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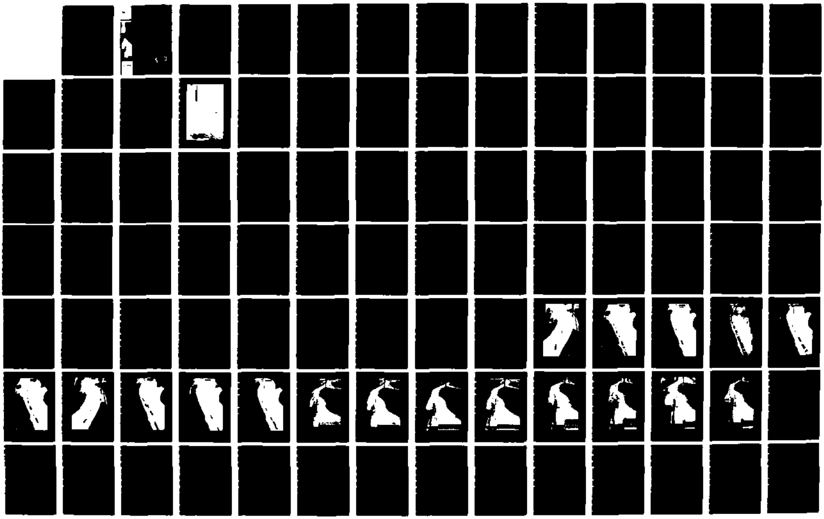

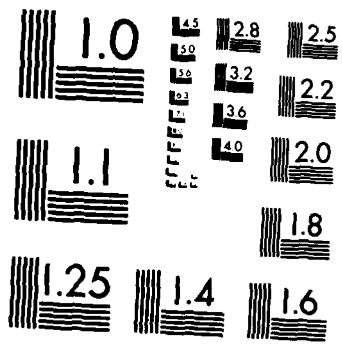

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US Army Corps of Engineers

TECHNICAL REPORT HL-86-6

LOCK AND DAM 1, RED RIVER WATERWAY

Hydraulic Model Investigation

by

James E. Foster, Charles R. O'Dell, J. Edwin Glover

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Lock and Dam 1 is the first navigation structure for the development of navigation on the Red River Waterway. The structure is located in a cutoff channel in the left overbank about 43.7 realigned channel miles above the Mississippi River. The structure includes one lock located along the left bank with clear chamber dimensions of 84 by 785 ft and a dam, consisting of a spillway with eleven 50-ft-wide gates, that is designed to provide a normal pool to

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20. ABSTRACT (Continued).

el 40 upstream to Lock and Dam 2 (mile 74) and to pass a project flood flow of 225,000 cfs.

A model reproducing two reaches of the Red River from 1967 river mile 52.0 to 49.8 and from mile 44.0 to 41.5 and the proposed cutoff connecting these two reaches, including Lock and Dam 1, was built for this study. The model was built with provisions to mold the channel bed either in pea rock to an undistorted scale of 1:120 for navigation tests so velocities and current directions could be taken or in crushed coal to a distorted scale of 1:120 horizontally and 1:80 vertically for channel development tests to study bed configuration changes.

The model study was conducted to determine navigation conditions and channel developments to be expected from the original design and to develop modifications that might be required to: (a) improve flow conditions that would be adverse to navigation, and (b) minimize the dredging required to maintain a channel of satisfactory dimensions along a desired alignment.

Results of the investigation revealed the following:

a. A navigation channel of adequate width and depth could be developed with Lock and Dam 1 located at the proposed site with the modifications developed in Plan B-34.

b. Little or no maintenance dredging of bed load should be required except after sustained high water occurs with extremely low tailwater conditions.

c. The channel should remain satisfactory with the proposed mooring facility constructed downstream of the lock as in Plan B-35.

d. Downbound tows would need to cross to the left side of the channel just upstream of the longitudinal dike, stay along the left side, and maintain speed until they are out of the main channel.

e. The difference in water-surface elevation across the dam with open river conditions was between 0.1 ft and 0.3 ft for the flows tested.

PREFACE

The model investigation reported herein was conducted for the US Army Engineer District, New Orleans (LMN), by the US Army Engineer Waterways Experiment Station (WES) during the period September 1972 to October 1978. The study was authorized by the Office, Chief of Engineers (OCE), US Army, in the 2nd indorsement dated 2 June 1971 to a letter of 14 May 1971 from LMN to the US Army Engineer Division, Lower Mississippi Valley (LMVD), subject: Red River Waterway-Model Studies.

The investigation was conducted in the Hydraulics Laboratory under the general supervision of Messrs. H. B. Simmons and F. A. Herrmann, Jr., former and present Chiefs of the Hydraulics Laboratory, and under the direct supervision of Messrs. J. J. Franco and J. E. Glover, former and present Chiefs of the Waterways Division. The engineer in immediate charge of the model study was Mr. J. E. Foster, retired Chief of the River Regulation Branch. He was assisted by Messrs. C. R. O'Dell, J. A. Holliday, and A. J. Cook. Mr. O'Dell prepared preliminary data for the report. This report was prepared by Mr. Foster, reviewed by Mr. Glover, and edited by Mrs. Beth F. Burris of the Publications and Graphic Arts Division.

During the course of the model study, representatives from OCE, LMVD, and LMN visited WES to observe model tests and discuss test results. LMN was kept informed of the progress of the study through monthly progress reports and periodic transmittal of preliminary test results.

Director of WES was COL Allen F. Grum, USA. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

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

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
miles (US statute)	1.609347	kilometres

LOCK AND DAM 1, RED RIVER WATERWAY

Hydraulic Model Investigation

PART I: INTRODUCTION

Location and Description of Prototype

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

Plan of Development

2. The 90th Congress authorized the development of the Red River Waterway with the passage of Public Law 90-483 on 13 August 1968. As presently authorized, the project provides for the improvement of the Red River and its tributaries in Louisiana, Arkansas, Texas, and Oklahoma through coordinated development to serve navigation, bank stabilization, flood control, recreation, fish and wildlife, and water quality control. The primary function of the project is to establish a 9-ft-deep by 200-ft-wide navigation channel from Old River to Lake O' the Pines near Dangerfield, Texas, by a system of nine locks and dams, a number of cutoffs, extensive channel realignment, and channel training and stabilization works. The project consists of four distinct reaches: (a) Mississippi River to Shreveport, Louisiana; (b) Shreveport to Dangerfield, Texas, by Twelve Mile Bayou; (c) Shreveport to Index, Arkansas;

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

and (d) Index to Denison Dam, Texas. The Appropriations Act of 1971, approved 7 October 1970 as Public Law 91-439, provided authority to initiate preconstruction planning in the Mississippi River-to-Shreveport reach, the only reach pertinent to this study.

Lock and Dam 1

3. The final location of Lock and Dam 1 is in a cutoff channel approximately 43.7 miles* above the Mississippi River and about 9.5 miles above the confluence of the Red and Black Rivers (Figure 1). This lock and dam was originally proposed for a site about mile 45.6; then it was decided to move the location downstream to the vicinity of the mouth of the Black River (mile 34.2). However, the location of the lock and dam was moved back near the original site because of drainage and environmental problems in the Larto Lake area (mile 42). Figure 2 shows the original and final locations of the lock and dam at Site 1 and the two locations (Sites 2 and 3) that were considered in the vicinity of the Black River. A model that encompassed Sites 2 and 3 was constructed and studies of channel alignment and river training works were conducted.** Lock and Dam 1 will be the downstream navigation structure on the Red River and will consist of a lock on the left side of the cutoff channel separated by an island from the dam on the right side. The lock will have a usable chamber of 84 by 785 ft with an upper sill to el 18,† a floor to el -11, a lower sill to el -9, and lock walls to el 60.5. The dam will be 640 ft long with eleven 50-ft-wide gates, a sill at el 11, and a stilling basin at el -14. The dam was designed to maintain a normal pool at el 40 upstream to Lock and Dam 2 (mile 74) and to pass the project flood flow of 225,000 cfs.

Need for and Purpose of Study

4. The general design of Lock and Dam 1 was based on sound theoretical

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* River miles are along the channel based on the proposed realignment unless otherwise stated.

** Results of this study are discussed in WES Technical Report, "Channel Development in the Lower Reach of the Red River," in preparation.

