Technical Report CHL-97-28
September 1997

US Army Corps of Engineers
Waterways Experiment Station

Navigation Conditions at Lock and Dam 25, Mississippi River

Hydraulic Model Investigation

by Ronald T. Wooley

WES

Prepared for U.S. Army Engineer District, Rock Island

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Vicksburg, MS 39180-6199

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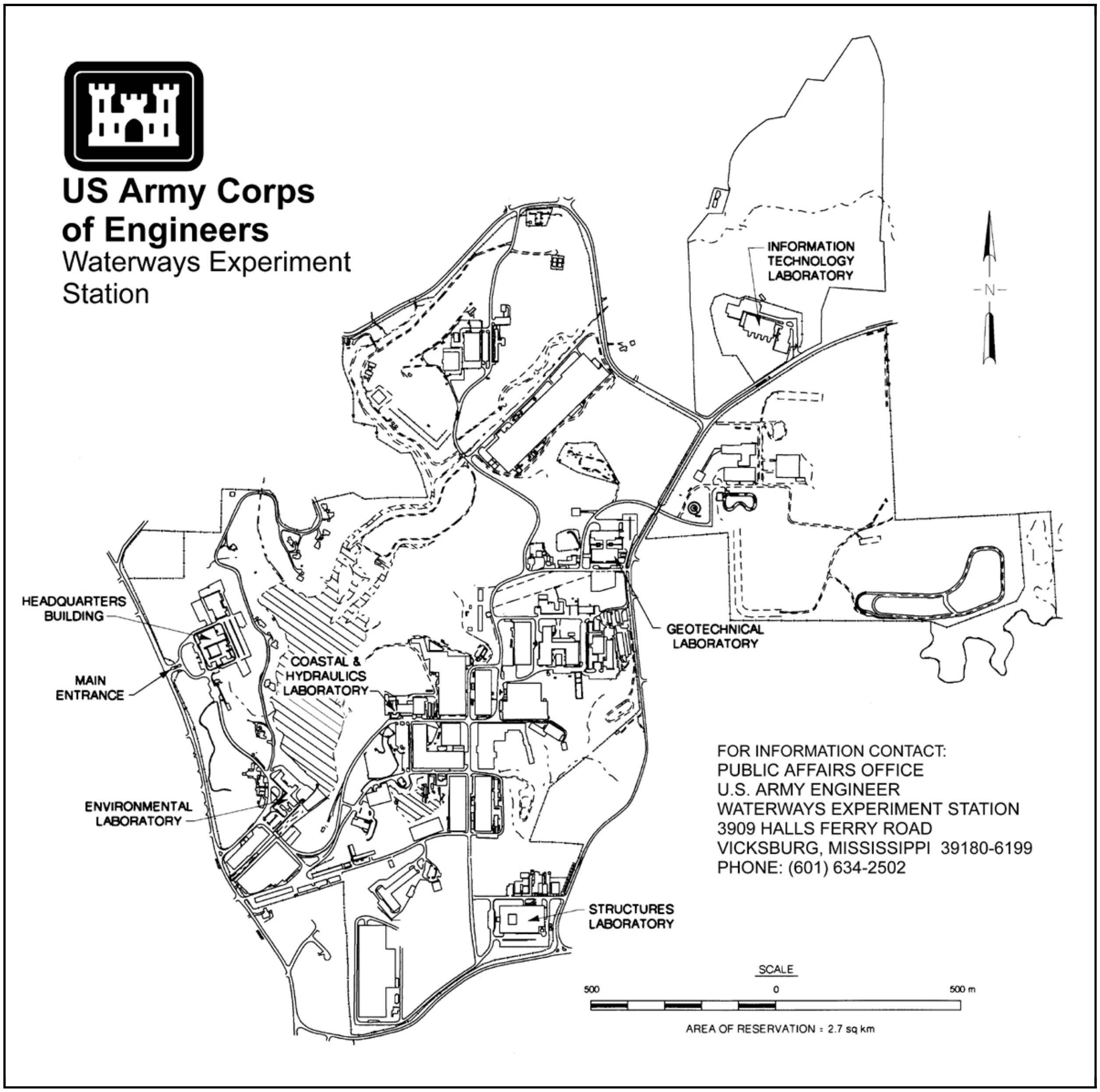

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Preface

The model investigation reported herein was authorized by Headquarters, U.S. Army Corps of Engineers, in an indorsement dated 17 February 1994 to the Division Engineer, U. S. Army Engineer Division, North Central. The study was conducted for the U. S. Army Engineer District, Rock Island, in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) during the period February 1994 to November 1995.

During the course of the model study, representatives of the Rock Island, St. Louis, and St. Paul Districts and other navigation interests visited WES at different times to observe special model experiments and to discuss the experiment results. Rock Island and St. Louis Districts were kept informed of the progress of the study through monthly progress reports and special briefings at the end of each experiment.

The investigation 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 Dr. L. L. Daggett, Acting Chief, Waterways Division, Hydraulics Laboratory. The principal investigator in immediate charge of the model study was Mr. R. T. Wooley, assisted by Messrs. R. A. McCollum, H. E. Park, and B. T. Crawford, and Ms. K. Anderson-Smith, all of the Navigation Division, and Mr. W. L. Hanks of the Soils Mechanics Branch, Geotechnical Laboratory. This report was prepared by Mr. Wooley.

This report is being published by the WES Coastal and Hydraulics Laboratory (CHL). The CHL was formed in October 1996 with the merger of the WES Coastal Engineering Research Center and the Hydraulics Laboratory. Dr. James R. Houston is the Director of the CHL, and Messrs. Richard A. Sager and Charles C. Calhoun, Jr., are Assistant Directors.

Director of WES during preparation of the report was Dr. Robert W. Whalin.

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
feet	0.3048	meters
miles (U.S. statute)	1.609347	kilometers

1 Introduction

Location and Description of Prototype

Lock and Dam 25 is located on the Mississippi River, 241.5 miles[1] upstream of its confluence with the Ohio River (Figure 1). The principal existing structures are the main 110- by 600-ft lock located along the right descending bank, an incomplete auxiliary lock located riverward of the main lock, and a 1,296-ft dam with fourteen 60-ft tainter gates and three 100-ft roller gates. An overflow dike with top el 434.0[2] extends from the dam to high ground on the left bank. The dam provides a navigation pool that extends upstream about 32 miles to Lock and Dam 24. The dam is operated to maintain a navigation pool that varies from el 434.0 to 429.7 at the dam and from el 434.0 to 437.0 at Mosier Landing (river mile 260.3). As the riverflow increases, the gates are raised to prevent exceeding the limits at Mosier Landing. The minimum pool elevation of 429.7 occurs with a riverflow of approximately 138,000 cfs.

History of Navigation Improvements on the Mississippi River

In its original condition prior to any improvements, the navigable channel of the Mississippi River at low water had a natural depth in many places of only 3 ft or less. The main channel was divided by islands and bars that formed chutes, sloughs, and secondary channels through which considerable parts of the low-water flow were diverted to the detriment of navigation.

As early as 1824, the Federal Government made appropriations to improve navigation on the Mississippi River from the Missouri River to New Orleans. The project adopted was for the removal of snags, logs, wrecks, etc. In 1878, Congress authorized the 4.5-ft channel, the first comprehensive project on the upper part of the river from St. Paul, MN, to the mouth of the Ohio River, and in 1907 authorized the 6-ft channel. The increase in depth was obtained mainly by the construction of hundreds of rock and brush dikes, low structures extending radially from the banks into the channel to constrict low-water flows.

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[1] A table of factors for converting non-SI units of measurement to SI units is found on page vi.
[2] All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

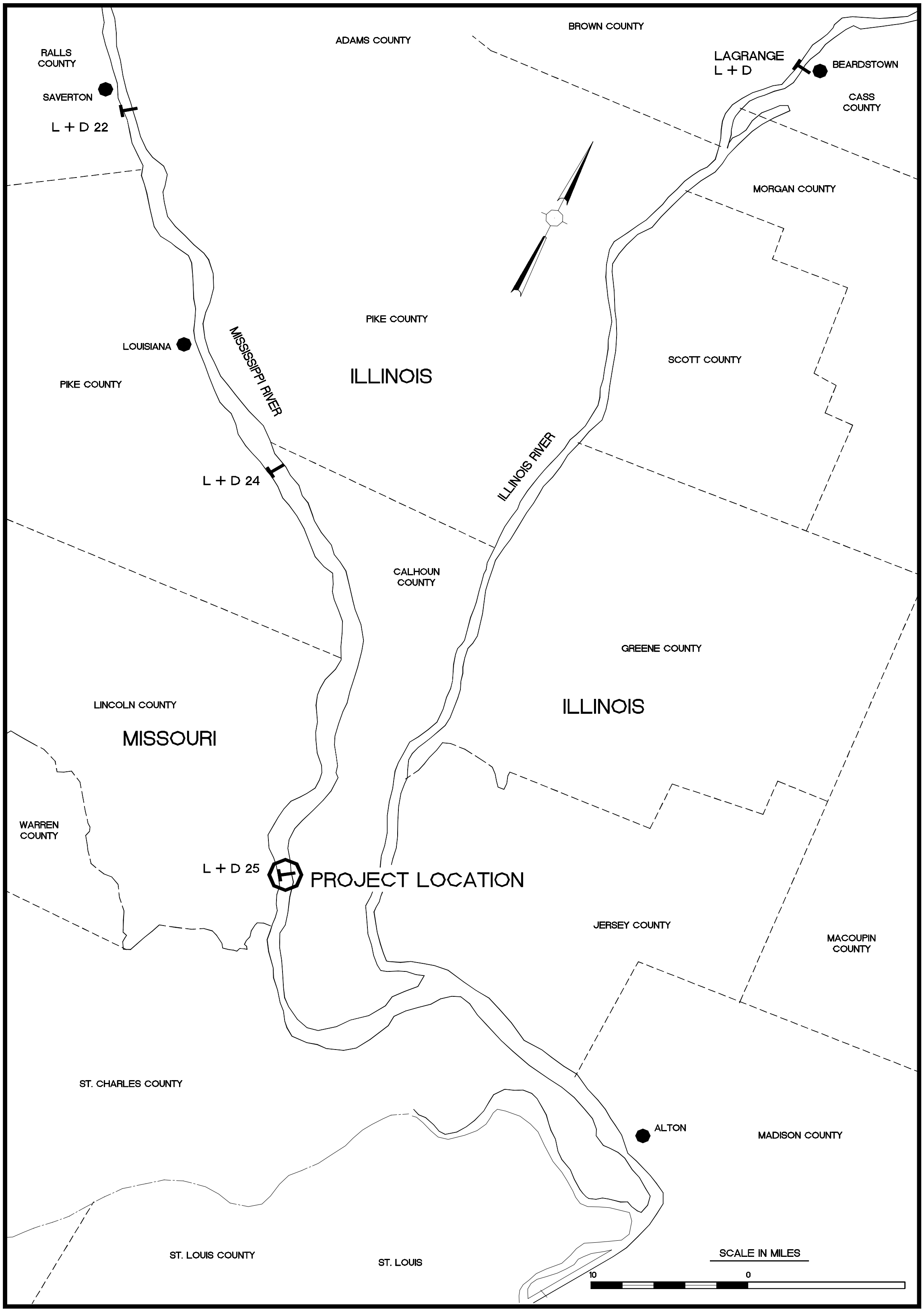


Figure 1. Vicinity map

A project adopted in 1880 provided for navigational improvements that included construction of 41 reservoirs at the headwaters of the Mississippi River. The reservoirs in Minnesota and Wisconsin, six of which were constructed, were intended to collect surplus water in the spring and release it during low-water periods. Congress passed an act in August 1894 providing for a separate water project on the Mississippi River between Minneapolis, MN, and St. Paul. This project established the groundwork for Locks and Dams 1 and 2. The channel depth was changed from 5 to 6 ft in 1907, and then on 3 July 1930, the Seventy-First Congress authorized the 9-ft channel. The 9-ft channel, from the mouth of the Illinois River to Minneapolis, was to be achieved by construction of a system of locks and dams, supplemented by dredging. In August 1935, the lower limit of the project was extended to the Missouri River, and on 26 August 1937, the upper limit of the project was extended to above St. Anthony Falls with extensions into the Minnesota and St. Croix Rivers.

The Mississippi River above St. Louis, MO, includes a system of 28 dams and 29 navigation locks, which makes navigation for long-haul commercial carriers possible almost year-round, with the exception of ice stoppage on the upper reaches. The major products moved on the waterway in this area are petroleum and petroleum products, which constitute about 29 percent of all tonnage passing through the locks; about 34 percent in grain, mostly downbound; 16 percent coal; and 21 percent other commodities, such as sulphur, sand, steel, bulk chemicals, and other manufactured items.

Existing Conditions

Dam 25 creates a wide shallow pool in the vicinity of the dam with numerous islands and backwater areas ranging from less than a foot to several feet deep. The navigation channel meanders through the pool making numerous crossings. The channel favors the left descending bank approximately 8,000 ft upstream of the dam, makes a crossing toward the right bank between 6,000 and 4,000 ft upstream of the dam, and approaches the lock along the right bank. Flow from along the right bank moves across the upper approach toward the dam, creating a serious outdraft near the upstream end of the guard wall. Due to the alignment of the channel and the crosscurrents, navigation conditions for downbound tows approaching the lock are extremely difficult. An L-head dike was constructed along the right bank upstream of the lock to improve navigation conditions. Although the dike may have improved navigation conditions, a helper boat is used most of the time to overcome the outdraft and align the tow with the guide wall (Photos 1 and 2).

The right bank immediately downstream of the lock juts riverward and forces downbound tows to make a hard left turn as they exit the lock to enter the main river channel (Photos 3 and 4). The navigation channel is along the left descending bank approximately 5,000 ft downstream of the dam and crosses the river channel to the lock. Upbound tows navigate along the left bank to a point about 3,000 ft downstream of the dam, then cross to the lock.

Need for and Purpose of Model Study

Several locations are being considered for a new lock at Dam 25. While sound engineering judgment was used in evaluation of the various proposals as a screening tool, it is very difficult to arrive at an analytical solution due to the complex nature of the flow through the reach. Therefore, it was considered necessary to determine the conditions that would develop at the various locations with the new lock in place and to identify any structures or channel alignments needed to improve navigation conditions. The purposes of the model study were to

a. Evaluate navigation conditions for each lock location.

b. Identify guard wall lengths, remedial structures, and channel alignment required to establish satisfactory navigation conditions.

c. Identify problems that may be associated with a particular lock location so information can be used in the preliminary design for new locks at other dam sites along the upper Mississippi River.

d. Determine approach times for various lock configurations at low, moderate, and high flows.

2 The Model

Description

The model (Figure 2) reproduced about 3.7 miles of the Mississippi River and the adjacent overbank areas from about 9,800 ft upstream to about 9,600 ft downstream of the existing dam. The model was of the fixed-bed type with overbank areas and channels molded of sand cement mortar to sheet metal templates set to the proper grade. Portions of the model where changes in bank alignment and placement of new structures could be anticipated were molded in sand and overlaid with a thin layer of sand cement mortar to facilitate modifications necessary to determine navigation conditions associated with the various plans. The lock, guide walls, guard walls, and dam were constructed of sheet metal and/or Plexiglas and set at the proper grade. The dam gates were simulated schematically with simple vertical sheet-metal slide-type gates. The channel portion of the model was molded to conform to a hydrographic survey dated 1994, and the overbanks were molded to a topographic survey dated 1991, except in the Batch Town area upstream of the dam which was molded to a hydrographic and topographic survey dated 1988.

Scale Relations

The model was built to an undistorted linear scale of 1:120, model to prototype. This scale allows accurate reproduction of velocities, eddies, and crosscurrents that would affect navigation. Other scale ratios resulting from the linear scale ratio are as follows:

Characteristic	Ratio[1]	Scale Relations Model:Prototype
Length	L_r	1:120
Area	$A_r = L_r^2$	1:14,400
Velocity	$V_r = L_r^{1/2}$	1:10.95
Time	$T_r = L_r^{1/2}$	1:10.95
Discharge	$Q_r = L_r^{5/2}$	1:157,744
Roughness (Manning's n)	$N_r = L_r^{1/6}$	1:2.22

[1] Dimensions are in terms of length *L*.

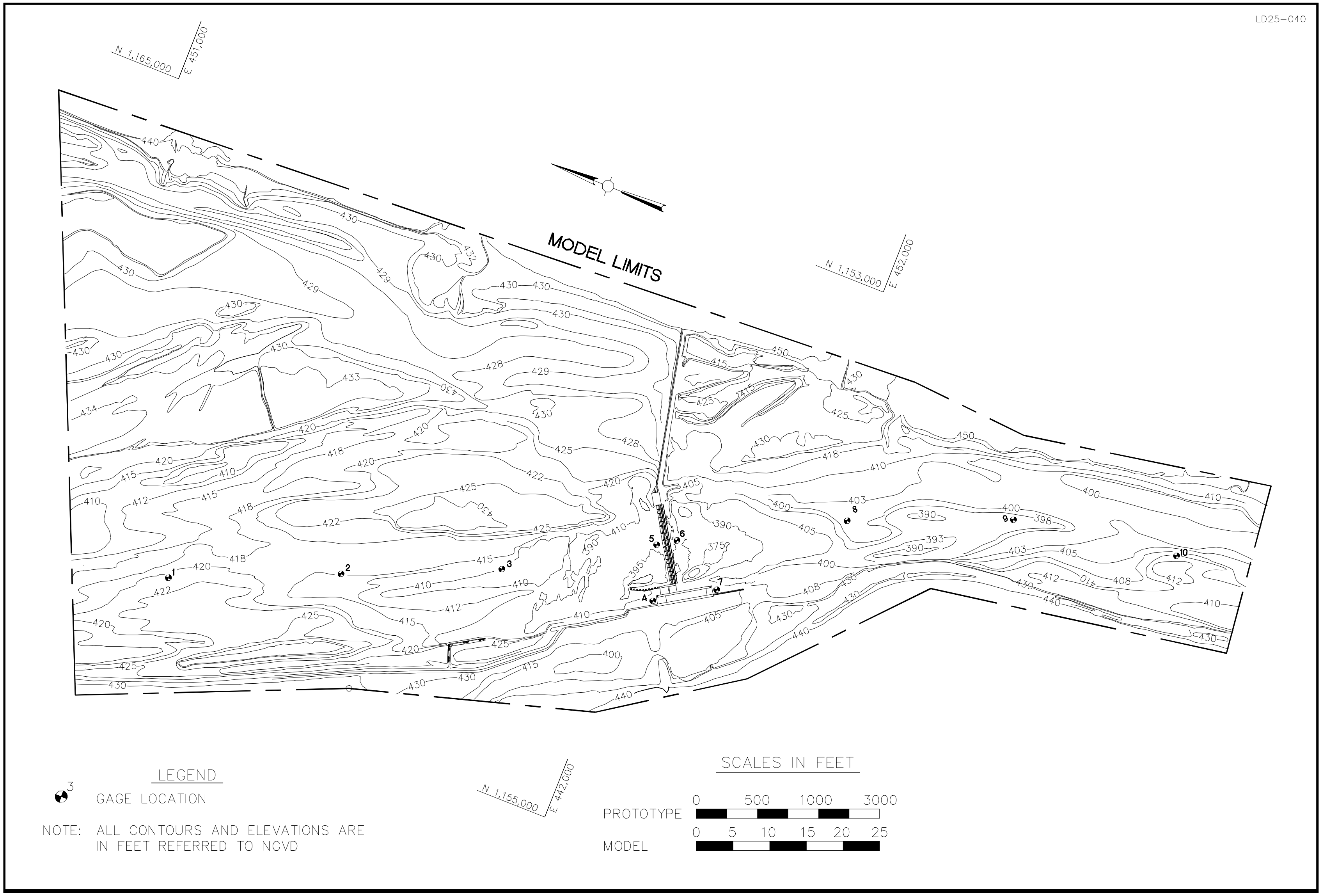


Figure 2. Existing conditions

Measurements of discharges, water-surface elevations, and current velocities can be transferred quantitatively from model to prototype using these scale relations.

Appurtenances

Water was supplied to the model by a 10-cfs pump operating in a recirculating system. The discharge was controlled and measured by a valve and a venturi meter. Water-surface elevations were measured by piezometer gauges located in the model channel and connected to a centrally located gauge pit (Figure 2). For controlled riverflows, upper pool stages were controlled at the dam by opening and closing the dam slide gates; for open riverflows, tailwater elevations were controlled by a tailgate located at the lower end of the model.

Model Adjustment

The surface of the model was constructed of brushed cement mortar to provide a roughness (Manning's n) of about 0.0135, which corresponds to a roughness in the prototype of about 0.030. With the existing lock and dam in place, the model was checked against available prototype data and the constant discharge design tailwater and headwater rating curves. The results indicated that the model reproduced with a reasonable degree of accuracy conditions in the prototype based on the available data.

A time-lapse video recorder and camera were installed at the project from December 1993 to October 1994 to record the path and maneuvering required for tows to enter and leave the upper lock approach (Photos 1-4). During this period, riverflows ranged from low to high and covered a range of outdraft conditions. This information was then compared to model data taken with model tows entering and leaving the upper lock approaches with various riverflows. This comparison indicated the model reproduced with a reasonable degree of accuracy prototype navigation conditions that exist at the project.

3 Experiments and Results

Experiment Procedures

The primary concerns of the experiments were the study of flow patterns, measurement of velocities and water-surface elevations, effects of currents on the movement of the model tow approaching and leaving the existing lock, and determination of how the placement of the new 1,200-ft lock would affect current patterns in the lock approaches. These conditions were studied with the existing 600-ft lock and with four proposals for positioning of the 1,200-ft lock:

a. Location 1: Adding a 1,200-ft lock landward of the existing 600-ft lock.

b. Location 2: Extending the existing 600-ft chamber to provide a 1,200-ft chamber.

c. Location 3: Adding a 1,200-ft lock at the auxiliary lock chamber.

d. Location 4: Adding a 1,200-ft lock riverward of the auxiliary lock by removing two gate bays.

The riverflows were reproduced by introducing the proper discharge and manipulating the tailgate until the required tailwater elevation was obtained. During controlled pool flow conditions, the upper pool was maintained by adjusting the gates of the dam, maintaining a uniform opening for all gates. During open river flows, all of the dam gates were removed. During base experiments (existing conditions), the pool elevation was controlled at Gauge 4 to settings supplied by the U.S. Army Engineer District, St. Louis, and the tailwater elevation was controlled at Gauge 7. For subsequent experiments, the tailwater was controlled at Gauge 10 to elevations obtained during the base experiment.

A selection of representative flows were used for experimenting based on information furnished by the St. Louis District, as follows:

Riverflow, cfs	Upper Pool El	Tailwater El
65,000 (controlled pool)	433.7	421.8
125,000 (controlled pool)	431.4	424.5
138,000 (max drawdown)	429.7	429.2
166,000 (open river)	431.5	430.8
200,000	433.7	433.0
240,000	436.5	435.7
303,000	439.7	438.8
327,000 (max navigable)	442.0	441.6

Current directions were determined by tracking the path of lighted floats with respect to ranges established for that purpose with the video camera tracking system mounted over the model. Velocities were measured by a desktop computer, which calculates velocity using the time required by floats to pass over a measured distance. This method provided detailed information on the currents that would affect tows moving through the reach. In the interest of clarity, in the case of plots of currents in turbulent areas or where eddies or crosscurrents existed, only the main trends are shown. Confetti was used to determine surface current patterns. Dye was also introduced in the model to illustrate the current patterns, and these patterns were recorded with time-lapse photography.

A radio-controlled model towboat and barges were used to evaluate and demonstrate the effects of currents on tows approaching and leaving the lock and in the critical reaches of the project. The towboat was equipped with twin screws, Kort nozzles, and forward and reverse rudders and powered by a small electric motor operating from batteries in the tow. The speed and rudders of the tow were remote controlled, and the towboat could be operated in forward and reverse at speeds comparable to those that could be expected to be used by the towboats on the Upper Mississippi River waterway. The tow used in the study represented a makeup of fifteen 195-ft-long by 35-ft-wide standard barges with a 150-ft-long pusher. This provided an overall size tow of 1,125 ft long by 105 ft wide loaded to a draft of 9 ft. The model towboat provided an accurate representation of the maneuvering characteristics of prototype towboats. The towboat was calibrated to the speed of a comparable size prototype towboat moving in slack water and was operated at 1 to 2 miles per hour above the speed of the currents to maintain rudder control but not overpower the currents. Multiple-exposure, time-lapse photography was used to record the path of the model tow navigating the reach. The video-tracking system was also used to track the model tow for evaluation of navigation conditions and to record approach times for downbound tows approaching the lock with the various plans.

Base Experiments (Existing Conditions)

Description

Base experiments were conducted with the model reproducing existing conditions as shown in Figure 2. The purposes of the experiments were to verify that the model was reproducing known prototype conditions and to provide information and data that could be used to evaluate the effect of the proposed modifications on water-surface elevations, current direction and velocities, and navigation conditions. The principal features reproduced or simulated in the model, shown in Figures 2 and 3 and Photo 5, included the following:

a. A lock with clear chamber dimensions of 110 ft wide by 600 ft long located along the right descending bank at about river mile 241.5, a 512-ft-long upper guide wall, a 502-ft-long lower guide wall, and provisions for a second lock on the riverward side. The top of lock walls were at el 444.0.

b. A 1,000-ft-long rock dike extending upstream from the upstream end of the upper guide wall. The center line of the rock dike was offset landward to provide navigation depth for tows aligned with the guide wall.

c. An auxiliary lock adjacent to the navigation lock that has only the upper miter gate and no usable chamber with a ported upper guard wall (top of ports el 428.9).

d. A 1,296-ft nonnavigable gated spillway including fourteen 60- by 25-ft tainter gates and three 100- by 25-ft roller gates with sill elevation of 409.0. The dam was connected to high ground on the left overbank with an earth dike, top el 434.0.

e. An L-head dike with top el 436.0 located along the right bank approximately 3,800 ft upstream of the upper end of the guide wall.

Results

Water-surface elevations. Water-surface elevations obtained with existing conditions (Table 1) indicate the average slope in the model upstream of the dam (Gauges 1-5) ranged from less than 0.1 to about 0.7 ft per mile with the 65,000- and 138,000-cfs riverflows, respectively. The average slope downstream of the dam (Gauges 6-10) ranged from less than 0.1 to about 0.3 ft per mile with riverflows of 65,000 and 327,000 cfs. The drop across the gated dam (Gauges 5 and 6) with open riverflows ranged from about 0.1 to 0.4 ft with the 327,000- and 200,000-cfs riverflows, respectively.

Current directions and velocities. Data shown in Plates 1-8 indicate the currents upstream of the dam generally angled slightly toward the right

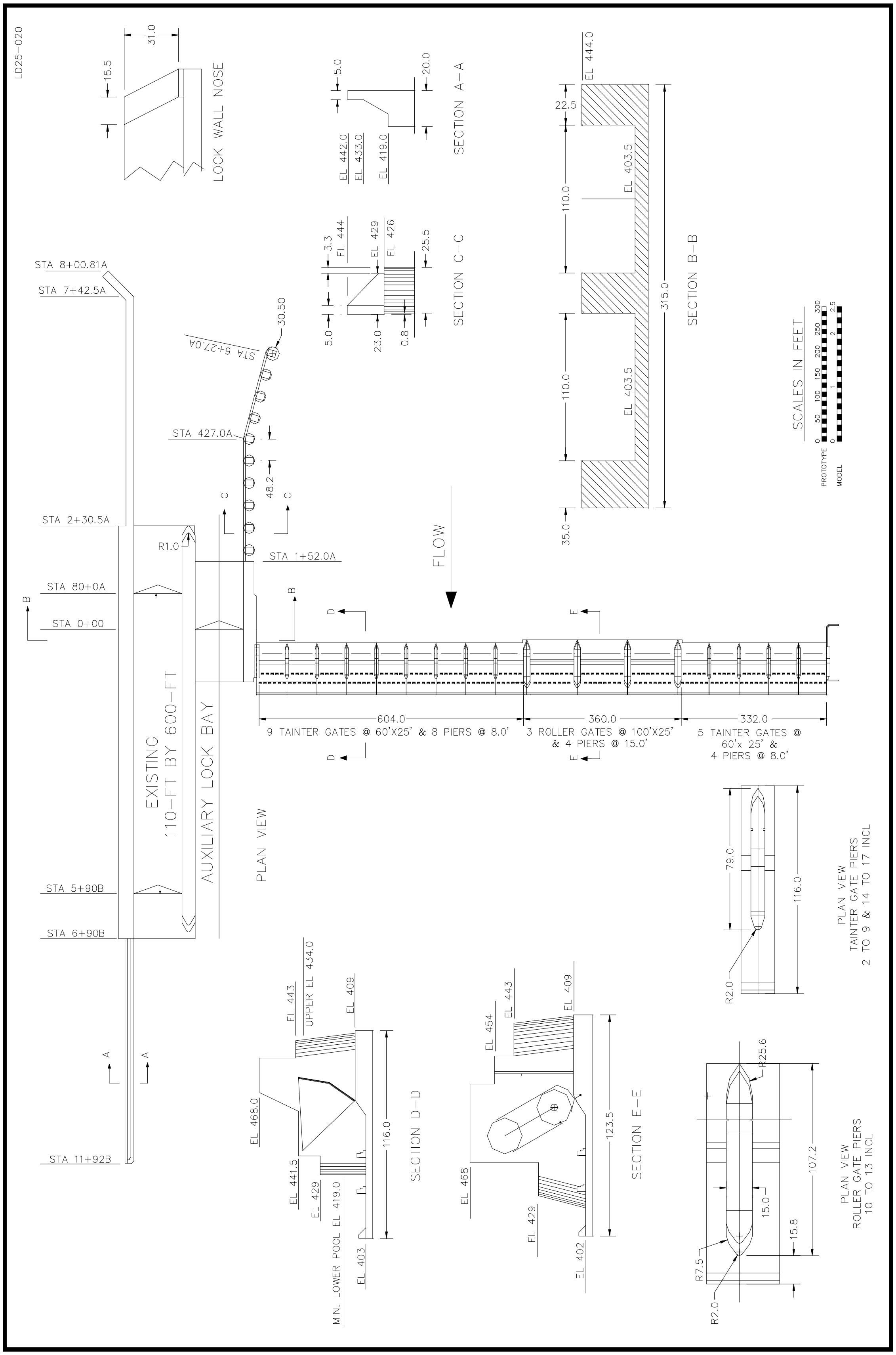


Figure 3. General plan and sections, existing structures

descending bank line until reaching the levee about 1,800 ft upstream of the lock. The current then ran nearly parallel to the levee until about 800 ft upstream of the lock. At that point, the current broke sharply and moved across the lock approach toward the dam (Photo 6). The currents below the dam generally moved parallel to the left descending bank line, except for current in the lower lock approach adjacent to and immediately downstream of the lower guidewall. The current tended to move toward the right descending bank, across the lower lock approach, and toward the scallop in the right bank immediately downstream of the lower guidewall. The maximum velocity of the currents in the navigation channel upstream of the lock varied from about 1.8 to 5.3 fps at about 6,000 ft upstream of the axis of the dam, 1.1 to 4.3 fps opposite the L-head dike about 3,600 ft upstream of the axis of the dam, and 1.4 to 4.4 fps adjacent to the right bank levee about 1,600 ft upstream of the axis of the dam with the 65,000- and 138,000-cfs riverflows, respectively. The maximum velocity of the currents in the navigation channel downstream of the lock varied from 1.8 to 4.3 fps near the end of the downstream guidewall about 1,600 ft downstream of the axis of the dam for riverflows of 65,000 and 240,000 cfs, respectively, and 2.2 to 6.0 fps near midchannel about 4,000 ft downstream of the lock for riverflows of 65,000 and 303,000 cfs, respectively.

Navigation conditions. Due to the alignment of the navigation channel upstream of the lock and the set of the currents moving across the upper lock approach toward the spillway, navigation conditions for downbound tows were extremely difficult even with the lower riverflows and could be hazardous under some conditions. Field data show that a helper towboat is used by downbound towboats to push their tows into the guide wall with most flow conditions. Downbound tows approach the upper guide wall by flanking the stern of the towboat in close to the rock dike running along the right bank, bringing the tow to a complete stop with the head of the tow swinging riverward (Photos 1 and 2), and allowing the helper towboat to push the head of the tow into the guide wall. The helper towboat holds the tow close to the guide wall as the tow moves into the lock chamber. Experiments made with the model tow show the same maneuvers were required for a downbound tow approaching the 600-ft lock (Photo 7). Upbound tows leaving the lock tended to be moved riverward as they left the lock approach, but no serious difficulties were indicated for tows with sufficient power and steerage to overcome the currents (Photo 8).

Due to the alignment of the lock with the navigation channel, downbound tows leaving the lock rotate the head of the tow riverward as the tow moves along the guide wall and makes a hard turn toward midchannel as the stern of the towboat clears the guide wall (Photo 9). No serious difficulties were indicated for tows with sufficient power and steerage to overcome the currents. However, upbound tows approach the lock from midchannel and considerable maneuvering is required to land on the guide wall. In some cases, the tow approaches the wall at a steep angle, but no serious difficulties were indicated for tows approaching the guide wall (Photo 10).

Lock Location 1, Plan A

Description

Lock Location 1 involved adding a new lock with clear dimensions of 110 ft wide by 1,200 ft long landward of the existing 600-ft lock.

The principal features of Lock Location 1 were as follows (Figures 4 and 5 and Photos 11 and 12):

a. A new 110-ft-wide by 1,200-ft-long lock located landward of the existing 600-ft lock. The upper gate pintle of the new lock was located at sta 6+98.12A, and the center line of the new lock was located 200 ft landward and parallel to the center line of the existing 600-ft lock.

b. A 1,225-ft-long ported guard wall with twenty-four 30-ft-diam cells spaced 50 ft on centers and a 50-ft-diam guard cell at the upper end of the wall. The guard wall extended upstream from the riverside lock wall. This provided twenty-three 20-ft-wide port openings and one 40-ft-wide port opening with the top of ports at el 418.7 (15 ft below normal pool of 433.7 or 11 ft below the maximum drawdown pool of 429.7). The effective length of the guard wall measured from the upstream end of the land-side lock wall to the upstream end of the guard wall was 1,225 ft and would provide protection for the design size tow. The upstream end of the existing guide wall, which was left in place, blocked the most downstream port of the new guard wall. Therefore, twenty-two 20-ft-wide port openings and one 40-ft-wide port opening could pass flow.

c. A 1,200-ft-long, solid lower guide wall extending downstream from the landside lock wall.

d. Modification of the upper lock approach by excavating the right bank to provide a 200-ft-wide navigation channel at the upstream end of the guard wall. The right bank was excavated to a 1V on 3H slope along a line extending upstream from the landside wall of the new lock to State Plane Coordinate N 1,157,509; E 443,729 about 3,800 ft upstream of the dam. The L-head dike was completely removed, and the navigation channel was a minimum of 600 ft wide. The 1V on 3H slope was extended up to el 444 with a 20-ft-wide berm to replace the existing levee along the right bank and to control the pool up to el 444. The entrance channel along the length of the upper guard wall was graded to el 410 to a point about 2,000 ft upstream of the dam and then made a transition to el 415.0.

e. Excavation of a 600-ft-wide navigation channel to el 415.0 extending along Azimuth 339° 38′ 59′′ upstream from State Plane Coordinate N 1,157,509; E 443,729. A channel width of 600 ft was considered the maximum channel width that could be maintained; therefore, it was

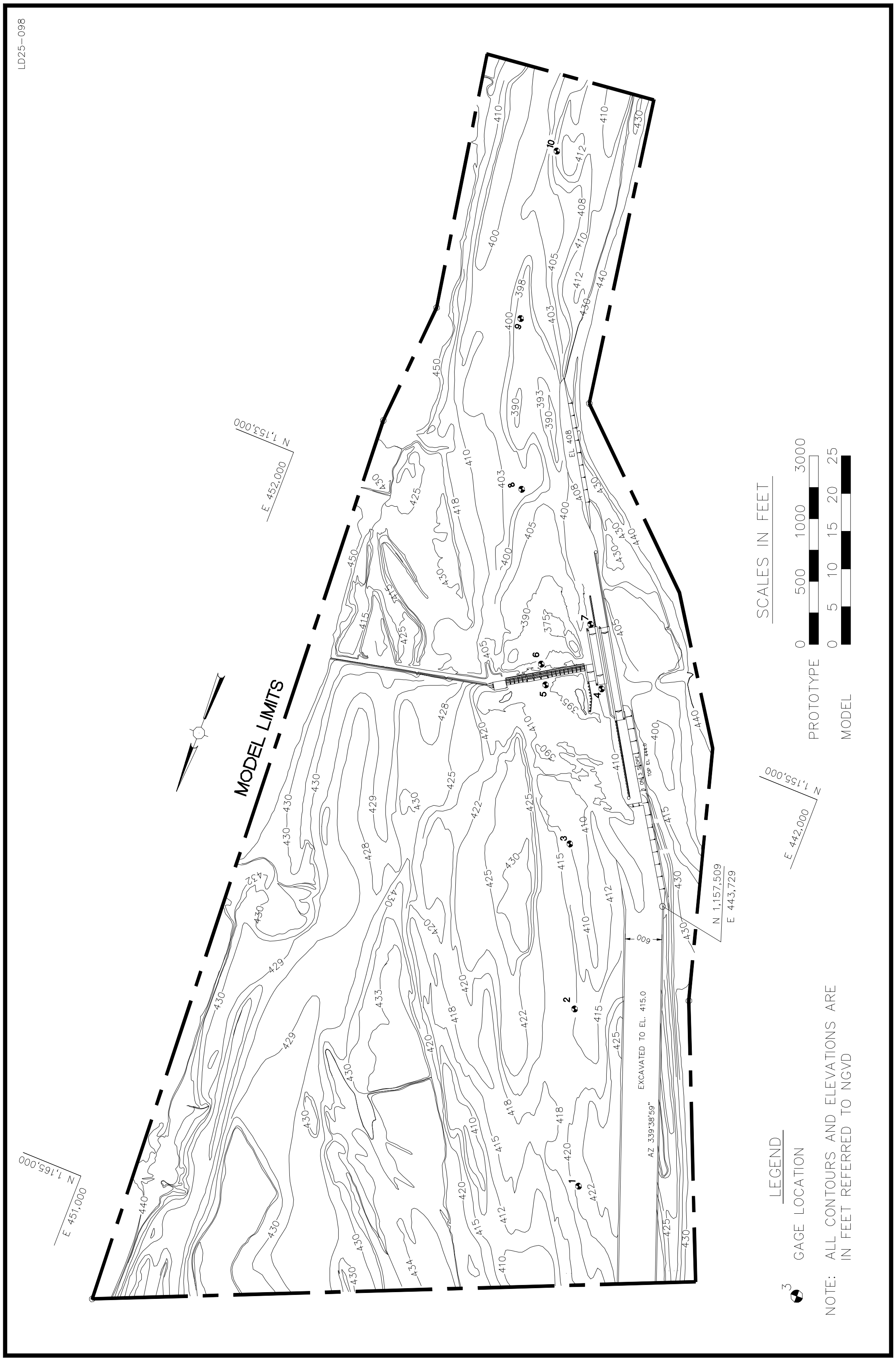


Figure 4. Lock Location 1, Plan A

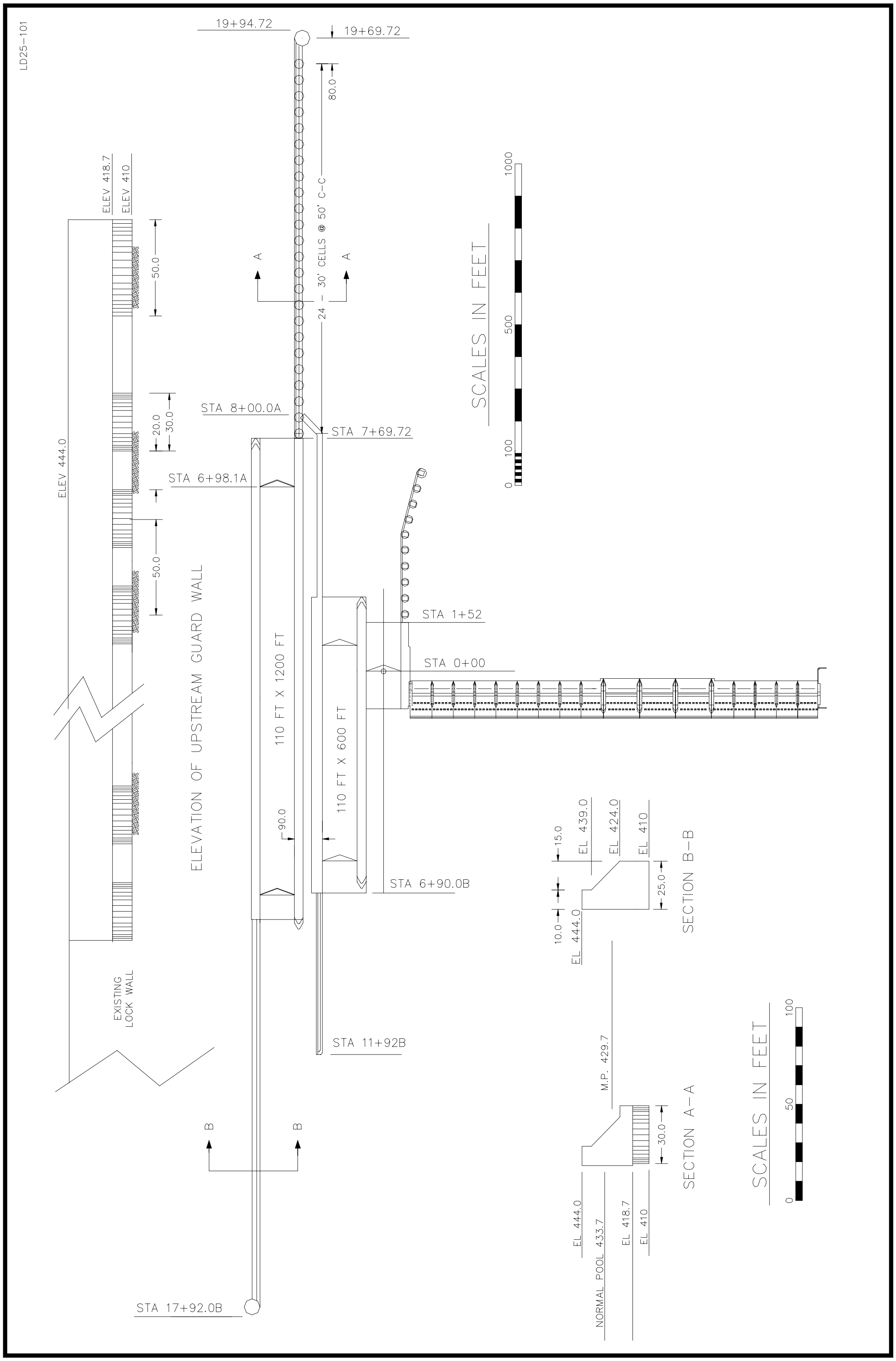


Figure 5. General plan and sections, Lock Location 1, Plan A

selected for the initial experiments. A 600-ft-wide channel was selected to demonstrate the improvement a realigned channel would provide for tows entering and leaving the upper lock approach.

f. Excavation of the right bank downstream of the new lock to el 408.0 to form a straight navigation channel extending from the downstream end of the landside guide wall into the main river channel approximately 2,000 ft downstream. The bank was excavated to a 1V on 3H slope.

