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NAVIGATION CONDITIONS AT THE UPSTREAM APPROACH TO LOCK AND DAM NO. 3 MISSISSIPPI RIVER

Hydraulic Model Investigation

by

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The Lock and Dam No. 3 navigation structure is located on the upper Mississippi River at about mile 797 above the mouth of the Ohio River and 44.2 miles above Lock and Dam No. 4. The structure is designed to maintain a minimum upper pool during low flows extending 18.3 miles upstream to Lock and Dam No. 2 on the Mississippi River and approximately 52 miles up the St. Croix River. The section of pool extending into the upper Mississippi River provides water access to Minneapolis and St. Paul, Minnesota. The four-gated

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20. ABSTRACT (Continued).

spillway section is located in the main river channel, and the lock with clear chamber dimensions of 110 by 600 ft and the upper lock gates for a proposed second lock are located in a bypass canal on the right overbank. A fixed-bed model reproducing about 2 miles of the Mississippi River channel, upstream lock approach, a portion of Sturgeon Lake, and adjacent overbank areas to an undistorted scale of 1:120 was used to determine the adequacy of the proposed plan and to develop modifications required to eliminate any adverse conditions indicated. The model investigation was concerned principally with navigation conditions in the upstream approach to the lock, the development of modifications required to improve navigation conditions in the upper lock approach, and the effects of the modifications on the movement of ice and debris. Results of the investigation revealed that satisfactory navigation conditions in the upper lock approach could be developed by replacement of the guide wall with a guard wall with some excavation along the right bank or with a rock dike extending upstream from the right abutment wall of the dam. Ice gaps or openings would be required to reduce the accumulation of ice in the lock approach with either of the plans.

PREFACE

The model investigation reported herein was authorized by the Office, Chief of Engineers, U. S. Army, in an indorsement dated 26 July 1973 to the Division Engineer, U. S. Army Engineer Division, North Central. The study was conducted for the U. S. Army Engineer District, St. Paul (NCS), in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) during the period September 1974 to May 1976.

The investigation was conducted under the general supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and F. A. Herrmann, Jr., Assistant Chief of the Hydraulics Laboratory; and under the direct supervision of Mr. J. E. Glover, Chief of the Waterways Division. The engineer in immediate charge of the model study was Mr. L. J. Shows, Chief of the Navigation Branch, assisted by Mr. R. T. Wooley. This report was prepared by Messrs. Shows and J. J. Franco.

During the course of the model study, Messrs. George Hebaus, Grant Westall, Peter Fischer, and Leonard Gloeb, along with other representatives from NCS visited WES at different times to observe special model tests and discuss the results. NCS was kept informed of the progress of the study through monthly progress reports and special reports at the end of each test.

Commanders and Directors of WES during the course of the investigation and the preparation and publication of this report were COL G. H. Hilt, CE, COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
miles (U. S. statute)	1.609344	kilometres
square miles (U. S. statute)	2.589988	square kilometres

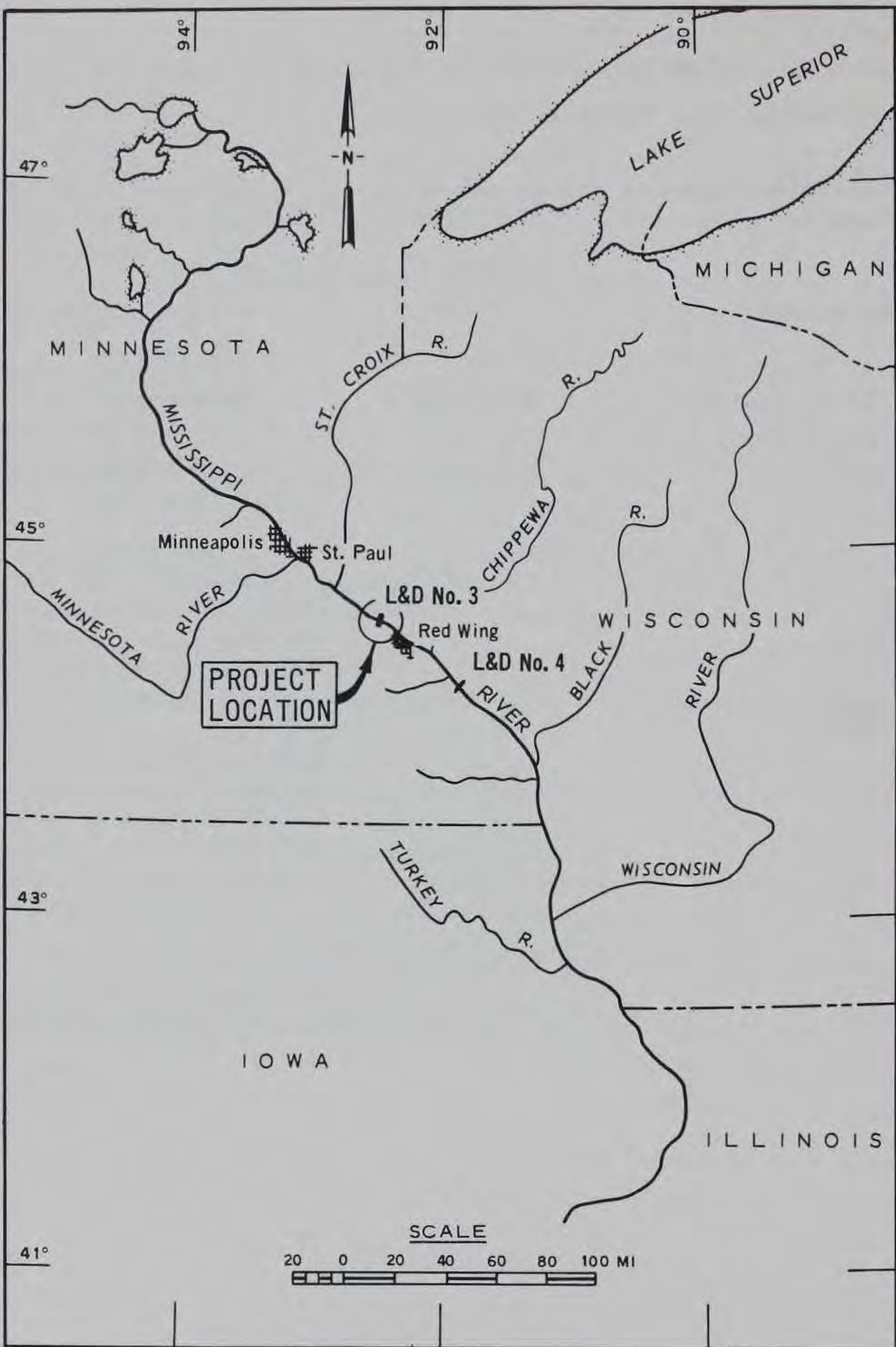

Figure 1. Location map

NAVIGATION CONDITIONS AT THE UPSTREAM APPROACH TO LOCK AND DAM NO. 3, MISSISSIPPI RIVER

Hydraulic Model Investigation

PART I: INTRODUCTION

1. Lock and Dam No. 3 is located on the Mississippi River at approximately mile 797,* about 44.2 miles** above Lock and Dam No. 4 and 6.1 miles above the town of Red Wing, Minnesota. The normal upper pool of Lock and Dam No. 3 is at el 675.0† and extends 18.3 miles upstream to Lock and Dam No. 2 and approximately 52 miles up the St. Croix River, the only significant tributary entering the pool. The section of the pool extending into the upper Mississippi River provides waterway access to Minneapolis and St. Paul, Minnesota (Figure 1).

2. The total drainage area of the Mississippi River at Lock and Dam No. 3 is 45,170 square miles, of which the St. Croix River contributes 7,650 square miles. The maximum flow of record occurred in 1881 and is estimated to be 134,000 cfs; the minimum flow, 2,200 cfs, occurred in 1934.

History of Navigation Improvements on the Mississippi River

3. 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.

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* Miles refer to river miles above the mouth of the Ohio River.

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

† Elevations (el) cited herein are in feet referred to mean sea level, 1912 adjustment.

4. 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, Minnesota, 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.

5. A project adopted in 1880 provided for navigational improvements which 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 and St. Paul. This project established the groundwork for Locks and Dams Nos. 1 and 2. The channel depth was changed from a 5- to a 6-ft channel 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, Minnesota, was to be achieved by construction of a system of locks and dams, supplemented by dredging. On 30 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.

6. The Mississippi River above St. Louis, Missouri, 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 Lock and Dam No. 3

7. Lock and Dam No. 3 consisted of: a 110- by 600-ft main lock, and the upper portion of a 110-ft-wide auxiliary lock to be completed in the future, if required; a gated dam consisting of four 20- by 80-ft roller gates; and a fixed section between the locks and gated dam. The locks are located in the southern channel and the dam in the northern channel divided by an island in the river. The structures are supported on timber pilings driven in sand and gravel with steel-sheet piling cutoff walls. The structures provide a normal upper pool at el 675.0, and with a normal lower pool el 667.0, the lock has a maximum lift of 8 ft.

The Problem

8. The upper approach to the lock is located on the concave side of a sharp bend with the dam located on the left just downstream of the convex side. Flow from along the right bank (concave side of the bend) moves sharply to the left toward the dam and across the approach to the lock. Because of the crosscurrents, navigation conditions for downbound tows approaching the lock are extremely difficult and hazardous, particularly during the higher flows. Many accidents have occurred caused by tows losing control and drifting into the dam while maneuvering for the approach to the lock. In 1963, a barge drifted into the dam and sank, causing serious scour near the dam. Scouring also occurred along the training dike upstream of the upper guide wall caused by tows attempting to become aligned to approach the guide wall during high flows.

Need for and Purpose of Model Study

9. Conditions in the upper approach to the lock were caused by crosscurrents affected by the alignment and configuration of the channel upstream and by the location of the gated dam with respect to the lock and alignment of the channel. Because of the factors involved and the complex nature of flow in the reach, an analytical solution to the

problem would be extremely difficult and inconclusive. Accordingly, a model study of the problem was considered necessary to determine the conditions that would develop with the various modifications proposed and to develop alternate solutions that might eliminate or minimize the problem. The purposes of the model study were to:

- a. Determine the relative effectiveness of proposed channel modifications and training structures.
- b. Determine the effectiveness of changes in the length of the guide wall and changes in the number and location of gates in the dam.
- c. Develop alternate plans that might be required.
- d. Determine the effects of proposed changes on the buildup of ice and debris in the lock approach.
- e. Demonstrate the conditions resulting from proposed modifications for the design engineers and navigation interests.

PART II: THE MODEL

Description

10. The model (Figure 2) was a scale reproduction of a short reach (about 2 miles) of the Mississippi River channel, and adjacent overbank area from about 9,000 ft upstream of the dam (mile 798.8) to 1,200 ft below the dam (mile 796.7). The model was of the fixed-bed type with the channel and overbank areas molded in sand-cement mortar to sheet-metal templates. Portions of the model, where changes in bank alignments and channel configurations were considered or could be anticipated, were molded in pea gravel to allow for easy modification. The lock, dam, crest, piers, and guard and guide walls were built from sheet metal. The dam gates were simulated schematically with simple vertical sheet-metal slide-type gates.

11. The model was molded to hydrographic and topographic surveys made in February 1974. Some of the overbank areas were molded to a maximum elevation of 690.0, depending on its effect on currents in the lock approach during all flows affecting navigation.

Scale Relations

12. The model was built to an undistorted linear scale ratio of 1:120, model to prototype, to obtain accurate reproduction of velocities, crosscurrents, and eddies that would affect navigation. Other scale ratios resulting from the linear scale ratio (based on Froudian criteria) are:

Area	1:14,000
Velocity	1:10.95
Time	1:10.95
Discharge	1:157,743
Roughness (Manning's n)	1:2.22

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

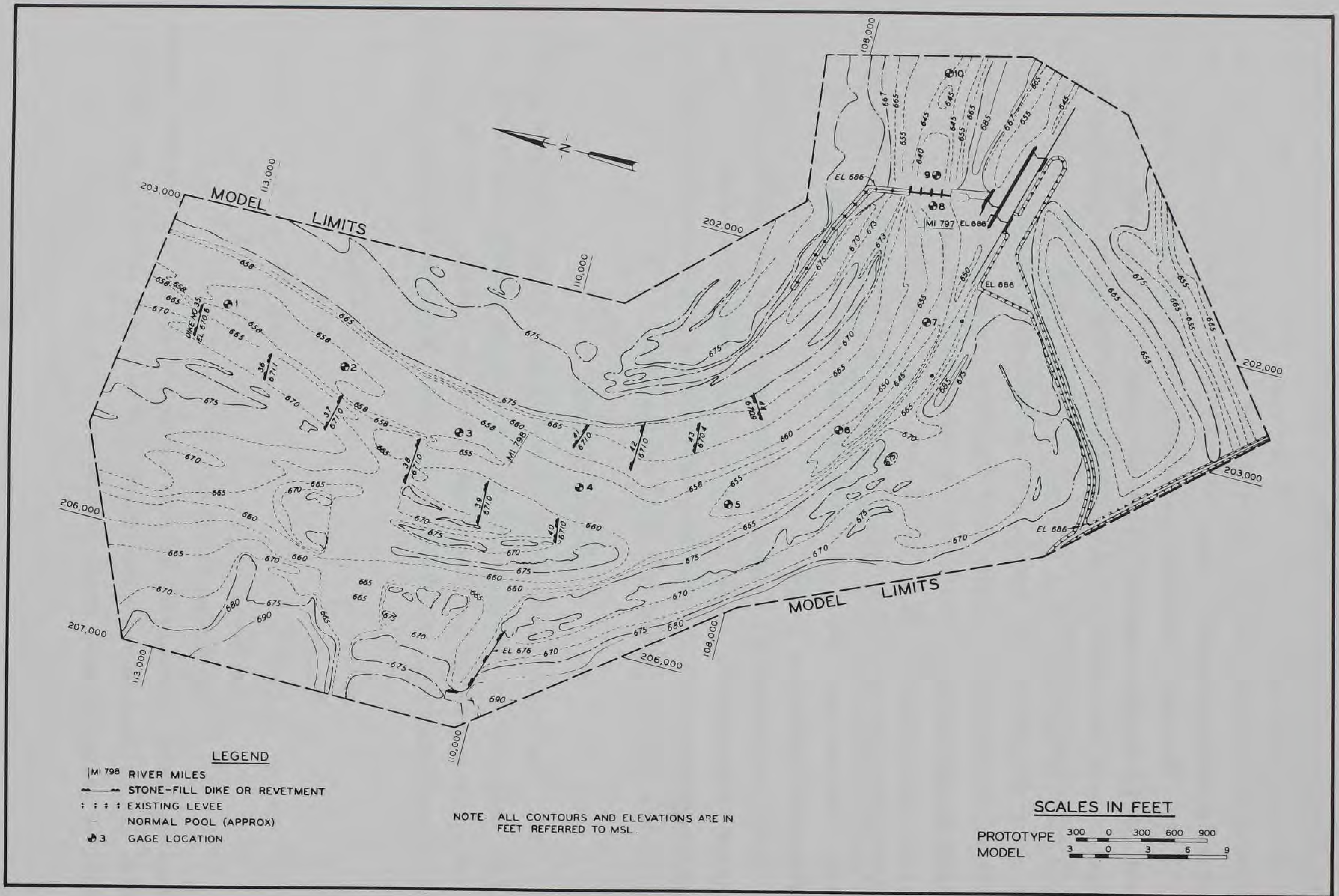


Figure 2. Model layout and location of gages

Appurtenances

13. Water was supplied to the model by a circulating comprehensive water supply system. Inflow was controlled and measured at the upper end of the model by means of valves and venturi meters. Water-surface elevations were measured by means of 10 piezometer gages located in the model channel and connected to a centrally located gage 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 means of a tailgate located at the lower end of the model.

14. Velocities and current directions in the model were determined by cylindrical wooden floats weighted on one end to simulate the maximum draft for loaded barges using the waterway (9 ft prototype). A model towboat and tow were used to determine and demonstrate the effects of currents on tows approaching and leaving the lock in the upper pool (Figure 3). The towboat was equipped with twin screws and propelled by two small electric motors operating from batteries in the tow. The rudders and speed of the tow were remote-controlled, and the tow could be operated in forward or reverse with the power adjusted by means of a rheostat to a maximum speed comparable to that of towboats using the upper Mississippi River waterway.

Model Adjustment

15. Before studies were undertaken, the model was checked and adjustments were made until it reproduced accurately the conditions observed in the prototype. Most of the adjustment was concerned with the distribution of flow between the channel and right overbank through Sturgeon Lake. Flow from the right overbank varied between 23 and 24 percent of the total during the lower flows up to about 32,000 cfs and increased to about 28 percent with a total discharge of 40,000 cfs. The model surface was constructed of brushed cement mortar to provide a roughness (Manning's n) of about 0.0135 which corresponds to a prototype

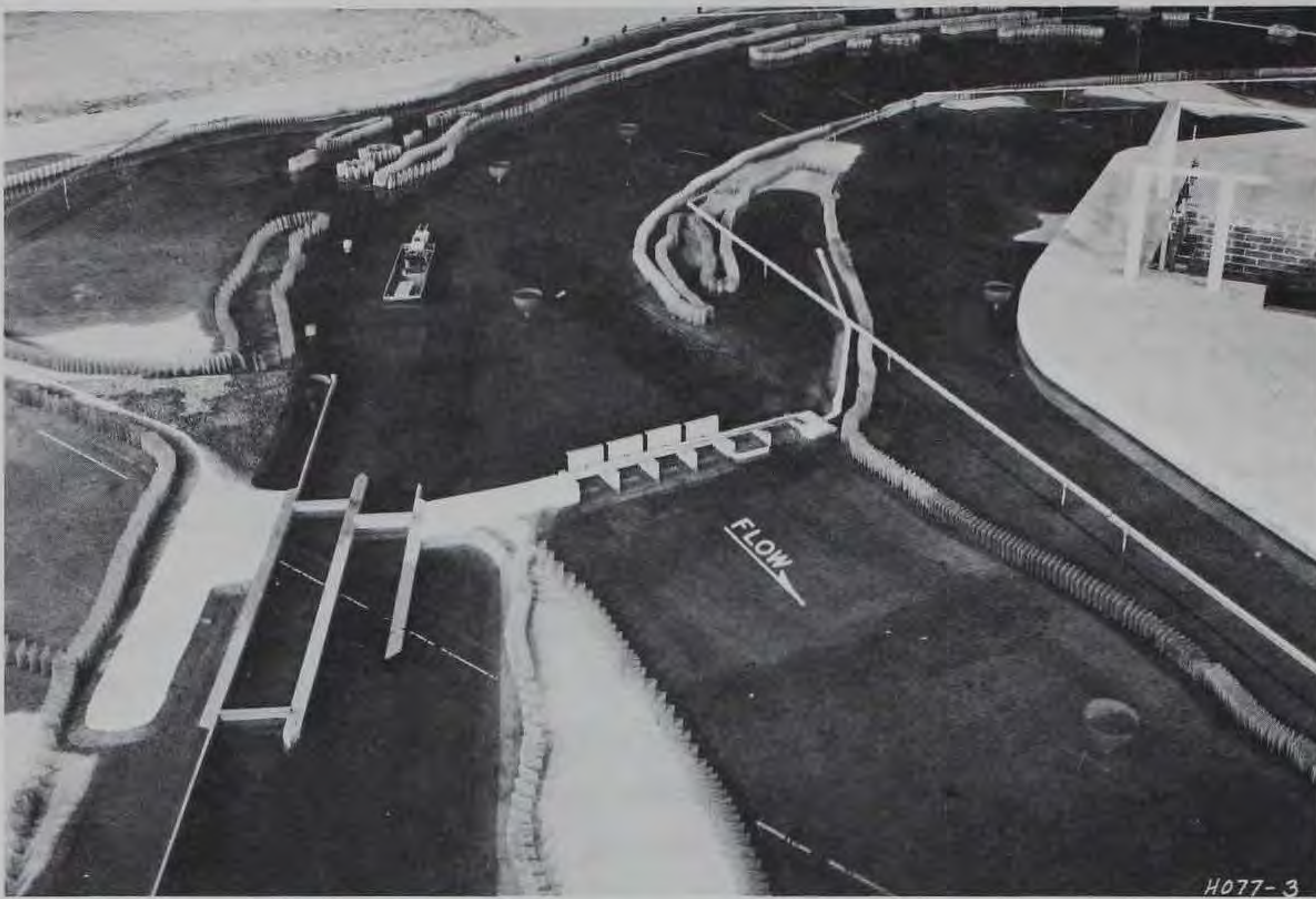


Figure 3. Remote-controlled towboat and tow approaching the lock

roughness of about 0.030. Roughness in the form of folded strips of 8-mesh wire screen was placed along the overbank to simulate the effects of vegetation indicated by data available. Since only a short reach of the river was reproduced in the model, any errors in the simulation of prototype roughness would have little effect on water-surface elevations and velocities. Results shown in Plates 1 and 2 indicate that the model reproduced with reasonable accuracy the current directions and velocities obtained in the prototype which indicate that the adjustment was adequate for the purpose of the study.

PART III: TESTS AND RESULTS

16. Tests were concerned primarily with the study of flow patterns, current velocities in the upper lock approach, and effects of various modifications proposed for the improvement of navigation conditions for downbound tows approaching the locks. The model towboat was used to observe the effects of the various modifications on the navigability of the reach and particularly in the lock approach. Since the worst conditions for navigation were obtained in the model during the higher river stages with uncontrolled riverflows, no tests were conducted to determine the effects of dam gate operation other than with flow distributed uniformly over the entire length of the dam. Most of the plans tested were submitted by the U. S. Army Engineer District, St. Paul.

Test Procedures

17. Tests were conducted by reproducing discharges and maintaining the upper pool elevation at the lock based on information furnished by the St. Paul District. The representative flows reproduced during the tests were as follows:

- a. Controlled riverflow of 15,000 cfs with normal upper pool el 674.0 (at the dam).
- b. Controlled riverflow of 30,000 cfs with normal upper pool el 674.0.
- c. Open riverflow of 36,000 cfs with normal upper pool el 674.0 (maximum flow at which normal upper pool can be maintained).
- d. Open riverflow of 70,000 cfs with upper pool el 678.5.
- e. Open riverflow of 100,000 cfs with upper pool el 681.2.
- f. Open riverflow of 134,000 cfs with upper pool el 683.5.

18. The controlled riverflow was reproduced by introducing the proper discharge, setting the tailwater elevation for the discharge, and manipulating the dam gates until the required upper pool elevation was obtained. Uncontrolled riverflows were reproduced by introducing the

proper discharge with the dam gates fully open and manipulating the tailgate to obtain the proper water-surface elevation at the control gage. All stages were permitted to stabilize before data were recorded.

19. Current directions were determined by plotting the paths of wooden floats (described in paragraph 14) with respect to ranges established for that purpose, and velocities were measured by timing the travel of the floats over measured distances. Surface currents were also indicated by time-exposure photographs recording the movement of paper confetti on the water surface. No data were obtained with the model tows other than observations of their behavior in the lock approach and in the reach upstream. Flow distributions along the length of the dam were based on velocity measurements through each gate bay.

20. Most of the modifications were developed during preliminary tests. Data and results obtained during these tests were sufficient only to assist in the development of plans that appeared to produce some improvement in conditions in the upper lock approach and are not included in this report.

Base Test (Existing Conditions)

Description

21. The base test was conducted with the model reproducing existing conditions as shown in Figures 4 and 5. The purposes of this test were to establish and record the conditions existing in the prototype with the flows selected for testing and to provide a basis for determining the effectiveness of proposed modifications. The principal features of the prototype that were reproduced or simulated in the model for this test included the following:

- a. The lock located in a canal along the right bank with clear chamber dimensions of 110 ft wide by 600 ft long, a 576-ft-long upper guide wall, and a 570-ft-long lower guide wall and provisions for a second lock on the riverward side. Tops of lock walls were at el 686.0.
- b. A nonnavigable gated spillway including four 80- by 20-ft roller gates located in the river channel. The dam was connected to high ground on the left overbank with an earth dike, top el 686.0.

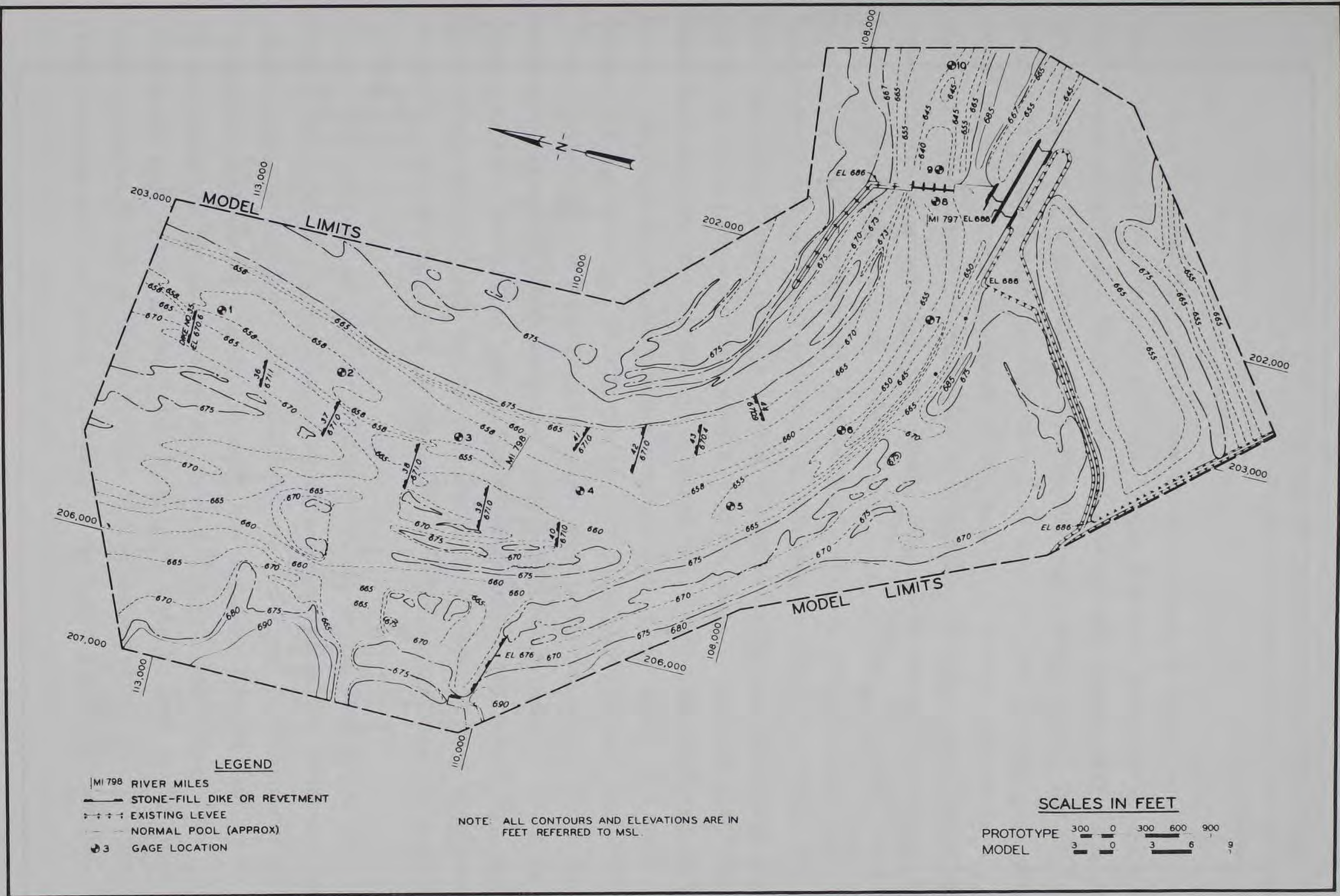


Figure 4. Existing conditions

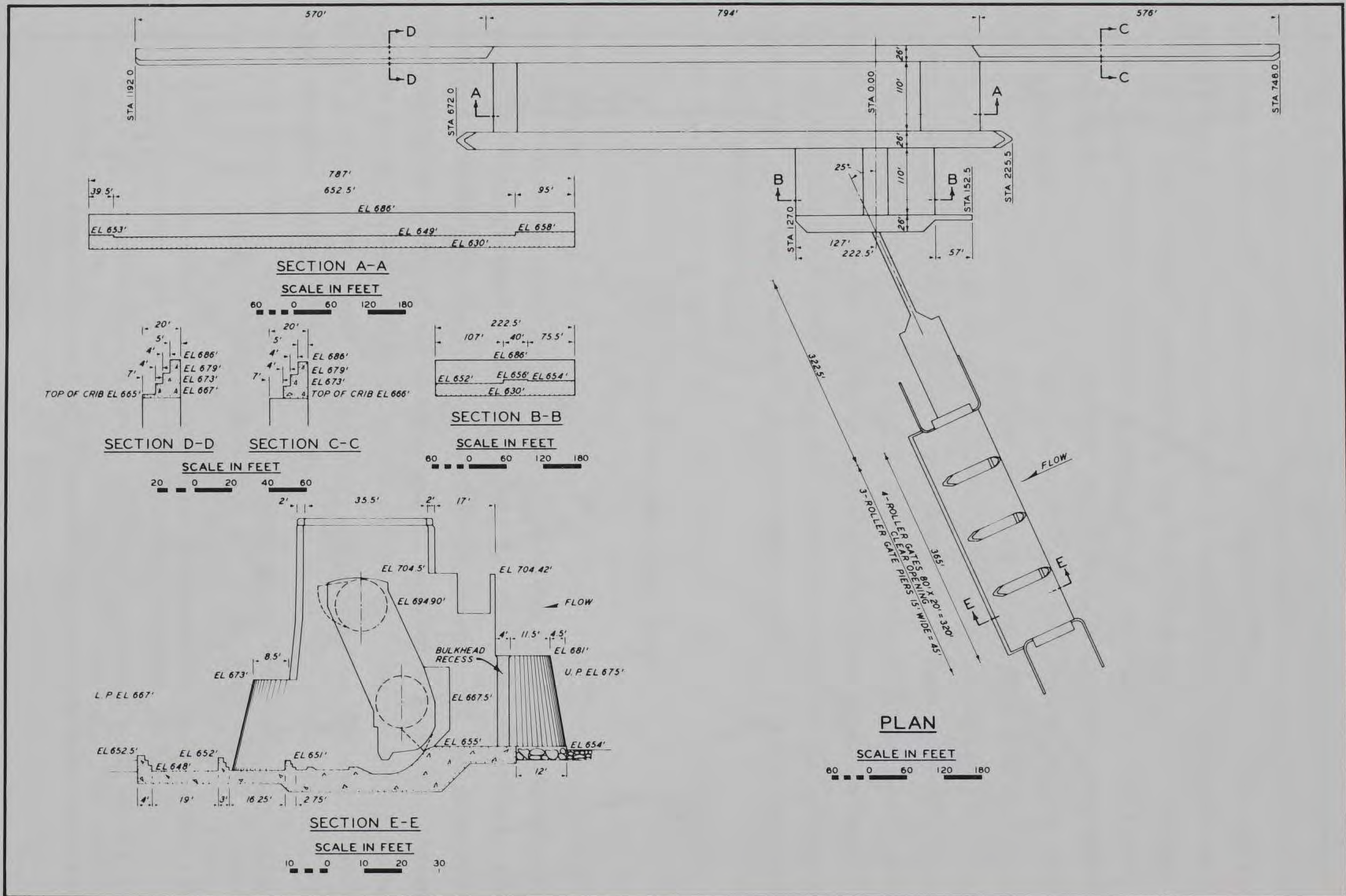


Figure 5. General plan and sections

c. Two cells located along the right bank upstream of the guide wall and a system of submerged dikes (wing dams) with crest el 671.0 located upstream of the lock on each side of the channel.

Results

22. Water-surface elevations shown in Table 1 indicated that the drop in water level through the dam (gages 8 and 9) ranged from about 0.2 to 0.3 ft with the lower flows (36,000 cfs and 70,000 cfs) and about 0.4 ft with the higher flows (100,000 cfs and 134,000 cfs). The difference in the water-surface elevation from near the end of the upper guide wall (gage 7) to just upstream of the dam (gage 8) was only about 0.2 ft with all open riverflows tested. With the higher discharges, there was considerable flow over the left overbank landward of the earth dike connected to the dam abutment.

23. The alignment and velocity of currents affecting navigation upstream of the lock and in the lock approach are shown in Plates 3-8 and Photo 1a. These results indicate that currents were generally parallel to the right bank line with all flows and then moved toward the spillway near the end of the upper guard wall across the approach to the lock. Maximum velocities approaching the end of the guide wall were about 1.8 fps with the 15,000-cfs flow to about 3.7 fps with 36,000-cfs flow. Velocities approaching the guide wall with the higher flows were somewhat less than those with the 36,000-cfs flow because of the flow over the left overbank. Velocities of currents moving toward the spillway across the approach to the guide wall were somewhat less than velocities of currents upstream of the wall, particularly during the higher flows.

24. Because of the set of the currents moving from along the right bank toward the spillway, navigation conditions for downbound tows were extremely difficult and hazardous even with the low flows tested. Downbound tows attempting to approach the guide wall would tend to be moved riverward by currents moving toward the spillway (Photo 1b). Downbound tows reaching the guide wall would tend to have their stern moved riverward unless mooring lines are attached to the wall. Upbound tows leaving the lock would also tend to be moved riverward, but no

serious difficulties were indicated for tows having sufficient power and steerage to overcome the effects of the currents (Photo 1c).

Existing Conditions-Modified

Description

25. This plan was the same as that for existing conditions (base test) except for modifications designed to assist tows in approaching the guide wall for passage through the lock. The modifications involved the following (Figure 6):

- a. The upper guide wall was extended 600 ft and the two cells along the right bank were removed.
- b. Two cells 25 ft in diameter with top at el 686.0 were placed 150 ft center to center, starting 150 ft from the upper end of the riverward lock wall and angled 15 degrees riverward of the lock center line.

Results

26. Extension of the upper guide wall and the cells included in this plan had little or no effect on water-surface elevations. There was also little change in the alignment of currents and velocities in the lock approach, as shown in Plates 9-11. Velocities along the guide wall were slightly higher than those along the shorter wall with little change in the crosscurrents compared with those obtained during the base test. Currents were generally straight along the guide wall extension before moving to the left toward the spillway.

27. Because of the alignment of the currents along the guide wall extension, downbound tows could approach the guide wall with less difficulty than with the existing wall. However, the head of the tow would tend to be moved riverward by the crosscurrents a short distance downstream of the end of the wall (Photo 2a). Although navigation conditions for downbound tows would be somewhat better than those with existing conditions, the attachment of mooring lines would be required to maintain the position of the tow along the wall and to control its movement along the wall for entrance into the lock (Photo 2b). The modifications had little effect on navigation conditions for upbound tows leaving the lock (Photo 2c).

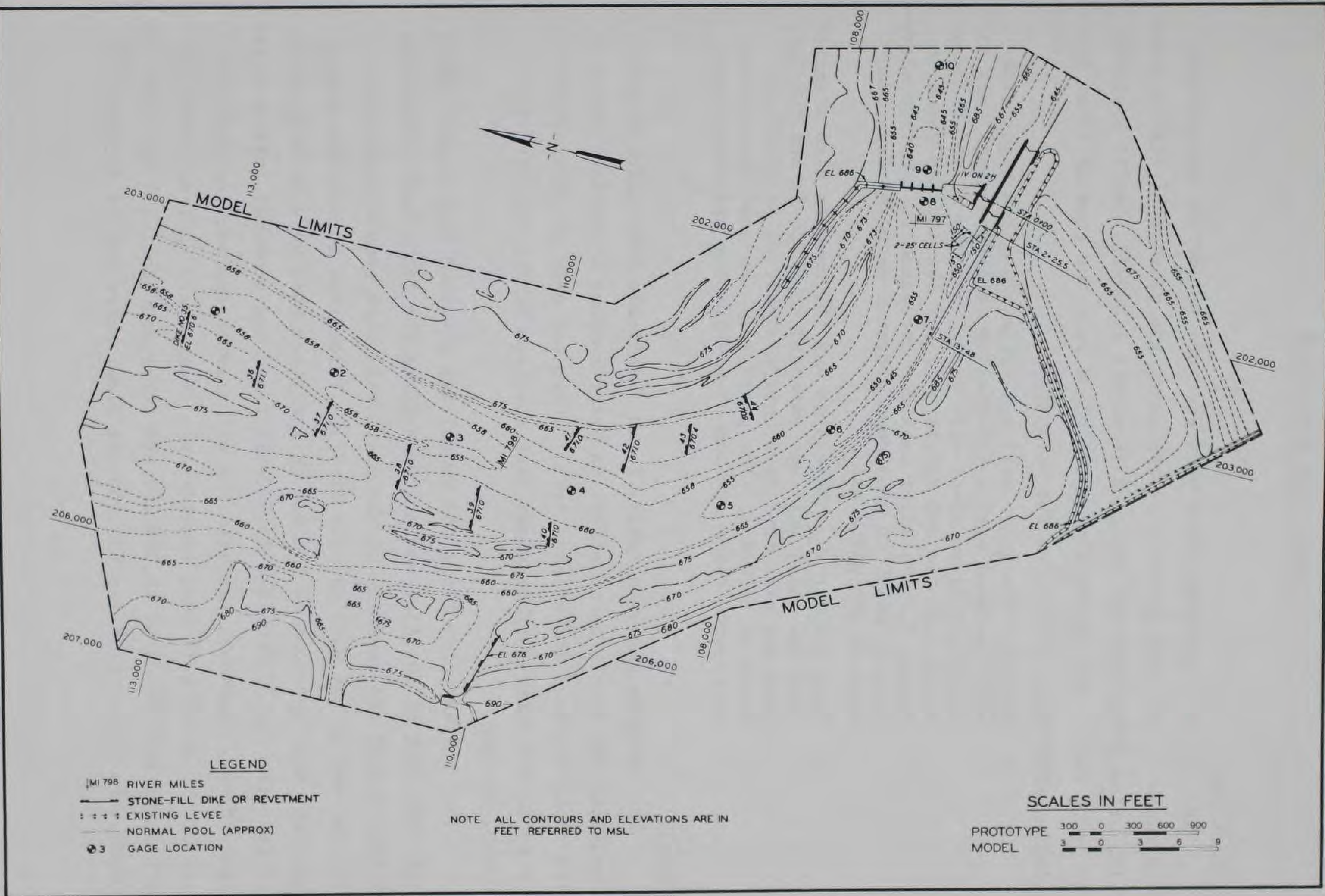


Figure 6. Existing conditions-modified

Plans A and A-Modified

Description

28. Plans A and A-modified were designed to improve navigation conditions in the lock approach by replacing the guide wall with a guard wall. Plan A-modified was designed to permit 1,200-ft tows to approach the guard wall. The features of these plans were the same as those for existing conditions except for the following:

a. Plan A. The guide wall and cells along the right bank were replaced with a 600-ft-long cell-type guard wall including fifteen 10-ft-wide ports with top el 665.0 and a 60-ft-wide ice and debris gap near the lock as shown in Figure 7. The right bank was excavated to a bottom elevation of 663.0 to provide additional maneuver area landward of the guard wall.

b. Plan A-modified. This plan was the same as plan A except that the guard wall was extended to 1,200 ft and the left bank was excavated to a bottom elevation of 660.0 as shown in Figure 8. The guard wall included thirty-five 10-ft-wide ports and the 60-ft-wide ice and debris gap.

Results

29. Results shown in Tables 2 and 3 indicate that plans A and A-modified had little or no effect on water-surface elevations compared with those obtained in the base test. There was only an increase of 0.1 ft in the water-surface elevations upstream of the dam with the 70,000-cfs flow.

30. Current directions and velocities obtained with plan A indicate that most of the flow moving close along the right bank would tend to move toward the landside of the guard wall with some crosscurrents near the end of the wall (Plates 12-17). Velocities of currents along the right bank upstream of the end of the guard wall were as much as 3.3 fps with the 30,000- and 36,000-cfs flows and somewhat less with the higher flows. However, the velocity of currents approaching and landward of the guard wall were considerably lower, varying from about 1.0 to 1.5 fps with flows of 70,000 cfs and lower and about 2.4 fps with the 100,000-cfs flow. With the 134,000-cfs flow, there was an increase in

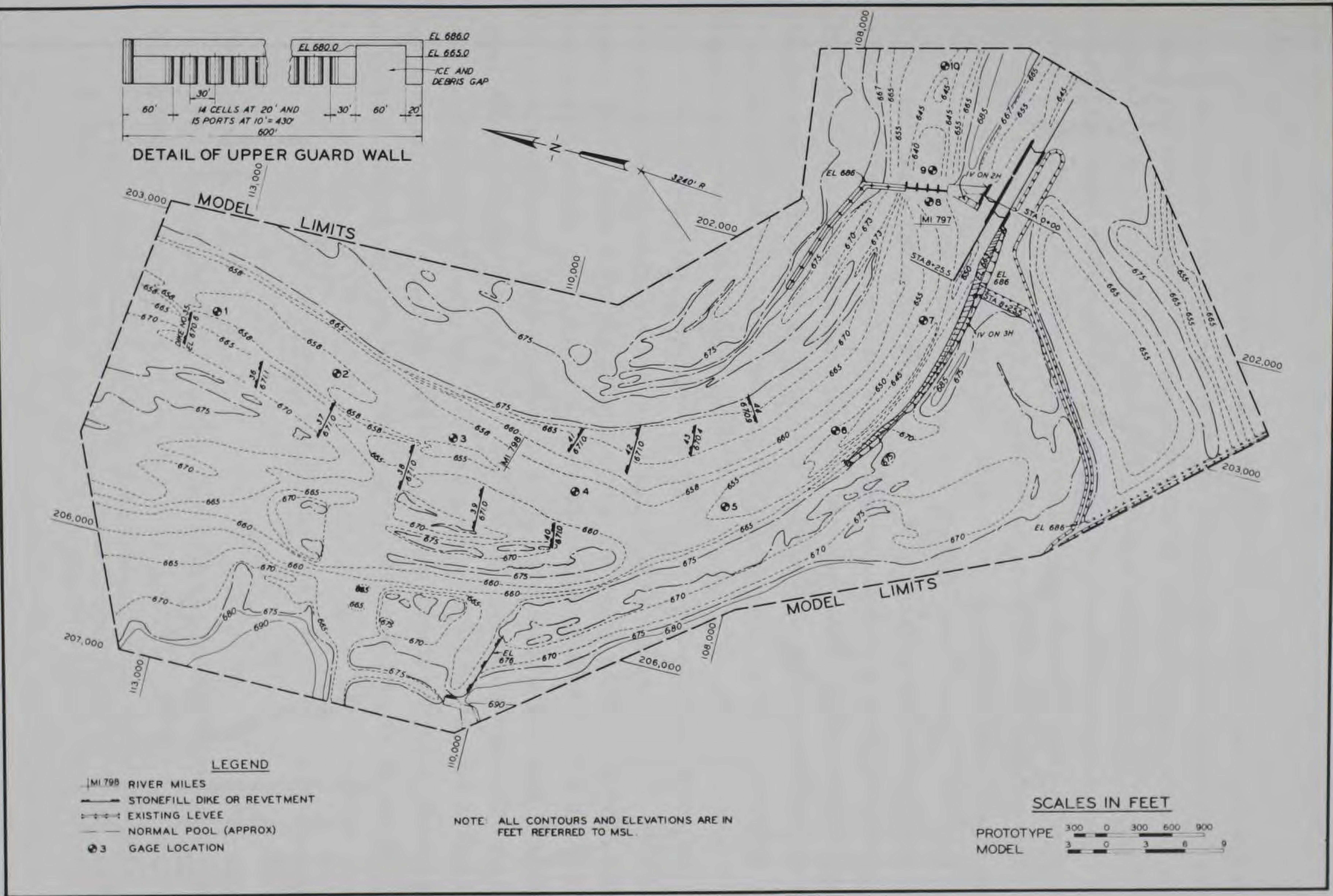


Figure 7. Plan A

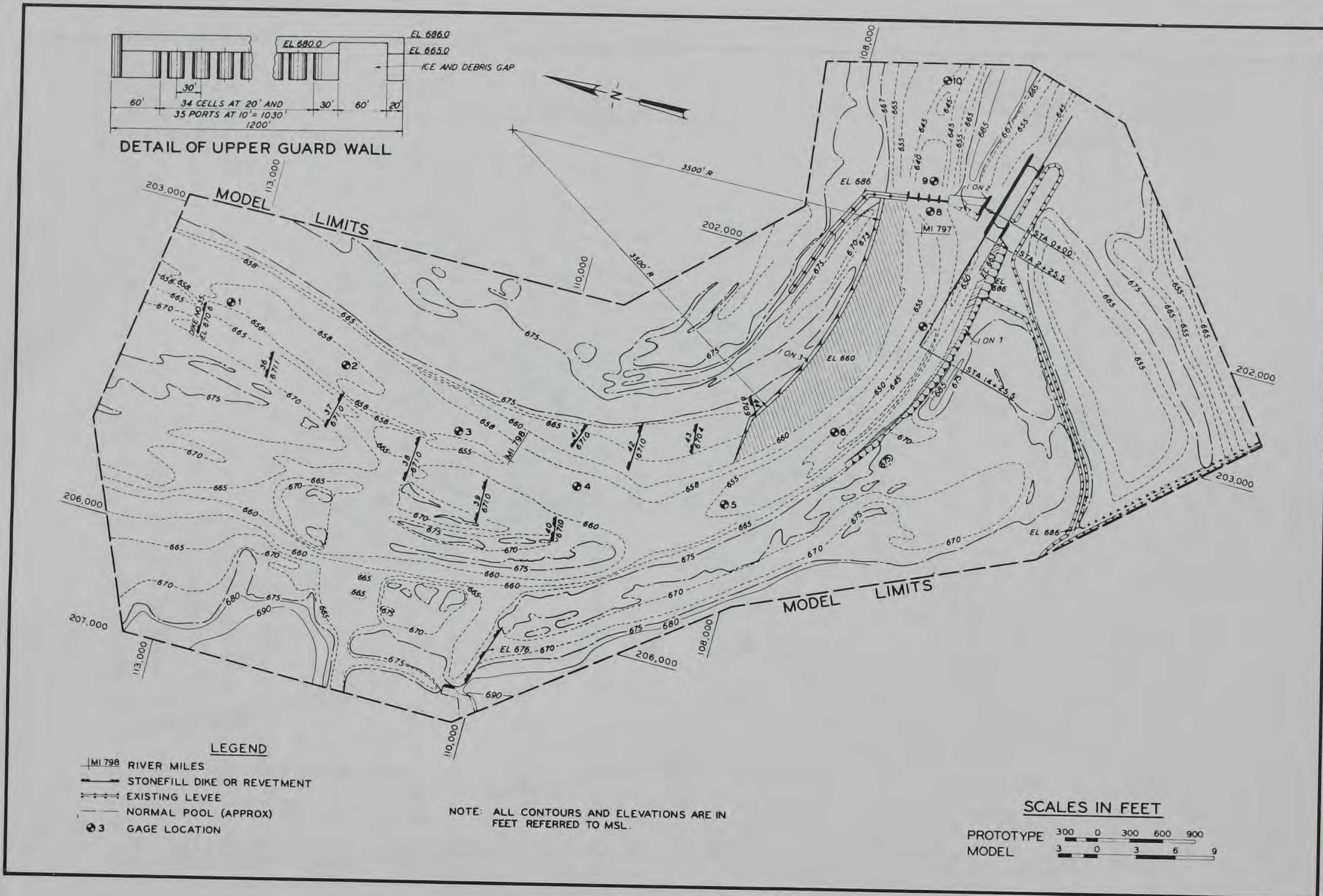


Figure 8. Plan A-modified

the amount of flow moving riverward of the guard wall from along the right bank upstream.