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

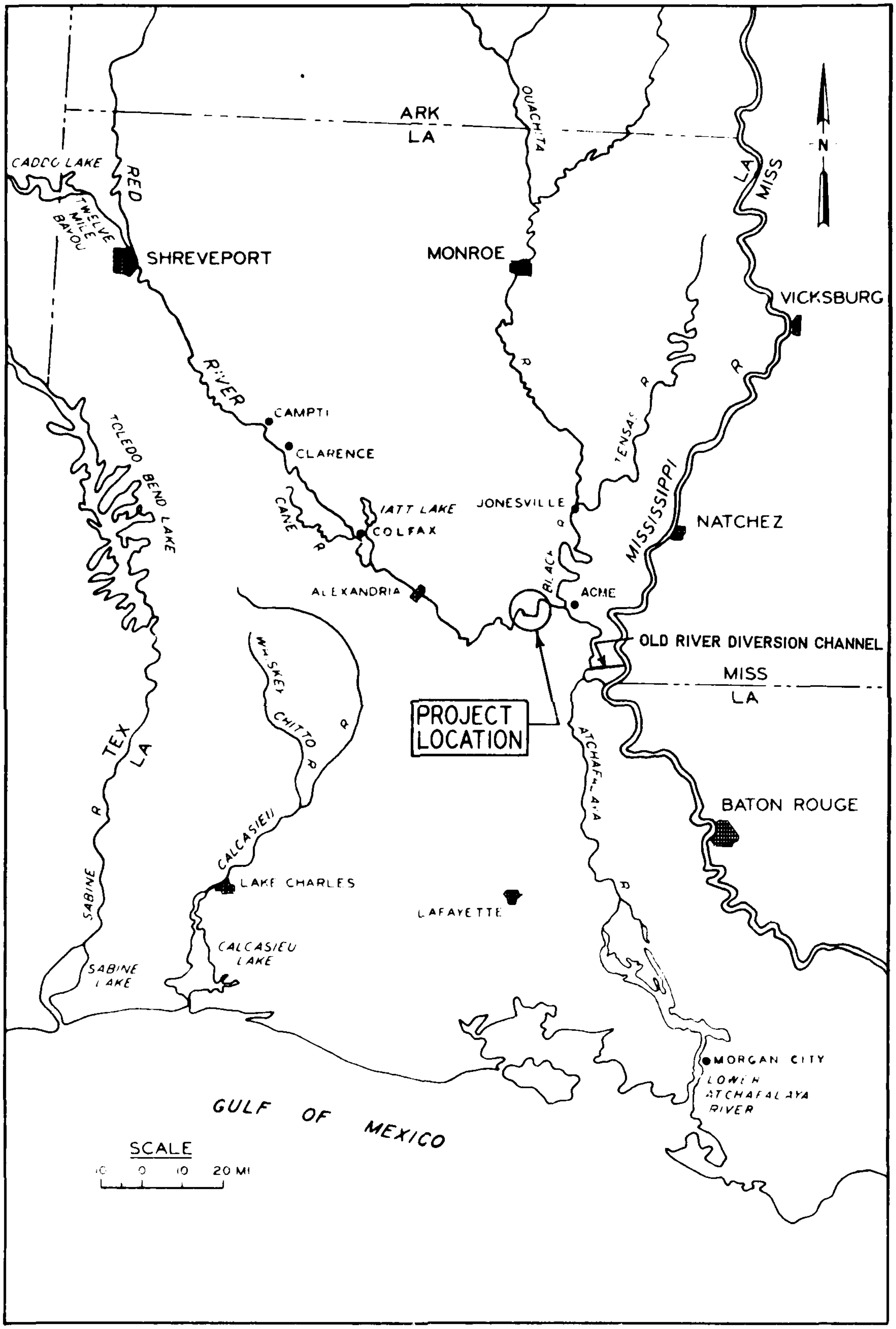

Figure 1. Location map

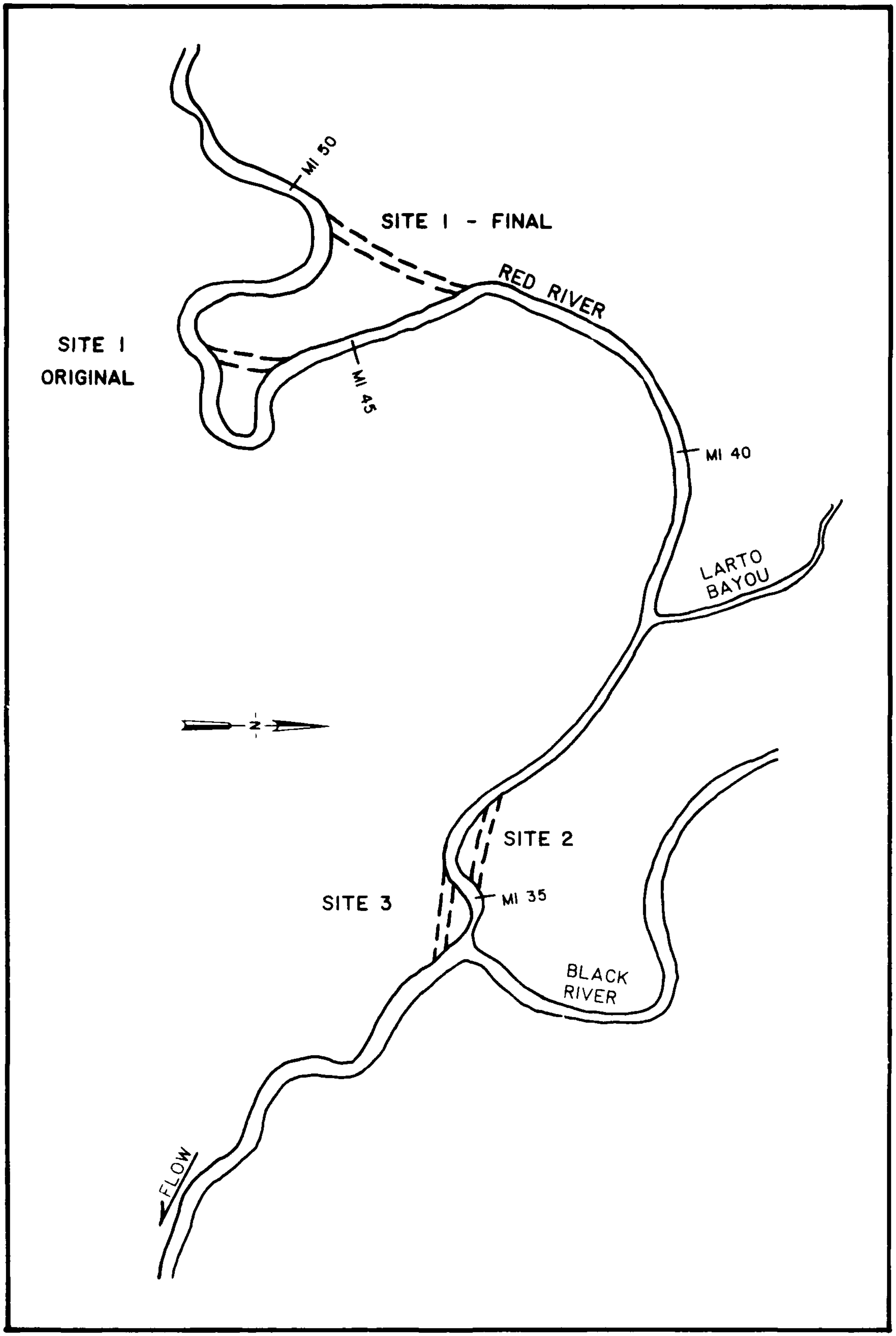

Figure 2. Alternate sites for Lock and Dam 1

design practice and experience with similar structures; however, problems concerning navigation conditions and channel development are site-specific and not amenable to analytic solution. In addition, Lock and Dam 1 is to be constructed in an excavated channel bypassing a long bend, the problems to be encountered were expected to be unusual and there were no existing flow conditions to use as a guide. Therefore a hydraulic model study, including provision for both fixed- and movable-bed tests, was considered necessary to determine the alignment of the canal and the arrangement of the lock and dam that would be the most satisfactory for both navigation and sediment movement. The purposes of the model study were:

a. To determine the adequacy of the channel aligrment and the arrangement of the lock and dam.

b. To study velocities and current patterns in the lock approaches and determine modifications needed to improve navigation conditions.

c. To determine optimum length, height, and width of the island separating the lock and dam.

d. To study tendency for scour and fill in the approaches to the lock and dam and determine training structures that would improve navigation conditions and minimize dredging requirements and scour problems.

e. To determine the effects on navigation and sedimentation of constructing a mooring area on the left bank just downstream of the lock.

PART II: THE MODEL

Description

5. A model reproducing two reaches of the Red River, from 1967 river mile 52.0 to 49.8 and from river mile 44.0 to 41.5, and the proposed cutoff connecting these two reaches including Lock and Dam 1 was built for this study (Figure 3). The bend from 1967 river mile 49.8 to 44.0 was not included in this model since it will be cut off from the Red River upon completion of the lock and dam. A concrete trough was built to carry flow from the upper reach of the river to the lower reach during the adjustment of the model to 1974 conditions. The model was built to linear scale ratios of 1:120 horizontally and 1:80 vertically except the upstream and downstream dimensions of the dam were constructed to the vertical scale to more nearly reproduce the hydraulic characteristics of the dam. The model was designed for both fixed- and movable-bed tests. Overbank areas were molded of sand-cement mortar, and the bed was molded in pea gravel to an undistorted scale of 1:120 for the fixed-bed (navigation) tests and in crushed coal to a distorted scale of 1:120 horizontally and 1:80 vertically using the fixed top bank elevation as a reference for the movable-bed (sedimentation) tests. The crushed coal had a median diameter of 4 mm and a specific gravity of 1.30. Dikes were molded of crushed stone. Folded strips of wire mesh were used to simulate the roughness effect of trees and underbrush on the overbank areas. The lock and dam were fabricated of sheet metal. Dam and lock gates were simulated with simple sheet-metal slide-type gates. Guard walls were made of wood and attached to metal cells so they would reproduce the vertical movement of floating guard walls with change in water-surface elevation.

6. The overbank portion of the model was molded to a combination of contours and elevations shown on the Red River, Louisiana, Hydrographic Survey of 1967-1968 and on US Geological Survey (USGS) quadrangle sheets dated 1960. The channel portion was molded to a hydrographic survey dated July-August 1974.* The proposed cutoff and lock and dam were installed according to plans furnished by the US Army Engineer District, New Orleans (LMN).

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* The channel portion was originally constructed to the hydrographic survey of March-April 1968 but problems during adjustment tests indicated the need for a new survey (see paragraph 11).

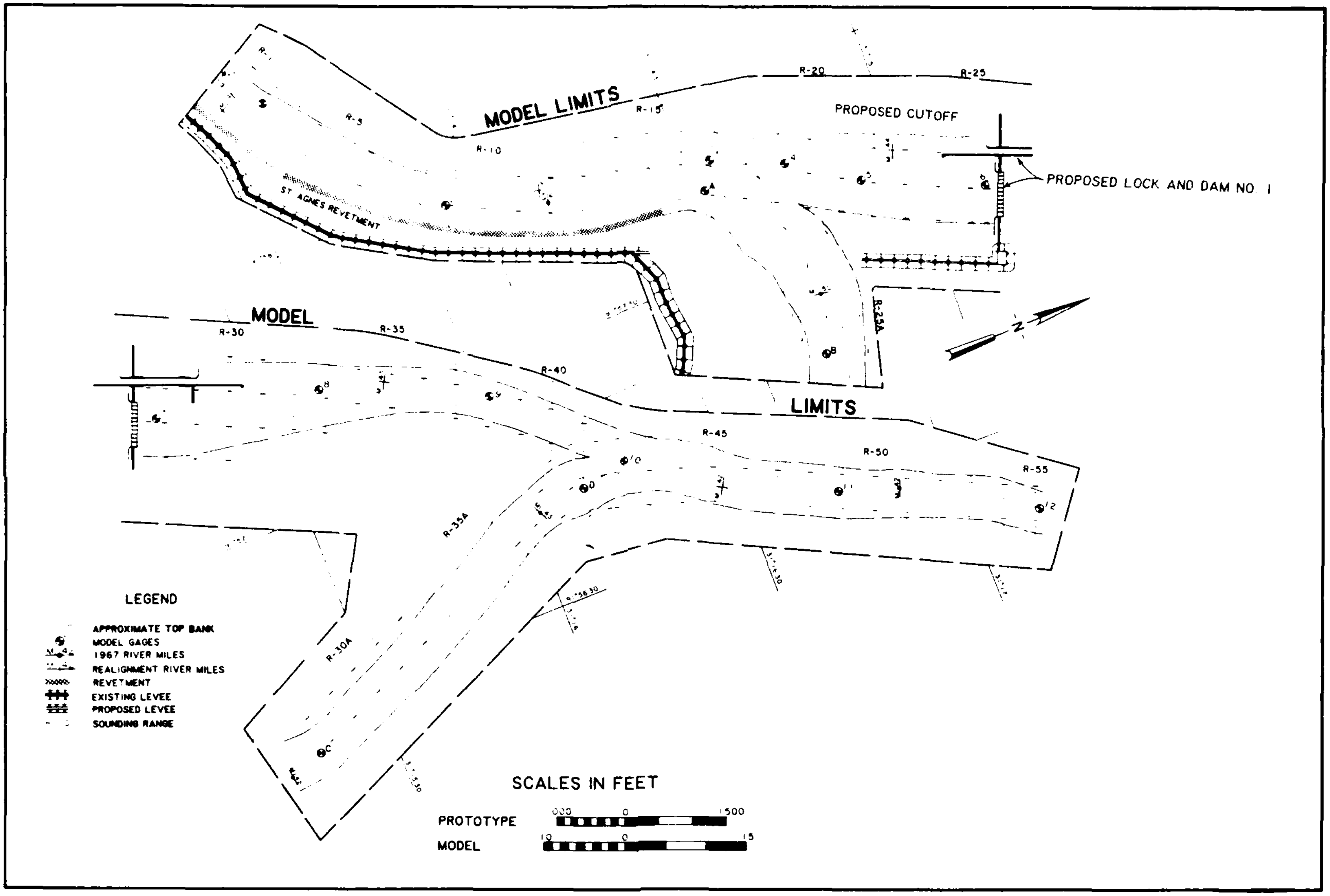

Figure 3. Model layout and gage locations

Appurtenances

7. Water was supplied to the model by a 10-cfs axial flow pump operating in a circulating system and was measured at the upstream end of the model by two venturi meters of different sizes to provide for accurate measurement of flow over the range of discharge to be reproduced. Water-surface elevations were measured at 12 model gaging stations (Figure 3) by means of 12 piezometers located in the model channel and connected to a centrally located gage pit. Adjustable tailgates were provided at the downstream end of each reach of the river to control the water-surface elevation during the model adjustment. During model tests the water-surface elevation upstream of the dam was controlled by manipulating the gates of the dam until the gates were out of the water. All gates were opened equally for each test. The water-surface elevation downstream of the dam was controlled by the tailgate at the downstream end of the model. A graduated container was used to measure the bed material introduced at the upstream end of the model. A sediment trap was provided at the downstream end of the model where extruded material could accumulate and be measured at the end of any specific period. Sheet-metal templates were used for molding the model bed prior to initiation of certain tests. A carefully graded rail was installed along each side of the channel to: (a) support the templates at the correct elevations; (b) support a rail used to survey the model bed; and (c) provide vertical control for installing structures in the model.

8. Current directions were determined by plotting the paths of wooden cylinder floats with respect to ranges established on the model for that purpose; the floats were weighted on one end to simulate the draft of a loaded barge (9 ft prototype). Velocities were measured by timing the travel of these floats over known distances. A midget current meter was used to measure velocities at special locations. A model towboat and tow were used to determine and demonstrate the effect of currents on tows approaching and leaving the lock (Figure 4). The overall size of the towboat and tow was 70 ft wide by 685 ft long and loaded to a draft of 9 ft. The towboat was equipped with forward and flanking rudders and twin screws that could be operated in forward or reverse. The rudder setting and the speed of the tow were remote-controlled. The maximum speed of the tow was controlled by a rheostat comparable to the maximum speed of the towboats expected to use the waterway.