Results

The model experiments were conducted using the same operating procedures and flow conditions as those used for Base Experiments.

Water-surface elevations. Elevations shown in Table 2 indicate that water-surface elevations were generally about the same as those taken during the Base Experiment conditions (Table 1).

Current directions and velocities. Data shown in Plates 9-16 indicate that the currents generally moved parallel to the right bank from the upstream end of the model to the lock approach with some flow moving around the upstream end of the guard wall (Photo 13). Currents downstream of the dam generally flowed parallel to the bank lines except immediately downstream of the dam. Currents tended to move across the existing lower lock approach into the lower approach of the new lock and parallel to the bank. The maximum velocity in the navigation channel upstream of the lock varied from 1.9 to 4.4 fps about 6,000 ft upstream of the axis of the dam and from 1.6 to 4.0 fps about 3,000 ft upstream of the axis of the dam with the 65,000- and 166,000-cfs riverflows, respectively. The maximum velocities in the navigation channel downstream of the dam varied from 2.6 to 4.3 fps near the downstream end of the lower guide wall and from 2.4 to 5.9 fps about 4,500 ft downstream of the axis of the dam with the 65,000- and 327,000-cfs riverflows, respectively.

Navigation conditions. Navigation conditions were improved for tows entering and leaving the upper lock approach with all riverflows evaluated compared with Base Experiments. Downbound tows could navigate along the right limits of the navigation channel, start turning to align with the guard wall about two tow lengths upstream of the guard wall, and enter the upper lock approach without any major difficulties with all riverflows (Photo 14). Tows could enter the lock approach with minimum power and at a slow speed, align with the guard wall, and enter the lock chamber without any difficulties. However, it should be noted that a relatively short length of straight channel upstream of the lock provided marginally acceptable navigation conditions for downbound tows because the margin for pilot error or misaligned tows was small. A downbound tow was still turning to align with the guard wall about one tow length upstream of the guard wall, and any error in alignment, adverse wind, or judgment could result in the tow striking the upper end of the guard wall or being moved into the right bank. Downbound tows approaching the lock from midchannel about 3,000 ft upstream of the guard wall could experience some difficulties entering the lock approach. Upbound tows could move away from the guard wall, turn to align with the navigation channel after clearing the upper end of the guard wall, and navigate upstream through the reach without any difficulties (Photo 15).

Tows could enter and leave the lower lock approach without any difficulties (Photos 16 and 17). Downbound tows could either move away from the guide wall and turn toward midchannel similar to existing conditions or drive straight downstream along the excavated bank line without any difficulties. Upbound tows could approach the new lock from midchannel similar to the path taken with existing conditions or navigate close along the excavated right bank without any difficulties.

Navigation conditions for downbound tows approaching the existing 600-ft lock were extremely difficult and could be hazardous even with the assistance of a helper towboat. The upstream 600 ft of the tow would be exposed to currents moving through the ported guard wall, which would tend to move the tow away from the lock toward the dam. Upbound tows could use the existing 600-ft lock much in the same manner as with existing conditions. However, an upbound tow leaving the lock would experience more currents on the upstream end of the tow because of the flow moving through the ported guard wall.

Recommendations for future experiments

If this location is selected as the recommended location, additional experiments should be conducted to improve navigation conditions at the site. Realignment of the navigation channel upstream of the lock or moving the lock downstream to allow the tow to align with the lock a minimum of two tow-lengths upstream of the guard wall should be investigated. Increasing the width of the upper lock approach to allow more clearance for downbound tows should also be investigated in the model.

Lock Location 2, Plan A

Description

The principal features of Lock Location 2, Plan A, were as follows (Figures 6 and 7 and Photo 18):

a. A 110-ft-wide by 1,200-ft-long lock chamber replacing the existing lock chamber.

b. A 1,200-ft-long ported upper guard wall with twenty-four 30-ft-diam cells spaced 50 ft on centers and a 50-ft-diam guard cell at the upstream end of the wall. This provides twenty-three 20-ft-wide port openings and one 40-ft-wide port opening with the top of ports at el 418.7 (15 ft

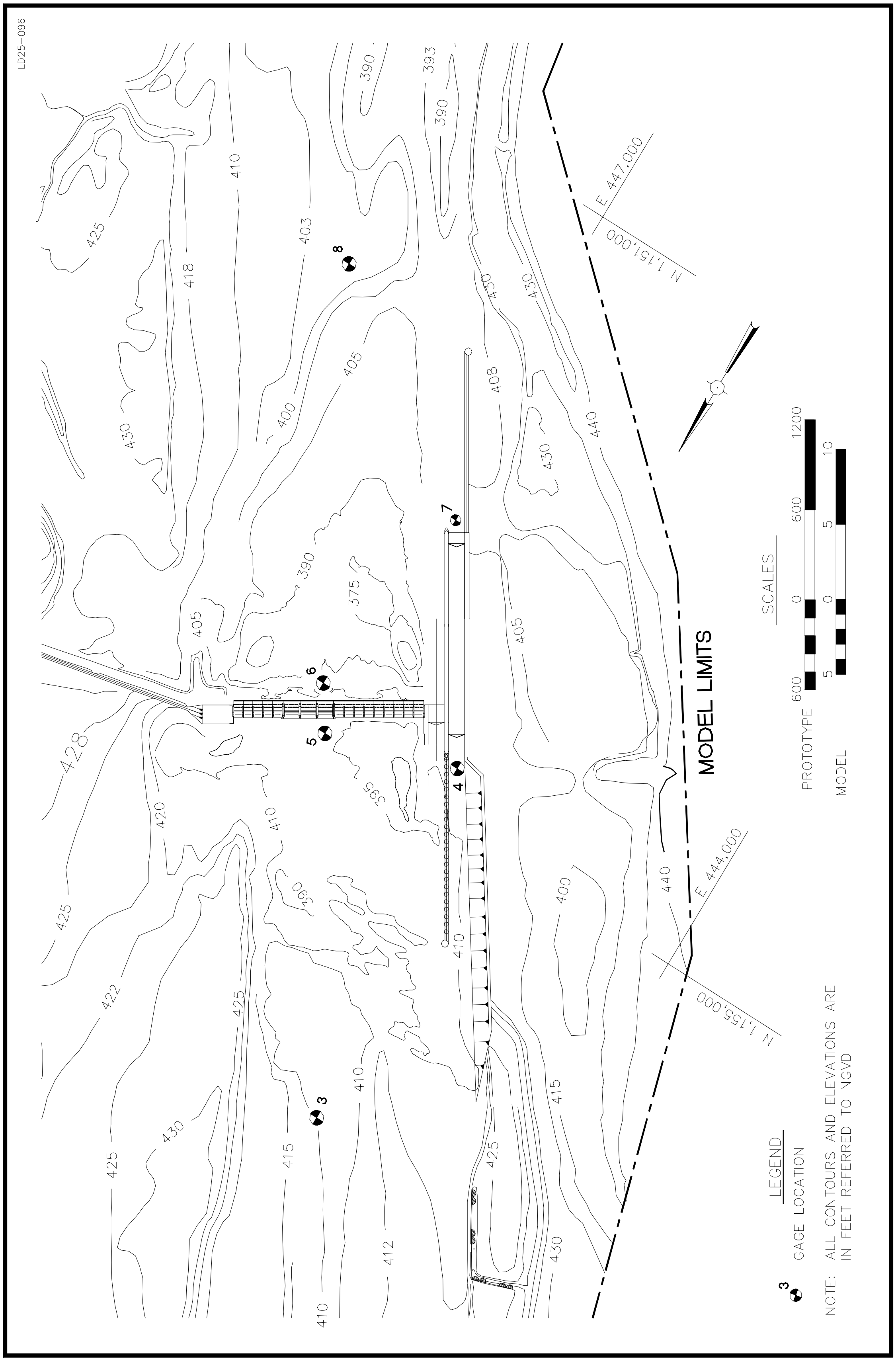


Figure 6. Lock Location 2, Plan A

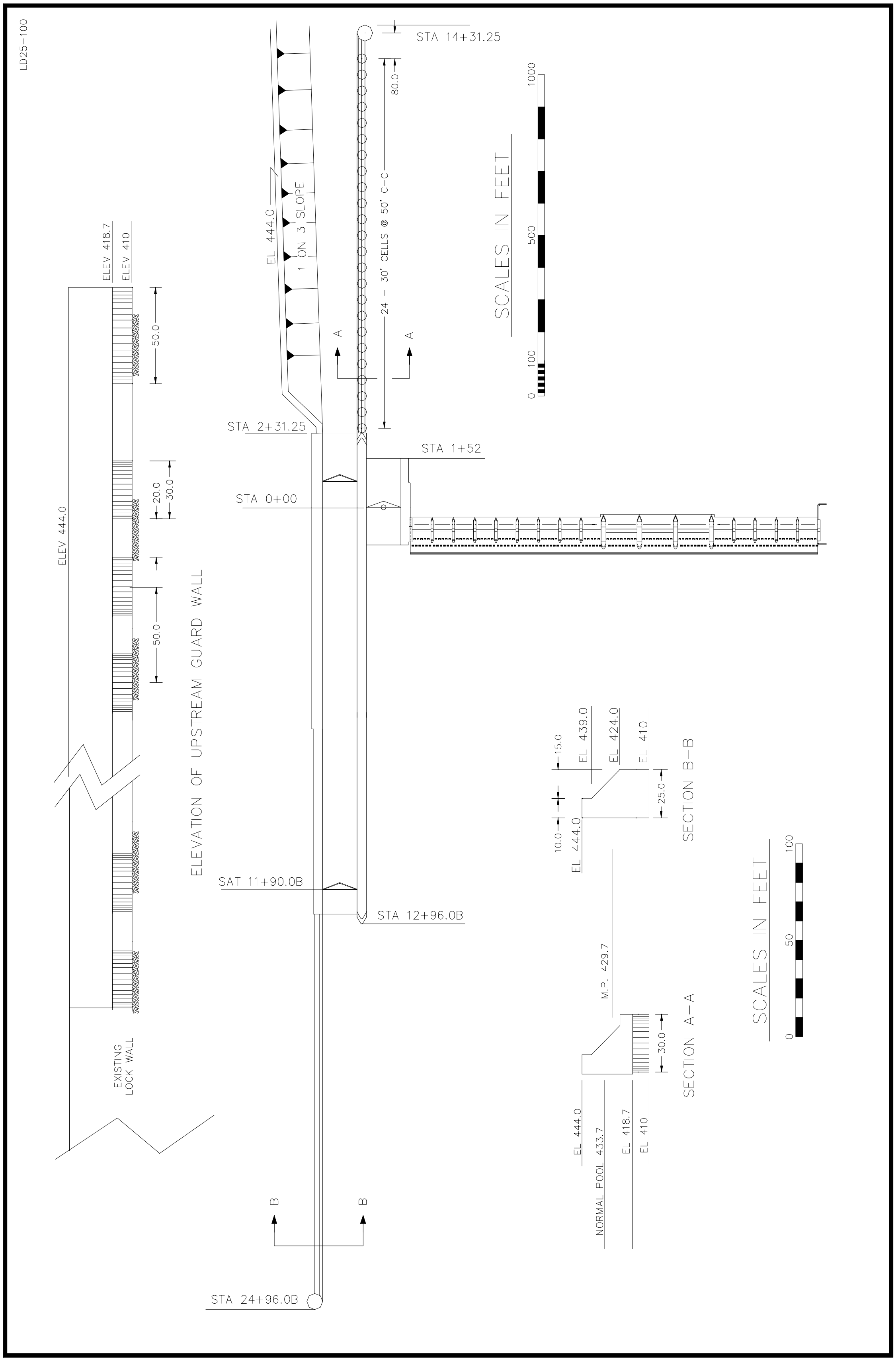


Figure 7. General plan and sections, Lock Location 2, Plan A

below normal pool of 433.7 or 11 ft below the maximum drawdown pool of 429.7). The effective length of the guard wall measured from the upstream end of the land-side lock wall to the upstream end of the guard wall is 1,200 ft and would provide protection for the design size tow.

c. A 1,200-ft-long solid lower guide wall extending downstream from the landside lock wall.

d. Modification of the upper lock approach by removing the existing upper guide wall and the stone dike along the right bank by excavating and reshaping the bank line to provide a 150-ft-wide entrance at the upstream end of the guard wall. The right bank was excavated to a 1V on 3H slope from a baseline at el 410 that extended from the landside wall of the lock chamber upstream to the right bank L-head dike. The 1V on 3H slope was extended up to el 444 with a 20-ft-wide berm to replace the existing levee along the right bank and to control the pool up to el 444. The entrance channel along the length of the upper guard wall was graded to el 410.

e. Removal of the existing ported guard wall on the auxiliary lock.

Results

The model experiments were conducted using the same operating procedures and flow conditions as those used for Base Experiments.

Water-surface elevations. Water-surface elevations shown in Table 3 indicate the slope in water-surface elevations was generally the same as during the Base Experiment conditions (Table 1).

Current directions and velocities. Current direction and velocity data shown in Plates 17-24 indicate the currents moved toward the right descending bank until reaching the L-head dike 3,500 ft upstream of the axis of the dam, then turned parallel with the right bank levee to enter the lock approach with some flow moving around the upstream end of the guard wall. Currents downstream of the dam generally flowed parallel to the bank lines. The maximum velocity in the navigation channel upstream of the lock varied from 1.9 to 5.1 fps about 6,000 ft upstream of the axis of the dam and from 1.6 to 4.6 fps about 3,000 ft upstream of the axis of the dam with the 65,000- and 166,000-cfs riverflows, respectively. The maximum velocities in the navigation channel downstream of the dam varied from 2.6 to 4.6 fps near the downstream end of the lower guide wall with the 65,000- and 240,000-cfs riverflows, respectively, and 2.4 to 6.2 fps about 4,500 ft downstream of the axis of the dam with the 65,000- and 327,000-cfs riverflows, respectively.

Navigation conditions. Navigation conditions were improved somewhat for tows entering and leaving the upper lock approach with all riverflows examined compared with Base Experiments. Downbound tows could drive through the crossing upstream of the lock, start reducing speed about one tow length upstream of the upper end of the guard wall, enter the lock approach at a slow speed, and align with the guard wall. As the tow entered the lock approach, the flow through the ports in the guard wall assisted the tow in aligning with and approaching the wall by moving the tow toward the wall. There was no indication of excessive flow through the ports. It should be noted that the short length of channel upstream of the lock provided marginally acceptable navigation conditions for downbound tows because the margin for pilot error or misaligned tows was small. A downbound tow was still turning to enter the upper approach less than one tow length upstream of the guard wall (Photo 19), and any error in alignment or judgment could have resulted in the tow either striking the end of the guard wall or being rotated around the upstream end of the guard wall. An upbound tow leaving the lock could move away from the guard wall, start turning riverward as the towboat cleared the upstream end of the guard wall, and navigate upstream through the reach without any major difficulties (Photo 20).

Tows could enter and leave the lower lock approach without any major difficulties. Downbound tows leaving the lock would maneuver in the same manner as with existing conditions. The tow would be required to rotate the head of the tow away from the guide wall prior to leaving the approach and then push toward midchannel to clear the right bank downstream of the lock. Upbound tows would follow the same path approaching the new lock as they follow when approaching the existing lock except they would land on the guide wall farther downstream.

Recommendations for future experiments

If this location is selected as the recommended location, additional experiments should be conducted to improve navigation conditions at the site. Realignment of the navigation channel upstream of the lock to allow the tow to align with the lock a minimum of two tow lengths upstream of the guard wall and excavation of the right bank downstream of the lock to allow more clearance for tows entering and leaving the lower lock approach should be investigated.

Lock Location 2, Plan A-1

Description

Plan A-1 was the same as Plan A except that a 60-ft section of the solid cap and one 30-ft-diam cell were removed from the upstream guard wall at the lock and replaced with a movable gate to pass ice and debris entering the upper lock approach. The second cell upstream from the lock was removed, and a 60-ft-wide gate was centered in the opening. The bottom of the gate could be raised above the water surface to pass ice and debris. Experiments were conducted using irregularly shaped pieces of paraffin that were of sufficient weight/density that they floated with approximately 80 percent of the thickness beneath the water surface to determine the movement of broken ice drifting toward and into the lock approach. The pieces were 5 ft thick and of random sizes and shapes with the longest dimension varying 5 to 15 ft. The pieces were introduced in the model starting at a point adjacent to the L-head dike and then at 50-ft intervals out to 500 ft riverward of the dike. At each location, 10 pieces were placed in the model and tracked to determine the number of pieces entering the lock approach and the number of pieces passing through the ice pass opening. The experiments were conducted with the 65,000-, 138,000-, and 327,000-cfs riverflows.

Results

The model experiments were conducted using the same operating procedures and flow conditions as those used for Base Experiments. The opening in the ported guard wall would be designed as an operational gate that could be regulated to pass ice when navigation is not using the lock. A rubbing surface would be provided to allow tows to slide along the wall without impacting a corner of the opening.

Water-surface elevations. There were no significant differences in water-surface elevations obtained with Plan A-1 compared with Plan A.

Current directions and velocities. There were only local changes in the current pattern in the vicinity of the opening in the guard wall compared with Plan A. The flow through the opening in the guard wall moved ice and debris through the opening into the main channel. However, its influence on the overall current pattern was minimal.

Navigation conditions. Navigation conditions were the same as with Plan A. The opening in the guard wall did not adversely affect tows entering and leaving the upper lock approach.

Ice passage. The ice passage opening in the guard wall provided good transport for ice or debris entering the upper lock approach. With the 65,000- and 138,000-cfs riverflows, 80-100 percent of the pieces dropped landward of a point 300 ft riverward of the L-head dike entered the lock approach with all of the pieces being pulled through the ice pass opening and into the dam. Ten to fifty percent of the pieces dropped riverward of that point entered the lock approach with all of the pieces being pulled through the ice pass opening. With the 327,000-cfs riverflow, pieces dropped within 100 ft of the L-head dike were pulled into or behind the dike and became lodged in the area. When the pieces were dropped between 100 and 300 ft riverward of the dike, 80-100 percent of the pieces entered the lock approach with all of the pieces passing through the ice pass gate. Riverward of that point less than 40 percent of the pieces entered the lock approach with all of the pieces passing through the ice pass gate.

Lock Location 3, Plan A

Description

Lock Location 3, Plan A, involved replacing the existing auxiliary lock with a new lock chamber with clear dimensions of 110 by 1,200 ft (Photos 21 and 22). The upstream miter gate of the auxiliary lock would serve as the upstream miter gate of the new lock.

The principal features, shown in Figures 8 and 9, were as follows:

a. Addition of a 110- by 1,200-ft lock chamber incorporating the auxiliary lock adjacent to the existing lock.

b. Replacement of the existing ported guard wall with a new 1,279.25-ft-long ported guard wall with twenty-four 30-ft-diam cells spaced 50 ft on centers and a 50-ft guard cell at the upper end of the wall. This provided twenty-three 20-ft-wide port openings and one 40-ft-wide port opening with the top of ports at el 418.7 (15 ft below normal pool of 433.7 or 11 ft below the maximum drawdown pool of 429.7). The effective length of the guard wall measured from the upstream end of the center wall to the upstream end of the guard wall was 1,200 ft and would provide protection for the design size tow.

c. A 1,200-ft-long solid lower guard wall extending downstream from the riverside lock wall.

d. A 600-ft-long extension to the downstream end of the landside guide wall of the 600-ft lock. This provided 415.5 ft of usable length of guide wall (measured from the downstream end of the center lock wall to the downstream end of the guide wall extension) for tows using the existing 600-ft lock.

Results

The model experiments were conducted using the same operating procedures and flow conditions as those used for Base Experiments.

Water-surface elevations. Water-surface elevations shown in Table 4 indicate that the average slope of the water surface through the reach was generally the same as those of the Base Experiments. The lower pool tended to have a slightly steeper slope from the dam to near the downstream end of the lower guide wall, then a slightly flatter slope to the end of the model than the Base Experiment.

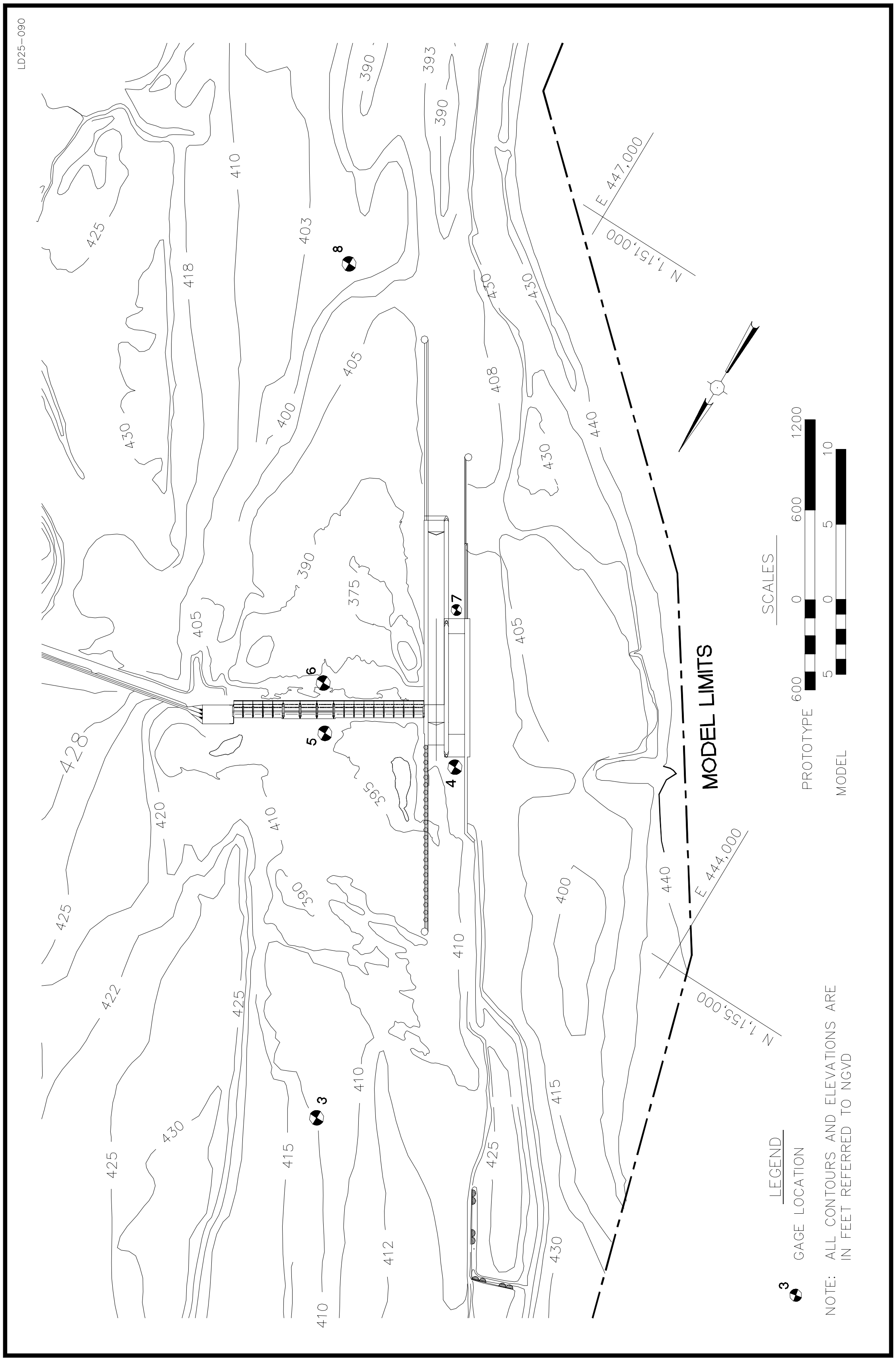


Figure 8. Lock Location 3, Plan A

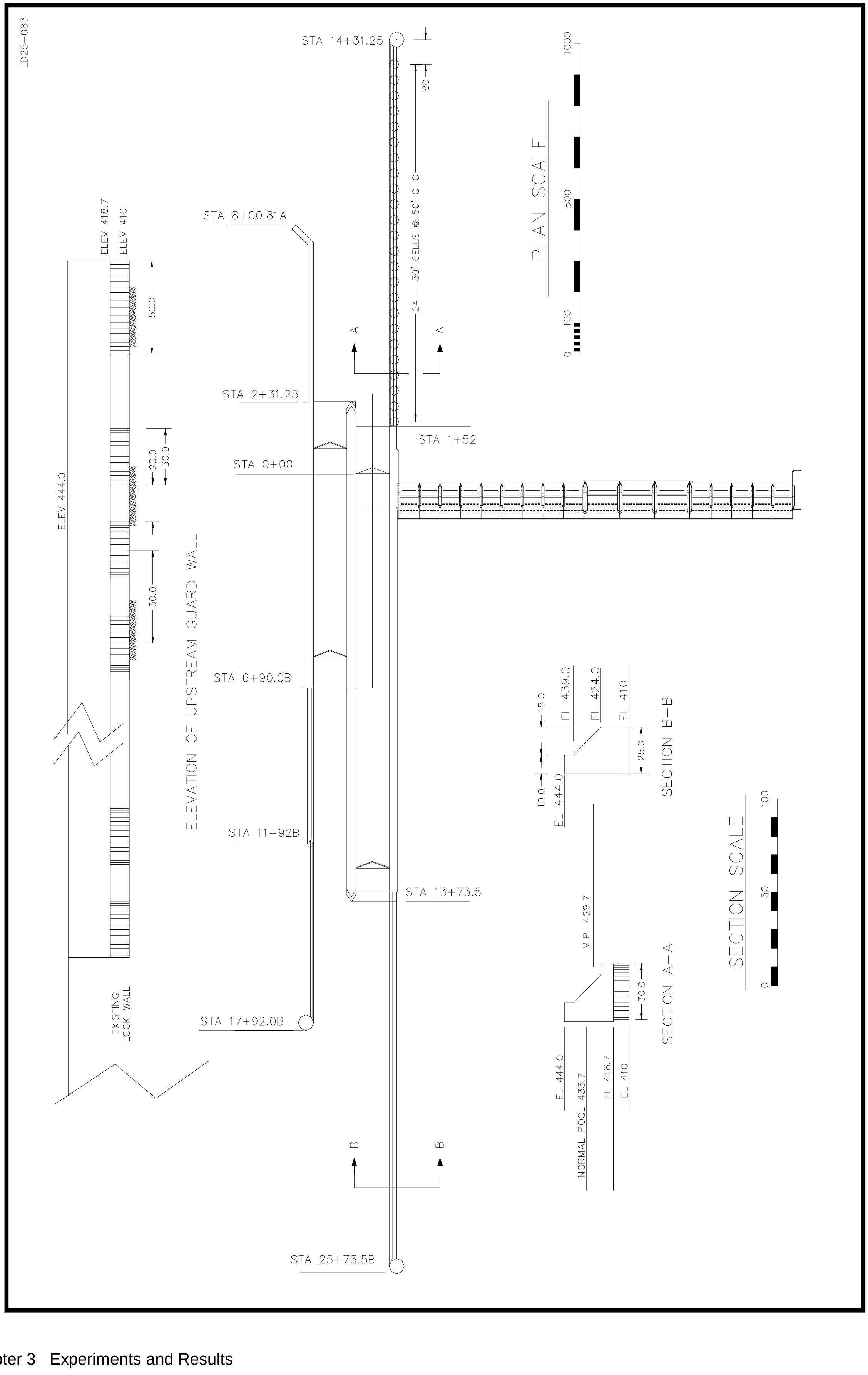


Figure 9. General plan and sections, Lock Location 3, Plan A

Current directions and velocities. Current direction and velocity data shown in Plates 25-32 indicate that the currents upstream of the dam generally moved toward the right descending bank with some of the flow moving into the area immediately downstream of the L-head dike, and then moved around the upstream end of the longitudinal stone dike running along the right bank. Currents moving around the upstream end of the longitudinal dike moved across the upper lock approach, with some of the flow moving around the upper end of the guard wall. Currents downstream of the dam tended to move parallel to the lock to the lower end of the solid guard wall then turn toward the right descending bank. For most flow conditions, a clockwise eddy formed near the downstream end of the lower guard wall. The maximum velocity in the navigation channel upstream of the lock varied from about 0.9 to 3.9 fps 3,600 ft upstream of the dam and 400 ft out from the L-head dike and 1.0 to 3.8 fps about 250 ft upstream of the upstream end of the guard wall with flows of 65,000 and 138,000 cfs, respectively. The maximum velocity in the navigation channel downstream of the lock varied from about 3.3 to 6.6 fps opposite of the downstream end of the lower guard wall with the 65,000- and 327,000-cfs riverflows, respectively, and from about 3.9 to 6.7 fps about 3,500 ft downstream of the axis of the dam for riverflows of 65,000 and 303,000 cfs, respectively.

Navigation conditions. Navigation conditions were improved for tows entering and leaving the upper lock approach with all riverflows evaluated compared with Base Experiments. Downbound tows could drive through the crossing upstream of the lock, start reducing speed, align with the upper guard wall about one tow length upstream of the upper end of the wall, and enter the lock approach at a slow speed. As the tow entered the lock approach, the flow through the ports of the guard wall assisted the tow by moving it slowly toward the wall. There was no indication of excessive flow through the ports. It should be noted that the short length of straight channel upstream of the lock provided marginally acceptable navigation conditions for downbound tows because the margin for pilot error or misaligned tows was small. A downbound tow would still be turning to align with the guard wall about one tow length upstream of the wall (Photo 23), and any error in alignment or judgment could result in the tow being moved either riverward of the guard wall or into the right bank as it entered the lock approach. An upbound tow leaving the lock (Photo 24) could move away from the guard wall without any difficulty, start turning riverward as the towboat cleared the upstream end of the guard wall, and navigate upstream through the reach without any major difficulties.

The clearance for tows entering and leaving the lower lock approach was reduced considerably due to the riverside guard wall of the new lock. Downbound tows could move away from the guard wall, turn around the downstream end of the guard wall, and move into the river channel with all riverflows. However, the clearance between the tow and the right bank was marginal especially with the lower riverflows (Photo 25). These model experiments did not account for high wind conditions, which could make the turning maneuver more difficult for a downbound tow. Considerable maneuvering was required for an upbound tow entering the lower lock approach (Photo 26). An upbound tow was required to make a turn from the river channel, move around the downstream end of the guard wall, and turn to align with the guard wall and lock chamber. During this maneuver, the clearance between the stern of the towboat and the right bank was marginal.

Downbound tows could use the existing 600-ft chamber if the 1,200-ft lock was out of operation. However, considerable maneuvering or some type of assistance may be required for the tow to align with and enter the 600-ft lock chamber. Upbound tows could use the 600-ft chamber similar to existing conditions except additional maneuvering would be required for upbound tows approaching the lock due to the limited channel width near the downstream end of the new guard wall.

Recommendations for future experiments

If this location is selected as the recommended location, additional experiments should be conducted to improve navigation conditions at the site:

a. Realignment of the navigation channel upstream of the lock to allow the tow to align with the lock a minimum of two tow lengths upstream of the guard wall.

b. Excavation of the right bank downstream of the lock to allow a wider channel between the downstream end of the guard wall and the right bank.

c. Removing several hundred feet of the downstream guard wall possibly acceptable in lieu of bank excavation.

Lock Location 4, Plan A

Description

Lock Location 4, Plan A, involved adding a new lock riverward of the existing auxiliary lock. Connecting walls were constructed to connect the upstream end of the new lock to the downstream end of the auxiliary lock and the riverward dam pier. A 60-ft-wide tainter gate with a design similar to that of the existing dam was installed in the chamber of the auxiliary lock with the gate located 100 ft upstream of the pintle of the auxiliary lock.

The principal features of this plan were as follows (Figures 10 and 11 and Photo 27):

a. A 110- by 1,200-ft lock riverward of the auxiliary lock. The upper gate pintle of the new lock was located at sta 3+28B. This placed the major components of the new lock downstream of the dam.

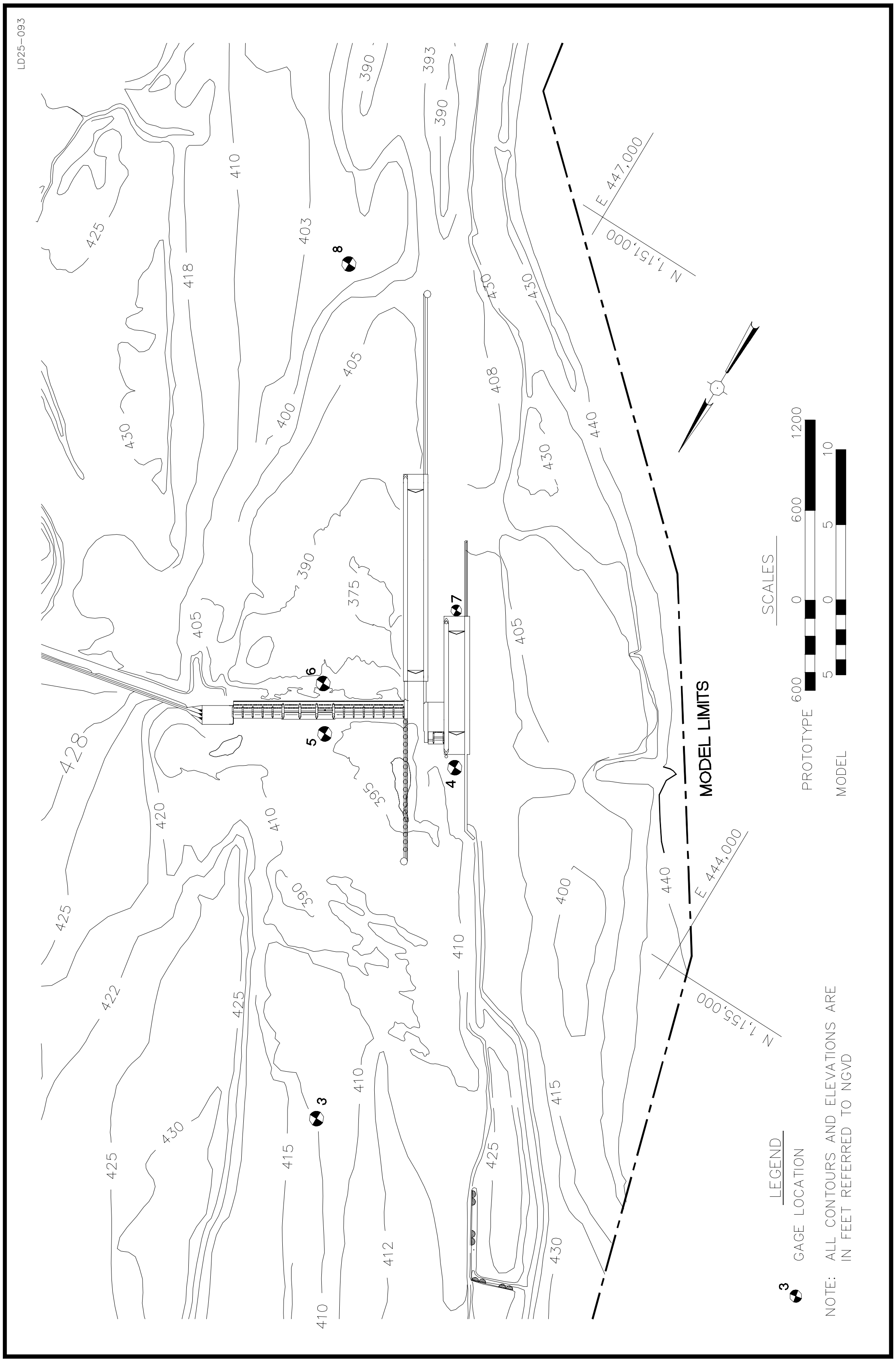


Figure 10. Lock Location 4, Plan A

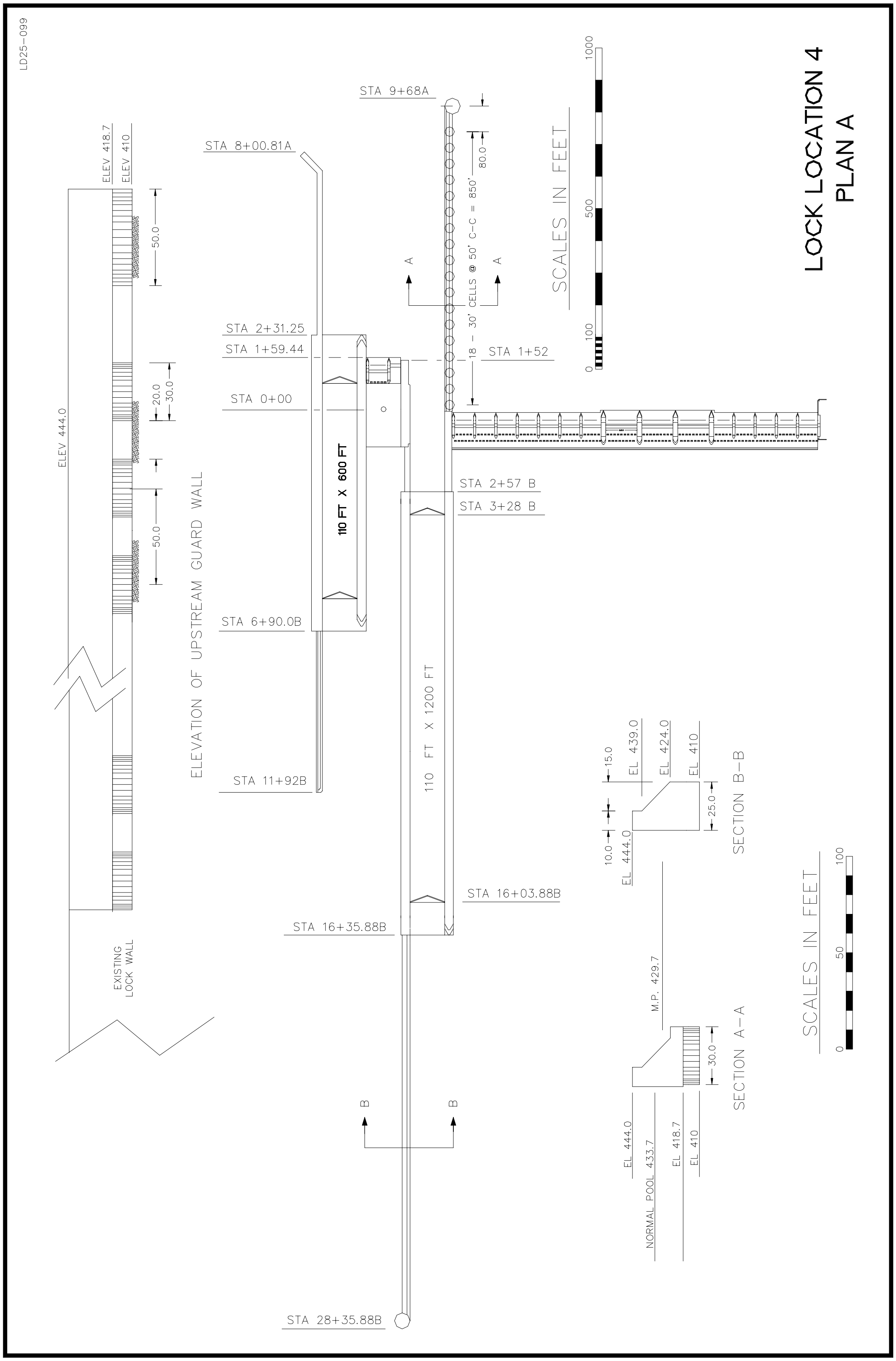


Figure 11. General plan and sections, Lock Location 4, Plan A

b. A 1,225-ft-long ported guard wall with eighteen 30-ft-diam cells spaced 50 ft on centers and 50-ft-diam guard cell at the upstream end of the wall. This provides seventeen 20-ft-wide port openings and one 40-ft port opening with the top of ports at el 418.7 (15 ft below normal pool 433.7 or 11 ft below the maximum drawdown pool of 429.7). The effective length of the guard wall measured from the upstream end of the riverside wall of the auxiliary lock to the upper end of the guard wall was 816 ft.

c. Removal of the existing guard wall, which extends upstream from the riverside wall of the auxiliary lock.

d. A 1,200-ft-long solid lower guide wall extending downstream from the landside lock wall.

e. Removal of the two dam piers and gates adjacent to the auxiliary lock to construct the new lock.

f. Construction of a 60-ft-wide tainter gate with the same design as the existing dam gates in the auxiliary lock chamber for passage of ice or flow during high riverflows.