31. With the longer guard wall of plan A-modified and larger number of ports, considerably more of the flow moving along the right bank continued downstream on the landward side of the wall than with plan A (Plates 18 and 19). The velocity of currents approaching and moving toward the guard wall was also higher but decreased toward the lower portion of the wall. Maximum velocities on the landward side of the guard wall varied from about 3.2 fps with the 36,000-cfs flow to about 2.4 fps with the 70,000-cfs flow. With the longer guard wall, there was little tendency for crosscurrents near the end of the wall.

32. With the guard walls of plan A and plan A-modified, there would be a tendency for most of the floating debris and ice moving along the right bank to drift into the lock approach. The ice and debris gap in the guard wall would be effective in passing a considerable amount of flow and most of the loose ice and debris entering the lock approach, particularly with the longer wall (Photo 3).

33. Navigation conditions in the upper lock approach were considerably better with the guard walls than with the existing or modified guide wall. Tows properly aligned along the right bank could drift into the lock approach with little or no maneuvering (Photos 4a and 5a). Conditions were better with the longer wall, particularly for tows longer than 600 ft. Flow through the ice and debris gap would have little effect on large tows but could be hazardous for small boats, and a closure or barrier might be required when not passing debris and ice. Conditions were also better for upbound tows leaving the lock (Photos 4b and 5b).

Plan B and Modifications

Description

34. Plan B and modifications involved the following changes from the existing conditions:

- a. Plan B (Figure 9). The submerged dikes along the left bank were removed and four dikes with top el 674.0 were added along the right bank upstream of the lock approach.

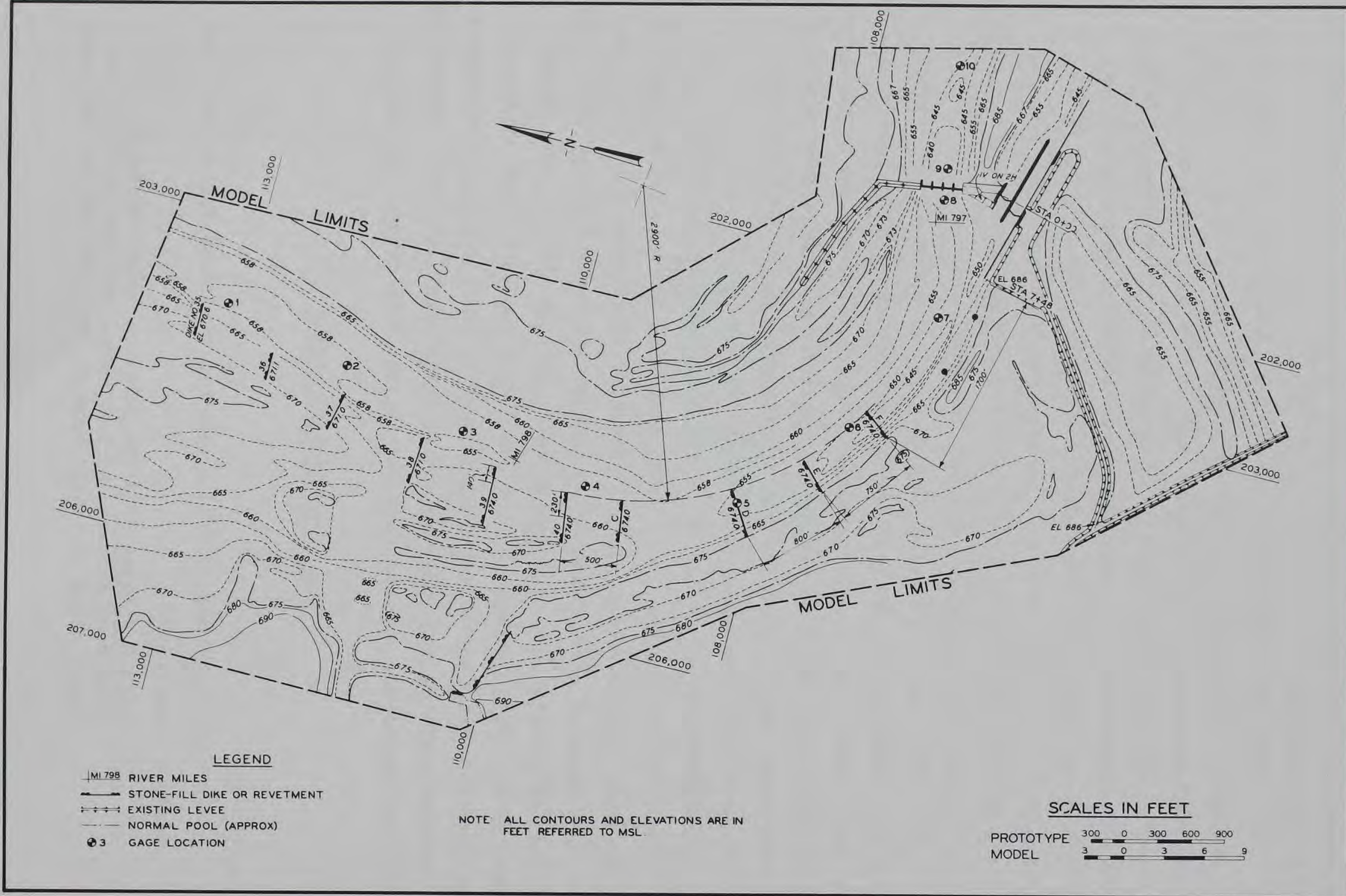


Figure 9. Plan B

Dikes 39 and 40 were raised to el 674.0 and lengthened 140 ft and 230 ft, respectively.

b. Plan B-modified. Same as plan B except that the upper guide wall was extended 600 ft and mooring cells along the right bank were removed.

c. Plan B-1. Same as plan B except that the upper guide wall was replaced with a 600-ft ported guard wall with ice and debris gap and excavation along the right bank the same as in plan A (Figure 7).

d. Plan B-2. Same as plan B-1 except that a 1,200-ft guard wall was added to the riverside lock wall of the proposed riverside lock. The guard wall was of the same type and construction as the 1,200-ft wall of plan A-modified (Figure 8).

Results

35. The modification of the dike system along the right bank included in plan B and modifications without changes in the channel bed increased stages upstream (gages 1-4) about 1.3 ft with the 36,000-cfs flow and 0.3 to 0.4 with 70,000-cfs flow compared with existing conditions (Table 4). The effect on water-surface elevations decreased downstream of the dikes.

36. Current directions and velocities obtained during the test of these plans are shown in Plates 20 and 21. These results indicate that velocities in the channel and along the ends of the proposed dikes were considerably higher than those with existing conditions, particularly with the 36,000-cfs flow. Maximum velocities in the lock approach with the 36,000-cfs flow varied from about 5.3 to 8.4 fps with plan B and somewhat higher with plan B-modified. Velocities were considerably lower with the 70,000-cfs flow. Velocities near the guide wall and in the crosscurrents varied from 2.4 to 3.6 fps with plan B and the 36,000-cfs flow and 3.6 to 4.2 fps with plan B-modified.

37. With the guard wall of plan B-1, velocities in the channel were about the same as those with the guide wall of plan B except that most of the currents moved riverward of the guard wall (Plate 22). There was very little flow moving into the lock approach and through the ports in the guard wall. The long guard wall on the riverside of the portion of the proposed lock in plan B-2 had little effect on the

velocity of currents in the channel upstream of the lock approach (Plate 23). There was considerable flow with high-velocity currents moving toward the landside of the long guard wall and a large eddy formed in the approach to the existing lock, particularly with the 36,000-cfs flow. Excavation along the left bank had little effect on the velocity of currents in the lock approach.

38. Navigation conditions with the plans described above were affected by the high-velocity currents and the location of the proposed dikes along the right bank upstream of the lock approach. Because of the dikes, downbound tows would have to approach the lock farther from the right bank and turn or flank toward the right bank to approach the guide or guard wall. This would require more maneuvering and tows would experience considerably more difficulties in approaching the lock than with existing conditions. Although current alignment was somewhat better with the long guard wall of plan B-2, conditions would continue to be hazardous because of the high-velocity currents and the short distance between the end of the long guard wall and the end of the proposed dike farthest downstream along the right bank.

Plan C and Modifications

Description

39. Plan C and modifications were the same as plan B, except for the following:

- a. Plan C (Figure 10). Two additional gate bays were installed on the left end of the dam and the left bank downstream of the dam was excavated to el 665.0 extending from the new left abutment to about 800 ft downstream. The left bank was excavated to el 665.0 starting at the left dam abutment and extending upstream about 2,400 ft on a 2,250-ft radius to provide a 650-ft-wide channel approaching the dam.
- b. Plan C-modified. Same as plan C except that the upper guide wall was extended upstream 600 ft and the two mooring cells along the right bank were removed.
- c. Plan C-1. Same as plan C except that the upper guide wall was replaced with a 600-ft-long ported guard wall and the right bank was excavated to el 663.0, same as in plan A (Figure 7). The two mooring cells were removed.

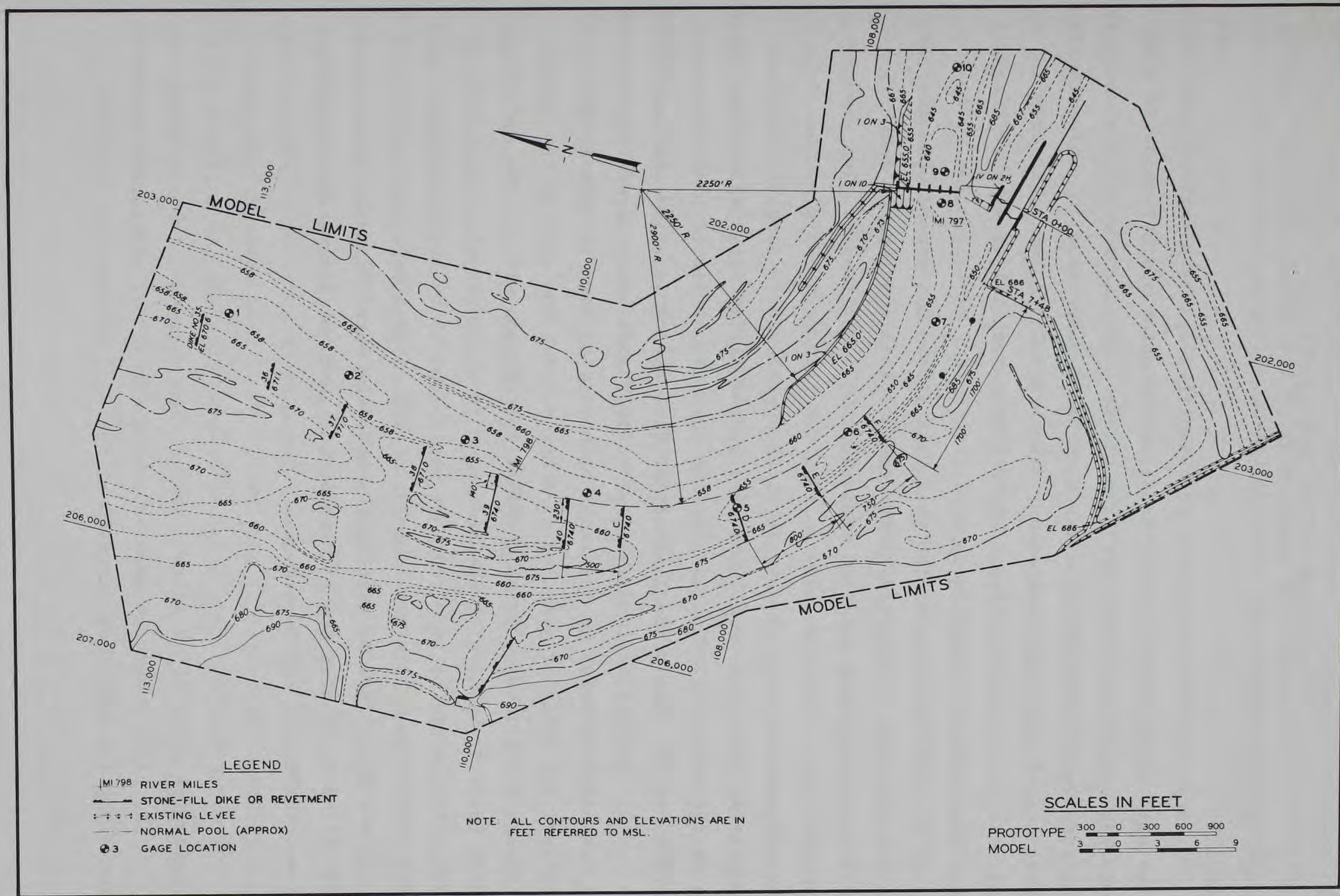


Figure 10. Plan C

d. Plan C-2. Same as plan C-1 except for the addition of a 1,200-ft-long ported upper guard wall located on the riverside of the portion of the uncompleted lock (same as plan B-2).

Results

40. Water-surface elevations with these plans and the 36,000-cfs flow were about 1.1 to 1.3 ft higher in the upper reach than those with existing conditions (Table 5). The highest elevations were obtained with the long guard wall of plan C-2. With the 70,000-cfs flow, water levels in the upper reach were only about 0.2 to 0.3 ft higher. The drop in water-surface elevation across the dam was about 0.1 ft which was less than that with the existing dam.

41. The addition of two gate bays in the dam caused some increase in the velocity of currents in the channel just upstream of the lock with open riverflows compared with plan B (Plates 24-27). There was a tendency for a clockwise eddy to form downstream of the proposed right bank dikes that extended into the lock approach with some of the plans. Velocities along the guide wall of plan C-modified were higher than those along the guide wall of plan C. With the guard walls of plans C-1 and C-2, there was only a small amount of flow moving into the lock approach.

42. Navigation conditions with these plans were adversely affected by the proposed dikes on the right bank forcing tows to make a turn to approach the guide or guard walls after passing the ends of the dikes. Although conditions would be somewhat better than without the additional gates (plan B) because of the reduction in crosscurrents, considerable maneuvering would be required that would tend to be hazardous under most flow conditions. With the long guard wall of plan C-2, tows would have to make a sharp turn to the right within the short distance between the end of the lower dike and the end of the guard wall that would be extremely difficult and hazardous.

Plan D

Description

43. Plan D was the same as plan C except for additional excavation along the left bank upstream of the dam, designed in an effort to

reduce velocities in the approach to the lock. The excavation shown in Figure 11 was on a 2,200-ft radius opposite the right bank dikes and tied in to the dike extending toward the left abutment of the modified dam.

44. Water-surface elevations with the 36,000-cfs flow shown in Table 6 were about the same as those with plan C in the upper reach (gages 1-4) but about 1.1 ft higher than those with existing conditions (base test). Although water-surface elevations at gage 7 were about 0.4 ft lower, it was determined that increases upstream would be excessive and test of this plan was limited to one flow.

45. Velocities in the channel were considerably lower than those with plans B and C but somewhat higher than those with existing conditions near the ends of the right bank dikes (Plate 28). Velocities approaching the guide wall varied from about 2.5 to 4.3 fps compared with 3.1 to 3.7 fps with existing conditions.

46. Navigation conditions with this plan would be somewhat worse than those with existing conditions because of the additional maneuvering required for downbound tows to become aligned with the right bank and the guide wall. The additional maneuvering is caused by the need for tows to turn toward the right bank after passing the ends of the proposed dikes.

Plans E and E-Modified

Description

47. These plans were designed to reduce water-surface elevations in the upper reach with the proposed right bank dikes. Plan E was the same as plan D except that the proposed additional gate bays in the dam were eliminated and excavation along the left bank was lowered to el 660.0 and extended upstream to river mile 798 as shown in Figure 12. Plan E-modified was the same as plan E except that the lock guide wall was extended 600 ft upstream and the two mooring cells along the right bank were removed.

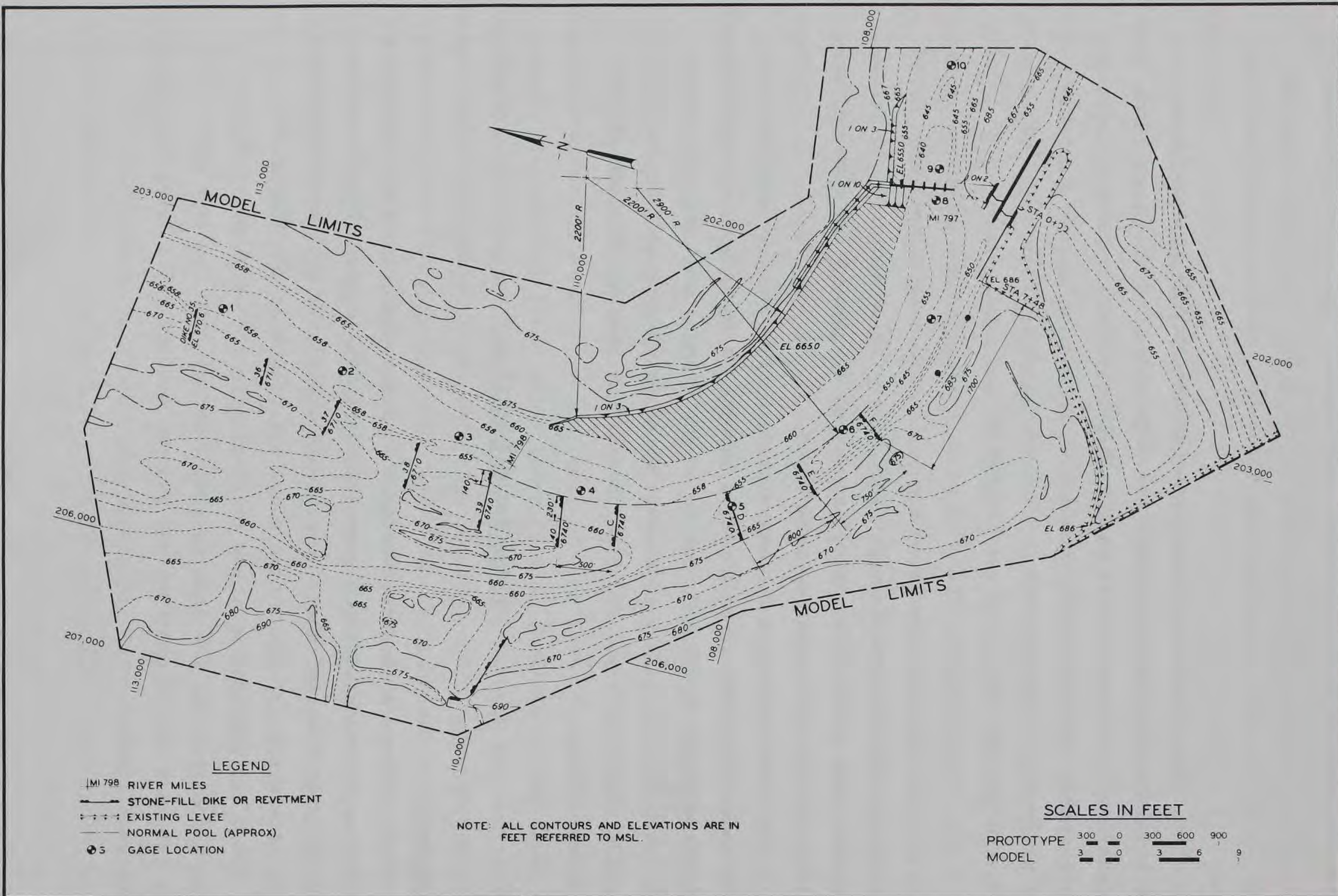


Figure 11. Plan D

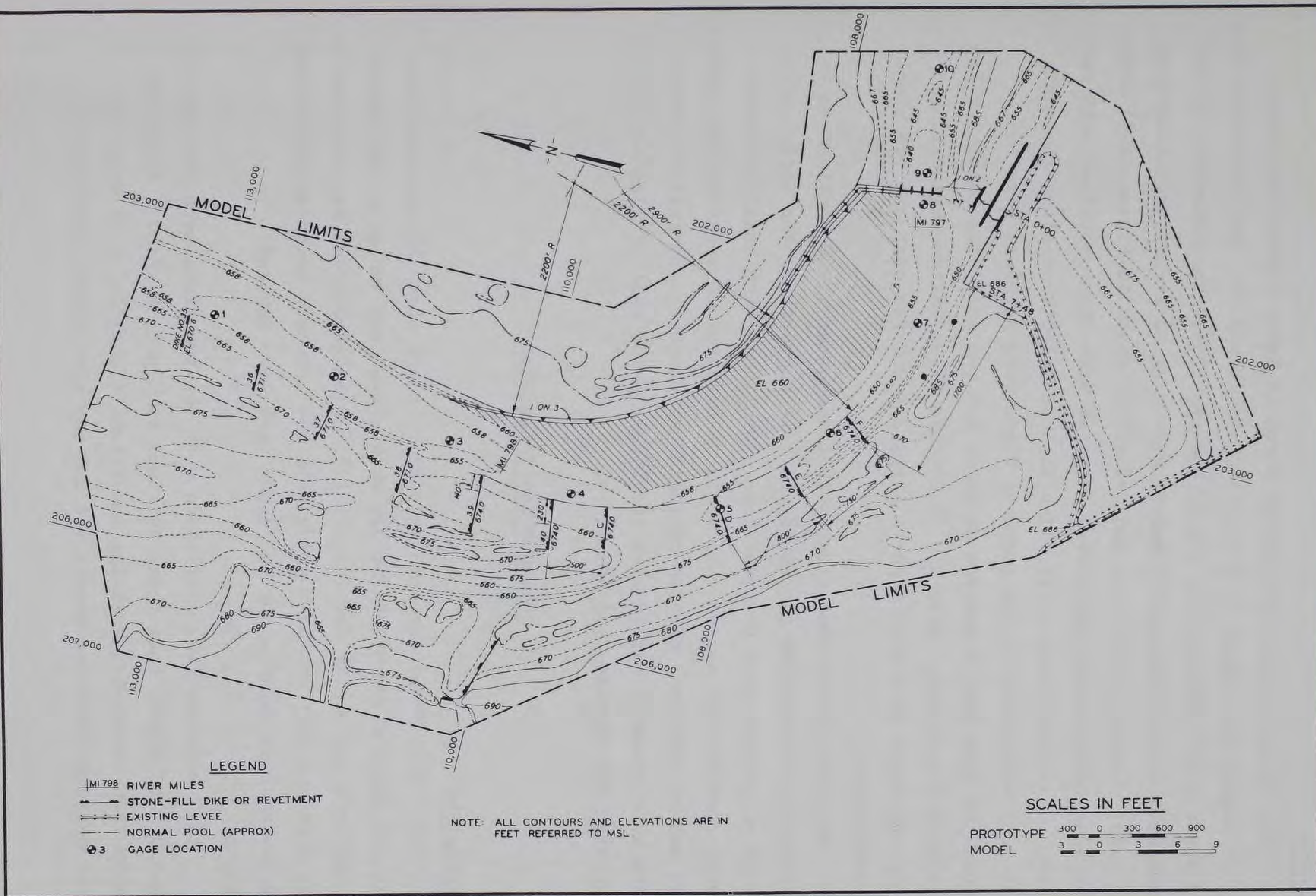


Figure 12. Plan E

Results

48. Water-surface elevations shown in Table 6 were only about 0.2 ft higher than those with existing conditions for the 36,000-cfs flow and about 0.1 ft higher with the 70,000-cfs flow. The extension of the guide wall in plan E-modified had no effect on water-surface elevations.

49. Current directions and velocities shown in Plates 29-32 indicate some reduction in velocities compared with those obtained with existing conditions (base test). The highest velocities along the right bank just downstream of the proposed dikes were obtained with the 36,000-cfs flow with a maximum of about 2.6 fps with plan E and 3.0 fps with plan E-modified. With the 70,000-cfs flow, maximum velocities along the right bank were about 1.4 fps and 2.0 fps with the two plans, respectively.

50. Navigation conditions with these plans would continue to be difficult and hazardous for downbound tows approaching the lock. Although velocities were somewhat lower than those with existing conditions, considerable maneuvering would be required to approach the guide wall and overcome the effects of the crosscurrents. Navigation conditions were somewhat better with the longer guide wall of plan E-modified than with the shorter wall of plan E.

Plans F and F-Modified

Description

51. Plan F was the same as plan E except that the two gate bays near the right abutment of the dam were closed and two gate bays added to the left end of the dam (Figure 13). Plan F-modified was the same as plan F except that the lock guide wall was extended upstream 600 ft and the two mooring cells along the right bank were removed.

Results

52. Water-surface elevations with the two plans were the same and about 0.2 ft higher than those obtained with plan E and 0.3 to 0.4 ft higher than those with existing conditions (Table 7). The drop in water-surface elevation across the dam was also higher, attributed

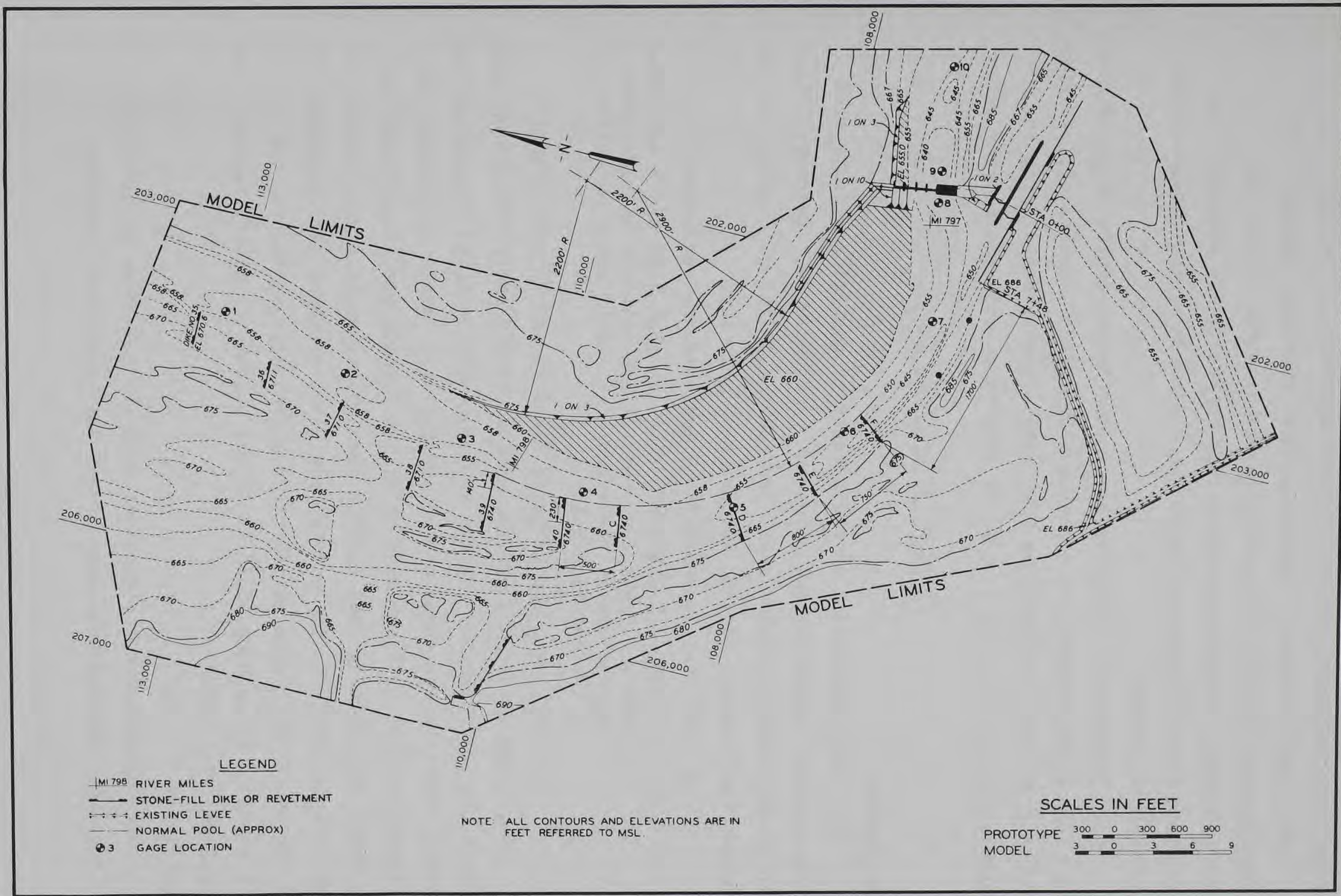


Figure 13. Plan F

mostly to the alignment of the currents approaching the dam.

53. With the dam as modified, there were some changes in the alignment and velocity of currents in the approach to the lock (Plates 33-36). Velocities in the lock approach were generally less than those with the previous plans but the angle of the crosscurrents was somewhat greater.

54. Navigation conditions were not affected appreciably and downbound tows would continue to experience considerable difficulties in approaching the lock. Conditions were only slightly better with the longer guide wall of plan F-modified than those with the shorter wall.

Plans G and G-Modified

Description

55. Plan G was based on the results of preliminary tests with various types, locations, and alignment of structures. The most effective of these modifications were incorporated in the plan which was the same as plan E except for the following (Figure 14):

a. The dam was restored to its existing condition.

b. A 1,300-ft-long rock dike with top at el 684.5 was added near the right dam abutment and extended upstream with its end 300 ft riverward of a line forming an extension of the existing guide wall.

c. The lower two proposed dikes (E and F) were removed.

56. Plan G-modified was the same at plan G except for an opening between the rock dike and the dam abutment wall designed to pass ice and debris. The size and shape of the opening were varied in a number of preliminary tests, and the most effective opening was incorporated in the plan. The opening used in this plan consisted of a gap between the lower end of the rock dike and the dam right abutment wall (Figure 15). The toe of the rock dike was 32 ft from the wall and the top, 80 ft. This provided an opening of 32 ft at the bottom (el 655.0) and 60 ft at normal pool (el 674.0).

Results

57. Water-surface elevations with the rock dike in place were about 0.4 ft higher in the upper reach than those with existing

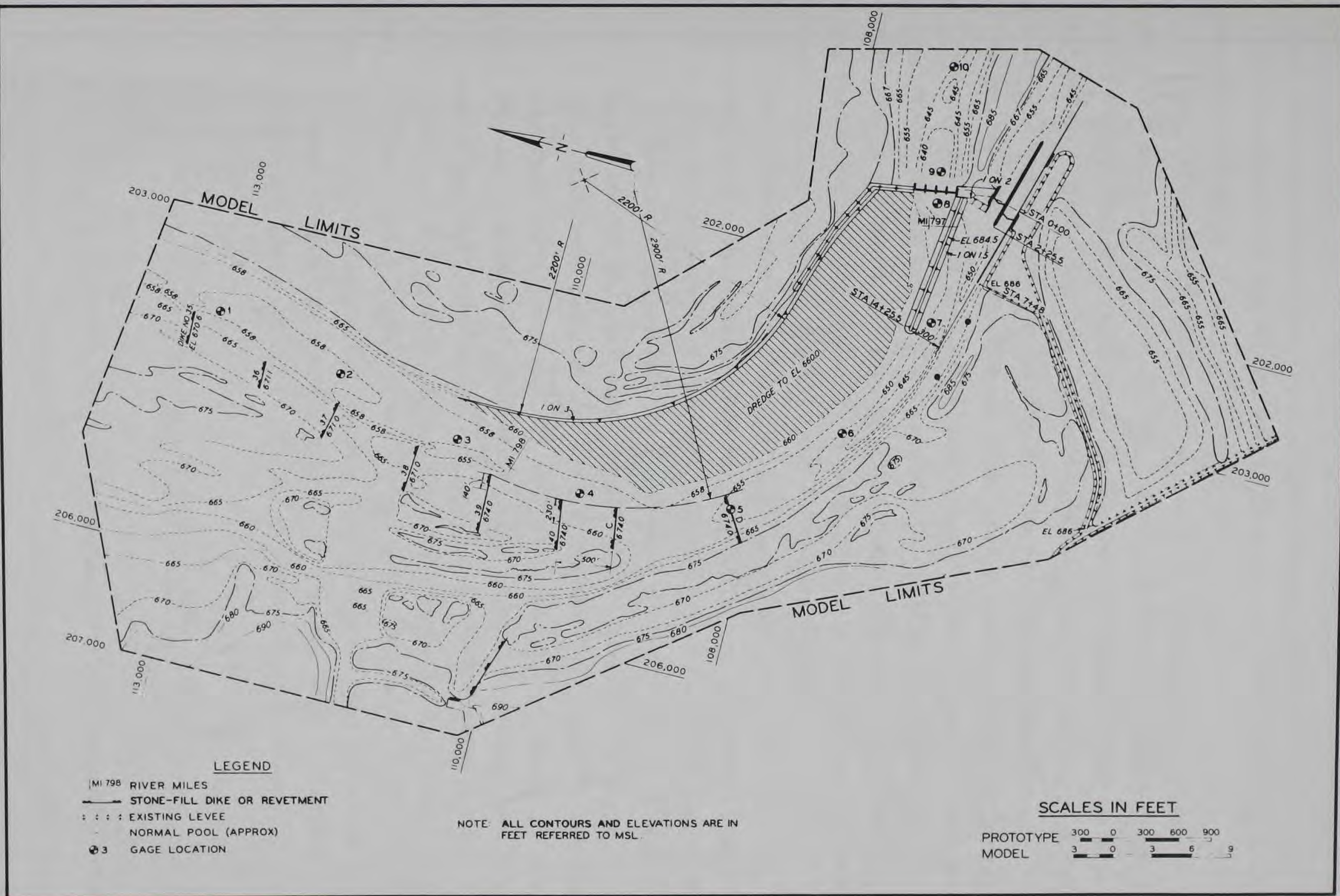


Figure 14. Plan G

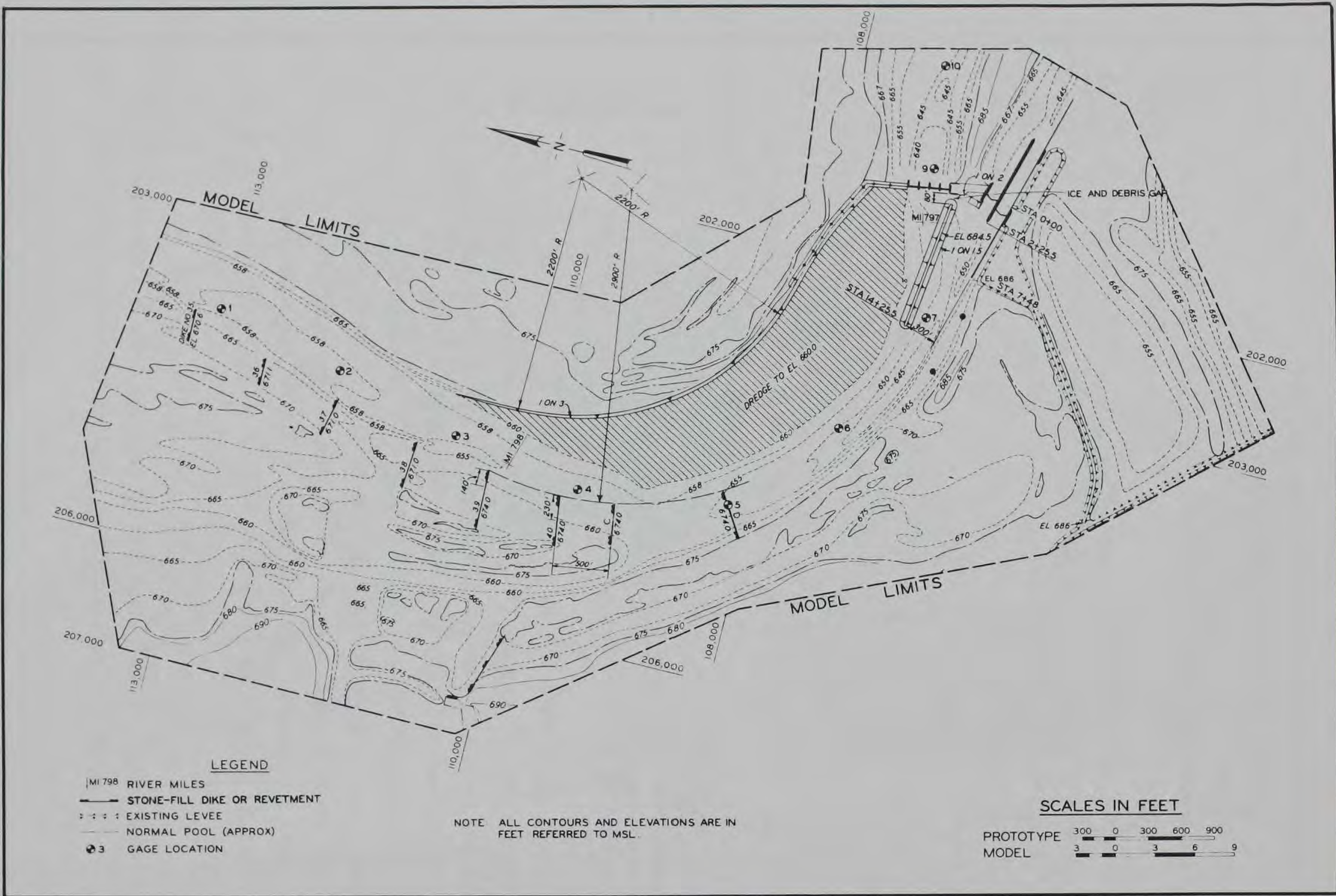


Figure 15. Plan G-modified

conditions (base test). There was little difference in water levels between the two plans except for a slight lowering of about 0.1 ft with plan G-modified and the 70,000-cfs flow (Table 8). The drop across the dam varied from about 0.4 to 0.6 ft.

58. With the 36,000-cfs flow, currents were generally parallel to the right bank line (Plates 37-39). With plan G, a slow eddy formed in the lock approach extending from the lock to the proposed dike on the right bank. With plan G-modified, there was some flow landward of the rock dike and through the opening and the eddy did not extend as far downstream. With the 70,000-cfs flow, some crosscurrents occurred near the upper end of the rock dike, particularly with plan G. The velocity of currents moving toward the upper end of the dike was about 1.6 fps with plan G and about 2.1 fps with plan G-modified. The velocity of currents along the lock side of the rock dike with plan G-modified was generally less than 1.0 fps with the 70,000-cfs flow.

59. Navigation conditions with the rock dike in place were considerably better than those with existing conditions. However, downbound tows could experience considerable difficulty in making the turn from the river channel toward the right bank within the short distance between the end of the rock dike and the right bank dike upstream.

60. Downbound tows moving close along the right side of the channel would tend to be moved against the right bank dike upstream of the lock approach. Because of the effects of currents, downbound tows turning toward the right bank would tend to be rotated clockwise and in trying to overcome the effects of the currents with additional power could hit the right bank. Tows with sufficient power in reverse could flank toward the right bank without serious difficulties. Once tows have become aligned close along the right bank, they would be in a position to move toward the guide wall with little or no danger of being moved toward the dam.

Plans H and H-Modified

Description

61. Plan H was the same as existing conditions (base test) except

for the following modifications (Figure 16):

- a. The left bank and adjacent channel were excavated along a 3,500-ft radius starting at the lower left bank dike (No. 44) and extending downstream to the dam.
- b. A rock dike extending upstream from the dam right abutment wall was similar to that tested in plan G-modified except that the upper end was moved riverward 10 ft and the side slopes were 1 on 2. With the change in the side slopes, the length of the opening at normal pool (el 674.0) was increased to 70 ft and the crest of the dike was 90 ft from the abutment wall.

62. Plan H-modified was the same as plan H except for modification designed to accommodate larger tows up to 1,200 ft in length. In this plan, the rock dike was extended upstream 50 ft and the upper end placed 310 ft from a line forming an upstream extension of the riverward face of the guide wall (Figure 17).

63. There was little or no difference in water-surface elevations between plans H and H-modified (Tables 9 and 10). Water-surface elevations in the upper reach were as much as 0.5 ft higher than those with existing conditions with the 30,000- and 36,000-cfs flows and 0.3 to 0.4 ft higher with the 100,000-cfs flow. With the 134,000-cfs flow, river stages upstream were only about 0.1 to 0.2 ft higher. The drop in water-surface elevations across the dam was about the same as that with existing conditions.

64. Current directions and velocities shown in Plates 40-47 indicate that because of the alignment of the channel, the higher velocity currents tend to move toward and along the right bank upstream of the lock. Since only a small portion of the total flow intercepted by the rock dike can pass through the opening between the dike and dam abutment wall, there will be some flow moving riverward of the upper end of the dike creating some crosscurrents that increase with an increase in discharge. Maximum velocities along the right bank upstream of the upper end of the dike were about 3.6 fps with the 36,000-cfs flow and decreased with lower and higher discharges. There was little difference in currents and velocities between plans H and H-modified.

