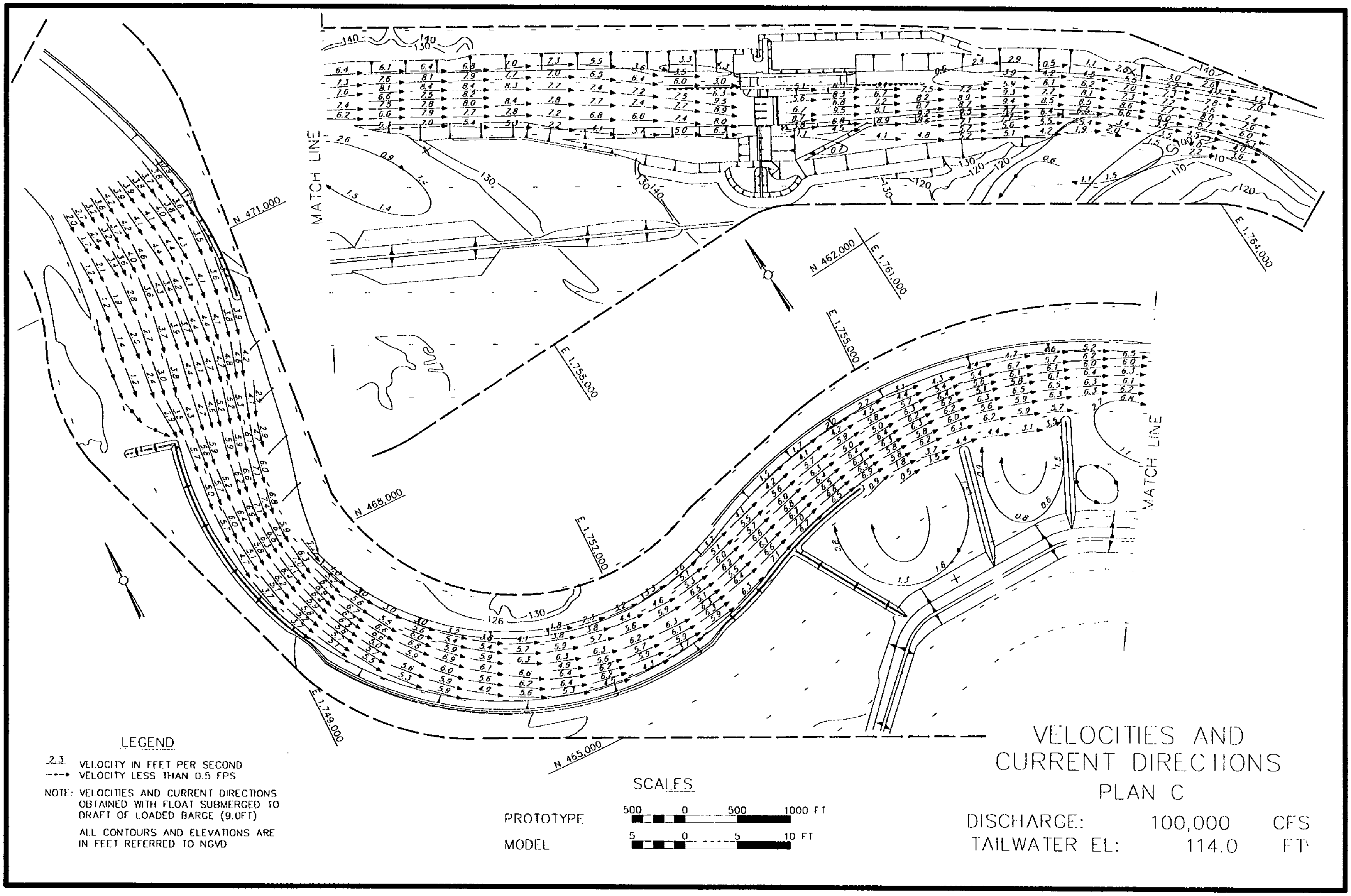

VELOCITIES AND
CURRENT DIRECTIONS
PLAN C
DISCHARGE: 80,000 CFS
TAILWATER EL: 111.3 FT
SCALES
PROTOTYPE 500 0 500 1000 FT
MODEL 5 0 5 10 FT
LEGEND
2.3 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FPS
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
MATCH LINE
MATCH LINE
E 1,764,000
E 1,761,000
E 1,758,000
E 1,755,000
E 1,752,000
E 1,749,000
N 462,000
N 465,000
N 468,000
N 471,000

Plate 8


VELOCITIES AND
CURRENT DIRECTIONS
PLAN C
DISCHARGE: 100,000 CFS
TAILWATER EL: 114.0 FT
SCALES
PROTOTYPE 500 0 500 1000 FT
MODEL 5 0 5 10 FT
LEGEND
2.3 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FPS
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
MATCH LINE
MATCH LINE
E 1,764,000
E 1,761,000
E 1,755,000
E 1,752,000
E 1,749,000
N 462,000
N 465,000
N 468,000
N 471,000

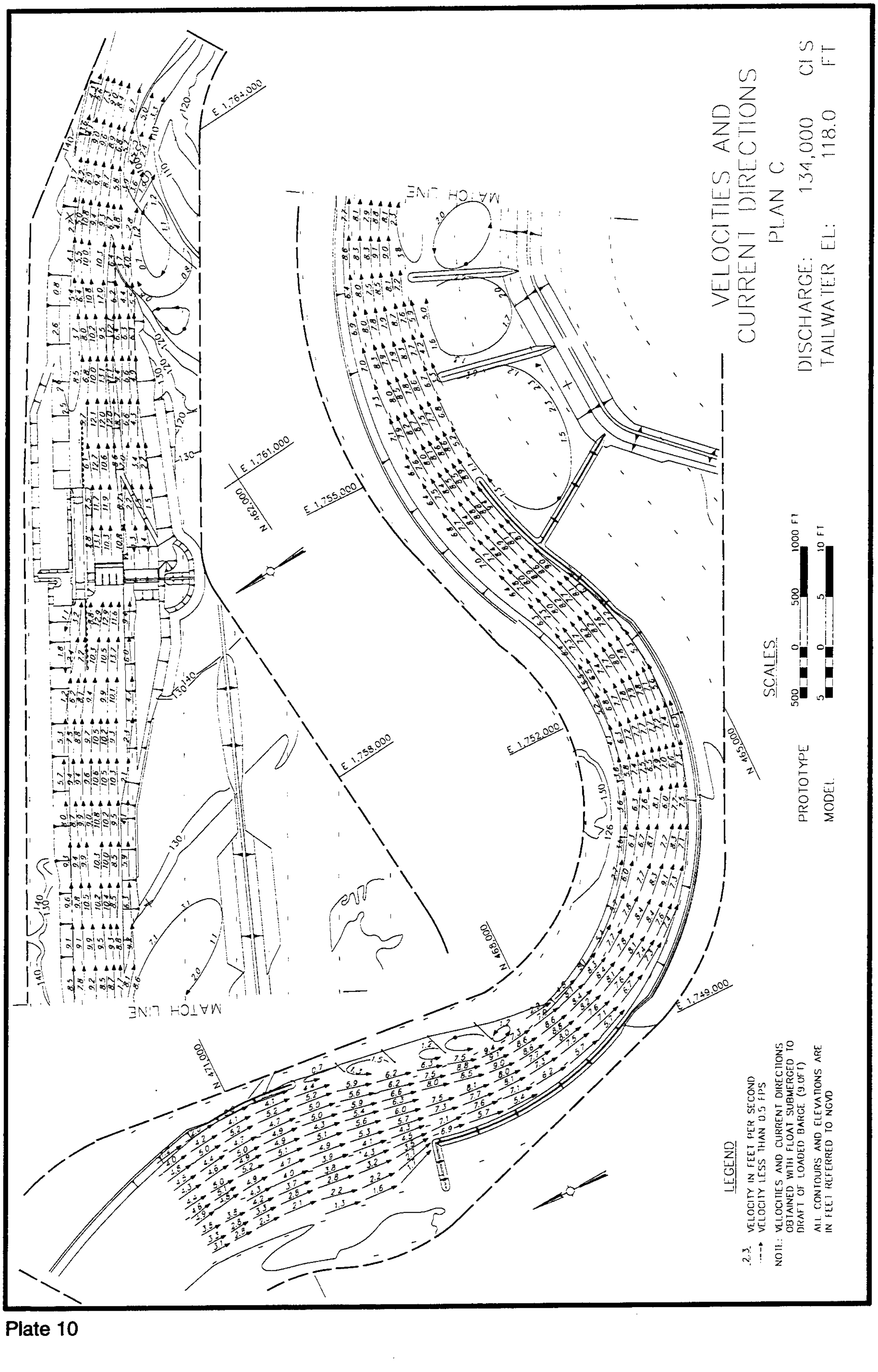
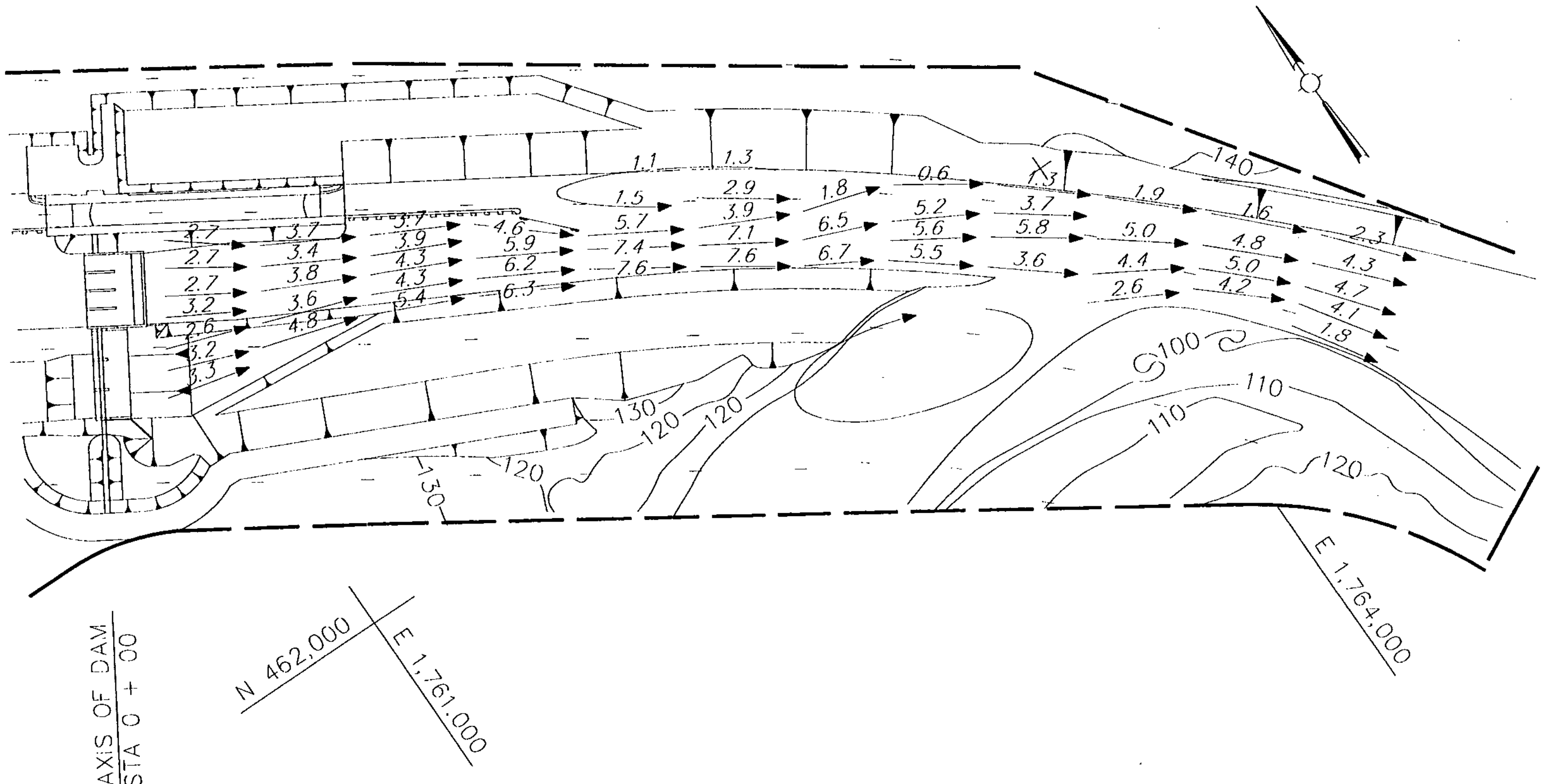