Results

The model experiments were conducted using the same operating procedures and flow conditions as those used for Base Experiments. The new 60-ft-wide tainter gate between the locks was operated with a gate opening equal to the openings of the gates in the main part of the dam.

Water-surface elevations. Water-surface elevations shown in Table 5 indicated the water-surface elevations were generally the same as with the Base Experiment (Table 1). During the higher discharge flows (240,000, 303,000, and 327,000 cfs), there was a slight rise (0.1 to 0.4 ft) at some of the gauges.

Current directions and velocities. Current direction and velocity data shown in Plates 33-40 indicate the currents generally moved toward the right descending bank until reaching the L-head dike about 3,500 ft upstream of the axis of the dam, then turned parallel to the right bank levee to enter the lock approach. Currents downstream of the dam were generally parallel with the lock from the dam to the downstream end of the lock then moved across the lower lock approach toward the right bank. The maximum velocity in the navigation channel upstream of the lock varied from 1.8 to 4.7 fps about 6,000 ft upstream of the axis of the dam and from 1.3 to 4.6 fps near the end of the upper guard wall about 1,500 ft upstream of the axis of the dam with the 65,000- and 138,000-cfs flows, respectively. The velocities approaching the center tainter gate ranged from 0.8 to 2.4 fps with the 65,000- and 138,000-cfs flows, respectively. The maximum velocities in the navigation channel downstream of the dam varied from 3.1 to 5.0 fps near the downstream end of the lower guide wall with the 65,000- and 303,000-cfs flows, respectively, and 2.5 to 6.5 fps about 4,200 ft downstream of the axis of the dam with the 65,000- and 327,000-cfs flows, respectively.

Navigation conditions. Navigation conditions were improved for tows entering the upper lock approach with all riverflows examined compared with Base Experiments. Downbound tows could drive through the crossing, drive toward the right bank L-head dike, and turn to align with the upper guard wall (Photo 28). However, the tow was still maneuvering to align with the guard wall one to one and one-half tow lengths upstream of the guard wall. With the lower riverflows, there was very little flow through the ported guard wall. Therefore, some maneuvering was required for the tow to align with the guard wall and enter the lock chamber. As the flow increased to 138,000 cfs and the upper pool was drawn down 4.0 ft, the flow through the guard wall increased and the tow was pulled toward the wall with considerable force. To control the movement of the head of the tow toward the wall, the tow should enter the approach 100 to 200 ft landward of the guard wall (Photo 29). Tows entering the approach within about 100 ft of the guard wall were moved into the guard wall with considerable force and rotated around the upstream end of the guard wall. As the riverflow increased to 327,000 cfs (maximum navigable flow), the flow through the guard wall decreased. Tows entering the lock approach 100 ft landward of the guard wall could require considerable maneuvering to land on the guard wall. There was a tendency for the head of the tow to be pulled toward the center gate by the flow moving through the gate (Photo 30).

Upbound tows could break free of the guard wall and move upstream without any major difficulties. However, about 200 ft of the tow extended upstream of the guard wall and was exposed to currents without any protection. With the 138,000-cfs riverflow, there was a tendency for the tow to be held against the guard wall by the current moving around the upstream end of the guard wall (Photo 31).

Tows could enter and leave the existing lock with all flow conditions. A downbound tow could enter the approach, maneuver the head of the tow into the landside guide wall, and enter the lock chamber without the assistance of a helper towboat. A line to the guide wall may be required for the tow to align with the wall prior to pushing into the lock chamber.

Tows could enter and leave the lower approaches of both the existing 600-ft and new 1,200-ft locks without any major difficulties with all riverflows (Photos 32-34). However, the clearance for tows entering and leaving the 600-ft lock was marginal (Photos 33 and 35).

Recommendations for future experiments

If this location is selected as the recommended location, additional experiments should be conducted to improve navigation conditions at the site:

a. Realignment of the navigation channel upstream of the lock to allow the tow to align with the lock a minimum of two tow lengths upstream of the guard wall.

b. Extension of the upper guard wall to provide 1,200 ft of useable length.

c. Modification of the upper guard wall ports or realignment of the currents entering the lock approach to improve the flow pattern approaching the guard wall. The currents should allow tows to approach the guard wall along the same path for all riverflows.

d. Excavation of the right bank downstream of the locks to allow more clearance for tows entering and leaving the existing lock.

e. Construction of a guard cell upstream of the center gate to prevent the head of a tow from being pulled into the gate bay.

f. Development of a gate operating schedule for the center gate to reduce the flow through the gate and improve flow through the guard wall with some riverflows.

Approach Time Experiments

The approach times for downbound tows were recorded both for existing conditions and all lock locations using a video tracking system. The time reported in Table 6 is the time required for a tow to navigate the reach from a point 7,320 ft upstream of the axis of the dam to a point where the tow is aligned to enter the lock chamber. The time reported for existing conditions is a combination of field data and model data. The field of view of the field camera did not provide a good view or means for measuring the location of the tow at the extreme upstream location. Therefore, model data were used to measure the time required for a tow to move from sta 73+20 to the upstream end of the right bank stone dike at sta 18+00. The field data provided better measurements of the time required for a tow to move from the upstream end of the dike into the lock chamber due to the maneuvering required and the need for a helper towboat. The two times were then combined to provide an overall time for a tow to approach the lock. The model tow was operated at about 2 miles an hour above the speed of the currents to maintain steerage except when the tow was entering the lock approach. As the tow approached the lock, it reduced speed to enter the lock approach at a slow speed.

These experiments were conducted to assist in economic analysis of alternative locations. The approach time measurements are relative to the alternative locations and plans and are not to be construed as absolute values.

All of the lock locations evaluated improved (reduced) the transit time compared with existing conditions. Most of the improvement in the transit times can be attributed to the new lock at all locations having a ported upper guard wall, and in some cases, an improved channel alignment approaching the lock. Lock Locations 2 and 4 showed the most improvement based on transit time. This can be attributed to downbound tows entering the lock approach without maneuvering to reduce speed or align with the guard wall. With Locations 1 and 3, the tow was required to reduce speed and maneuver to align with the guard wall. With all locations except Location 1, the transit time decreased as the riverflow increased due to the tow being able to drive about 2 mph faster than the currents until it entered the lock forebay. When the lock was at Location 1, as the riverflow increased, the tow was required to reduce speed farther upstream to navigate the bend in the navigation channel; and the transit time increased compared with the lower riverflows.

It should be noted that using the approach times as the only criterion for selection of a location is not advisable.

4 Discussion of Results and Conclusions

Limitations of Model Results

Analysis of the results of this investigation is based on a study of the effects of various plans and modifications on water-surface elevations and current directions and velocities, and the effects of the resulting currents on the behavior of the model towboat and tow. In evaluating experiment results, it should be considered that small changes in current directions and velocities are not necessarily changes produced by a modification in the plan since several floats introduced at the same point may follow a different path and move at somewhat different velocities because of pulsating currents and eddies. Current directions and velocities shown in the plates were obtained with floats submerged to a depth of a loaded barge (9-ft prototype) and are indicative of the currents that would affect the behavior of tows.

The small scale of the model made it difficult to reproduce accurately the hydraulic characteristics of the prototype structures or to measure water-surface elevation within an accuracy greater than about ±0.1 ft prototype. Also, current directions and velocities were based on steady flows and would be somewhat different with varying flows. The model was of the fixed-bed type and was not designed to reproduce overall sediment movement that might occur in the prototype with the various plans; therefore, changes in channel configuration resulting from scouring and deposition and any resulting changes in current directions and velocities were not evaluated.

Recommendations for improving navigation conditions with the various plans are presented for planning purposes and should not be used for final design of the project without additional model experiments to verify navigation conditions with the proposed modification.

Summary of Results and Conclusions

The following results and conclusions were developed during the investigation:

g. With all locations evaluated, realigning the navigation channel upstream of the lock would improve navigation conditions. The navigation channel upstream of the lock should provide sufficient straight channel approaching the lock to allow a downbound tow to align with the guard wall a minimum of two tow lengths upstream of the upper end of the guard wall.

h. A design that features a ported upper guard wall would eliminate the need for a helper towboat if an acceptable navigation channel is provided approaching the lock. The effective length of the guard wall should be long enough to provide protection for the full length of the design size tow.

c. Model data indicate satisfactory navigation conditions can be established for tows entering and leaving the new lock with all lock locations evaluated. However, Lock Locations 3 and 4 would require the least amount of modifications to the existing navigation channel or bank lines to provide acceptable navigation conditions, but realignment of the navigation channel would improve navigation conditions at either location.

d. Lock Location 1 requires extensive excavation upstream of the lock to provide an acceptable navigation channel approaching the lock. This location also requires excavation of the right bank immediately downstream of the lock.

e. While the evaluated design for Lock Location 2 provided marginally acceptable navigation conditions for downbound tows approaching the lock, realignment of the navigation channel upstream of the lock and excavation of the right bank downstream of the lock would improve navigation conditions.

f. Lock Location 3 provided marginally acceptable navigation conditions for tows entering and leaving the new lock without any modification to the existing navigation channel. However, realignment of the navigation channel upstream of the lock and excavation of the right bank immediately downstream of the lock would improve navigation conditions for tows entering and leaving the lock.

g. Lock Location 4 provided acceptable navigation conditions for tows entering and leaving the new lock without any modification to the existing navigation channel. However, the ported upper guard wall should be extended about 400 ft to provide protection for the design size tow, and the gate between the locks should be closed when downbound tows are approaching the lock.

h. The ice pass gate installed in the ported guard wall with Lock Location 2, Plan A-1, would pass most of the ice entering the upper lock approach.

Table 1
Water-Surface Elevations, Base Experiment

Gauge	Water-Surface Elevations for Discharge, cfs							
	65,000	125,000	138,000	166,000	200,000	240,000	303,000	327,000
1	433.9	432.0	430.8	432.3	434.4	437.1	440.1	442.5
2	433.8	431.7	430.1	431.8	434.0	436.7	439.9	442.2
3	433.8	431.5	429.7	431.5	433.8	436.5	439.7	442.1
4	433.7[1]	431.5[1]	429.7[1]	431.5[1]	433.7[1]	436.5[1]	439.7[1]	442.0[1]
5	433.7	431.4	429.6	431.4	433.6	436.3	439.5	442.0
6	422.0	425.0	429.4	431.1	433.2	436.1	439.3	441.9
7	422.0[1]	425.0[1]	429.5	431.2	433.3	436.1	439.3	441.9
8	421.9	424.9	429.4	431.1	433.2	436.0	439.2	441.7
9	421.8	424.7	429.3	431.0	433.1	435.8	439.0	441.5
10	421.8	424.6	429.2	430.8	433.0	435.7	438.8	441.4

[1] Controlled elevation.

Table 2
Water-Surface Elevations, Location 1, Plan A

Gauge	Water-Surface Elevations for Discharge, cfs							
	65,000	125,000	138,000	166,000	200,000	240,000	303,000	327,000
1	433.9	432.0	430.3	432.1	434.2	436.9	440.1	442.5
2	433.8	431.7	430.0	431.7	434.0	436.7	439.9	442.2
3	433.8	431.5	429.7	431.4	433.8	436.4	439.7	442.1
4	433.7[1]	431.5[1]	429.7[1]	431.3	433.6	436.3	439.7	442.0
5	433.7	431.4	429.6	431.3	433.6	436.2	439.5	442.0
6	421.9	424.7	429.4	431.1	433.3	435.9	439.3	441.9
7	422.0	425.0	429.5	431.1	433.3	435.8	439.3	441.7
8	421.9	424.9	429.4	431.1	433.3	435.8	439.2	441.6
9	421.8	424.7	429.3	430.9	433.1	435.8	439.0	441.5
10[1]	421.8	424.6	429.2	430.8	433.0	435.7	438.8	441.4

[1] Controlled elevation.

Table 3
Water-Surface Elevations, Location 2, Plan A

Gauge	Water-Surface Elevations for Discharge, cfs							
	65,000	125,000	138,000	166,000	200,000	240,000	303,000	327,000
1	433.9	432.0	430.8	432.3	434.4	437.1	440.1	442.5
2	433.8	431.7	430.1	431.8	434.0	436.7	439.9	442.2
3	433.8	431.5	429.7	431.5	433.8	436.5	439.7	442.1
4	433.7[1]	431.5[1]	429.7[1]	431.5	433.8	436.5	439.7	442.0
5	433.7	431.4	429.6	431.4	433.7	436.3	439.5	442.0
6	422.1	425.0	429.4	431.1	433.4	436.1	439.3	441.9
7	422.1	425.0	429.5	431.2	433.4	436.1	439.3	441.8
8	421.9	424.9	429.4	431.1	433.4	436.0	439.2	441.7
9	421.8	424.7	429.3	431.0	433.3	435.8	439.1	441.5
10[1]	421.8	424.6	429.2	430.8	433.0	435.7	438.8	441.4

[1] Controlled elevation.

Table 4
Water-Surface Elevations, Location 3, Plan A

Gauge	Water-Surface Elevations for Discharge, cfs							
	65,000	125,000	138,000	166,000	200,000	240,000	303,000	327,000
1	433.9	432.1	430.8	432.3	434.4	437.1	440.1	442.5
2	433.8	431.8	430.1	431.8	434.0	436.7	439.8	442.2
3	433.7	431.6	429.8	431.5	433.8	436.5	439.7	442.2
4	433.7[1]	431.5[1]	429.7[1]	431.5	433.7	436.6	439.6	442.2
5	433.7	431.5	429.6	431.2	433.5	436.3	439.4	441.9
6	421.9	425.0	429.4	431.1	433.2	436.1	439.2	441.7
7	421.8	424.8	429.3	431.1	433.1	435.9	438.9	441.5
8	421.8	424.8	429.3	431.1	433.1	436.0	439.0	441.5
9	421.8	424.8	429.3	430.9	433.0	435.9	438.9	441.5
10[1]	421.8	424.6	429.2	430.8	433.0	435.7	438.8	441.4

[1] Controlled elevation.

Table 5
Water-Surface Elevations, Location 4, Plan A

Gauge	Water-Surface Elevations for Discharge, cfs							
	65,000	**125,000**	**138,000**	**166,000**	**200,000**	**240,000**	**303,000**	**327,000**
1	433.9	432.1	430.8	432.5	434.4	437.1	440.4	442.5
2	433.8	431.8	430.1	431.9	433.9	436.8	440.2	442.2
3	433.8	431.6	429.8	431.6	433.8	436.6	440.0	442.1
4	433.7[1]	431.5[1]	429.7[1]	431.6	433.6	436.6	440.0	442.0
5	433.7	431.4	429.6	431.3	433.6	436.4	439.8	442.0
6	421.9	424.7	429.4	431.0	433.2	436.0	439.5	442.0
7	421.8	424.8	429.3	431.0	433.1	436.0	439.2	441.9
8	421.8	424.8	429.3	431.0	433.1	436.0	439.2	441.7
9	421.8	424.7	429.3	430.9	433.0	435.8	438.9	441.5
10[1]	421.8	424.6	429.2	430.8	433.0	435.7	438.8	441.4

[1] Controlled elevation.

Table 6
Downbound Tow Approach Times

Lock Location	Discharge, cfs	Time, min[1]
Existing condition	Low - 65,000 Medium - 138,000 High - 327,000	19.42+27.22 = 46.64 21.14+19.52 = 40.66 24.89+18.99 = 43.88
1	65,000 138,000 327,000	20.11 20.71 25.06
2	65,000 138,000 327,000	20.12 16.10 16.57
3	65,000 138,000 327,000	29.91 24.70 21.34
4	65,000 138,000 327,000	25.59 15.15 17.88

Note: Existing Conditions measurements are a combination of field data and model data. Model data were used from sta 73+20 to upstream end of right bank longitudinal dike at sta 18+00, and field data were used to time maneuvering required for tow to enter lock chamber (including time required for helper tow).
[1] Approach times are measured from sta 73+20 to lock chamber.

Photo 1. A helper towboat pushing a downbound tow into the right bank, looking upstream

Photo 2. A helper towboat pushing the head of a downbound tow into the guide wall, looking upstream

Photo 3. Path of downbound tow leaving existing 600-ft lock, looking downstream

Photo 4. Path of downbound tow entering channel, looking downstream

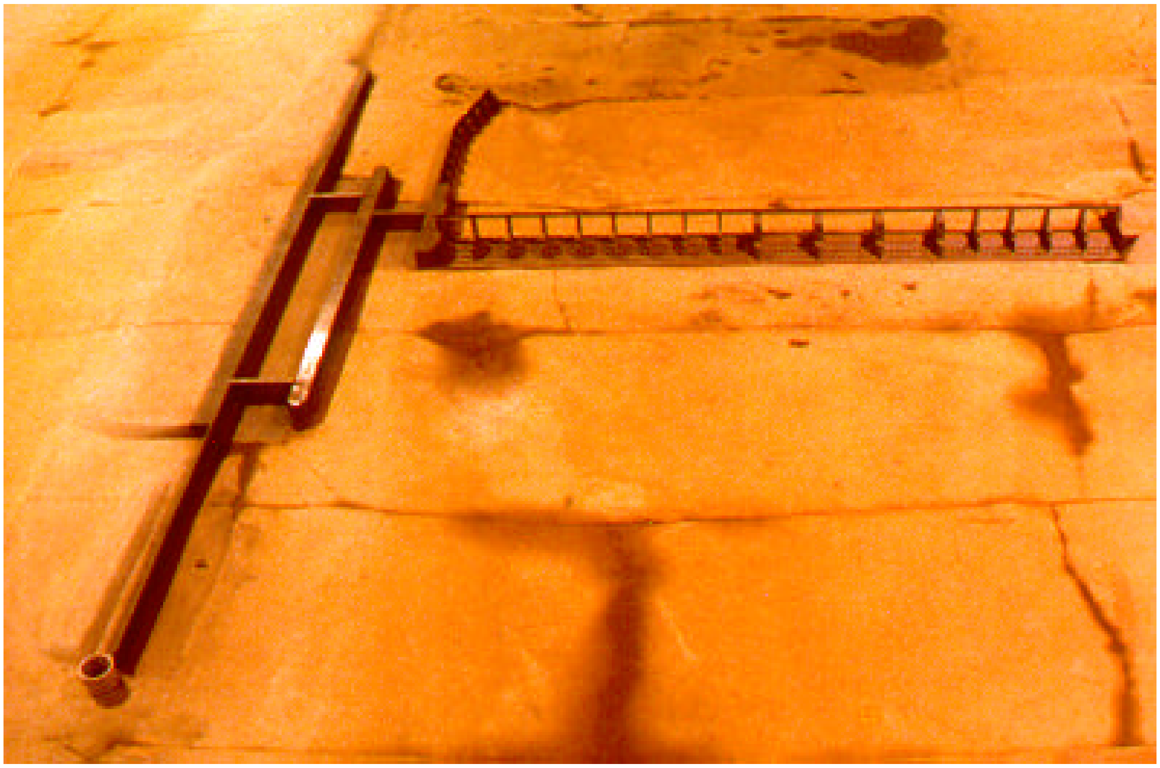


Photo 5. Existing structures looking upstream

Photo 6. Existing conditions, looking upstream, discharge 166,000 cfs. Dye showing current pattern approaching existing lock

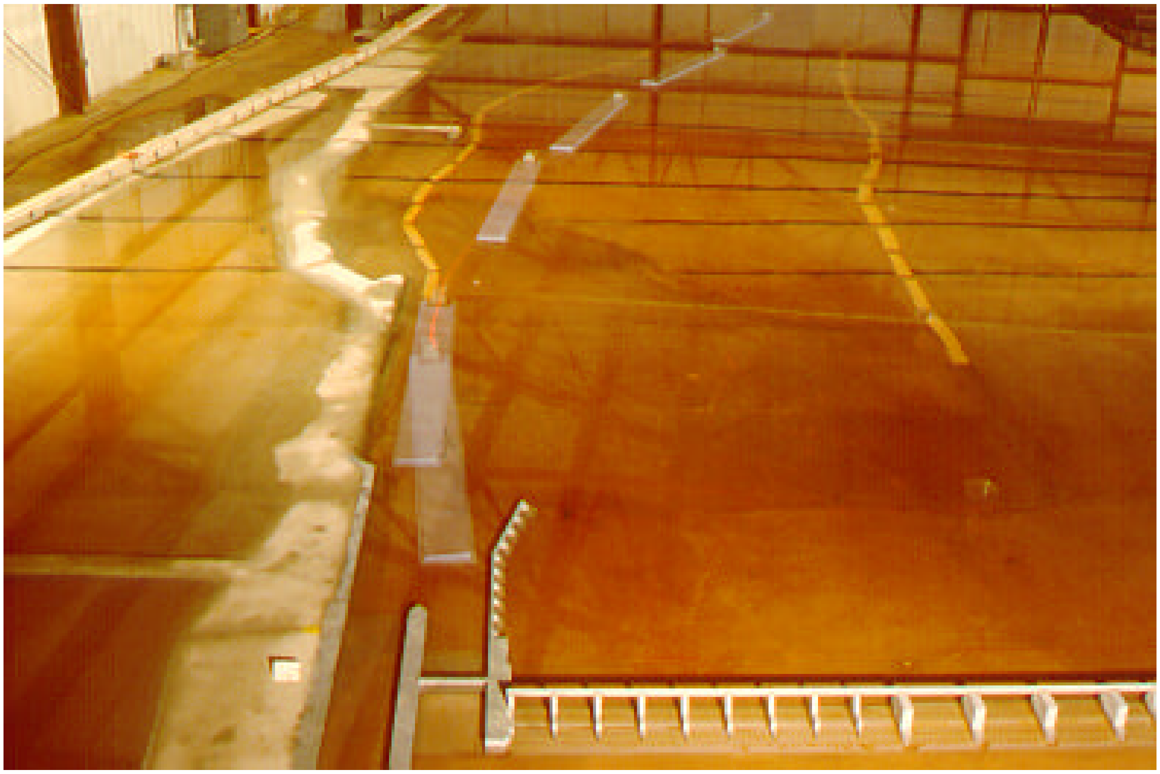


Photo 7. Existing conditions, looking upstream, discharge 166,000 cfs, path of downbound tow approaching existing lock

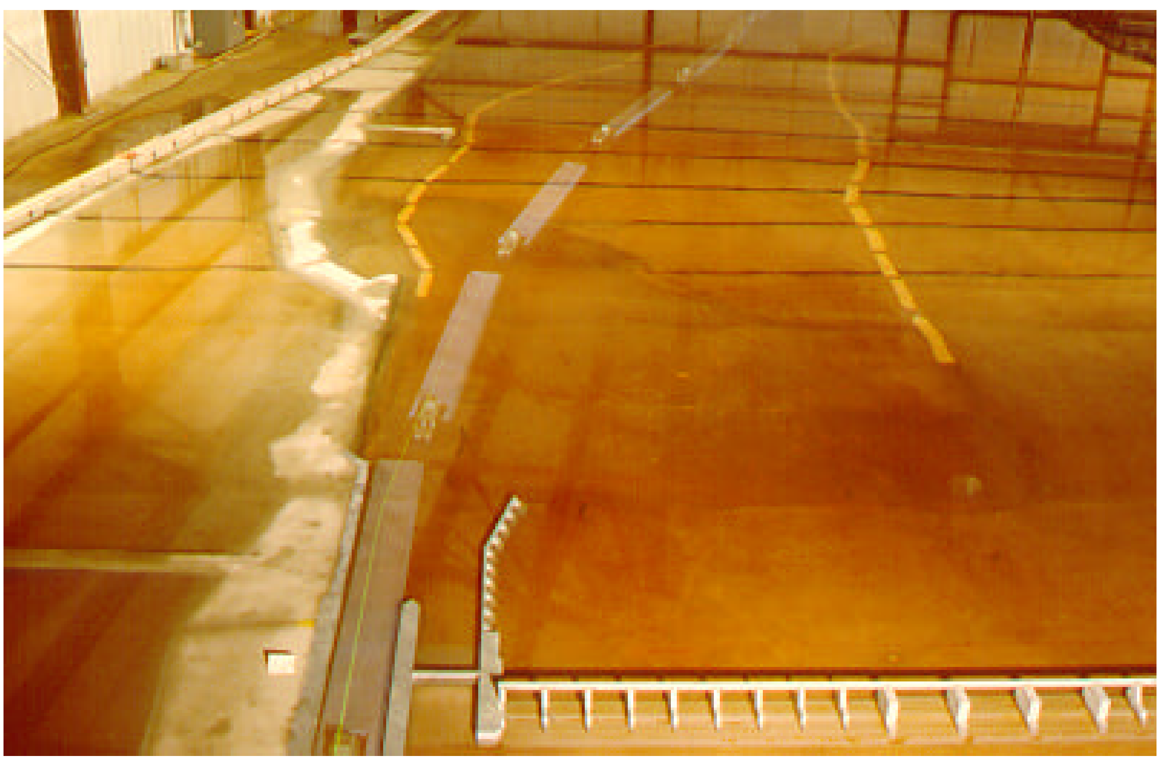


Photo 8. Existing conditions, looking upstream, discharge 166,000 cfs, path of upbound tow leaving existing lock

Photo 9. Existing conditions, looking downstream, discharge 166,000 cfs, path of downbound tow leaving existing lock

Photo 10. Existing conditions, looking downstream, discharge 166,000 cfs, path of upbound tow approaching existing lock

Photo 11. Lock Location 1, Plan A, looking upstream, showing upper lock approach

Photo 12. Lock Location 1, Plan A, looking downstream, showing lower lock approach

Photo 13. Lock Location 1, Plan A, looking upstream, discharge 138,000 cfs, dye showing current pattern approaching lock

Photo 14. Lock Location 1, Plan A, looking upstream, discharge 138,000 cfs, path of down-bound tow approaching 1,200-ft lock

Photo 15. Lock Location 1, Plan A, looking upstream, discharge 138,000 cfs, path of upbound tow leaving 1,200-ft lock

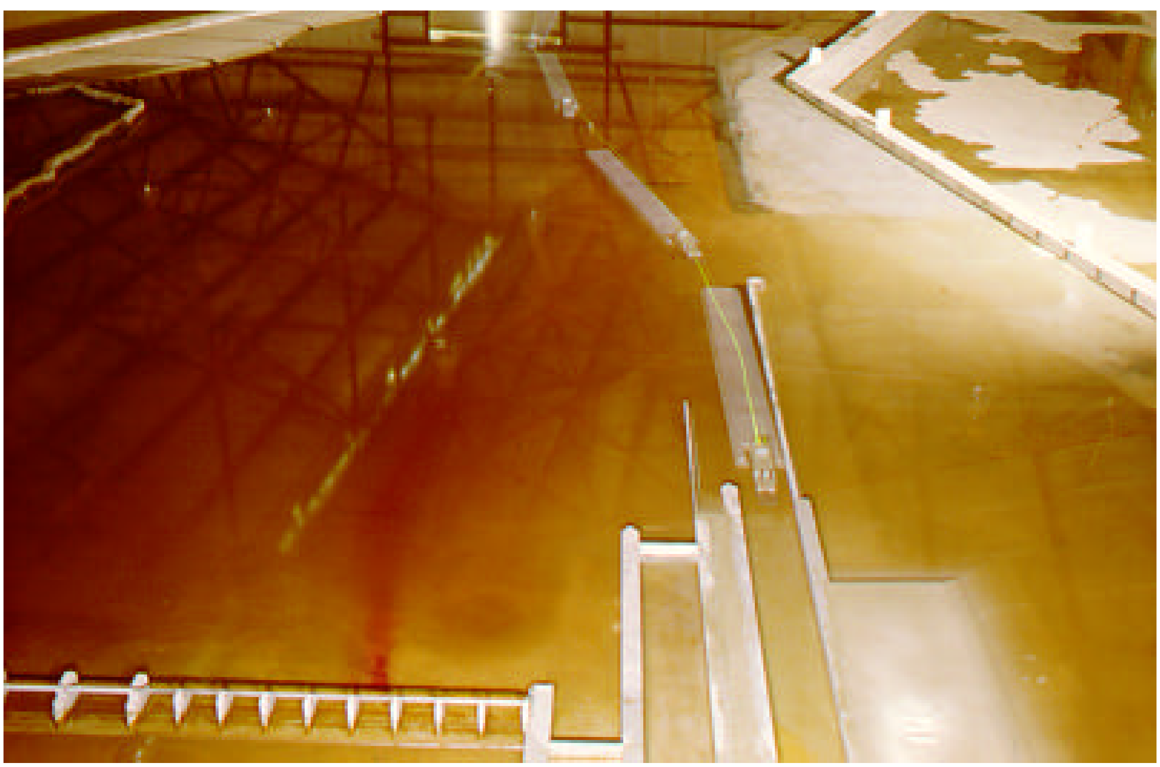


Photo 16. Lock Location 1, Plan A, looking downstream, discharge 138,000 cfs, path of downbound tow leaving 1,200-ft lock

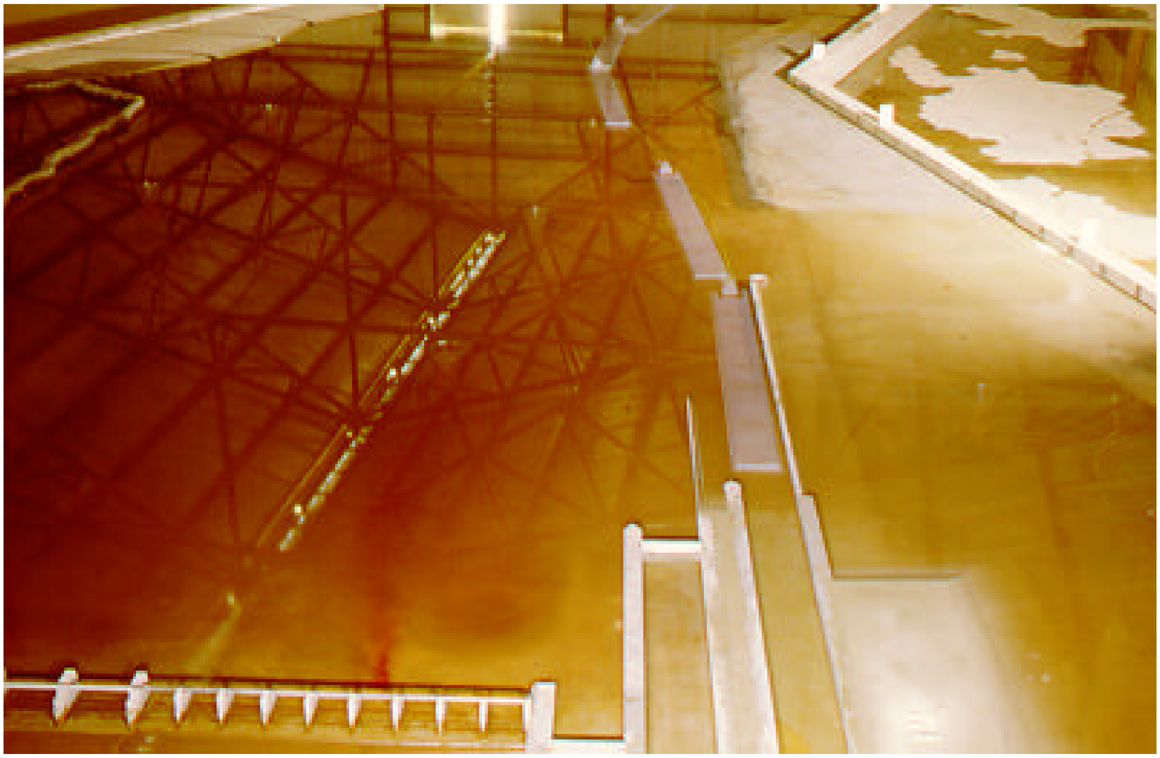


Photo 17. Lock Location 1, Plan A, looking downstream, discharge 138,000 cfs, path of upbound tow approaching 1,200-ft lock

Photo 18. Lock Location 2, Plan A, looking upstream, showing upper lock approach

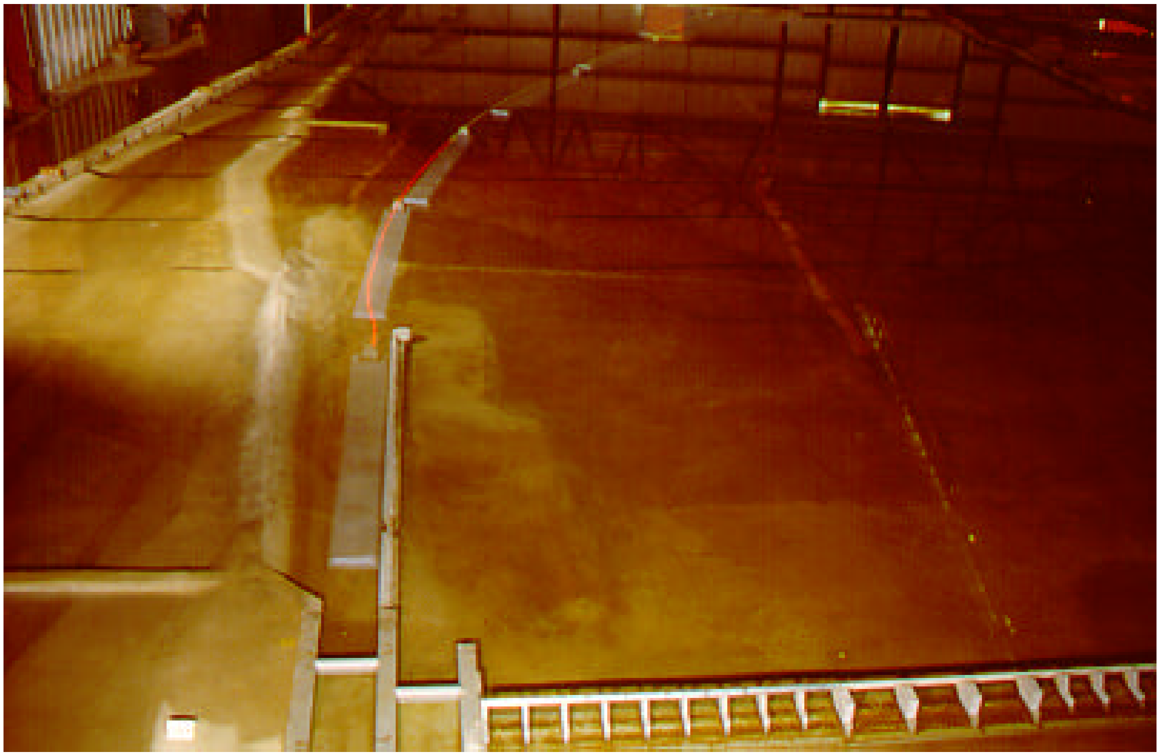


Photo 19. Lock Location 2, Plan A, looking upstream, discharge 138,000 cfs, path of downbound tow approaching 1,200-ft lock