65. The maximum velocities measured near the bottom in the

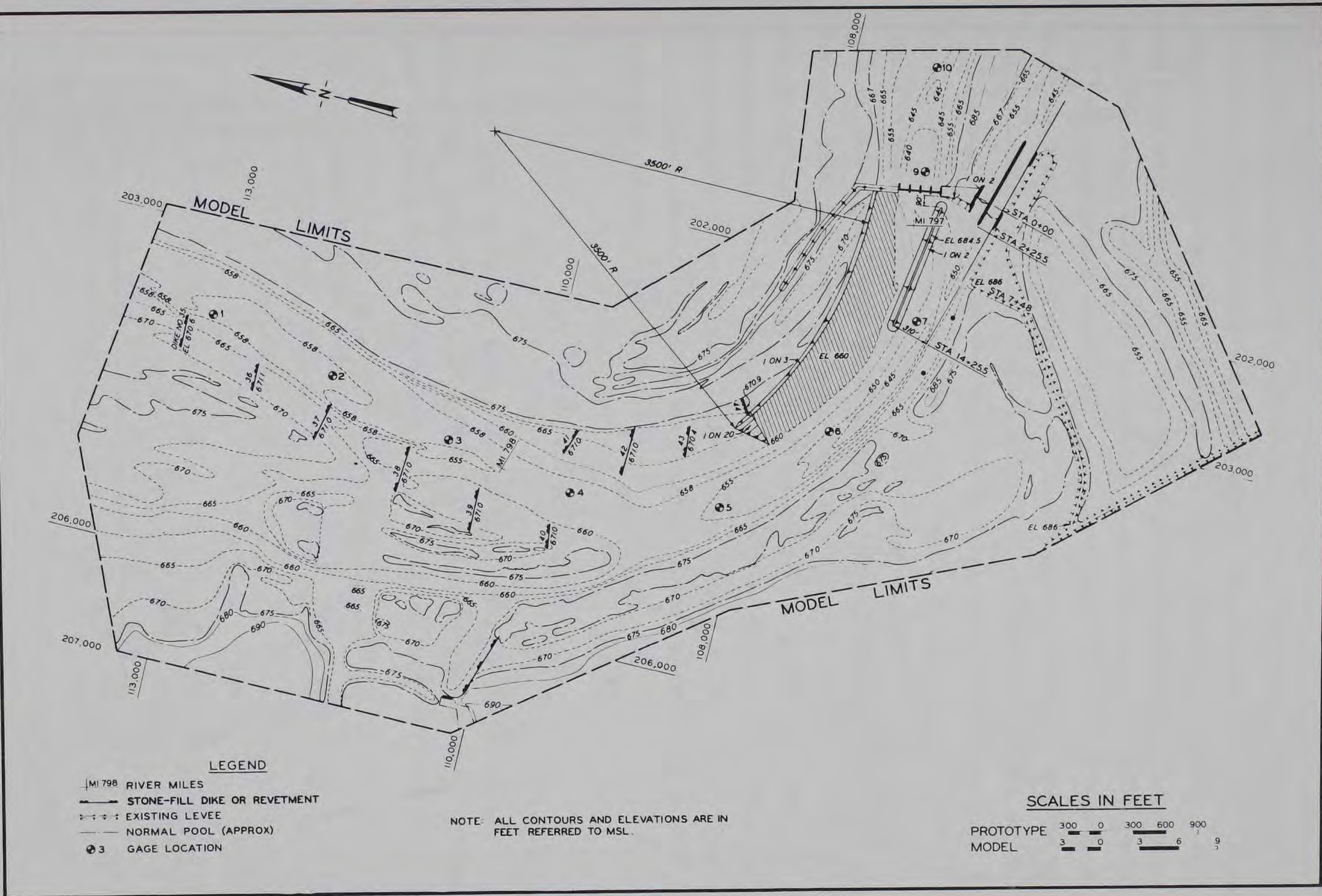


Figure 16. Plan H

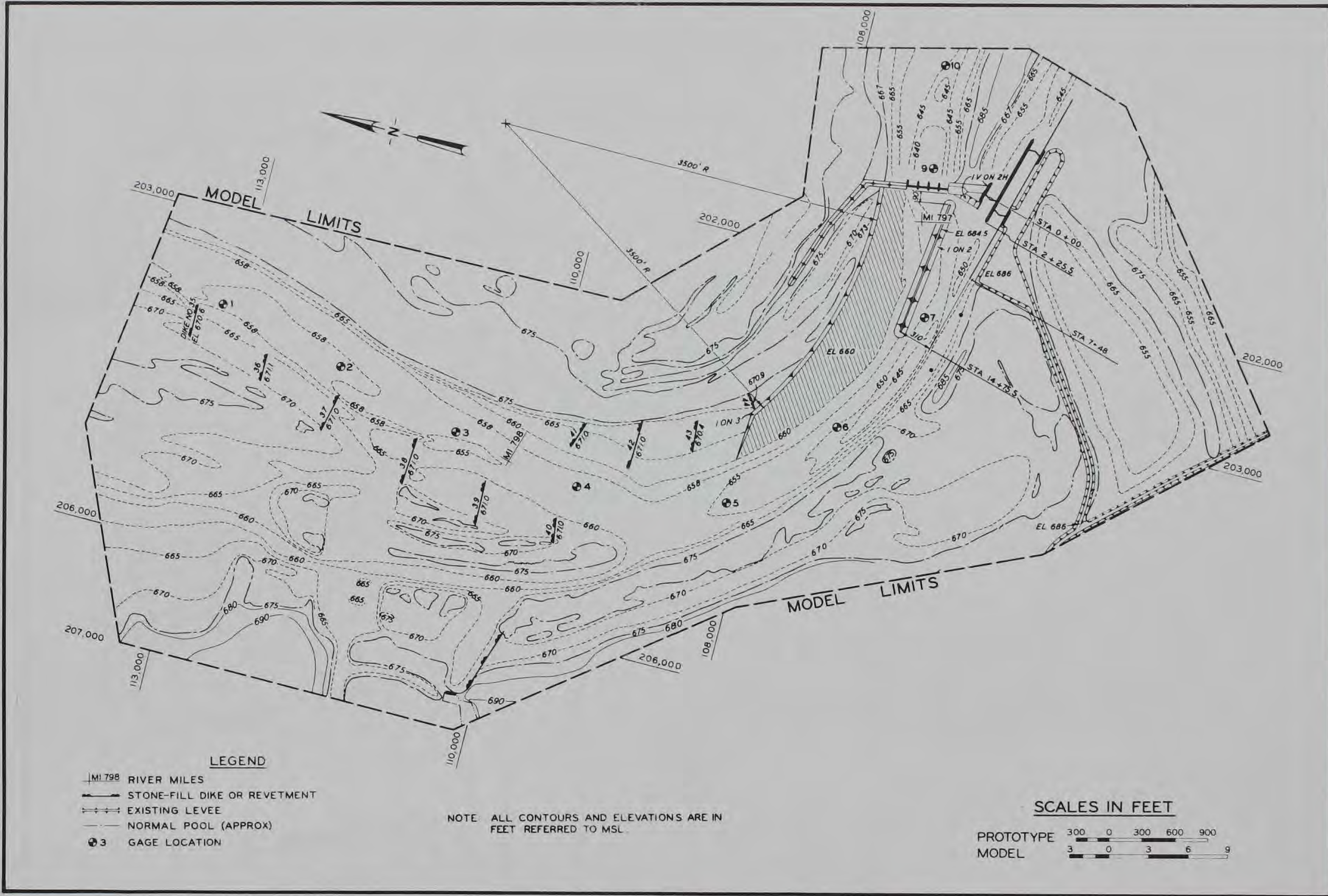


Figure 17. Plan H-modified

opening at the lower end of the rock dike were about 7.6 fps. Maximum velocities measured on the upstream end of the dike on the riverside were about 5.6 fps and 100 ft downstream of the upper end, about 5.0 fps (Plate 48). Bottom velocities obtained 100 to 200 ft riverward of the rock dike were generally between 6.0 and 6.9 fps, sufficient to produce some scouring depending on the composition of the bed.

66. Navigation conditions with plans H and H-modified were considerably better than those with existing conditions or with any of the other plans tested except with plans A and A-modified. Removal of the two proposed dikes along the right bank eliminated the need for tows to make a turn toward the right bank, and tows properly aligned could drift into the approach from a considerable distance upstream. Unless controlled, tows would tend to drift toward the opening at the lower end of the rock dike and land alongside the dike. However, once past the upper end of the dike downbound tows could easily be maneuvered to approach the guide wall with no danger of being moved toward the dam (Photo 6a). Conditions for larger tows would be better with plan H-modified than with plan H. No difficulties were indicated for upbound tows with either of the two plans (Photo 6b).

Dam Flow Distribution

67. The following is a comparison of the flow distribution through the dam gate bays with a 36,000-cfs flow between existing conditions and plans A and H-modified.

Gate Bay No.*	Percent of Total Flow		
	Existing Conditions	Plan A	Plan H-Modified
1	23.2	22.3	18.3
2	26.8	27.4	26.4
3	26.2	26.1	27.1
4	23.8	24.2	28.2

* Gate bays numbered from right to left.

68. The distribution of flow, particularly through gate bay 1, was affected by the alignment of the currents approaching the dam. With plan H-modified, flow through gate bay 1 was affected by flow through the opening at the lower end of the rock dike which moved almost parallel to the alignment of the dam.

Floating Ice Tests

69. Tests to determine the movement of broken ice drifting toward and into the lock approach were conducted with pieces of polyethylene simulating ice 24 in. thick of random sizes and shapes with the longest dimension varying from 5 to 15 ft. Most of the floating ice and debris from upstream would tend to move toward and along the right bank and toward the lock approach. With existing conditions, most of the ice would be moved riverward by the crosscurrents but some would be moved into and be trapped in the lock approach just upstream of the lock gates.

70. With plan A, about 40 to 70 percent of the ice moving along the right bank would tend to move into the lock approach during controlled flows and somewhat less with the uncontrolled flows. Some of the ice moving into the lock approach would tend to be trapped between the guard wall and the right bank. With plan A-modified, most of the ice entering the lock approach would be moved through the ice and debris gap in the lower end of the guard wall, but there would be some accumulation in the approach, particularly during the lower flows.

71. With plan H-modified, more ice would tend to move in the approach but most of the ice would move through the opening between the lower end of the rock dike and the dam abutment wall. Although there would be some accumulation on the lock side of the dike, the amount in the lock approach would tend to be only little more than that with existing conditions. Bottom velocities in the opening on the downstream end of the rock dike indicated the possibility of some scouring unless protected which could increase flow and the movement of ice through the opening. The movement of downbound tows could force more ice through the ice gap, particularly with plans A and A-modified.

PART IV: DISCUSSION OF RESULTS AND CONCLUSIONS

Limitation of Model Results

72. The analysis of the results of this investigation is based principally on a study of (a) the effects of various plans and modifications on water-surface elevations, current directions, and velocities, and (b) the effects of resulting currents on the behavior of the model towboat and tow. In evaluating test results, consideration should be given to the fact that small changes in direction of flow or in velocities are not necessarily changes produced by a modification in plan since several floats introduced at the same point may follow a different path and move at slightly 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.

73. The small scale of the model made it difficult to reproduce accurately the hydraulic characteristics of the prototype structures or to measure water-surface elevations within an accuracy greater than ±0.1 ft prototype. Also, the model limits did not include all of the floodway areas covered by the higher flows. The model was of the fixed-bed type and was not designed to simulate the movement of sediment in the prototype; therefore, changes in channel configurations and slopes resulting from changes in the channel bed and banks that might be caused by the structure or changes in flow conditions could not be developed naturally.

Summary of Results and Conclusions

74. The following results and indications were developed during the investigations:

a. Navigation conditions in the lock approach are affected by the alignment of the channel upstream and the location of the dam with respect to that of the lock. With existing conditions, serious crosscurrents develop in the approach to the lock guide wall from the concentration of flow along the right bank moving toward the dam to the left. Because of the crosscurrents, navigation conditions for downbound tows approaching the lock are extremely difficult and hazardous, particularly during the higher flows.

b. Extending the length of the upper guide wall without other modifications would not produce any significant improvement in navigation conditions in the upper lock approach. However, downbound tows could approach the upper end of the longer guide wall before being affected by crosscurrents.

c. Navigation conditions in the upper lock approach would be considerably better with a guard wall (riverside of lock) in place of the guide wall and excavation of the right bank as in plan A or plan A-modified. With the guard wall, tows could approach the lock close along the right bank landward of the wall. However, replacement of the guide wall with a guard wall could present construction problems and interference with traffic.

d. Most of the navigation difficulties could be eliminated and downbound tows could approach the lock with much greater safety than with existing conditions with the rock dike extending upstream from the right dam abutment as in plan H-modified. However, navigation conditions with this plan would not be as good as with plan A or plan A-modified because of the maneuvering required to approach the guide wall.

e. With plan H-modified, water-surface elevations upstream of the lock approach during some flows would tend to be as much as 0.5 ft higher initially than those with existing conditions. This could decrease as the channel configuration becomes adjusted, based on the change in velocity distribution. There would also be some reduction in the distribution of flow through the dam gate bay near the rock dike but the drop in water level across the dam would not be affected appreciably.

f. Extension of the right bank dike system downstream as in plans B to F would adversely affect navigation conditions for downbound tows approaching the lock since they would force tows to make a turn toward the right bank a short distance upstream. In making the turn, tows would have their stern in high-velocity currents that would tend to rotate the tow clockwise. If approaching along the right side of channel upstream, tows would tend to be moved toward and against the dikes. The dikes would increase stages upstream and could cause shoaling in the lock approach.

g. With plans A and A-modified, there would be a tendency for broken ice to drift into the lock approach, all of which would not be moved through the ice gap in the upper guard wall. The accumulation would tend to be greater with plan A-modified than with plan A. Flow through the ice gap would have litle effect on tows but could be hazardous for small boats and a closure or barrier might be required when not passing ice and debris.

h. With plan H-modified, the tendency for broken ice to drift into the lock approach would be greater than with plan A or A-modified. However, most of the ice would move through the opening at the lower end of the dike and the accumulation on the lock side of the dike should be only slightly more than with existing conditions.

Table 1

Water-Surface Elevations, Bast Test

(Existing Conditions)

Gage No.	Water-Surface Elevations, ft msl Q, cfs 15,000	Q, cfs 30,000	Q, cfs 36,000	Q, cfs 70,000	Q, cfs 100,000	Q, cfs 134,000
1	674.1	674.3	674.5	678.8	681.5	683.7
2	674.1	674.3	674.5	678.8	681.5	683.7
3	674.1	674.2	674.4	678.7	681.4	683.7
4	674.1	674.1	674.2	678.6	681.4	683.6
5	674.1	674.1	674.1	678.6	681.4	683.6
6	674.0	674.0	674.1	678.6	681.3	683.6
7	674.0*	674.0*	674.0*	678.5*	681.2*	683.5*
8	673.9	673.9	673.8	678.3	681.0	683.3
9	668.7	672.4	673.5	678.1	680.6	682.9
10	668.6*	672.4*	673.5	678.1	680.6	682.9

* Controlled elevation.

Table 2

Water-Surface Elevations, Plan A

Gage No.	Water-Surface Elevations, ft msl					
	Q, cfs 15,000	Q, cfs 30,000	Q, cfs 36,000	Q, cfs 70,000	Q, cfs 100,000	Q, cfs 134,000
1	674.1	674.3	674.5	678.8	681.5	683.7
2	674.1	674.3	674.5	678.8	681.5	683.7
3	674.1	674.2	674.4	678.8	681.4	683.7
4	674.1	674.1	674.2	678.7	681.4	683.6
5	674.1	674.1	674.1	678.7	681.4	683.6
6	674.0	674.0	674.1	678.7	681.3	683.6
7	674.0*	674.0*	674.0	678.6	681.2	683.5
8	674.0	673.8	673.8	678.4	681.0	683.3
9	668.6	672.4	673.5	678.1	680.6	682.9
10	668.6*	672.4*	673.5*	678.1*	680.6*	682.9*

* Controlled elevation.

Table 3

Water-Surface Elevations, Plan A-Modified

Gage No.	Water-Surface Elevations ft msl	
	Q, cfs 36,000	Q, cfs 70,000
1	674.5	678.8
2	674.5	678.8
3	674.4	678.8
4	674.2	678.7
5	674.2	670.7
6	674.2	678.6
7	674.1	678.5
8	673.9	678.3
9	673.6	678.1
10	673.5*	678.1*

* Controlled elevations.

Table 4

Water-Surface Elevations, Plan B and Modifications

Gage No.	Plan B Discharge, cfs 36,000	Plan B Discharge, cfs 70,000	Plan B-Modified Discharge, cfs 36,000	Plan B-Modified Discharge, cfs 70,000	Plan B-1 Discharge, cfs 36,000	Plan B-1 Discharge, cfs 70,000	Plan B-2 Discharge, cfs 36,000	Plan B-2 Discharge, cfs 70,000
1	675.8	679.1	675.8	679.1	675.8	679.1	675.8	679.2
2	675.8	679.0	675.8	679.0	675.8	679.0	675.8	679.1
3	675.7	679.0	675.7	679.0	675.7	679.0	675.8	679.1
4	675.5	678.9	675.5	678.9	675.5	678.9	675.6	679.0
5	674.6	678.7	674.6	678.7	674.6	678.7	674.7	678.7
6	674.5	678.6	674.5	678.6	674.5	678.6	674.6	678.7
7	673.9	678.5	673.9	678.4	673.9	678.5	674.0	678.6
8	673.8	678.3	673.8	678.3	673.8	678.3	673.7	678.3
9	673.5	678.1	673.5	678.1	673.5	678.1	673.5	678.1
10	673.5*	678.1*	673.5*	678.1*	673.5*	678.1*	673.5*	678.1*

Water-Surface Elevations, ft msl

* Controlled elevation.

Table 5

Water-Surface Elevations, Plan C and Modifications

Gage No.	Plan C Discharge, cfs 36,000	Plan C Discharge, cfs 70,000	Plan C-Modified Discharge, cfs 36,000	Plan C-Modified Discharge, cfs 70,000	Plan C-1 Discharge, cfs 36,000	Plan C-1 Discharge, cfs 70,000	Plan C-2 Discharge, cfs 36,000	Plan C-2 Discharge, cfs 70,000
1	675.6	679.0	675.6	679.0	675.6	679.0	675.8	679.1
2	675.6	679.0	675.6	679.0	675.6	679.0	675.8	679.1
3	675.5	678.9	675.5	678.9	675.5	678.9	675.7	679.0
4	675.3	678.8	675.3	678.8	675.3	678.8	675.4	678.9
5	674.2	678.5	674.2	678.5	674.2	678.5	674.3	678.7
6	673.9	678.4	673.9	678.4	673.9	678.4	673.9	678.6
7	673.7	678.3	673.7	678.3	673.7	678.3	673.8	678.4
8	673.6	678.2	673.6	678.2	673.6	678.2	673.6	678.2
9	673.5	678.1	673.5	678.1	673.5	678.1	673.5	678.1
10	673.5*	678.1*	673.5*	678.1*	673.5*	678.1*	673.5*	678.1*

Water-Surface Elevations, ft msl

* Controlled elevation.

Table 6

Water-Surface Elevations, Plan D and Plan E and Modifications

Gage No.	Water-Surface Elevations, ft msl				
	Plan D Discharge, cfs	Plan E Discharge, cfs		Plan E-Modified Discharge, cfs	
	36,000	36,000	70,000	36,000	70,000
1	675.6	674.7	678.9	674.7	678.9
2	675.6	674.6	678.9	674.6	678.9
3	675.5	674.5	678.8	674.5	678.8
4	675.3	674.4	678.8	674.4	678.8
5	674.1	674.3	678.7	674.3	678.7
6	674.0	674.3	678.7	674.3	678.7
7	673.6	674.2	678.6	674.2	678.6
8	673.6	674.0	678.5	674.0	678.5
9	673.5	673.5	678.2	673.5	678.2
10	673.5*	673.5*	678.1*	673.5*	678.1*

* Controlled elevation.

Table 7

Water-Surface Elevations, Plan F and Modifications

Gage No.	Water-Surface Elevations, ft msl			
	Plan F Discharge, cfs		Plan F-Modified Discharge, cfs	
	36,000	70,000	36,000	70,000
1	674.8	679.1	674.8	679.1
2	674.7	679.1	674.7	679.1
3	674.7	679.0	674.7	679.0
4	674.6	679.0	674.6	679.0
5	674.5	678.9	674.5	678.9
6	674.5	678.9	674.5	678.9
7	674.4	678.9	674.4	678.9
8	674.3	678.8	674.3	678.8
9	673.5	678.2	673.5	678.2
10	673.5*	678.1*	673.5*	678.1*

* Controlled elevation.

Table 8

Water-Surface Elevations, Plan G and Modifications

Gage No.	Water-Surface Elevations, ft msl			
	Plan G Discharge, cfs		Plan G-Modified Discharge, cfs	
	36,000	70,000	36,000	70,000
1	674.9	679.2	674.9	679.1
2	674.9	679.2	674.9	679.1
3	674.7	679.1	674.8	679.0
4	674.6	679.0	674.6	679.0
5	674.5	679.0	674.5	678.9
6	674.5	679.0	674.5	678.9
7	674.5	679.0	674.4	678.9
8	674.0	678.7	674.1	678.6
9	673.5	678.2	673.5	678.2
10	673.5*	678.1*	673.5*	678.1*

* Controlled elevation.

Table 9

Water-Surface Elevations, Plan H

Gage No.	Water-Surface Elevations, ft msl Q, cfs 36,000	Q, cfs 70,000
1	674.8	678.9
2	674.8	678.9
3	674.7	678.8
4	674.6	678.8
5	674.5	678.8
6	674.4	678.7
7	674.5	678.6
8	673.7	678.2
9	673.5	678.1
10	673.5*	678.1*

* Controlled elevation.

Table 10

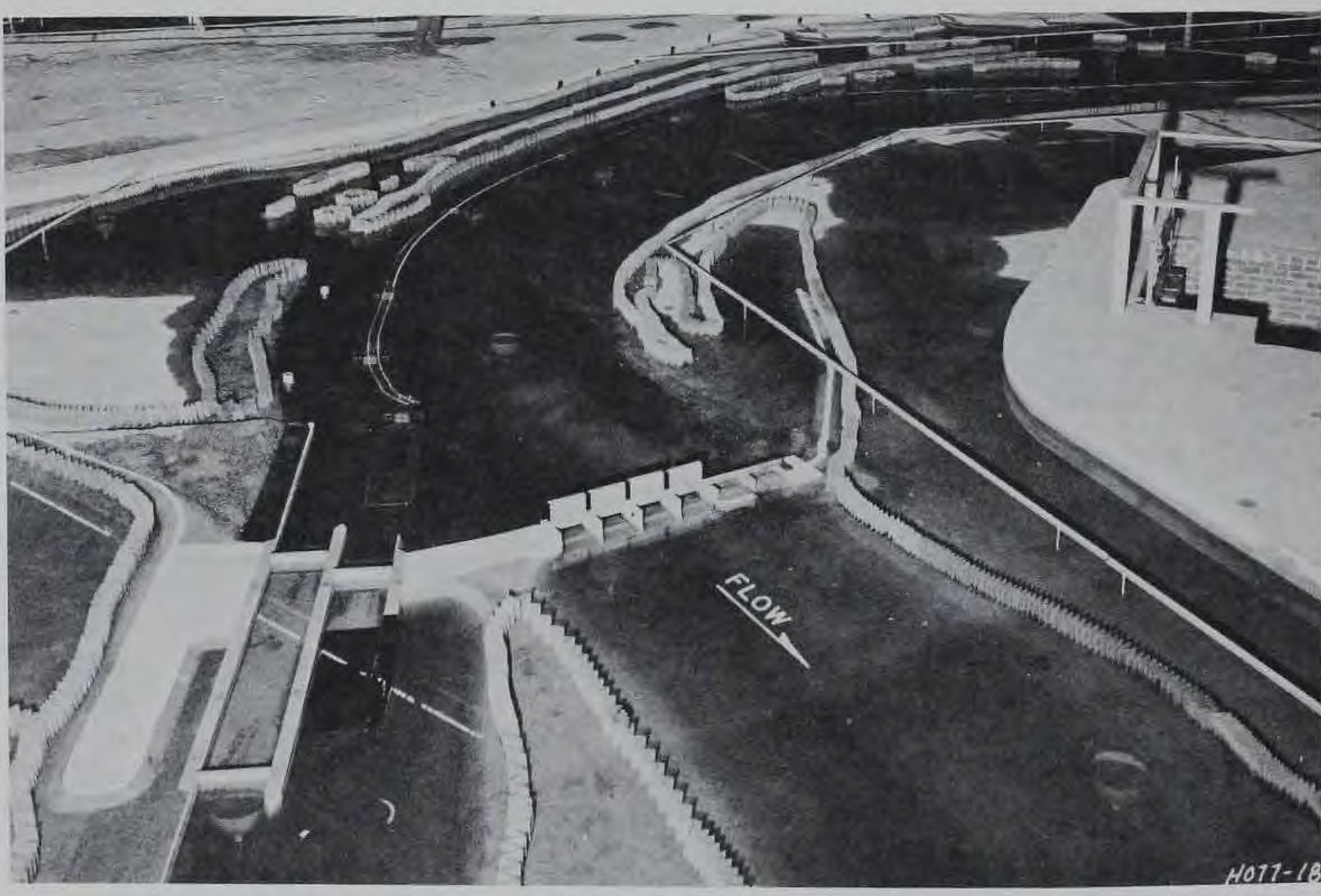
Water-Surface Elevations, Plan H-Modified

Gage No.	Water-Surface Elevations, ft msl Q, cfs 15,00	Q, cfs 30,000	Q, cfs 36,000	Q, cfs 70,000	Q, cfs 100,000	Q, cfs 134,000
1	674.3	674.8	674.8	678.9	681.9	683.9
2	674.3	674.8	674.8	678.9	681.8	683.9
3	674.2	674.7	678.7	678.8	681.7	683.8
4	674.1	674.6	674.6	678.8	681.7	683.8
5	674.0	674.5	674.5	678.8	681.6	683.7
6	674.0	674.4	674.4	678.7	681.6	683.7
7	674.1	674.5	674.5	678.6	681.6	683.7
8	673.9*	673.9*	673.7	678.2	681.0	683.3
9	668.6	672.4	673.5	678.1	680.7	682.9
10	668.6**	672.4**	673.5**	678.1**	680.6**	682.9**

* Elevation was controlled at gage 8 instead of gage 7 to eliminate the effect of the rock dike on the upper gage.

** Controlled elevation.

a. Surface currents in lock approach and in approach to gated dam

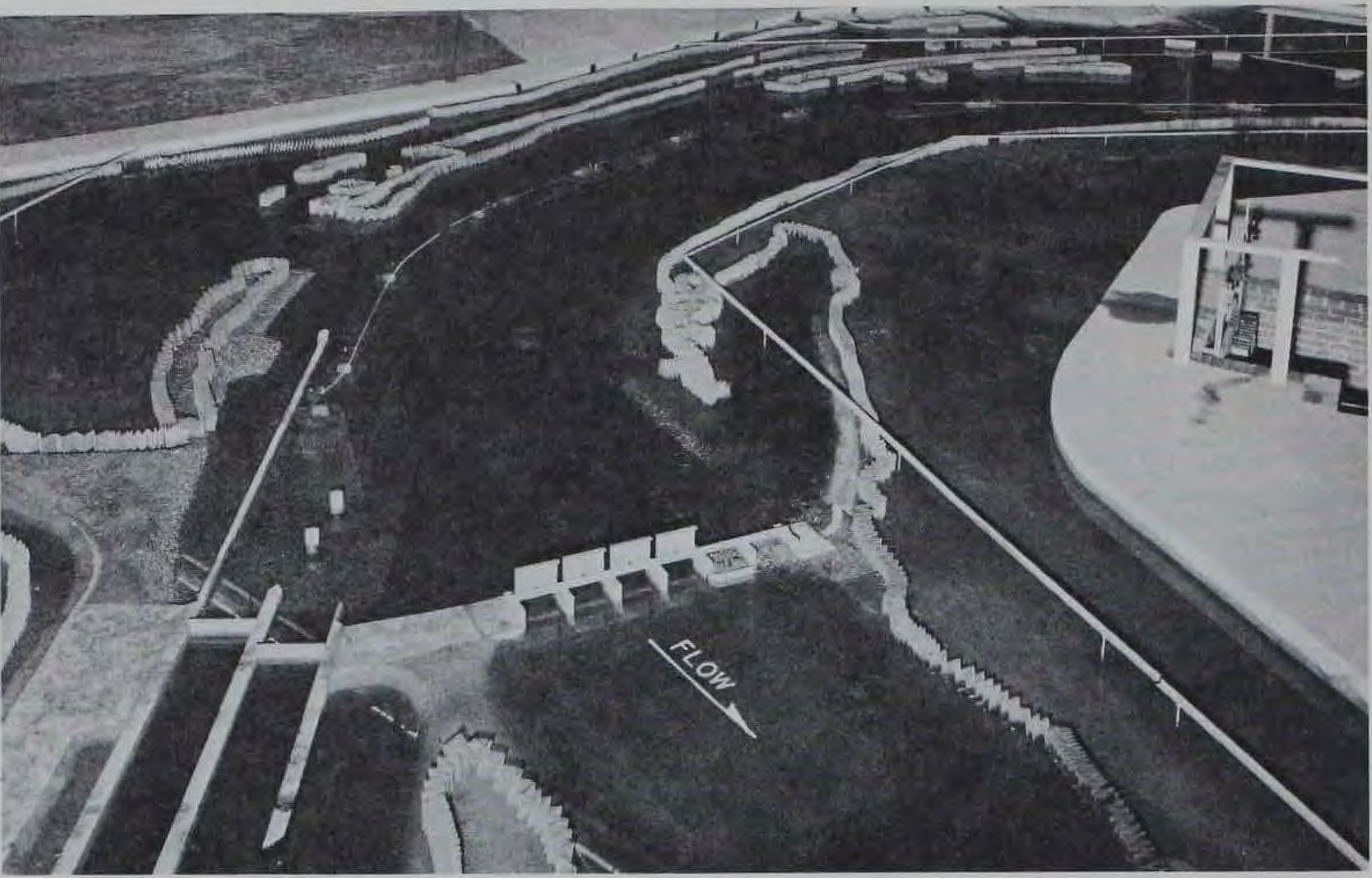


b. Path of 600-ft downbound tow approaching lock guide wall with existing conditions. Note tendency for tow to be moved away from guide wall

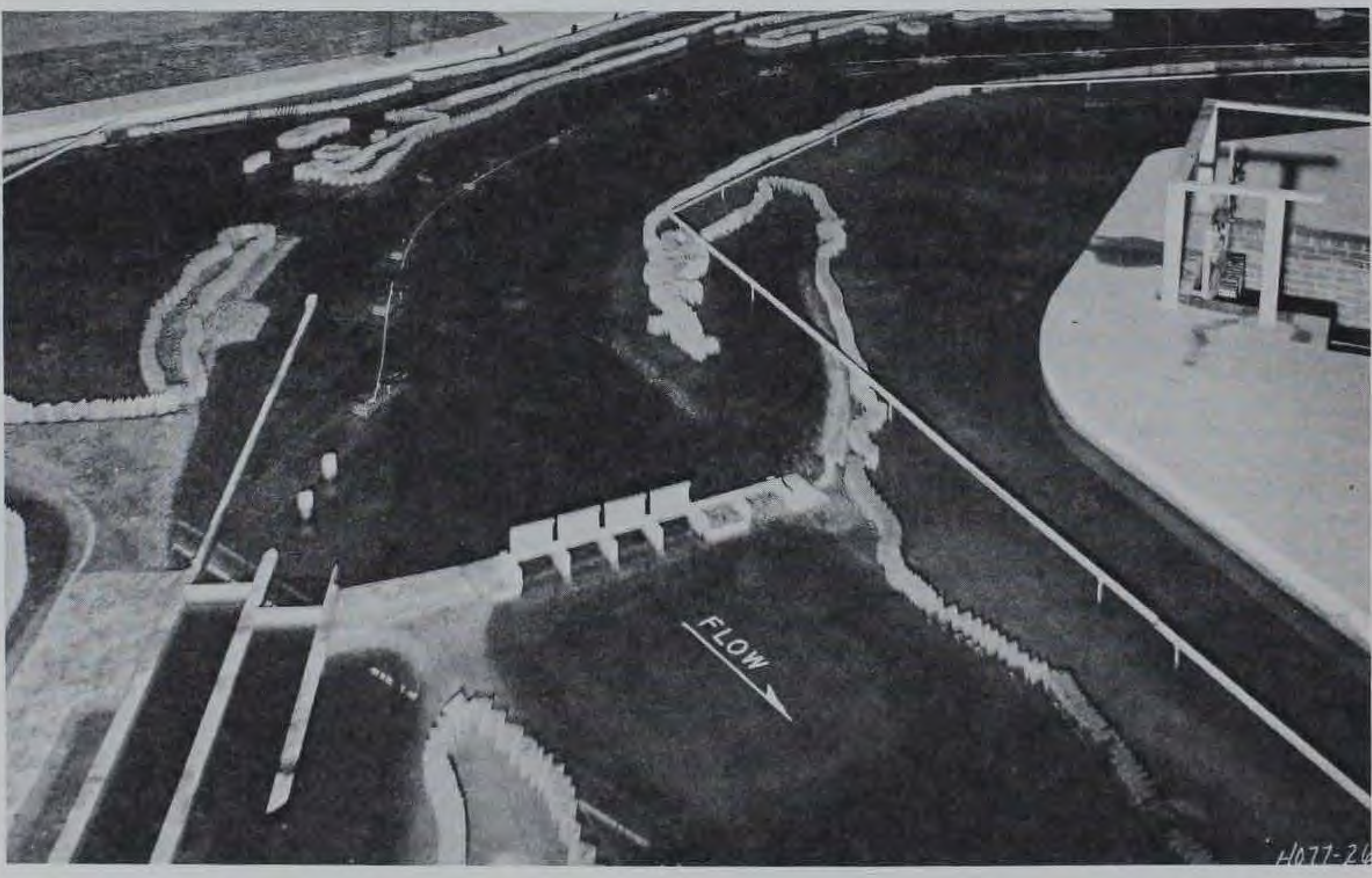
Photo 1. Base test; discharge 36,000 cfs, upper pool el 674.0
(Sheet 1 of 2)

c. Path of 600-ft upbound tow leaving lock showing effects of crosscurrents on head of tow

Photo 1 (Sheet 2 of 2)

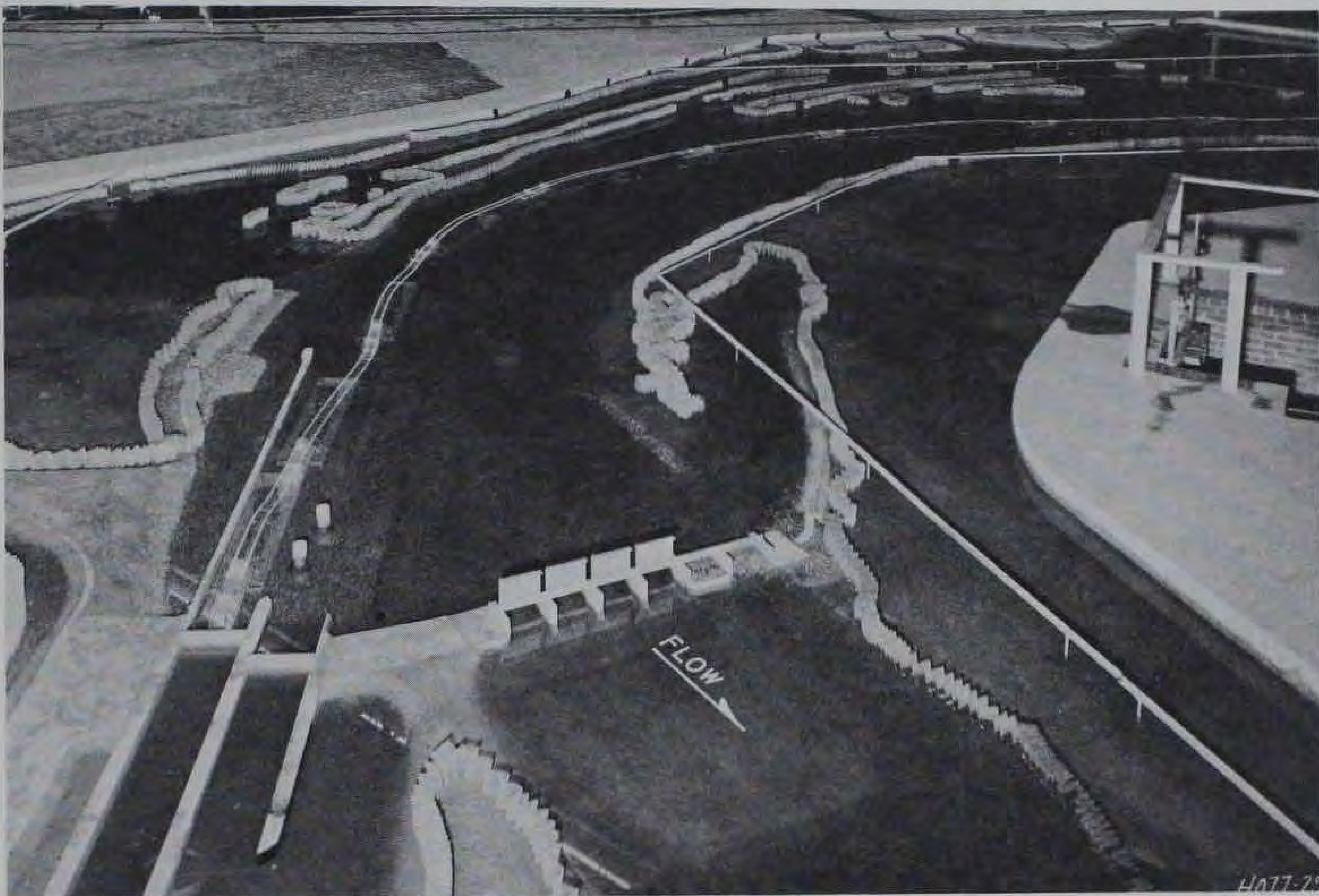


a. Path of downbound 600-ft tow approaching extended guide wall at a slight angle to wall. Note tendency for tow to be moved riverward after passing end of wall



b. Path of downbound 600-ft tow approaching extended guide wall at a slight angle to wall. Note tendency for tow to be rotated clockwise

Photo 2. Existing conditions-modified; discharge 36,000 cfs, upper pool el 674.0 (Sheet 1 of 2)



c. Path of upbound 600-ft tow leaving lock. Conditions for upbound tows were somewhat better than with shorter existing guide wall

Photo 2 (Sheet 2 of 2)

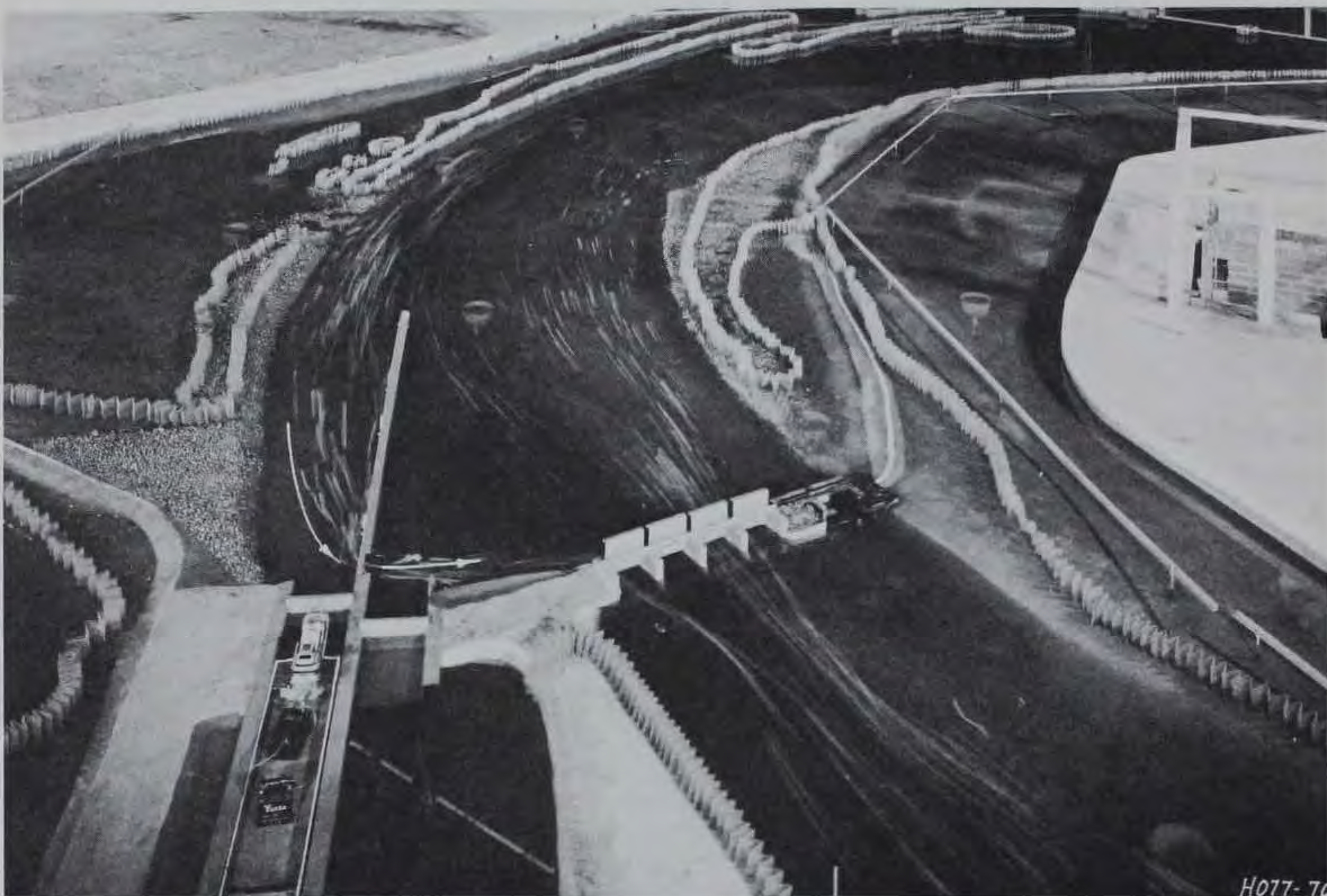
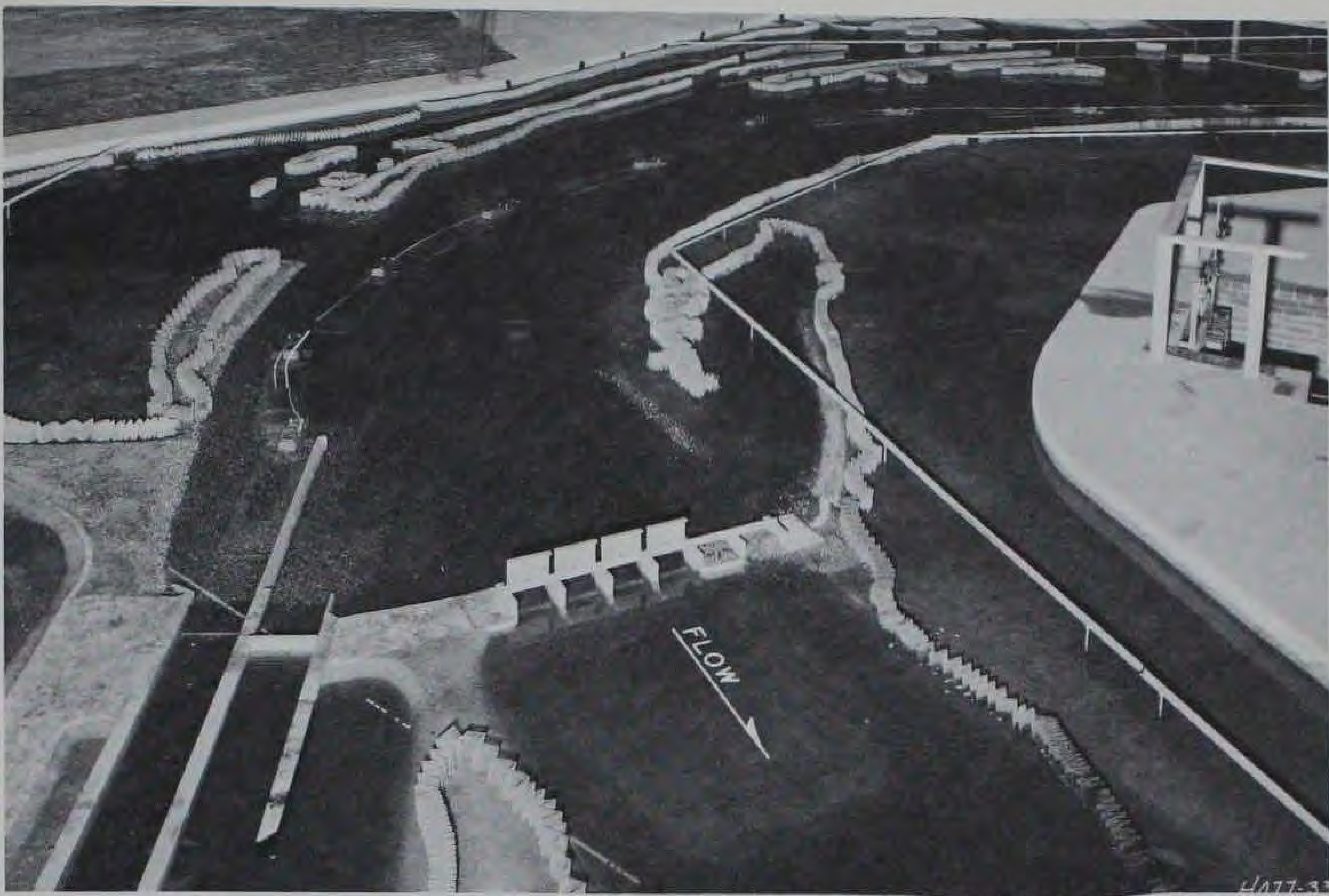