VELOCITIES AND CURRENT DIRECTIONS
PLAN C
DISCHARGE: 134,000 CFS
TAILWATER EL: 118.0 FT
SCALES
PROTOTYPE 500 0 500 1000 FT
MODEL 5 0 5 10 FT
LEGEND
2.3 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FPS
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
MATCH LINE
MATCH LINE

Plate 10



LEGEND

2.3 VELOCITY IN FEET PER SECOND
---→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

VELOCITIES AND
CURRENT DIRECTIONS
PLAN C-1

DISCHARGE: 20,000 CFS
TAILWATER EL: 100.8 FT

LEGEND

2.3 VELOCITY IN FEET PER SECOND
---▸ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 500 0 500 1000 FT

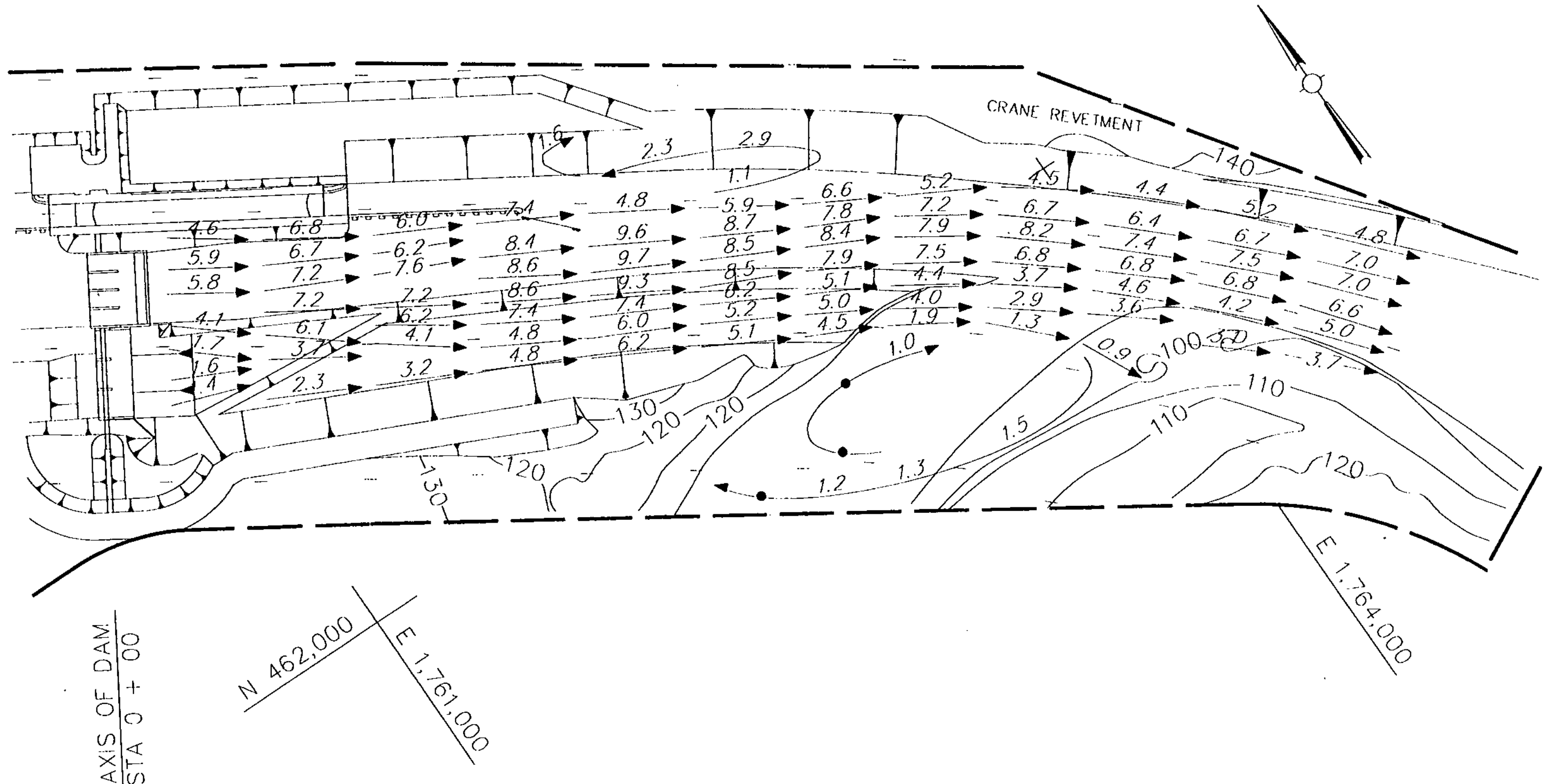
MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS

PLAN C-1

DISCHARGE: 60,000 CFS

TAILWATER EL: 108.4 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
---→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

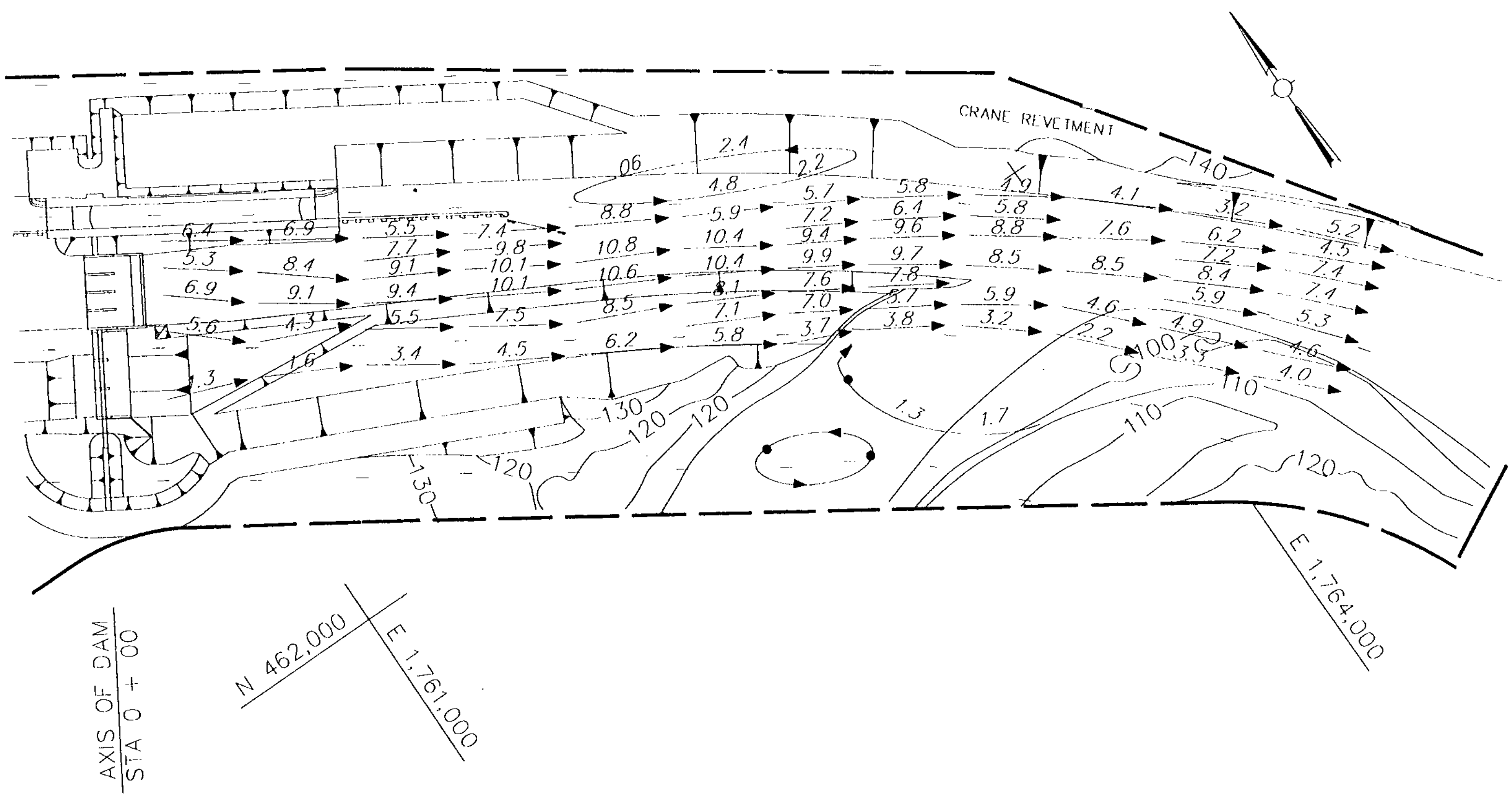
SCALES

PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS
PLAN C-1

DISCHARGE: 80,000 CFS
TAILWATER EL: 111.3 FT



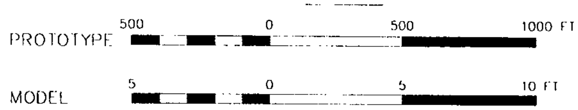
LEGEND

2.3 VELOCITY IN FEET PER SECOND
--→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

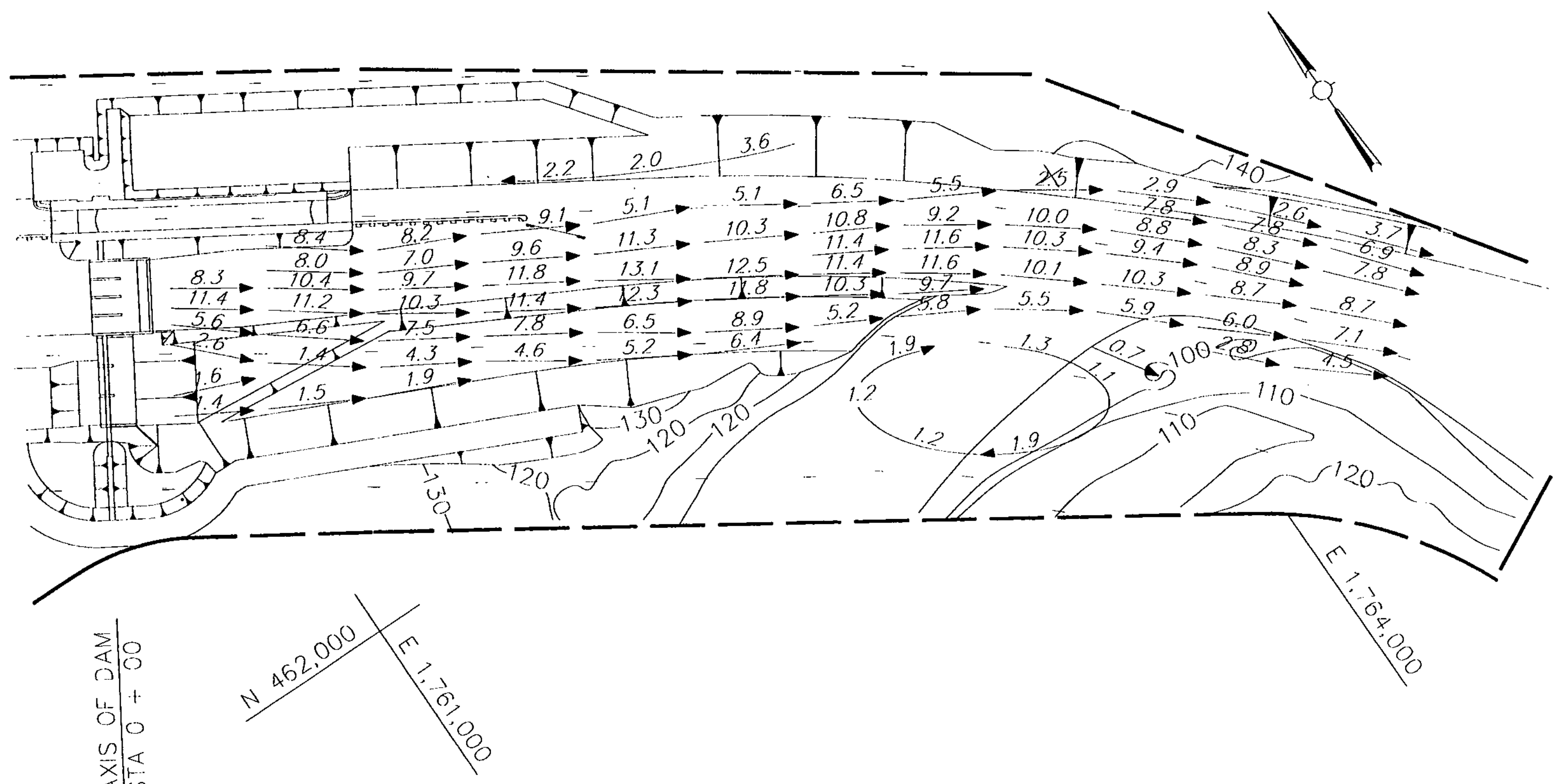


VELOCITIES AND CURRENT DIRECTIONS

PLAN C-1

DISCHARGE: 100,000 CFS

TAILWATER EL: 114.0 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD.