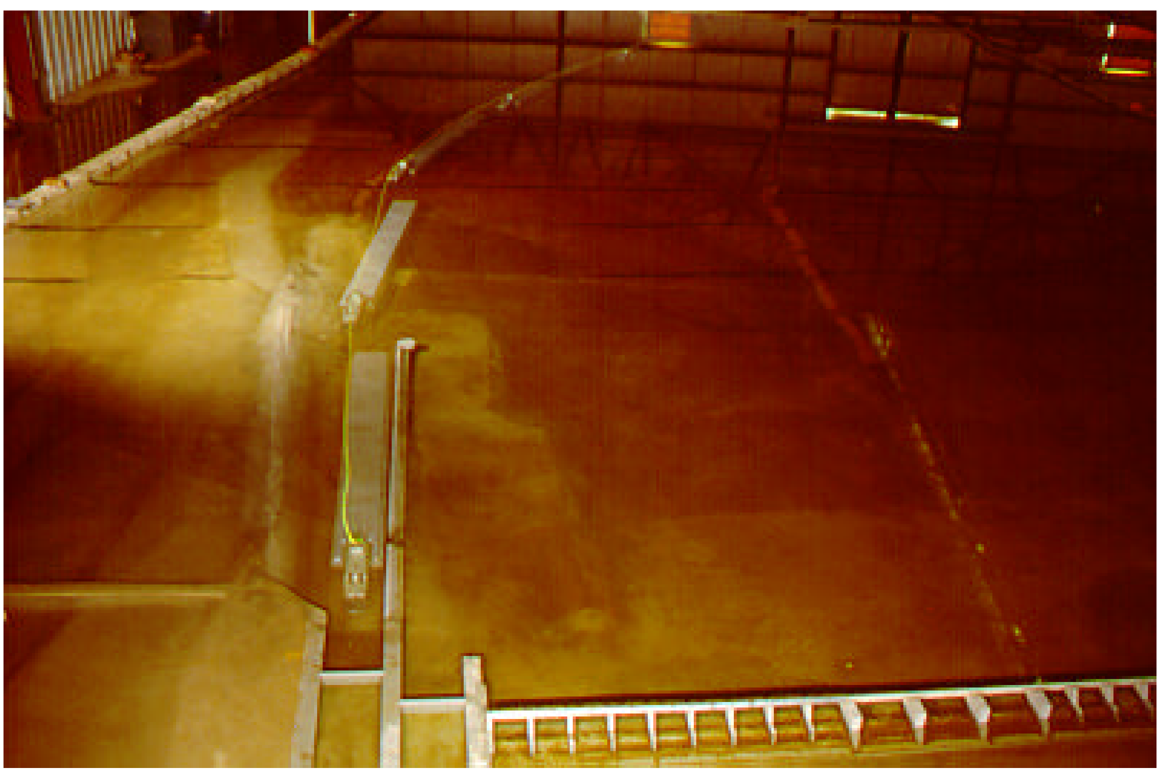


Photo 20. Lock Location 2, Plan A, looking upstream, discharge 327,000 cfs, path of upbound tow leaving 1,200-ft lock

Photo 21. Lock Location 3, Plan A, looking upstream, showing upper lock approach

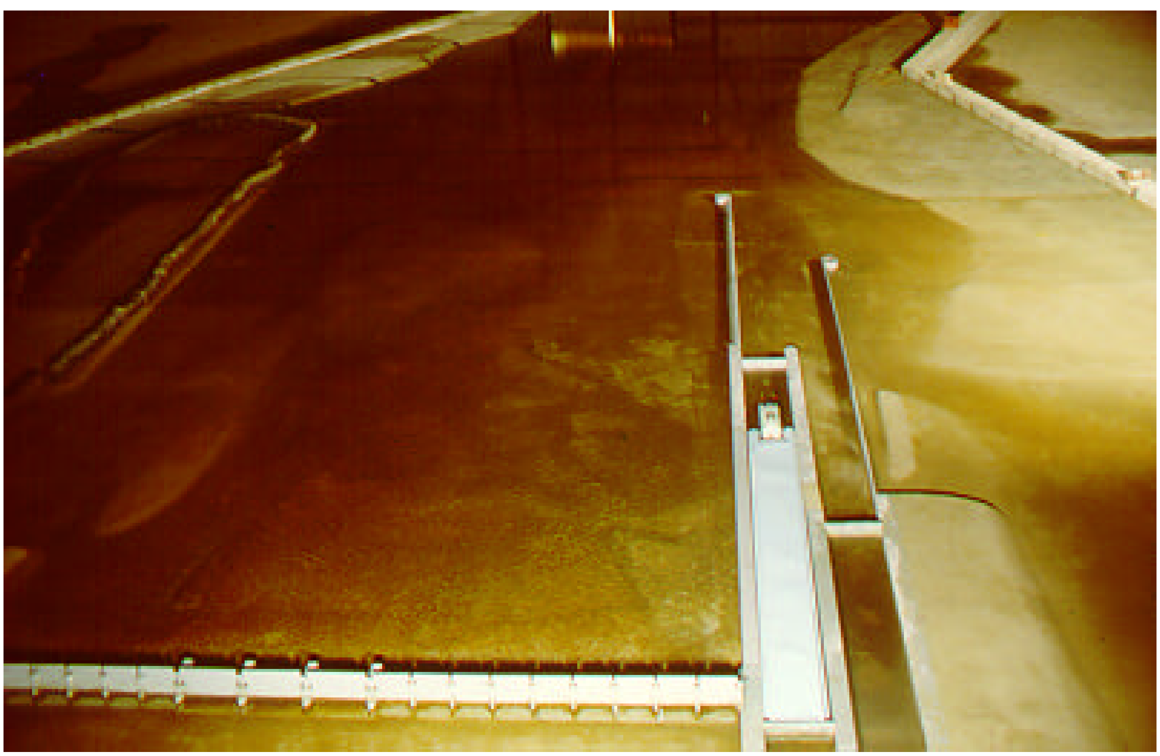


Photo 22. Lock Location 3, Plan A, looking downstream, showing lower lock approach

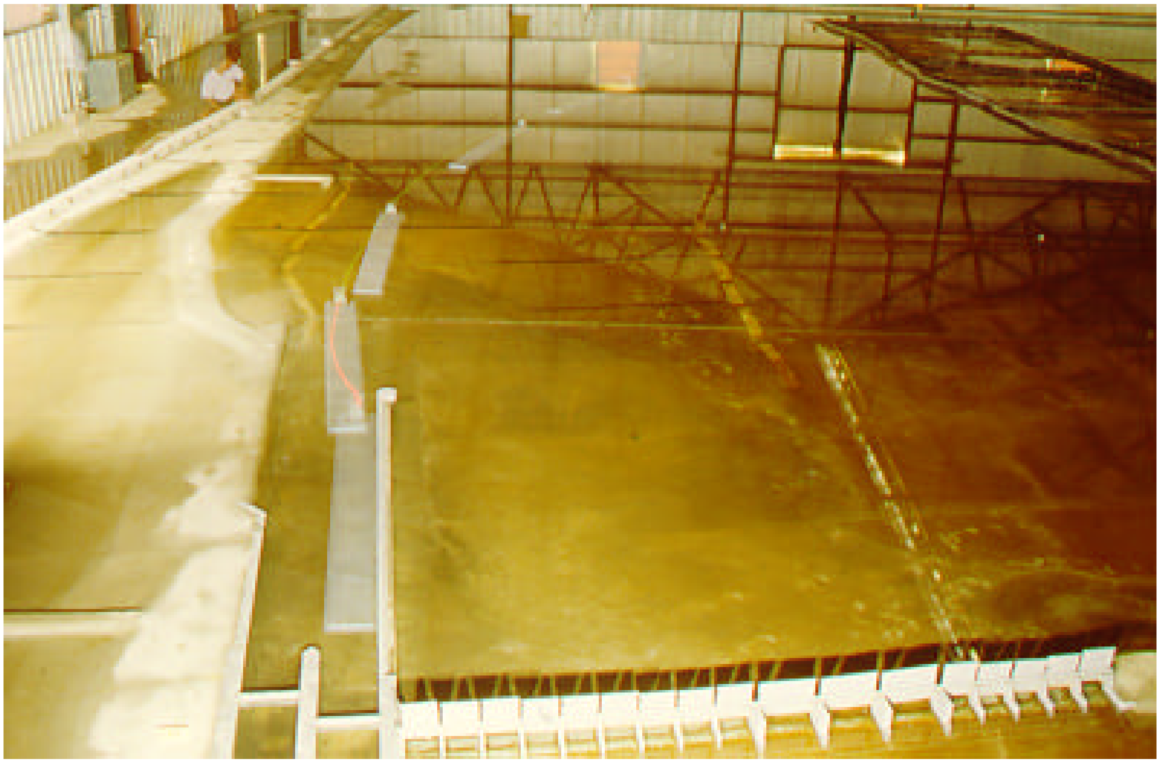


Photo 23. Lock Location 3, Plan A, looking upstream, discharge 138,000 cfs, path of down-bound tow approaching 1,200-ft lock

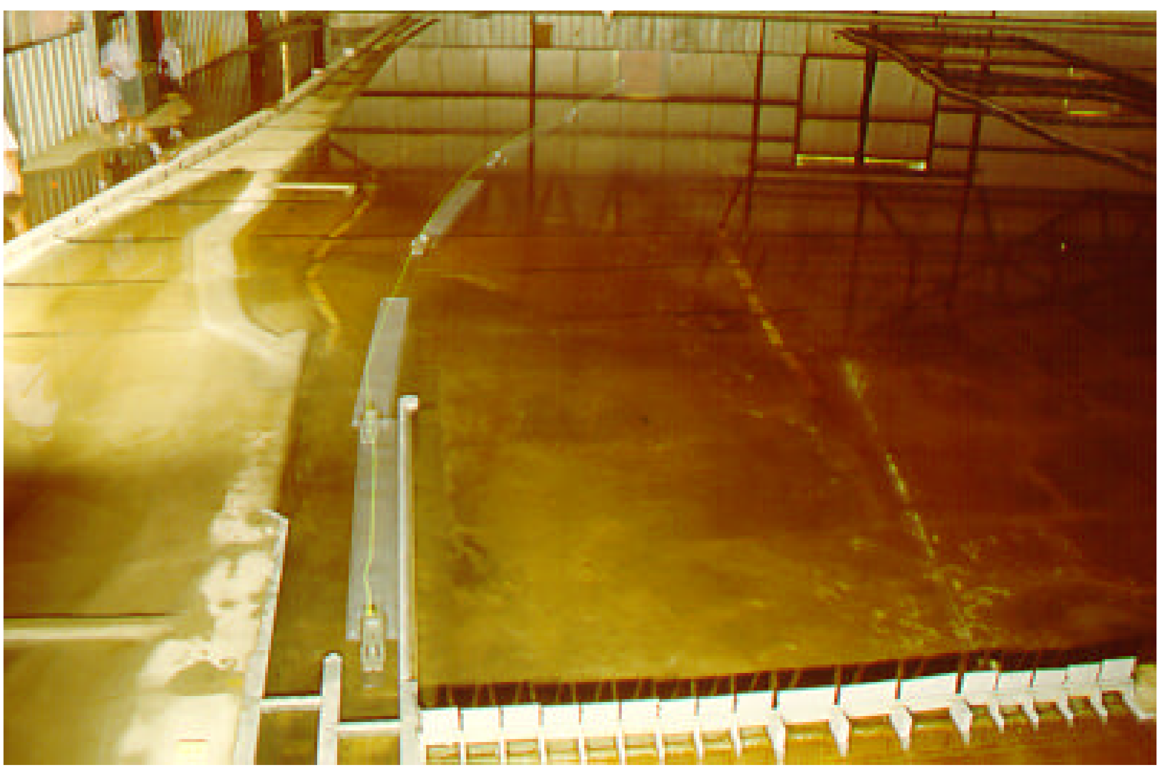


Photo 24. Lock Location 3, Plan A, looking upstream, discharge 138,000 cfs, path of upbound tow leaving 1,200-ft lock

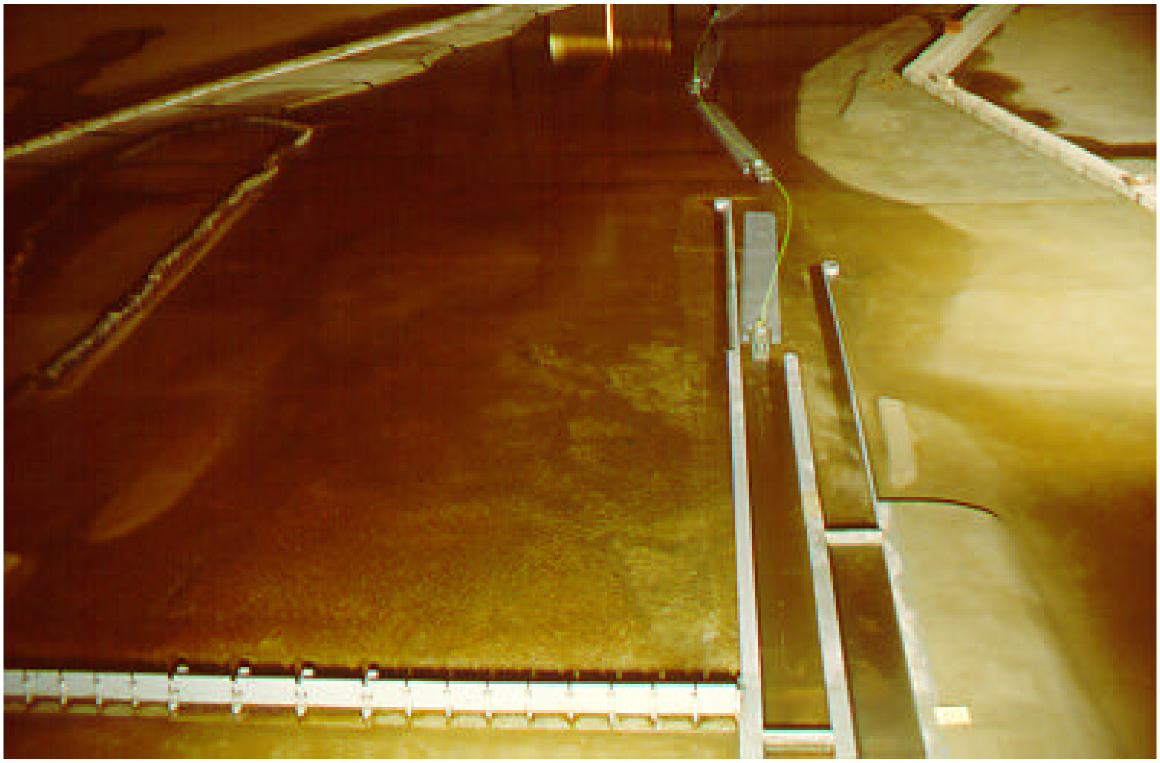


Photo 25. Lock Location 3, Plan A, looking downstream, discharge 65,000 cfs, path of downbound tow leaving 1,200-ft lock

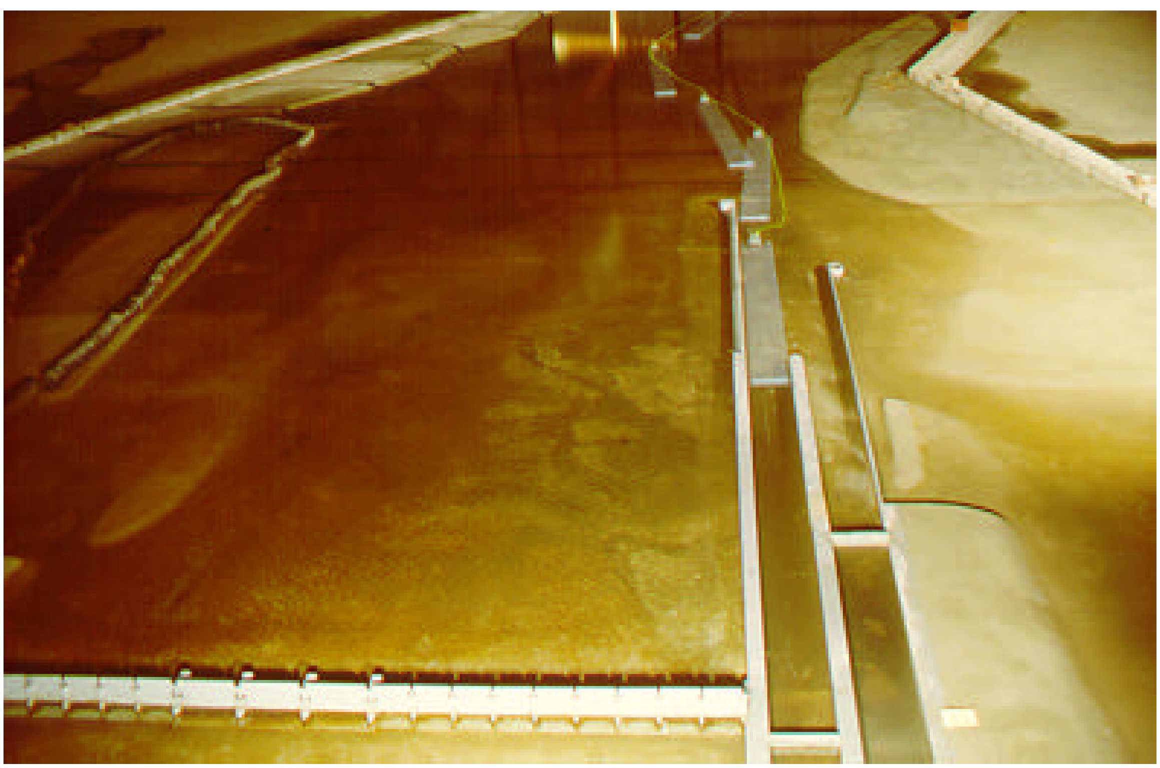


Photo 26. Lock Location 3, Plan A, looking downstream, discharge 65,000 cfs, path of upbound tow approaching 1,200-ft lock

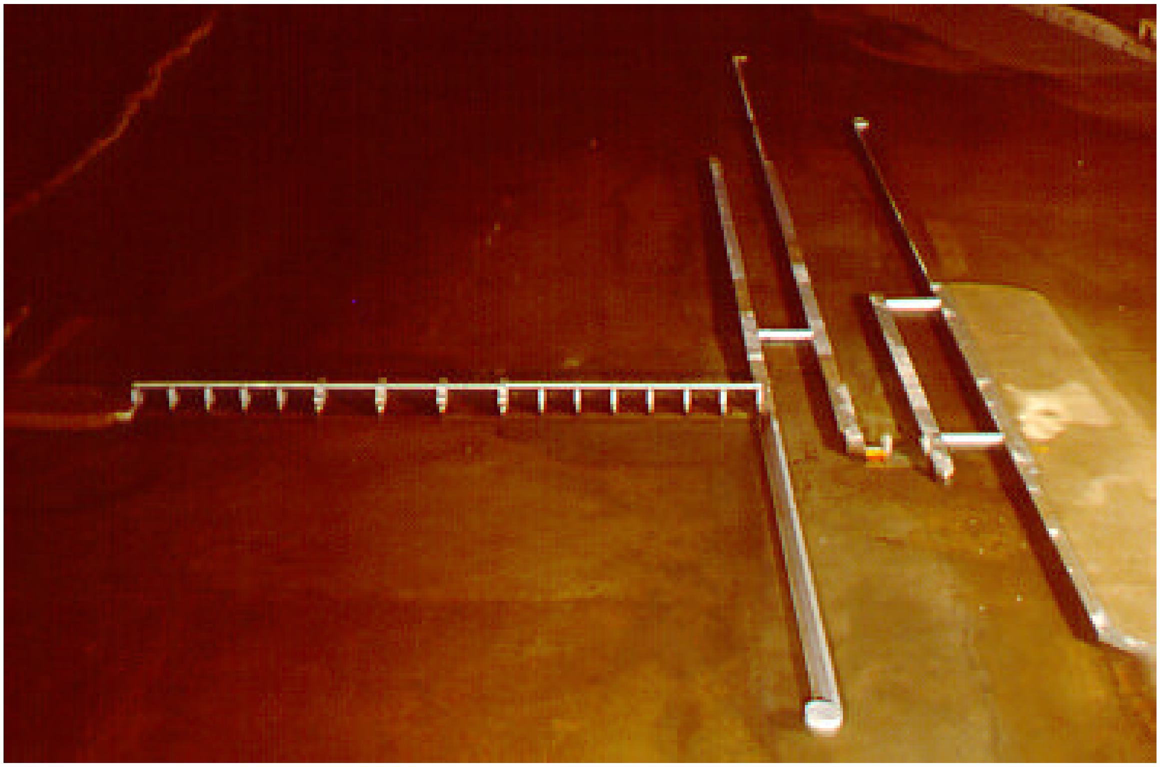


Photo 27. Lock Location 4, Plan A, looking downstream, showing structures

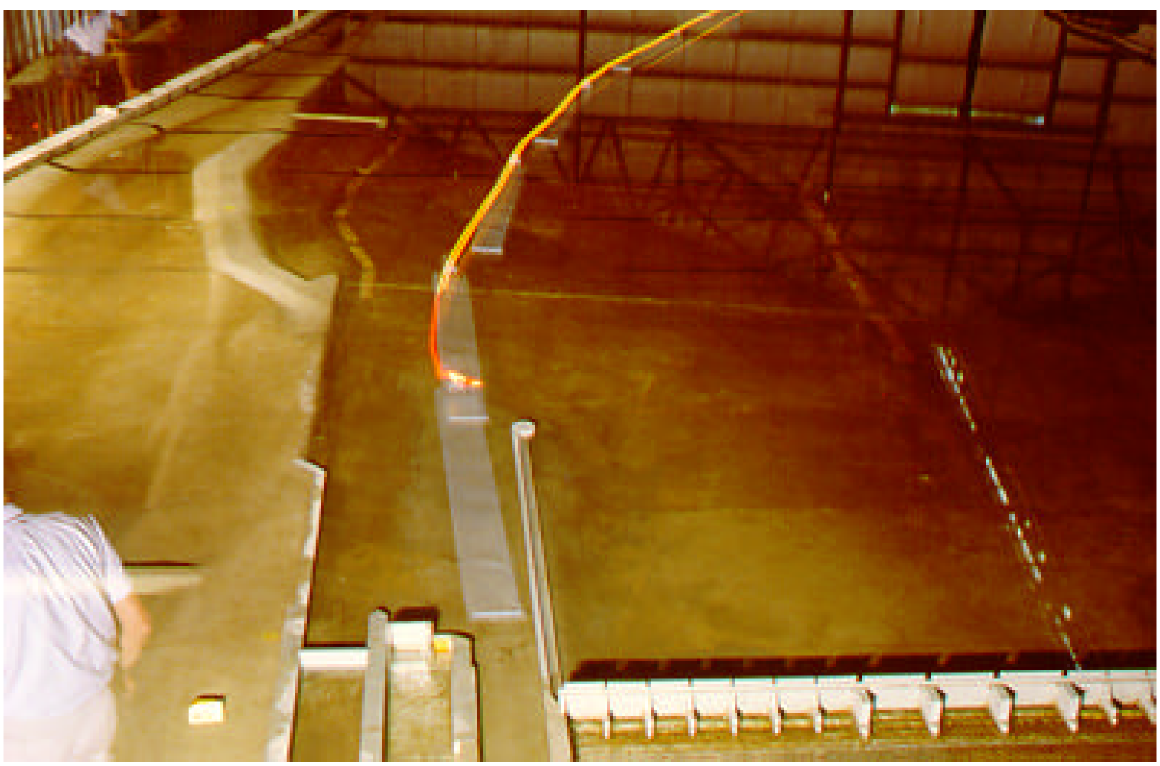


Photo 28. Lock Location 4, Plan A, looking upstream, discharge 65,000 cfs, path of down-bound tow approaching 1,200-ft lock

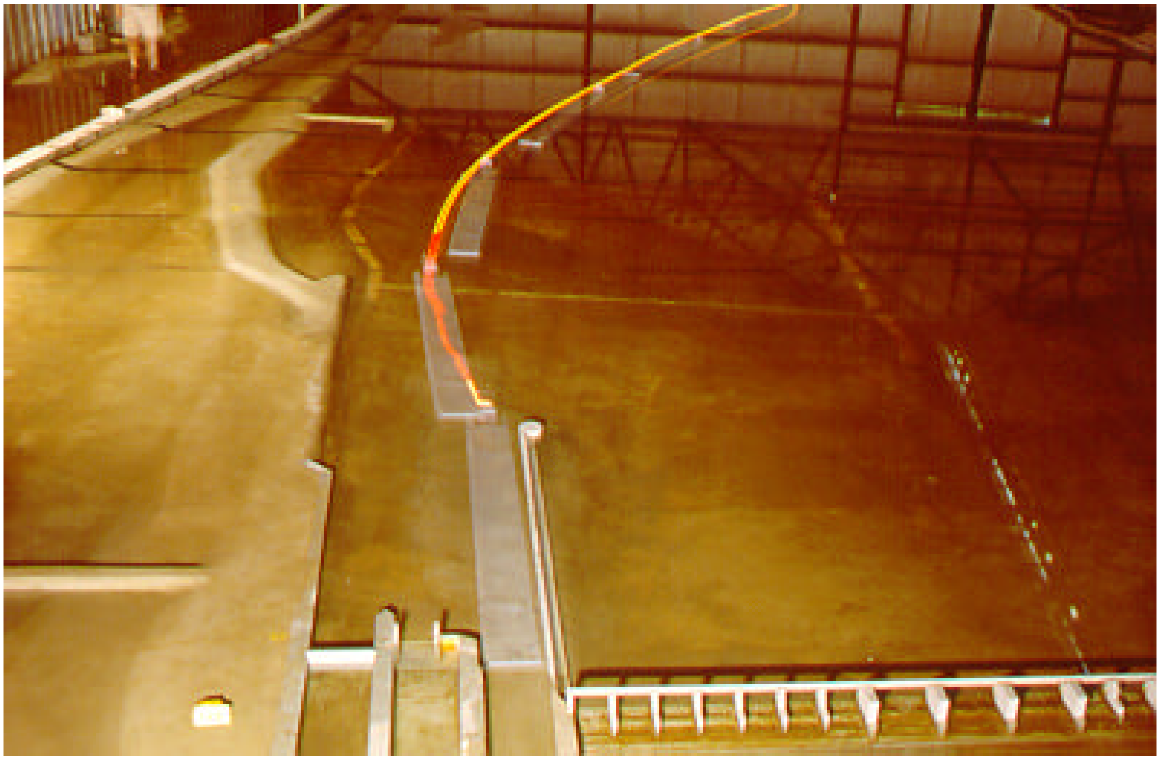


Photo 29. Lock Location 4, Plan A, looking upstream, discharge 138,000 cfs, path of downbound tow approaching 1,200-ft lock

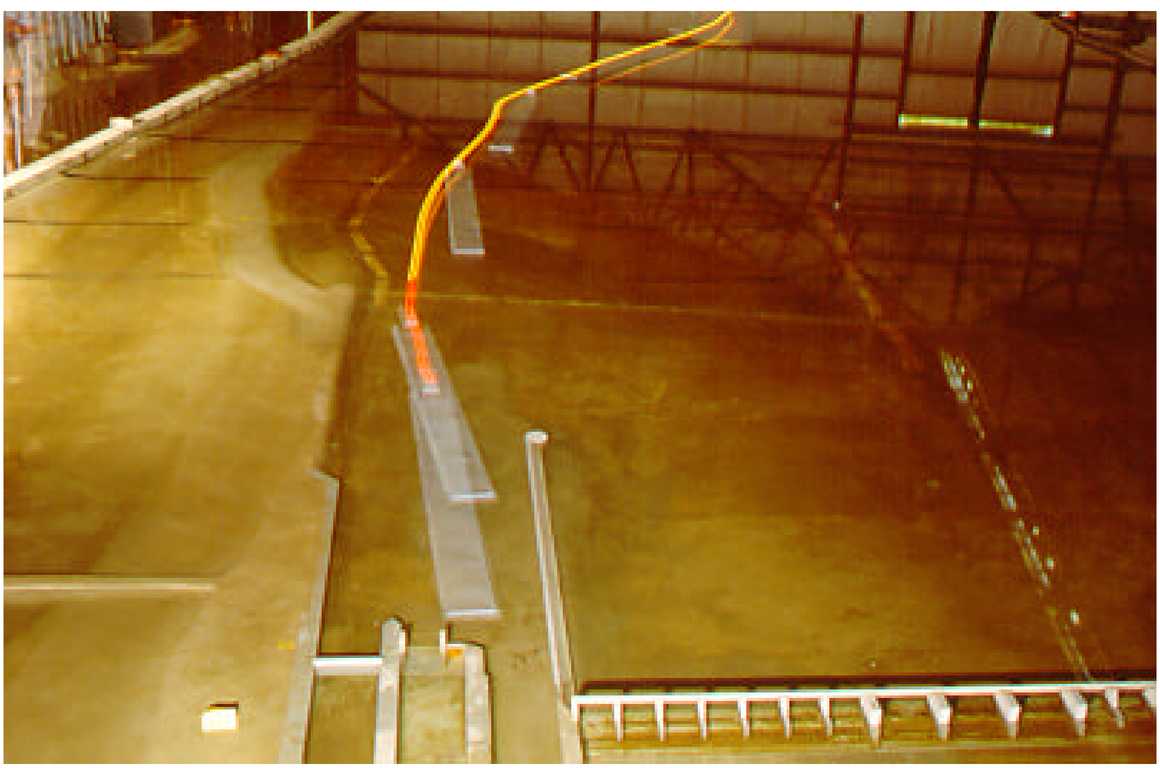


Photo 30. Lock Location 4, Plan A, looking upstream, discharge 327,000 cfs, path of downbound tow approaching 1,200-ft lock

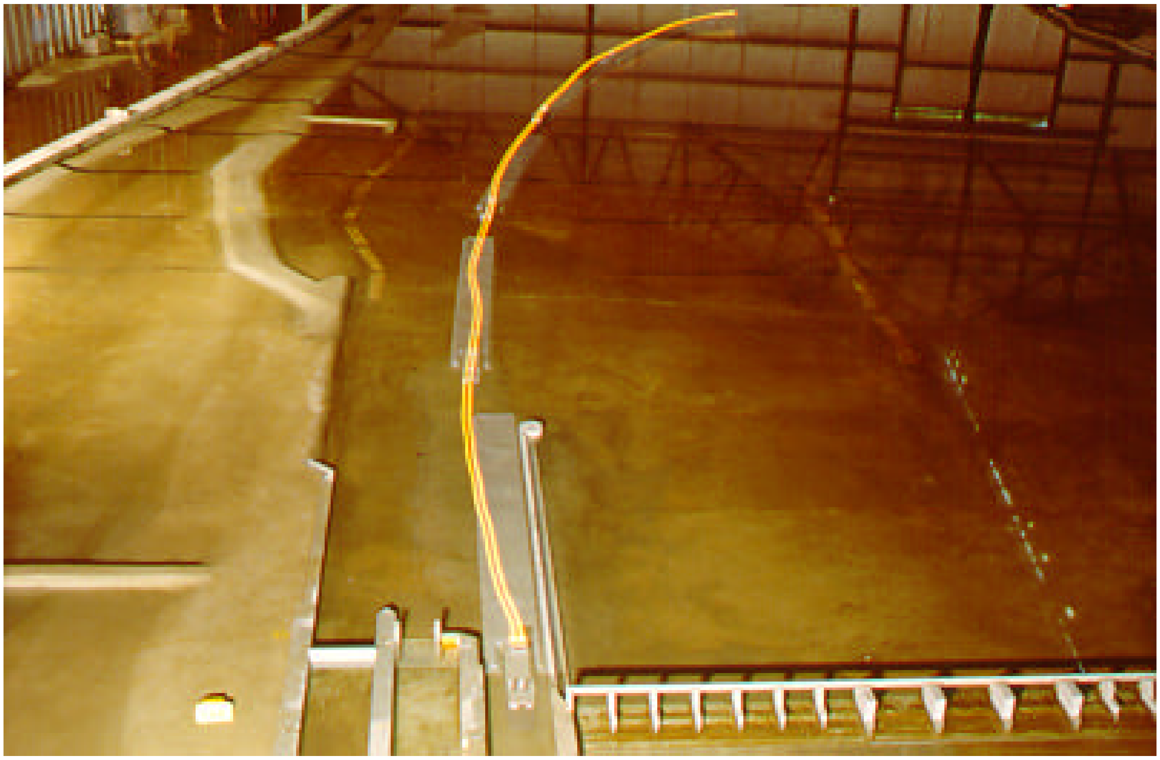


Photo 31. Lock Location 4, Plan A, looking upstream, discharge 138,000 cfs, path of upbound tow leaving 1,200-ft lock

Photo 32. Lock Location 4, Plan A, looking downstream, discharge 138,000 cfs, path of downbound tow leaving 1,200-ft lock

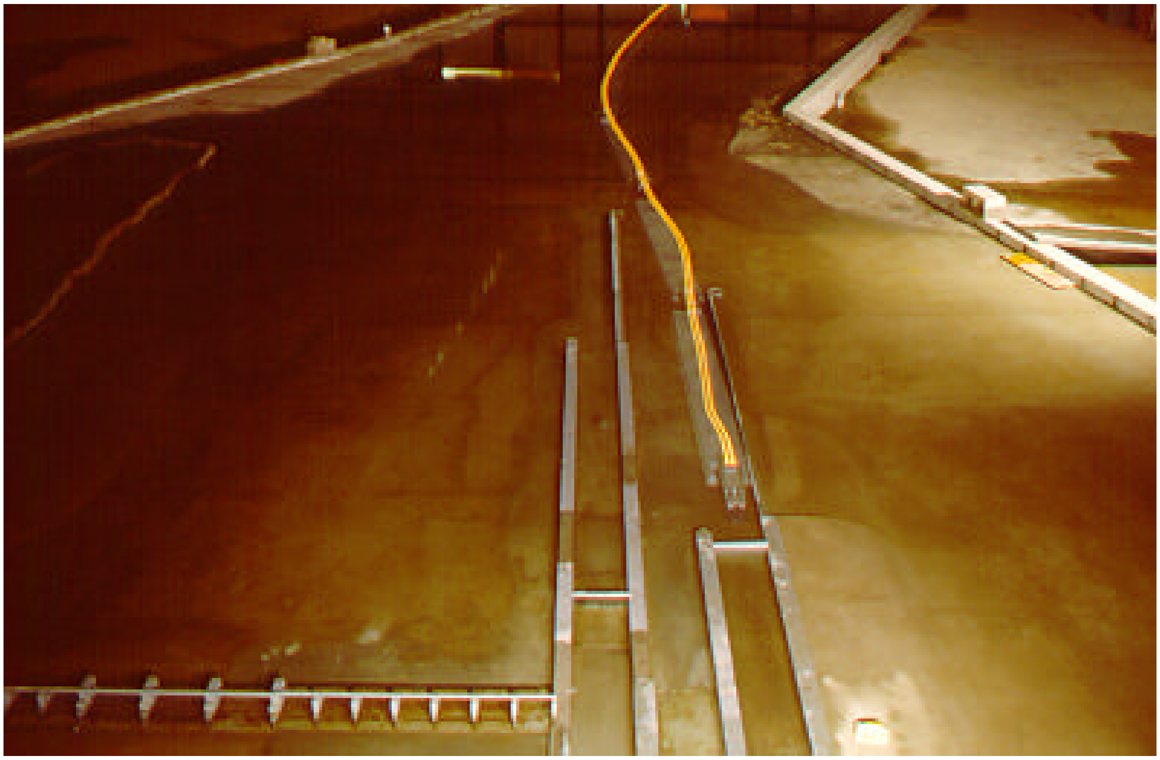


Photo 33. Lock Location 4, Plan A, looking downstream, discharge 327,000 cfs, path of down-bound tow leaving 600-ft lock

Photo 34. Lock Location 4, Plan A, looking downstream, discharge 138,000 cfs, path of upbound tow approaching 1,200-ft lock

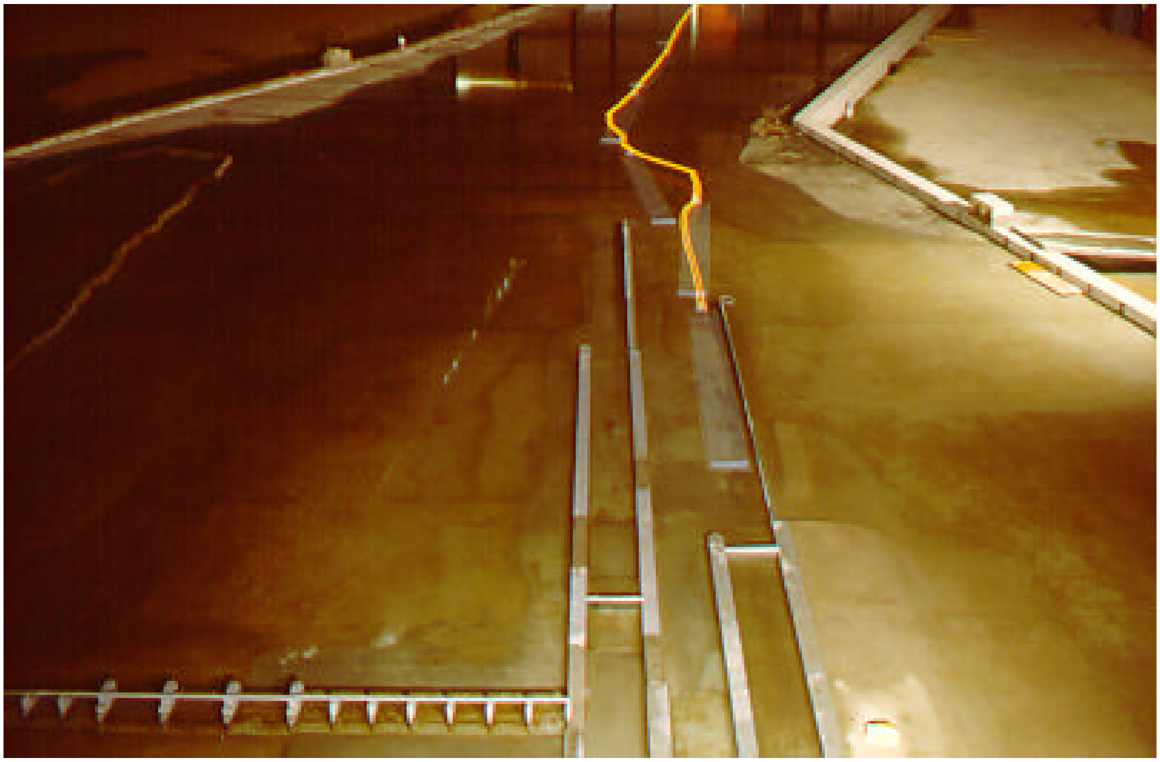
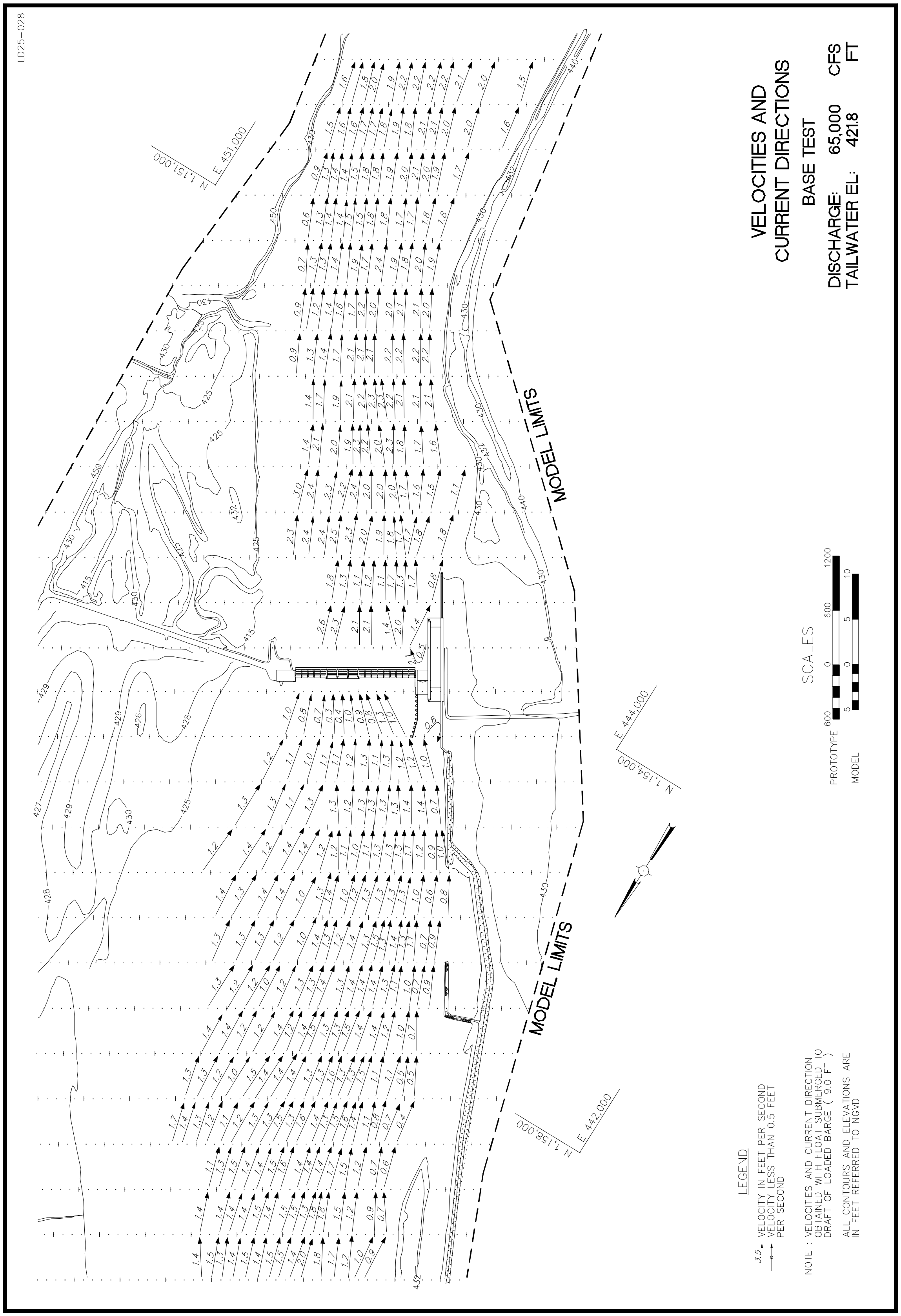