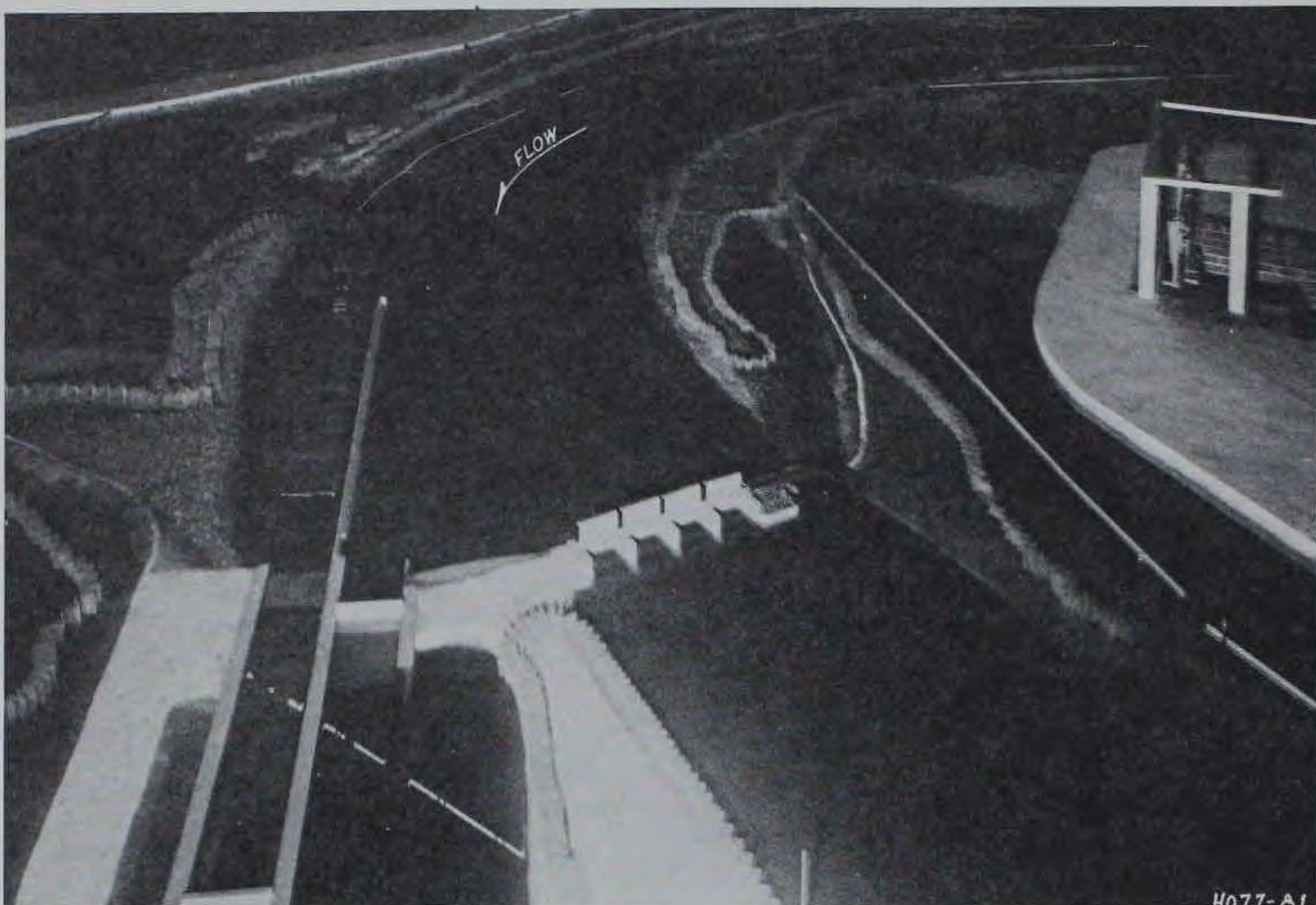
Photo 3. Plan A-modified; discharge 36,000 cfs, upper pool el 674.0. Surface currents in approaches to lock and dam. Note flow through the ice gap in upper guard wall



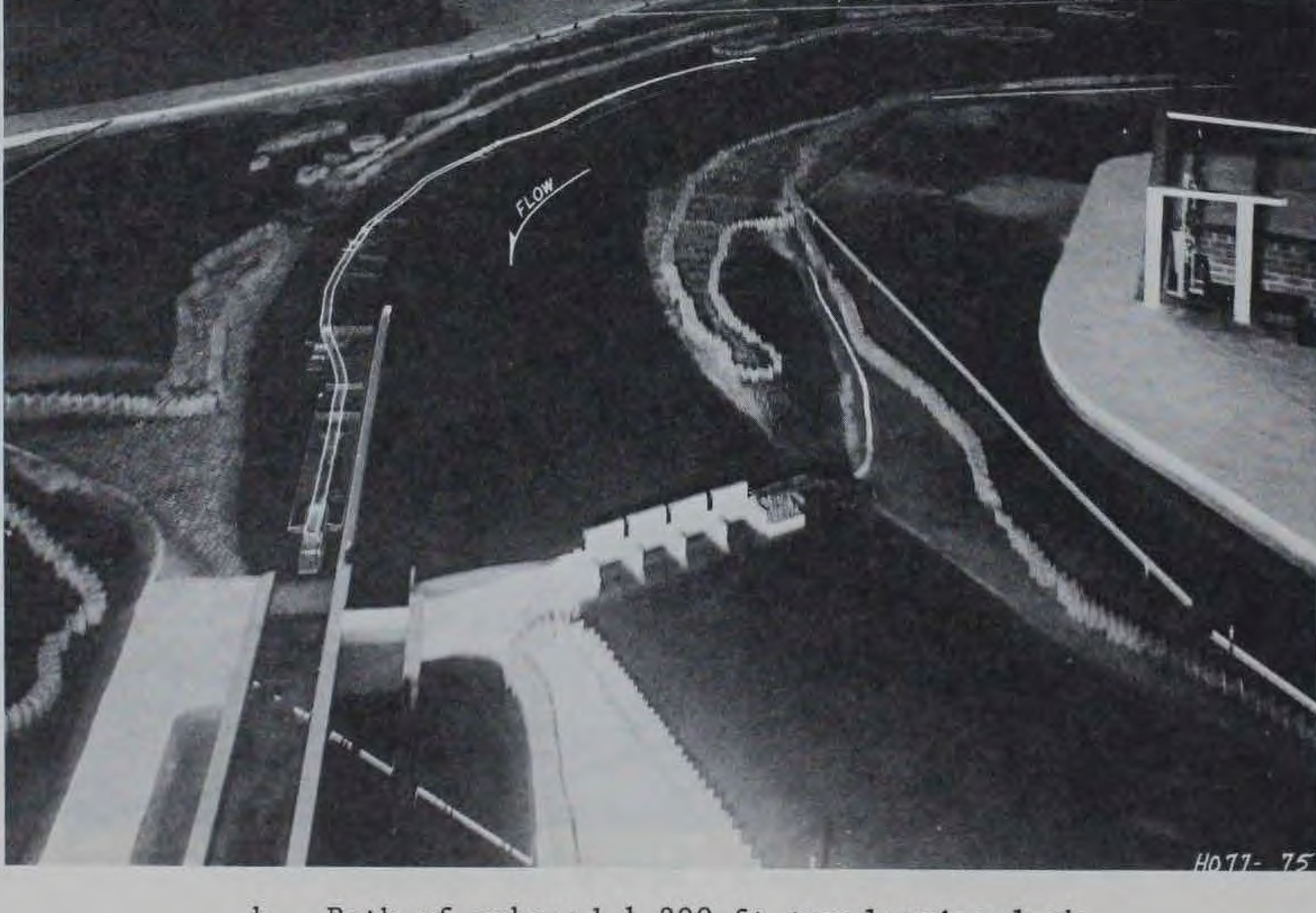
a. Path of downbound 600-ft tow approaching lock

b. Path of upbound 600-ft tow leaving lock

Photo 4. Plan A; discharge 36,000 cfs, upper pool el 674.0

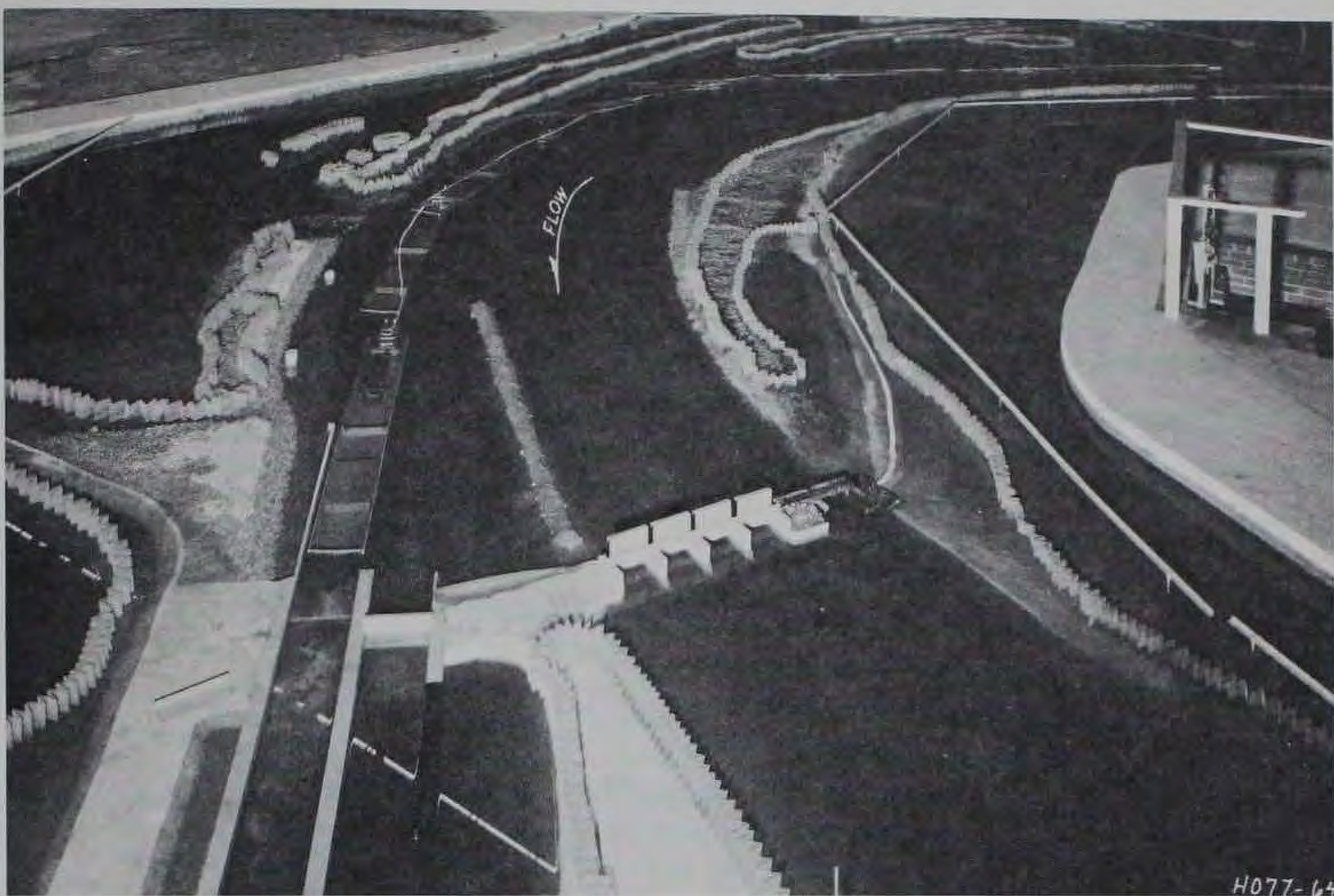


a. Path of downbound 1,200-ft tow approaching lock

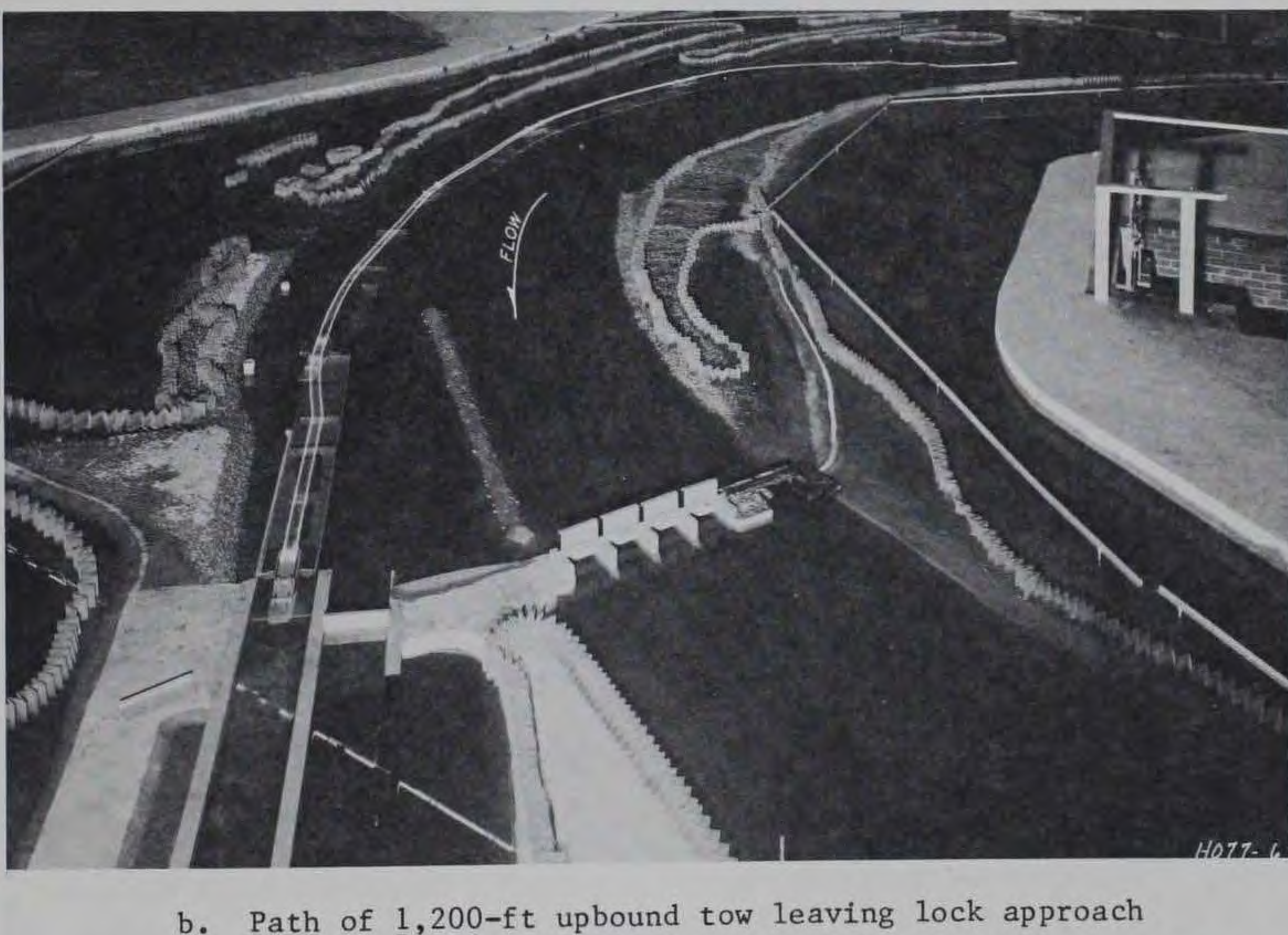


b. Path of upbound 1,200-ft tow leaving lock

Photo 5. Plan A-modified; discharge 36,000 cfs, upper pool el 674.0

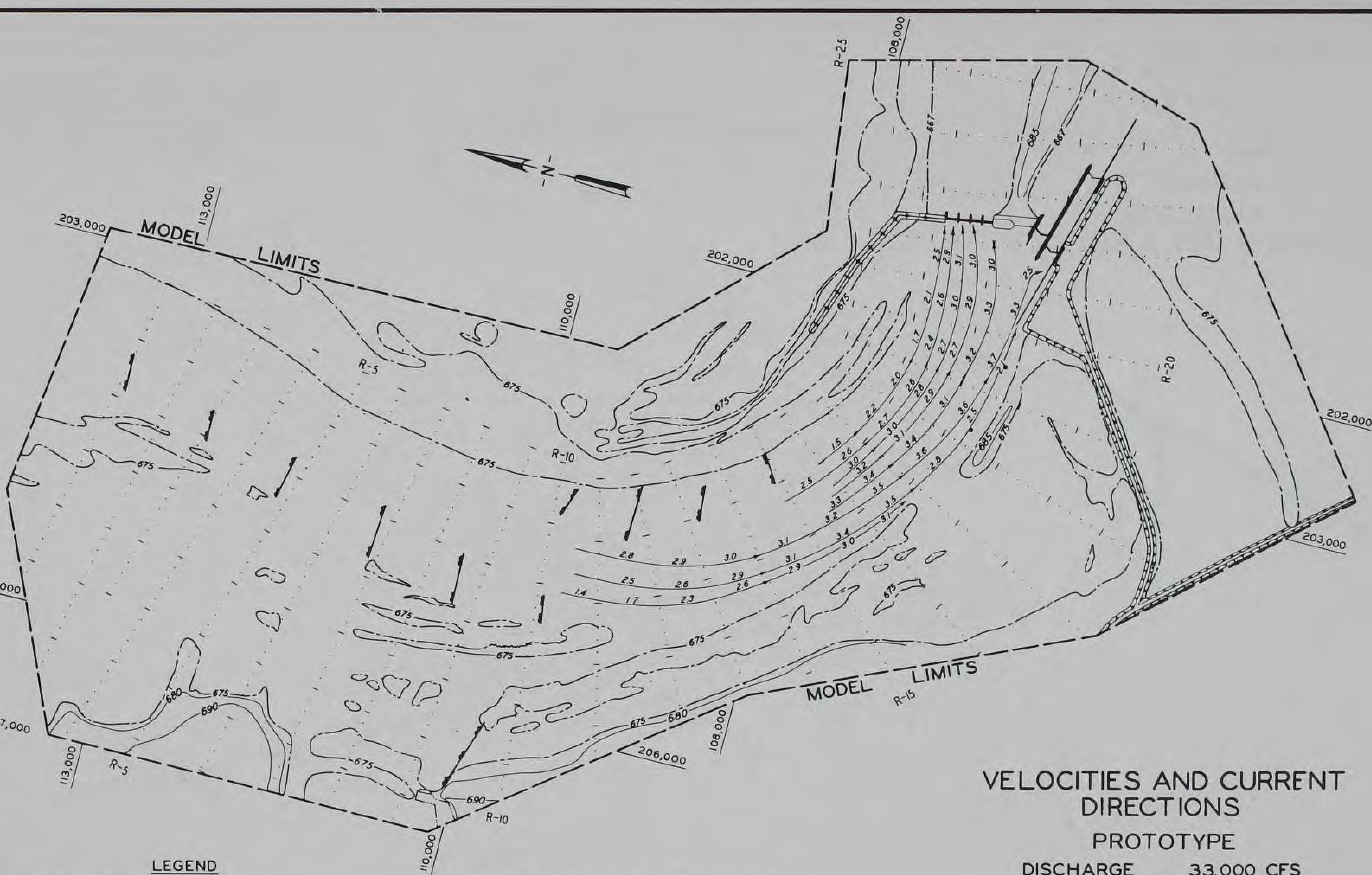


a. Path of 1,200-ft downbound tow approaching lock



b. Path of 1,200-ft upbound tow leaving lock approach

Photo 6. Plan H-modified; discharge 36,000 cfs, upper pool el 673.7



VELOCITIES AND CURRENT DIRECTIONS

PROTOTYPE

DISCHARGE	33,000 CFS
TAILWATER EL	673.0 FT

SCALES IN FEET

PROTOTYPE 300 0 300 600 900

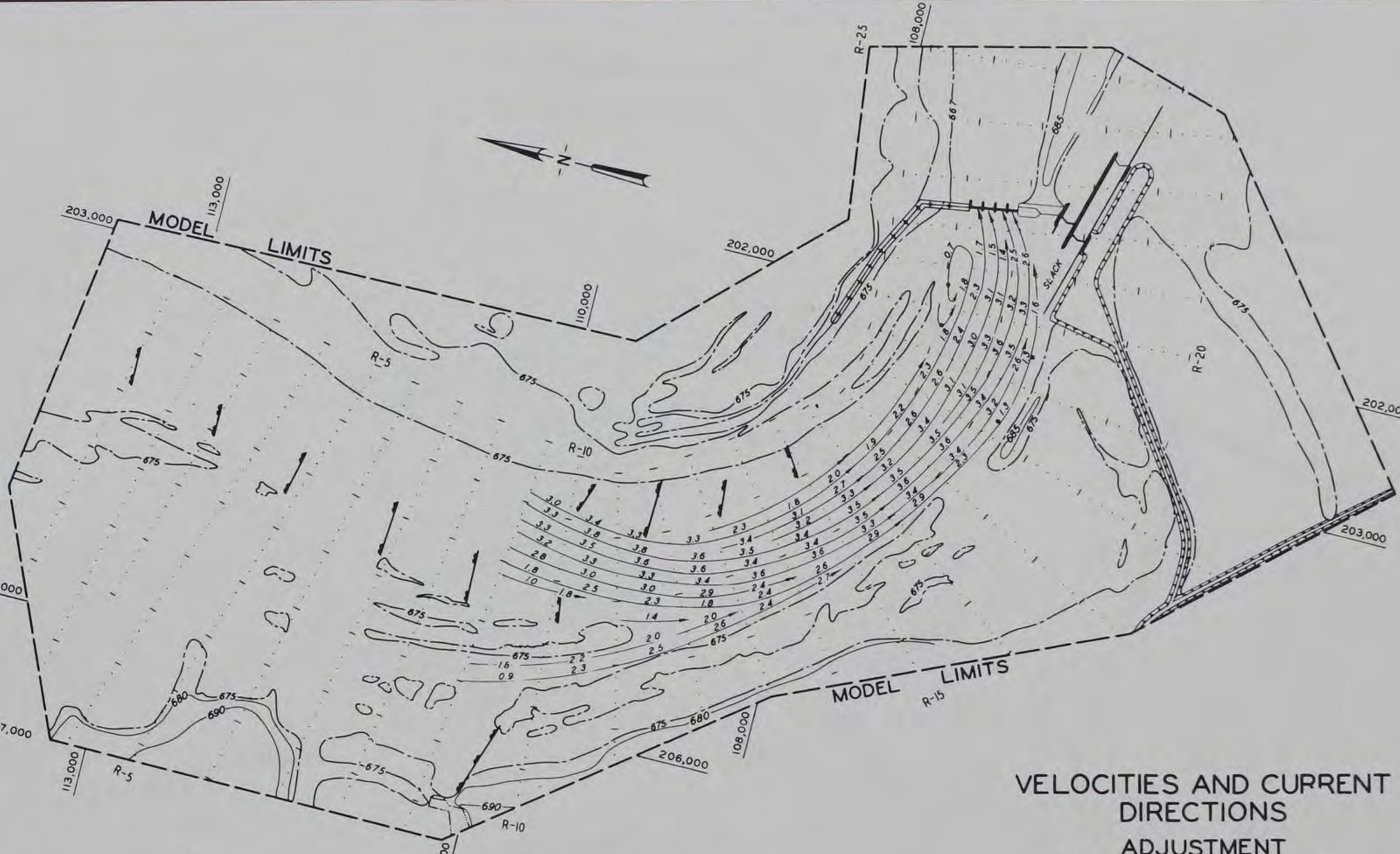
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND,
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO 6.0 FT.

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

ADJUSTMENT

DISCHARGE 33,000 CFS
TAILWATER EL 673.0 FT

SCALES IN FEET

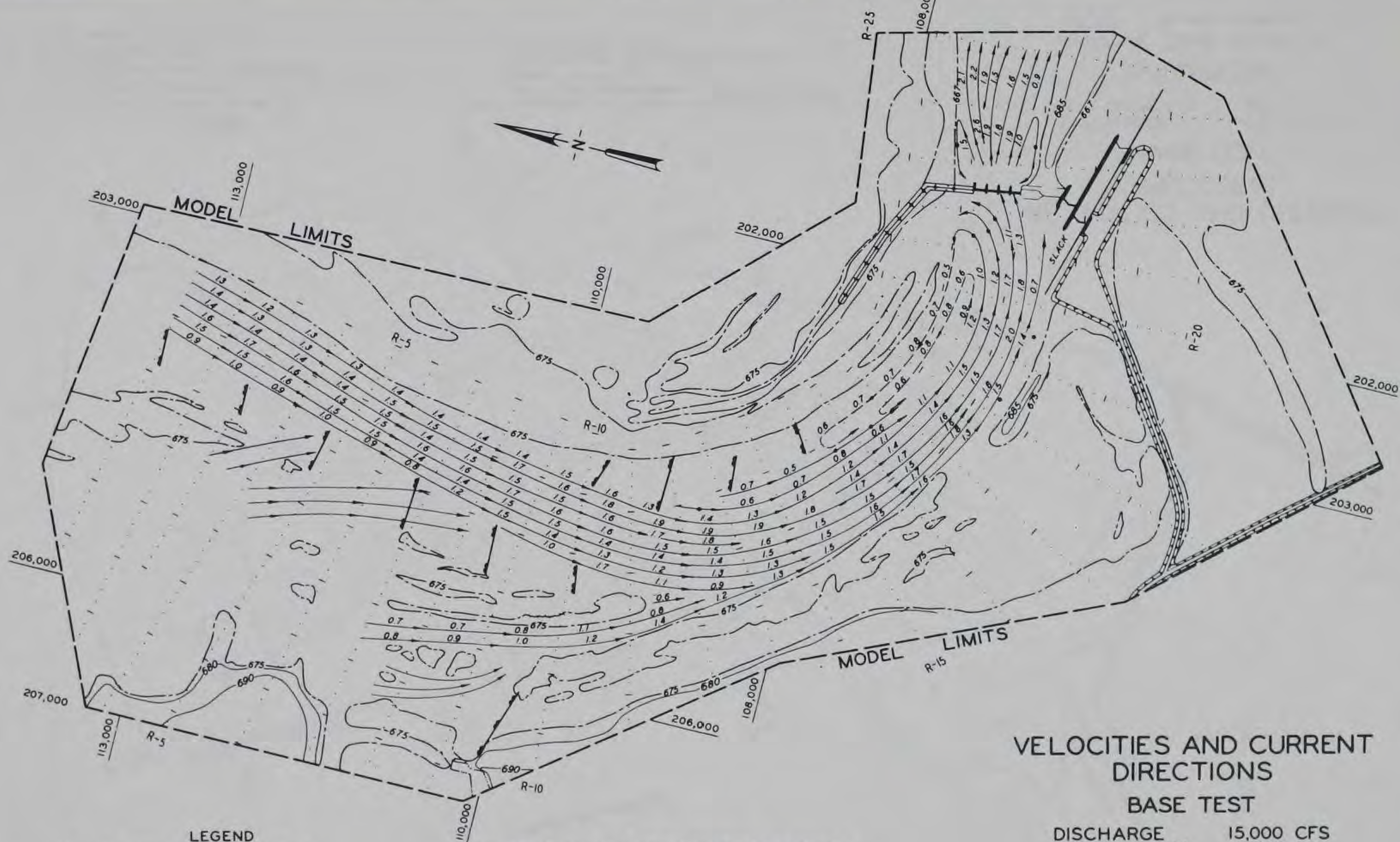
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO 6.0 FT.

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE 15,000 CFS
TAILWATER EL 668.6 FT

SCALES IN FEET

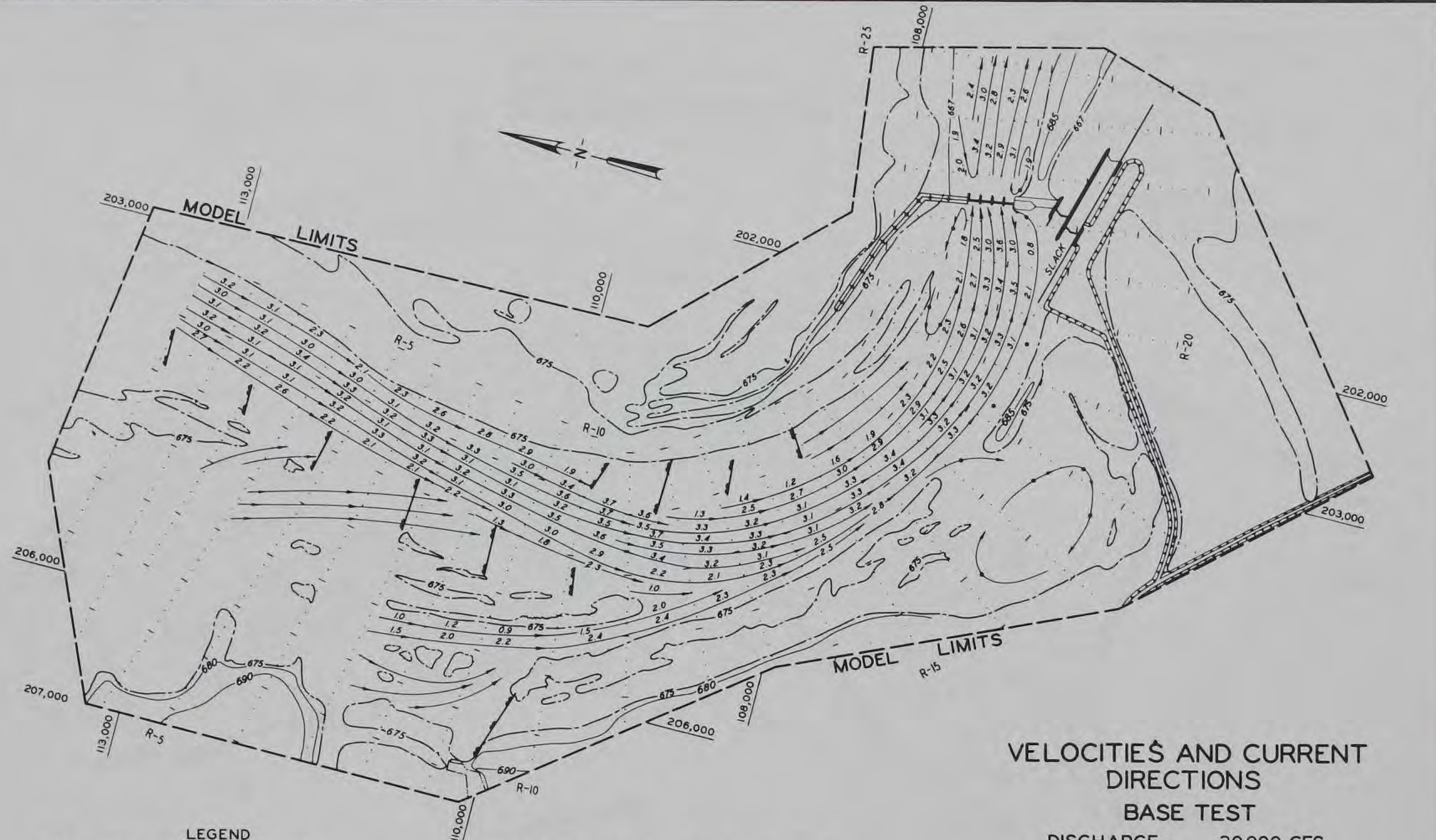
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 → VELOCITY IN FEET PER SECOND
- → VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)
- 0.7 → VELOCITY IN FEET PER SECOND WITH FLOAT SUBMERGED TO 3.0 FT

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

PLATE 3



VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE 30,000 CFS
TAILWATER EL 672.4 FT

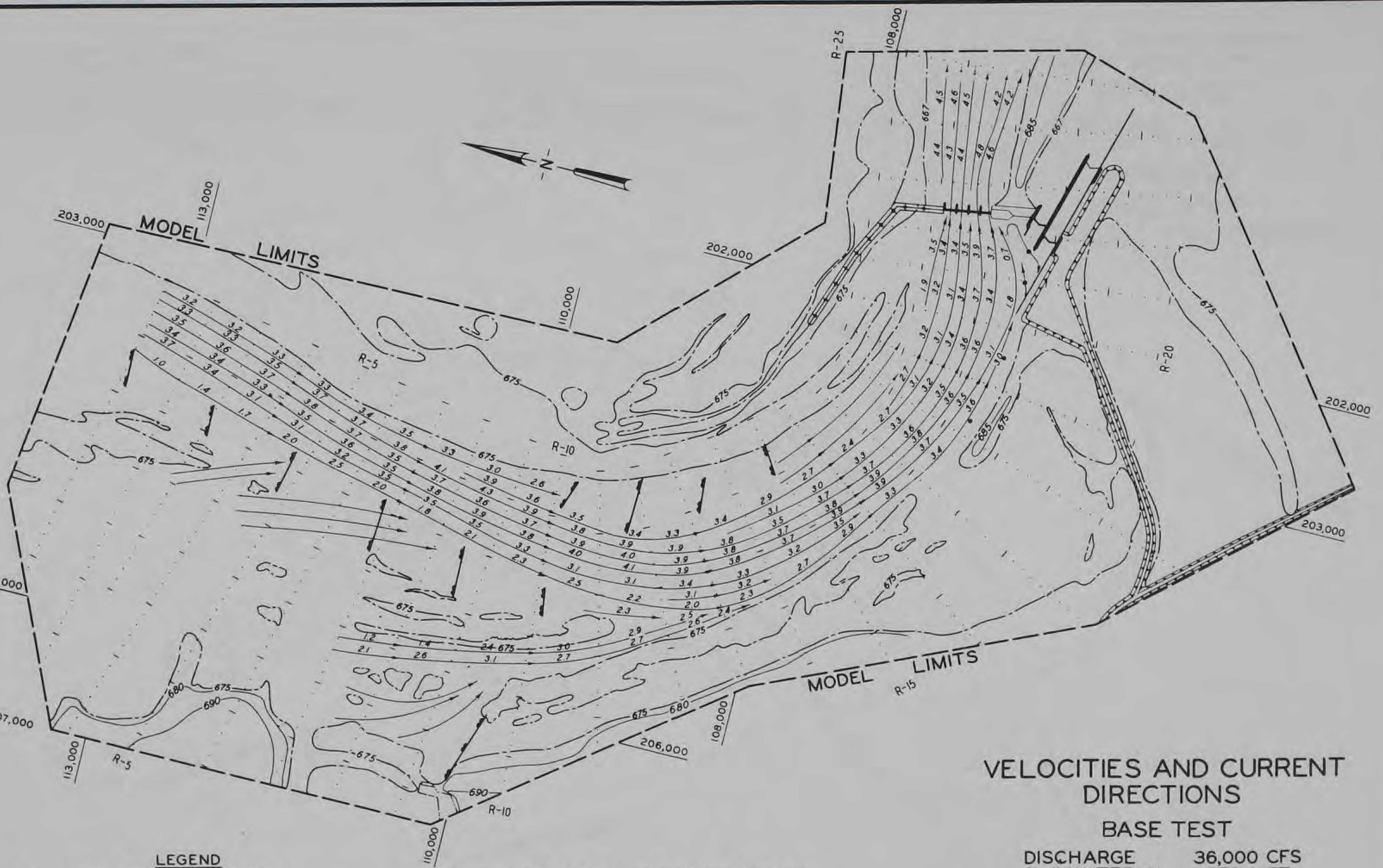
SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE 36,000 CFS
TAILWATER EL 673.4 FT

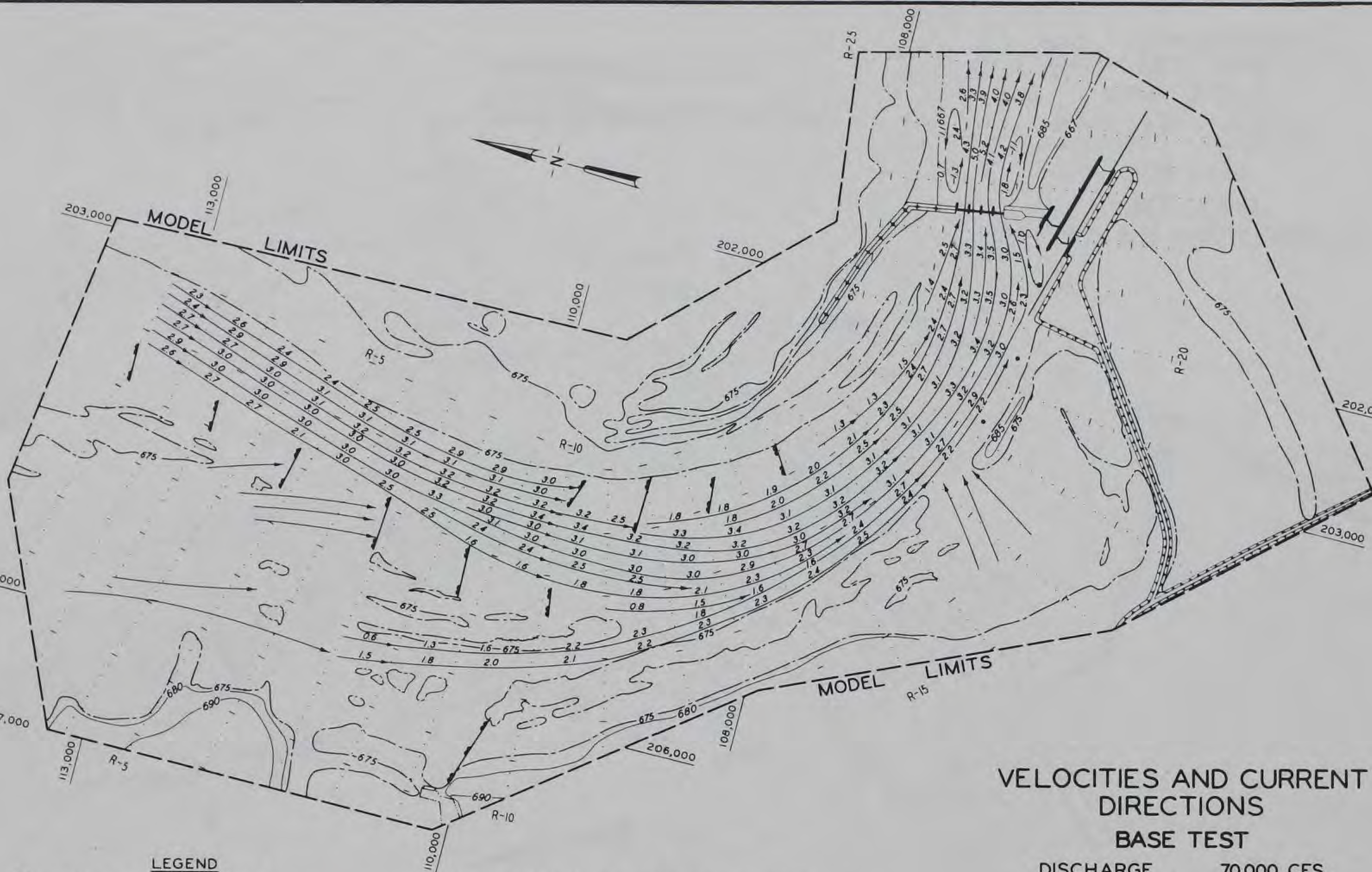
SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



LEGEND

- 4.2 → VELOCITY IN FEET PER SECOND
- —•→ VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

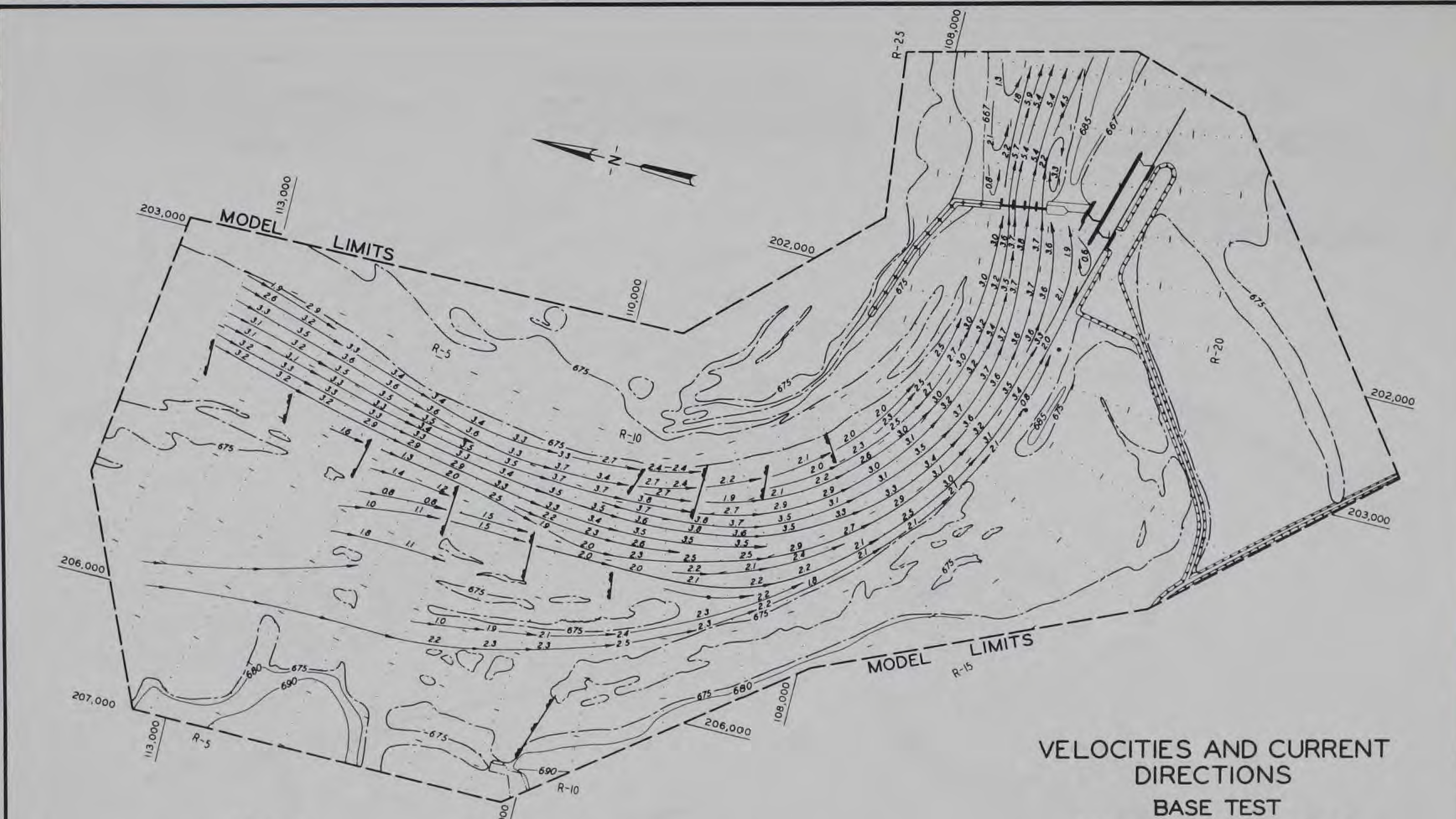
VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE 100,000 CFS
TAILWATER EL 680.6 FT