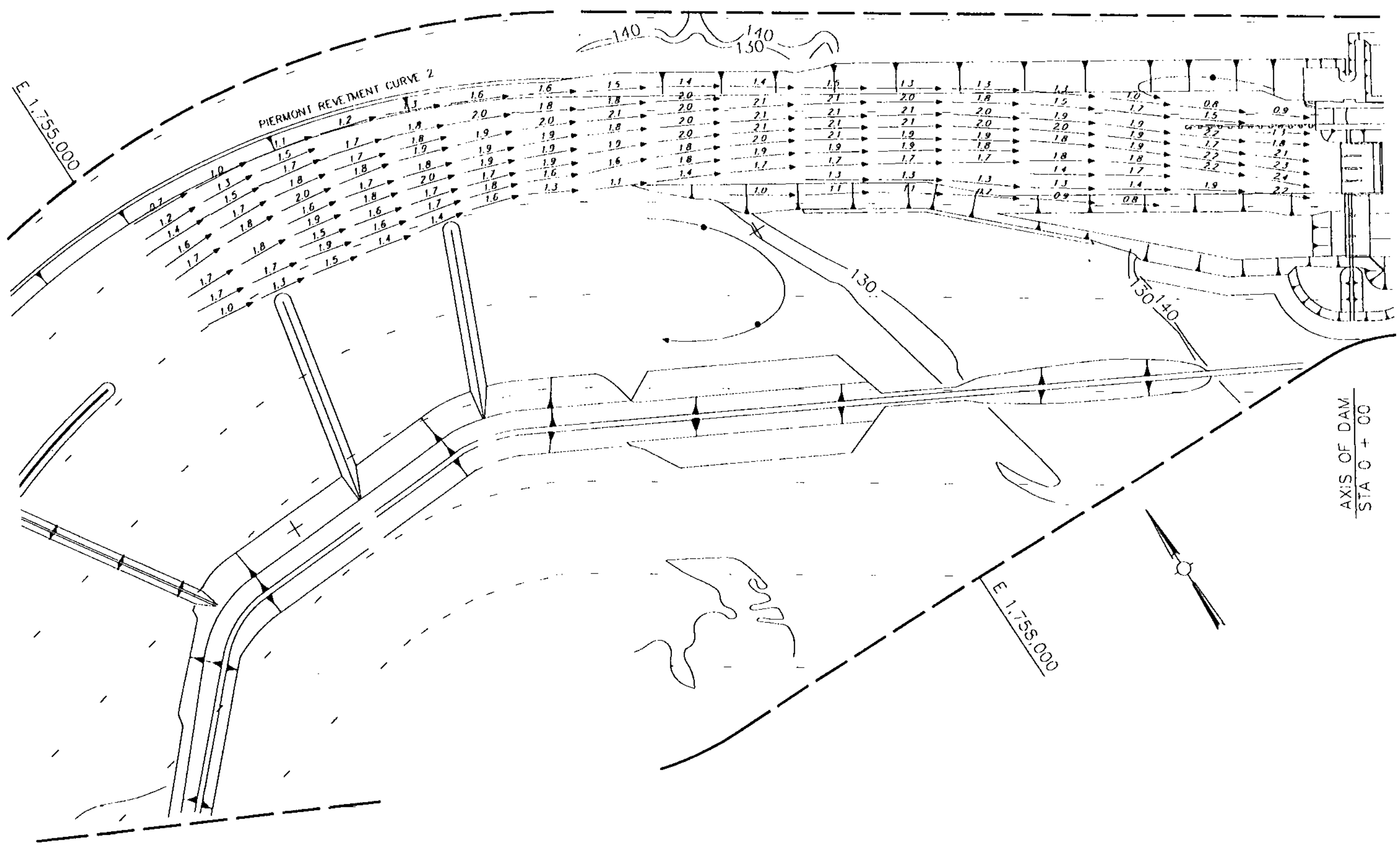
SCALES

PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS
PLAN C-1

DISCHARGE: 134,000 CFS
TAILWATER EL: 118.0 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

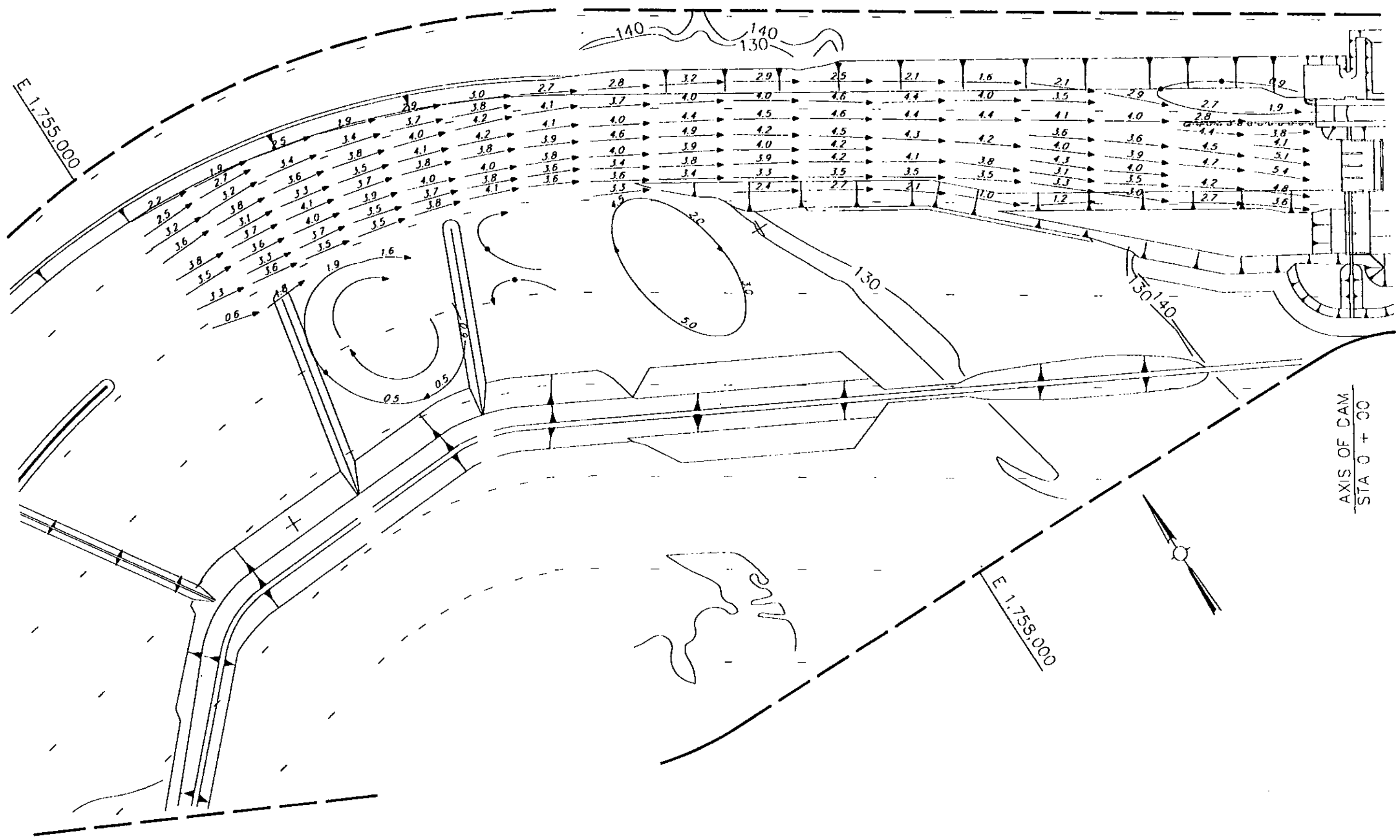
PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS

PLAN C-2

DISCHARGE: 20,000 CFS
TAILWATER EL: 100.8 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 500 0 500 1000 FT

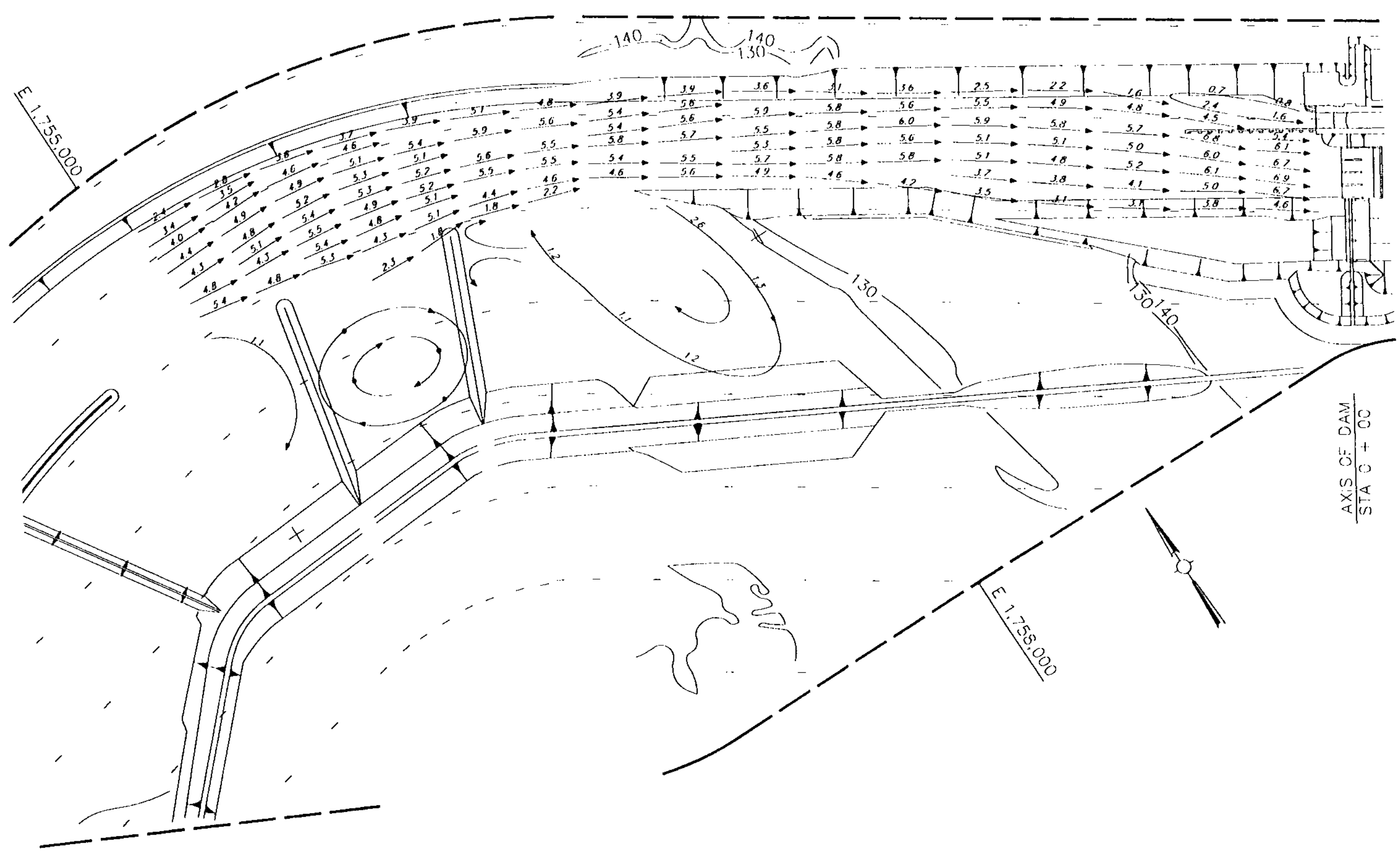
MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS

PLAN C-2

DISCHARGE: 60,000 CFS

TAILWATER EL: 108.4 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

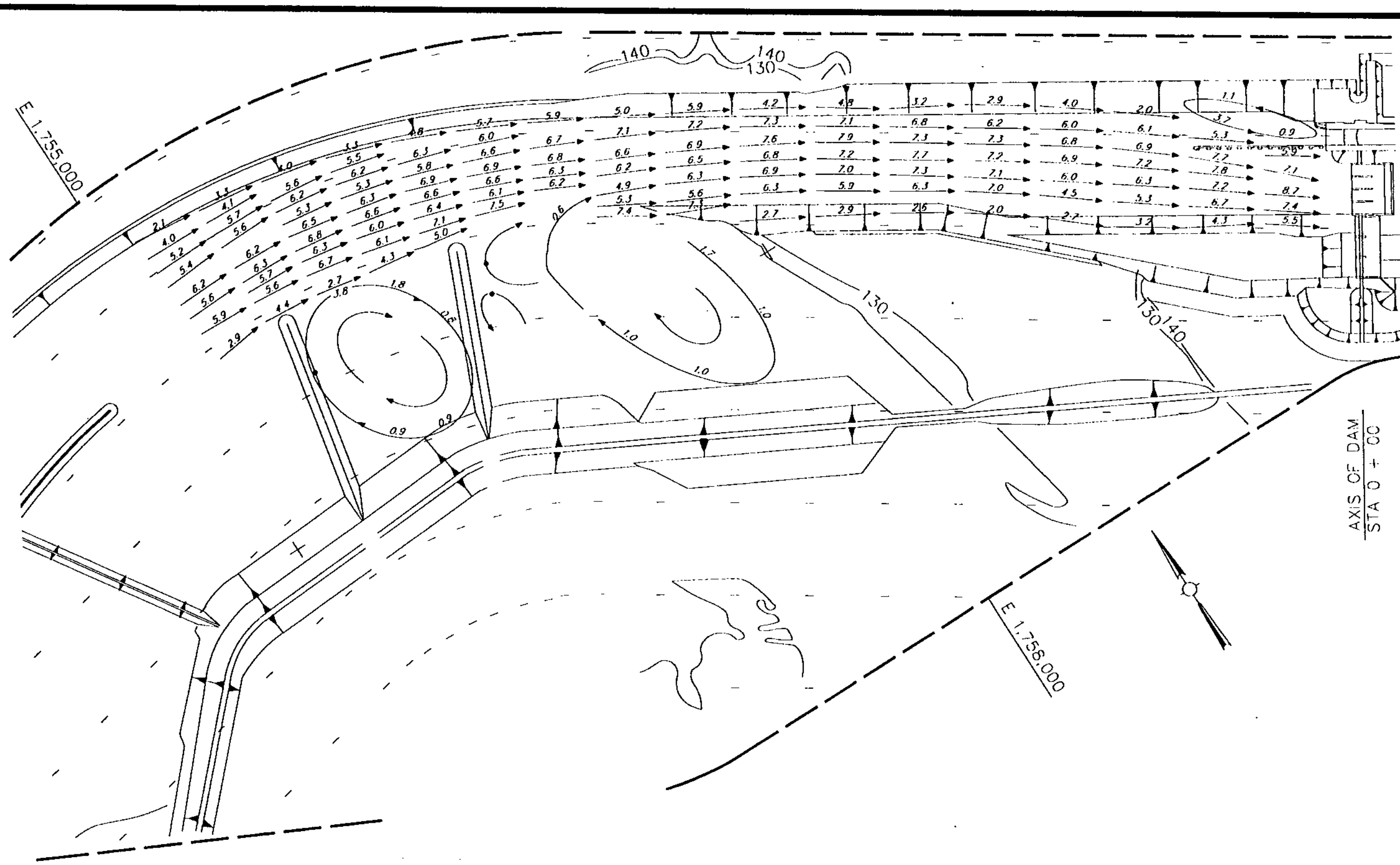
SCALES

PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS
PLAN C-2

DISCHARGE: 80,000 CFS
TAILWATER EL: 111.3 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
—•→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 500 0 500 1000 FT

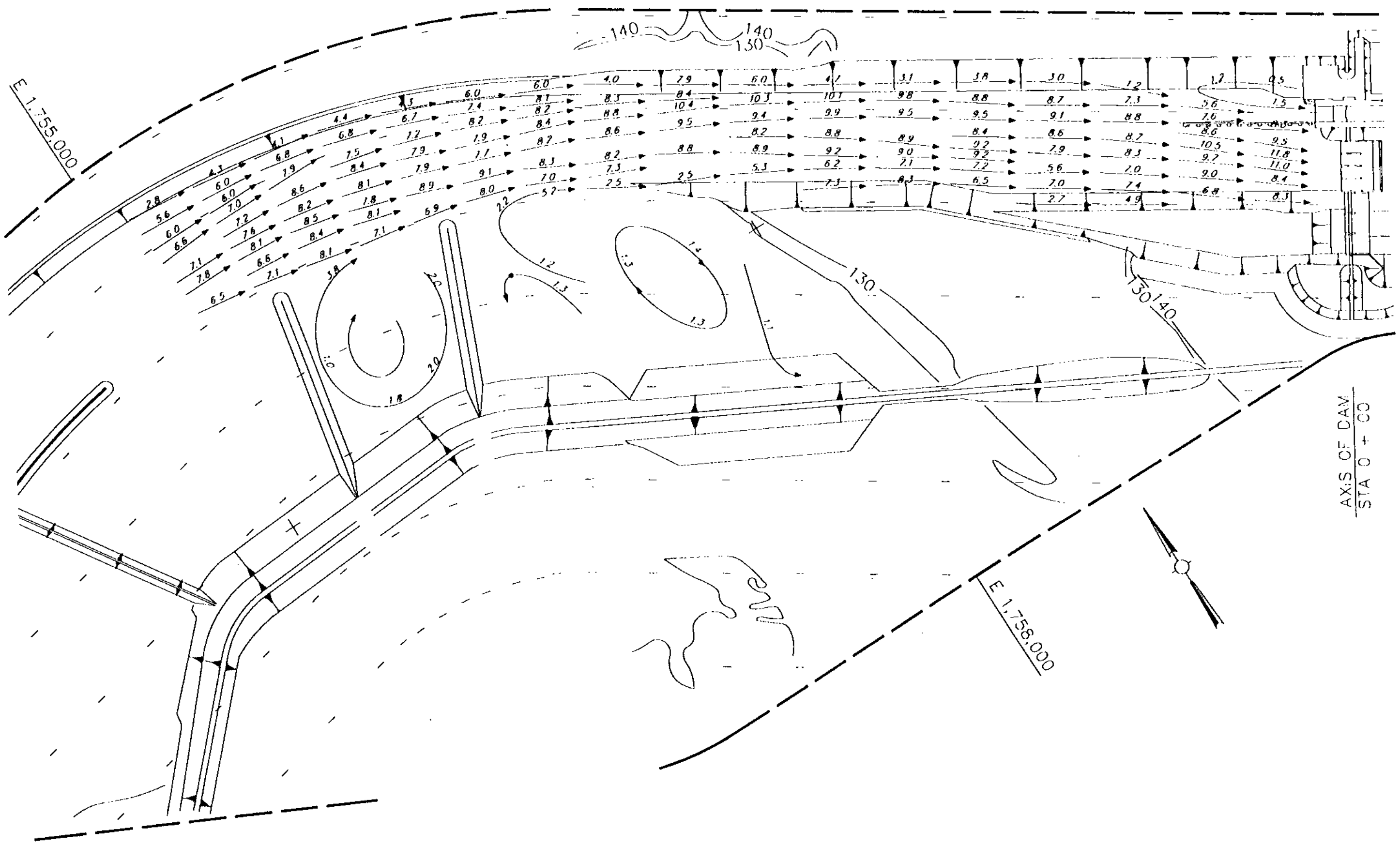
MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS

PLAN C-2

DISCHARGE: 100,000 CFS

TAILWATER EL: 114.0 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

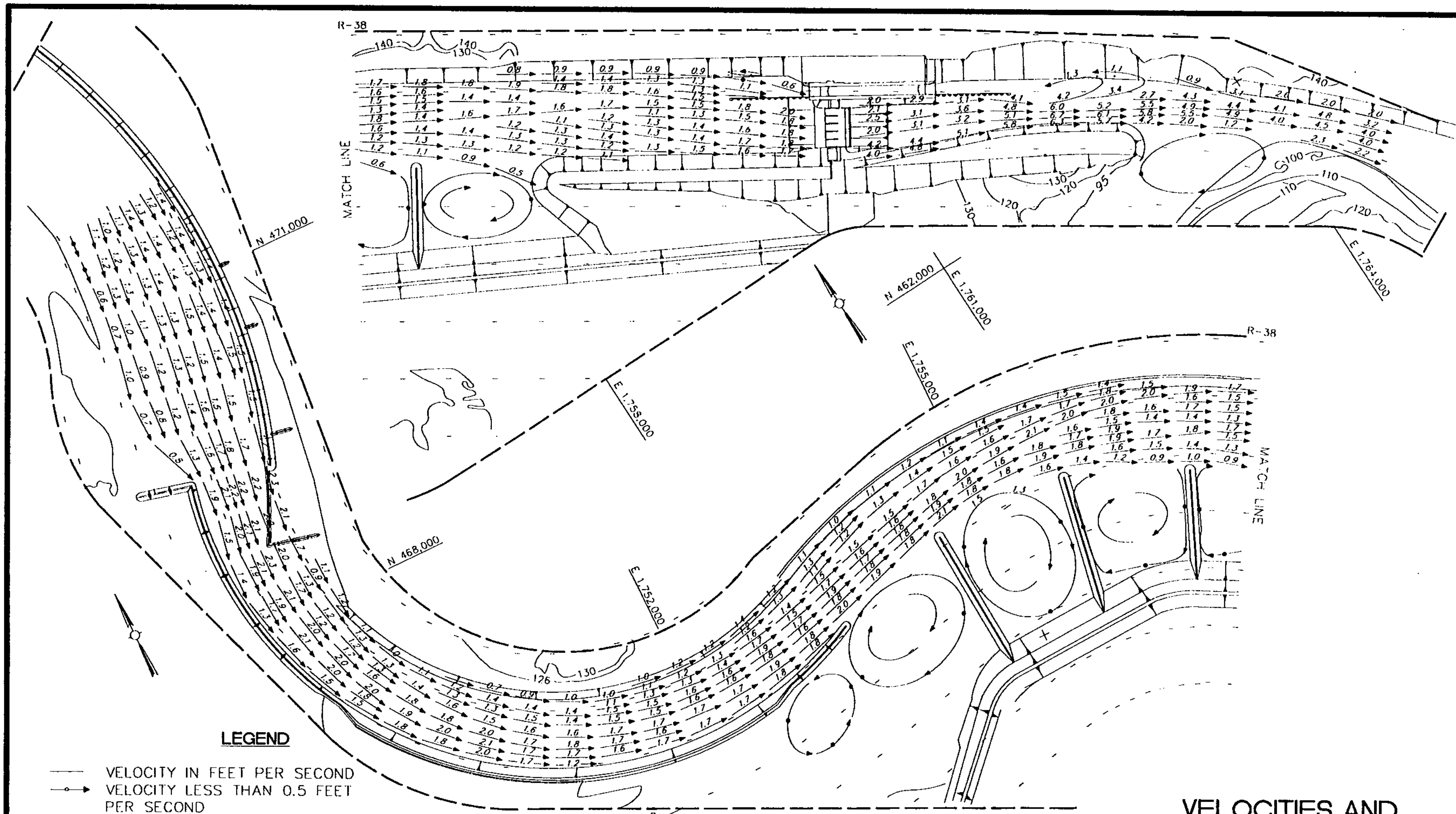
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE	500	0	500	1000 FT
MODEL	5	0	5	10 FT