Photo 35. Lock Location 4, Plan A, looking downstream, discharge 327,000 cfs, path of upbound tow approaching 600-ft lock



VELOCITIES AND
CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 65,000 CFS
TAILWATER EL: 421.8 FT
LD25-028
MODEL LIMITS
MODEL LIMITS
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000

Plate 1

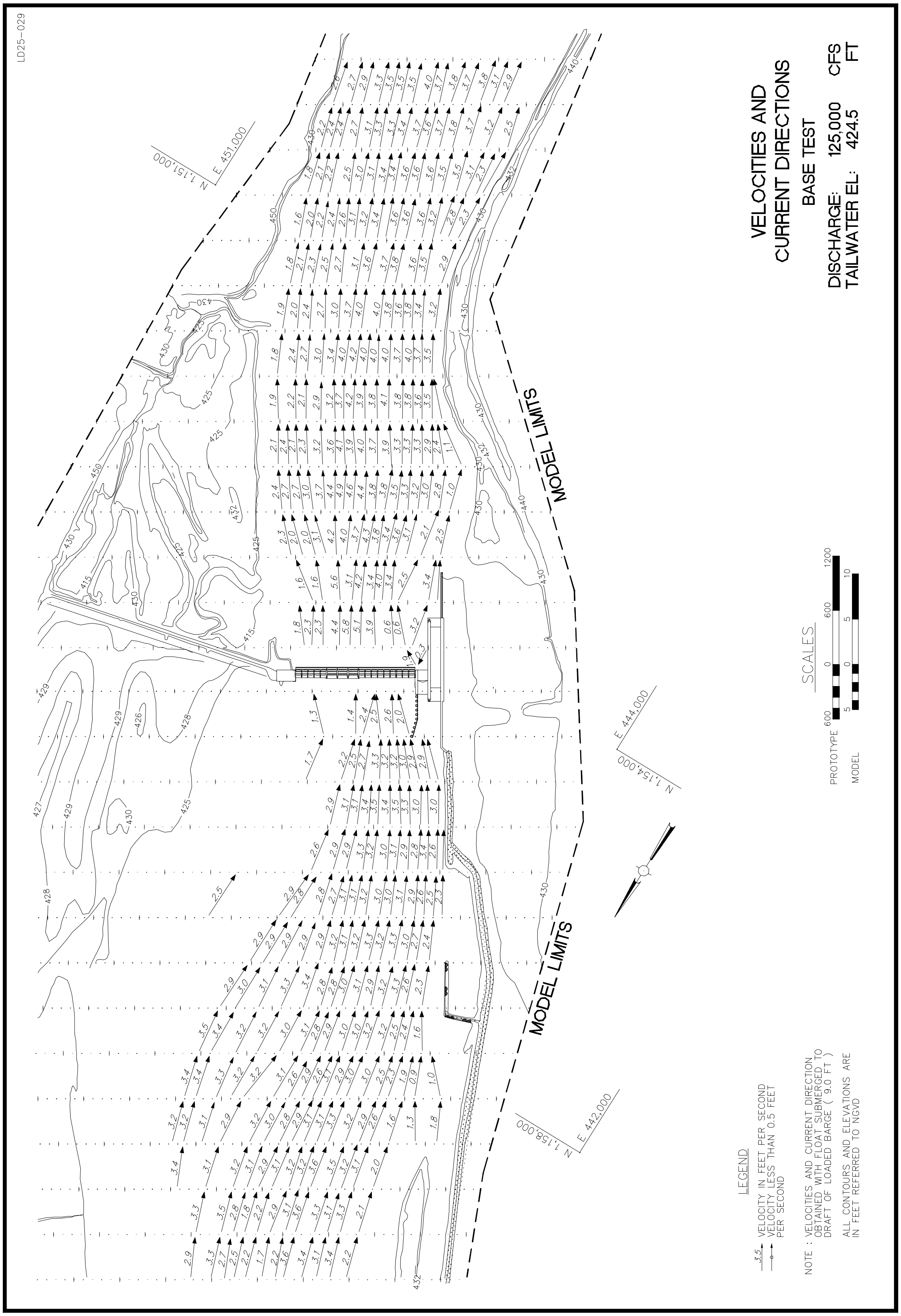
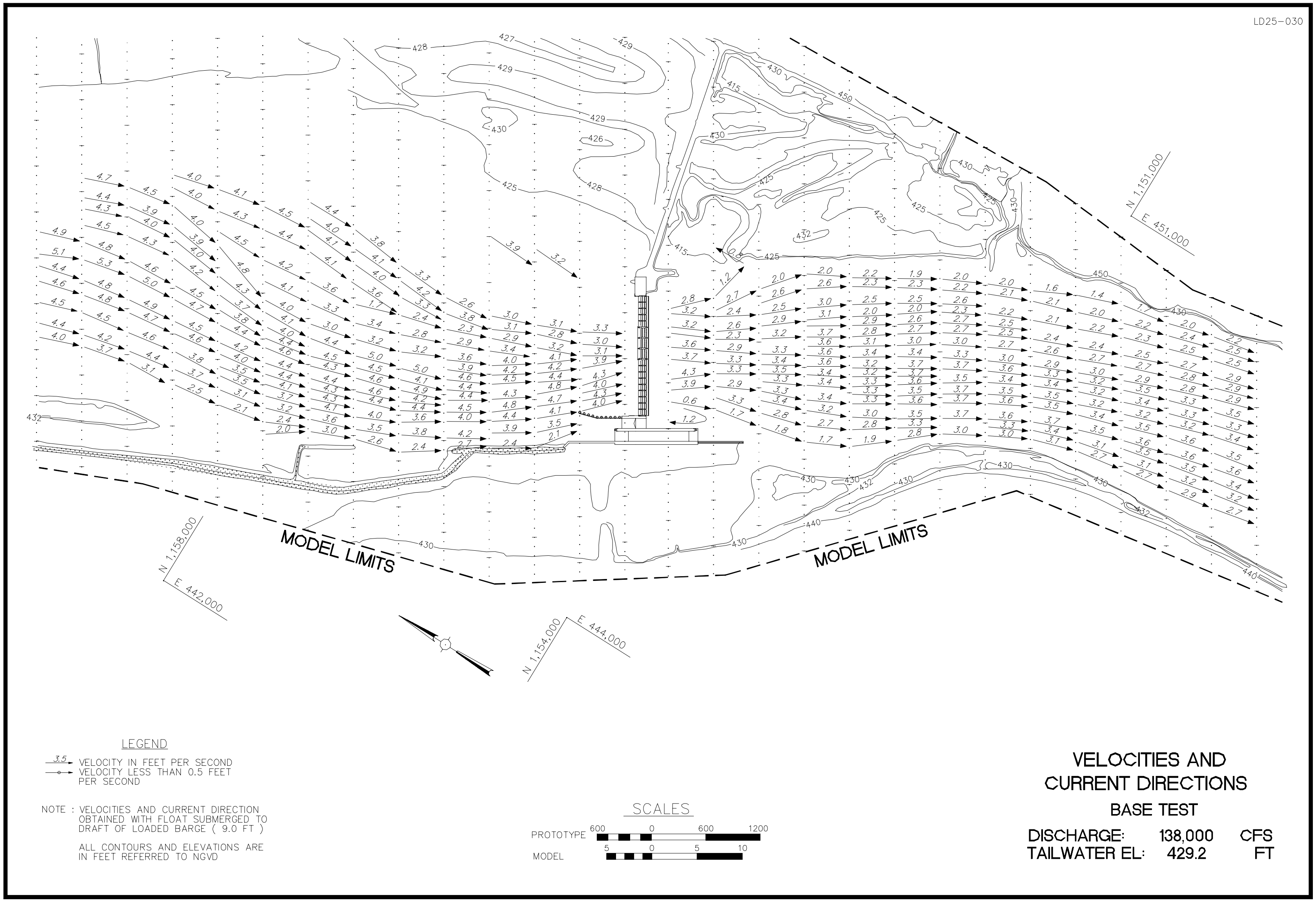

LD25-029
VELOCITIES AND
CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 125,000 CFS
TAILWATER EL: 424.5 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 2



LD25-030
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
VELOCITIES AND CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 138,000 CFS
TAILWATER EL: 429.2 FT

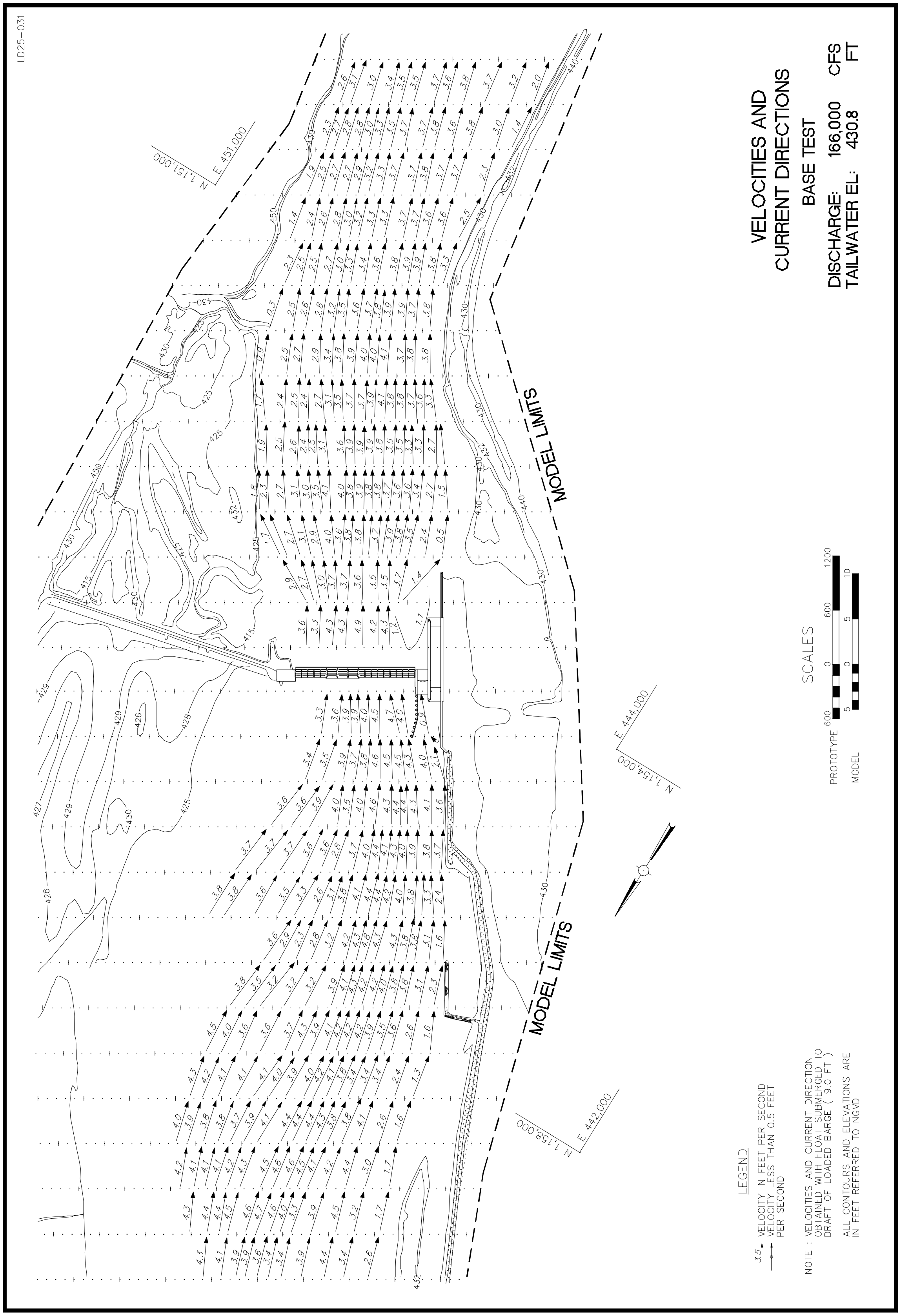

LD25-031
VELOCITIES AND
CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 166,000 CFS
TAILWATER EL: 430.8 FT
MODEL LIMITS
MODEL LIMITS
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 4

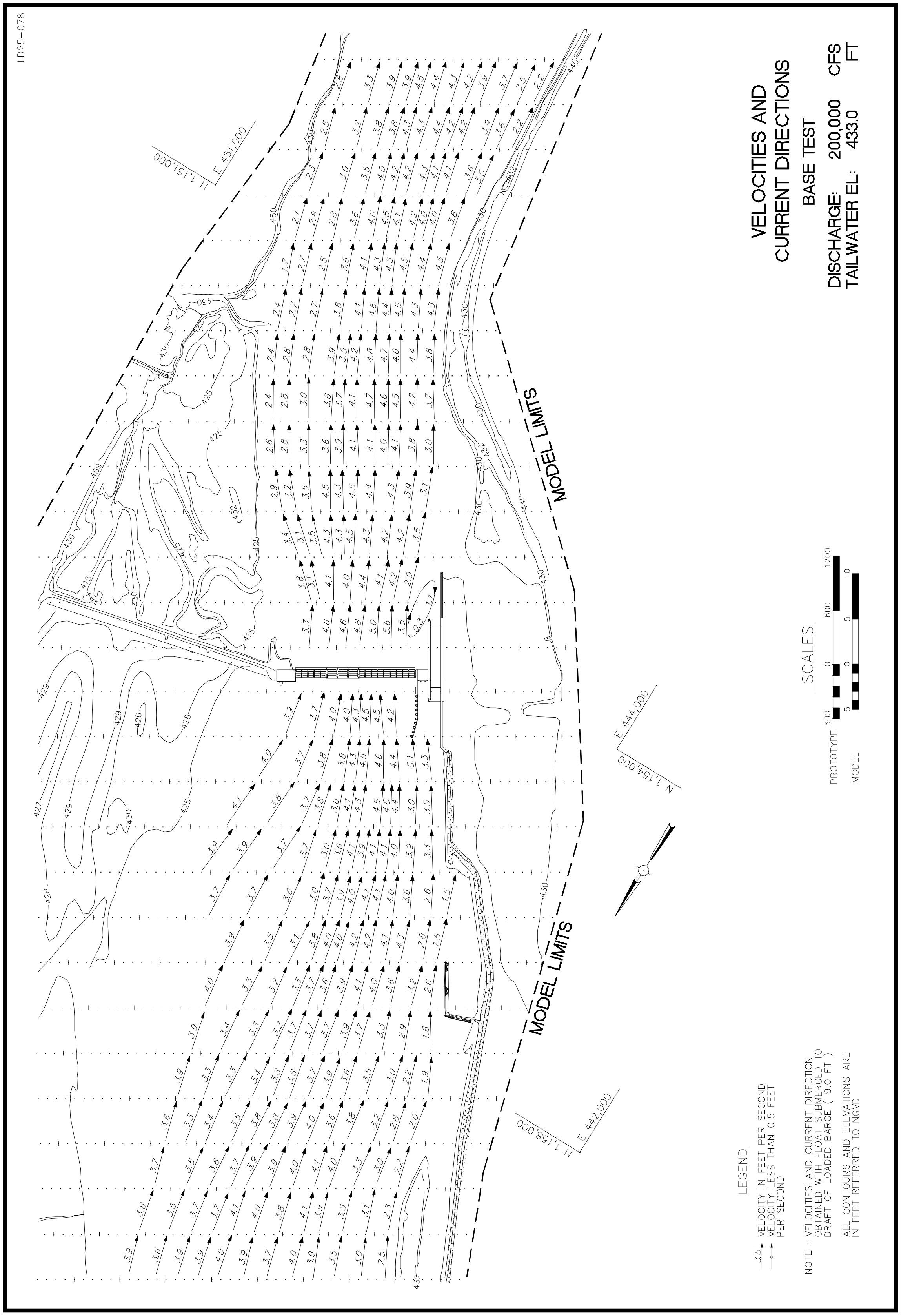
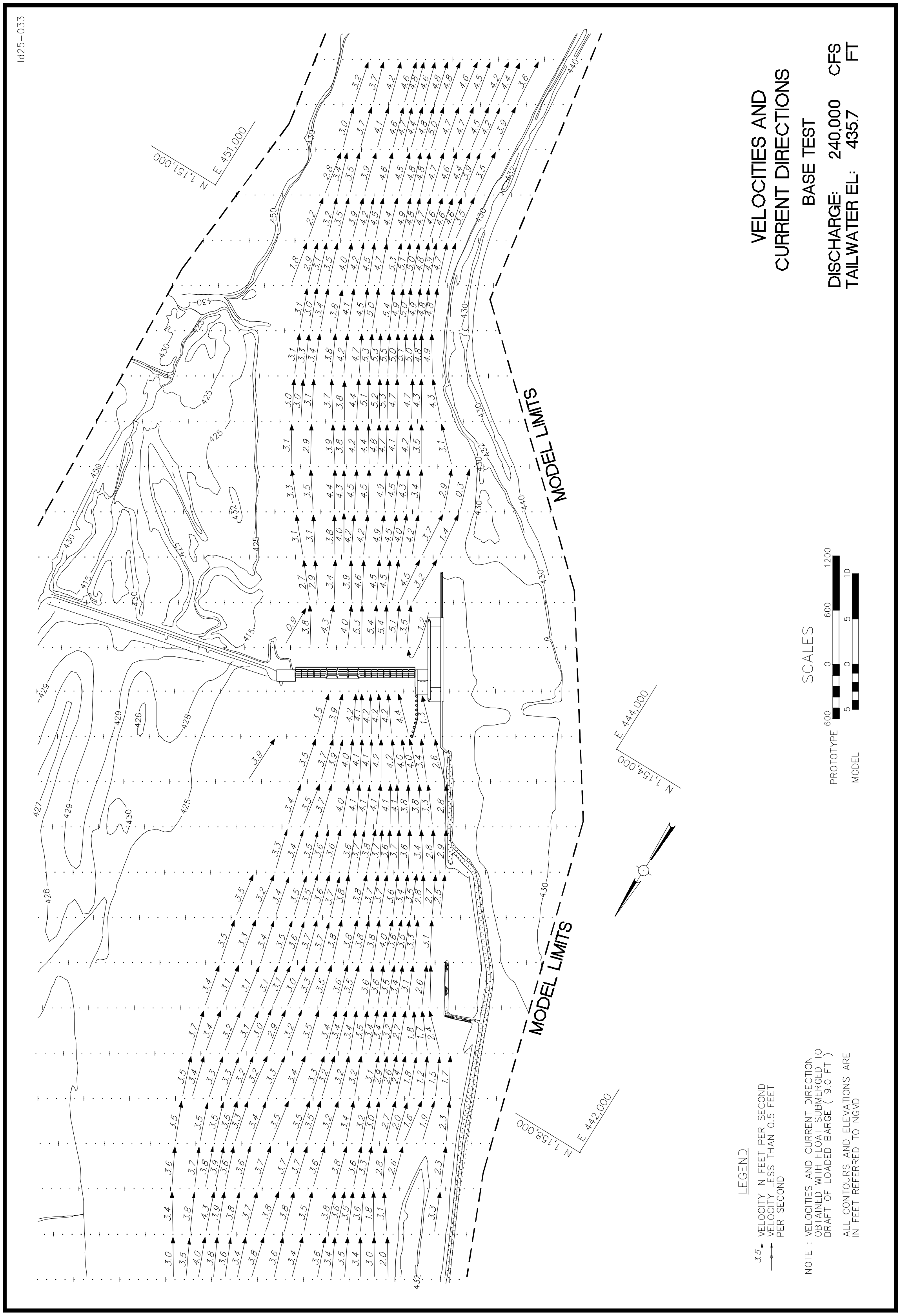

VELOCITIES AND
CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 200,000 CFS
TAILWATER EL: 433.0 FT
MODEL LIMITS
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
LD25-078

Plate 5



VELOCITIES AND CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 240,000 CFS
TAILWATER EL: 435.7 FT
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION 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
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
ld25-033

Plate 6

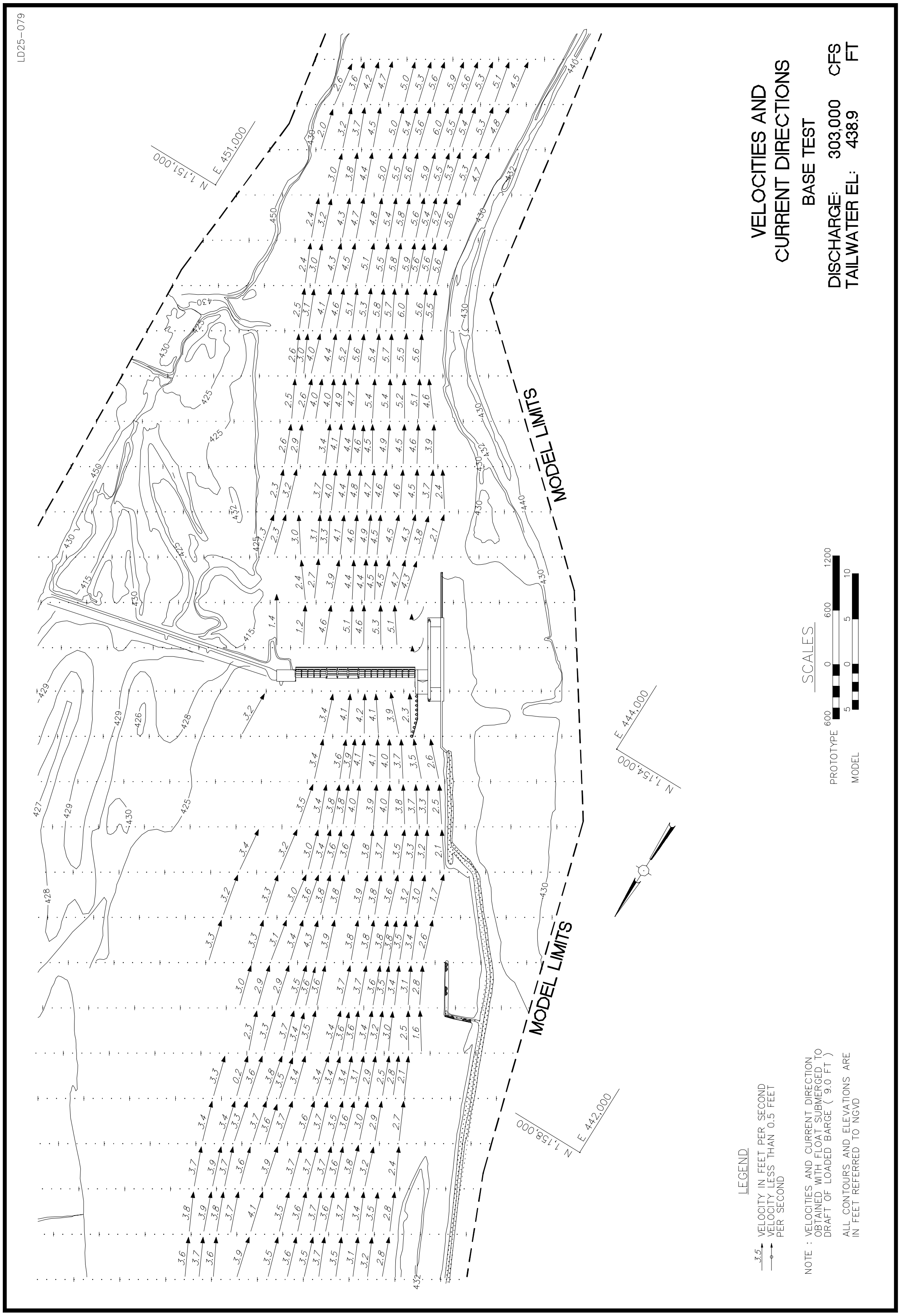

LD25-079
VELOCITIES AND CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 303,000 CFS
TAILWATER EL: 438.9 FT
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE
MODEL
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000

Plate 7

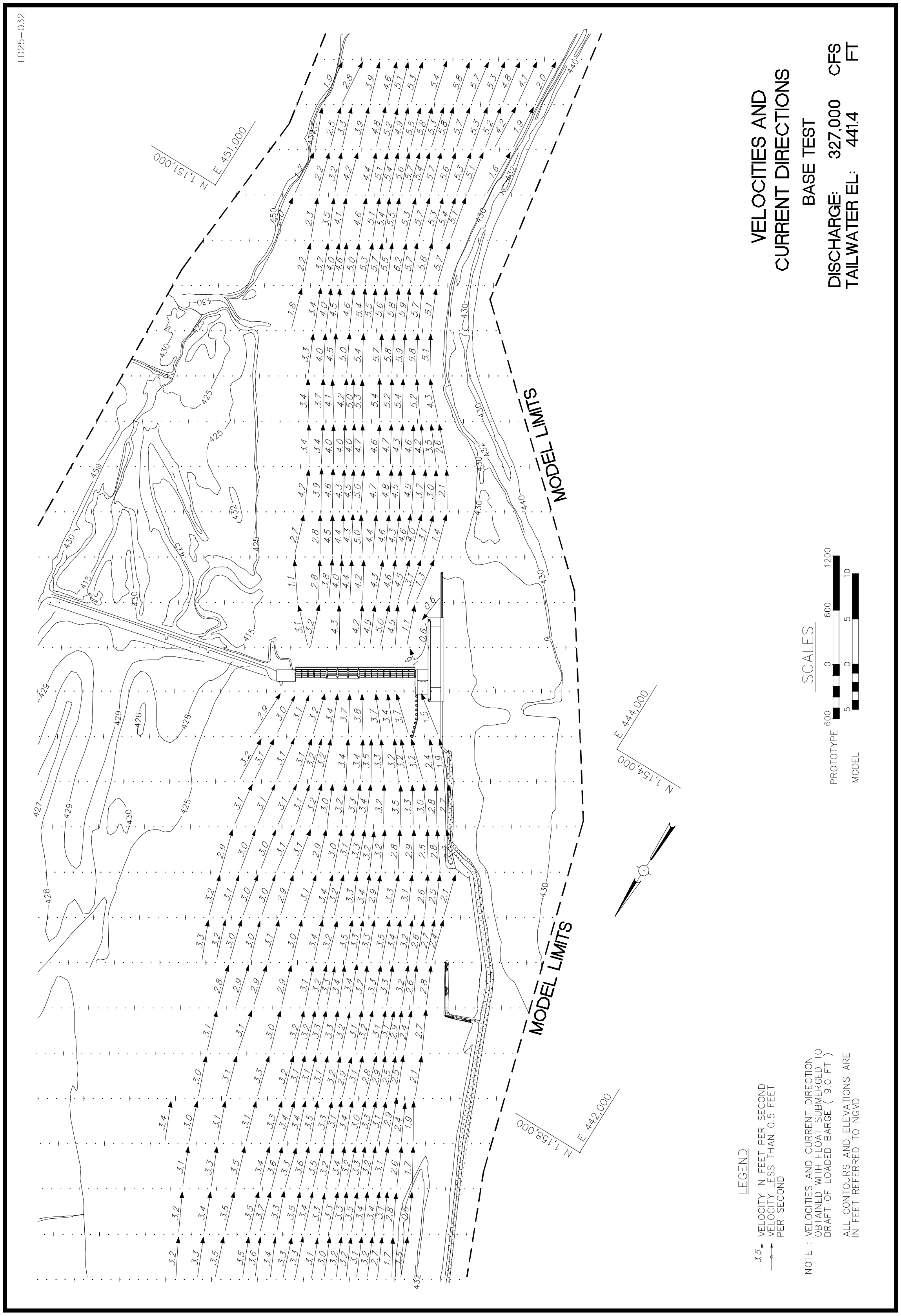
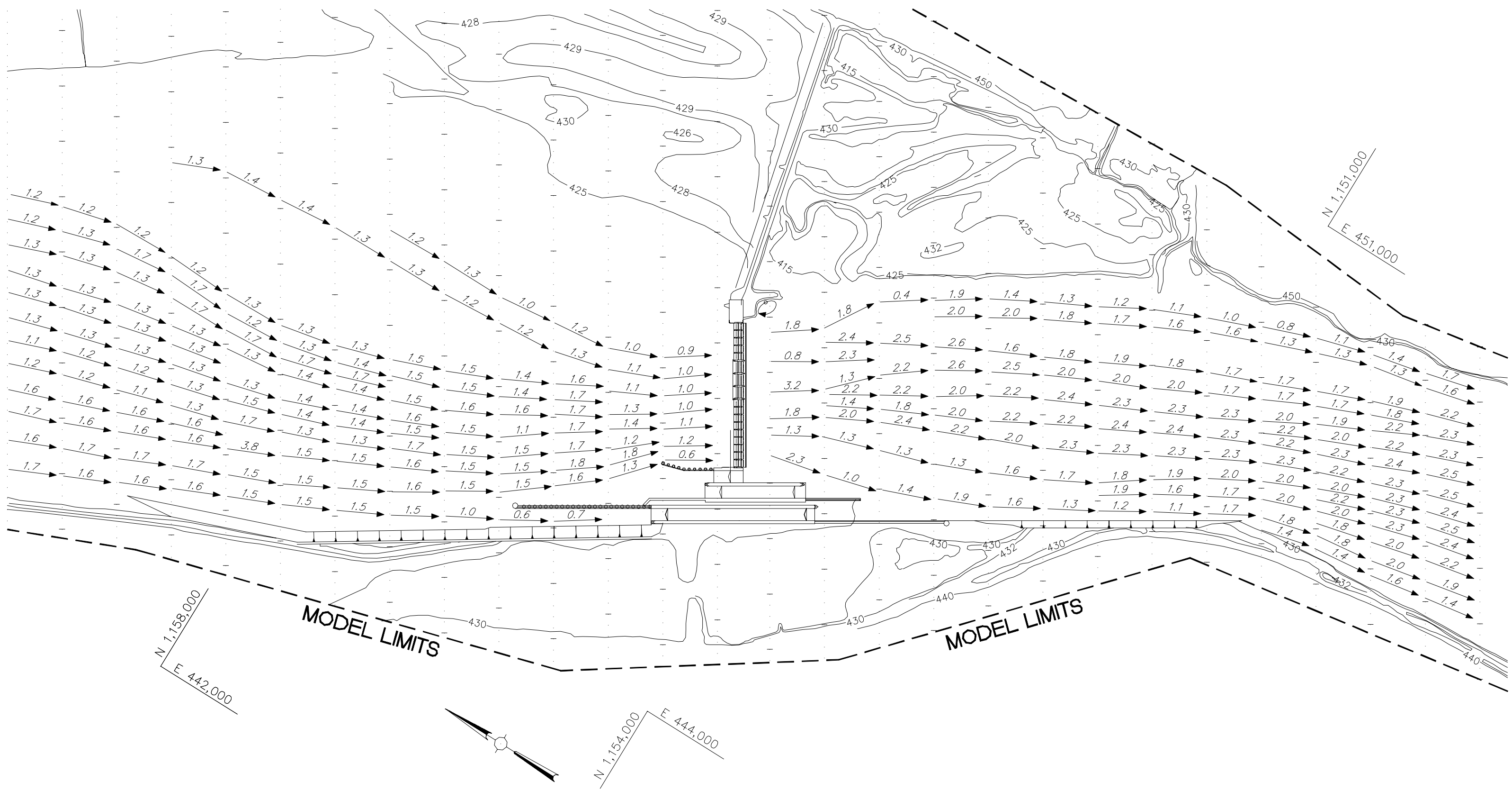

LD25-032
VELOCITIES AND
CURRENT DIRECTIONS
BASE TEST
DISCHARGE: 327,000 CFS
TAILWATER EL: 441.4 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 8



LEGEND

3.5 → VELOCITY IN FEET PER SECOND
—∘— VELOCITY LESS THAN 0.5 FEET PER SECOND

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

SCALES

PROTOTYPE 600 0 600 1200

MODEL 5 0 5 10

VELOCITIES AND CURRENT DIRECTIONS

LOCK LOCATION 1

PLAN A

DISCHARGE: 65,000 CFS

TAILWATER EL: 421.8 FT

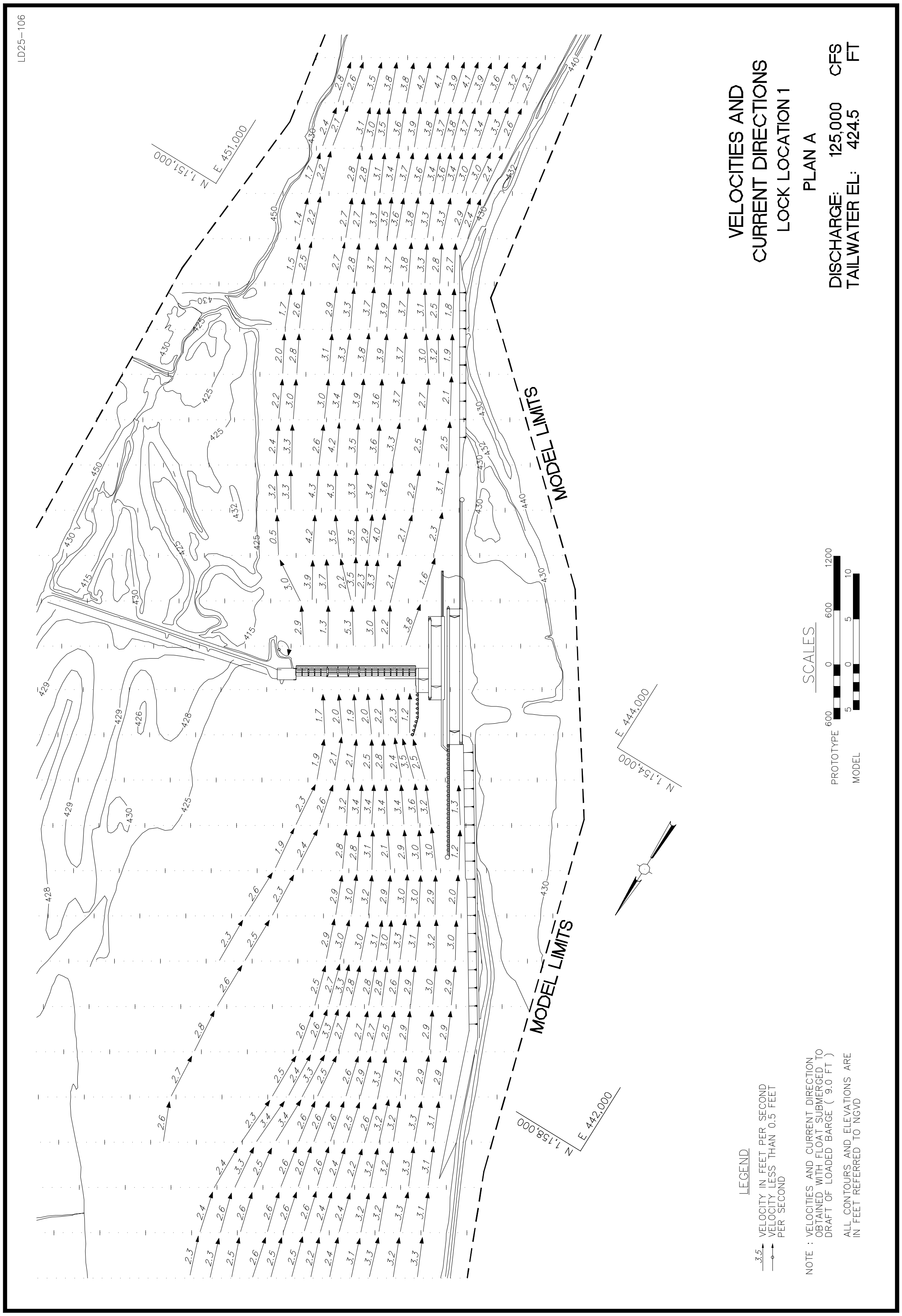

LD25-106
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 1
PLAN A
DISCHARGE: 125,000 CFS
TAILWATER EL: 424.5 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 10

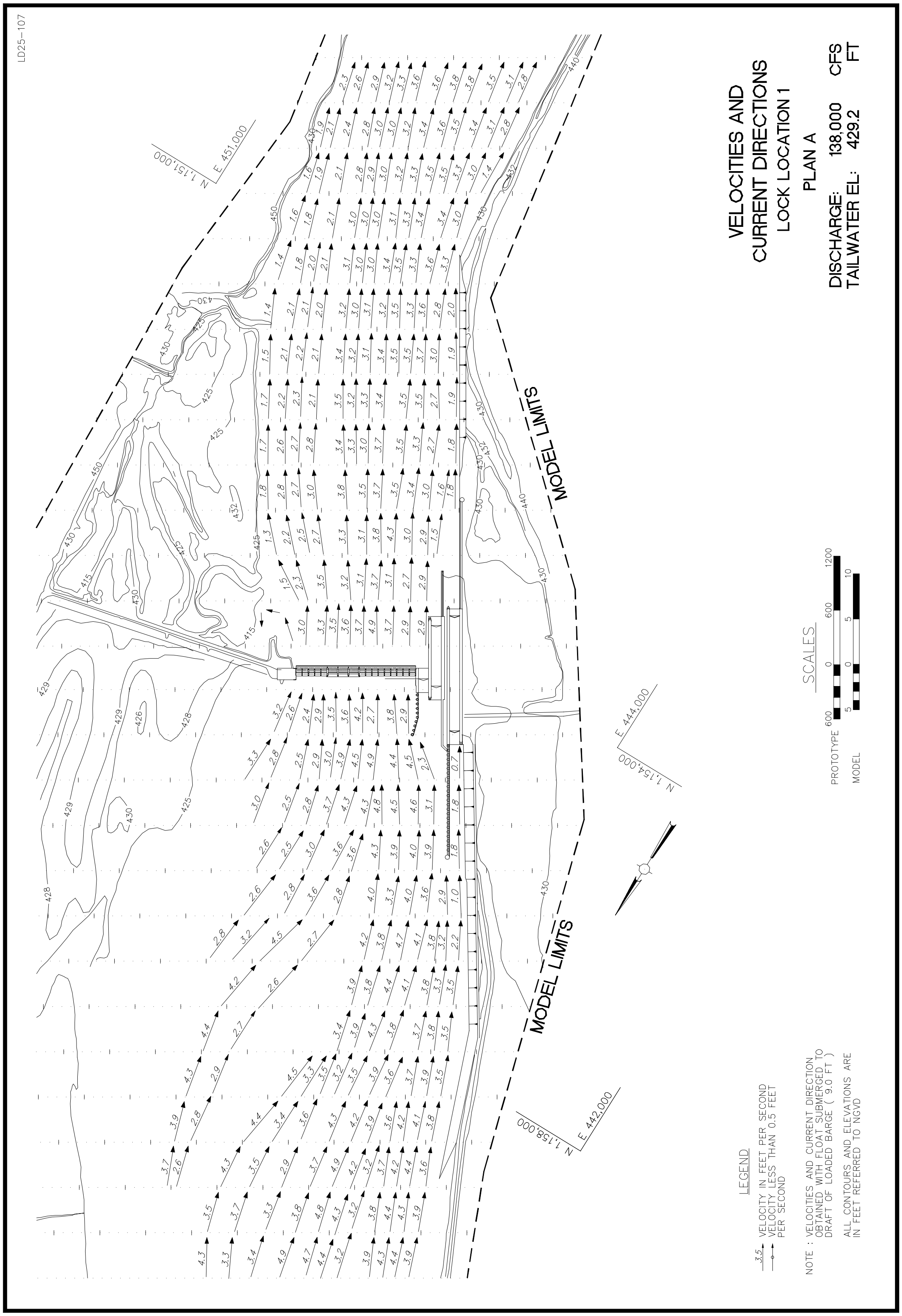

VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 1
PLAN A
DISCHARGE: 138,000 CFS
TAILWATER EL: 429.2 FT
LD25-107
MODEL LIMITS
MODEL LIMITS
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000