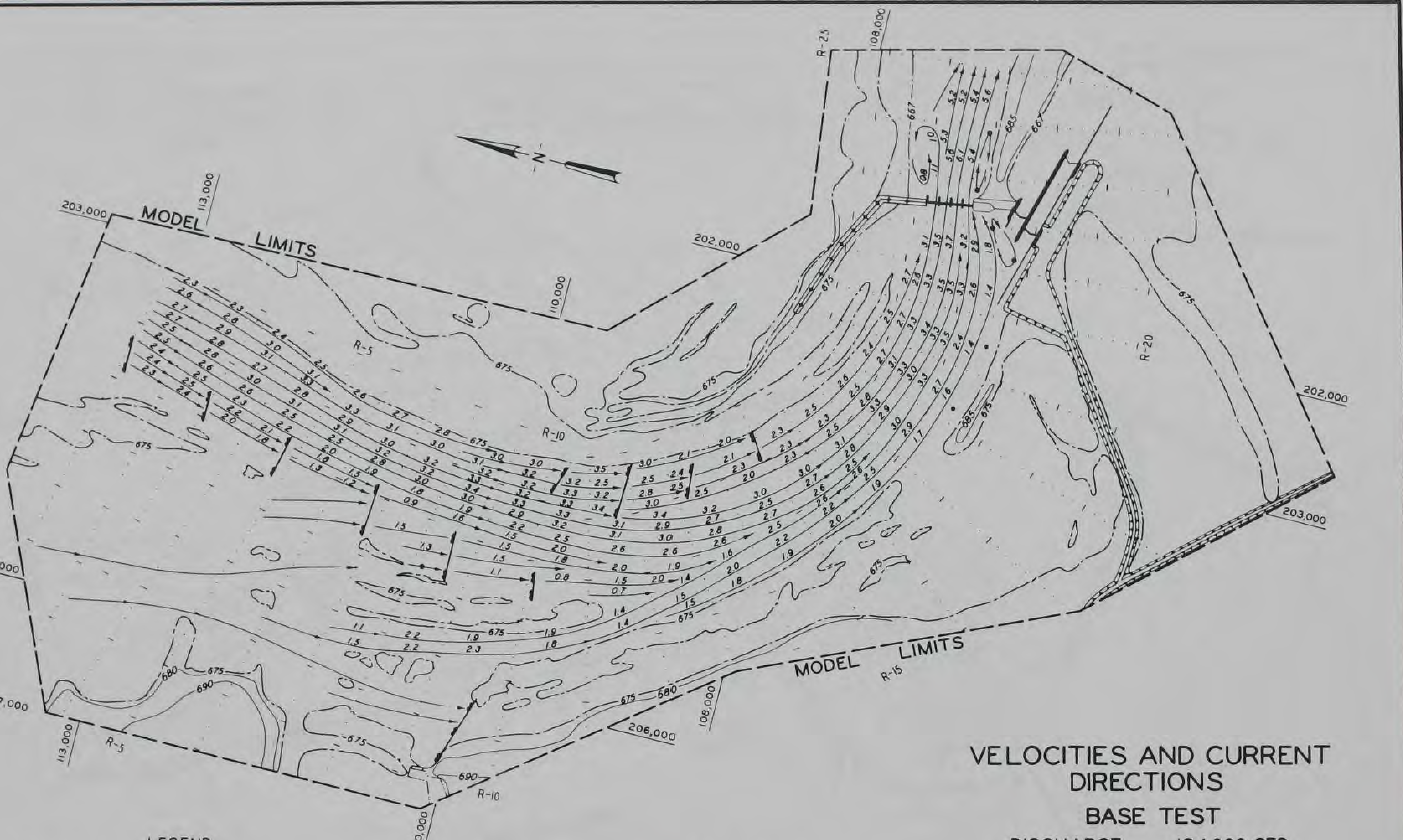
SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 — VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

BASE TEST

DISCHARGE 134,000 CFS
TAILWATER EL 682.9 FT

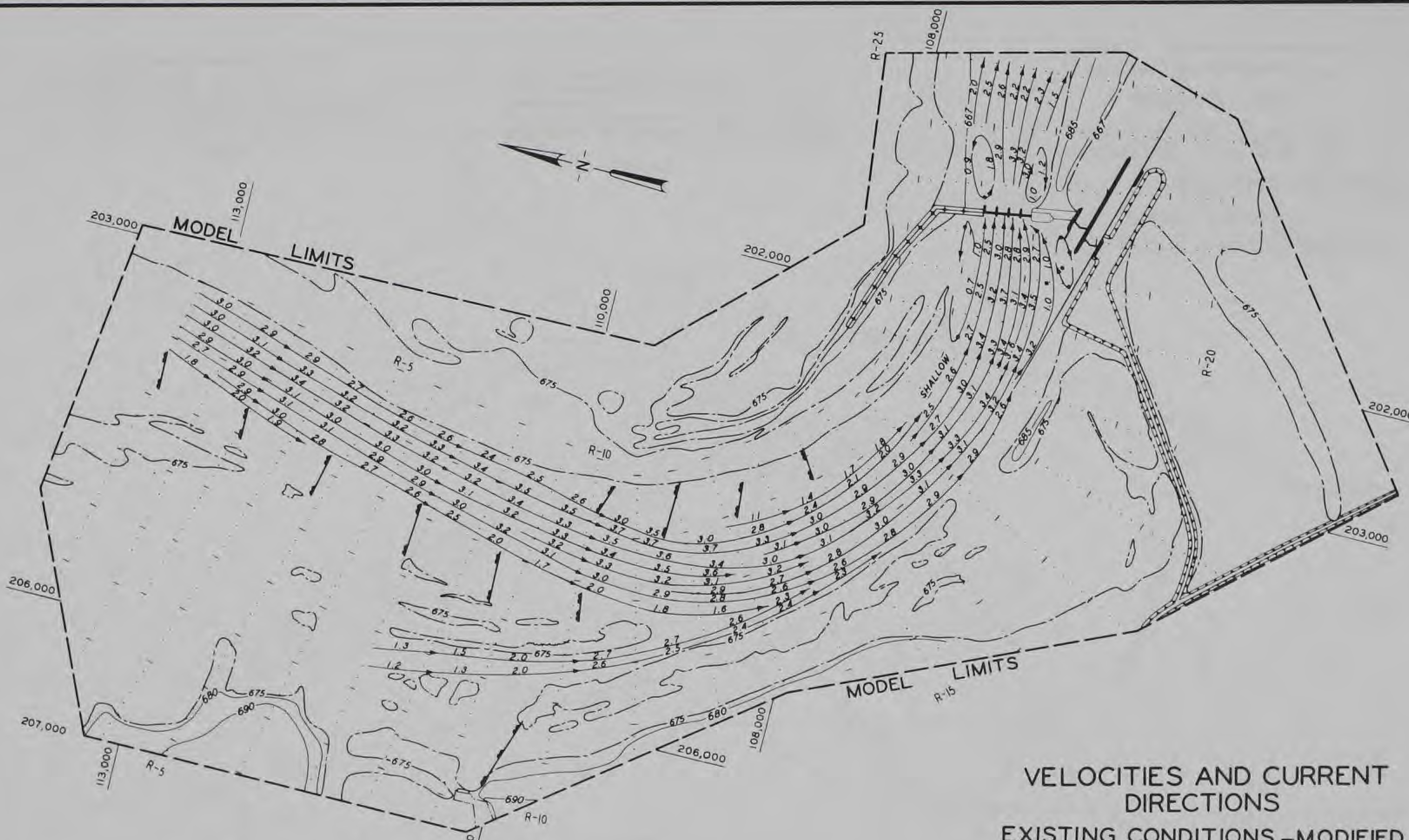
SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

EXISTING CONDITIONS–MODIFIED

DISCHARGE 30,000 CFS
TAILWATER EL 672.4 FT

SCALES IN FEET

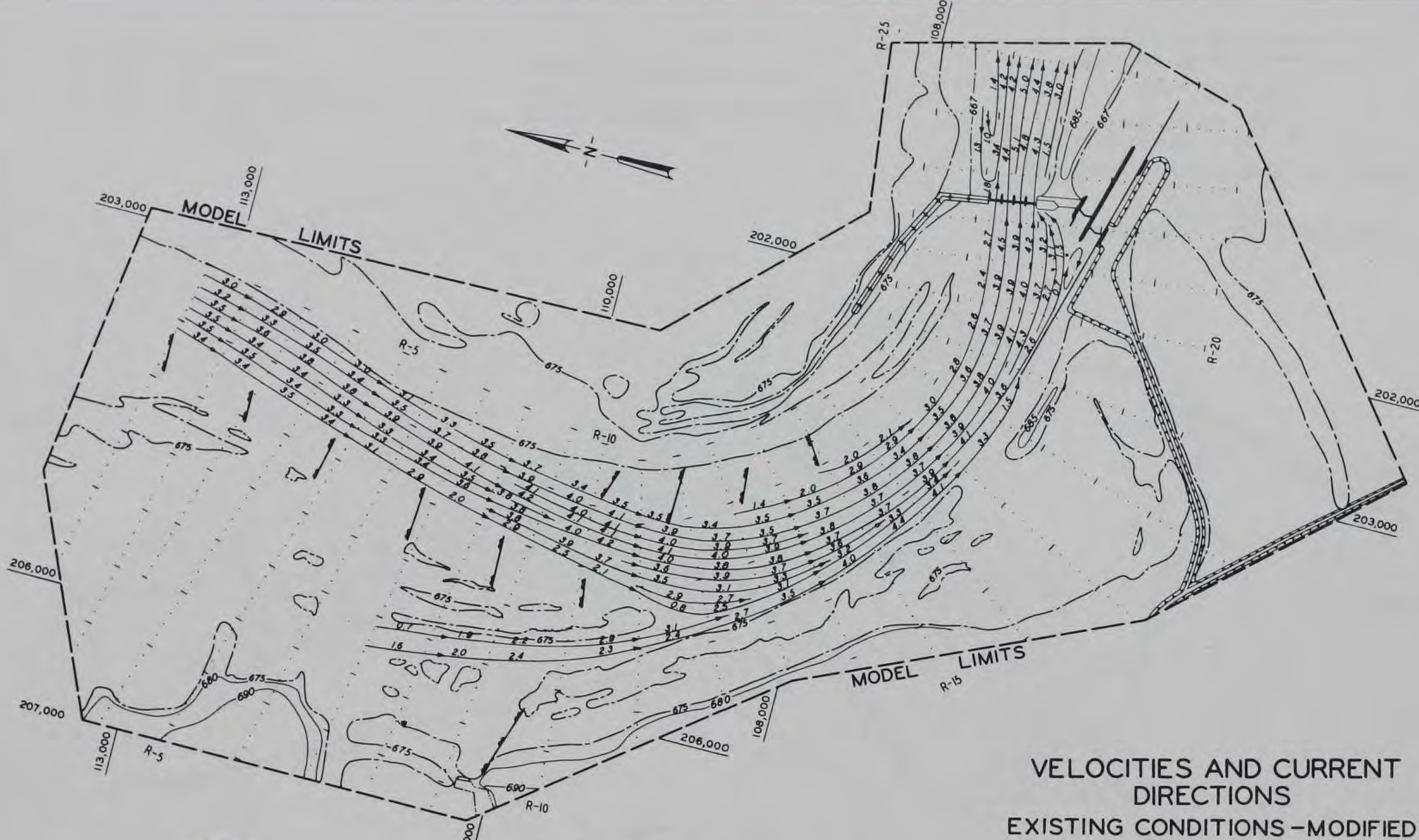
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

PLATE 9



VELOCITIES AND CURRENT DIRECTIONS
EXISTING CONDITIONS - MODIFIED

DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT

SCALES IN FEET

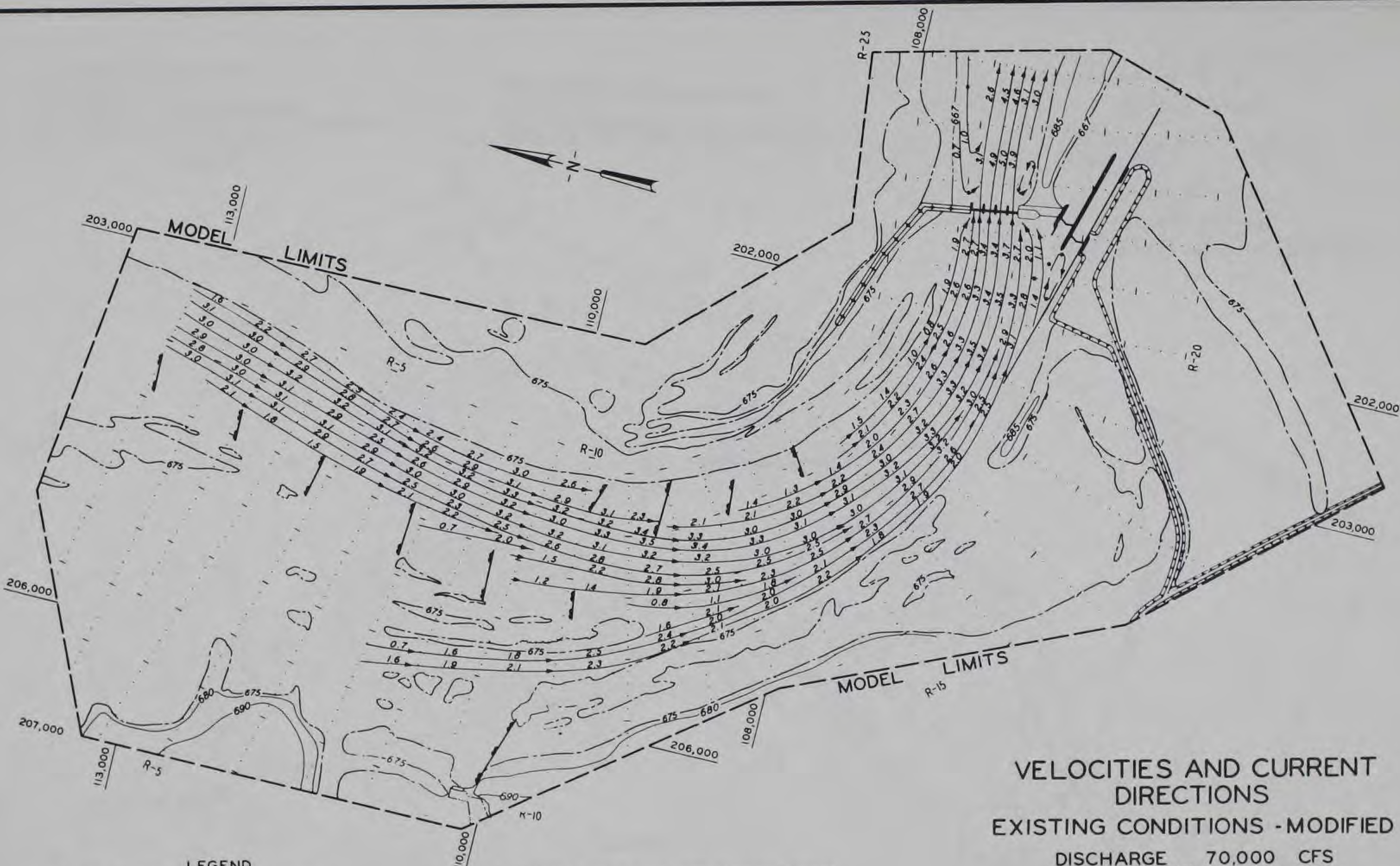
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

EXISTING CONDITIONS - MODIFIED

DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

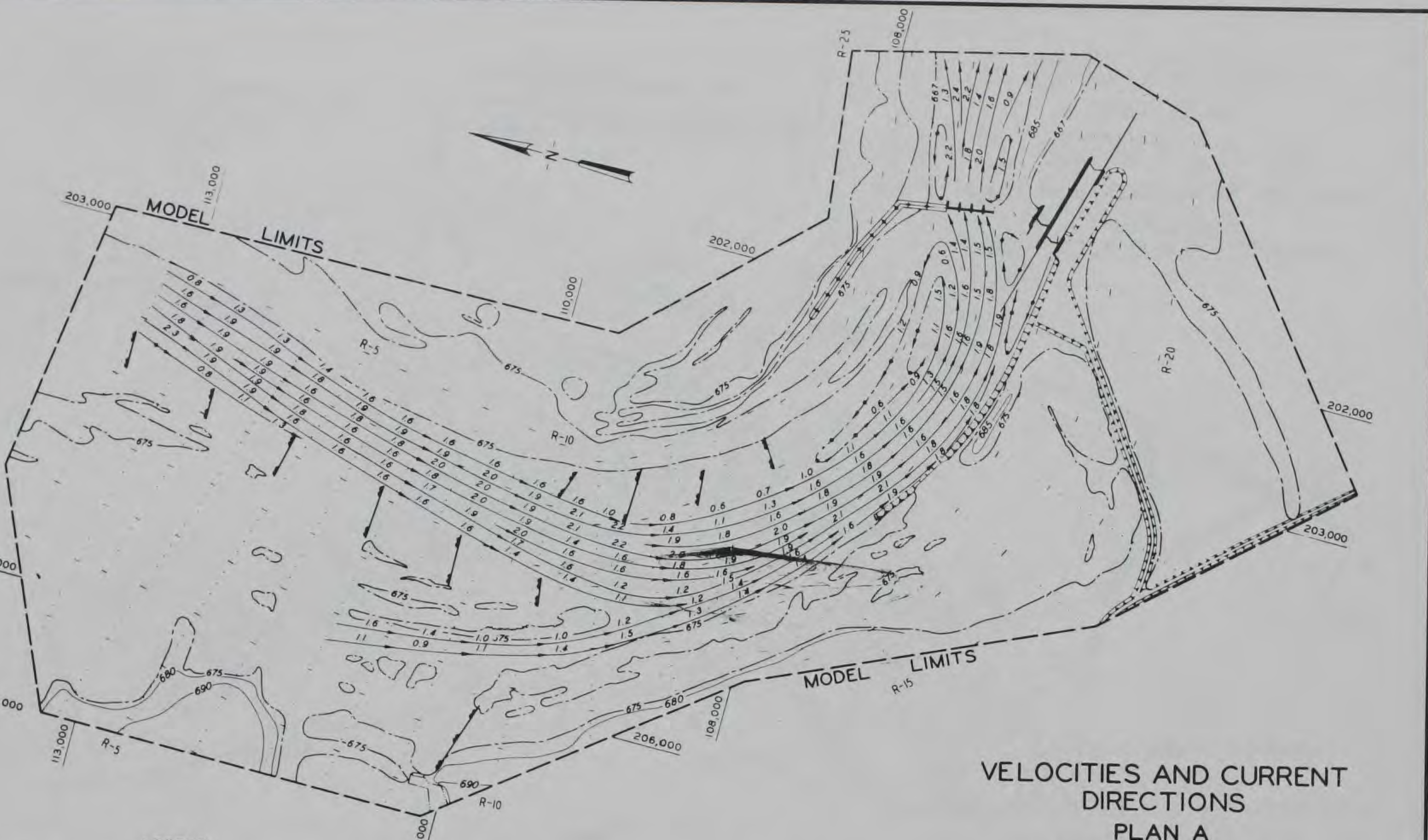
SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 → VELOCITY IN FEET PER SECOND
- —•→ VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- —·— NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

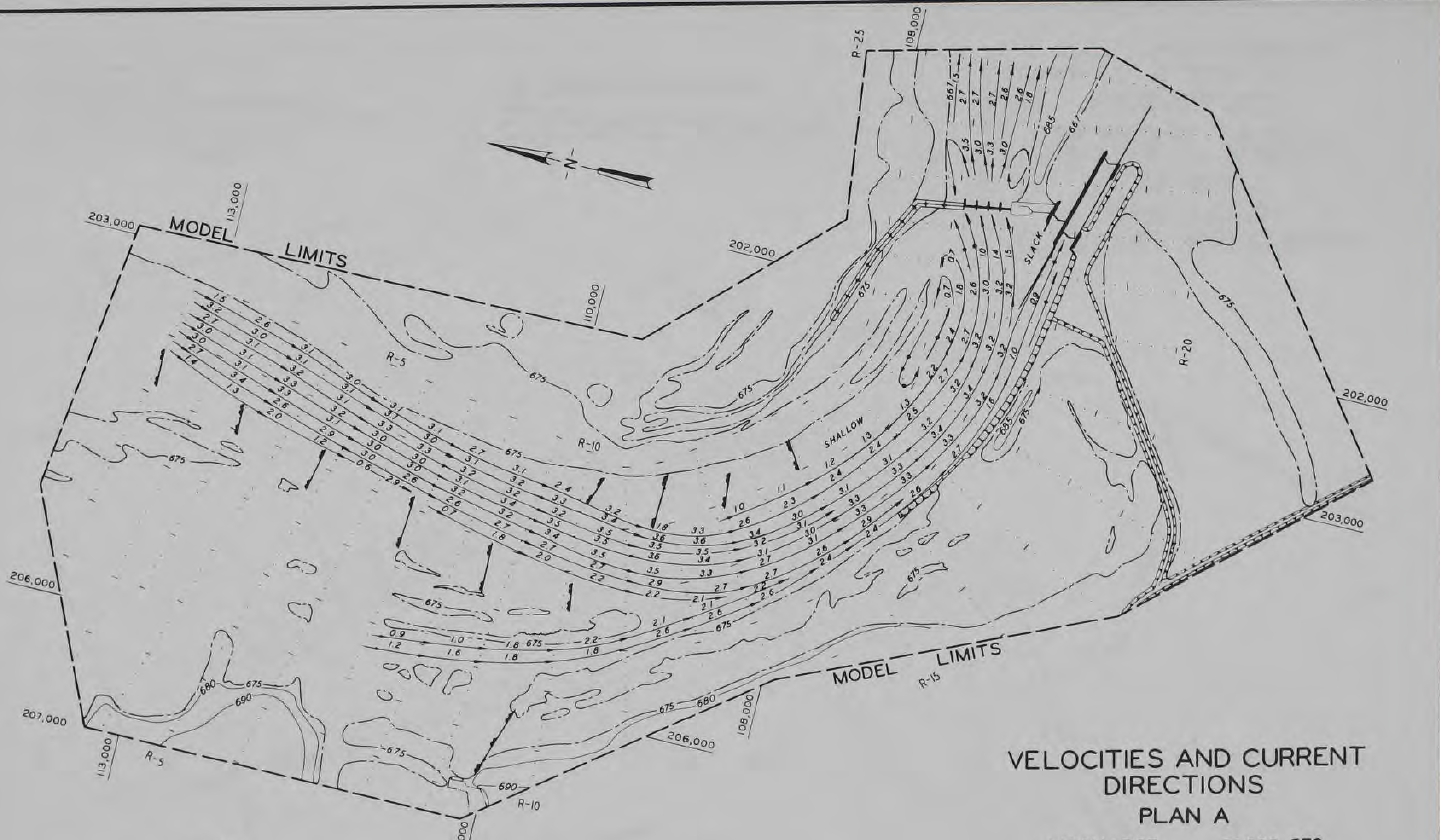
VELOCITIES AND CURRENT DIRECTIONS

PLAN A

DISCHARGE 15,000 CFS
TAILWATER EL 668.6 FT

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



VELOCITIES AND CURRENT DIRECTIONS

PLAN A

DISCHARGE 30,000 CFS
TAILWATER EL 672.4 FT

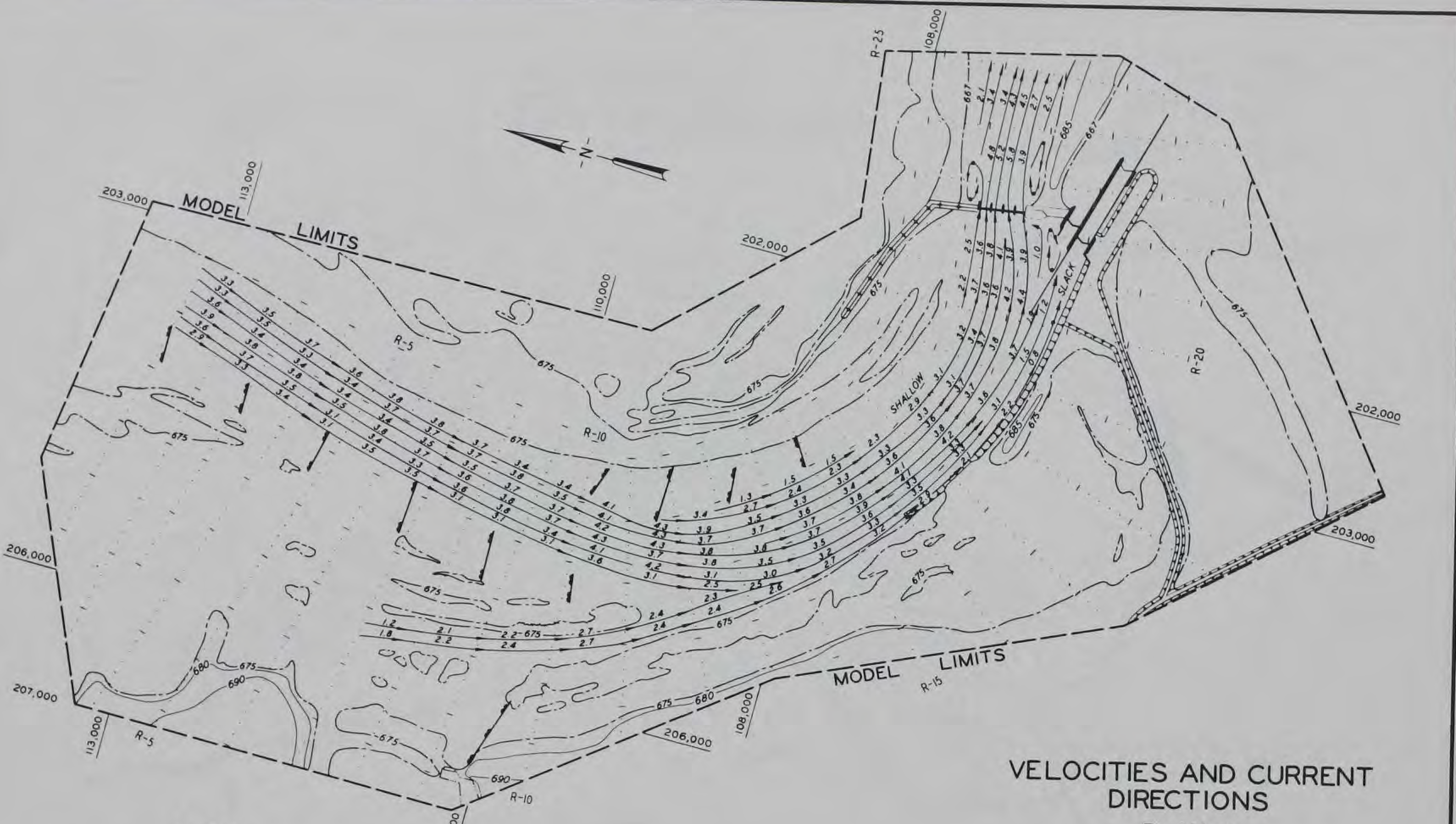
SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



LEGEND

- 4.2 — VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

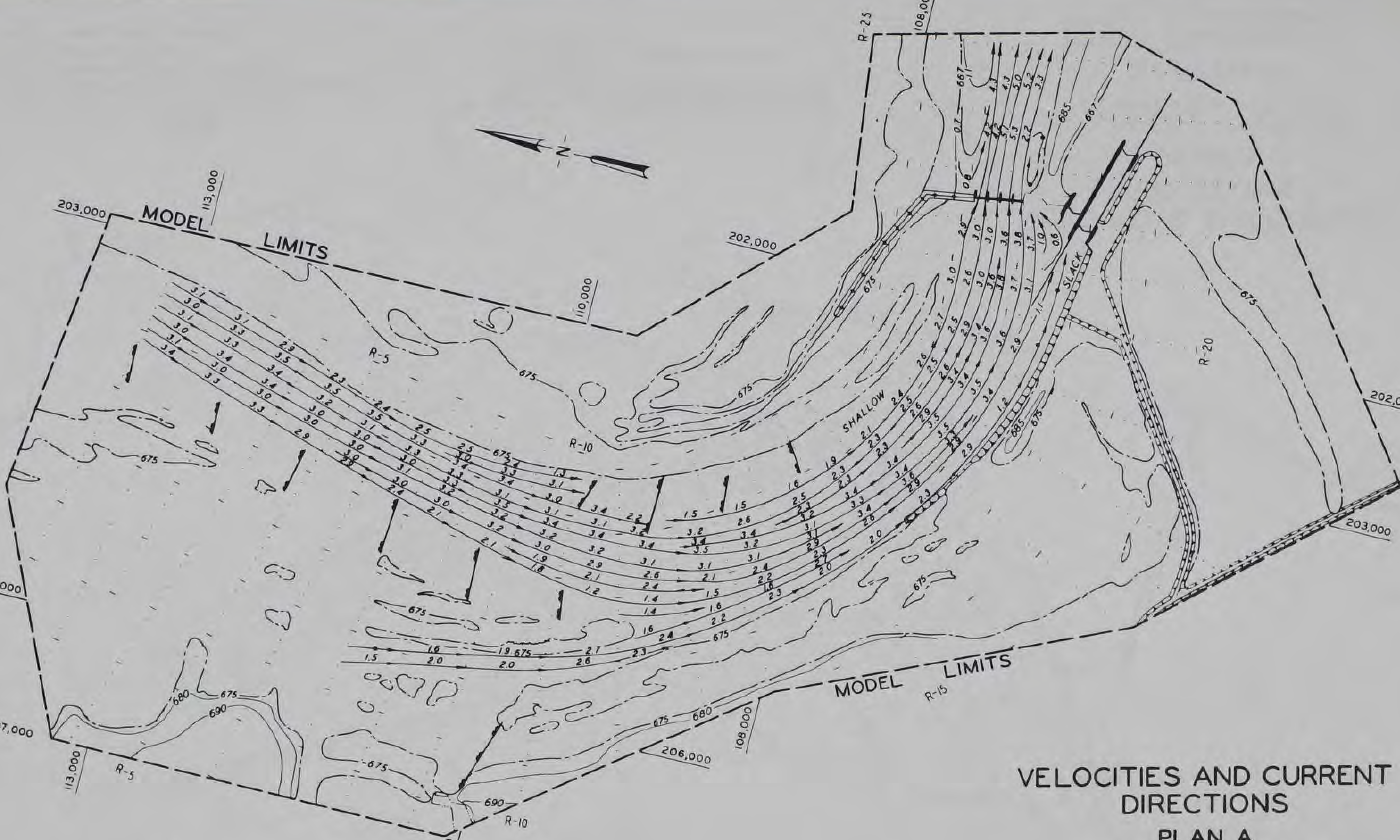
VELOCITIES AND CURRENT DIRECTIONS

PLAN A

DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



VELOCITIES AND CURRENT DIRECTIONS

PLAN A

DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

SCALES IN FEET

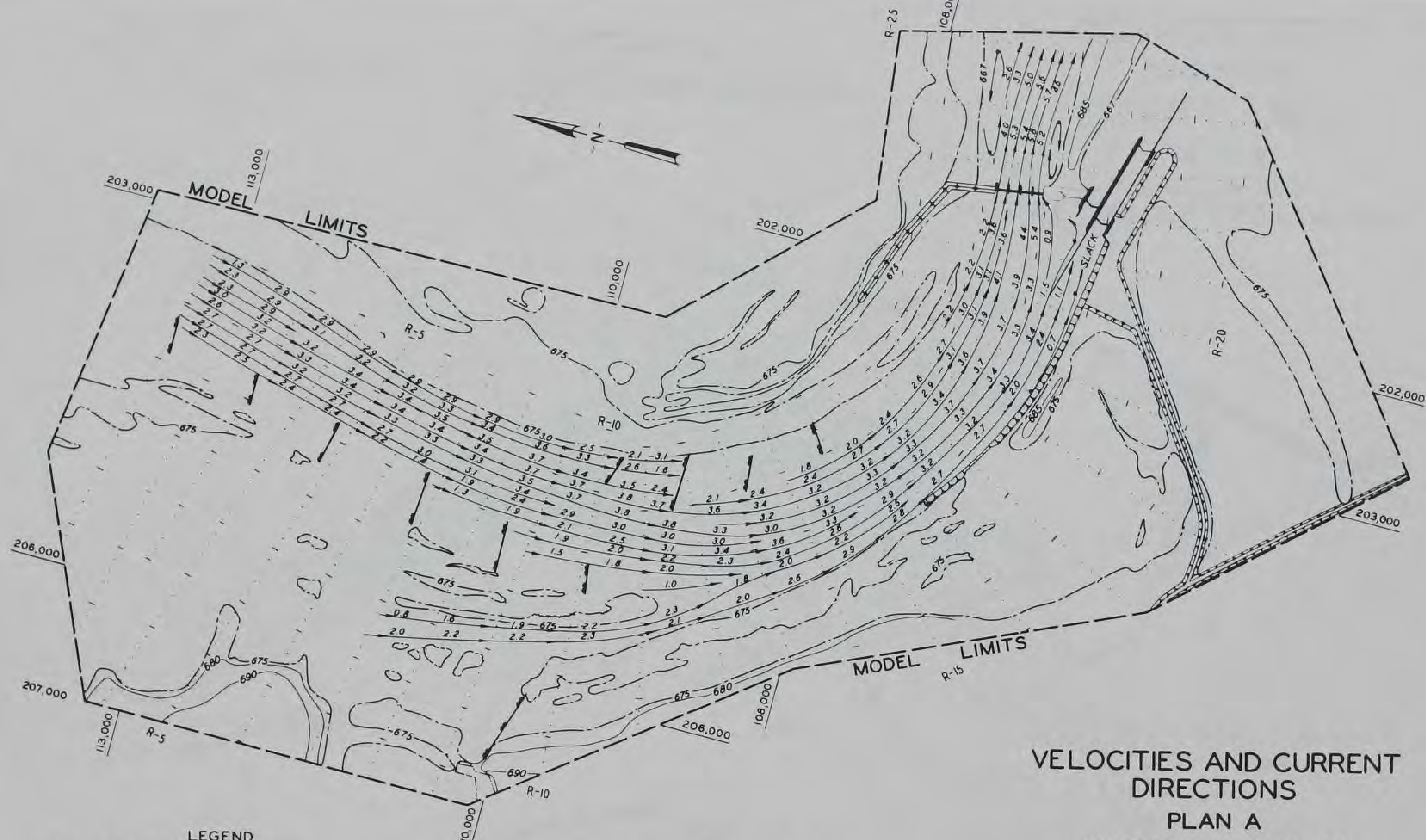
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

PLAN A

DISCHARGE 100,000 CFS
TAILWATER EL 680.6 FT

SCALES IN FEET

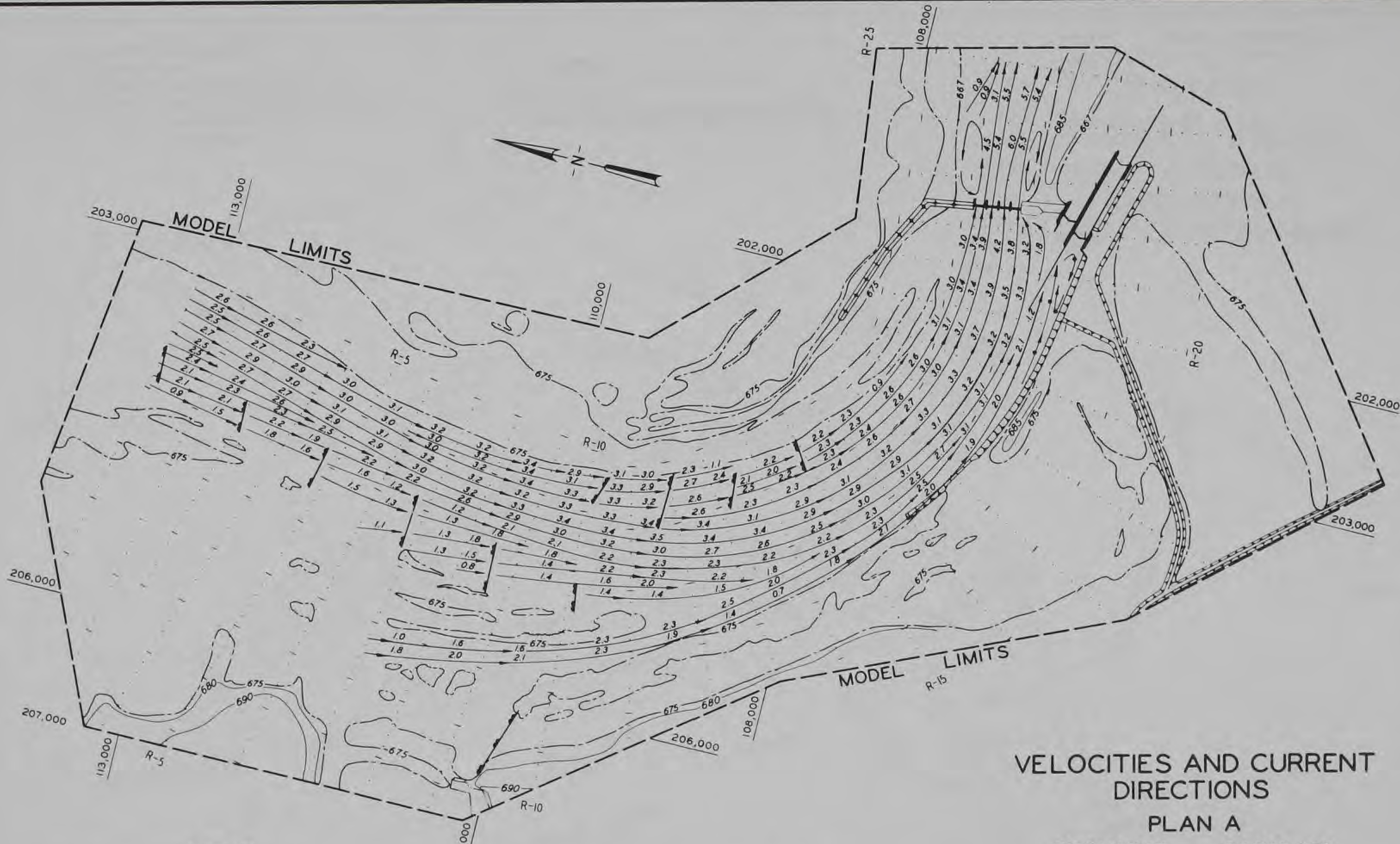
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

PLAN A

DISCHARGE 134,000 CFS
TAILWATER EL 682.9 FT

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

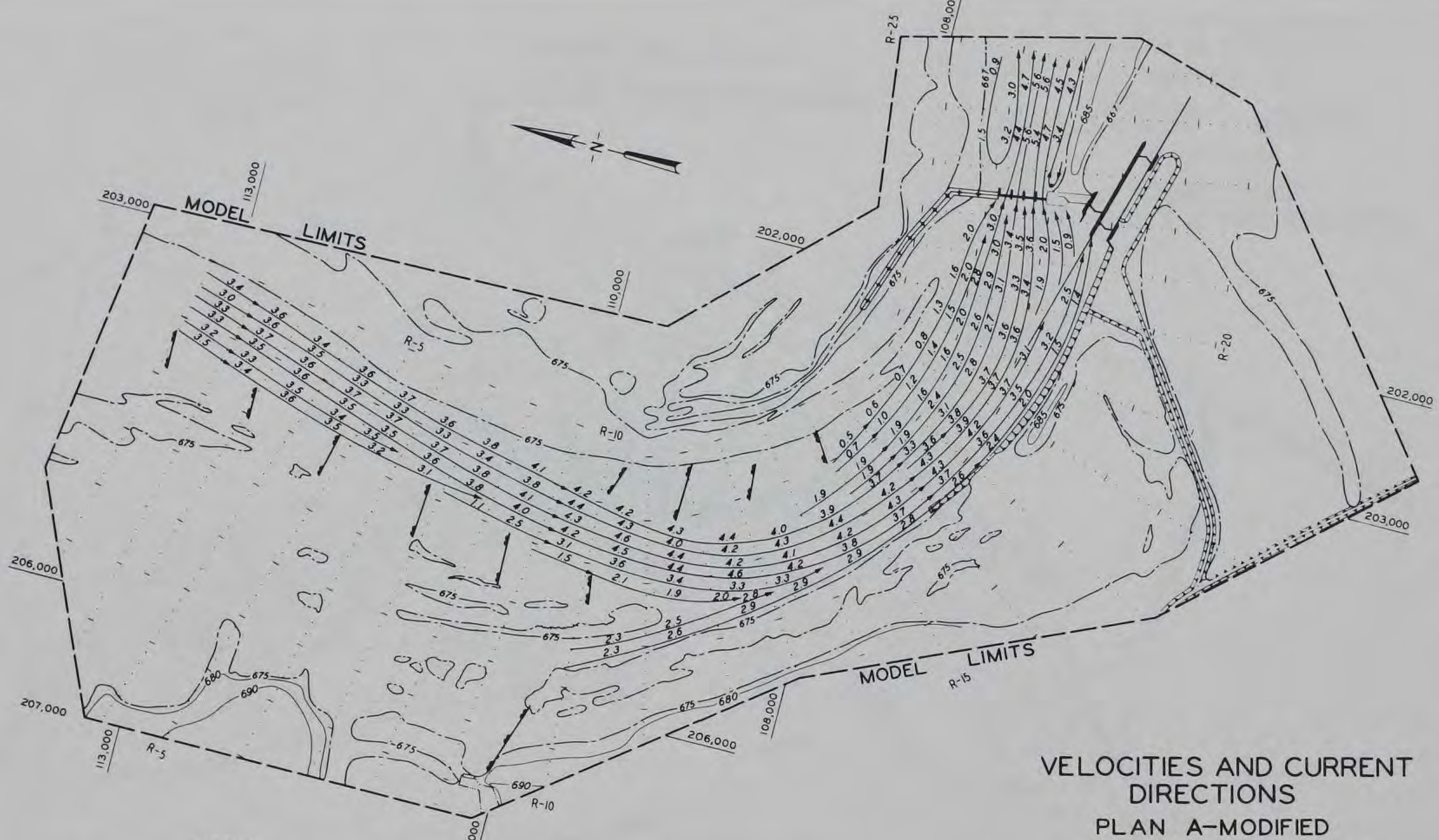
LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