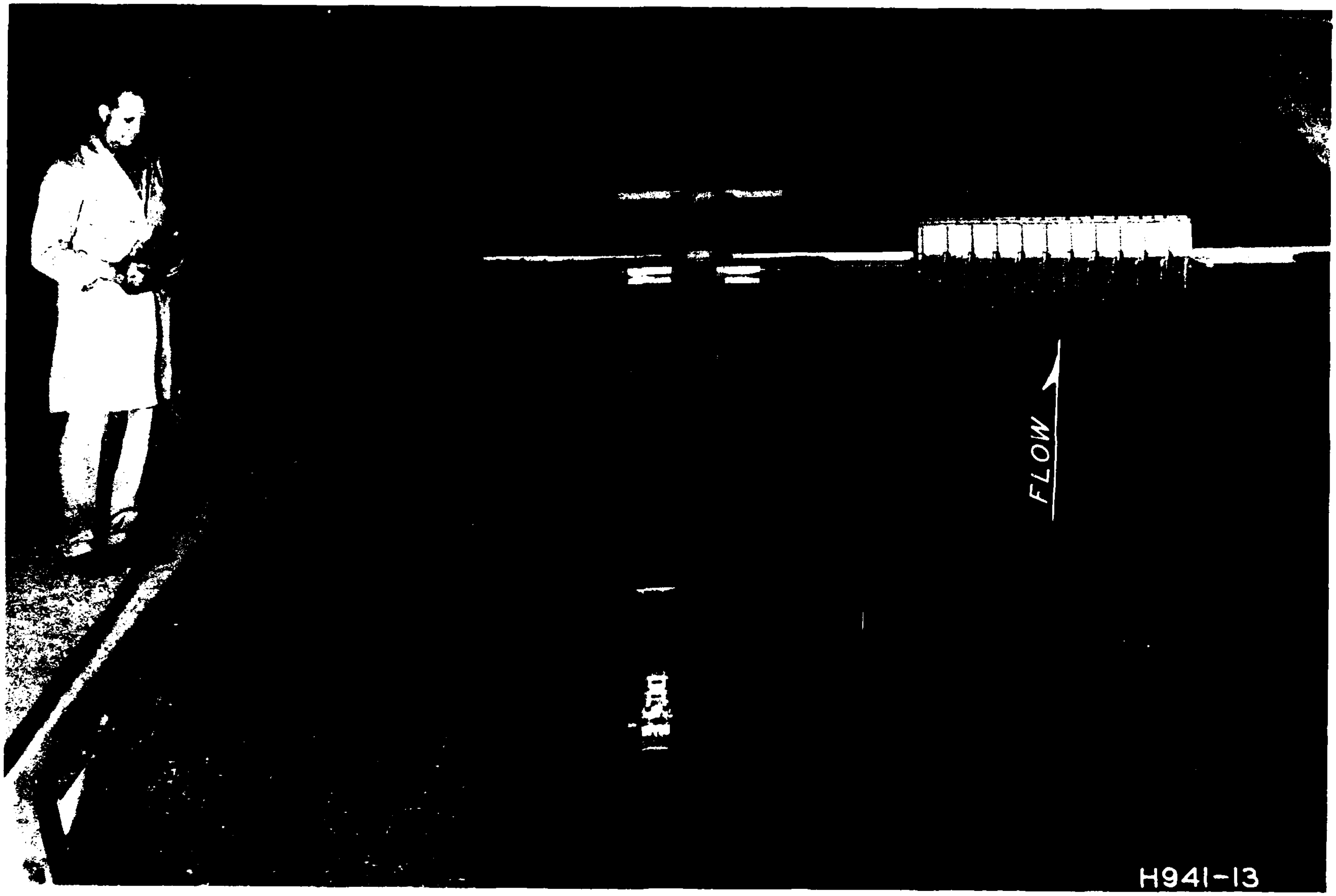

Figure 4. Remote-controlled towboat and tow in upper lock approach

Model Adjustment

Movable-bed model adjustment

9. As the name implies, the bed and bars of movable-bed models are composed of material capable of being transported as bed load. Bank lines are normally fixed unless caving banks are expected to have a major impact on the study. Models capable of reproducing only bed-load movement are adequate to study shoaling and deposition problems since suspended sediments do not normally play a significant role in scour and deposition in sand-bed streams where significant bed-load movement is occurring. Fixed bank lines and a coal bed were used in this study. Before a movable-bed model is used to test the effectiveness of proposed improvement plans, its ability to reproduce conditions similar to those that can be expected in the prototype must be demonstrated. Complete agreement between the model and the prototype is seldom obtained because of the inherent distortions incorporated in the model design and in the operation of the model. Because of these dissimilarities, the degree of reliability of this type of model cannot be fully established by mathematical analysis and must be based on model verification. Verification of the model involves the adjustment of various hydraulic forces, time scale, rate of introducing bed material, and model operating techniques until the model reproduces with acceptable accuracy the changes known to have occurred in the prototype during a given period. Various scale relationships and model operation procedures established during model verification are used in tests of various improvement plans. The degree of similarity between model and prototype data obtained during model verification is considered in the analysis of model test data.

10. Conventional procedure. To accomplish a normal verification of a movable-bed model requires two prototype bed surveys about 1 year apart (to provide a full range of discharges) and the stages and discharges that occurred in the test reach between the surveys. The model bed is molded to the first prototype survey. The flows that occurred between the surveys are introduced at the upper end of the model and the water surface at the downstream end of the model is controlled so the stages in the center of the model agree with the stages that occurred in the prototype for the period. Bed material is introduced at the upper end of the model with each flow. At the end of the period the model bed is surveyed and the bed configurations are compared with

those of the prototype survey at the end of the period. If the model does not reproduce the prototype survey close enough, the process is repeated with modifications to the time and discharge scales, the rate of introduction of bed material, and model operating techniques. This process is repeated until the model satisfactorily reproduces the prototype bed configurations. Once the model has been verified, these scales and procedures are used in the testing program.

11. Procedure used. Since only one recent prototype survey of the test reach (that of March-April 1968) was available, a conventional verification of the model was not possible. However, for the model to be of value it was essential that it be adjusted to reproduce channel configurations generally representative of those expected in this reach of the Red River under similar circumstances. As only one survey was available, it was used as the beginning survey and to compare with the survey obtained from the model at the end of the adjustment hydrograph. The model was molded to the prototype survey, the flows that occurred during the preceding 12 months were reproduced, and the resulting bed configurations were compared with the prototype surveys. This procedure assumes no radical changes in channel alignment and that the hydrograph which shaped the bed should not significantly change the bed if it is repeated. Also implicit in this method of adjustment is the requirement that discharge scales are adjusted so that there is adequate bed-load transport. The amount of sediment introduced at the upstream model limit is adjusted so that the most upstream section of the model neither aggrades nor degrades significantly.

12. The adjustment of the model was initiated with the 1968 survey but model results did not agree as closely as desired with those of the prototype. A comparison of aerial photographs taken before the adjustment period and after the survey revealed that extensive bank caving occurred in the bend just upstream of the proposed cutoff during the adjustment period. A study of the prototype survey revealed that the upstream portion was surveyed during high discharges and the downstream portion was surveyed during low discharges, thus introducing a change in channel configuration between the surveys of the two reaches. It was decided that to obtain a reasonable adjustment which would be reliable for developing solutions to sedimentation and navigation problems in the entrances to the lock and dam, a new prototype survey was necessary.

13. A new prototype survey was made of the test reach during July and August 1974 to use for adjusting the model. Initial navigation tests with a 1:120-scale, undistorted model were conducted with the existing channel molded to the 1974 survey and the proposed cutoff and structures installed according to plans furnished by LMN. Following these initial navigation tests, the 1974 survey (Plate 1) was molded in the model to the distorted scale of 1:120 horizontally and 1:80 vertically for the movable-bed study, and the flow hydrograph for the period August 1973 to July 1974 (Plate 2) was reproduced. The stages were controlled at the downstream end of each section of the model to those of the prototype. The resulting bed configurations were compared with the July-August 1974 prototype survey. This process was repeated with adjustments to the discharge scale, the rate of bed material introduced, and model operating techniques until the model reproduced bed movement that could normally be expected in the Red River for these flows and the model bed configurations existing at the end of the flow hydrograph agreed closely with those of the prototype survey.

Results

14. A comparison of the model bed configurations resulting from the final adjustment test (Plate 3) with bed configurations of the 1974 prototype survey (Plate 1) indicates that the model satisfactorily reproduced the general characteristics of the prototype. The alignment of the deeper part of the channel was generally the same in the model as that in the prototype with the bars and crossings in the proper places. The model channel was generally deeper than that indicated by the prototype survey with the bar areas slightly higher. Considering that there was no prototype survey available for the beginning of the adjustment period to use in correctly molding the model bed prior to the adjustment test, this adjustment was considered adequate for the purposes of this study. As a result of the adjustment, the discharge and time scales, the rate of introducing bed material, and operating procedures were established for use in the tests of the improved plans.

Fixed-bed model adjustment

15. The normal adjustment for this type of model consists of adjusting roughness to reproduce water-surface profiles and flow distribution. No prototype water-surface profile or flow distribution information was available for the study reach; therefore little adjustment was possible. Since little prototype information was available and the proposed plan made radical changes

to the existing river, the locks and dam were included in the model initially and checks of water-surface profiles and current distribution were made to ensure that they were reasonable. Experience with other undistorted fixed-bed models of this type has indicated that there is little compromise in study results using this procedure since small errors in model reproduction of prototype roughness have little effect on water depth and velocities in the short reaches of river reproduced.

PART III: TESTS AND RESULTS

Test Procedure

16. Fixed-bed navigation tests to the undistorted scale and movable-bed channel development tests to the distorted scale were conducted alternately in this study. A series of navigation tests was conducted first with the model bed molded to the prototype survey of July-August 1974 and the proposed lock and dam and cutoff channel were installed in the model as shown in Design Memorandum No. 10.* The St. Agnes revetment was installed as shown on construction drawings furnished by LMN dated September 1974. Tests were conducted with the original design (Plan A) and four modifications (Plans A-1 through A-4). Following these tests the existing channel was converted to a movable bed and the model was adjusted to reproduce the 1974 survey as described in paragraphs 13 and 14. After the adjustment tests the proposed lock and dam and cutoff channel was installed according to plans in Design Memorandum No. 10, and the bank alignment and channel regulating structures developed in the navigation tests were installed. Channel development tests of this plan (Plan A-5) and modifications to it (Plans A-6 through A-14) were conducted. In accordance with instructions from LMN the lock and dam were relocated with the lock and dam separated by 622 ft rather than 850 ft as for the original design. The model was converted to a fixed bed in preparation for navigation tests with the lock and dam at the new location (Plan B). The channel alignment, bed configurations, and channel regulating structures developed in the movable-bed tests of Plan A were molded and/or installed in the model. Navigation tests of Plan B and modifications to it (Plans B-1 through B-11) were conducted. The model was converted back to a movable bed with the conditions developed in the navigation tests (Plan B-4) molded in the model. Channel development tests of Plan B-12 and modifications to it (Plans B-13 through B-35) were conducted. The model was again converted to the undistorted fixed bed, and navigation tests were conducted with conditions of the recommended plan (Plan B-34) and its modification (Plan B-35).

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* US Army Engineer District, New Orleans. 1974 (Jan). "Red River Waterway, Louisiana, Texas, Arkansas, and Oklahoma, Mississippi River to Shreveport, Louisiana," Design Memorandum No. 10, Hydrology and Hydraulic Design Lock and Dam 1.

Navigation tests

17. Navigation tests were concerned with the study of flow patterns, measurement of velocities and water-surface elevations, and effect of currents on the movement of model tows. For each navigation test the model was molded to an undistorted scale and the theoretical discharge scale was used. The following flows were used for testing as requested by LMN:

a. A controlled flow of 31,000 cfs with a normal pool upstream of the dam at el 40 and a normal tailwater at el 21 at the downstream end of the model (gage 13 at mile 41.6).

b. The maximum flow (96,000 cfs) at which the normal pool could be maintained at the dam (all gates open) with a normal tailwater at el 37.9.

c. The maximum navigable flow (145,000 cfs--a 10-year frequency) with a normal tailwater at el 57.5 and a minimum tailwater at el 42.9.

18. The controlled flow was reproduced by introducing 31,000 cfs at the upstream end of the model, setting the tailgate to provide a water surface of el 21 at gage 13, and adjusting the openings in the dam gates (all dam gates were opened the same amount) until the water surface just upstream of the dam was el 40. Uncontrolled flows of 96,000 and 145,000 cfs were reproduced by introducing the proper discharge at the upstream end of the model and setting the tailgate to provide the correct tailwater for the discharge. For these flows all of the gates were fully opened. All stages were permitted to stabilize before the data were recorded. Water-surface elevations were recorded at model gaging stations. Velocities and current directions were determined with floats and a current meter as described in paragraph 8. Observations were made of the effect of currents on the behavior of the model tow with each plan. Multiexposure photographs and a video tape were also made of the movement of the tow to document navigation conditions with the recommended plan and its modification.