Plate 11

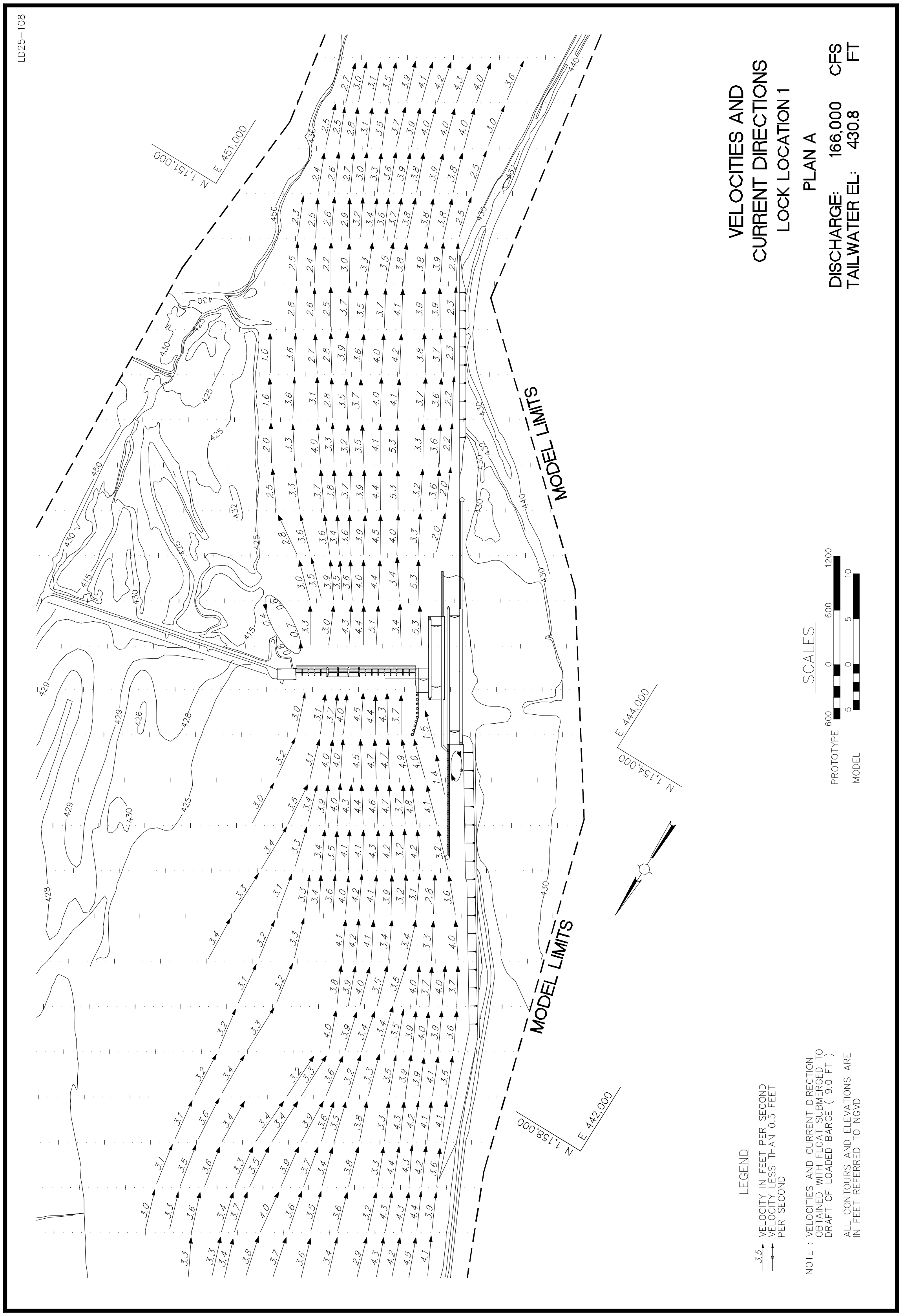

LD25-108
VELOCITIES AND CURRENT DIRECTIONS
LOCK LOCATION 1
PLAN A
DISCHARGE: 166,000 CFS
TAILWATER EL: 430.8 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 12

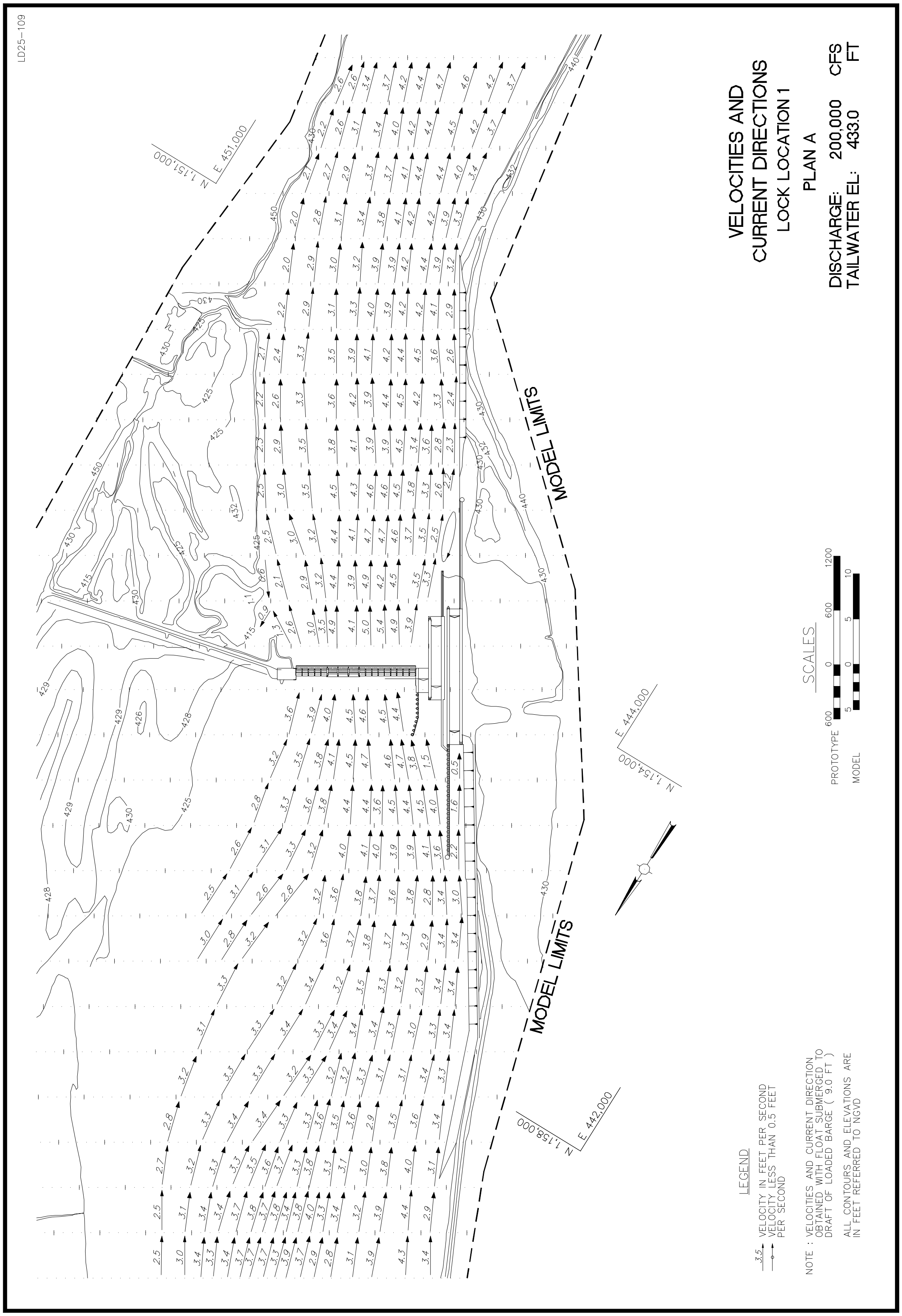

LD25-109
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 1
PLAN A
DISCHARGE: 200,000 CFS
TAILWATER EL: 433.0 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 13

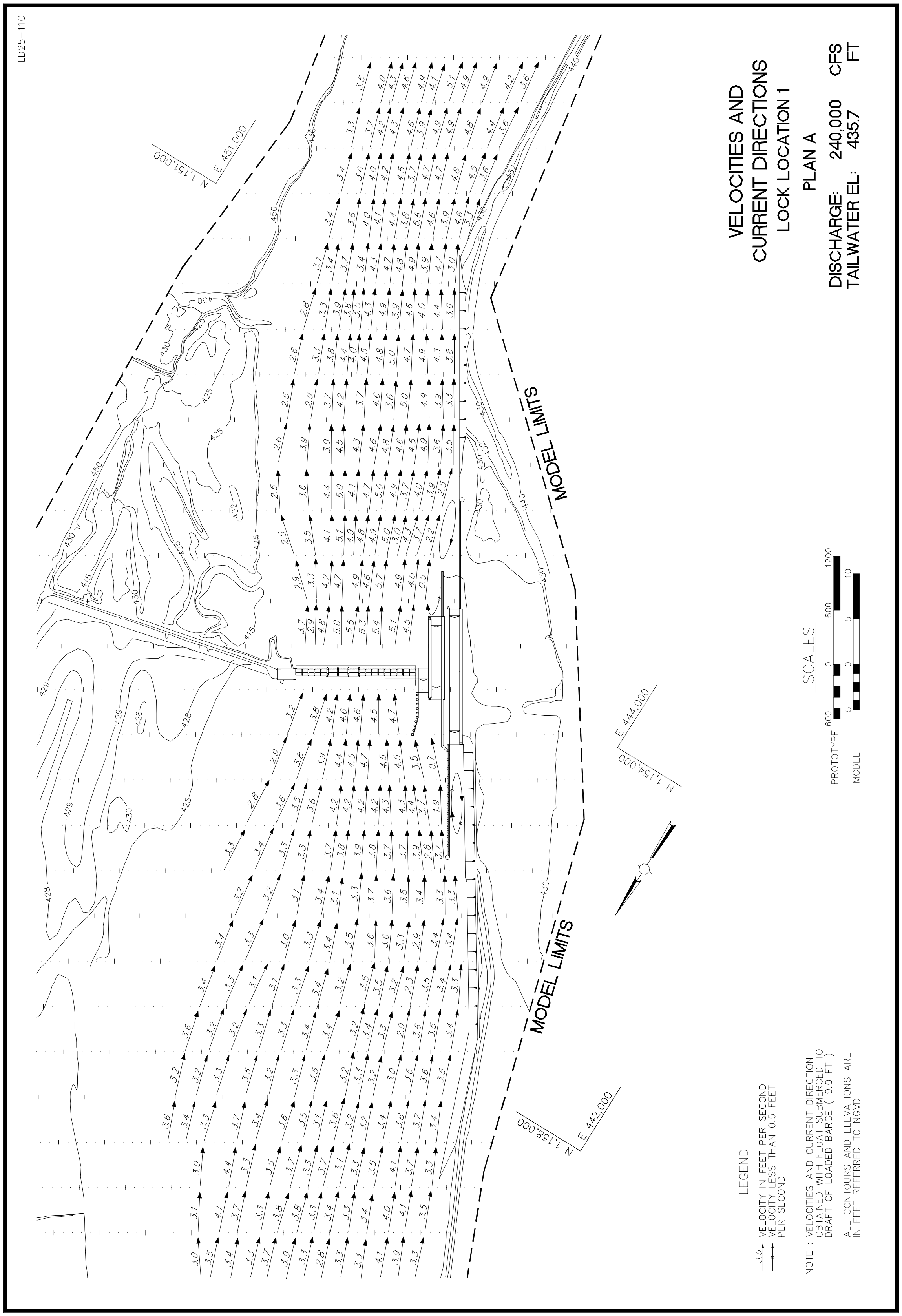

LD25-110
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 1
PLAN A
DISCHARGE: 240,000 CFS
TAILWATER EL: 435.7 FT
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000

Plate 14

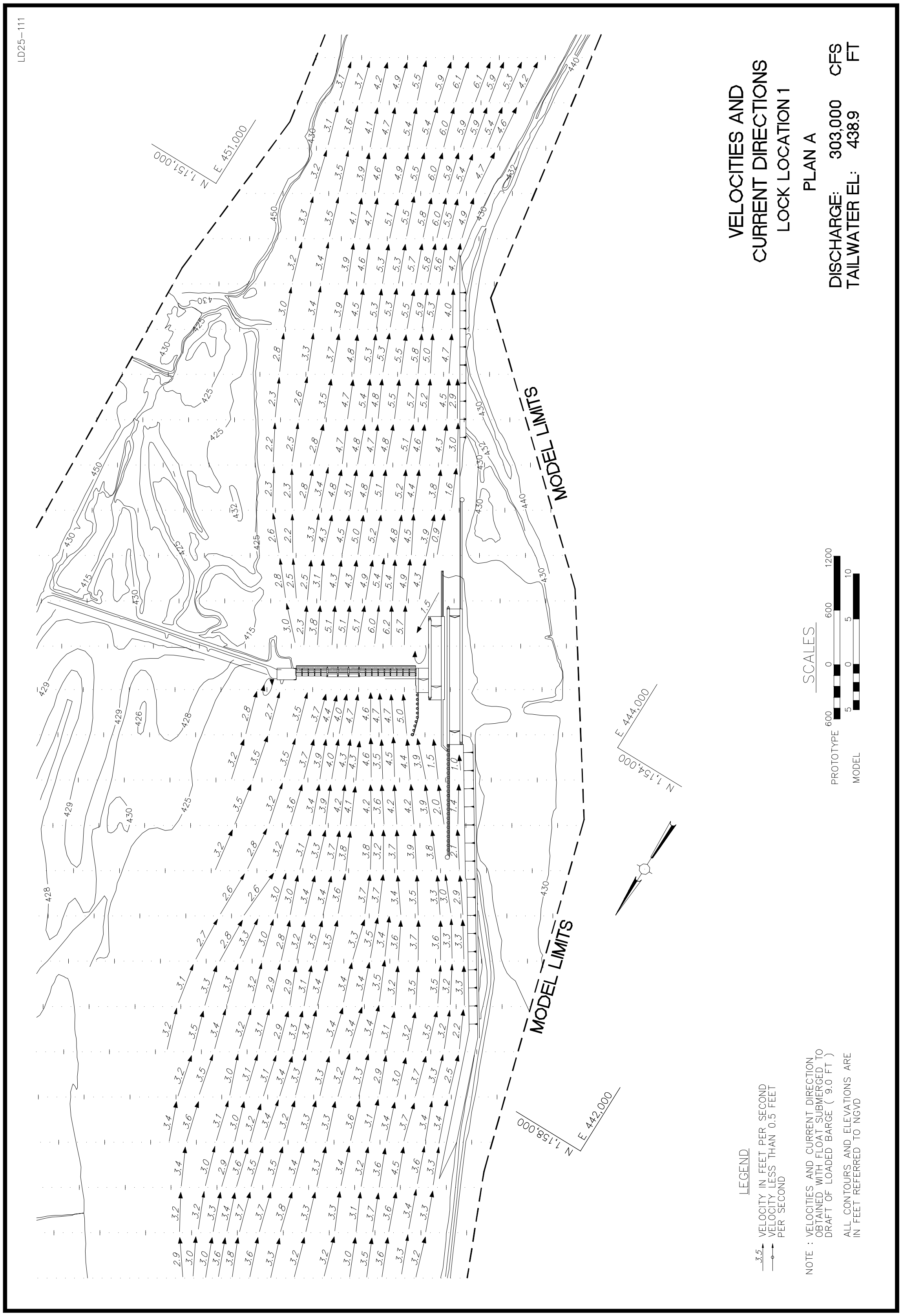

LD25-111
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 1
PLAN A
DISCHARGE: 303,000 CFS
TAILWATER EL: 438.9 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 15

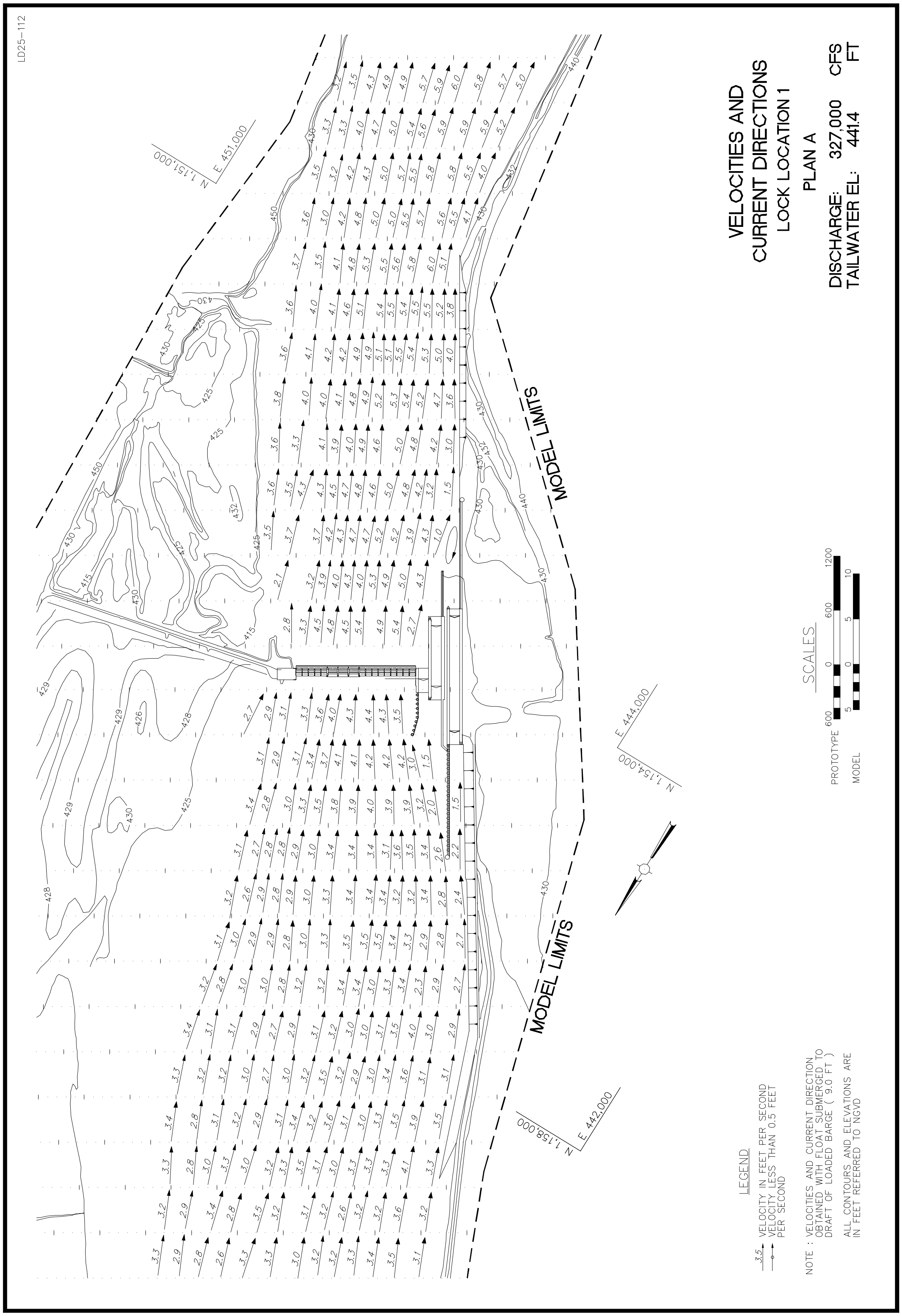

LD25-112
VELOCITIES AND CURRENT DIRECTIONS
LOCK LOCATION 1
PLAN A
DISCHARGE: 327,000 CFS
TAILWATER EL: 441.4 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 16

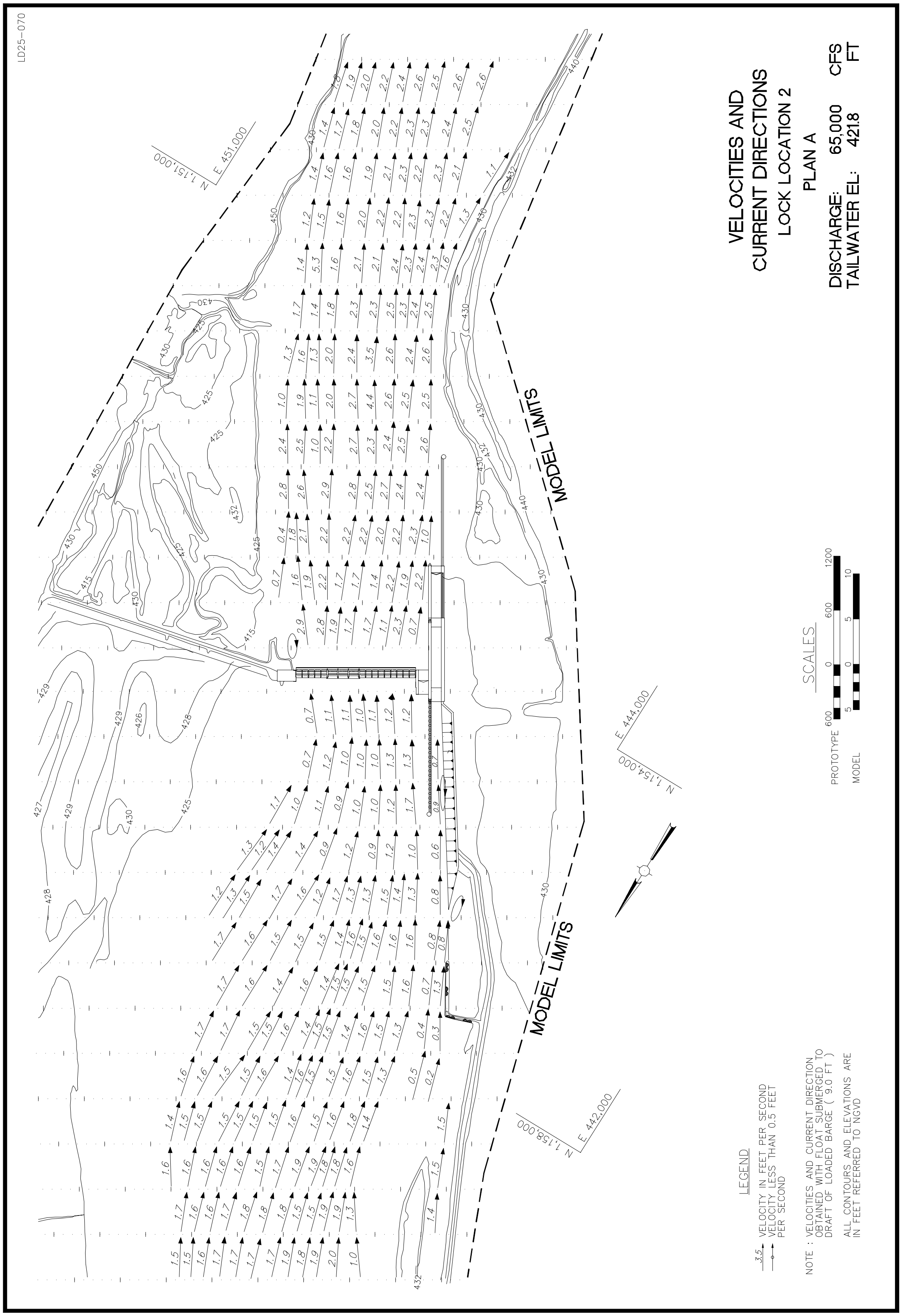

LD25-070
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 2
PLAN A
DISCHARGE: 65,000 CFS
TAILWATER EL: 421.8 FT
MODEL LIMITS
MODEL LIMITS
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000

Plate 17

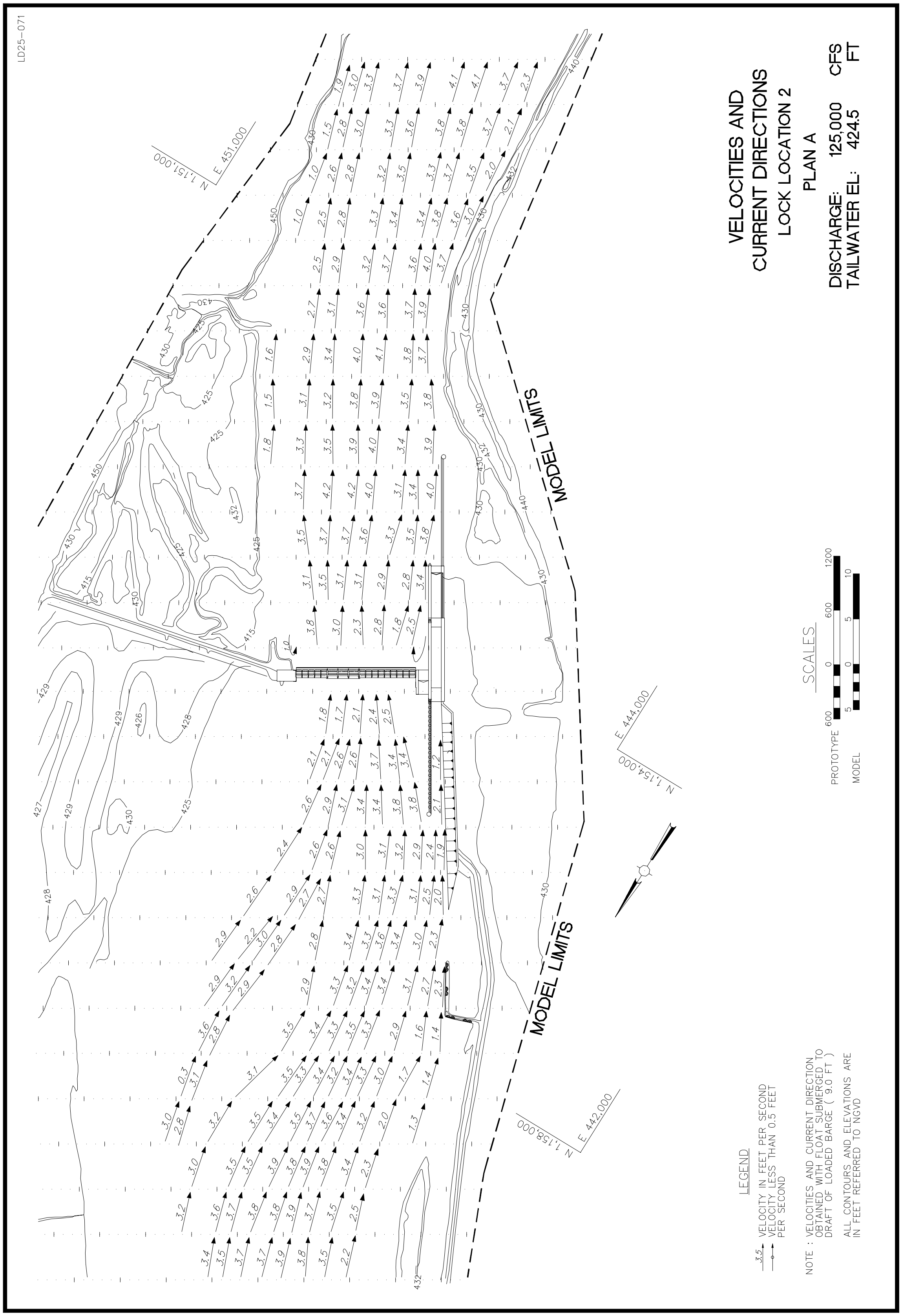

LD25-071
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 2
PLAN A
DISCHARGE: 125,000 CFS
TAILWATER EL: 424.5 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 18

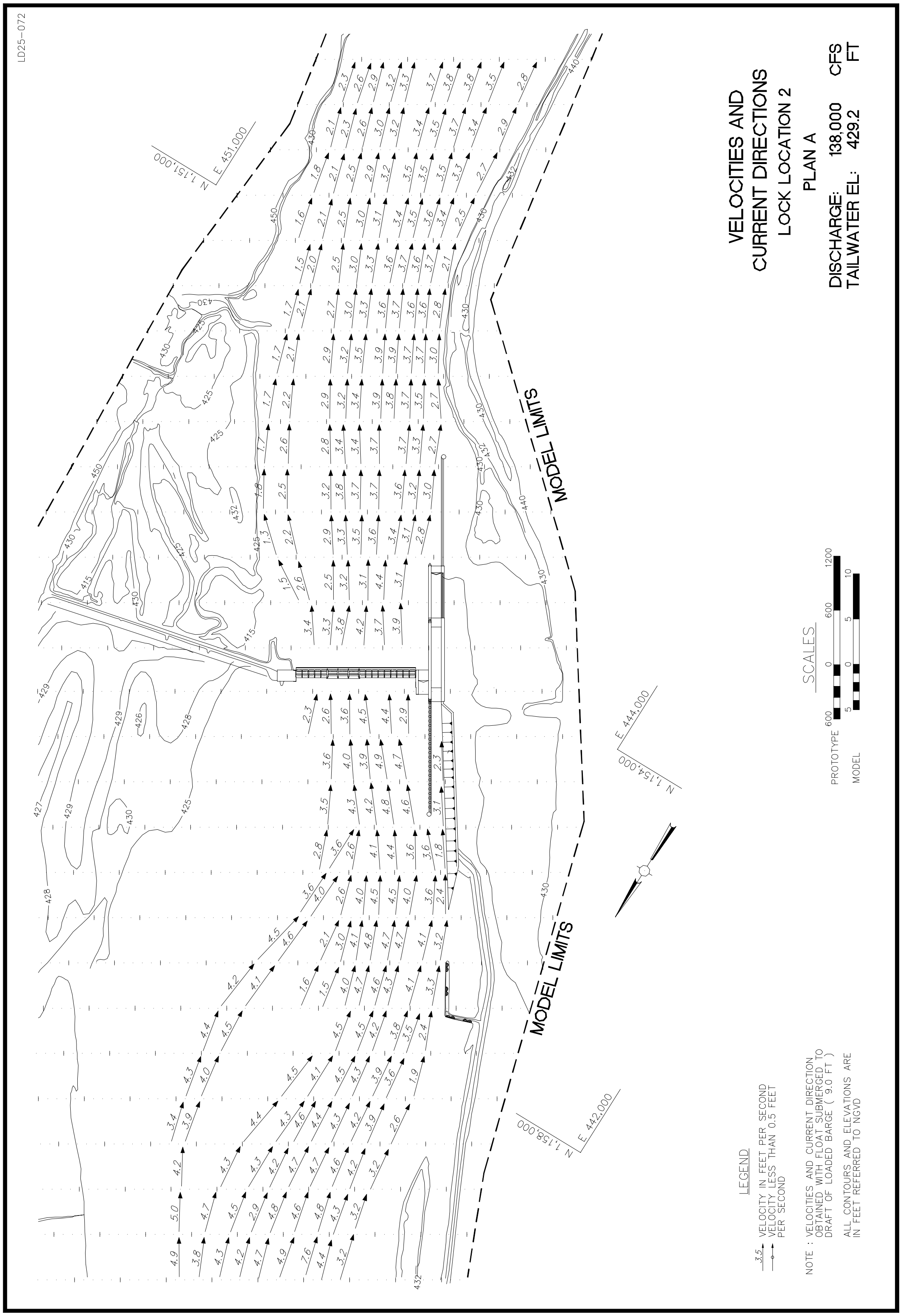

LD25-072
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 2
PLAN A
DISCHARGE: 138,000 CFS
TAILWATER EL: 429.2 FT
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000

Plate 19

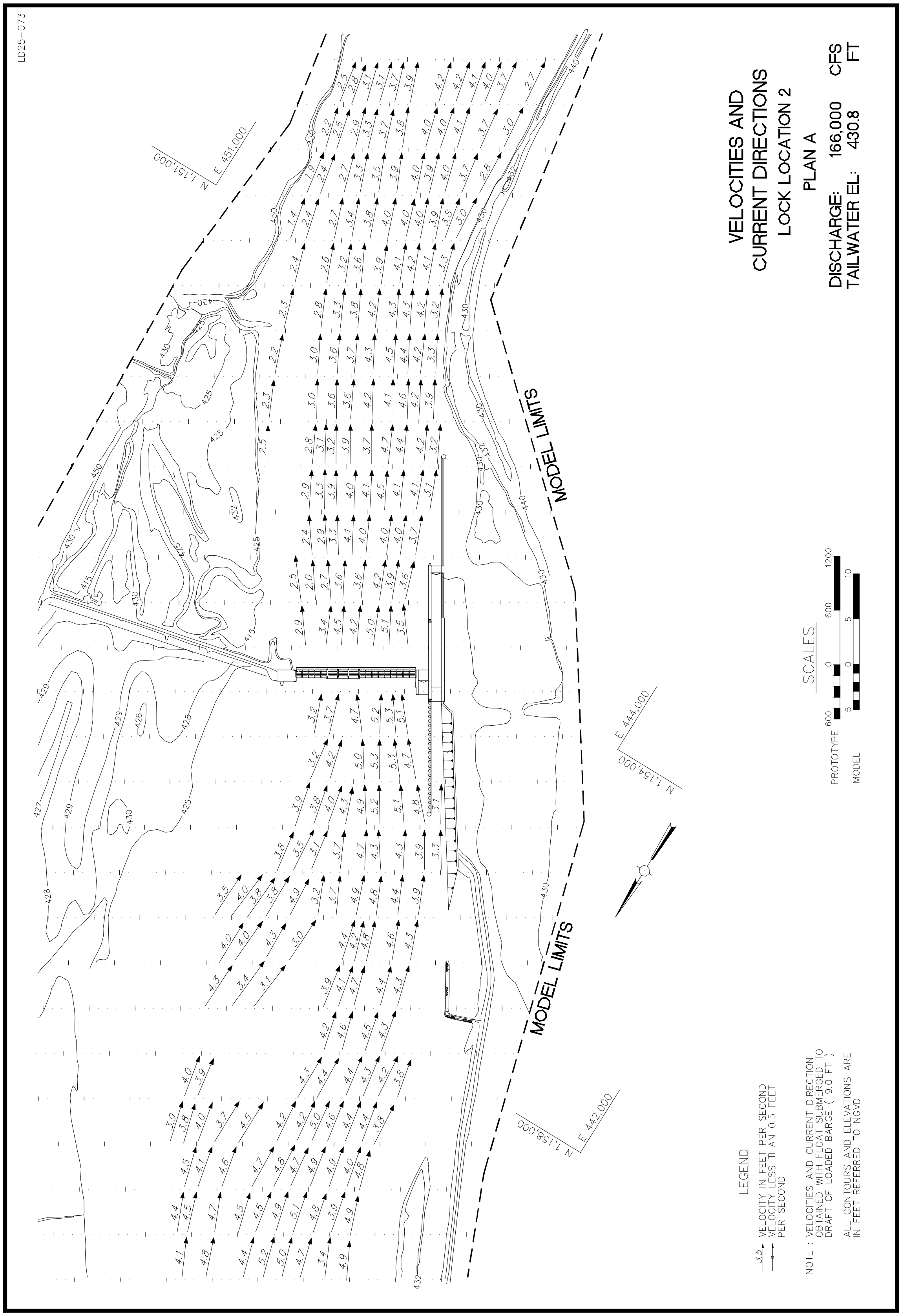
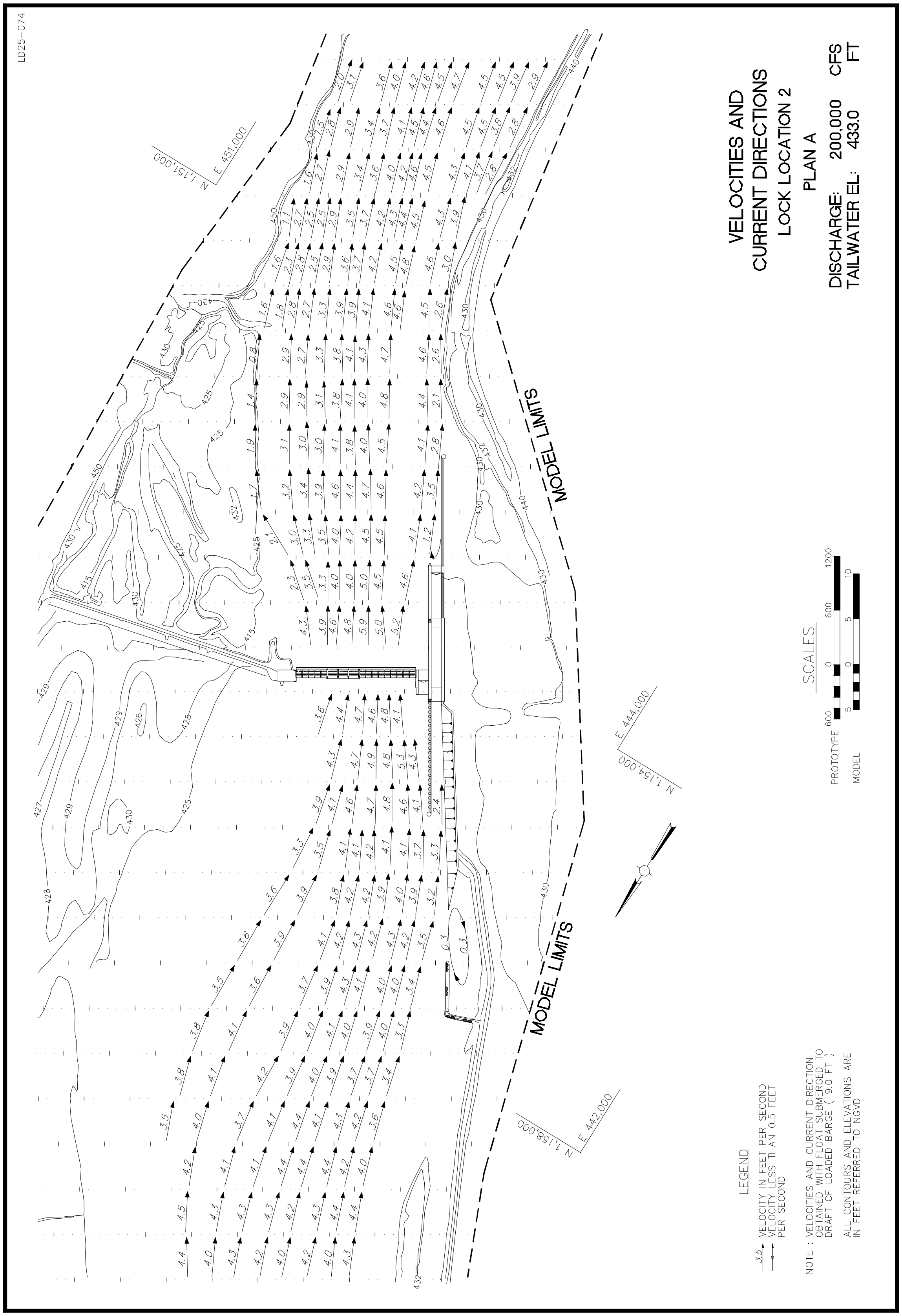