PLATE 17



LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

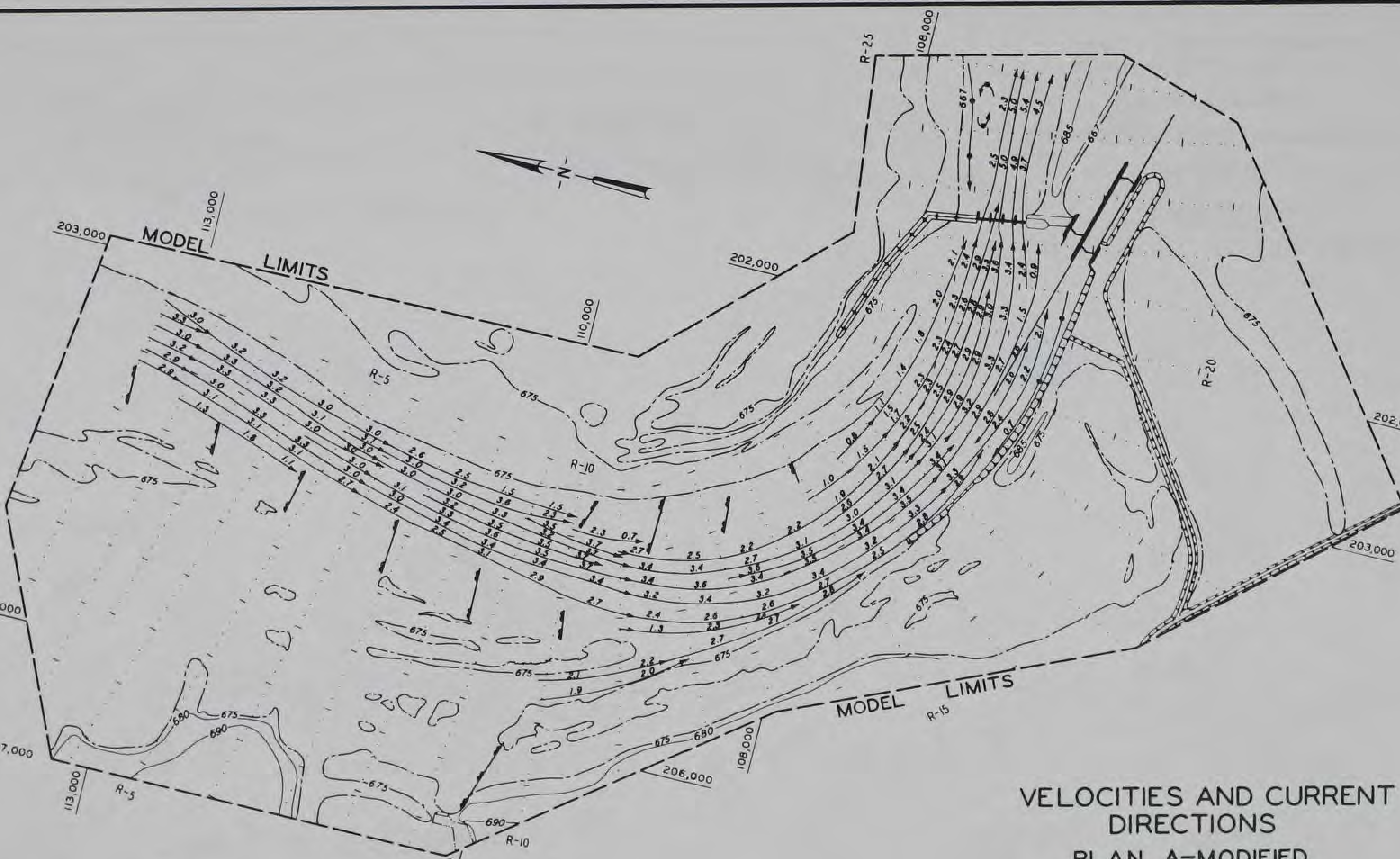
VELOCITIES AND CURRENT DIRECTIONS

PLAN A–MODIFIED

DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



VELOCITIES AND CURRENT DIRECTIONS

PLAN A-MODIFIED

DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

SCALES IN FEET

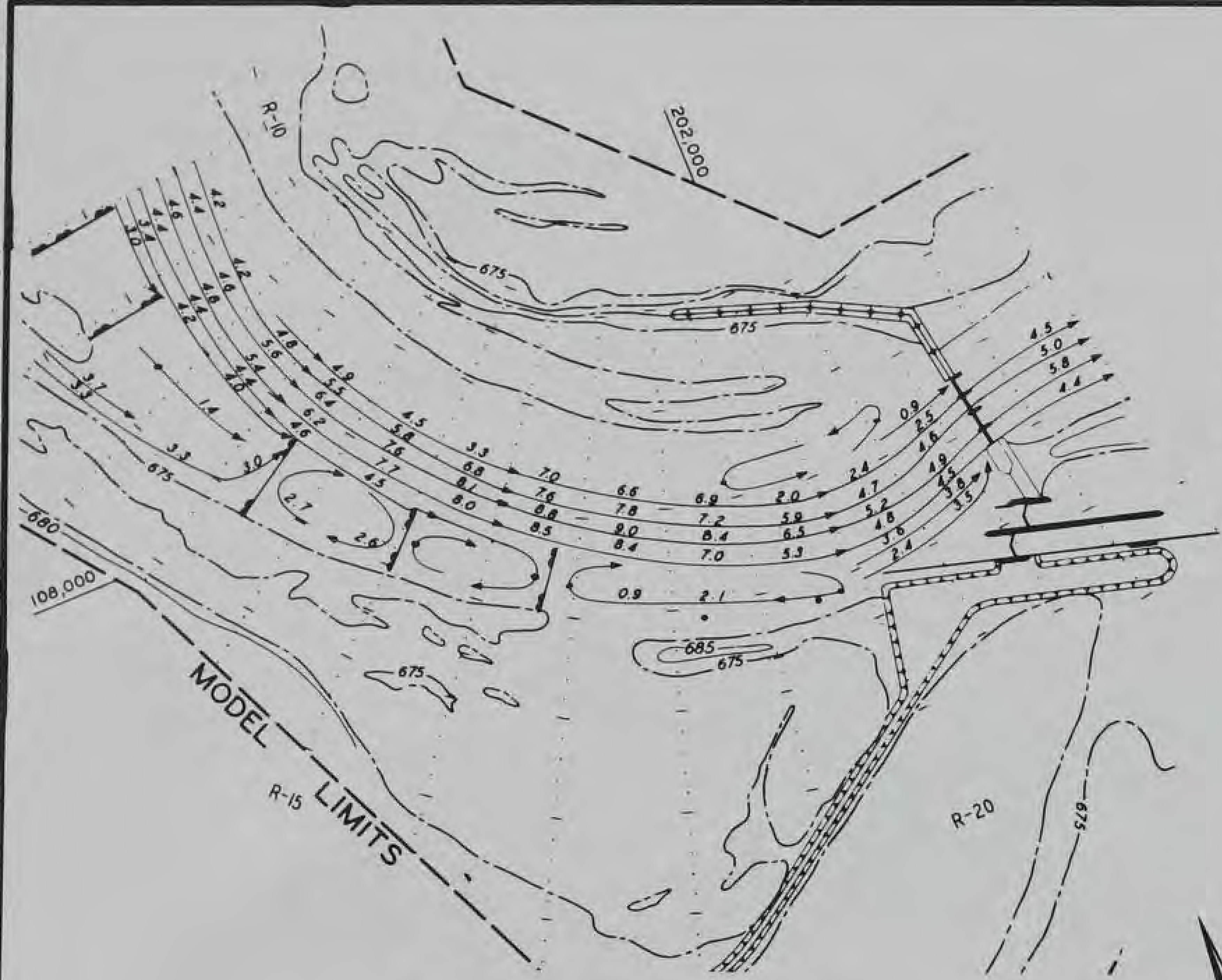
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

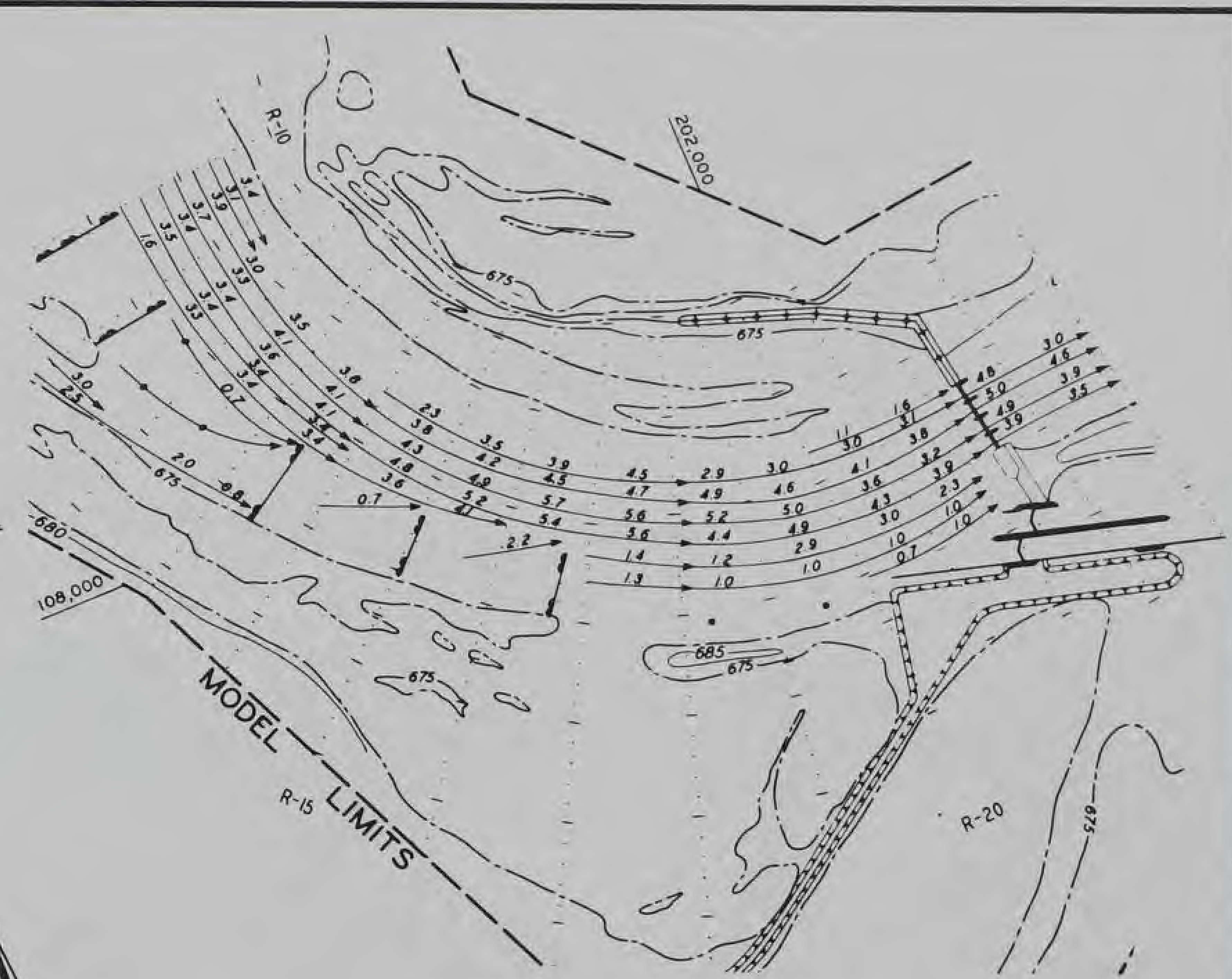
- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

PLATE 19



DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT



DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

N

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

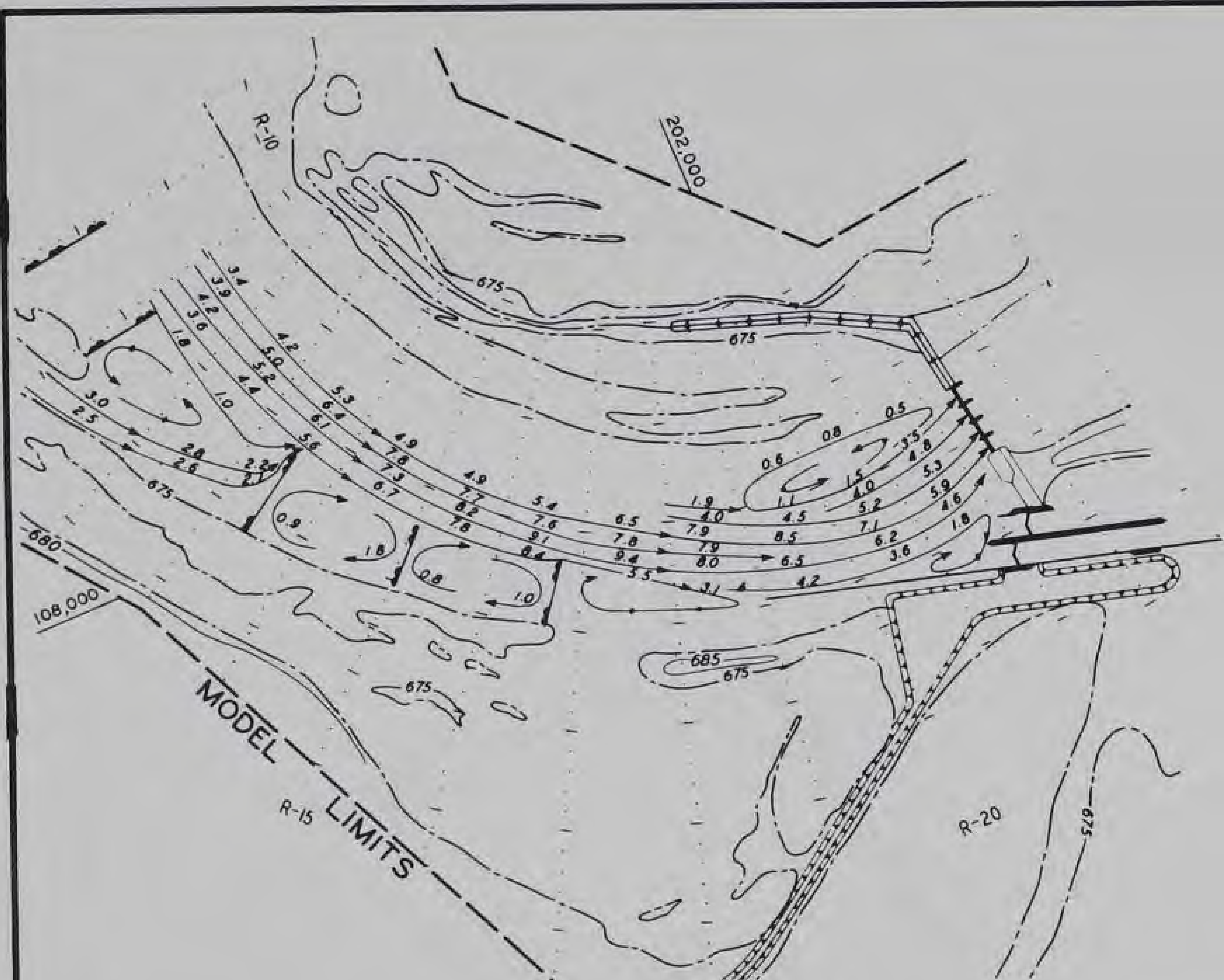
VELOCITIES AND CURRENT DIRECTIONS

PLAN B

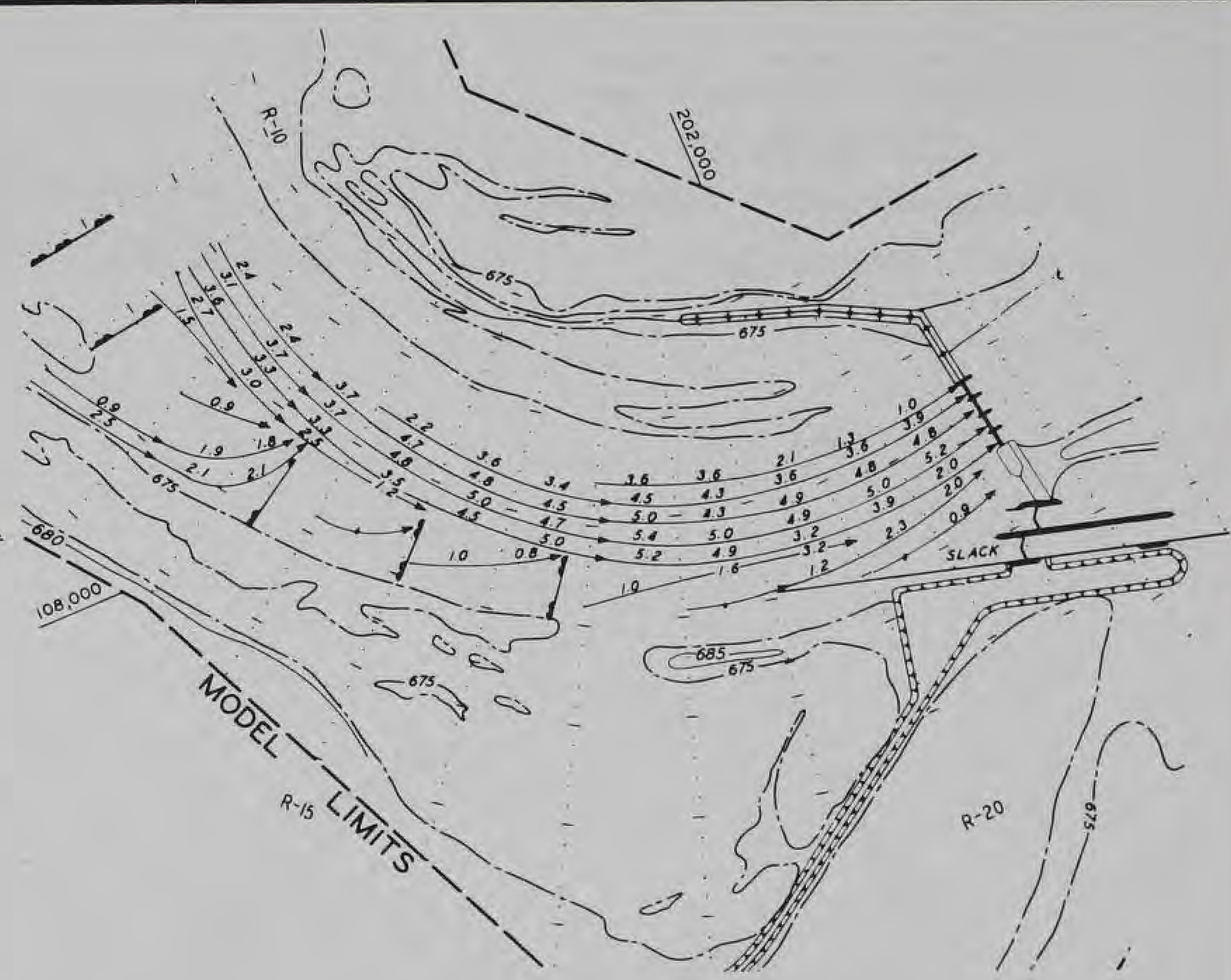
DISCHARGES 36,000 AND 70,000 CFS

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT



DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

LEGEND

- 4.2 → VELOCITY IN FEET PER SECOND
- → VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

VELOCITIES AND CURRENT DIRECTIONS

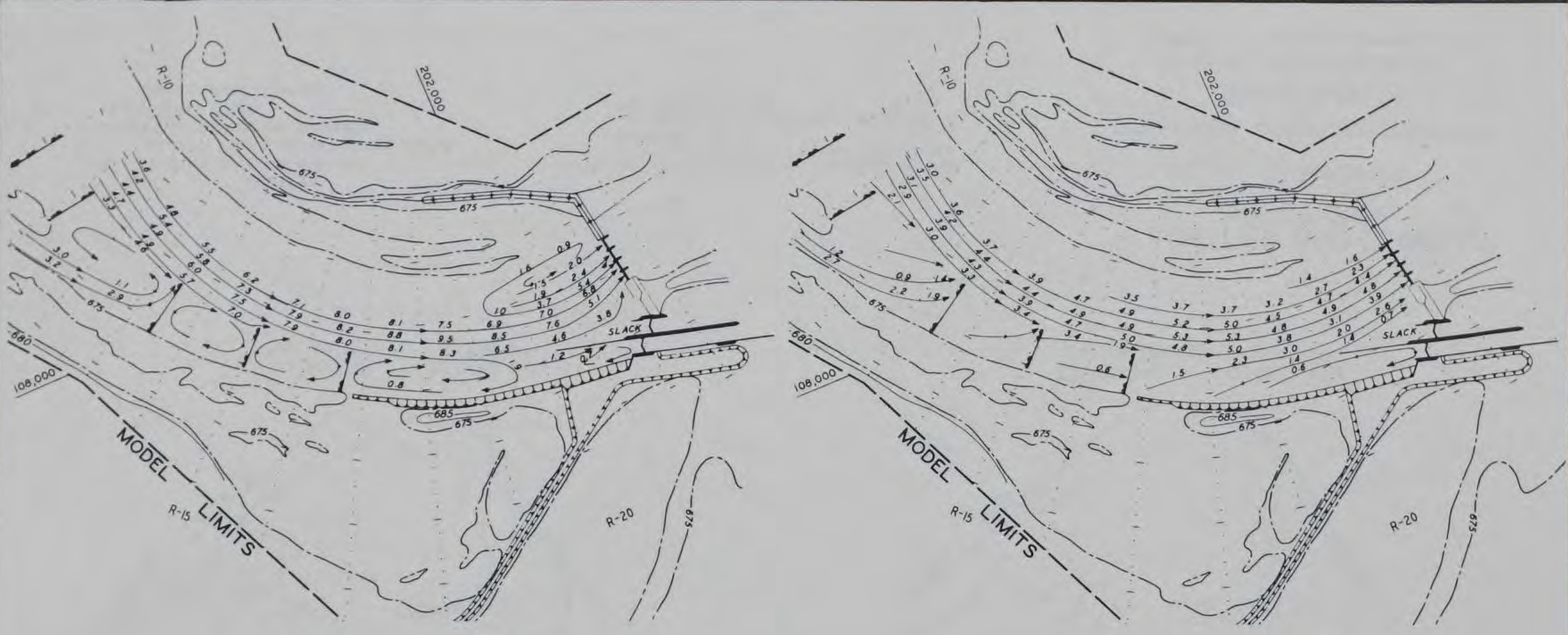
PLAN B-MODIFIED

DISCHARGES 36,000 AND 70,000 CFS

SCALES IN FEET

PROTOTYPE 300 0 300 600 900

MODEL 3 0 3 6 9



DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT

DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

MODEL STUDY OF LOCK AND DAM 3
MISSISSIPPI RIVER

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

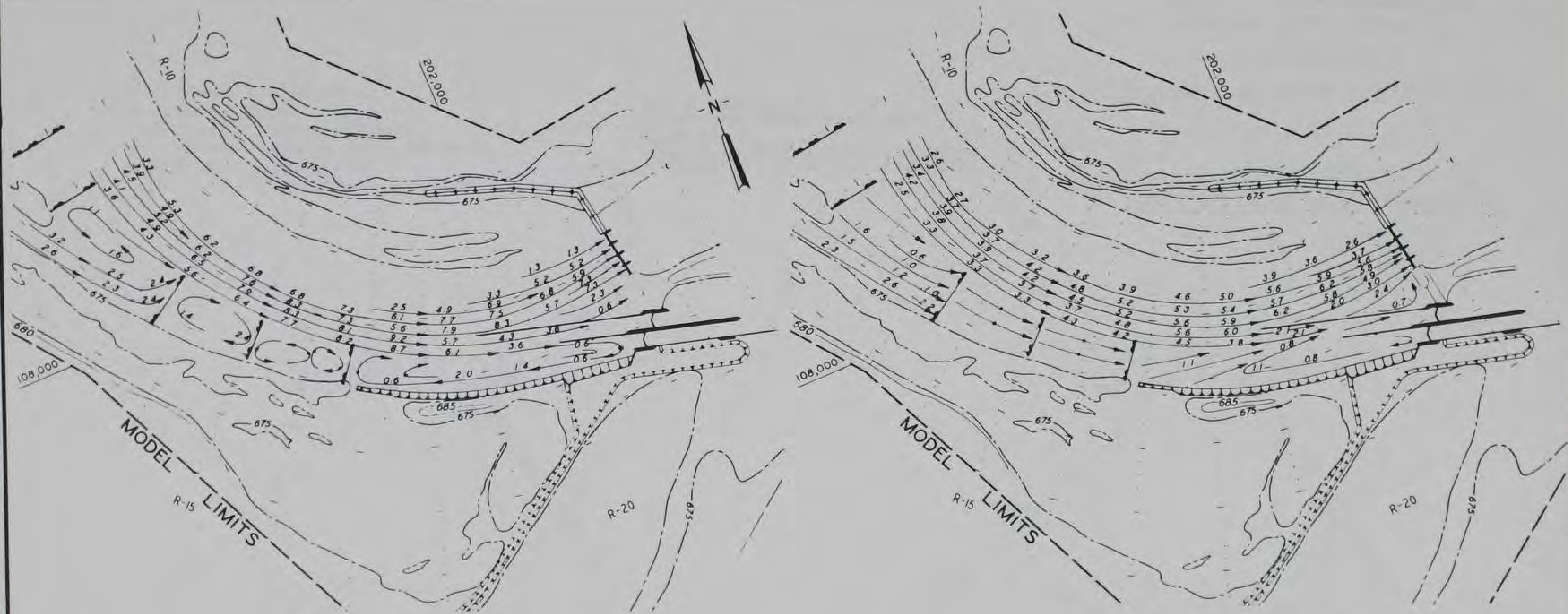
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

PLAN B-1

DISCHARGES 36,000 AND 70,000 CFS

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT

DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

LEGEND

4.2 VELOCITY IN FEET PER SECOND

VELOCITY LESS THAN 0.5 FEET PER SECOND

STONE-FILL DIKE OR REVETMENT

EXISTING LEVEE

NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

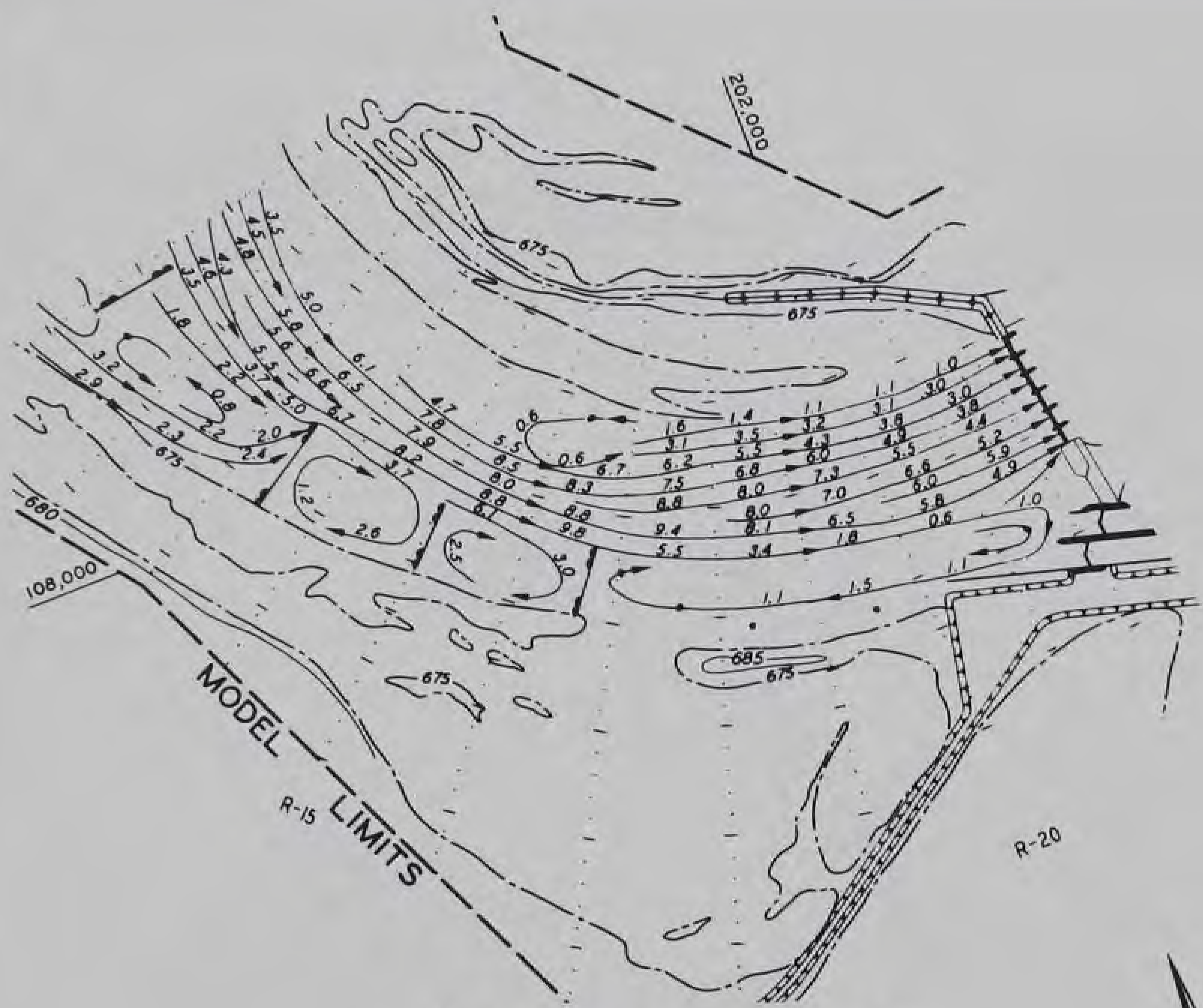
VELOCITIES AND CURRENT DIRECTIONS

PLAN B-2

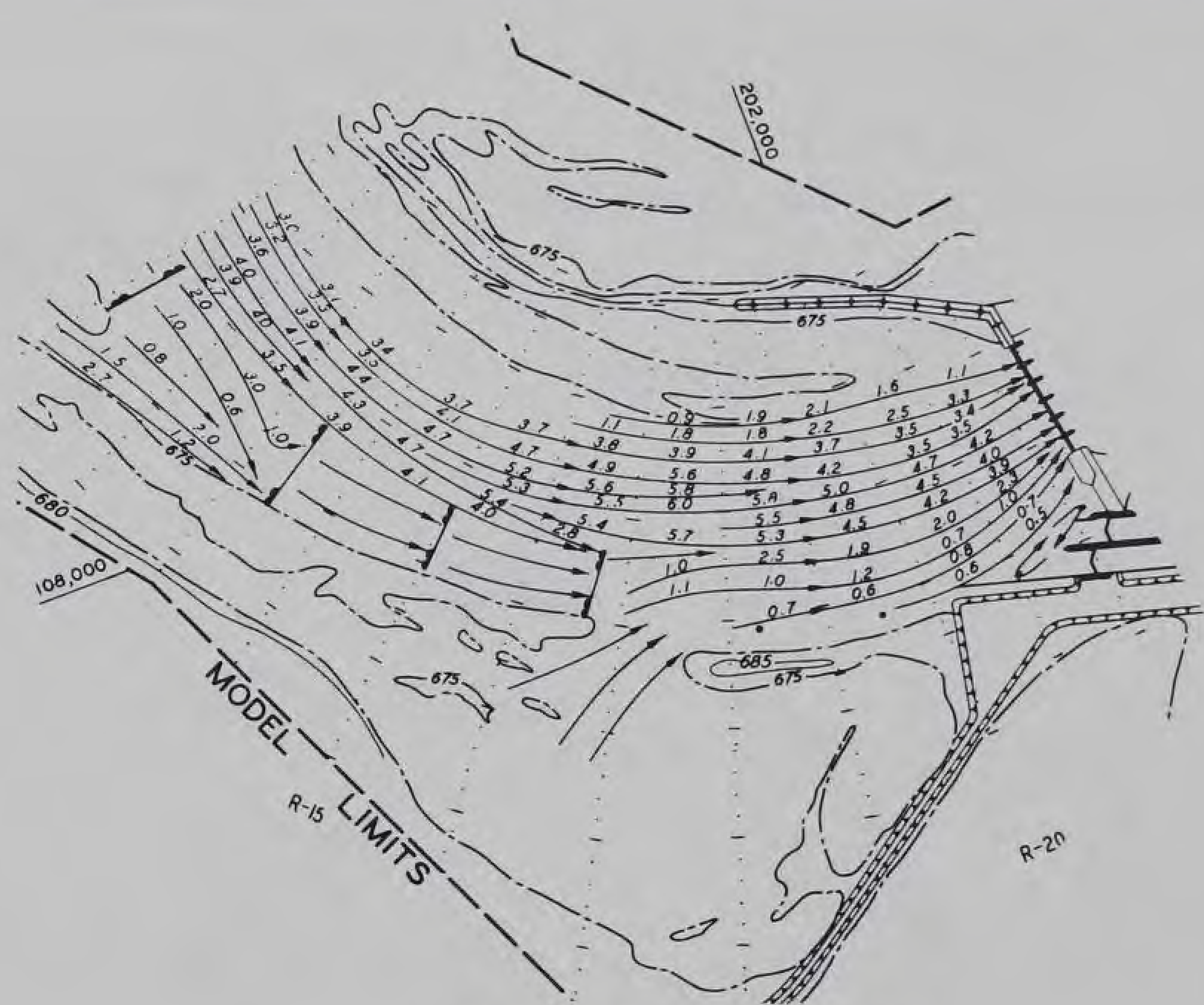
DISCHARGES 36,000 AND 70,000 CFS

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT



DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

LEGEND

- 4.2 → VELOCITY IN FEET PER SECOND
- → VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