Channel development tests

19. Channel development tests were concerned with the development of a stable channel with a satisfactory alignment and adequate dimensions for navigation. Plans tested were designed to provide a satisfactory approach to the navigation canal, to prevent excessive scour and fill in the approaches to the lock and dam, and to determine the optimum length and height of the island separating the lock and dam. All plans were tested with one reproduction of the Average Hydrograph (1971-1972 Hydrograph shown in Plate 4) unless

otherwise noted. Plan B-34 was also tested with the Low-Water Hydrograph (1970-1971 Hydrograph shown in Plate 5), the High-Water/High Tailwater Hydrograph (1972-1973 Hydrograph shown in Plate 6), and the High-Water/Low Tailwater Hydrograph (1958 Hydrograph shown in Plate 7). The water-surface elevations upstream of the dam were controlled to normal pool (el 40) by manipulating the dam gates until all of the gates were fully opened. Water-surface elevations downstream of the dam were controlled with a tailgate at the downstream end of the model based on prototype data for that location. The channel bed was surveyed at the end of each hydrograph.

Navigation Tests - Plan A Series

20. This series of tests, Plans A through A-4, was conducted to determine if the proposed location for the cutoff channel and the lock and dam would be satisfactory for navigation and what modifications could be made to the design that would correct any adverse conditions that were noted.

Plan A

21. Description. The model bed was molded in pea gravel to an undistorted scale of 1:120. The existing channel was molded to conditions shown in the prototype survey of 1974 (Plate 1) except that the St. Agnes revetment was installed along the right bank upstream of the proposed cutoff according to construction drawings dated September 1974 furnished by LMN. The proposed cutoff canal, the proposed lock and dam, and proposed regulating structures were installed according to plans shown in Design Memorandum No. 10 furnished by LMN. This plan (Figure 5) includes the following principal features:

a. A 640-ft-long spillway to el +11 with eleven 50-ft tainter gates separated by 9-ft-wide piers. The stilling basin floor was at el -14.

b. A lock with usable dimensions of 84 by 785 ft with an upper sill at el 18, a floor at el -11, a lower sill at el -9, and lock walls at el 60.5.

c. An island separating the lock and dam (850 ft center of lock to center of dam). The island extended upstream to sta 14+00* with a crest to el 48 and downstream to sta 40+00 with a crest to el 34.

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* The axis of the dam is sta 0+00.

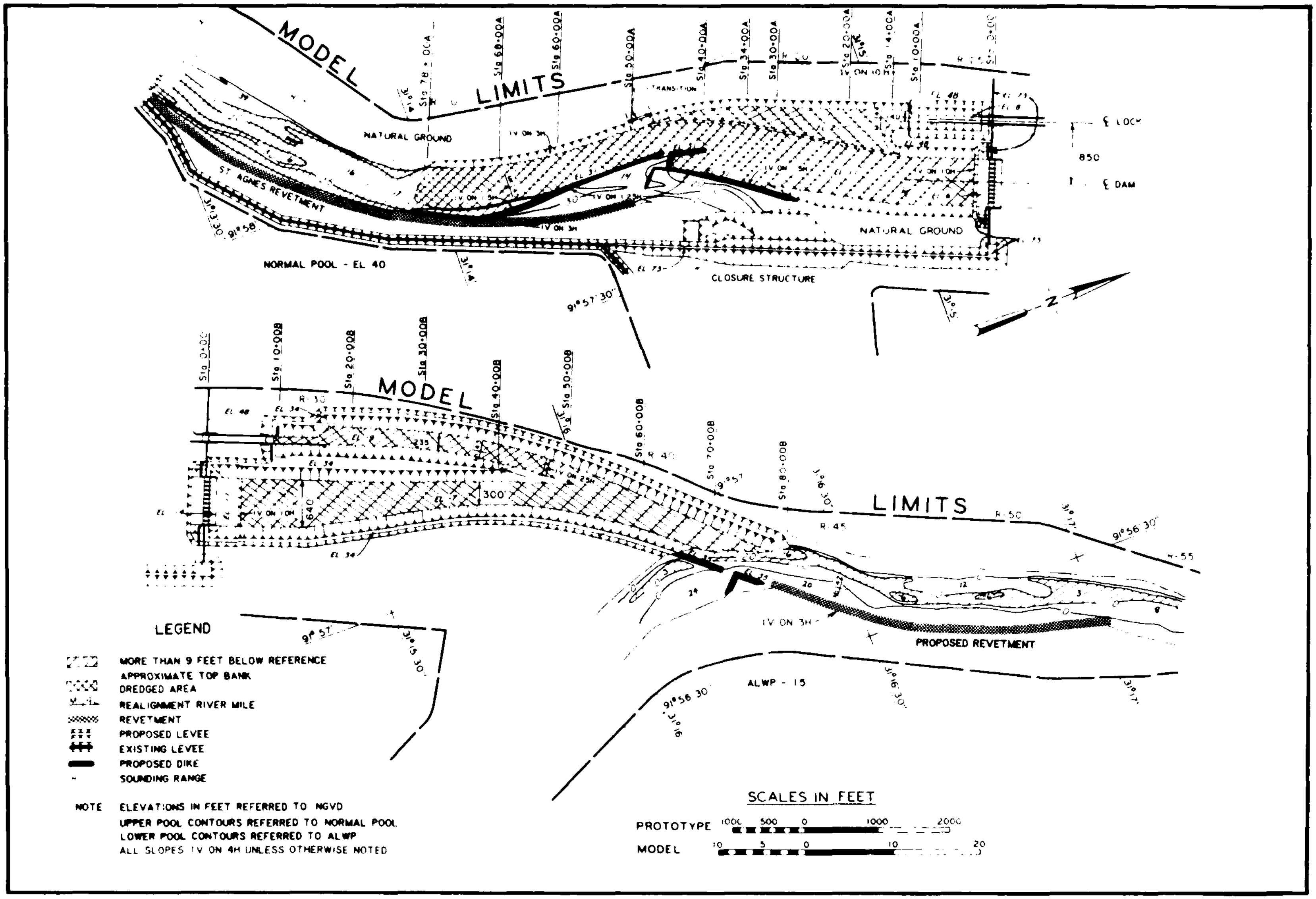


Figure 5. Plan A

d. Three sections of a wall at sta 0+00 to el 73.0 tied the lock to a levee on the left bank, the lock to the dam, and the dam to a levee on the right bank.

e. A wall at about sta 10+00 to el 60.5 extended from the lock wall to the center of the island.

f. Floating guide walls 685 ft long upstream and downstream of the lock.

g. River channels excavated upstream and downstream of the dam. The upstream channel was excavated to el 6 for 200 ft then to el 11 to sta 78+00. The downstream channel was excavated to el -11 for 300 ft downstream of the stilling basin, then to el -7 to the existing channel.

h. Navigation channels excavated upstream and downstream of the lock. The upstream channel was excavated to el 8 to sta 10+00 where it transitioned to el 21. The channel was 140 ft wide from sta 10+00 to the head of the island. Upstream of the island it extended from the left bank to the excavated river channel. The downstream channel was excavated to a width of 80 ft at el -9 to sta 15+00 then to a width of 235 ft at el -9 to the downstream end of the island where it transitioned to the dredged river channel.

i. The left bank upstream of the lock was straight and parallel to the lock wall to the end of a berm at sta 11+00 where it offset away from the channel 60 ft and continued straight and parallel to the lock wall to sta 34+00 where it began a long S-shaped curve to tie into the existing bank line at sta 78+00.

j. A closure dike at el 73 across the upstream entrance to the old channel and a system of longitudinal dikes to el 31 on the right bank in and upstream of the cutoff channel.

k. The right bank downstream of the dam was straight and perpendicular to the dam for 1,400 ft then transitioned toward the island separating the lock and dam to provide a channel bottom width of 300 ft at the downstream end of the island.

l. A system of dikes to el 35 in the downstream entrance to the old channel.

m. A realigned and revetted right bank downstream of the cutoff channel.

22. Current directions, velocities, and water-surface elevations were taken upstream and downstream of the lock and dam for flows of 145,000 cfs with a normal tailwater (el 57.5), 145,000 cfs with a minimum tailwater (el 42.9), and 96,000 cfs with a normal tailwater (el 37.9). Observations were made of the effects of currents on the operation of the model tow for a flow of 145,000 cfs at the minimum tailwater.

23. Results. Data in Plates 8-10 show the direction of currents in the existing channel upstream of the navigation canal to be generally toward the

right bank and the dam with considerable crosscurrent at the upstream end of the island separating the lock and dam. These currents would tend to pull a tow navigating downward along the right side of the channel over the longitudinal dikes on the right bank (their crests were 9 ft below normal pool) and toward the dam. The crosscurrents would tend to pull the bow end of a tow navigating downstream along the left bank into the head of the island. Velocities were high in the approach to the navigation canal but a tow with sufficient power to navigate the existing channel and which approached along the left bank line should be able to enter the navigation canal. Maximum velocities in the upstream existing channel were 7.6 fps with a flow of 145,000 cfs and a normal tailwater, 11.0 fps with a flow of 145,000 cfs and a minimum tailwater, and 9.0 fps with a flow of 96,000 cfs. Maximum velocities in the dredged upstream approach to the navigation canal for these flows were 2.9, 6.3, and 5.5 fps, respectively.

24. Downstream of the dam the currents moved across the island toward the left bank and downstream to the existing channel where they generally became parallel to the right bank line. The maximum velocities in the lock approach from flows across the island were 2.9 fps for a flow of 145,000 cfs with a minimum tailwater. Maximum velocities in the dredged navigation canal to the left of the inland were 1.1 fps with a flow of 145,000 cfs and a normal tailwater, 2.4 fps with a flow of 145,000 cfs and a minimum tailwater, and 1.9 fps with a flow of 96,000 cfs (Plates 8-10). Maximum velocities for these flows in the dredged channel downstream of the island were 4.4, 7.1, and 5.3 fps, respectively, and in the natural downstream channel were 5.9, 12.5, and 9.0 fps, respectively.

25. Observations of the model tow with a flow of 145,000 cfs at a minimum tailwater indicated that:

a. A downbound tow would occupy about 500 ft of channel width through the first bend upstream of the lock and about 400 ft of channel width through the first bend downstream of the lock. This would make passing of tows in these reaches hazardous.

b. Navigation conditions for a downbound tow in the upper pool would be difficult and hazardous because of adverse currents in the vicinity of the longitudinal dikes and at the head of the island separating the lock and dam. To avoid these adverse currents a tow would have to cross to the left side of the channel upstream at the longitudinal dikes and drive at a speed necessary to override the high channel velocities until the tow was out of the channel. Then the tow would have only about 1,000 ft to reduce speed before entering the lock.

c. Upbound tows would have no problems navigating the upper pool but forward speed would be reduced considerably by the high-velocity currents in the natural channels.

d. Downstream of the dam, a downbound tow would have no problem navigating the test reach. An upbound tow would have no problem entering the cutoff channel but as it approached the lower guard wall there would be a slight tendency for it to be pushed toward the left bank.

26. Water-surface elevations presented in Table 1 indicate that the drop in water level across the dam (gage 6 versus 7) would be 0.1 ft for the three flows tested. The total drop from the upstream end of the island to the downstream end (gage 4 versus 8) was 0.5, 0.4, and 0.8 ft for flows of 96,000 cfs, 145,000 cfs with a normal tailwater, and 145,000 cfs with a minimum tailwater, respectively.

Plans A-1 through A-3

27. These plans were progressive modifications to Plan A designed to improve navigation conditions in the upstream approach to the lock with the lock and dam separated by 850 ft. Modifications were made upstream of the lock and dam and consisted of:

a. Extending the island separating the lock and dam upstream 1,400 ft (to sta 28+00) to provide better navigation conditions at the upstream end of the island and to provide more distance for the tow to align with the lock and to reduce its speed.

b. Cutting a 50-ft gap in the island at sta 18+00 to allow some flow into the navigation canal and reduce the outdraft at the upstream end of the island.

c. Excavating the left bank to provide a wider navigation channel.

d. The longitudinal dikes to el 31 on the right bank just upstream of the cutoff channel were replaced by a 1,150-ft-long longitudinal dike to el 56 from mile 44.90 to 44.68. The channel end of this dike was 600 ft from the left bank.

28. Results of tests of Plans A-1 through A-3 are not included in this report but were considered in the development of Plan A-4. Results of these tests indicated that: (a) extending the island upstream would improve flow conditions at the head of the island and provide a longer canal for the tow to use in reducing its speed before entering the lock; (b) excavating the left bank and installing the higher longitudinal dike on the right bank would make it easier for a tow to enter the navigation canal; and (c) cutting a 50-ft gap in the island would have little effect on the outdraft and could bring sediment into the lock approach.