VELOCITIES AND
CURRENT DIRECTIONS
PLAN C-2

DISCHARGE: 134,000 CFS
TAILWATER EL: 118.0 FT



LEGEND

- VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

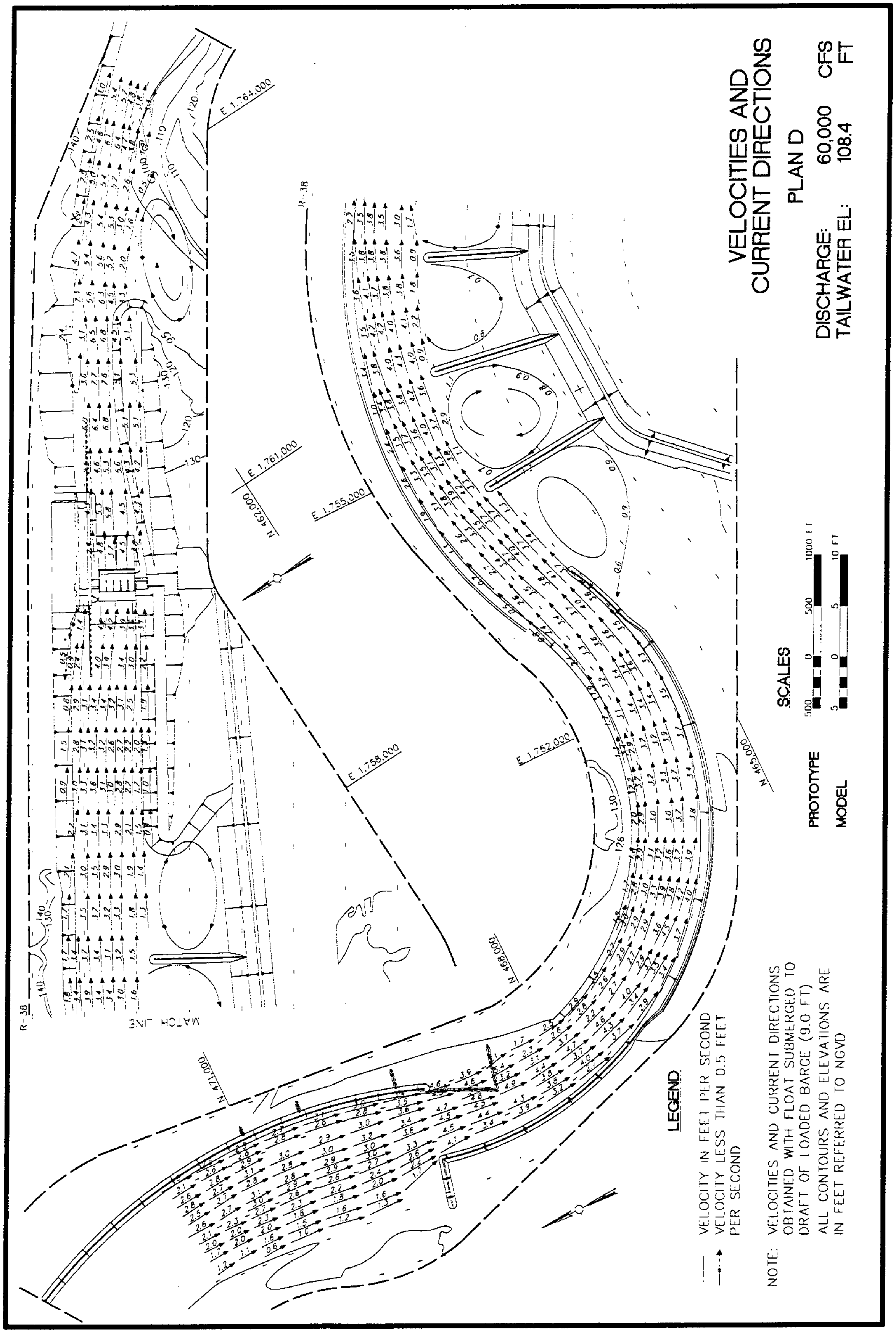
PROTOTYPE 500 0 500 1000 FT

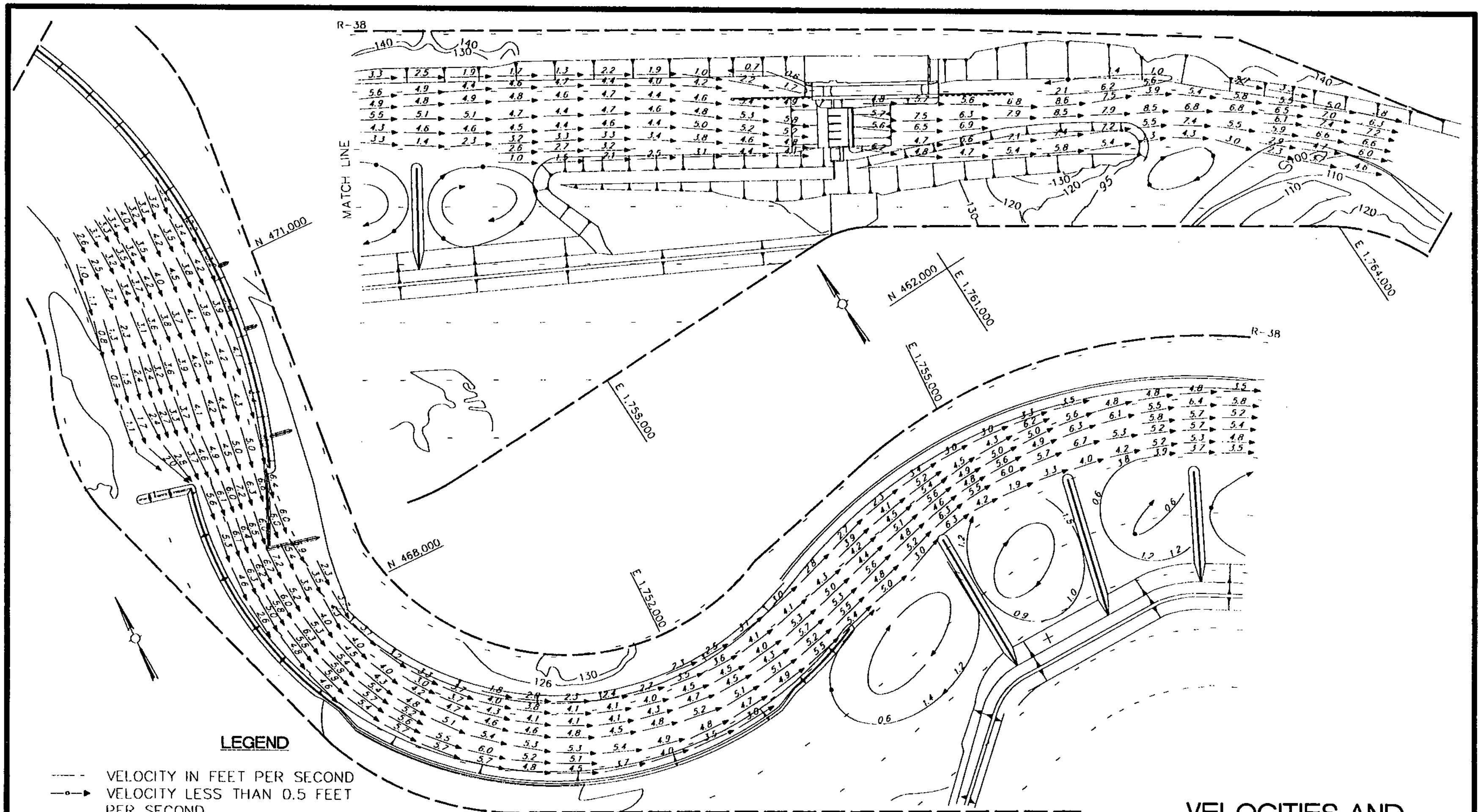
MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS

PLAN D

DISCHARGE:	20,000	CFS
TAILWATER EL:	100.8	FT


VELOCITIES AND CURRENT DIRECTIONS
PLAN D
DISCHARGE: 60,000 CFS
TAILWATER EL: 108.4 FT
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE
MODEL
500 0 500 1000 FT
5 0 5 10 FT
MATCH LINE
E 1,764,000
E 1,761,000
E 1,758,000
E 1,755,000
E 1,752,000
N 462,000
N 465,000
N 468,000
N 471,000
R-38



LEGEND

---- VELOCITY IN FEET PER SECOND

—o—► VELOCITY LESS THAN 0.5 FEET PER SECOND

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

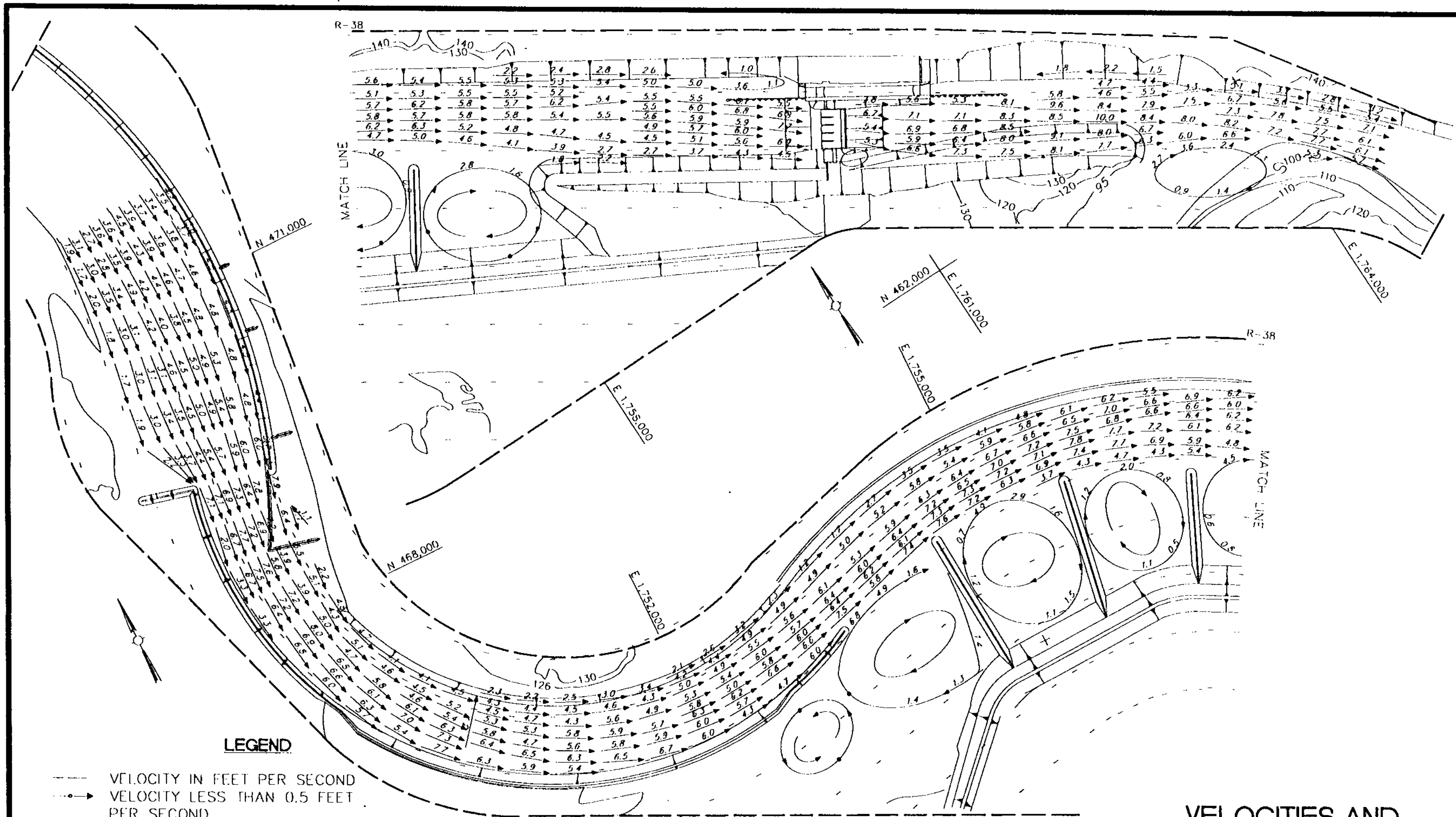
PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS

PLAN D

DISCHARGE:	80,000	CFS
TAILWATER EL:	111.3	FT



LEGEND

- VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

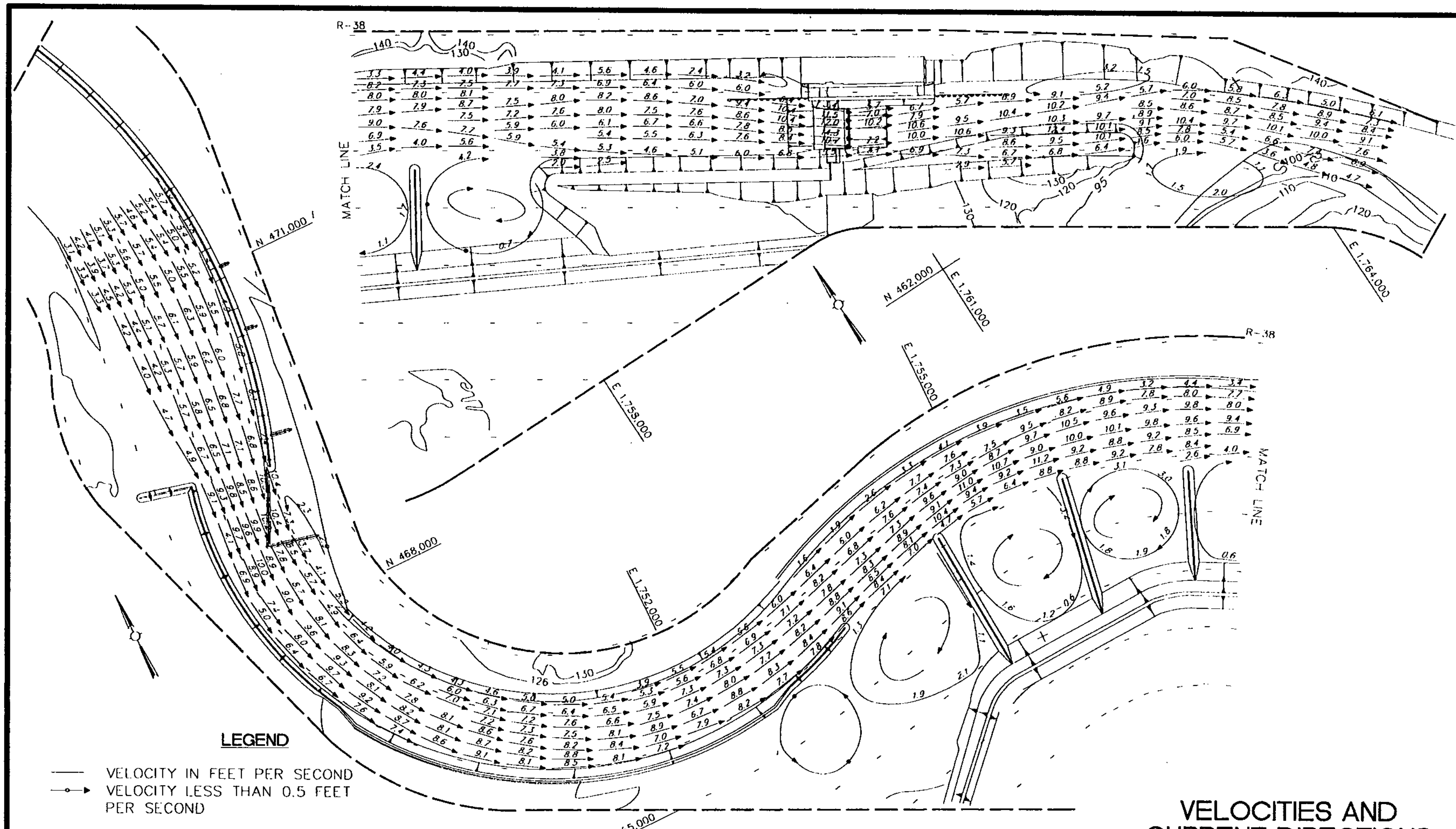
SCALES

PROTOTYPE	500	0	500	1000 FT
MODEL	5	0	5	10 FT

VELOCITIES AND CURRENT DIRECTIONS

PLAN D

DISCHARGE:	100,000	CFS
TAILWATER EL:	114.0	FT



LEGEND

- VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 500 0 500 1000 FT

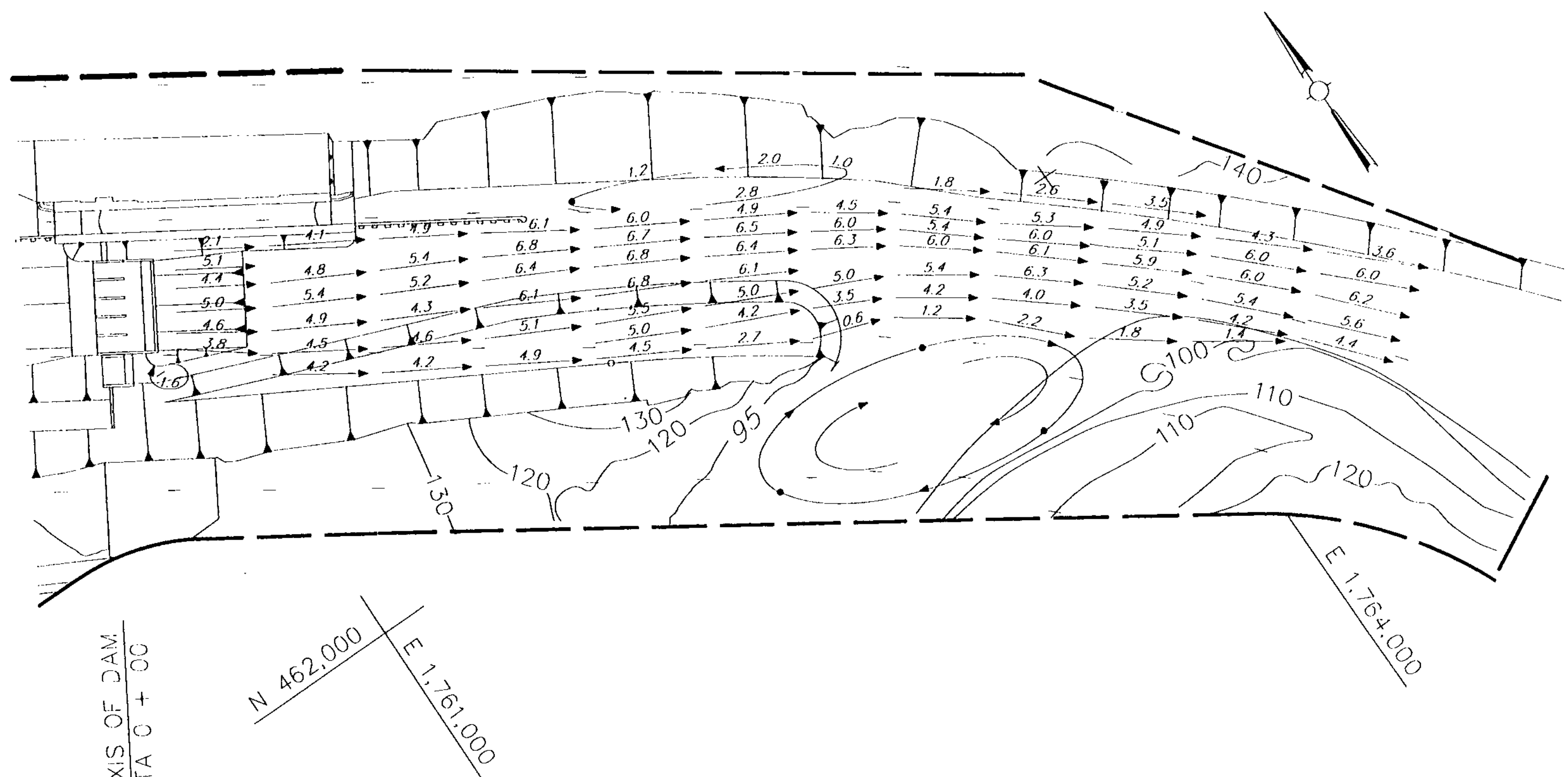
MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS

PLAN D

DISCHARGE: 134,000 CFS

TAILWATER EL: 118.0 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
—•→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

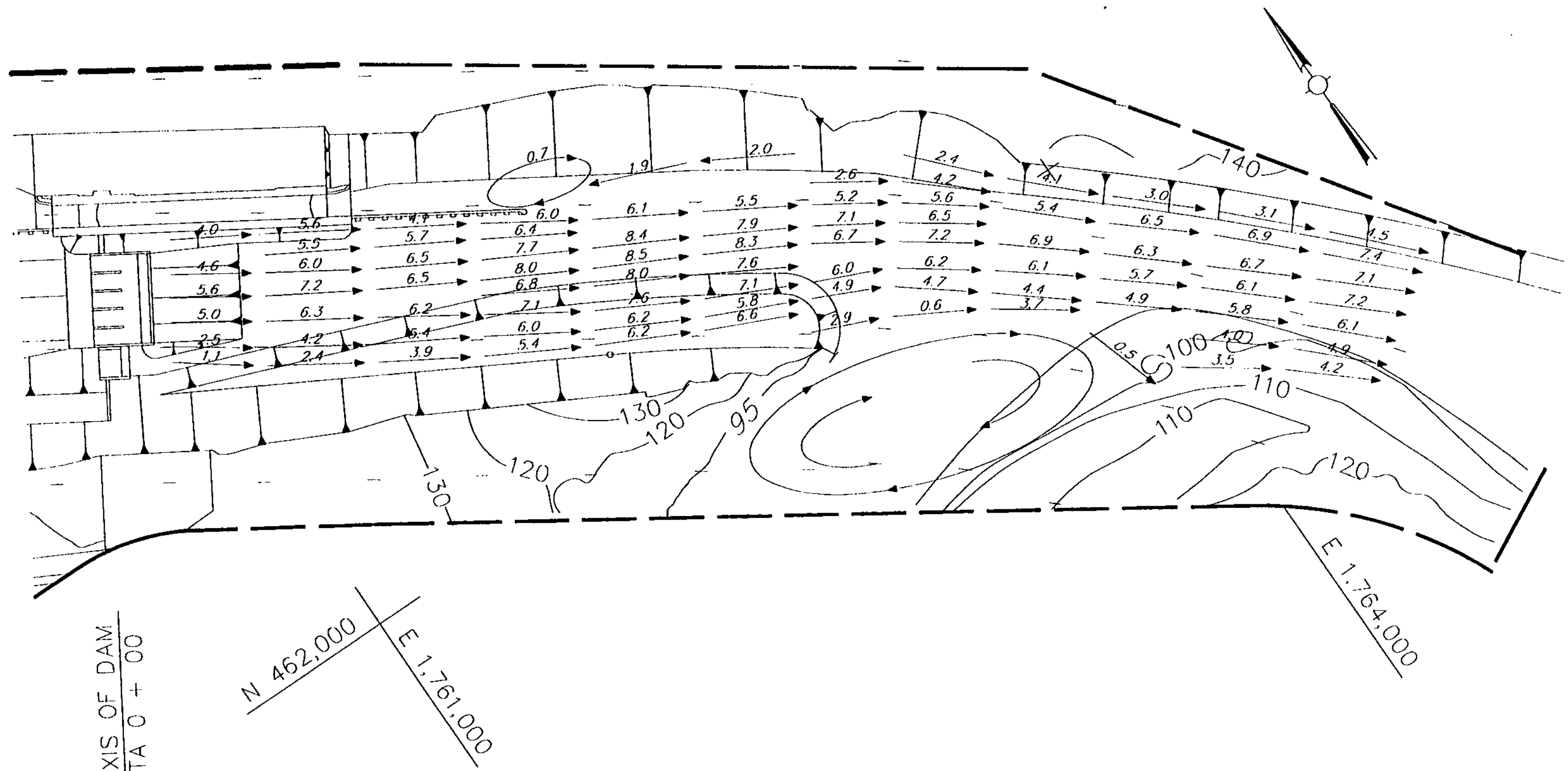
PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

MODEL STUDY OF
LOCK AND DAM NO. 4
RED RIVER

VELOCITIES AND
CURRENT DIRECTIONS
PLAN D-1

DISCHARGE: 60,000 CFS
TAILWATER EL: 108.4 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
····➝ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