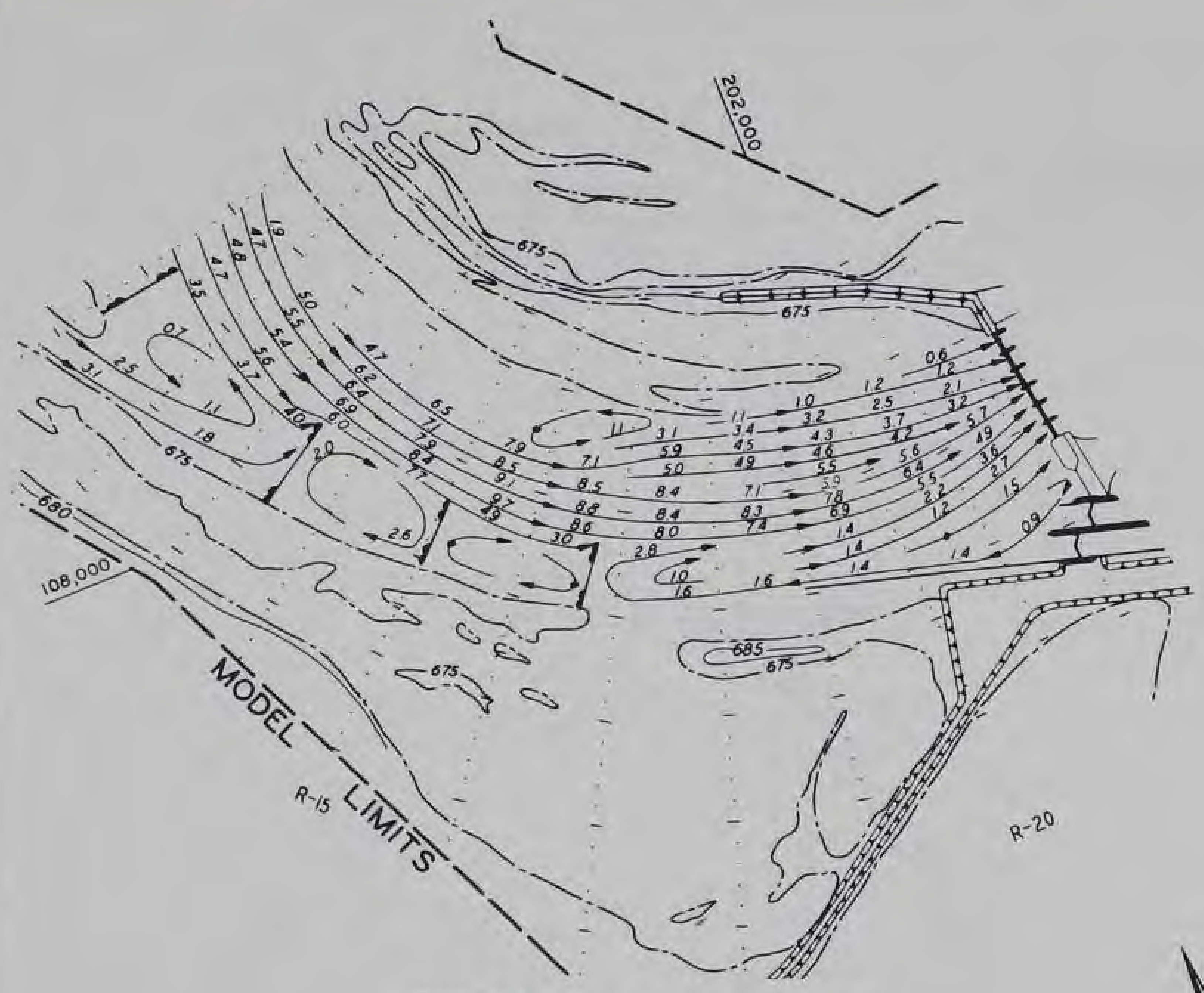
VELOCITIES AND CURRENT DIRECTIONS

PLAN C

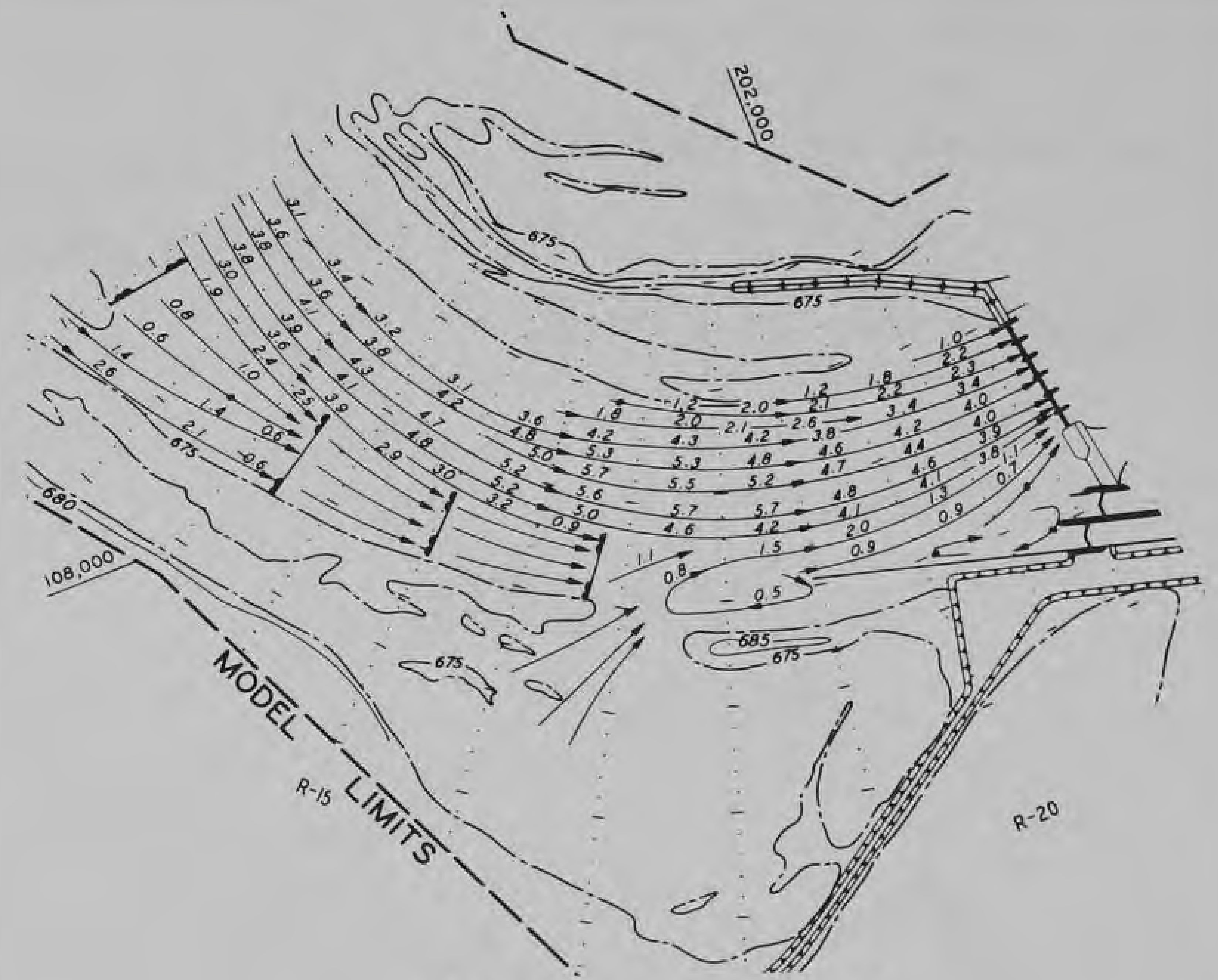
DISCHARGES 36,000 AND 70,000 CFS

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT



DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

N

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

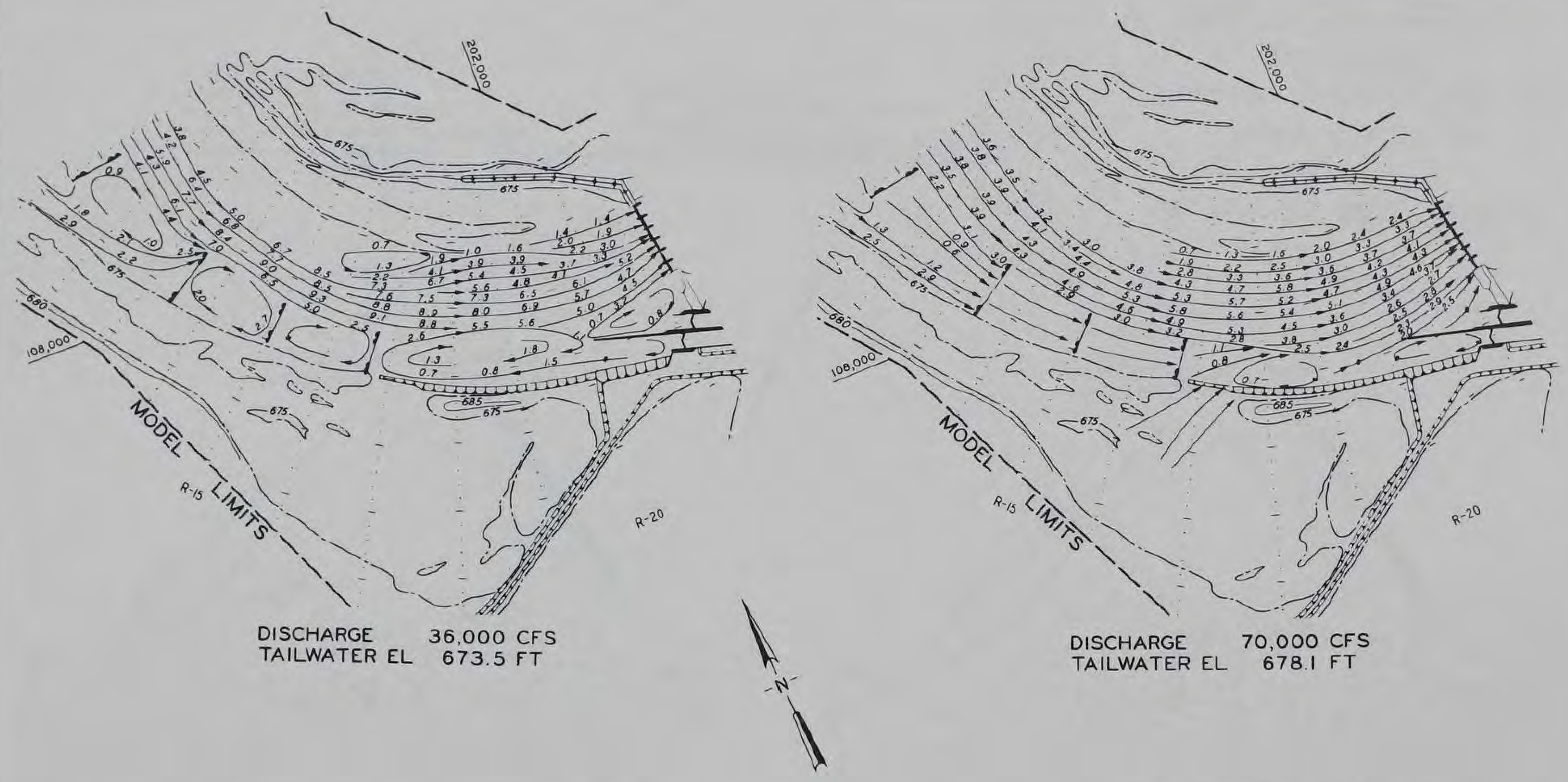
VELOCITIES AND CURRENT DIRECTIONS

PLAN C-MODIFIED

DISCHARGES 36,000 AND 70,000 CFS

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

VELOCITIES AND CURRENT DIRECTIONS

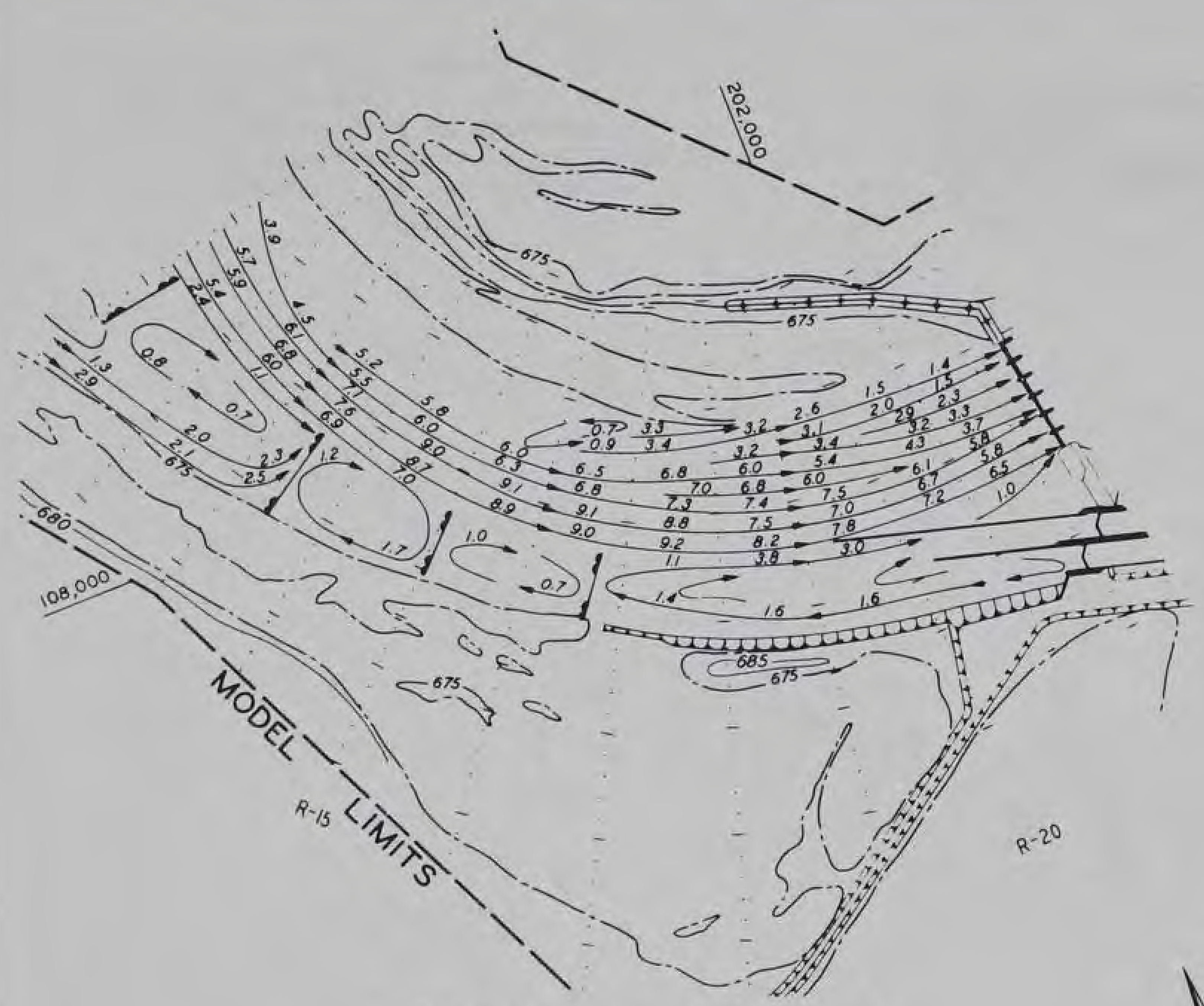
PLAN C-1

DISCHARGES 36,000 AND 70,000 CFS

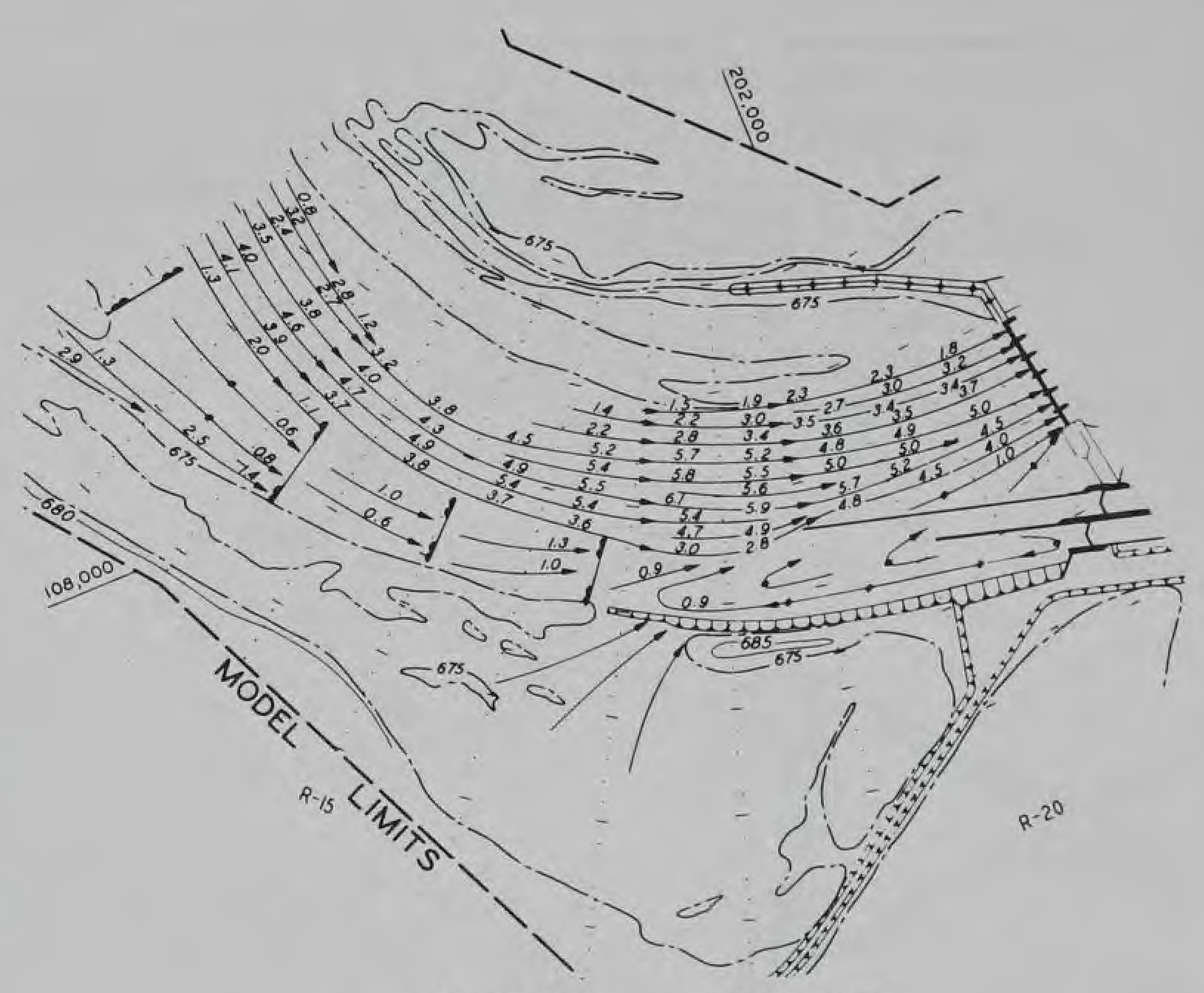
SCALES IN FEET

PROTOTYPE 300 0 300 600 900

MODEL 3 0 3 6 9



DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT



DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

N

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

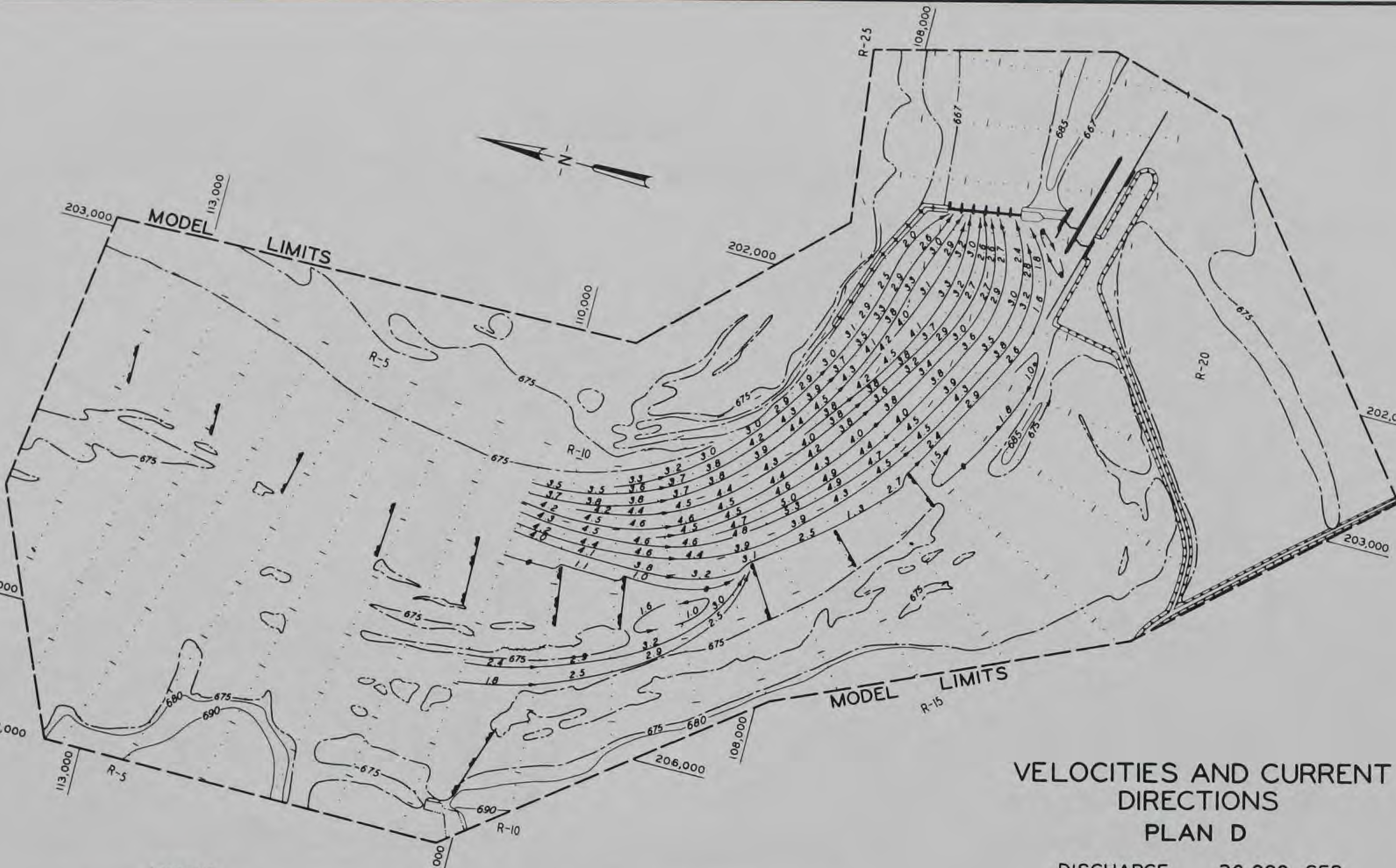
VELOCITIES AND CURRENT DIRECTIONS

PLAN C-2

DISCHARGES 36,000 AND 70,000 CFS

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



VELOCITIES AND CURRENT DIRECTIONS

PLAN D

DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT

SCALES IN FEET

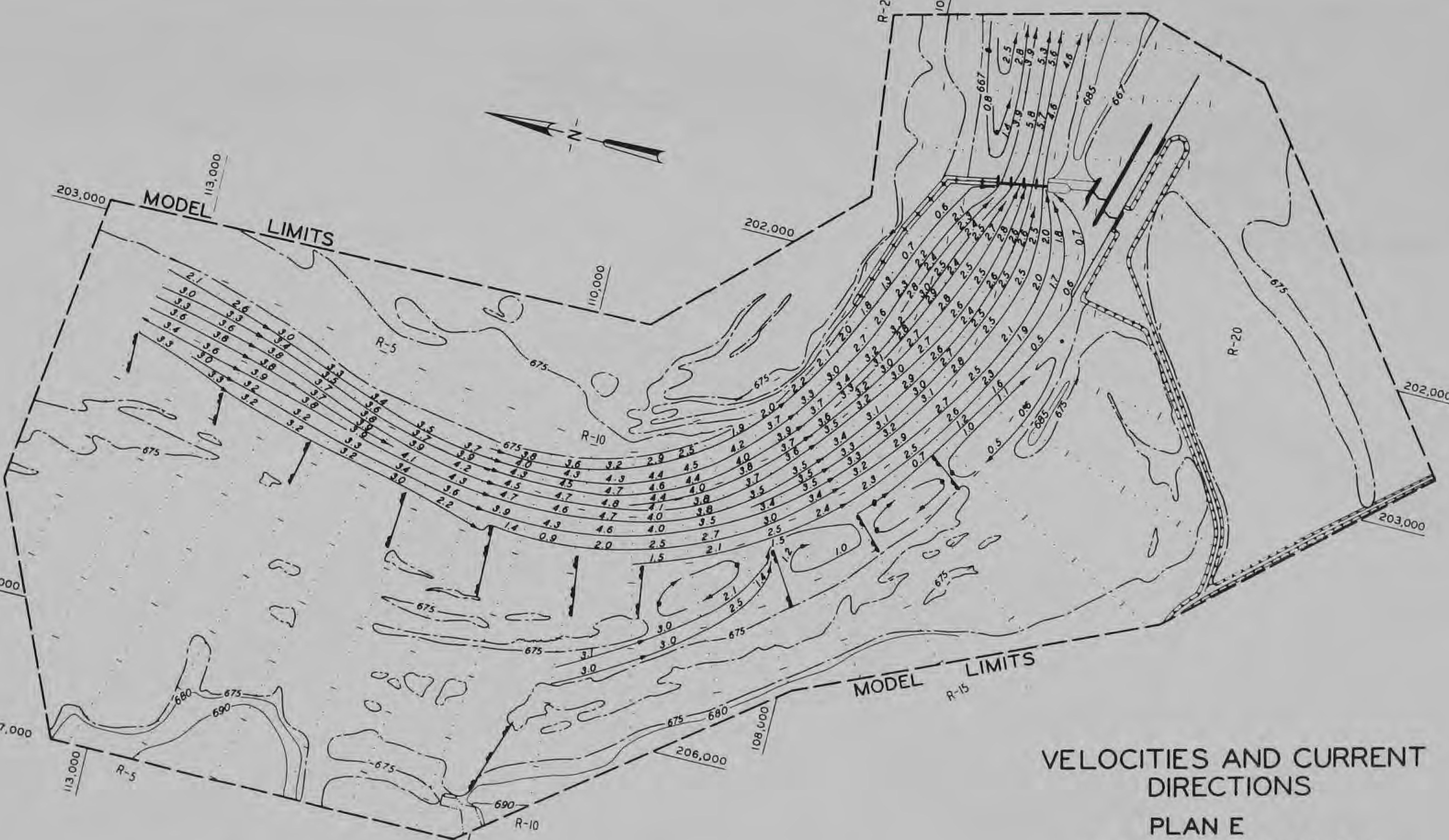
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 → VELOCITY IN FEET PER SECOND
- •→ VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

PLAN E

DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT

SCALES IN FEET

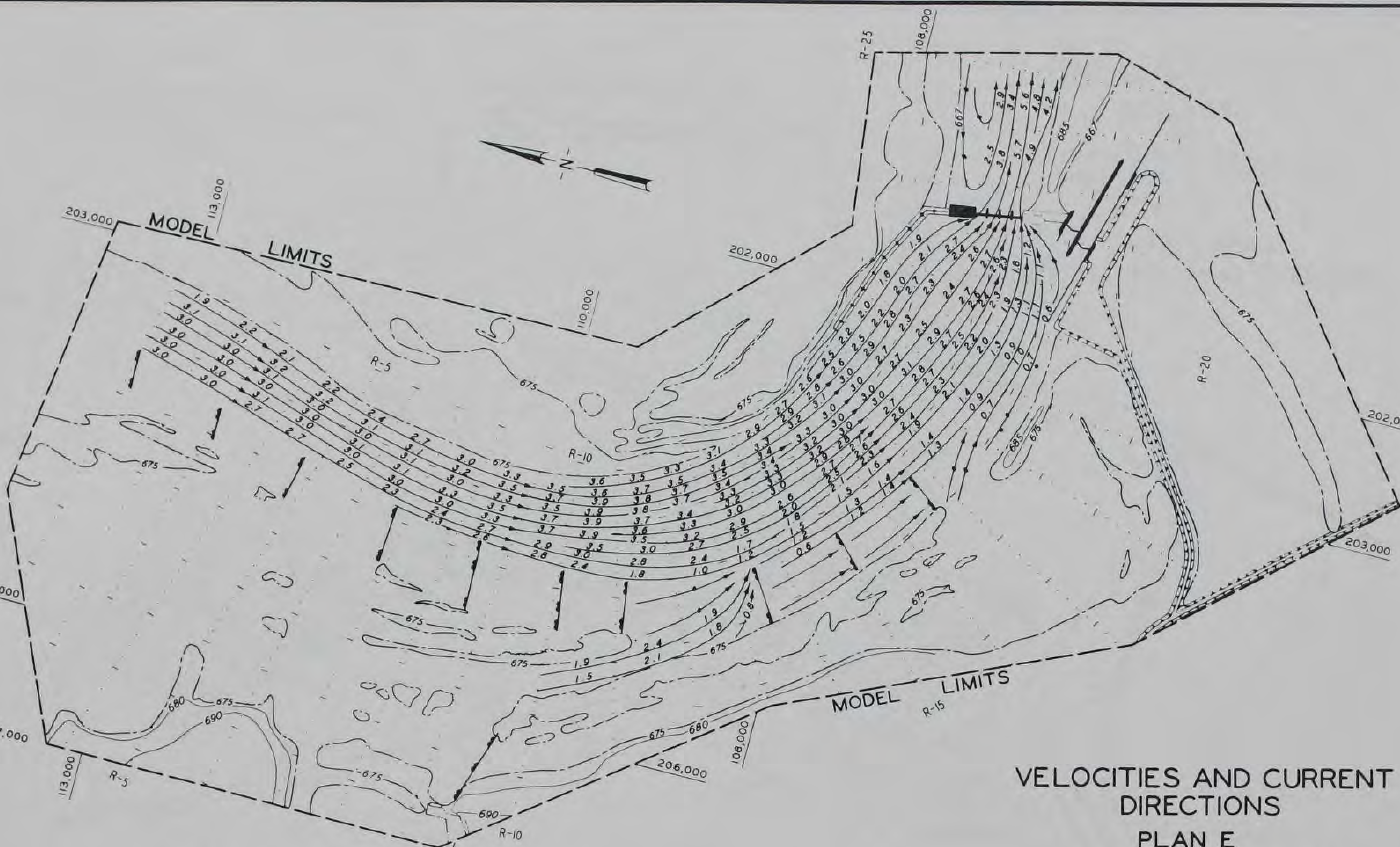
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



LEGEND

- 4.2 — VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

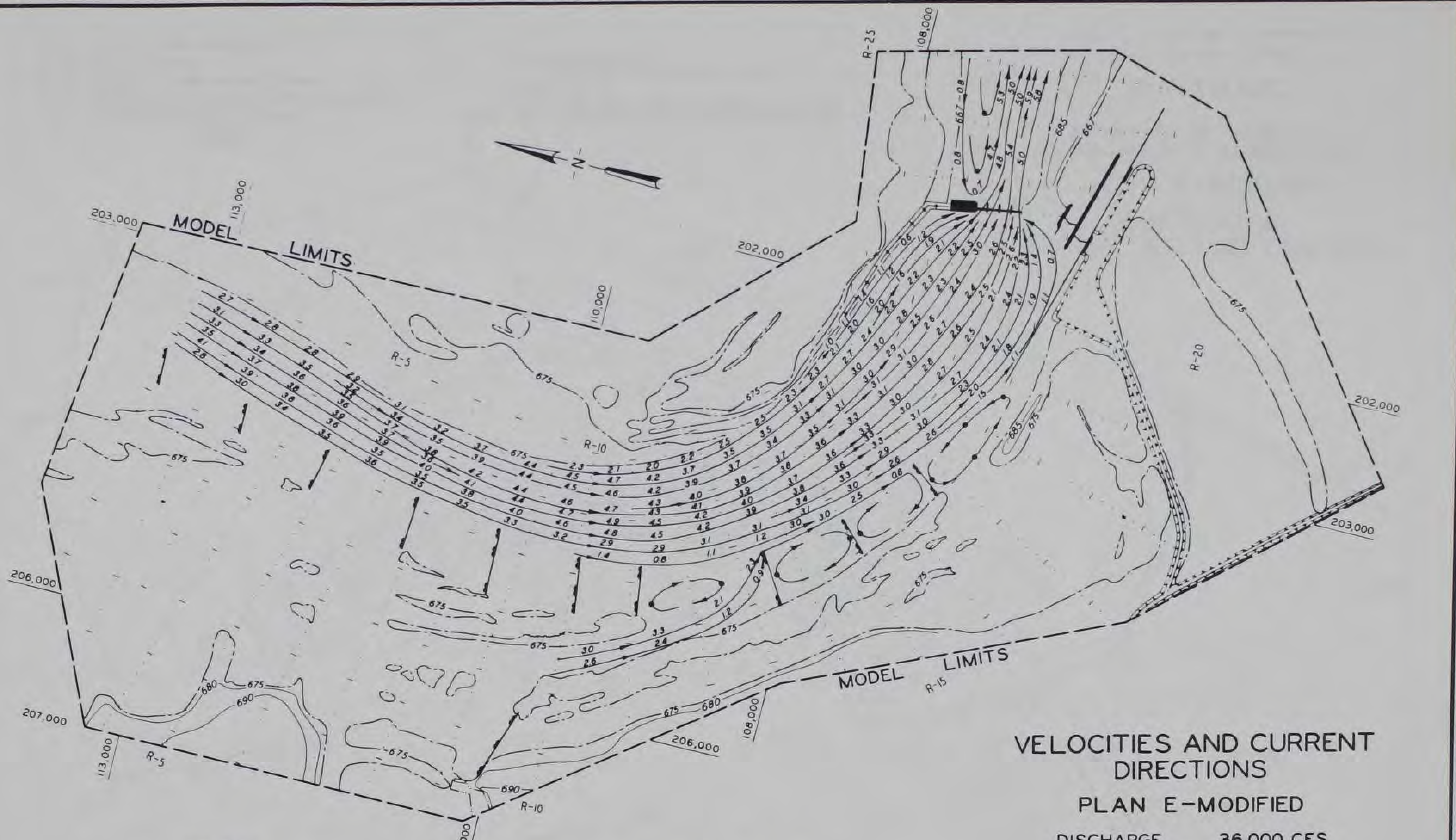
VELOCITIES AND CURRENT DIRECTIONS

PLAN E

DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



VELOCITIES AND CURRENT DIRECTIONS

PLAN E-MODIFIED

DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT

LEGEND

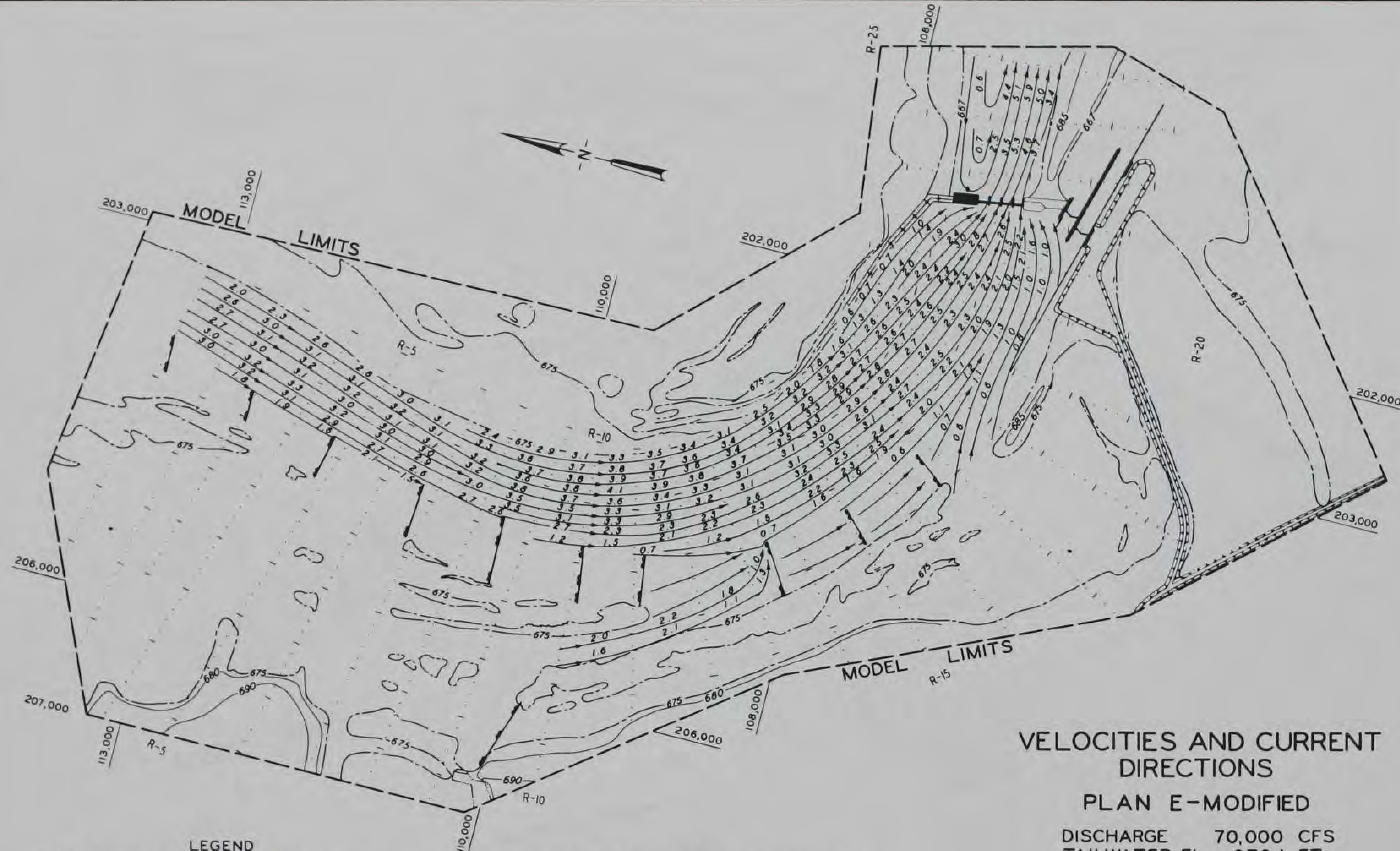
- 4.2 → VELOCITY IN FEET PER SECOND
- —•→ VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



VELOCITIES AND CURRENT DIRECTIONS

PLAN E-MODIFIED

DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

SCALES IN FEET

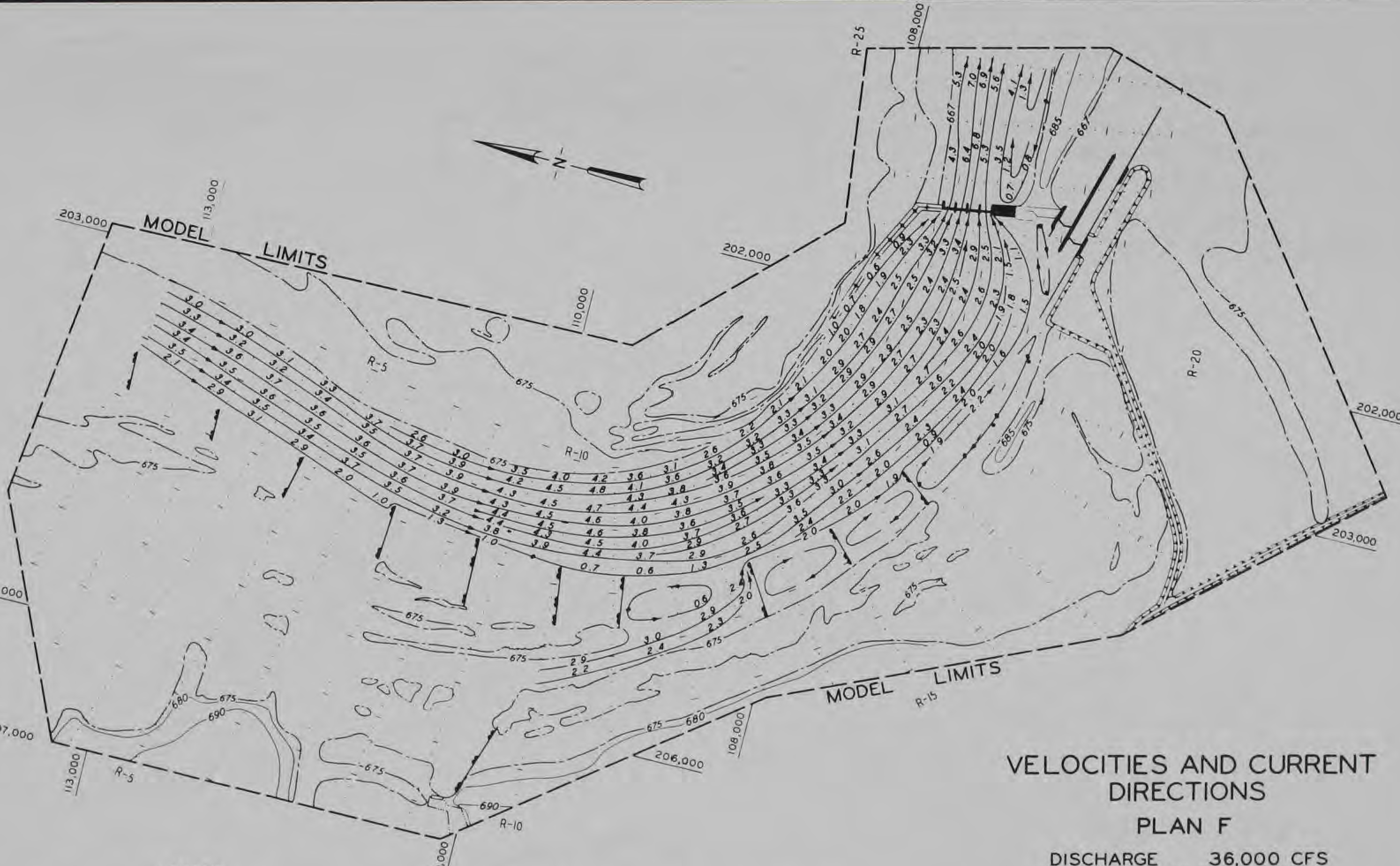
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 → VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

PLAN F

DISCHARGE 36,000 CFS
TAILWATER EL 373.5 FT

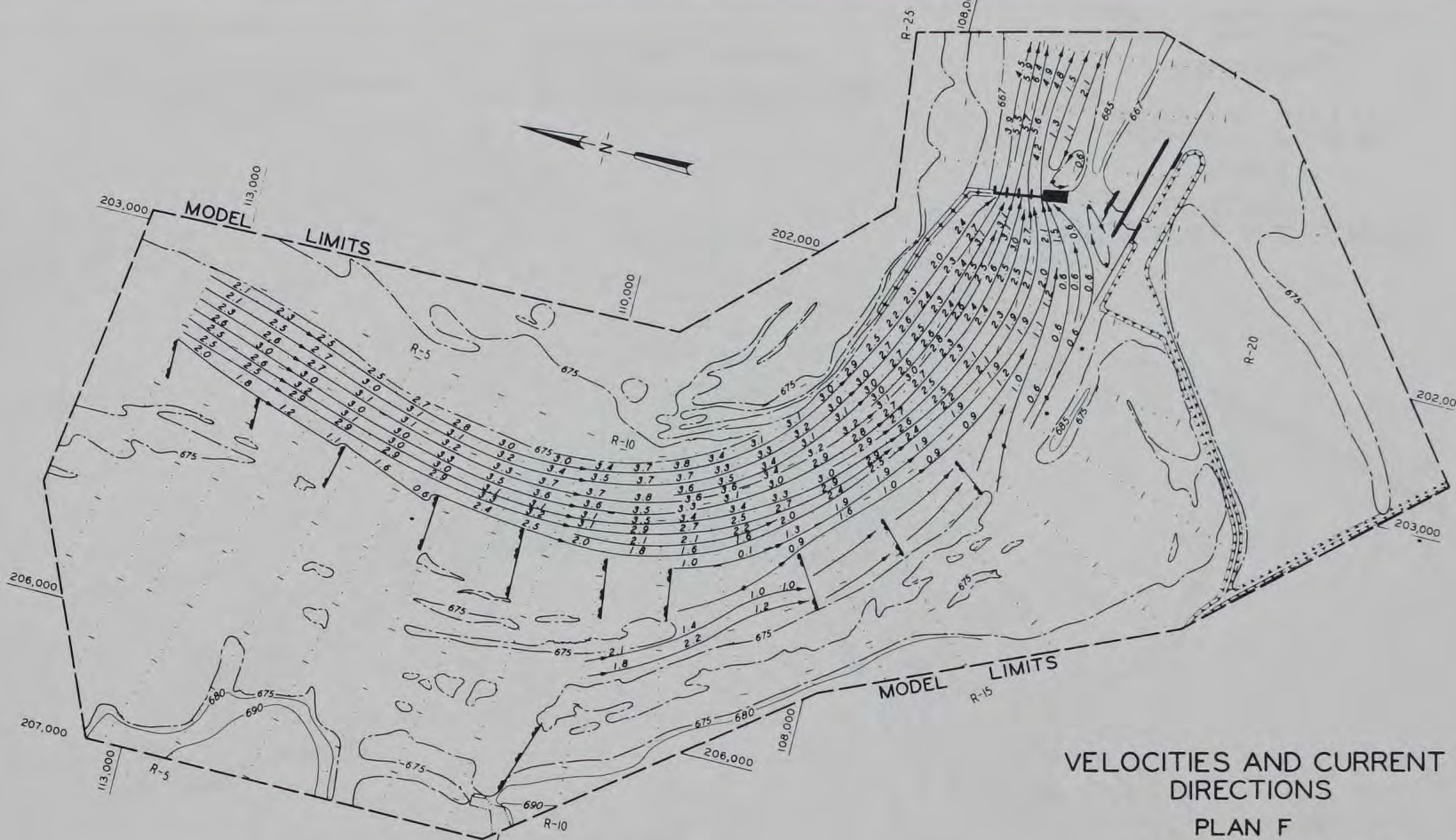
SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

PLAN F

DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

SCALES IN FEET

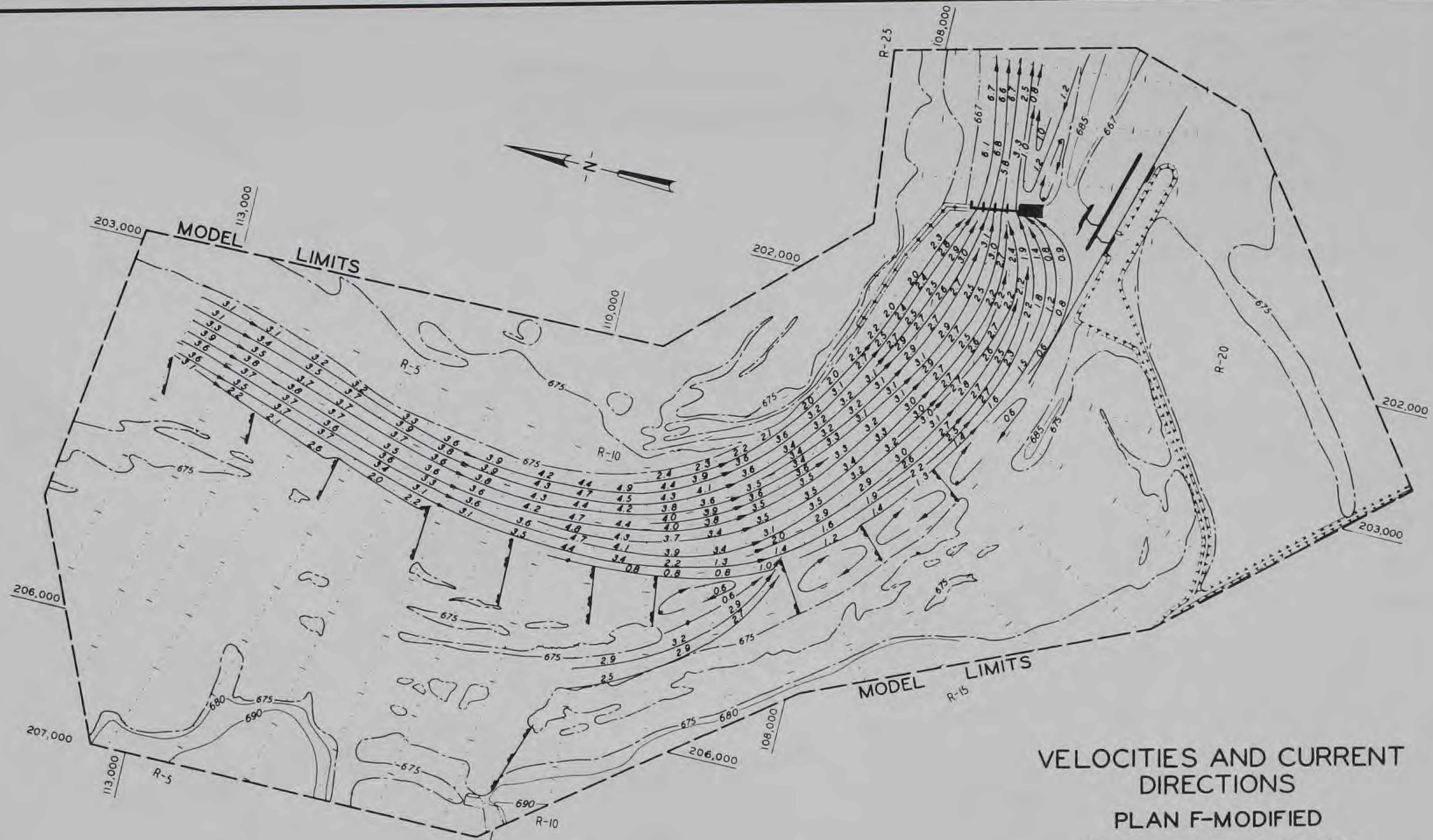
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

PLAN F-MODIFIED

DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT

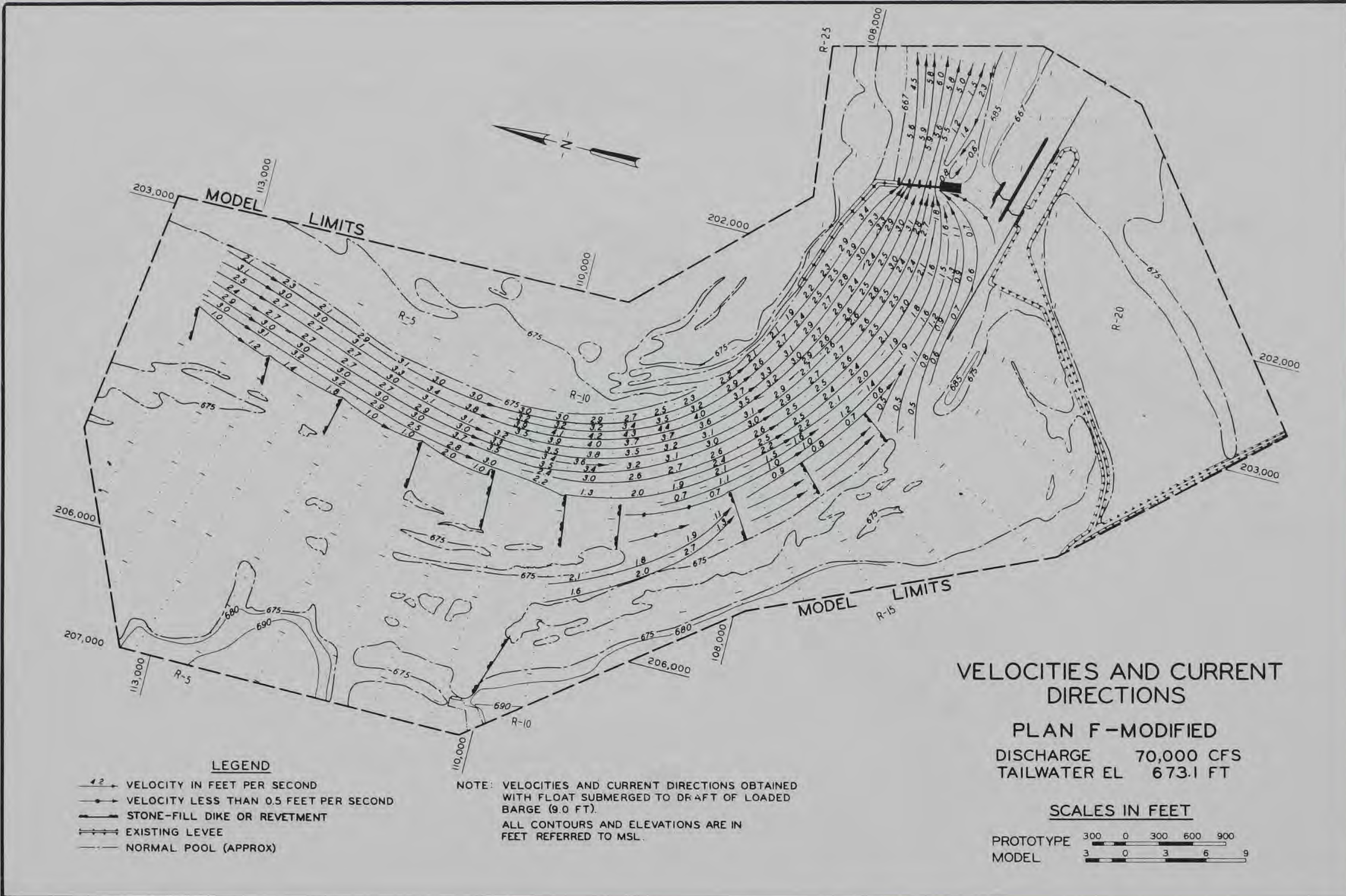
SCALES IN FEET

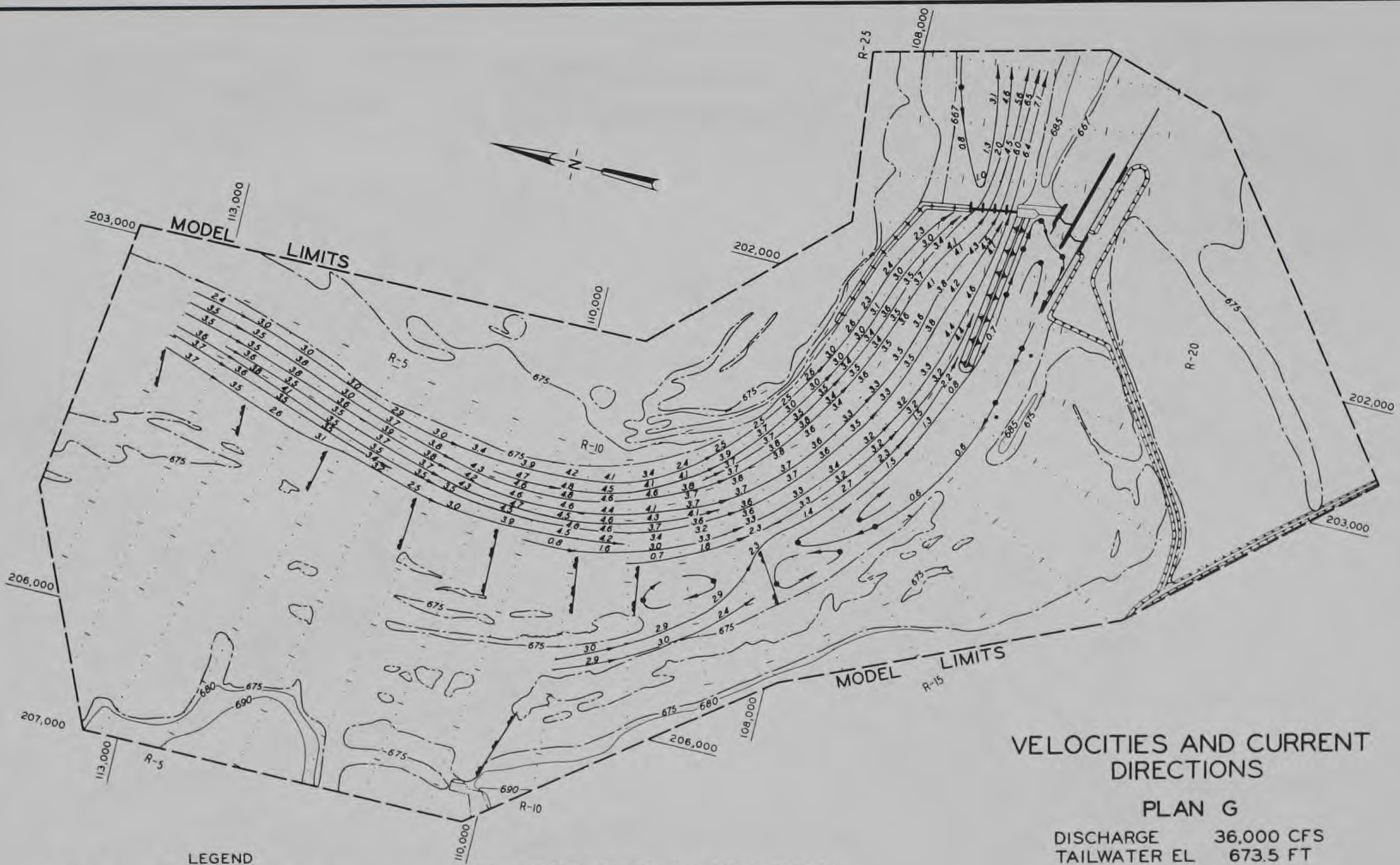
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 → VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.