Plan A-4

29. Description. Plan A-4 (Figure 6) was the same as Plan A except that the island was extended upstream 1,400 ft (to sta 28+00) at el 48; the left bank was excavated from sta 11+00 to 78+00 which increased the bottom width of the navigation channel just upstream of the lock to 180 ft; and the longitudinal dikes to el 31 on the right bank were replaced by a 1,150-ft stepped-down longitudinal dike from mile 44.90 to 44.68. Seven hundred and fifty feet of this longitudinal dike was to el 56 and 300 ft was to el 28 with a 100-ft transition between the two sections, and the channel end was 600 ft from the left bank.

30. Current directions and velocities were taken upstream and water-surface elevations were taken both upstream and downstream of the lock and dam for flows of 145,000 cfs with normal and minimum tailwaters and 96,000 cfs with a normal tailwater.

31. Results. Resulting velocities and current directions shown in Plate 11 indicated that replacing the low dikes on the right bank with a higher longitudinal dike would make current directions generally parallel to the left bank from the downstream end of the dike to the head of the island but would increase the maximum velocities in the navigation channel at the dike by as much as 1.3 fps. The maximum velocity in the navigation channel at the dike was 9.0 fps with a flow of 145,000 cfs and a minimum tailwater. Excavating the left bank allowed the tow to align with the lock farther upstream. Extending the island upstream reduced the width of the head of the island and decreased the intensity of the outdraft. This would allow tows to enter the lock approach at slower speeds. The longer island would also provide a greater distance in low velocities to reduce speed before approaching the guard wall. Velocities in the approach to the canal were as much as 9.0 fps (with a flow of 145,000 cfs and a minimum tailwater) but this was 2 fps less than those in the natural channel and 3.5 fps less than those in the downstream natural channel. Tows that were able to navigate the existing channels should have no trouble navigating the high velocities of the approach to the lock approach cutoff channel. Navigation conditions for Plan A were considered generally satisfactory. Water-surface elevations were the same as for Plan A except at gages 1 and 2 which were 0.1 and 0.2 ft higher (Table 1).

Results of navigation tests - Plan A

32. Results of tests of the originally proposed plan, Plan A, indicated

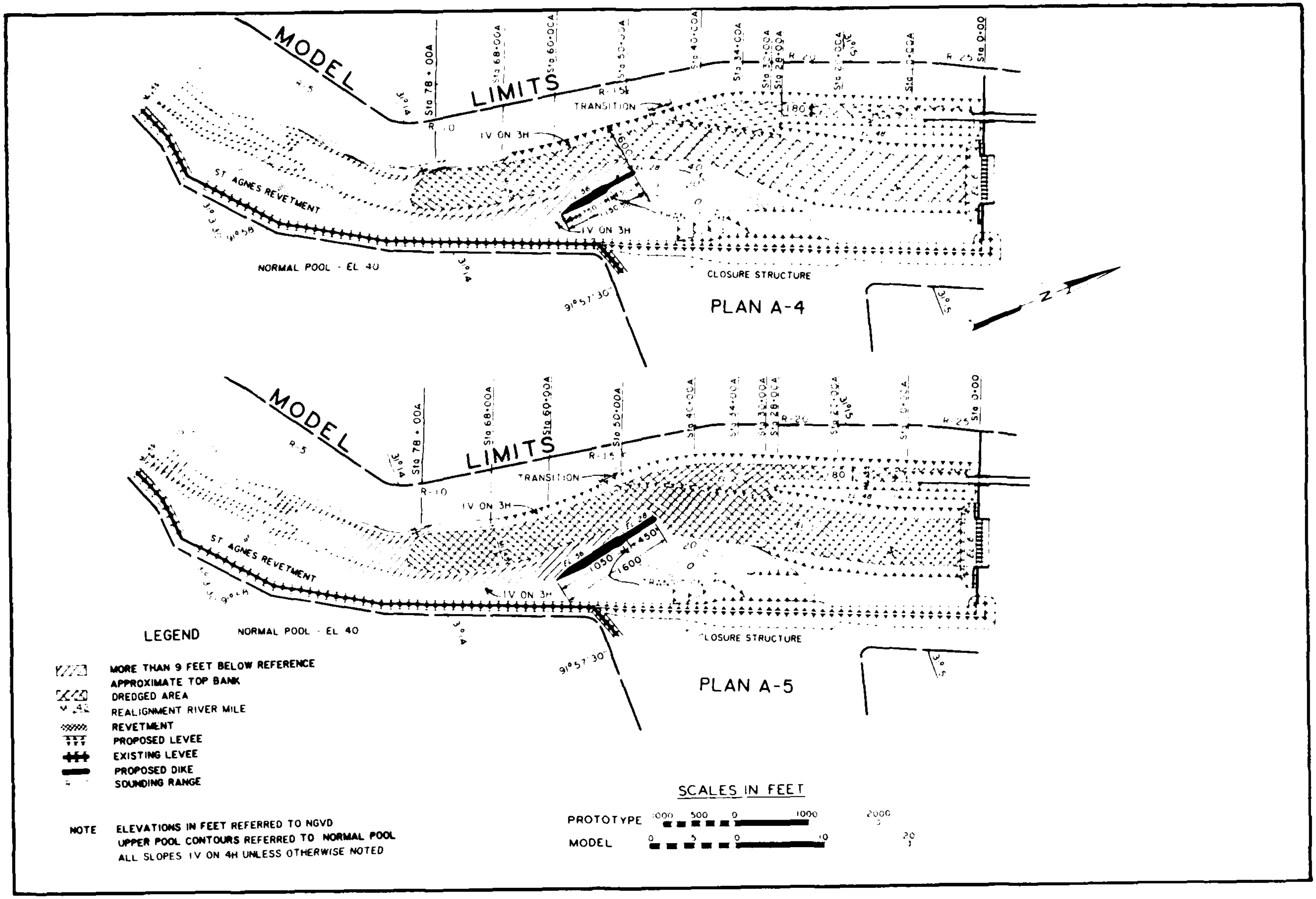


Figure 6. Plans A4 and A5

that navigation conditions in the upper pool would be difficult and hazardous because of adverse currents in the vicinity of the longitudinal dike and at the head of the island separating the lock and dam. Conditions in the reach downstream of the lock would present no problems to navigation except that as an upbound tow approached the lower guard wall, there would be a slight tendency for it to be pushed toward the left bank. Results of tests of Plan A4 indicated that modifying the bank lines, lengthening the island, modifying the location and height of the longitudinal dikes upstream of the dam, and widening the upper lock approach channel would provide a plan suitable for navigation.

33. These tests were made without consideration for changes in channel configuration that are expected to occur as a result of scour and deposition when the structure is placed in operation. Other modifications needed to maintain a channel of adequate dimensions along a desired alignment were developed in channel development tests discussed in subsequent paragraphs of this report. Modifications developed in this series of tests were used as a starting point for the channel development tests.

Channel Development Tests - Plan A Series

34. This series of tests, Plans A-5 through A-14, was conducted to determine: (a) the bed configurations that would result with the plan developed in the navigation tests and (b) what modifications were needed to minimize maintenance dredging while maintaining or improving the navigation conditions.

Plan A-5

35. Description. Plan A-5 (Figure 6) was essentially the same as Plan A-4 except that the model was molded in crushed coal to a distorted scale of 1:120 horizontally and 1:80 vertically, the left bank upstream of the lock was excavated from sta 34+00 to 55+00, and the longitudinal dike on the right bank was extended 450 ft (to mile 44.60). One thousand and fifty feet was to el 56 and 450 ft was to el 28 with the same 100-ft transition. The average annual hydrograph (Plate 4) was repeated until bed material moved throughout the model and bed configurations at the end of a hydrograph were generally the same as those at the end of the previous hydrograph.

36. Results. Model results (Plate 12) indicated that this plan would

develop a channel of adequate dimensions for navigation in the upper pool but the alignment would be hazardous for navigation. A bar would develop along the left bank from mile 45.2 to 44.6 that would prevent a tow from crossing to the left side of the channel as far upstream as desirable to avoid the outdraft at the head of the island. A scour hole to el -13 would develop off the upstream end of the island that could threaten the stability of the island. Downstream of the lock a bar would develop off the end of the island that would block the navigation channel from the end of the island to mile 42.7. Downstream of mile 42.7 the navigation channel would not be less than 200 ft wide through the test reach except for three 1/2-mile sections, each of which would have several spots less than 100 ft wide.

Plans A-6 through A-13

37. Plans A-6 through A-13 were progressive modifications of Plan A-5 designed to develop a channel of adequate width and depth for navigation along a satisfactory alignment through the reach with the lock and dam separated by 850 ft. Modifications consisted of changes in the alignment of the left bank upstream of the lock; alignment of the right bank downstream of the dam; and the number, location, length, and elevation of dikes along the right bank both upstream and downstream of the dam and off the downstream end of the island separating the lock and dam. Since these tests were in the nature of preliminary tests during which a satisfactory channel did not develop, the results are not included in this report but were considered in the development of Plan A-14.

Plan A-14

38. Description. Plan A-14 (Figure 7) was the same as Plan A-5 except for the following:

a. The left bank upstream of the lock was not excavated as far landward from sta 34+00 to 78+00. The maximum reduction in channel width between Plans A5 and A14 was 190 ft at sta 64+00.

b. The scour protection at the upstream edge of the el 21 shelf upstream of the lock was removed.

c. The longitudinal dike on the right bank was reduced in length from 1,600 to 1,150 ft, and the channel end was shifted so the end would remain 600 ft from the left bank. The channel end was raised from el 28 to 56.

d. The right bank excavation was reduced downstream of the dam from sta 6+00 to the existing channel. This provided a channel with a bottom width of 200 ft at sta 27+00 and 235 ft at sta 40+00.

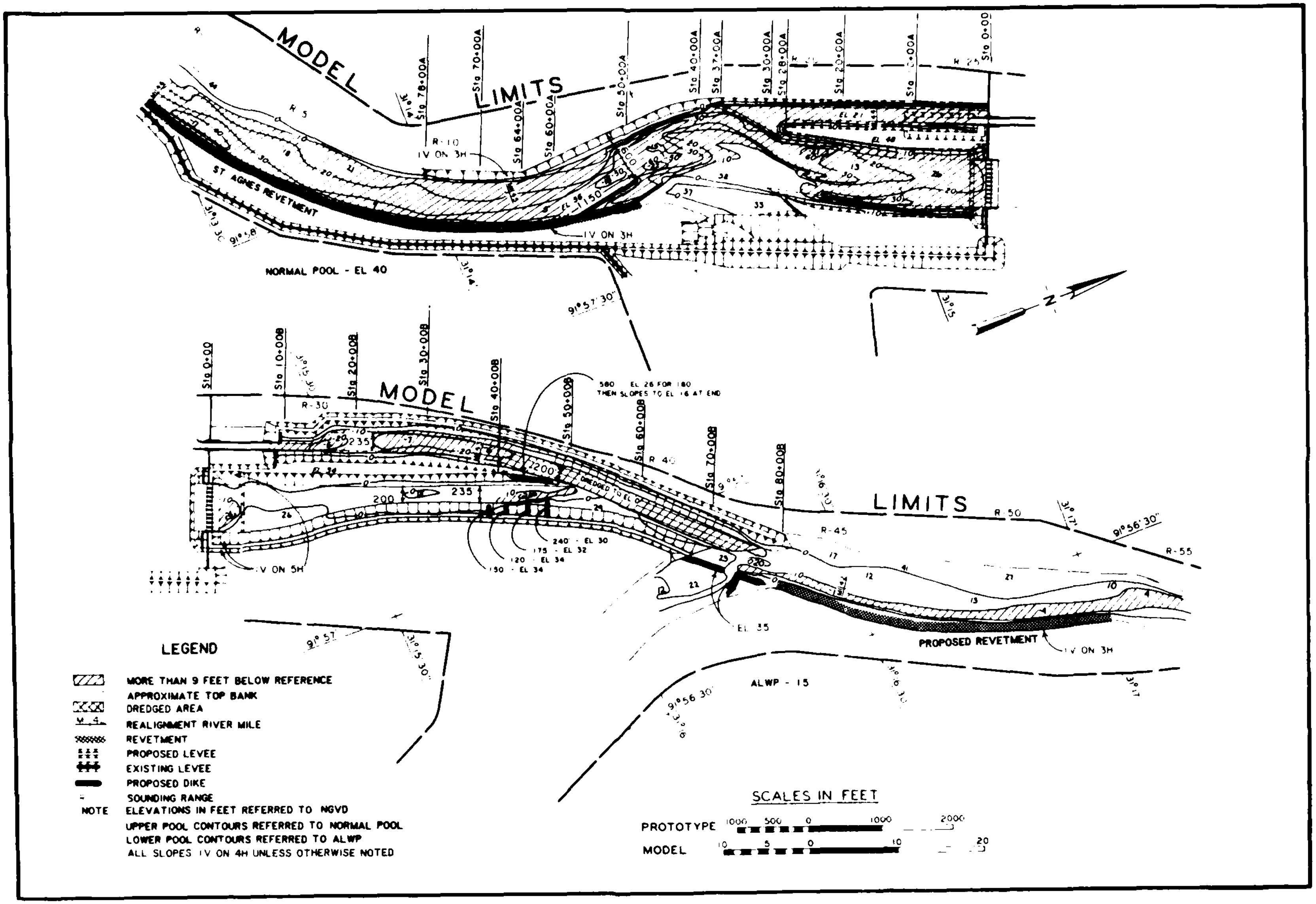


Figure 7. Plan A-14

e. A 580-ft-long trail dike was installed off the downstream end of the island. The upstream 180 ft of this dike was to el 26 and the remaining 400 ft was sloped from el 26 to 16.

f. Four spur dikes were installed on the right bank downstream of the dam as follows: a 150-ft dike to el 34 at mile 42.98, a 120-ft dike to el 34 at mile 42.92, a 175-ft dike to el 32 at mile 42.87, and a 240-ft dike to el 30 at mile 42.82.

g. The channel bed was to conditions existing at the end of Plan A-13 tests except that a 200-ft-wide navigation channel was dredged to el 0 along the downstream end of the island separating the lock and dam.