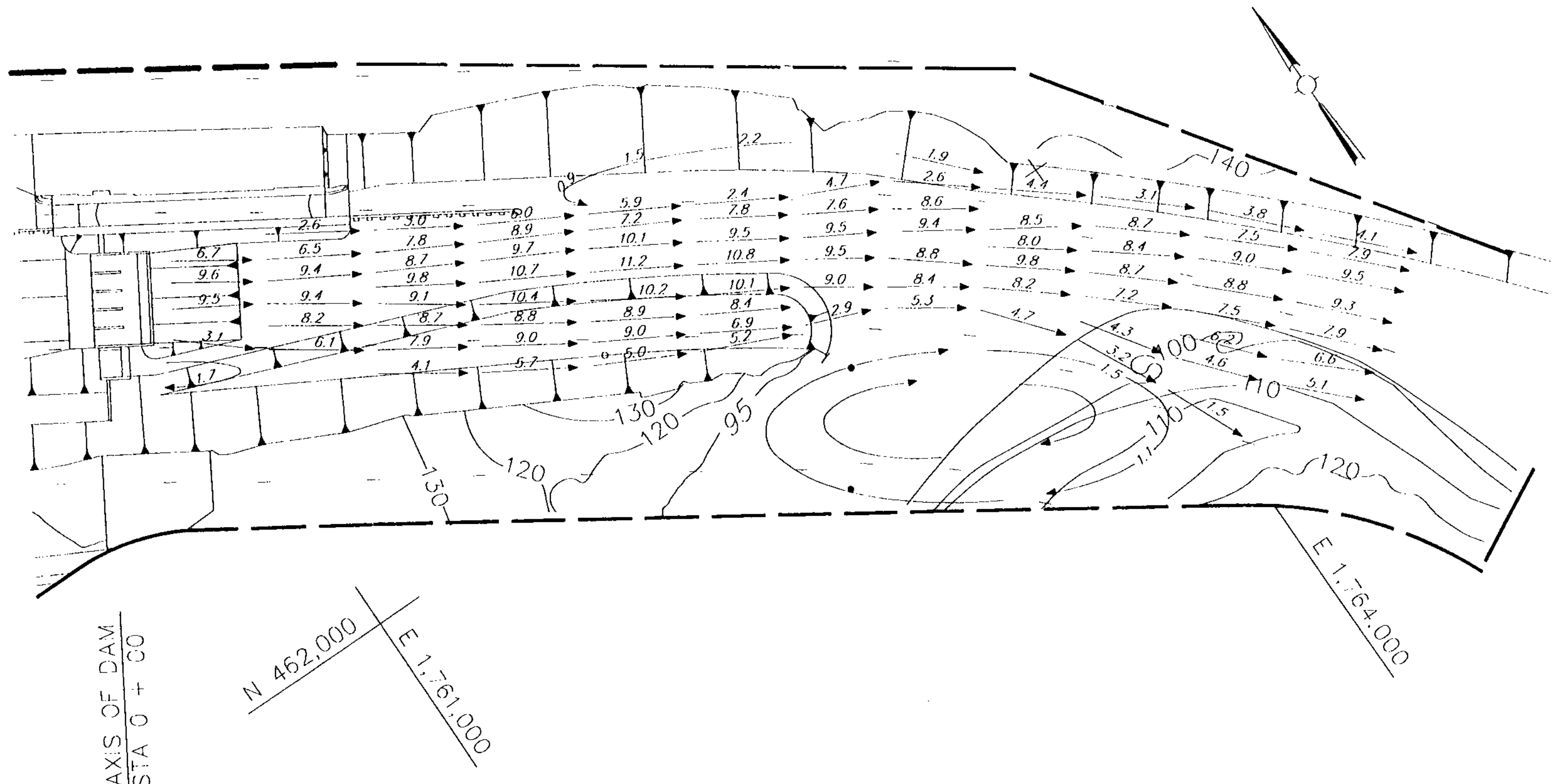
SCALES

PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS
PLAN D-1

DISCHARGE: 80,000 CFS
TAILWATER EL: 111.3 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
---→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

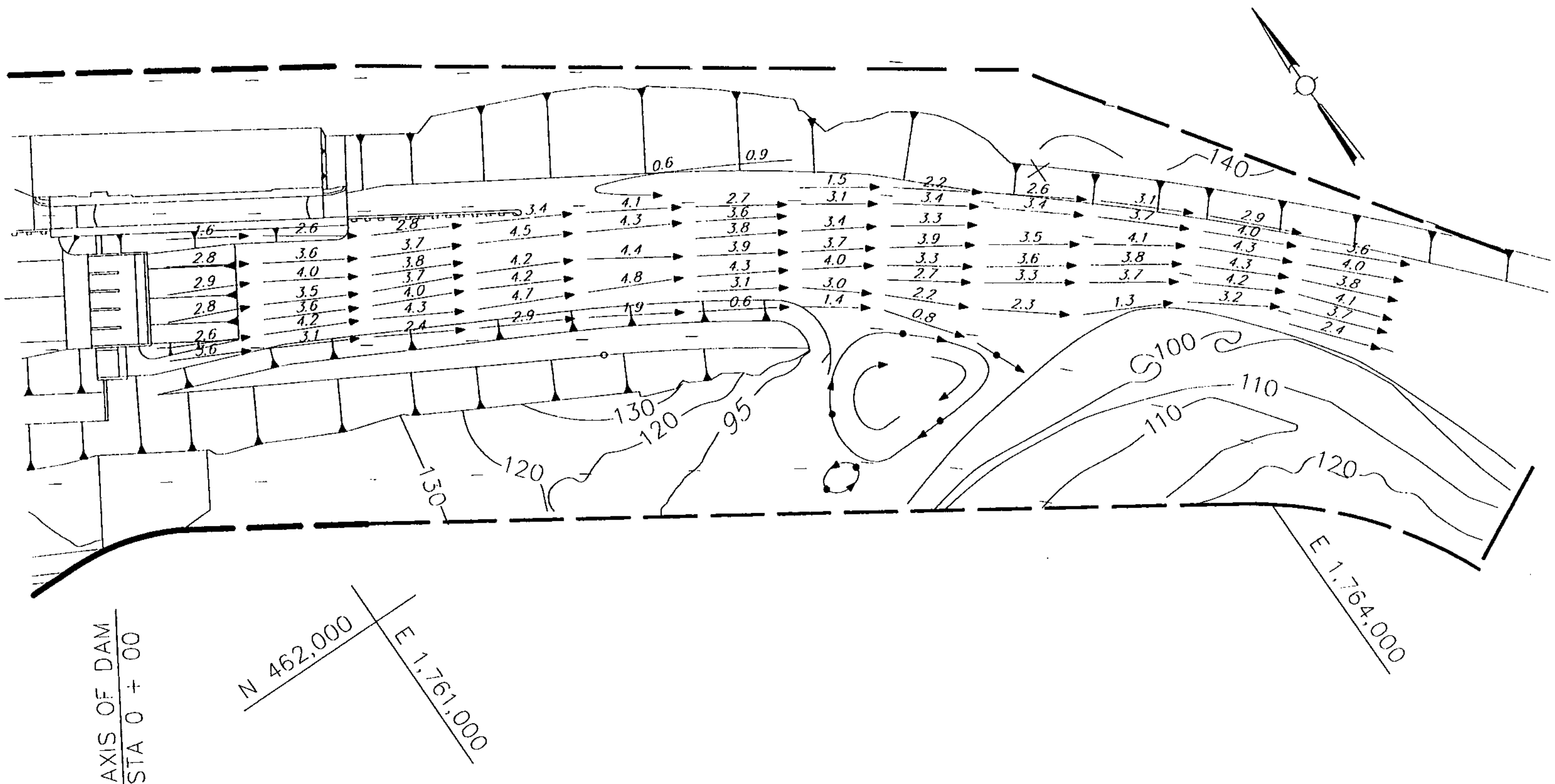
SCALES

PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS
PLAN D-1

DISCHARGE: 134,000 CFS
TAILWATER EL: 118.0 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

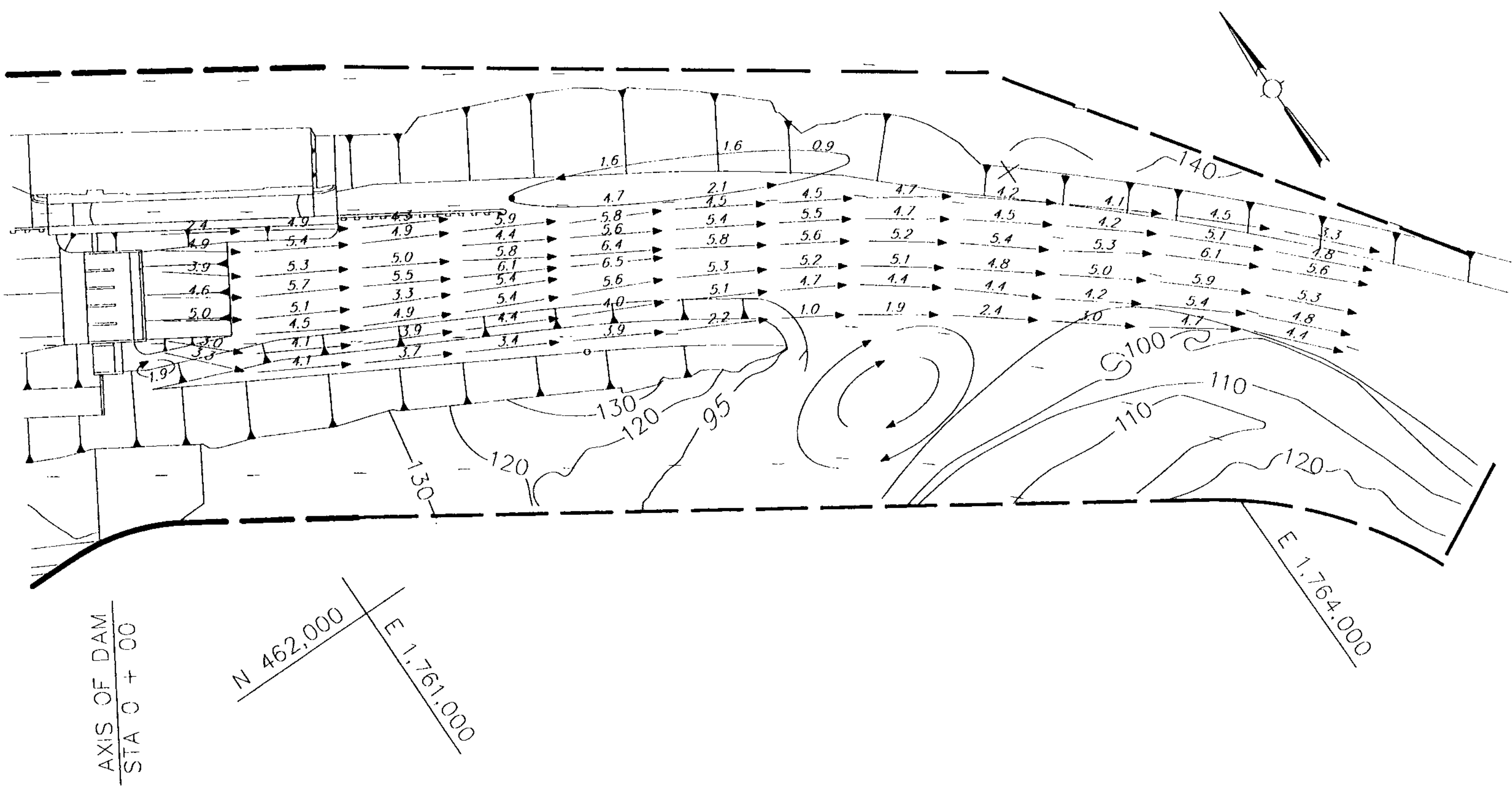
SCALES

PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS
PLAN D-2

DISCHARGE: 20,000 CFS
TAILWATER EL: 100.8 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
—·—▸ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