LD25-073
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 2
PLAN A
DISCHARGE: 166,000 CFS
TAILWATER EL: 430.8 FT
MODEL LIMITS
MODEL LIMITS
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000

Plate 20


VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 2
PLAN A
DISCHARGE: 200,000 CFS
TAILWATER EL: 433.0 FT
LD25-074
MODEL LIMITS
MODEL LIMITS
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
Plate 21

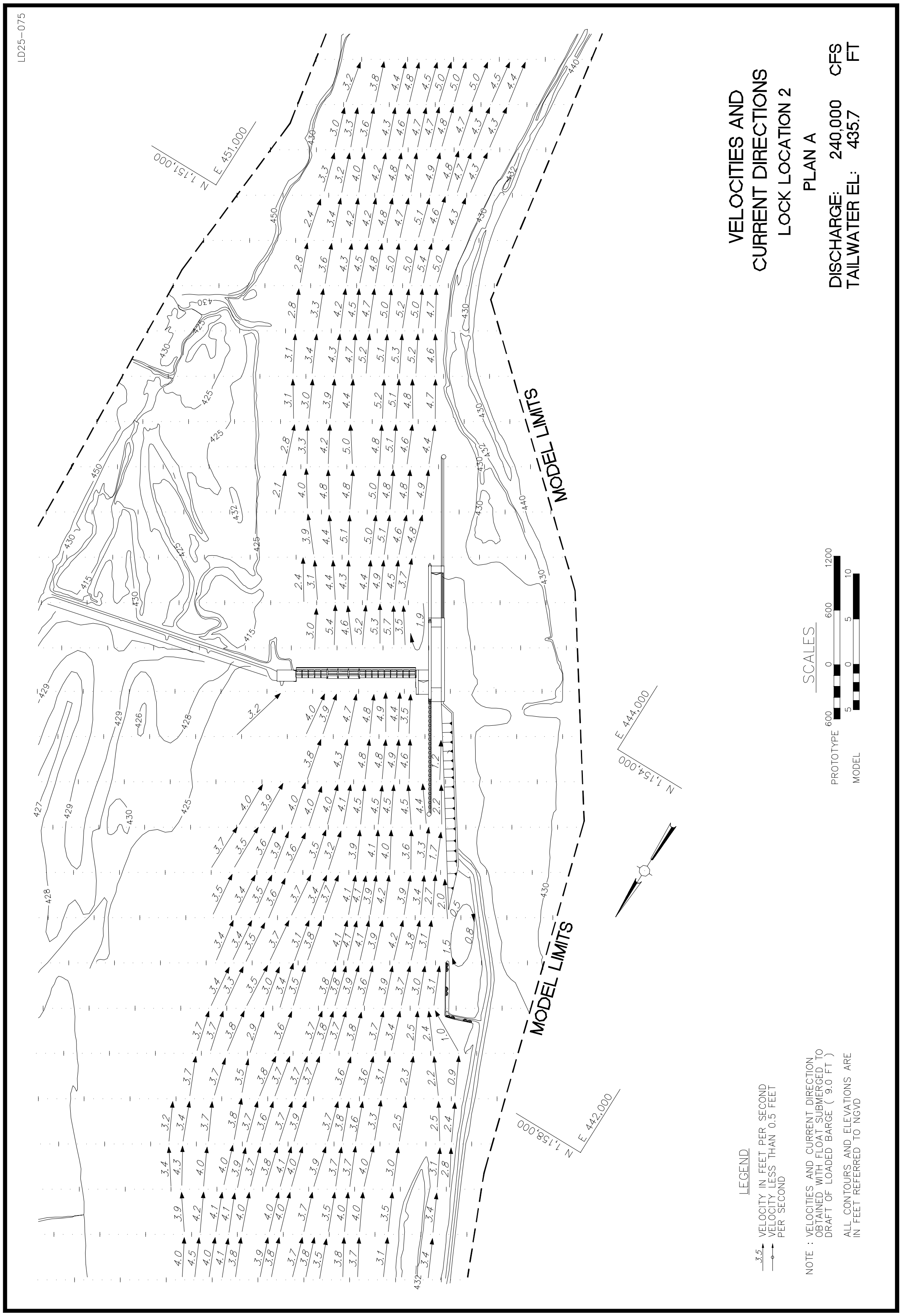
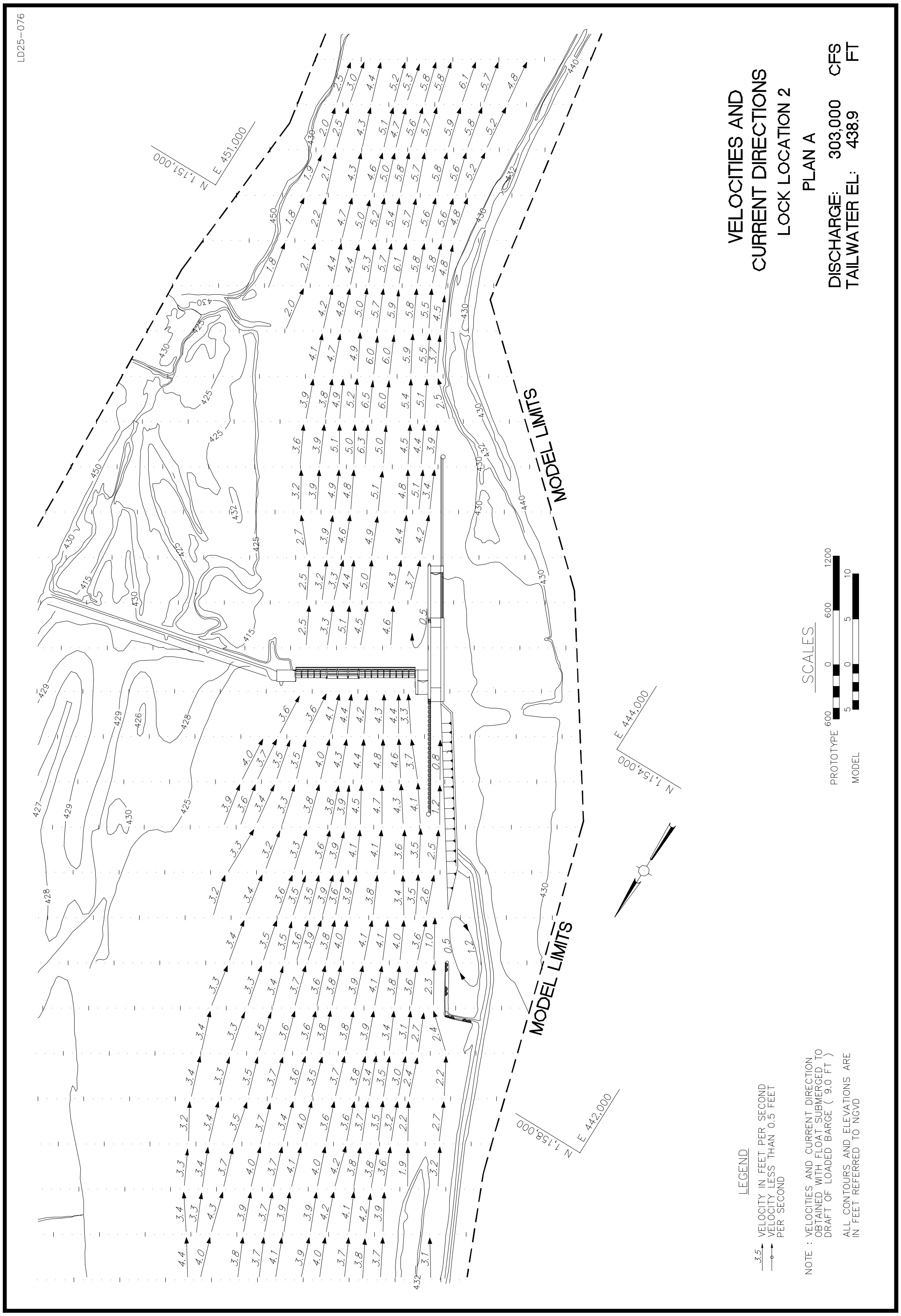

VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 2
PLAN A
DISCHARGE: 240,000 CFS
TAILWATER EL: 435.7 FT
LD25-075
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 22



LD25-076
VELOCITIES AND CURRENT DIRECTIONS
LOCK LOCATION 2
PLAN A
DISCHARGE: 303,000 CFS
TAILWATER EL: 438.9 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 23

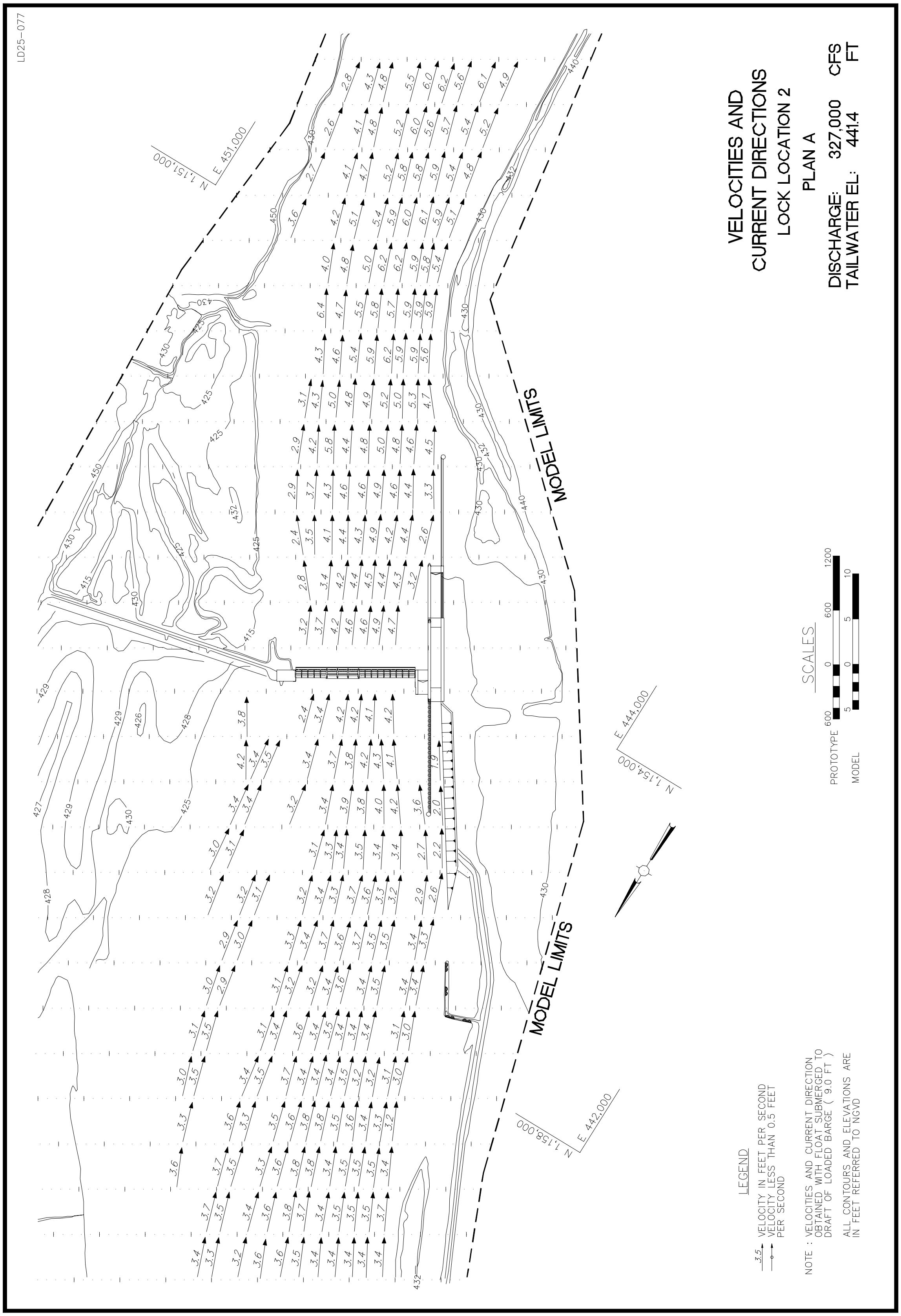

LD25-077
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 2
PLAN A
DISCHARGE: 327,000 CFS
TAILWATER EL: 441.4 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE
MODEL
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 24

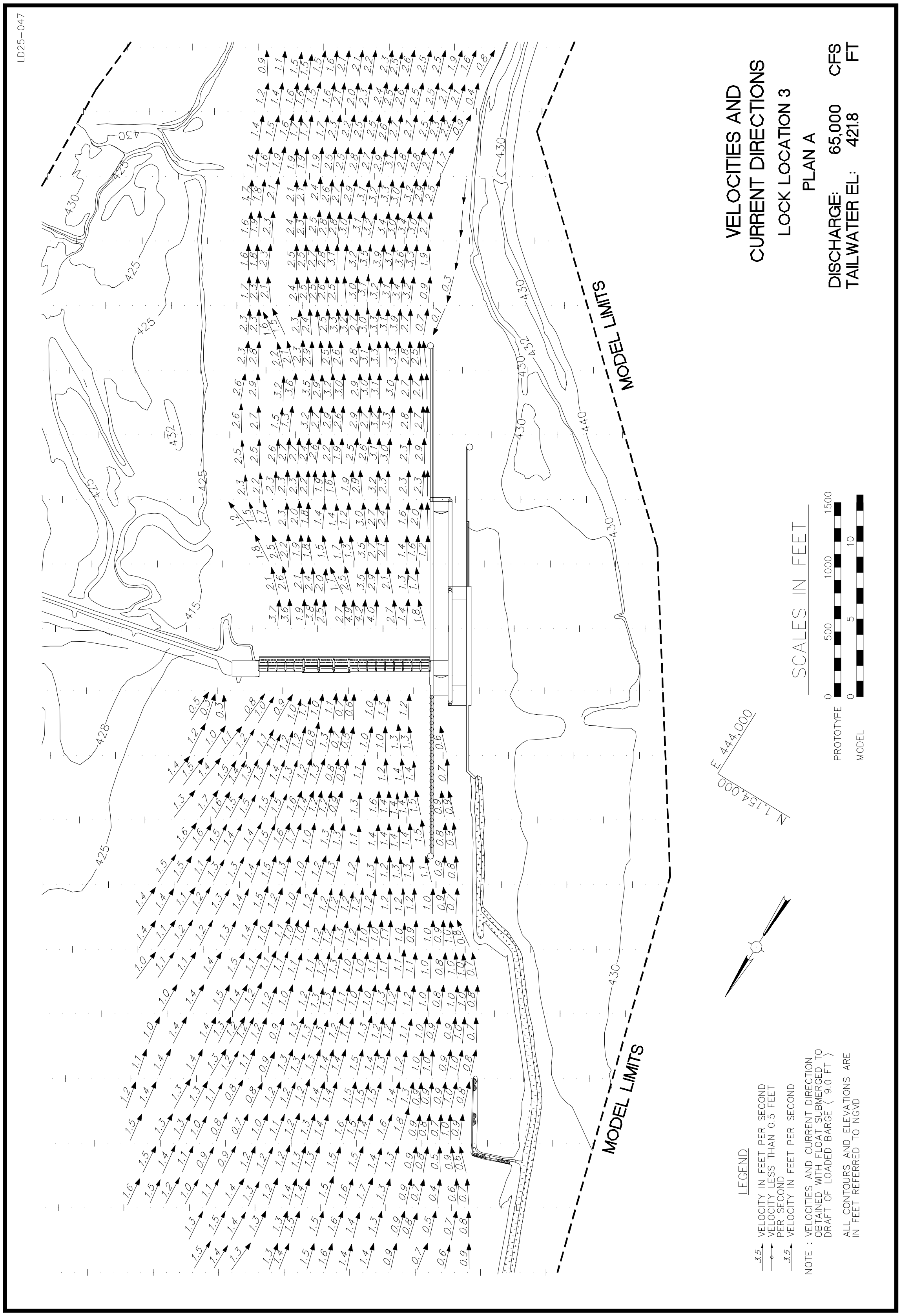
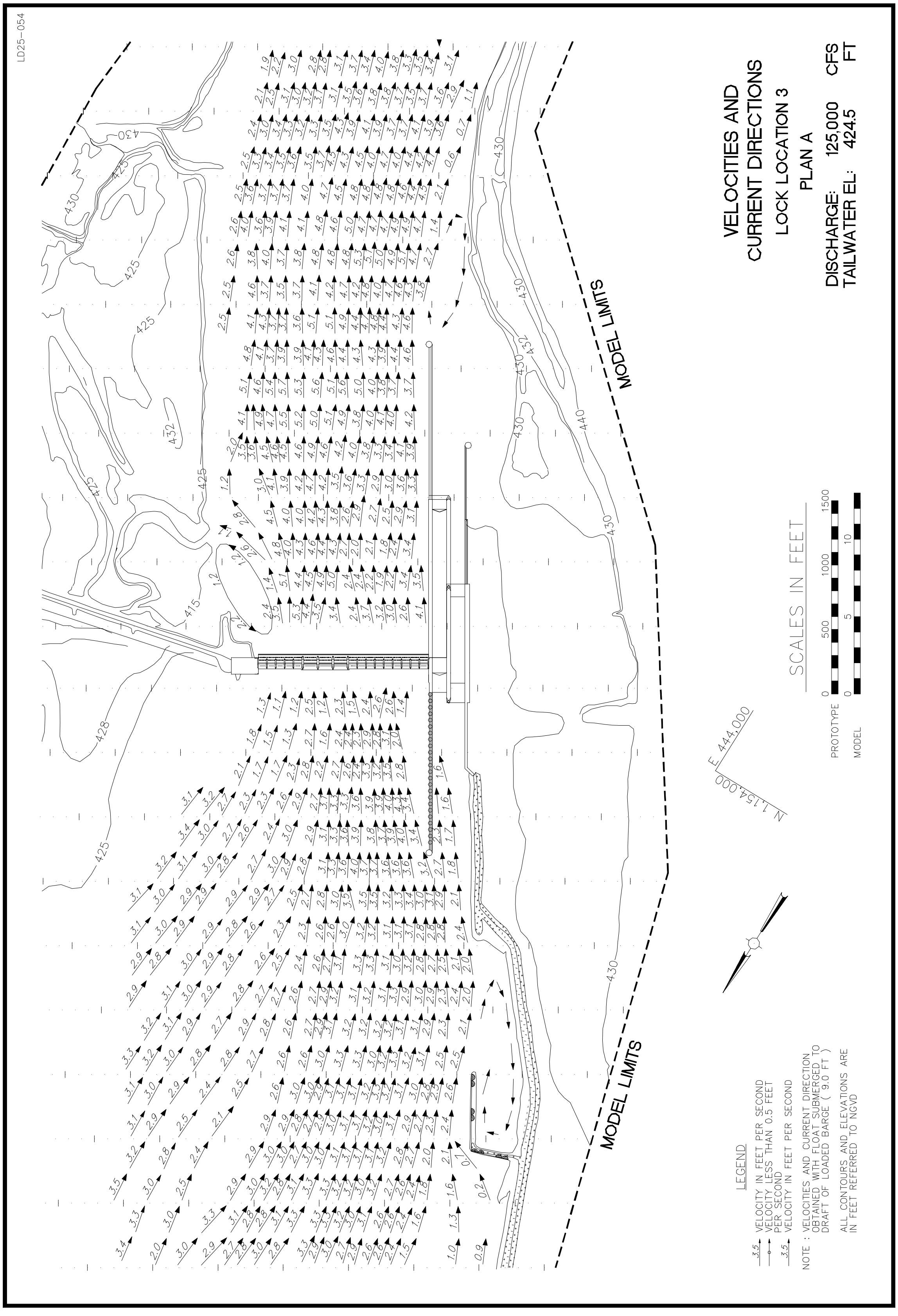
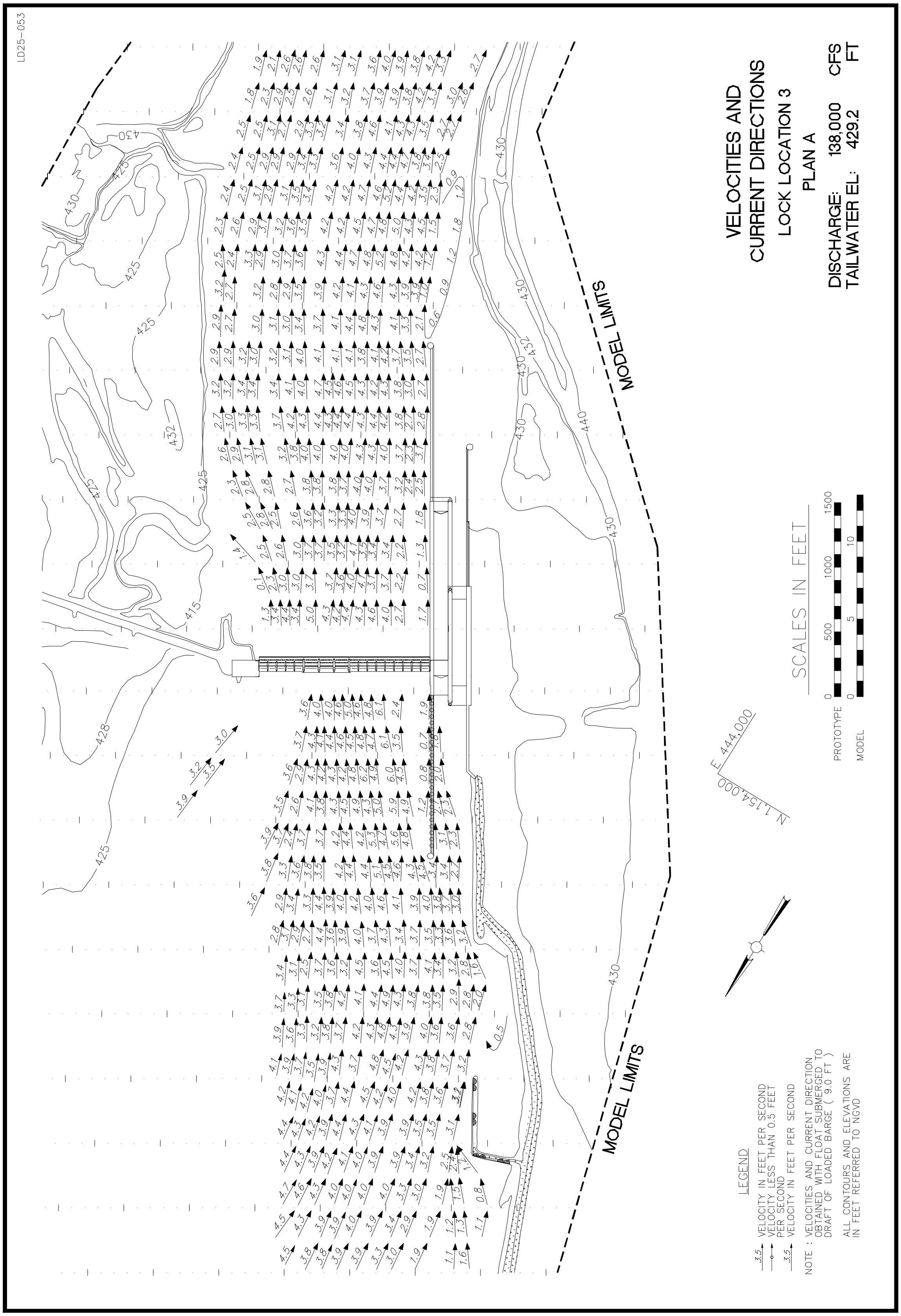

VELOCITIES AND CURRENT DIRECTIONS
LOCK LOCATION 3
PLAN A
DISCHARGE: 65,000 CFS
TAILWATER EL: 421.8 FT
LD25-047
MODEL LIMITS
MODEL LIMITS
SCALES IN FEET
PROTOTYPE 0 500 1000 1500
MODEL 0 5 10
E 444,000
N 1,154,000
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
3.5 VELOCITY IN FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

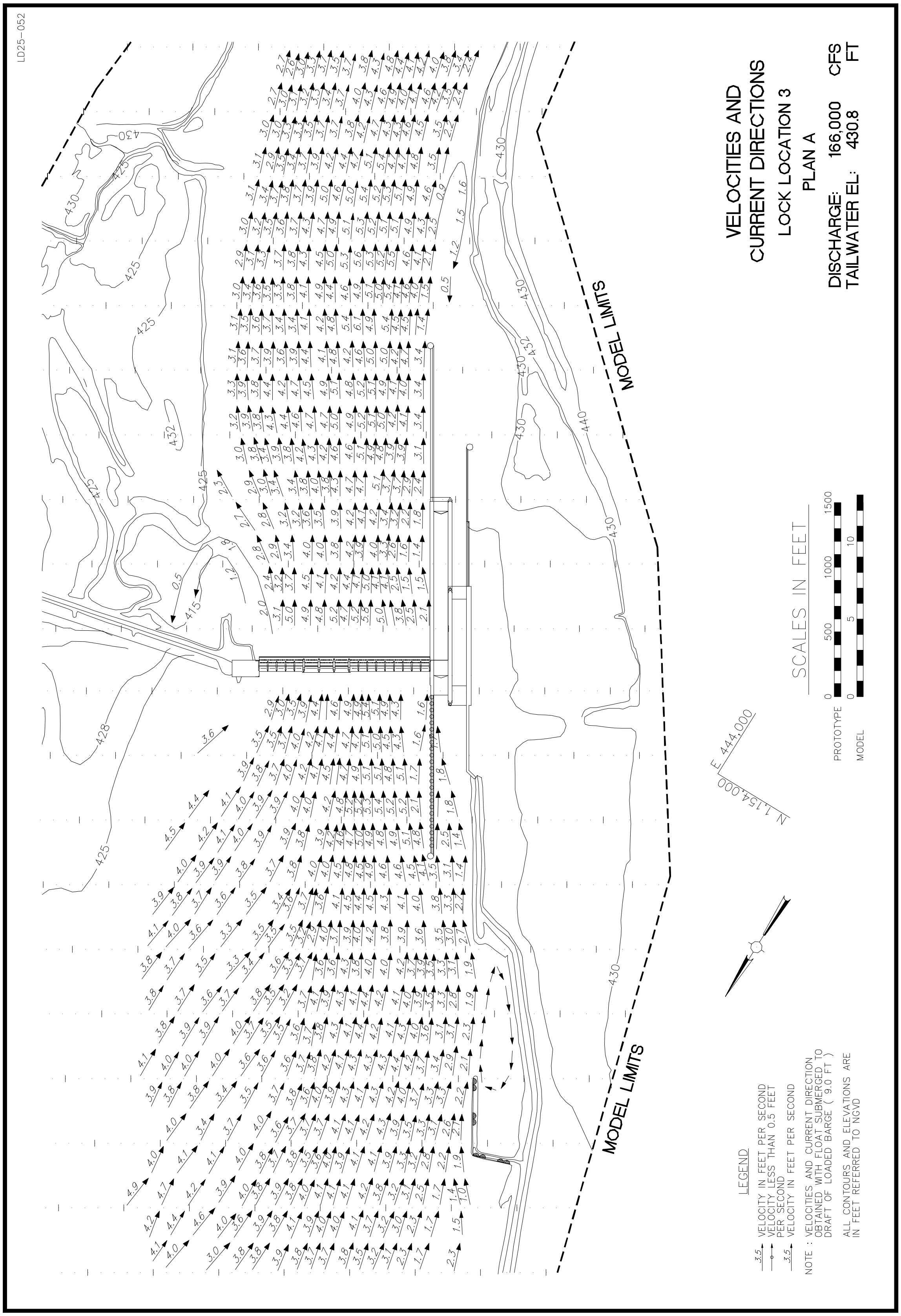
Plate 25



LD25-054
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 3
PLAN A
DISCHARGE: 125,000 CFS
TAILWATER EL: 424.5 FT
MODEL LIMITS
MODEL LIMITS
SCALES IN FEET
PROTOTYPE 0 500 1000 1500
MODEL 0 5 10
E 444,000
N 1,154,000
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
3.5 VELOCITY IN FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 26


VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 3
PLAN A
DISCHARGE: 138,000 CFS
TAILWATER EL: 429.2 FT
SCALES IN FEET
PROTOTYPE 0 500 1000 1500
MODEL 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
3.5 VELOCITY IN FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
MODEL LIMITS
MODEL LIMITS
E 444,000
N 1,154,000
LD25-053



VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 3
PLAN A
DISCHARGE: 166,000 CFS
TAILWATER EL: 430.8 FT
MODEL LIMITS
MODEL LIMITS
SCALES IN FEET
PROTOTYPE 0 500 1000 1500
MODEL 0 5 10
E 444,000
N 1,154,000
LD25-052
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
3.5 VELOCITY IN FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 28

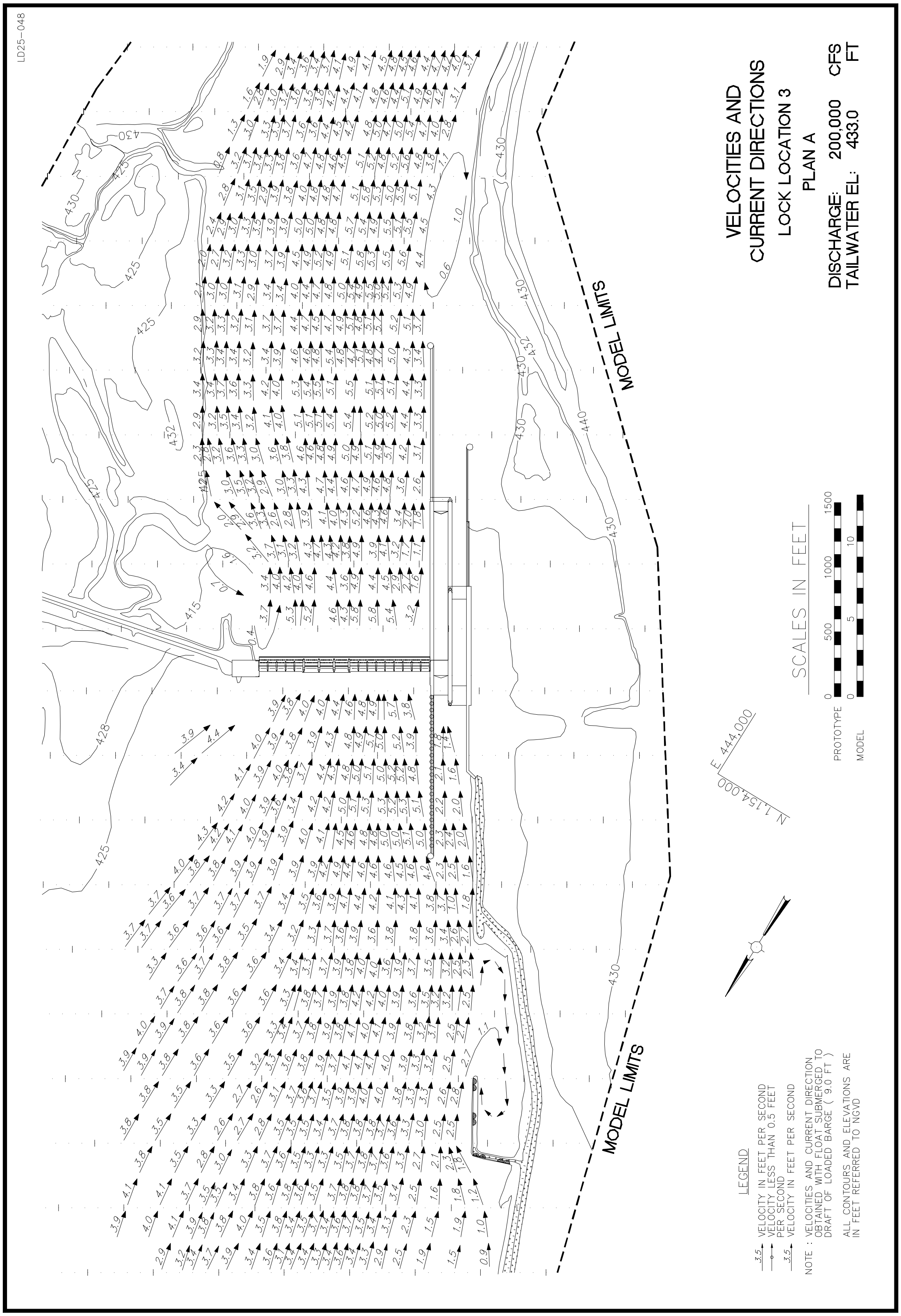

VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 3
PLAN A
DISCHARGE: 200,000 CFS
TAILWATER EL: 433.0 FT
LD25-048
MODEL LIMITS
MODEL LIMITS
SCALES IN FEET
PROTOTYPE 0 500 1000 1500
MODEL 0 5 10
E 444,000
N 1,154,000
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
3.5 VELOCITY IN FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 29

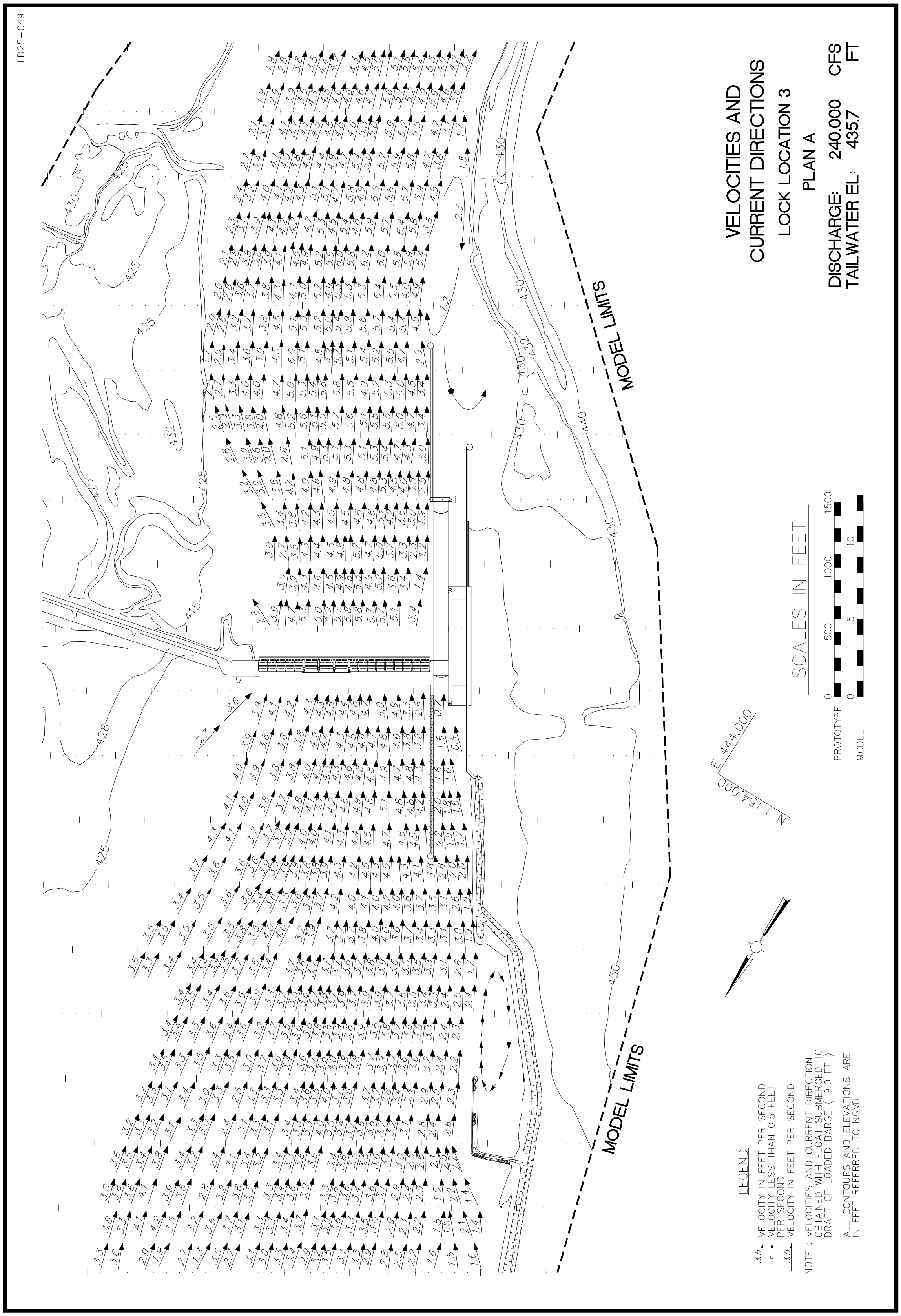
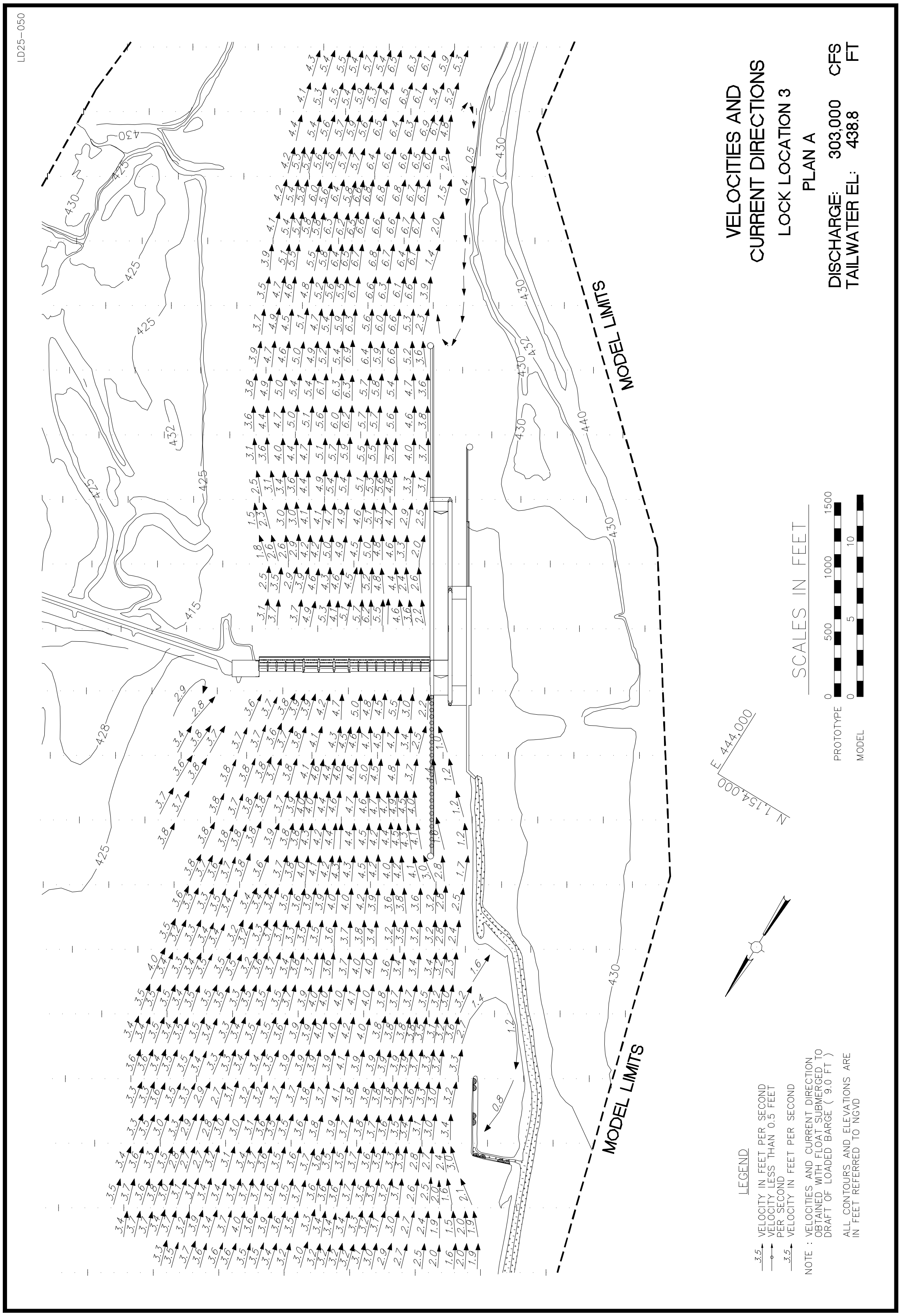