39. Results. Bed configurations resulting from tests of Plan A-14 (Plate 13) indicated that reducing the excavation along the left bank upstream of the island and shortening the longitudinal dike caused the channel to scour a little wider at the downstream end of the longitudinal dike and to scour the channel side of the head of the island. However, the bar on the left bank opposite the center of the transition dike was not changed sufficiently to eliminate the navigation hazard. The scour hole off the upstream end of the island did not develop with this plan as it did for Plan A-5. The bar off the end of the island downstream of the lock was reduced considerably. The navigation channel was not completely blocked anywhere but was only 75 to 100 ft wide at several places.

Results of channel development tests - Plan A

40. The modifications to Plan A that were tested did not develop a satisfactory navigation channel but analysis of the results of tests conducted indicated that with additional modifications a much improved channel could be developed. However, before these additional modifications could be tested, LMN notified the US Army Engineer Waterways Experiment Station (WES) that it had been decided that the lock and dam would be moved to a new location (Plan B) and that there would be only 622 ft between the center lines of the lock and dam rather than the 850 ft for Plan A as shown in Figure 8. LMN requested WES to discontinue tests of Plan A and begin tests with the lock and dam at the new location. Results of tests of Plan A were used to develop the initial conditions for Plan B.

Navigation Tests - Plan B Series

41. This series of tests of Plans B through B-11 was conducted to

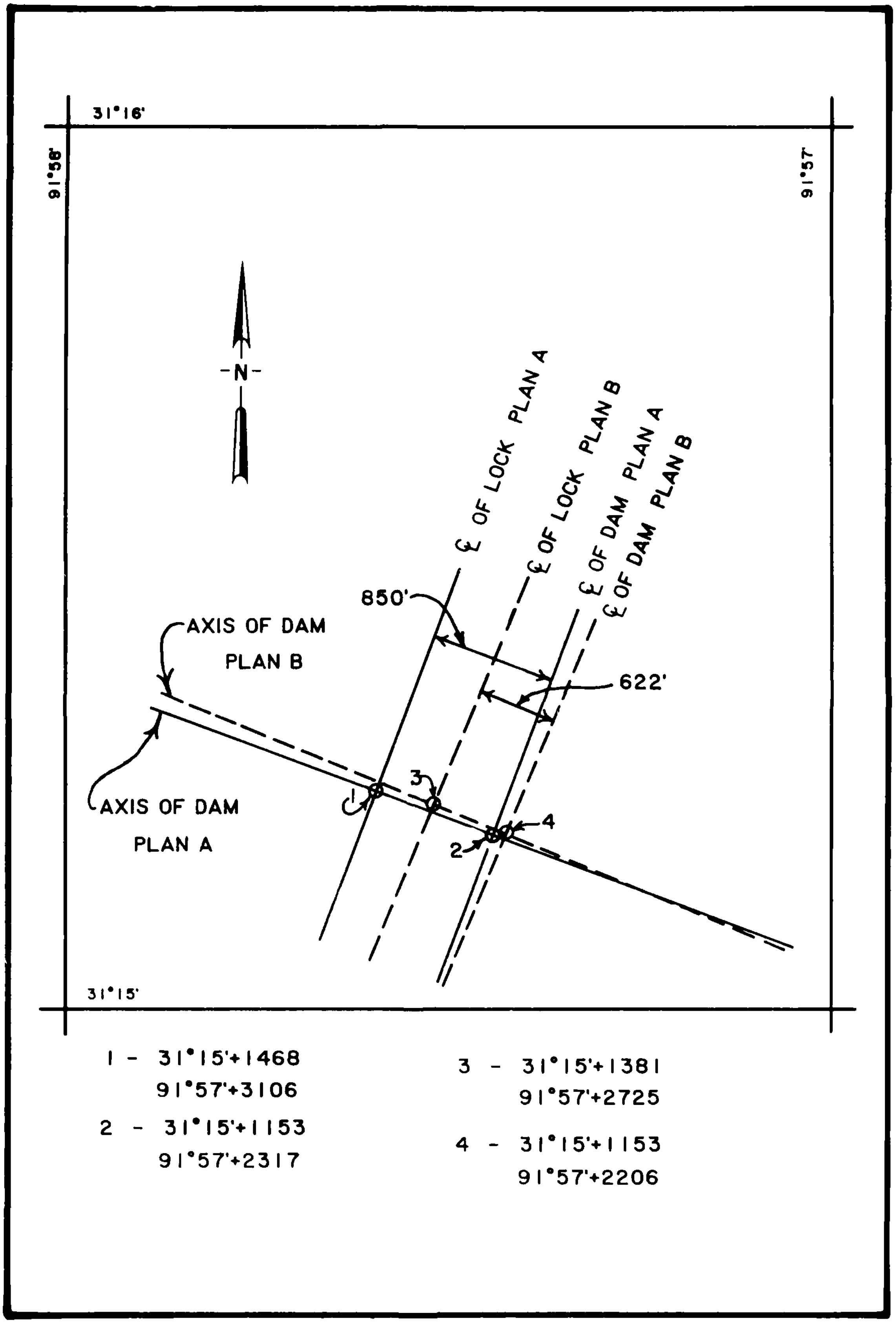


Figure 8. Lock and dam locations for Plans A and B

determine the navigation conditions that would exist if the lock and dam were located 622 ft apart to determine any modifications needed to develop satisfactory navigation conditions.

Plan B

42. Description. For Plan B (Figure 9) the model bed was changed to an undistorted scale of 1:120 to develop a navigation plan. The dam was moved southeasterly approximately 110 ft and the lock was moved southeasterly to a point where the center line of the lock was 622 ft from the center line of the dam (Figure 8). The lock and dam and cutoff channel were installed in accordance with plans and instructions furnished by LMN. The channel bed configuration existing at the end of Plan A-14 was used as a guide to mold the channels upstream and downstream of the dam. The channels were modified to intersect the cutoff channel at the new location. Except for the undistorted scale and the new location of the lock and dam, the model conditions were generally the same as the conditions existing at the end of the test of Plan A-14 (Plate 13) except that:

a. The island separating the lock and dam extended upstream 2,800 ft with a top width of 4 ft to el 48 and extended downstream 2,850 ft to el 20.

b. The left bank upstream of the lock was straight and parallel to the lock wall to the end of a berm at sta 11+00 where it was offset 60 ft toward the channel then continued straight and parallel to the lock wall to sta 28+00. The left bank tied into the existing bank line at sta 54+00.

c. A navigation channel was dredged to el 21 upstream of the lock to sta 47+00.

d. A 1,150-ft longitudinal dike to el 56 was installed on the right bank from mile 44.90 to 44.68. The channel end of this dike was 600 ft from the left bank.

e. The right bank line downstream of the dam was straight and generally perpendicular to the dam for 600 ft, then angled toward the downstream end of the island where the bottom width of the river channel was 235 ft.

f. The channel downstream of the lock was not as wide as it was for Plan A-14. The left bank was straight and parallel to the lock walls to sta 24+00 with a channel width between toes of the slopes of 180 ft; then it angled riverward so that the width of the channel was reduced 40 ft at sta 29+00.

g. The two el 35 dikes in the downstream entrance to the old channel were replaced by one 700-ft-long dike to el 35 across the upstream portion of the entrance channel.

43. Velocities, current directions, and water-surface elevations were

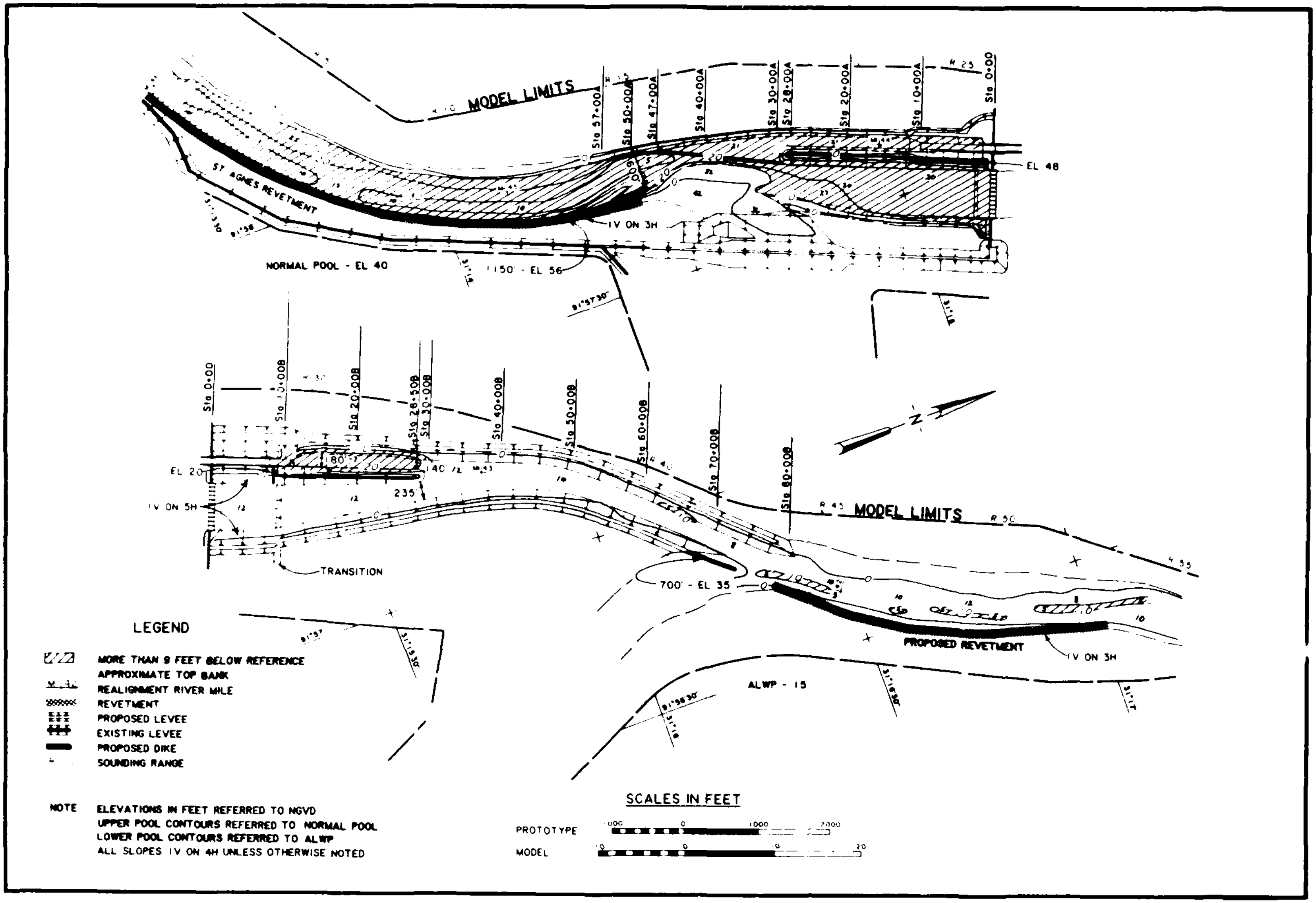


Figure 9. Plan B

taken for a flow of 145,000 cfs with normal and minimum tailwaters and a flow of 96,000 cfs with a normal tailwater. The model tow was tested with a flow of 145,000 cfs with a minimum tailwater. This flow represented the most adverse navigation conditions.