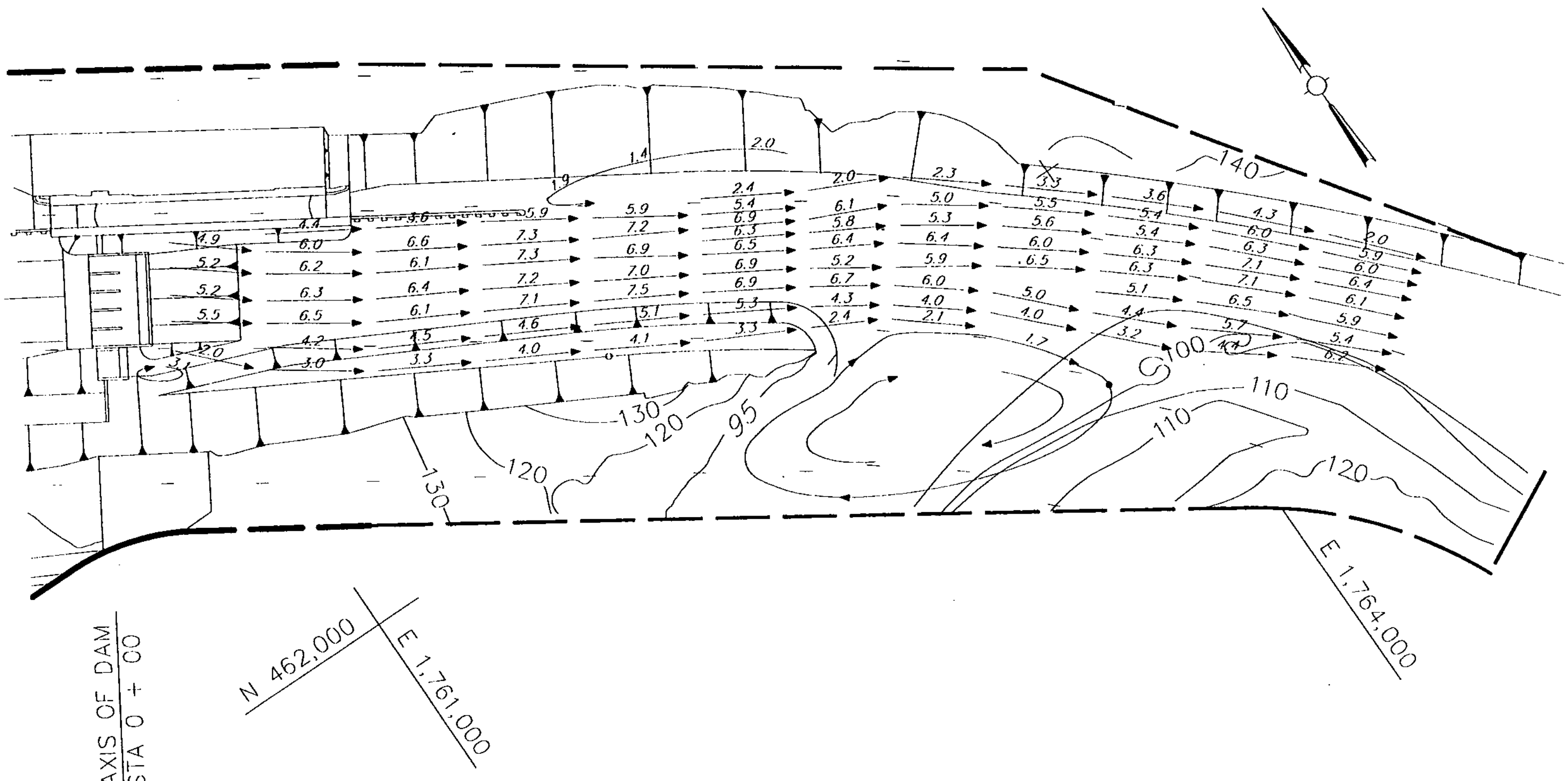
SCALES

PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS
PLAN D-2

DISCHARGE: 60,000 CFS
TAILWATER EL: 108.4 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

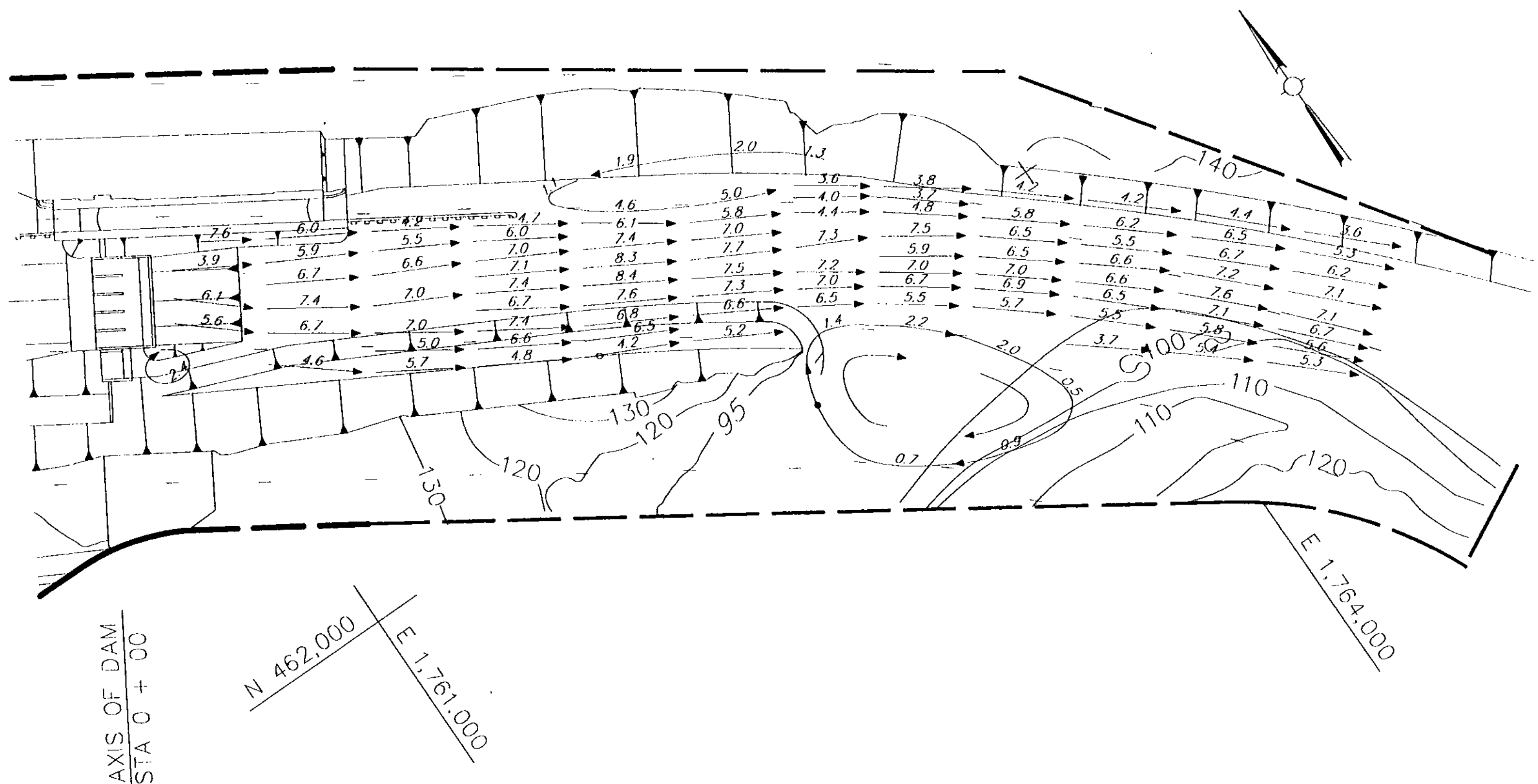
SCALES

PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS
PLAN D-2

DISCHARGE: 80,000 CFS
TAILWATER EL: 111.3 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
—•→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

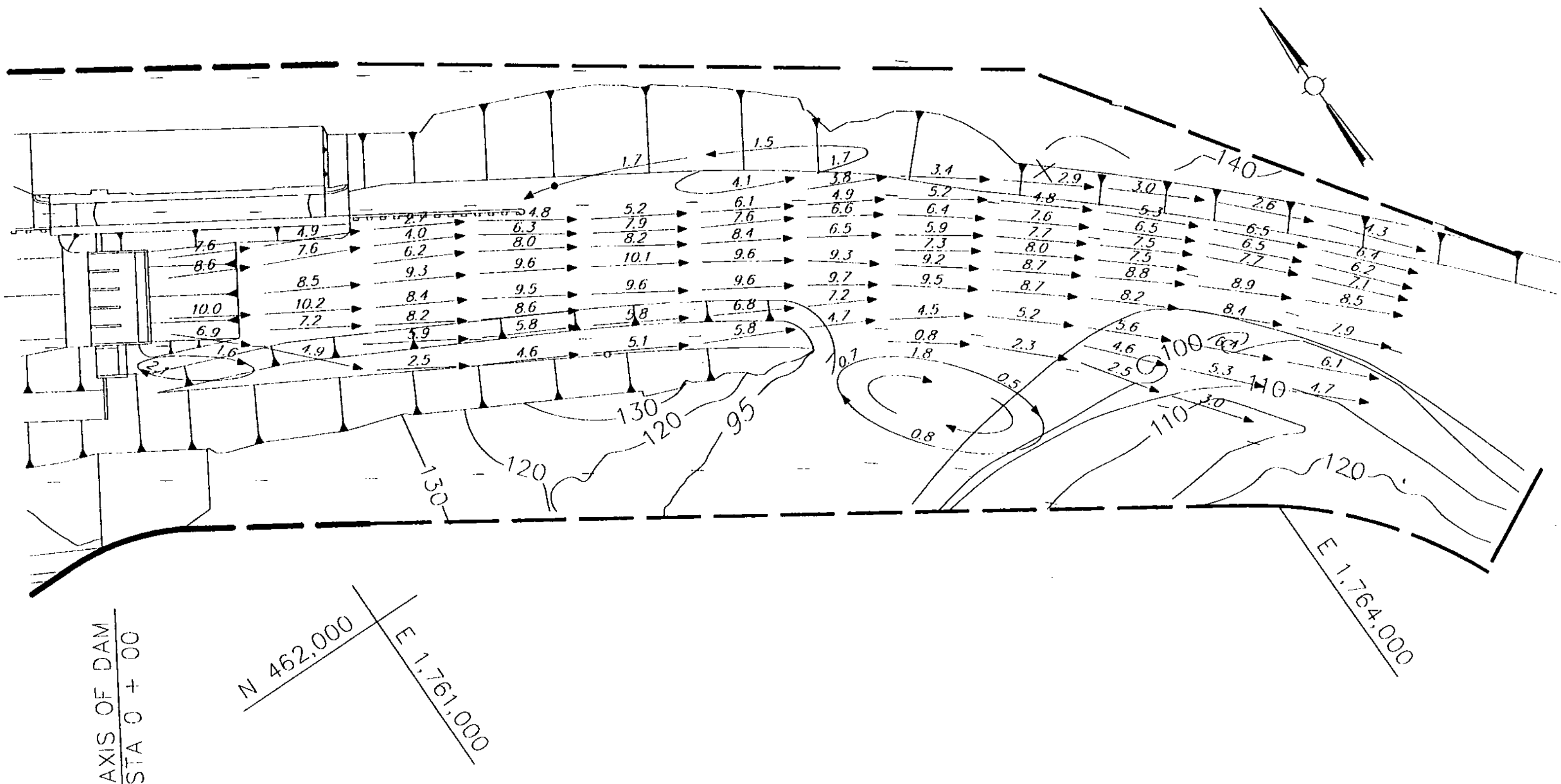
SCALES

PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS
PLAN D-2

DISCHARGE: 100,000 CFS
TAILWATER EL: 114.0 FT



LEGEND

2.3 VELOCITY IN FEET PER SECOND
--•→ VELOCITY LESS THAN 0.5 FPS

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0FT)

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 500 0 500 1000 FT

MODEL 5 0 5 10 FT

VELOCITIES AND CURRENT DIRECTIONS
PLAN D-2

DISCHARGE:	134,000	CFS
TAILWATER EL:	118.0	FT

REPORT DOCUMENTATION PAGE

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13. ABSTRACT *(Maximum 200 words)*

Lock and Dam No. 4 is the fourth lock in a series of five to be constructed on the Red River Waterway from the vicinity of Old River to Shreveport, LA. Lock 4 is located in a cutoff canal on the left descending bank about 169 postproject river miles above the mouth of the Red River. The principal structures include an 84- by 785-ft lock, a gated spillway containing five tainter gates, and a hinged crest gate 100 ft wide. The fixed-bed model reproduced about 3.5 miles of realigned river channel and adjacent overbank area at an undistorted model scale of 1:100.

The model investigation was concerned with determining the effects on navigation through the study reach for the proposed design and developing modifications required to the design that would provide satisfactory navigation conditions.

14. SUBJECT TERMS

Hydraulic models	Lock	Lock and Dam No. 4
Navigation conditioins	Red River	

15. NUMBER OF PAGES
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17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
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