MODEL LIMITS
MODEL LIMITS
VELOCITIES AND CURRENT DIRECTIONS
PLAN F-MODIFIED
DISCHARGE 70,000 CFS
TAILWATER EL 673.1 FT
SCALES IN FEET
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
STONE-FILL DIKE OR REVETMENT
EXISTING LEVEE
NORMAL POOL (APPROX)
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

PLAN G

DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT

SCALES IN FEET

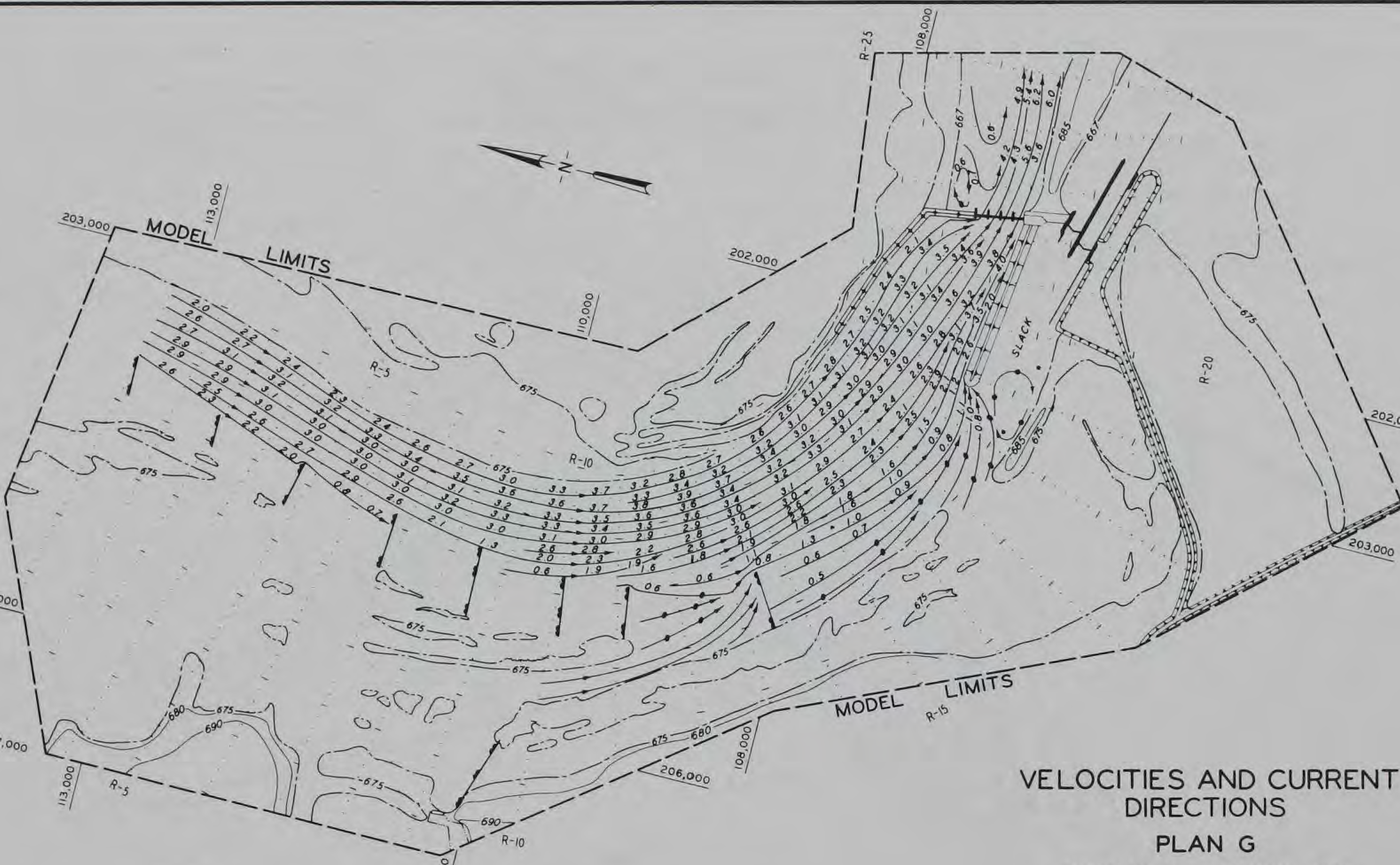
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

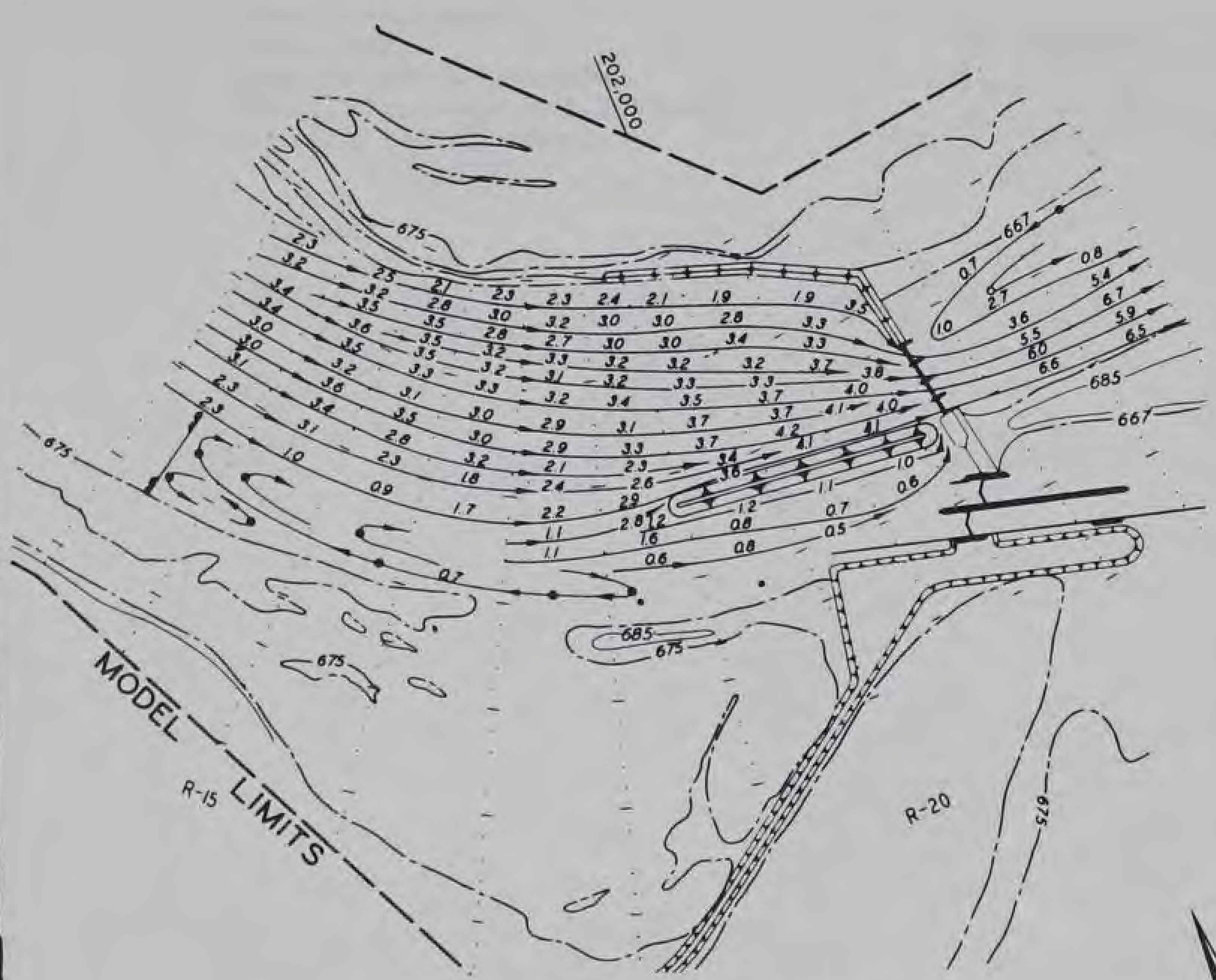
VELOCITIES AND CURRENT DIRECTIONS

PLAN G

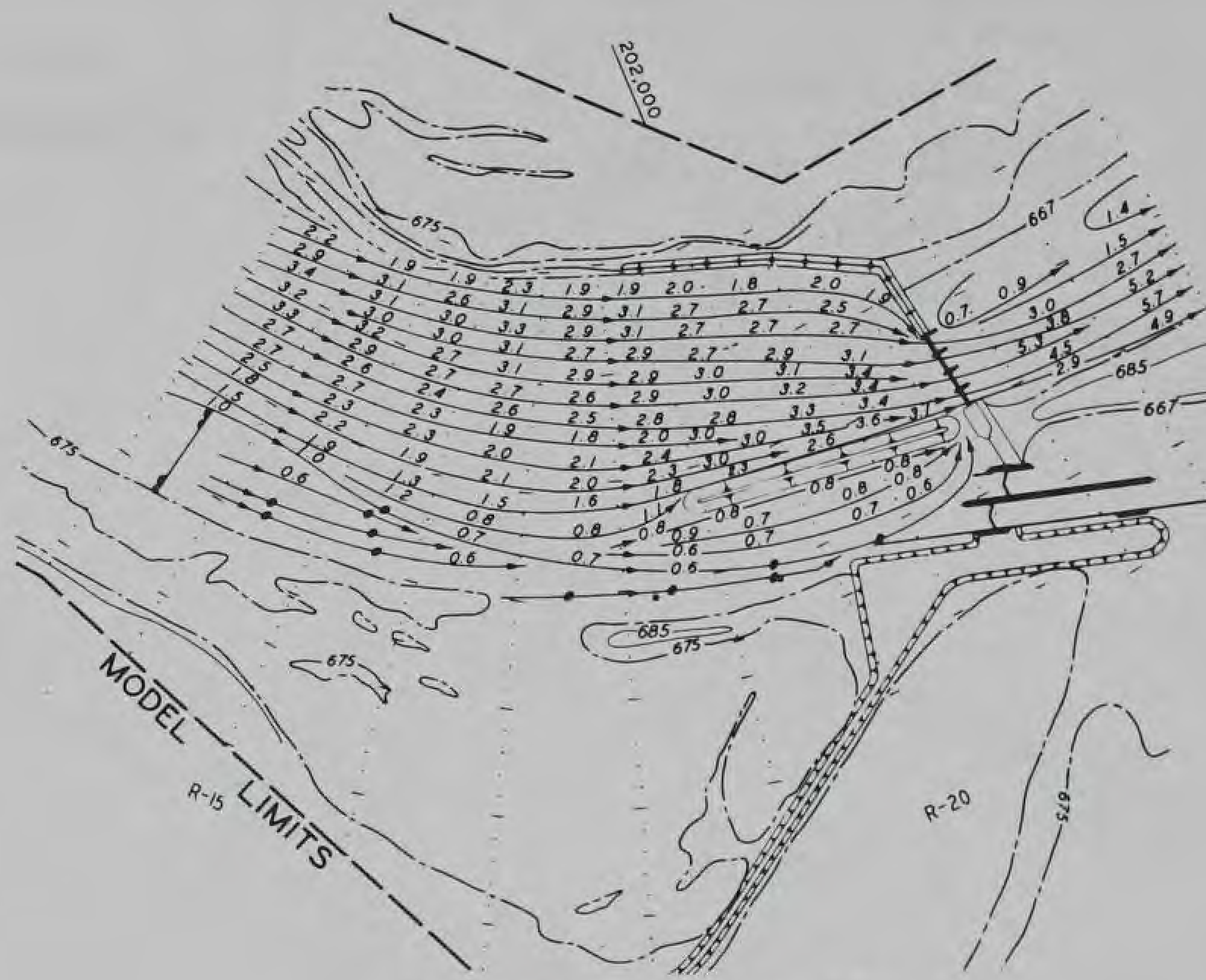
DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT



DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

N

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

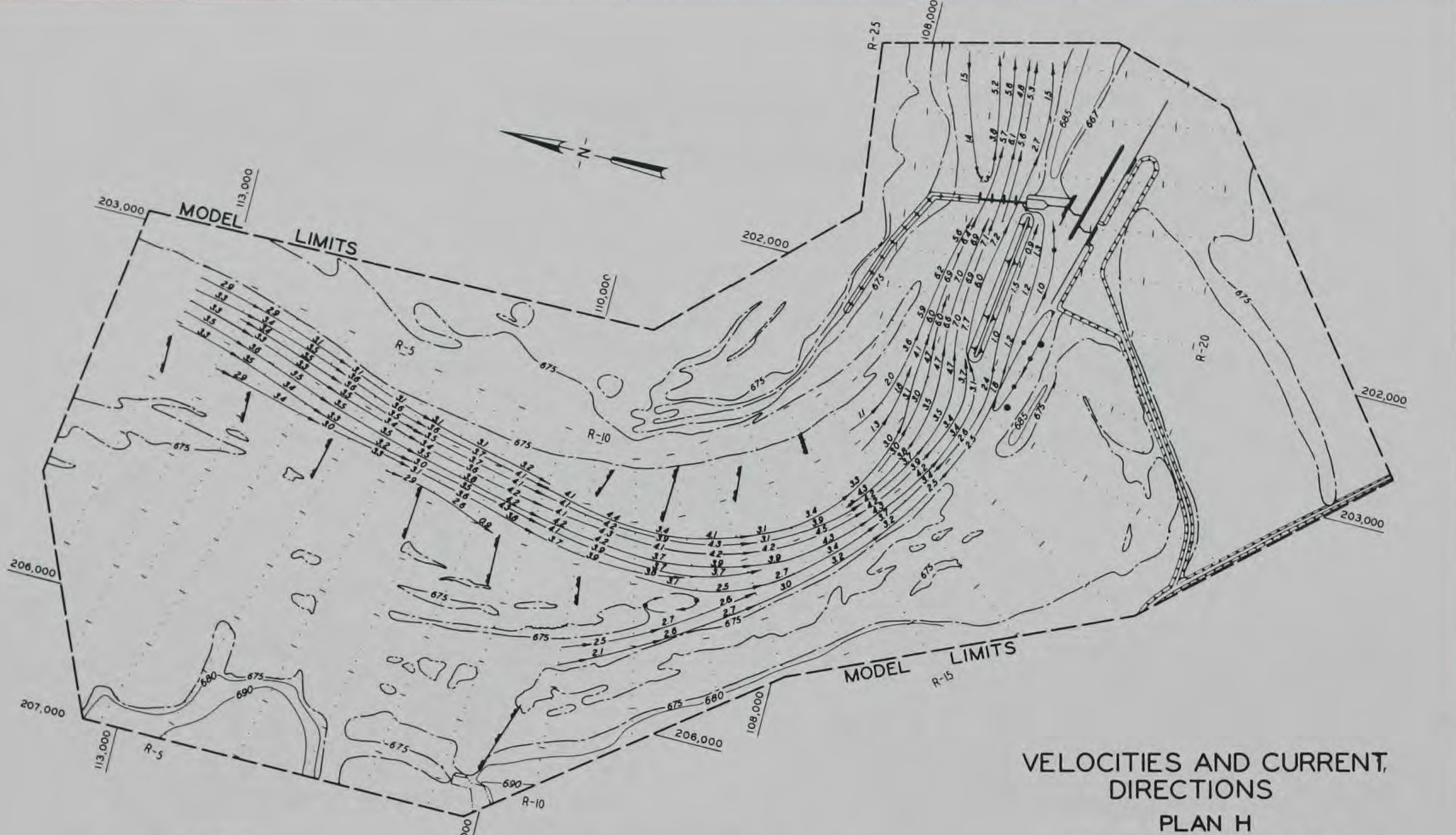
VELOCITIES AND CURRENT DIRECTIONS

PLAN G-MODIFIED

DISCHARGES 36,000 AND 70,000 CFS

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



VELOCITIES AND CURRENT DIRECTIONS

PLAN H

DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT

SCALES IN FEET

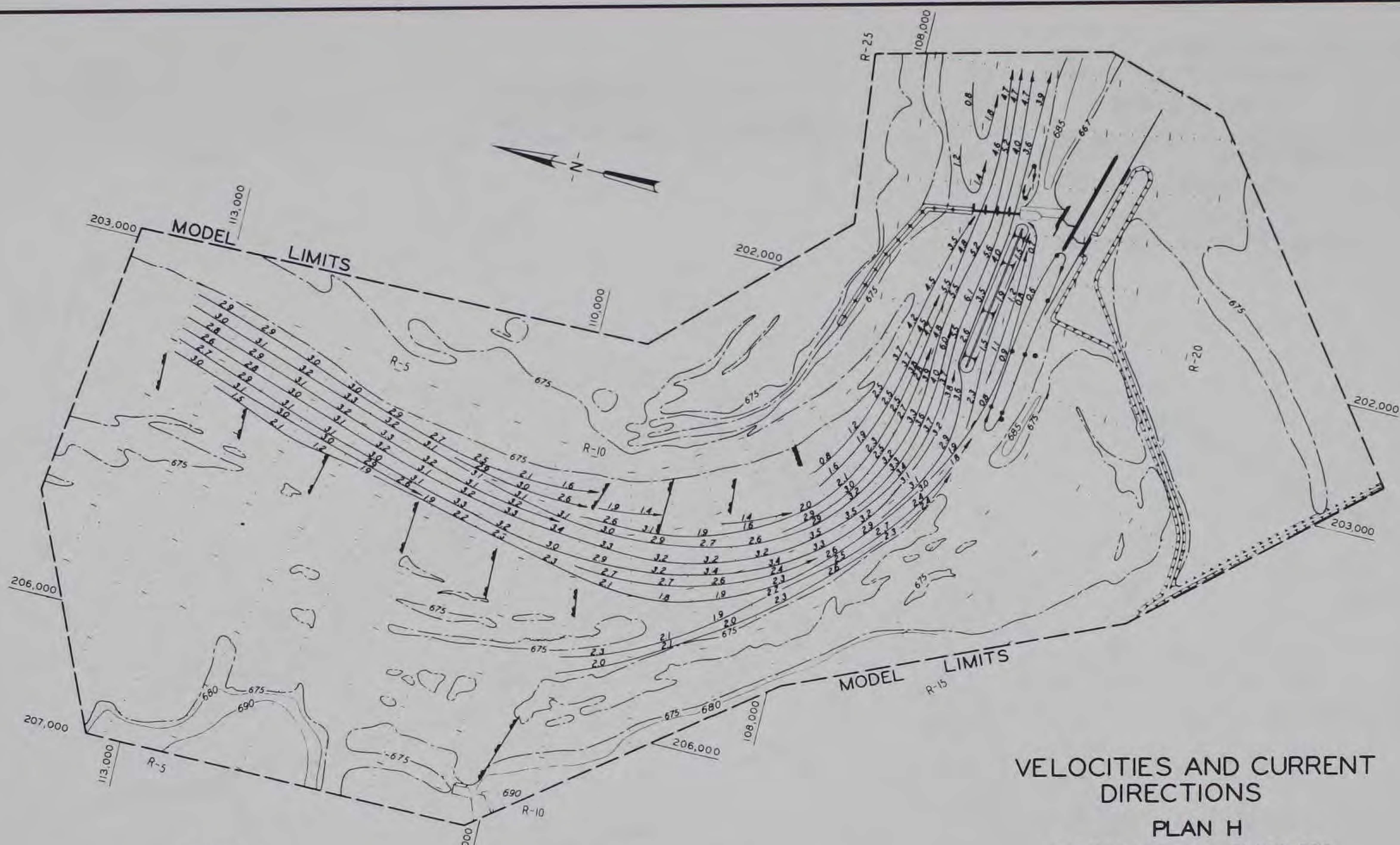
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 → VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

PLAN H

DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

4.2 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
STONE-FILL DIKE OR REVETMENT
EXISTING LEVEE
NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

VELOCITIES AND CURRENT DIRECTIONS

PLAN H-MODIFIED

DISCHARGE 15,000 CFS
TAILWATER EL 668.6 FT

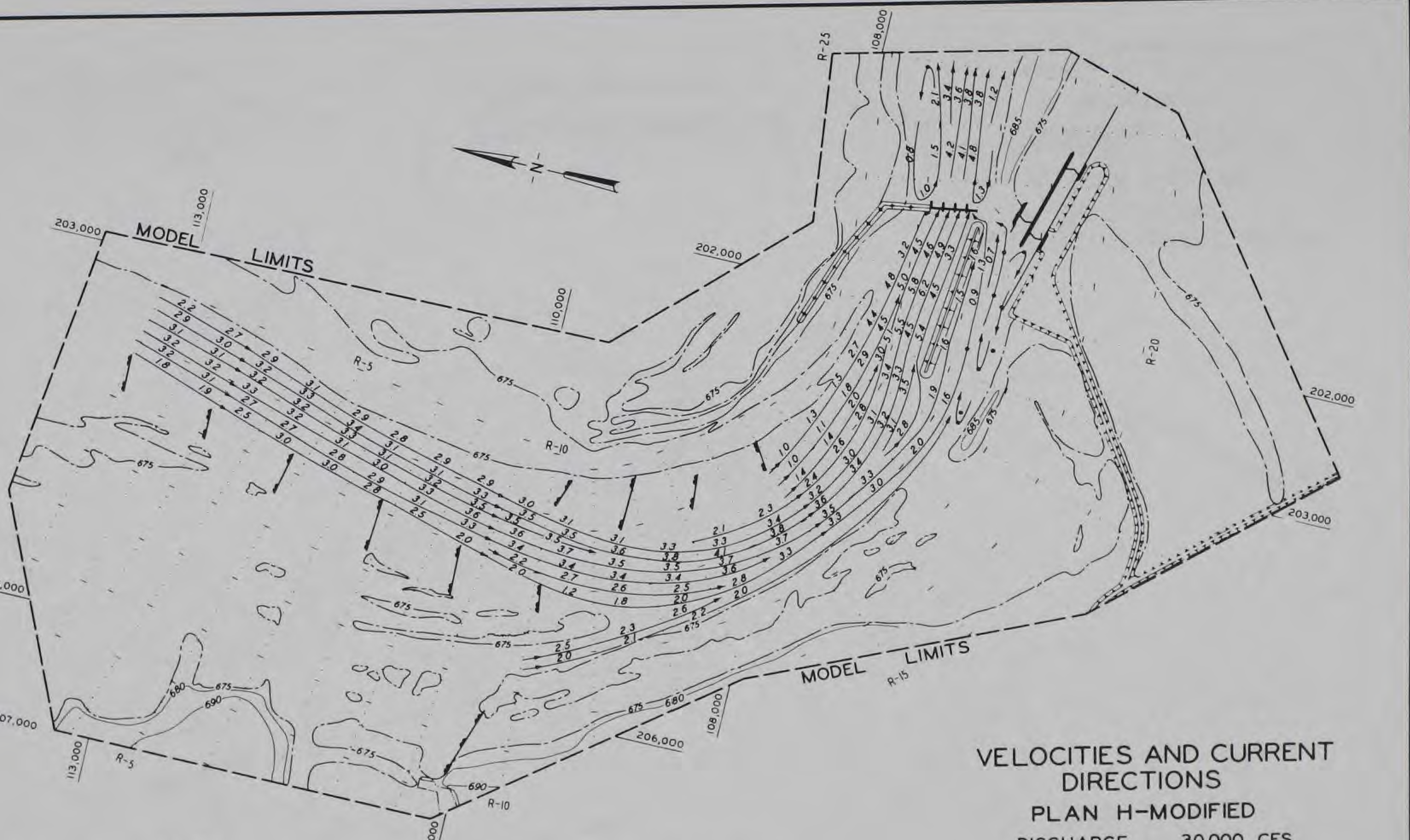
SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 → VELOCITY IN FEET PER SECOND
- → VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

PLAN H-MODIFIED

DISCHARGE 30,000 CFS
TAILWATER EL 672.4 FT

SCALES IN FEET

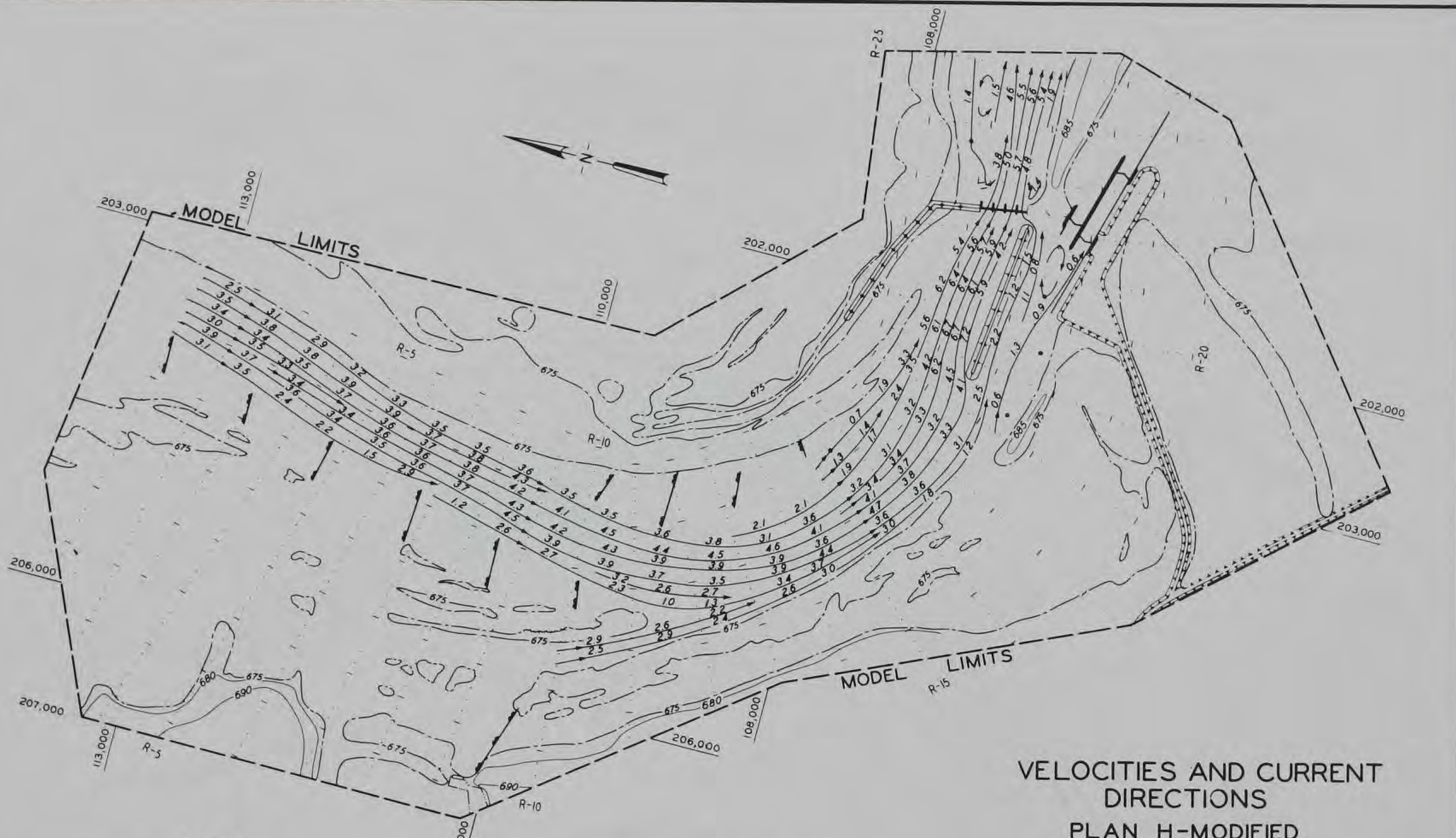
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

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

ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



VELOCITIES AND CURRENT DIRECTIONS

PLAN H-MODIFIED

DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

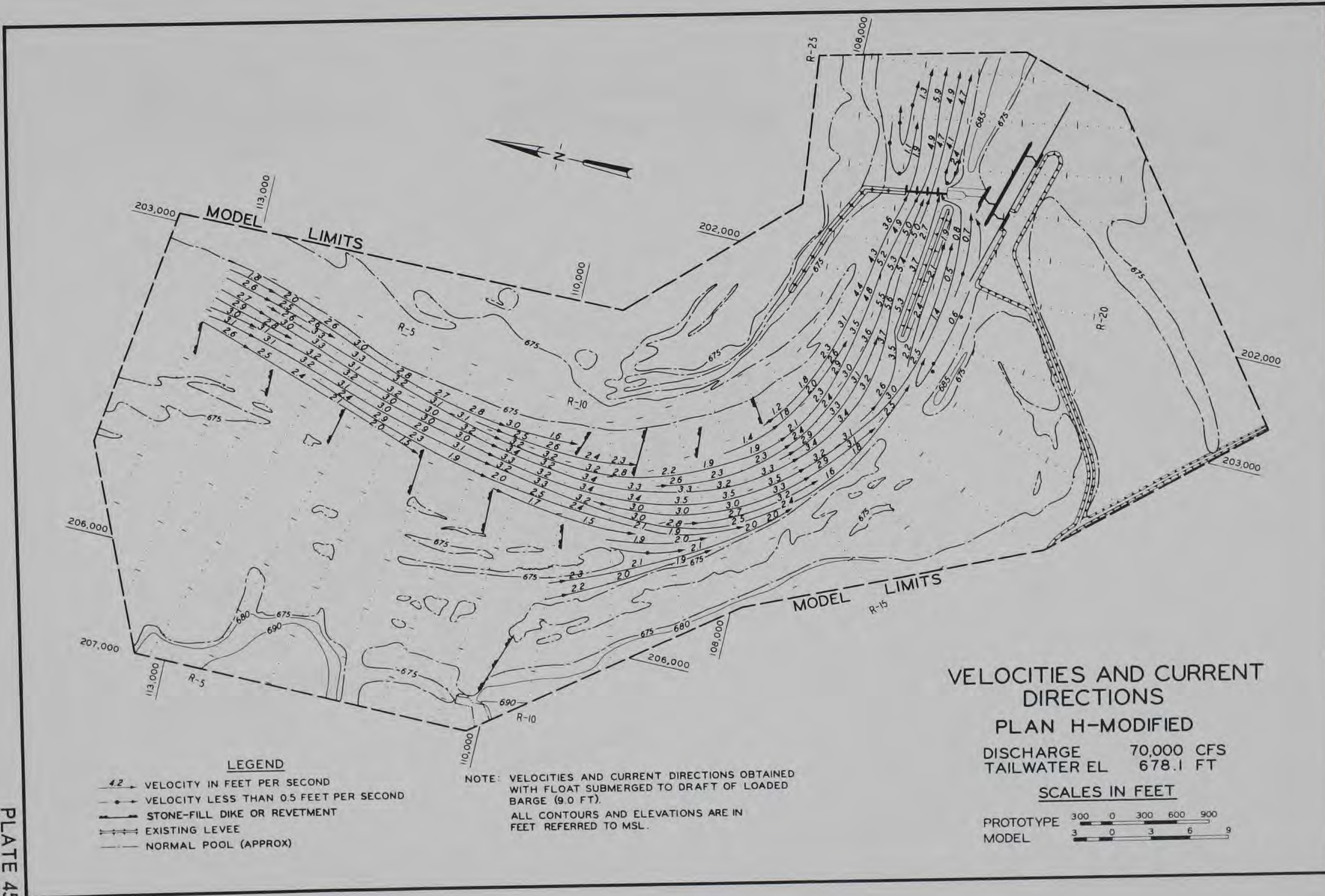
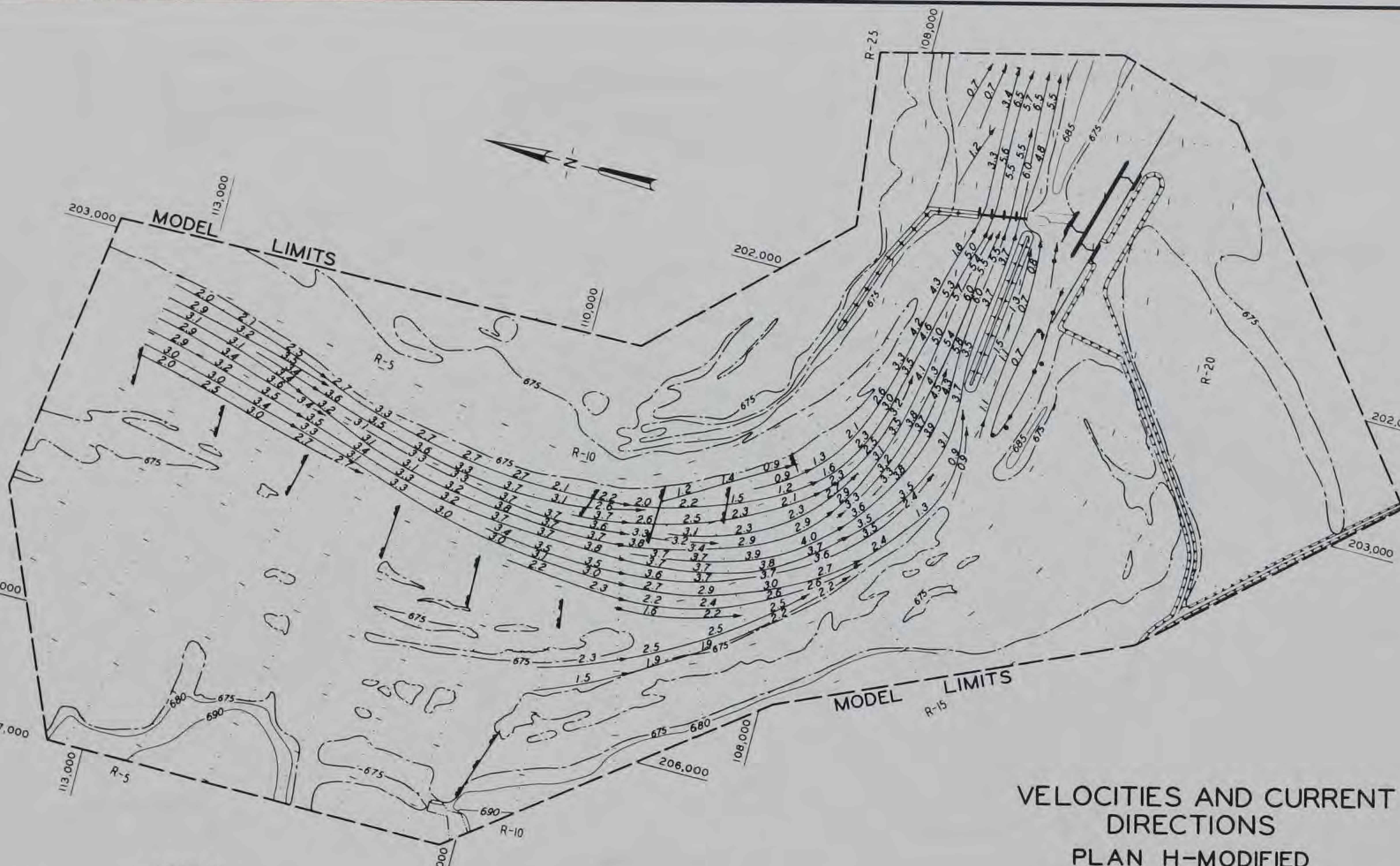

VELOCITIES AND CURRENT DIRECTIONS
PLAN H-MODIFIED
DISCHARGE 70,000 CFS
TAILWATER EL 678.1 FT
SCALES IN FEET
PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9
LEGEND
4.2 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
STONE-FILL DIKE OR REVETMENT
EXISTING LEVEE
NORMAL POOL (APPROX)
NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.
MODEL LIMITS
MODEL LIMITS
N
203,000
113,000
110,000
202,000
108,000
206,000
207,000
R-5
R-10
R-15
R-20
R-25
675
680
685
690

PLATE 45



VELOCITIES AND CURRENT DIRECTIONS

PLAN H-MODIFIED

DISCHARGE 100,000 CFS
TAILWATER EL 680.6 FT

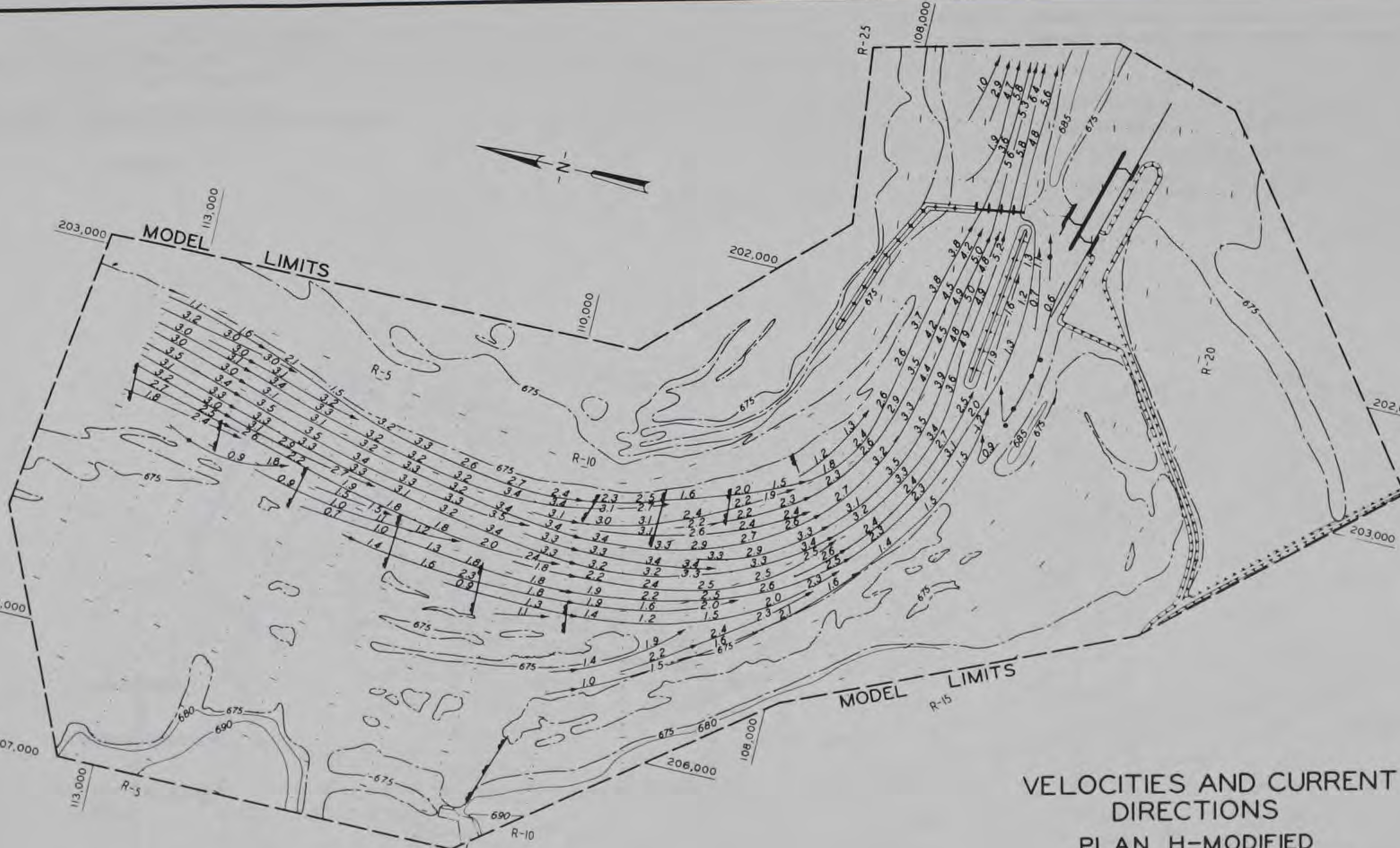
LEGEND

- 4.2 → VELOCITY IN FEET PER SECOND
- →•→ VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.

SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9



VELOCITIES AND CURRENT DIRECTIONS

PLAN H-MODIFIED

DISCHARGE 134,000 CFS
TAILWATER EL 682.9 FT

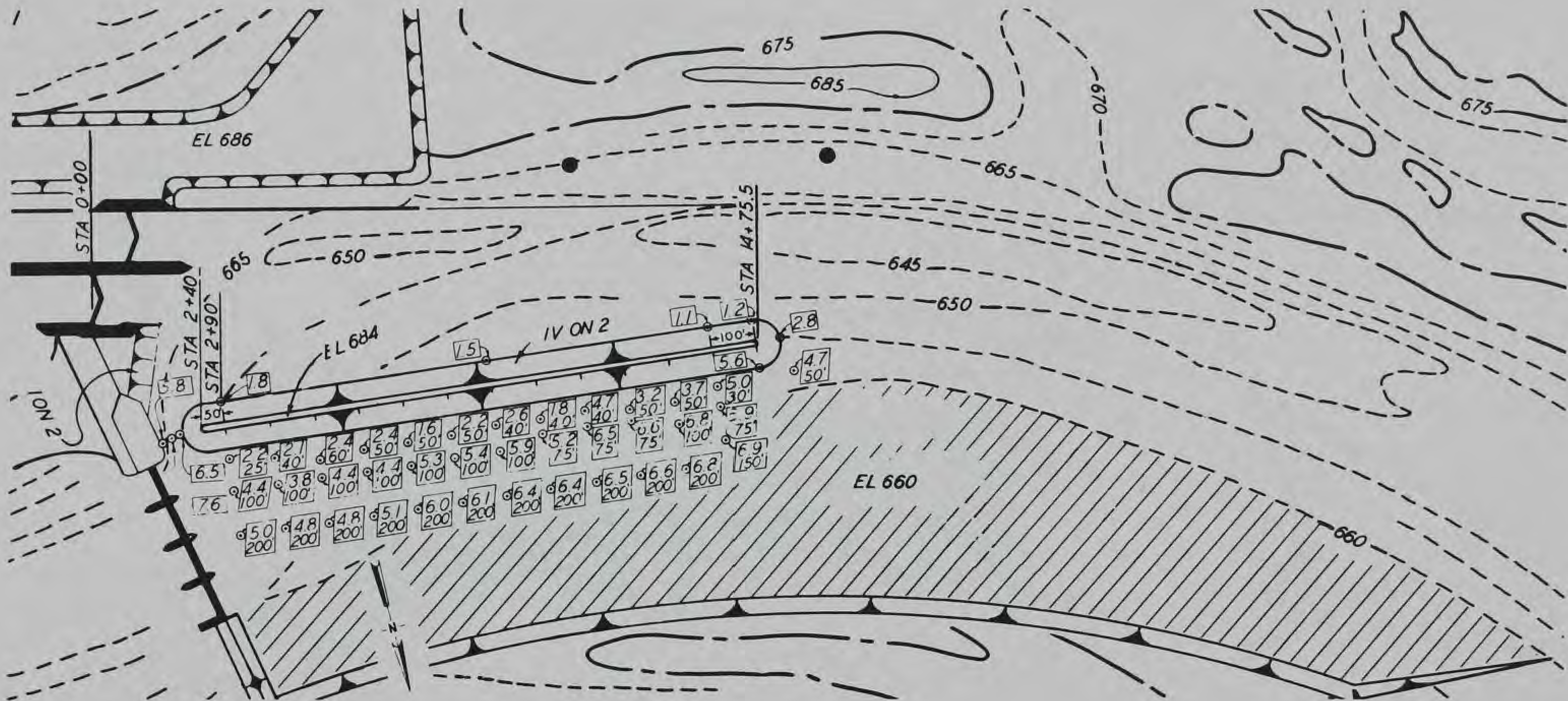
SCALES IN FEET

PROTOTYPE 300 0 300 600 900
MODEL 3 0 3 6 9

LEGEND

- 4.2 VELOCITY IN FEET PER SECOND
- VELOCITY LESS THAN 0.5 FEET PER SECOND
- STONE-FILL DIKE OR REVETMENT
- EXISTING LEVEE
- NORMAL POOL (APPROX)

NOTE: VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT).
ALL CONTOURS AND ELEVATIONS ARE IN FEET REFERRED TO MSL.



LEGEND

5.0 / 200' - METER VELOCITIES TAKEN NEAR BOTTOM - FEET OUT FROM TOE OF DIKE

— — — — NORMAL POOL (APPROX)

NOTE: ALL ELEVATIONS ARE IN FEET REFERRED TO MEAN SEA LEVEL

VELOCITIES

PLAN H-MODIFIED

DISCHARGE 36,000 CFS
TAILWATER EL 673.5 FT

SCALE

PROTOTYPE 300 0 300 600 FT
MODEL 3 0 3 6