44. Results. Resulting velocities and current directions (Plates 14-16) showed the velocities upstream of the lock to be higher than those for Plan A, but the direction of currents was generally straight and parallel to the left bank except for the outdraft at the upstream end of the island. Velocities were as high as 10 fps in the existing channel, 11 fps along the longitudinal dike, and 10 fps at the entrance to the cutoff channel for a flow of 145,000 cfs with a minimum tailwater. Velocities for other flows tested were considerably less. Observations of the movement of the model tow indicated that in the upper pool, a downstream tow should keep at least 100 ft from minimum navigation depths on the right bank as it approaches the longitudinal dike to avoid being pulled into the dike, then cross to the left bank as soon as possible, and stay on the left side of the channel until it enters the navigation canal. The greatest problem observed was the speed necessary for a tow to override the outdraft at the upstream end of the island and the short distance to reduce speed before entering the lock. Upbound tows with adequate power to navigate the existing channel should have no problem navigating the upper pool. Downstream of the lock, currents moved toward the left bank downstream to the existing channel and generally paralleled the right bank from there downstream. The maximum velocities in the navigation channel were from 5.7 fps at the downstream end of the island to 9 fps in the existing channel.

45. Water-surface elevations presented in Table 2 indicate that the drop in water surface across the dam (gage 6 versus 7) would be 0.2 ft or less for the three flows tested. The total drop from the upstream to the downstream end of the island (gage 4 versus 8) was 0.8 ft, 0.3 ft, and 0.8 ft for flows of 96,000 cfs; 145,000 cfs with a normal tailwater and 145,000 cfs with a minimum tailwater, respectively. The tailwater for the 96,000-cfs flow was inadvertently held to el 38.9 rather than el 37.9; therefore the difference in the water-surface elevations listed above may be slightly lower than would have been if the correct tailwater had been maintained.

Plans B-1 through B-3

46. Description. Modifications for Plans B-1 through B-3 consisted of

shifting the left bank landward upstream of the island to provide more room for the tow to line up with the navigation canal, installing cells in line with and upstream of the island to reduce the outdraft at that point, and lowering the elevation of the island adjacent to the guide wall to allow flow into the navigation canal at a lower stage in an effort to reduce the outdraft at the head of the island.

47. Results. Moving the left bank back gave the tow more room to maneuver into the navigation canal and reduced the velocities at the entrance to the canal. Installing the cells upstream of the island and lowering the island adjacent to the guide wall had little effect on the outdraft at the head of the island and lowering the island could bring sediment into the navigation canal. Data for these plans are not presented in this report but were considered in the development of Plan B-4.

Plan B-4

48. Description. Plan B-4 (Figure 10) was the same as Plan B except for the following modifications: (a) the left bank was cut back from sta 66+00 (mile 45.00) to sta 18+10, (b) the shelf to el 21 was extended upstream to sta 52+00, (c) the longitudinal dike was shifted so that its channel end would be 600 ft from the left bank, (d) a shelf to el 27 was dredged along the left bank from mile 45.50 to 47.70, and (e) six 20-ft-diam cells were installed at 60-ft intervals in line with and upstream of the island. Velocities, current directions, and water-surface elevations were obtained for flows of 145,000 cfs with a minimum tailwater and 96,000 cfs with a normal tailwater.

49. Results. Velocities and current directions (Plate 17) indicated that widening the upstream channel would reduce the maximum velocities in the navigation channel about 1 fps in the existing channel and in the lock approach. This wider channel would also provide a wider entrance to the navigation canal. Observations of the tow's movement indicated that with this plan the tow could enter the navigation canal at a slower speed and have more maneuver room to align with the lock. The cells upstream of the island had little effect on the outdraft. The water-surface elevations presented in Table 2 indicated that with this plan, the drop in water surface across the dam (gage 6 versus 7) would be 0.1 ft or less and the drop from the upstream to the downstream end of the island (gage 4 versus 8) would be 1.2 and 1.5 for

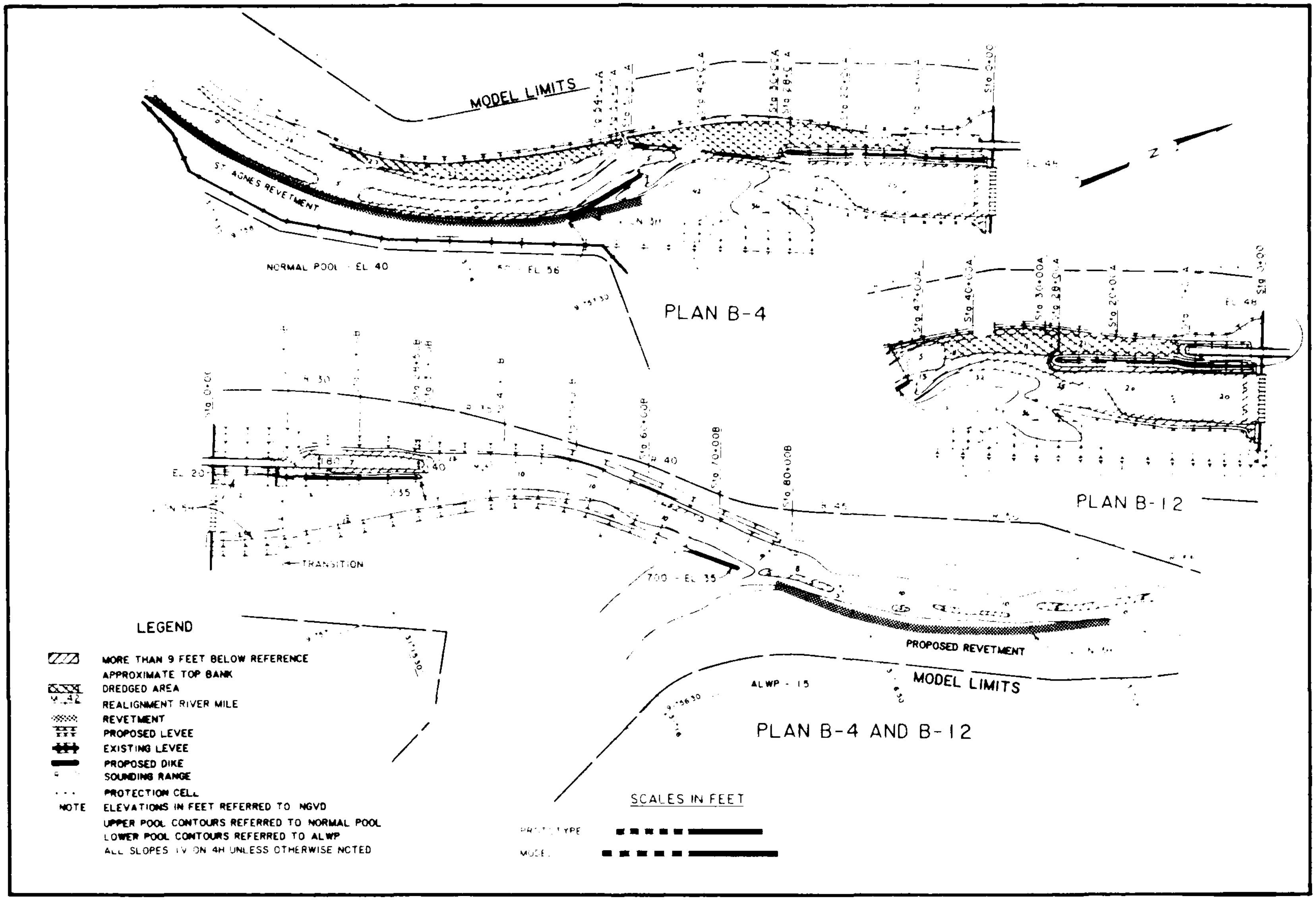


Figure 10. Plans B-4 and B-12

flows at 96,000 cfs with a normal tailwater and 145,000 cfs with a minimum tailwater, respectively.

Plans B-5 through B-11

50. Description. Plans B-5 through B-11 were designed to give a preliminary indication of the effect of various changes on flow conditions in the upstream lock approach. Plan modifications consisted of:

a. Installing four sills to el 27 from bank to bank at 500-ft intervals between miles 45.15 and 44.80.

b. Lowering the upstream end of the island from sta 28+00 to 14+00 to el 21 and from sta 14+00 to the dam to el 11.

c. Changing the upstream alignment of the shelf in the upstream lock approach.

d. Changing the alignment of the left bank upstream of the lock.

e. Moving the longitudinal dike on the right bank downstream and replacing it with three spur dikes.

f. Installing a ported guard wall.

51. Results. Results of tests of these plans indicated that the changes made would not improve the navigation conditions of Plan B-4. The four sills made the surface velocities across the channel a little more uniform but had little effect on the movement of the tow. Lowering the island to el 21 moved the outdraft downstream to the upstream end of the guard wall and made it more adverse to navigation. Neither the floating nor the ported guard walls provided good navigation conditions with the island removed.

Overall results of navigation tests - Plan B series

52. Initial navigation tests with Plan B produced higher velocities in the existing channels and in the approaches to the cutoff canal than did tests with Plan A but the alignment of the current was more suitable for navigation. The greatest problem was the tow speed necessary to override the outdraft at the upstream end of the island and the short distance to reduce speed before entering the lock. A comparison of the results of tests of modifications to Plan B showed that Plan B-4 would produce the best navigation conditions of the 12 modifications tested. Widening the channel upstream reduced velocities and provided a wider entrance approaching the lock approach canal; thus the tow was able to enter the lock approach canal at a slower speed and have more room to maneuver to line up with the lock. The cells installed upstream of the island were not effective in reducing the outdraft at that

point. Features of Plan B-4, except for the cells upstream of the island, were installed as the initial plan for Plan B channel development.

Channel Development Tests - Plan B Series

53. This series of tests, Plans B-12 through B-35, was conducted to determine the bed configurations that would result from the plan developed during the navigation tests and to determine what modifications would be needed to develop a channel of adequate dimensions and satisfactory alignment for navigation while maintaining or improving the satisfactory flow conditions developed during the navigation tests.

Plan B-12

54. Description. Plan B-12 (Figure 10) was the same as Plan B-4 except that the model bed was molded in crushed coal to a distorted scale of 1:120 horizontally and 1:80 vertically, the navigation channel upstream of the island was dredged to el 11, and the six 20-ft-diam cells upstream of the island were not installed.

55. Results. The bed configurations resulting from one repetition of the hydrograph with Plan B-12 are presented in Plate 18. A shoal to el 31 developed along the left bank from mile 45.2 to 44.9. This shoal was 9 ft below normal pool. If it continued to develop a downbound tow would not be able to cross to the left bank until it was opposite the longitudinal dike. This would leave a distance of only about 3,000 ft for a tow to cross to the left bank and align with the navigation canal. A scour hole deep enough (el -21) to threaten the stability of the island developed off the right side of the upstream end of the island. A deep channel developed along the right bank just upstream of the dam indicating that the gates on the right end of the dam were carrying more flow than those in the center and on the left. This concentrated flow on the right bank discharging into the wide channel downstream of the dam caused deposition on both sides of that portion of the island separating the lock and dam in the lower pool to el 20. This deposition was, in some places, as high as the island and limited the width of the navigation channel downstream of the island to about 120 ft at 10 ft below the low-water reference plane (LWRP).