VELOCITIES AND CURRENT DIRECTIONS
LOCK LOCATION 3
PLAN A
DISCHARGE: 240,000 CFS
TAILWATER EL: 435.7 FT
SCALES IN FEET
PROTOTYPE 0 500 1000 1500
MODEL 0 5 10
MODEL LIMITS
MODEL LIMITS
E 444,000
N 1,154,000
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
3.5 VELOCITY IN FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
LD25-049

Plate 30


VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 3
PLAN A
DISCHARGE: 303,000 CFS
TAILWATER EL: 438.8 FT
SCALES IN FEET
PROTOTYPE 0 500 1000 1500
MODEL 0 5 10
MODEL LIMITS
MODEL LIMITS
E 444,000
N 1,154,000
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
3.5 VELOCITY IN FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
LD25-050

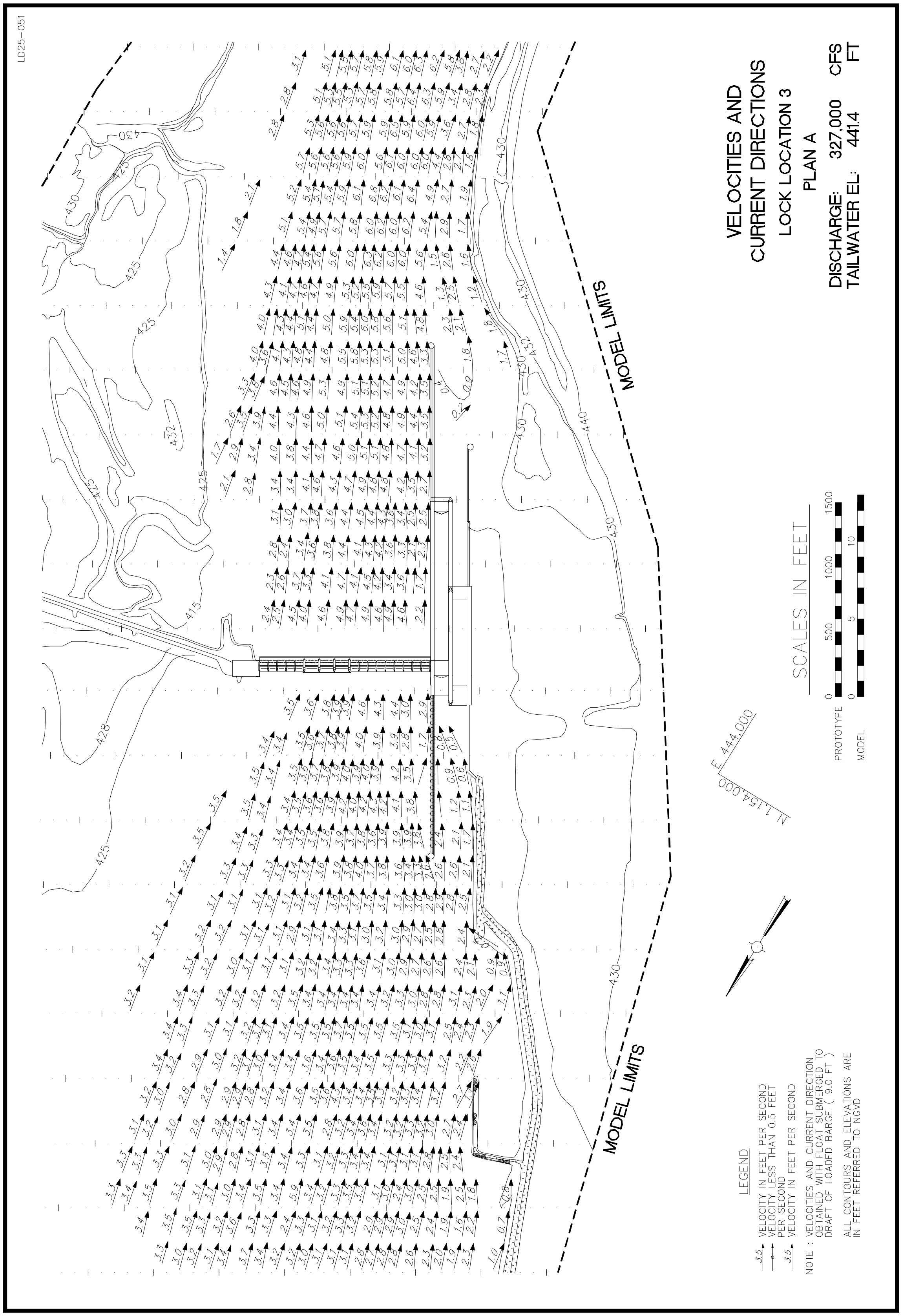

VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 3
PLAN A
DISCHARGE: 327,000 CFS
TAILWATER EL: 441.4 FT
SCALES IN FEET
PROTOTYPE 0 500 1000 1500
MODEL 0 5 10
MODEL LIMITS
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
3.5 VELOCITIES IN FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
E 444,000
N 1,154,000
LD25-051

Plate 32

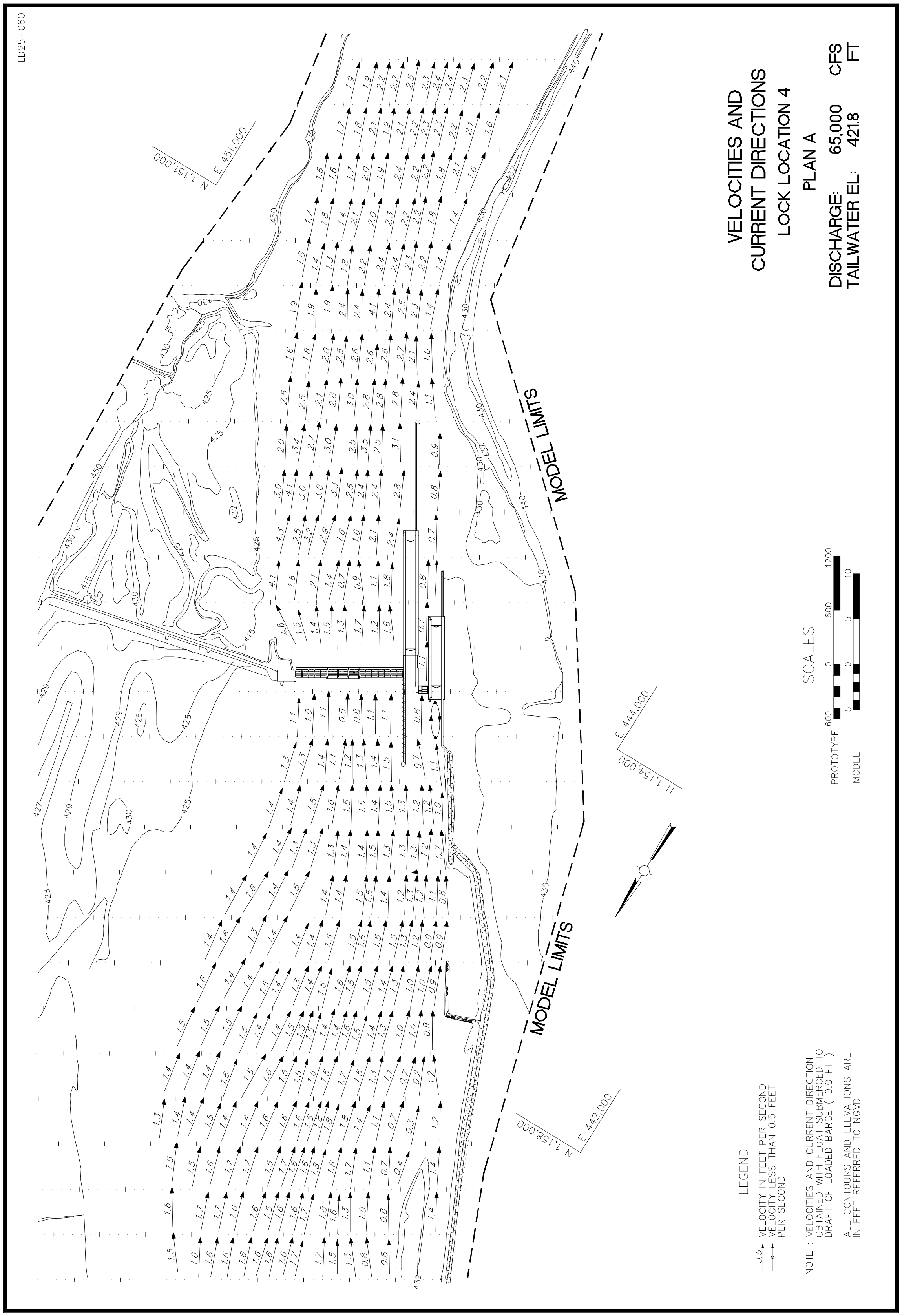

LD25-060
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 4
PLAN A
DISCHARGE: 65,000 CFS
TAILWATER EL: 421.8 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 33

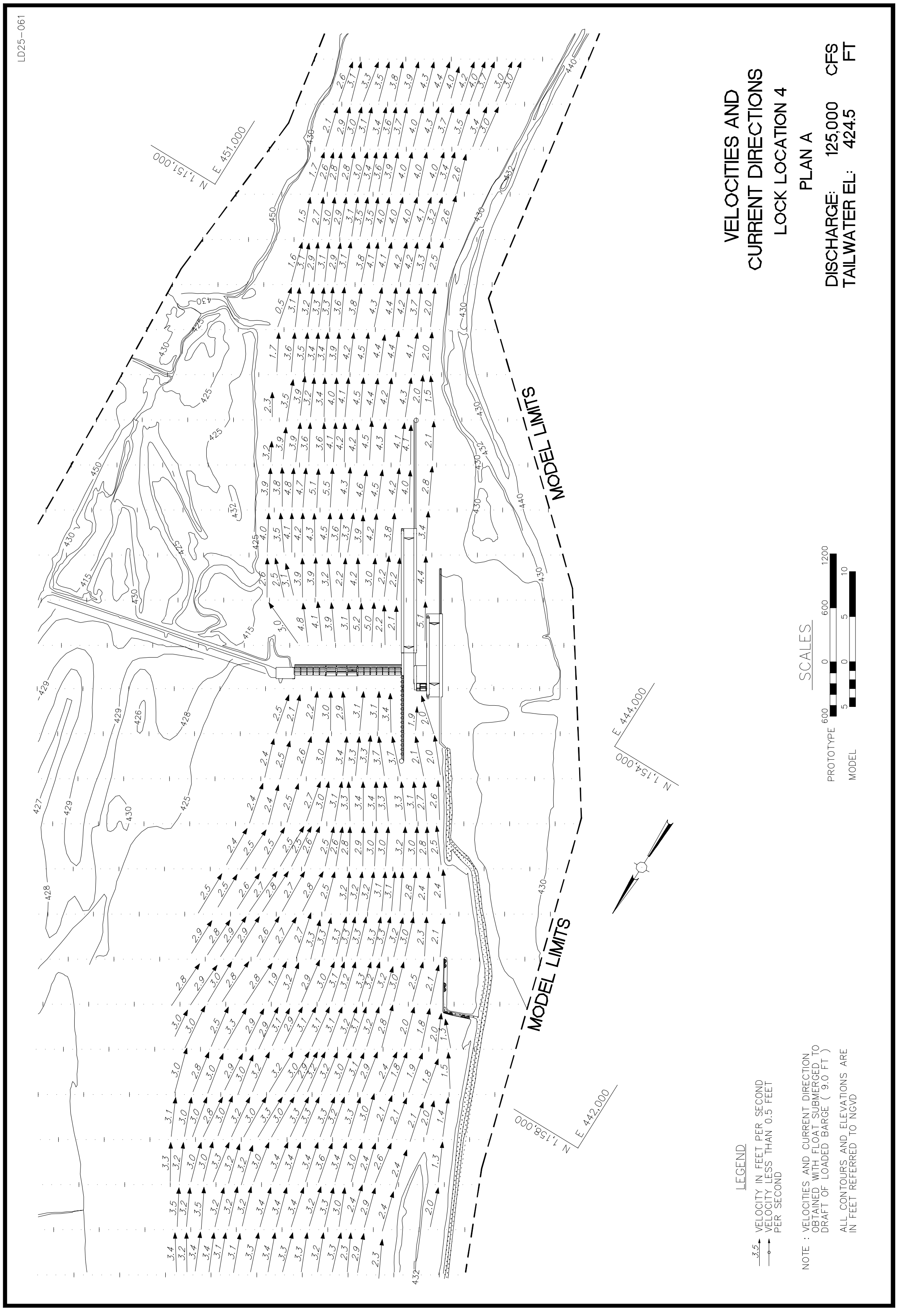
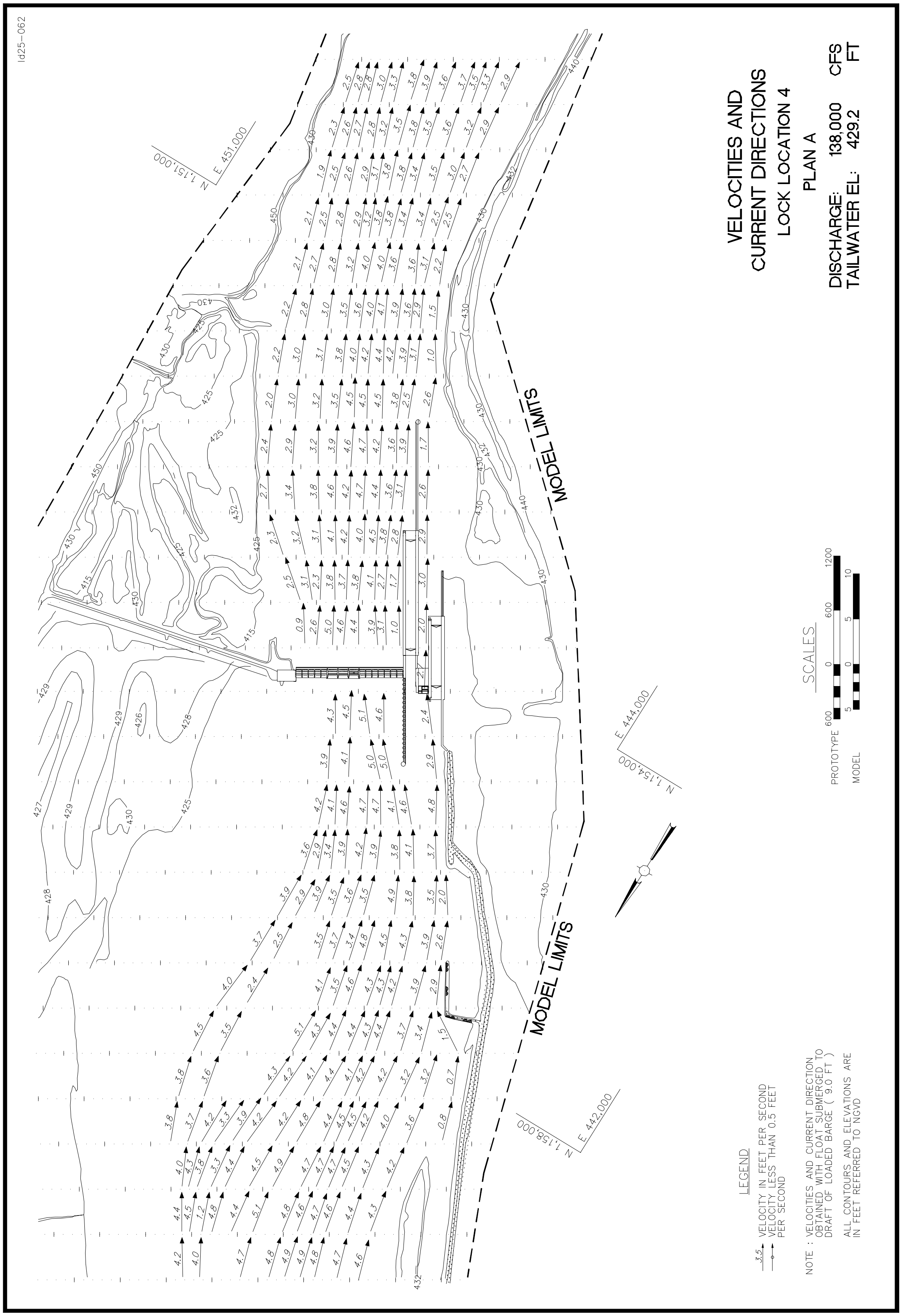

LD25-061
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 4
PLAN A
DISCHARGE: 125,000 CFS
TAILWATER EL: 424.5 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 34



VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 4
PLAN A
DISCHARGE: 138,000 CFS
TAILWATER EL: 429.2 FT
MODEL LIMITS
MODEL LIMITS
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
ld25-062

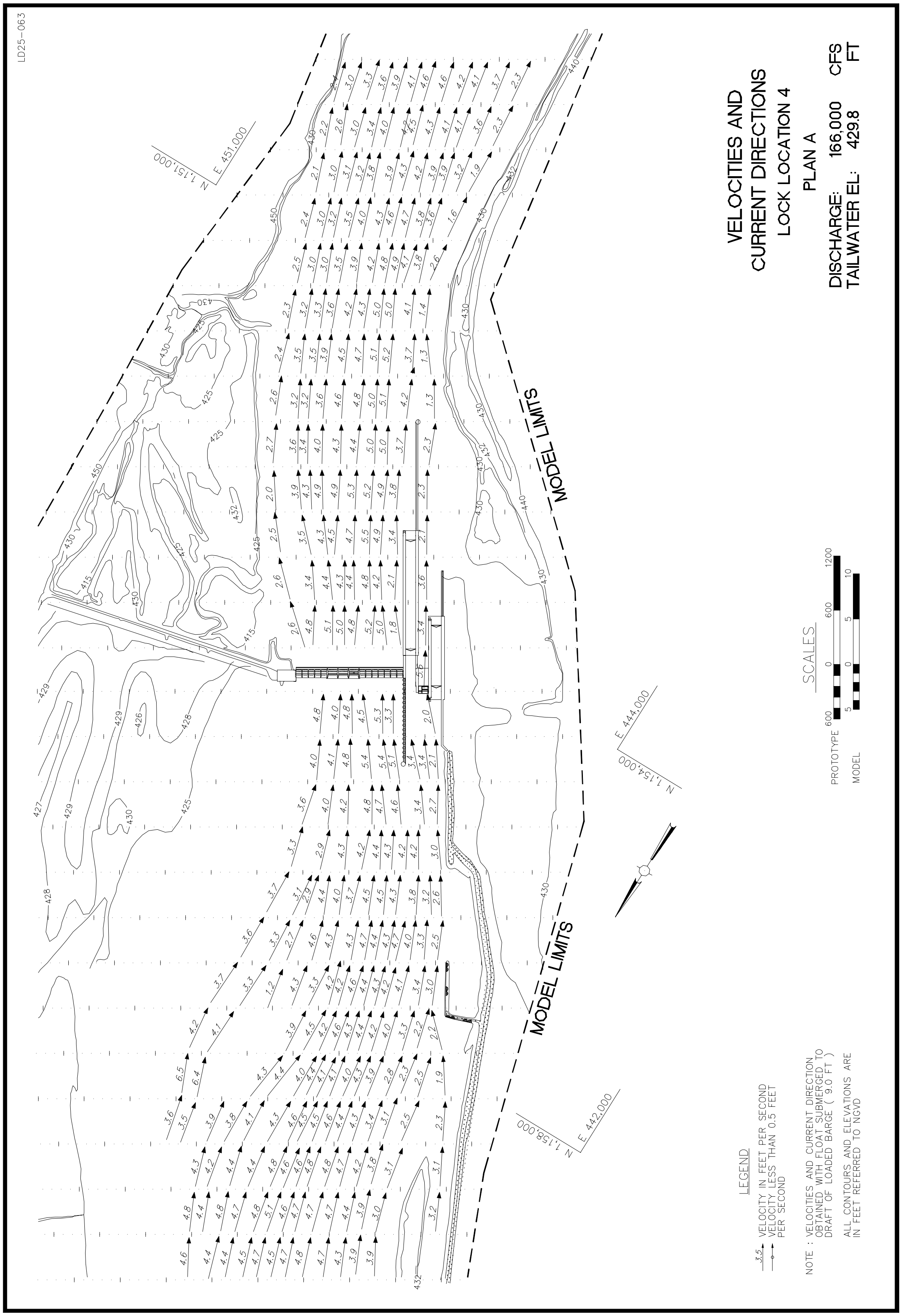
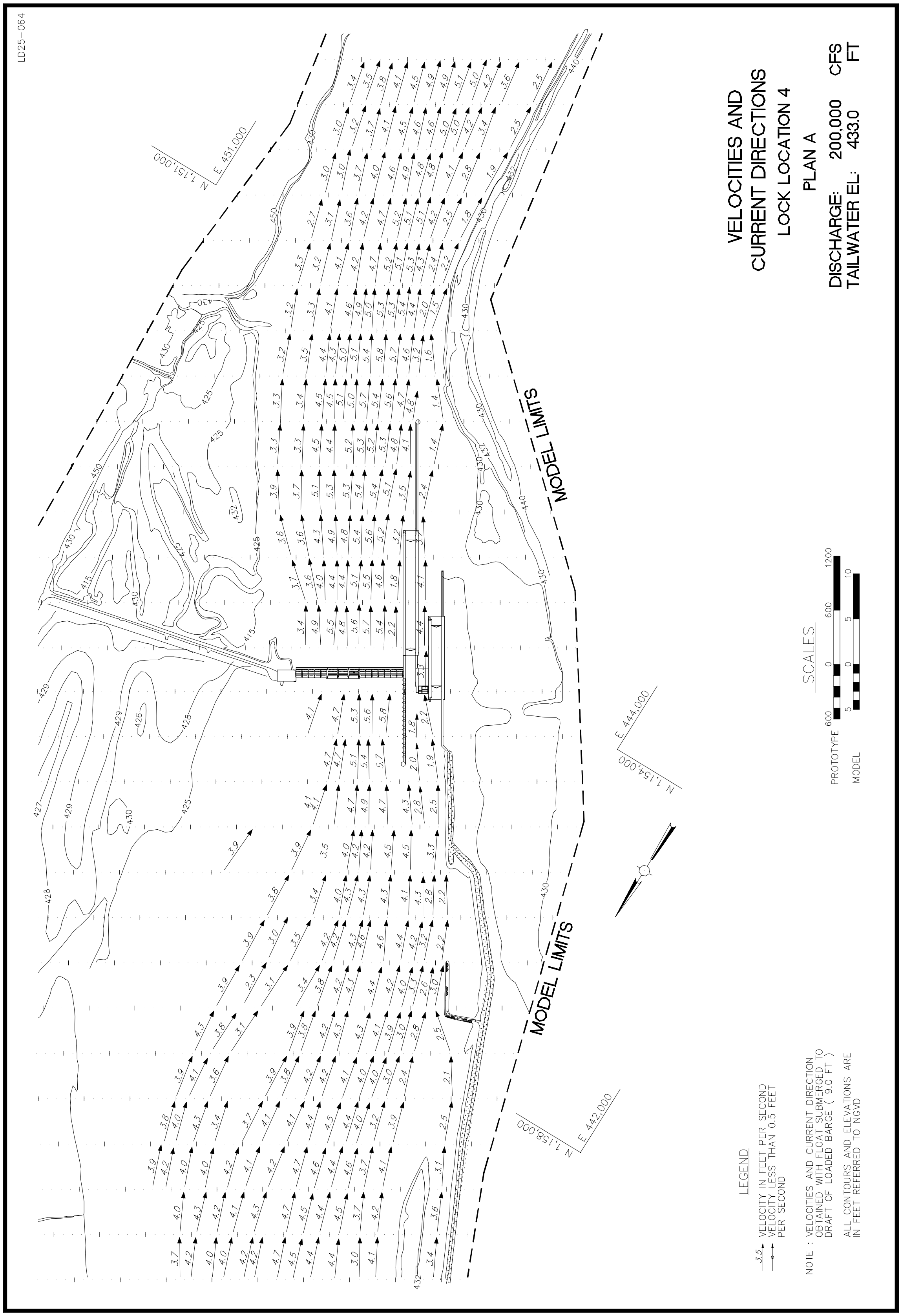

LD25-063
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 4
PLAN A
DISCHARGE: 166,000 CFS
TAILWATER EL: 429.8 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 36



LD25-064
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 4
PLAN A
DISCHARGE: 200,000 CFS
TAILWATER EL: 433.0 FT
MODEL LIMITS
MODEL LIMITS
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 37

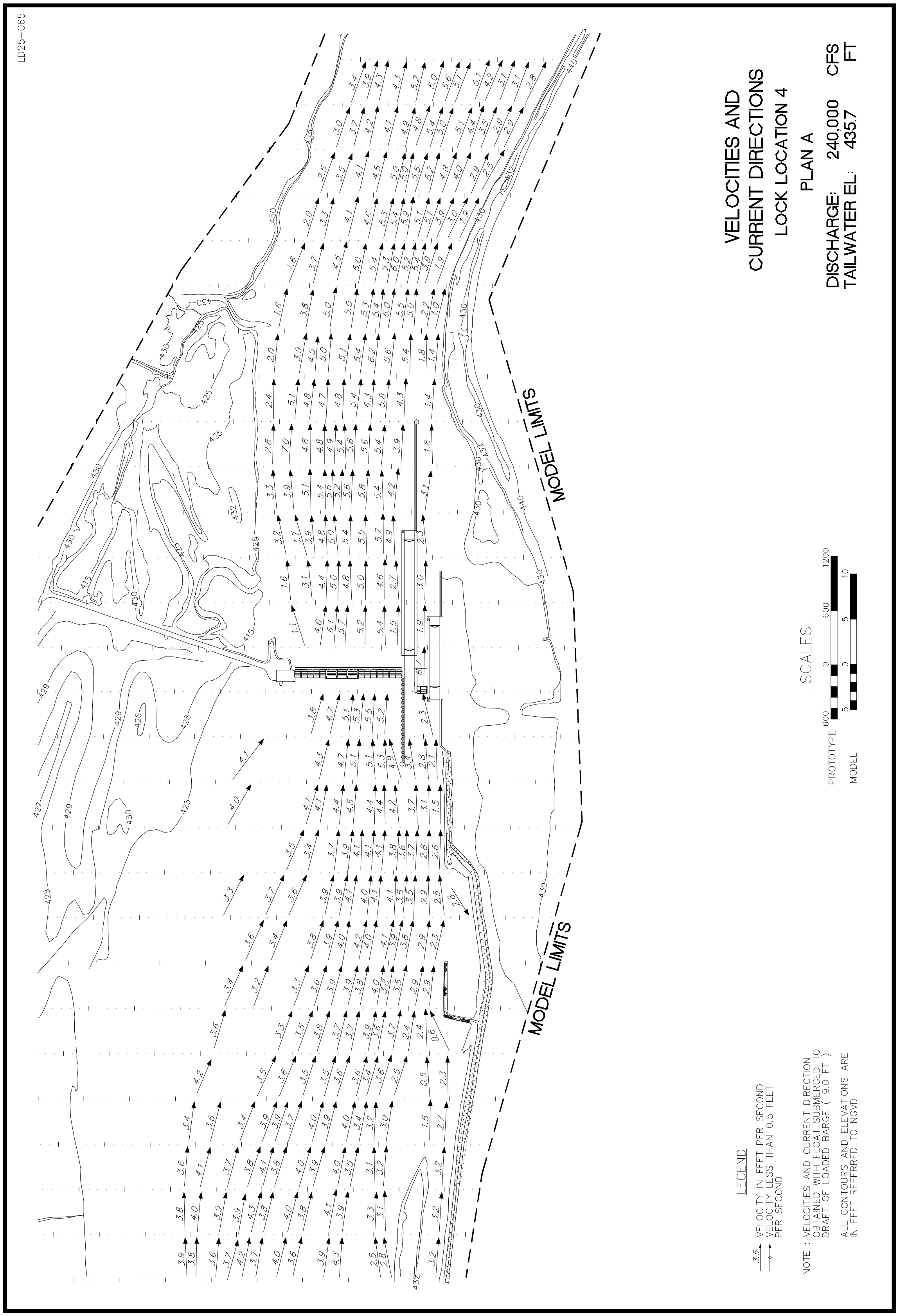
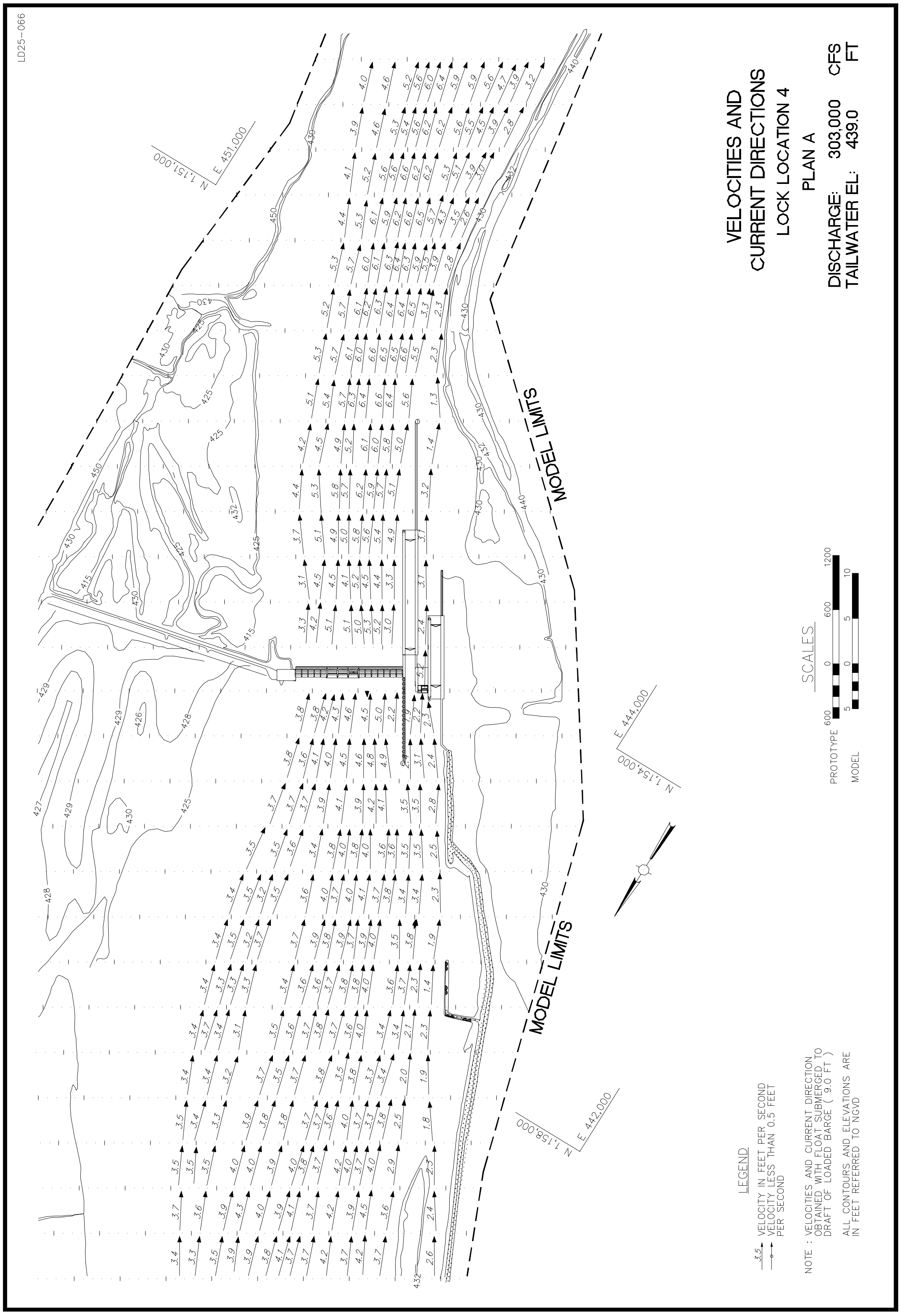
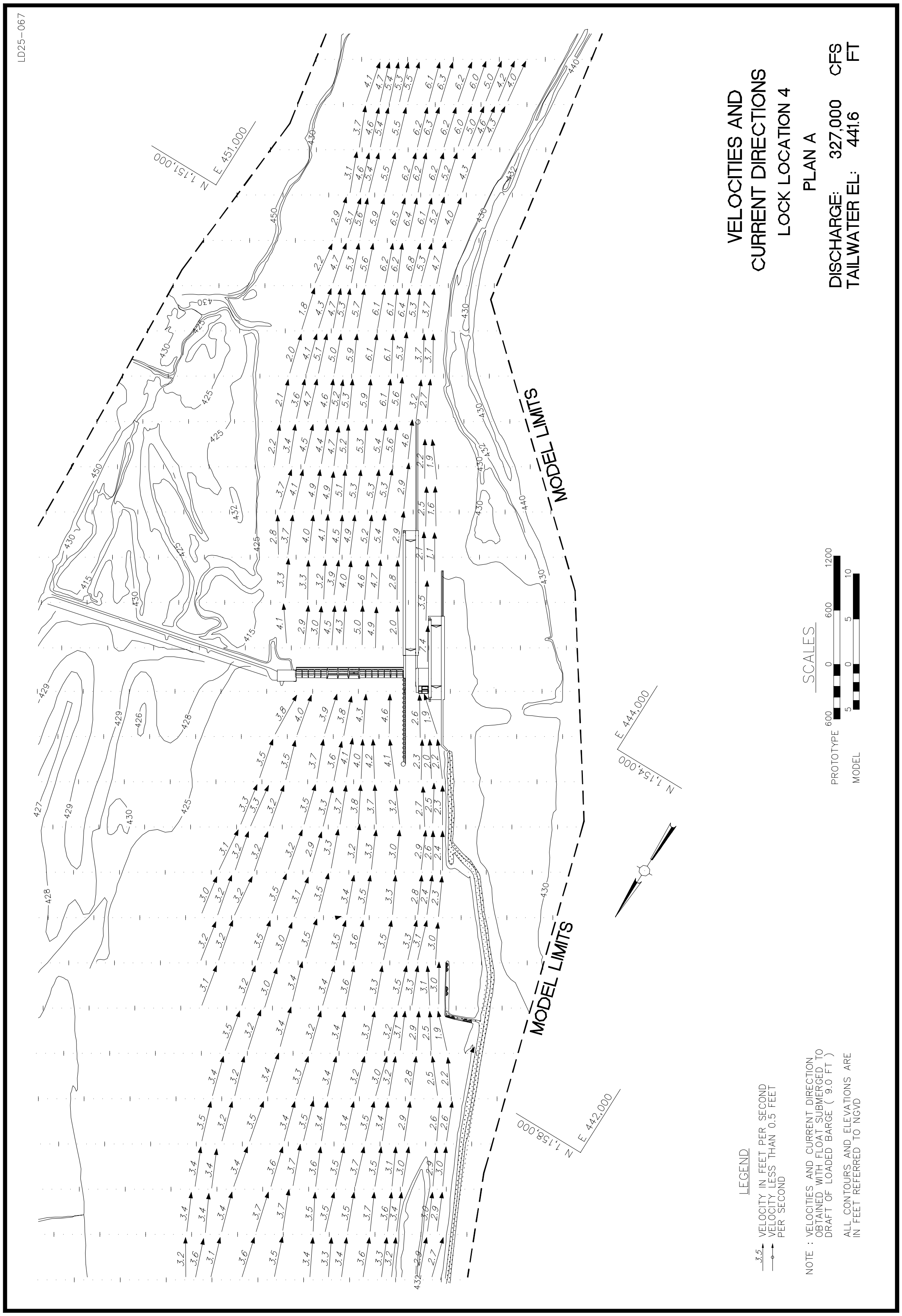

LD25-065
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 4
PLAN A
DISCHARGE: 240,000 CFS
TAILWATER EL: 435.7 FT
MODEL LIMITS
MODEL LIMITS
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD

Plate 38



LD25-066
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 4
PLAN A
DISCHARGE: 303,000 CFS
TAILWATER EL: 439.0 FT
MODEL LIMITS
MODEL LIMITS
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000

Plate 39



LD25-067
VELOCITIES AND
CURRENT DIRECTIONS
LOCK LOCATION 4
PLAN A
DISCHARGE: 327,000 CFS
TAILWATER EL: 441.6 FT
MODEL LIMITS
MODEL LIMITS
SCALES
PROTOTYPE 600 0 600 1200
MODEL 5 0 5 10
LEGEND
3.5 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
NOTE : VELOCITIES AND CURRENT DIRECTION OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO NGVD
N 1,151,000
E 451,000
N 1,154,000
E 444,000
N 1,158,000
E 442,000

Plate 40

REPORT DOCUMENTATION PAGE

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13. ABSTRACT ***(Maximum 200 words)***

Lock and Dam 25 is located on the Mississippi River, 241.5 miles upstream of its confluence with the Ohio River. The principal existing structures are the main 110- by 600-ft lock located along the right descending bank, an incomplete auxiliary lock located riverward of the main lock, and a 1,296-ft dam with fourteen 60-ft tainter gates and three 100-ft roller gates. An overflow dike with top elevation of 434.0 (elevations (el) are in feet referred to the National Geodetic Vertical Datum) extends from the dam to high ground on the left bank. The dam provides a navigation pool that extends upstream about 32 miles to Lock and Dam 24. The dam is operated to maintain a navigation pool that varies from el 434.0 to 429.7 at the dam and from el 434.0 to 437.0 at Mosier Landing (river mile 260.3). As the riverflow increases, the gates are raised to prevent exceeding the limits at Mosier Landing. A fixed-bed model reproduced about 3.7 miles of the Mississippi River and adjacent overbank from about 9,800 ft upstream to about 9,600 ft downstream of the existing dam to an undistorted scale of 1:120.

Four locations are being considered for a new lock at Dam 25. The model investigation was concerned with evaluating navigation conditions for each lock location and identifying any needed modifications to the navigation channel alignment, guard wall lengths, or remedial structures. This information will also be used in the preliminary design of locks at other dam

(Continued)

14. SUBJECT TERMS

Fixed-bed models	Locks (Waterways)
Hydraulic models	Mississippi River
Lock and Dam 25	Navigation conditions

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UNCLASSIFIED	UNCLASSIFIED		

13. (Concluded).

sites along the upper Mississippi River. Results of the investigation revealed that with all locations, realigning the navigation channel upstream of the lock and adding a ported upstream guard wall would reduce the outdraft, eliminate the need for a helper towboat, and improve navigation conditions for tows entering and leaving the upper lock approach. Lock Locations 1 and 2 would require a ported upper guard wall, extensive modification of the right bank upstream and downstream of the lock, and realignment of the navigation channel upstream of the lock to provide satisfactory navigation conditions for tows entering and leaving the lock. Marginally acceptable navigation conditions could be established at Lock Location 3 by adding a ported guard wall, but realignment of the navigation channel upstream of the lock and excavation of the right bank immediately downstream of the lock would improve navigation conditions considerably for tows entering and leaving the locks. Lock Location 4 with a ported upper guard wall provided acceptable navigation conditions for tows entering and leaving the new lock without any modification to the existing navigation channel. However, the ported guard wall should be extended about 400 ft to provide protection for the design size tow, and the gate between the locks should be closed when downbound tows are approaching the lock.