Plan B-13

56. Description. Modifications for Plan B-13 (Figure 11) consisted of

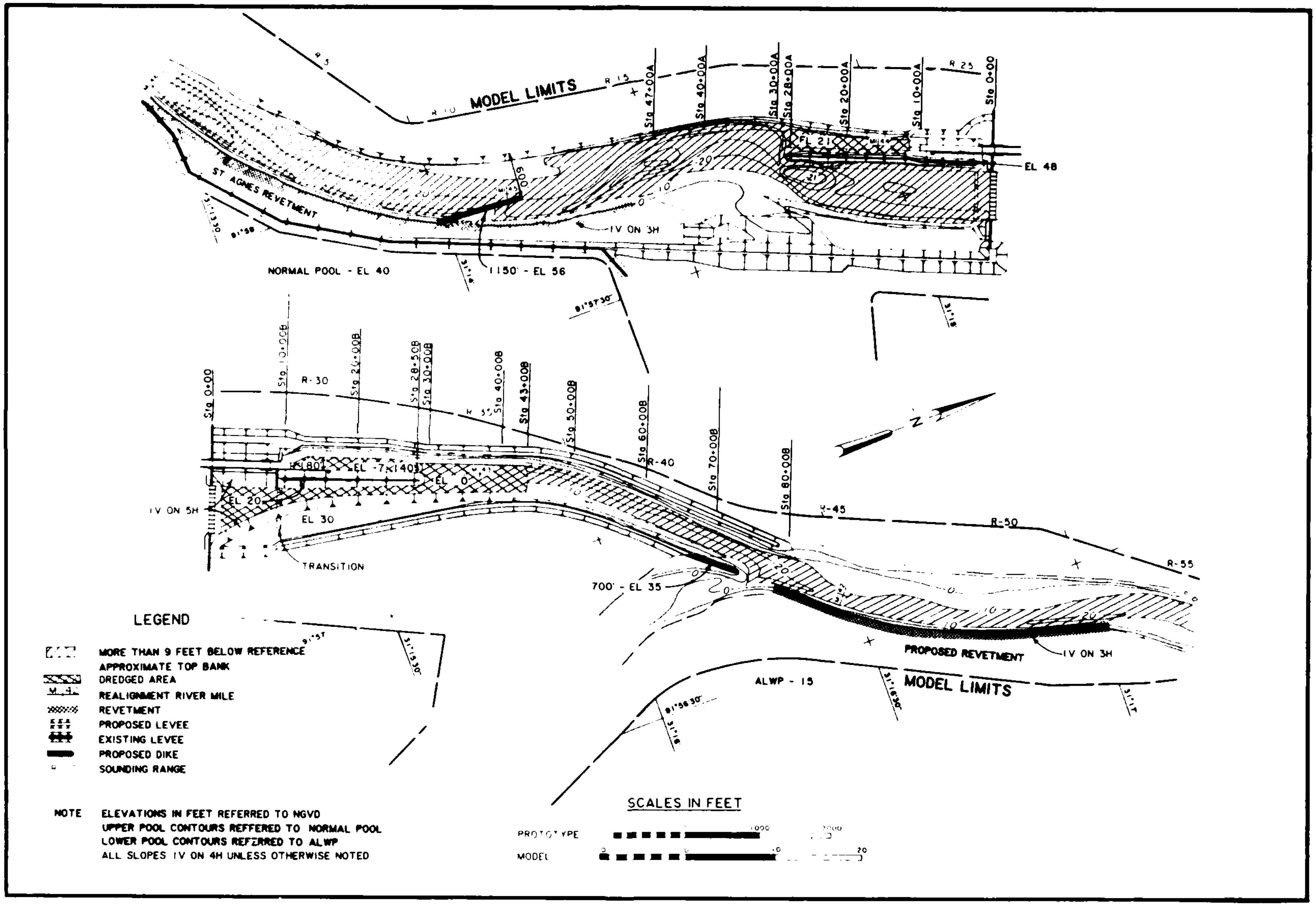


Figure 11. Plan B-13

moving the 1,150-ft longitudinal dike upstream 1,700 ft to mile 45.20 and excavating a shelf to el 30 along the right bank downstream from the dam to sta 42+00. The channel configurations were the same as those at the end of testing of Plan B-12 except that the river channel downstream of the dam was dredged to el 0.00 to sta 43+00 and the navigation canal was dredged to el -7.

57. Results. Bed configurations resulting from test of Plan B-13 as shown in Plate 19 indicated that moving the longitudinal dike upstream eliminated the deposition on the left bank between miles 45.2 and 44.9. This would allow the tow to cross to the left bank farther upstream and stay in slower velocities along the left bank as it approached the navigation canal. The tow could approach the canal at a slower speed because of the slower velocities, and it would have more room to align with the canal and to reduce its speed. The scour hole off the upstream end of the island remained a threat to the stability of the island. The shelf installed to el 30 along the right bank downstream of the dam reduced considerably the deposition along the right side of the island separating the lock and dam and the deposition in the navigation channel just downstream of the island. However, subsequent hydrographs with no changes downstream of the dam showed a tendency to develop a shoal to el 15 that would limit the navigation channel to a width of about 100 ft about 1,500 ft downstream of the island.

Plans B-14 through B-30

58. Plans B-14 through B-30 were progressive modifications to Plan B-13 and were designed to develop a navigation channel of adequate dimensions while maintaining or improving the flow conditions developed during testing of Plan B-4. Modifications consisted of:

a. Installing spur dikes on the left bank just upstream of the navigation canal entrance to reduce the scour and outdraft at the upstream end of the island.

b. Moving the 1,150-ft longitudinal dike farther upstream and installing spur dikes on the right bank between the longitudinal dike and the navigation canal to improve flow conditions so the tow could cross to the left bank farther upstream.

c. Installing spur dikes on the right bank just upstream of the dam to more evenly distribute the flow through the dam gates and reduce the deposition along the island downstream of the dam.

d. Raising the crest of the island downstream of the dam to reduce the sediment coming over the island and the deposition in the navigation canal.

e. Shortening the island downstream of the dam, realigning the right bank, installing dikes off the downstream portion of the island, and dredging a shelf to el 30 along the right bank to reduce the deposition in the navigation channel at the end of the island.

f. Changing the elevation and moving the downstream end of the dike in the downstream entrance to the old bendway to scour the navigation channel on the riverside of the dike and to maintain an access channel into the old bendway.

g. Installing dikes on the left bank in the existing channel below the dam to provide a channel of adequate dimensions for navigation.

59. None of these plans developed a satisfactory channel throughout the reach; therefore the results are not included in this report.

Plan B-31

60. Description. Plan B-31 (Figure 12) was the same as Plan B-13 except that:

a. The 1,150-ft longitudinal dike was moved 800 ft upstream to mile 45.3 with the channel end 600 ft from the left bank.

b. Three dikes were installed off the head of the island upstream of the dam. A 400-ft-long dike was installed at mile 44.24 off the upstream end of the island at an angle of 20 deg with the island with a sloping crest from el 48 at the island to el 20 upstream. Two spur dikes (one 350 ft long at mile 44.26 and one 225 ft long at mile 44.22) were installed off the channel side of the island. They had sloping crests from el 40 at the island to el 16 in the channel.

c. The island downstream of the dam was shortened from 2,850 to 2,200 ft and raised to el 24. A sheet-pile wall was installed to el 38 along the center line of the island for the upstream 1,700 ft.

d. The right bank line was realigned to conform to the shorter island. The channel was narrowed to 120 ft at el -7 at the downstream end of the island (sta 22+00) and to 150 ft at el -7 from sta 32+00 to the existing channel.

e. Three dikes were installed off the island near the downstream end. Two 200-ft-long dikes were installed at mile 43.40 and 43.33 angling downstream 35 deg with the island to el 18 and 20, respectively. One 300-ft-long trail dike to el 20 was installed at mile 43.27 off the downstream end of the island.

f. The dike in the downstream entrance to the old channel was moved toward the channel 50 ft and was raised from el 35 to 48.

g. The left bank line downstream of the lock was straightened from sta 26+00 to 44+00.

h. Seven dikes were installed on the left bank from mile 42.20 to 41.52. A 630-ft longitudinal dike was installed at mile 42.20

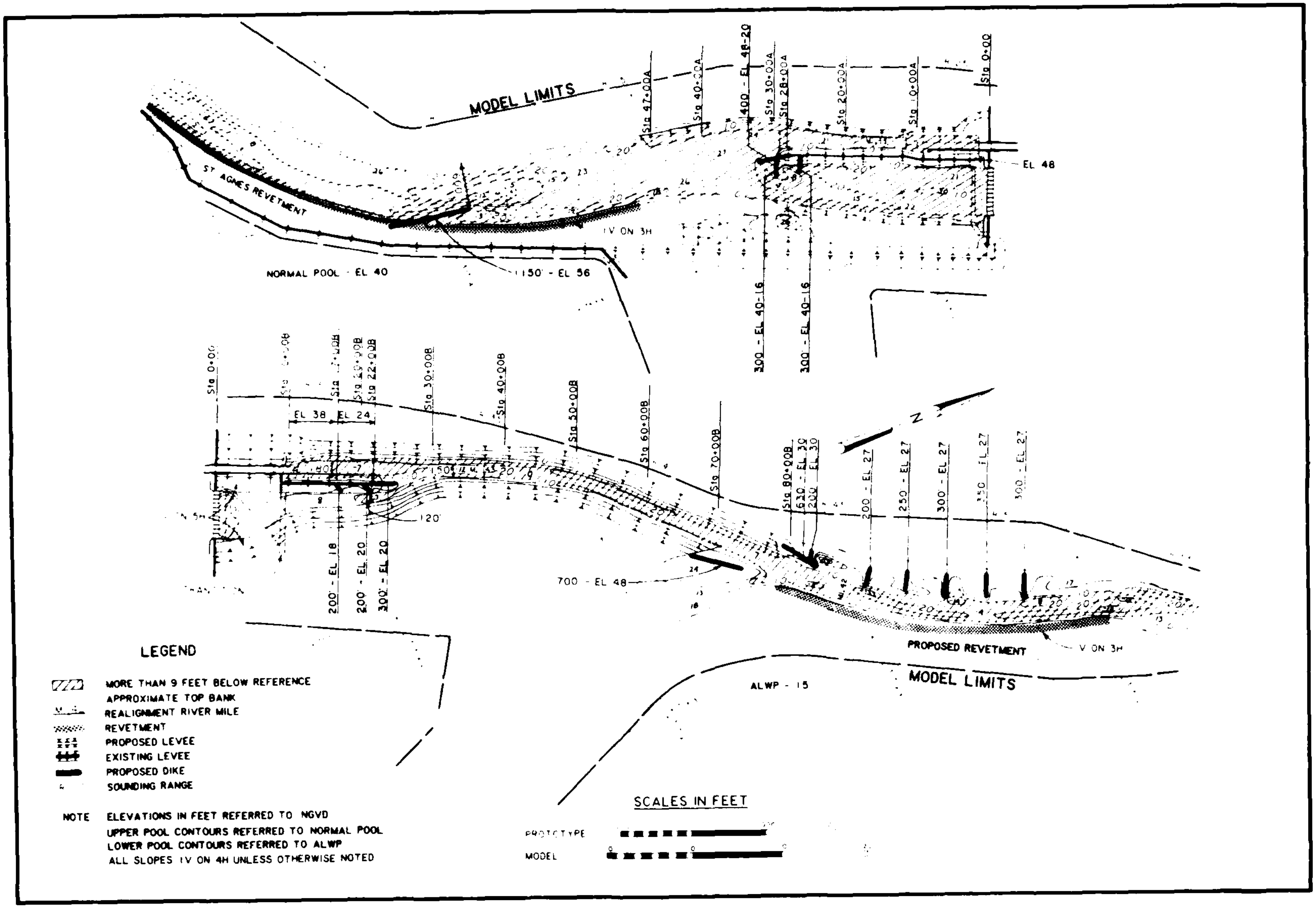


Figure 12. Plan B-31

to el 30 with a 200-ft spur dike at mile 42.11 to el 30 connected to the longitudinal dike. The other five dikes were spur dikes--200 ft long at mile 41.94, 250 ft at mile 41.84, 300 ft at mile 41.73, 350 ft at mile 41.62, and 300 ft at mile 41.52--all to el 27.

61. Results. Test results presented in Plate 20 indicated that moving the upper pool longitudinal dike upstream an additional 800 ft would produce scouring along the left side of the channel opposite the dike which would make it easier for the tows to cross to the left bank farther upstream and allow more distance for the tow to align with the navigation canal. Moving this dike and installing dikes off the upstream end of the island reduced considerably the scour at the upstream end of the island and shifted the deep scour hole away from the foot of the slope of the island. Shortening the island downstream of the dam, realigning the right bank, and installing dikes off the downstream end of the island reduced the deposition in the navigation channel downstream of the island. The downstream navigation channel was 200 ft wide except at miles 42.3 and 42.0 where deposition along the banks limited the width of the navigation channel to about 130 ft. With very little dredging (500 lin ft) in these two areas the navigation channel would have a minimum width of 200 ft. The channel developed with this plan was considered satisfactory for navigation but an analysis of the results indicated a need for further modifications to control the scour off the upstream end of the island.

Plan B-32

62. The only modifications for Plan B-32 were the removal of the dikes near the upstream end of the island and changing the slope of the upstream end of the island from 1V on 4H to 1V on 10H. This moved the scour hole away from the upstream end of the island, but the scour along the channel side of the head of the island was considered to be too deep and too close to the island. Results of this test are not presented in this report.

Plan B-33

63. Description. Plan B-33 (Figure 13) was the same as Plan B-31 except that the slope off the head of the island and 200 ft down the channel side of the island was changed from 1V on 4H to 1V on 10H and the downstream end of the island was raised from el 24 to 28.

64. Results. Removing the dikes off the upstream end of the island and changing the slope of the island from 1V on 4H to 1V on 10H reduced the size and depth of the scour hole at the head of the island and moved the hole away

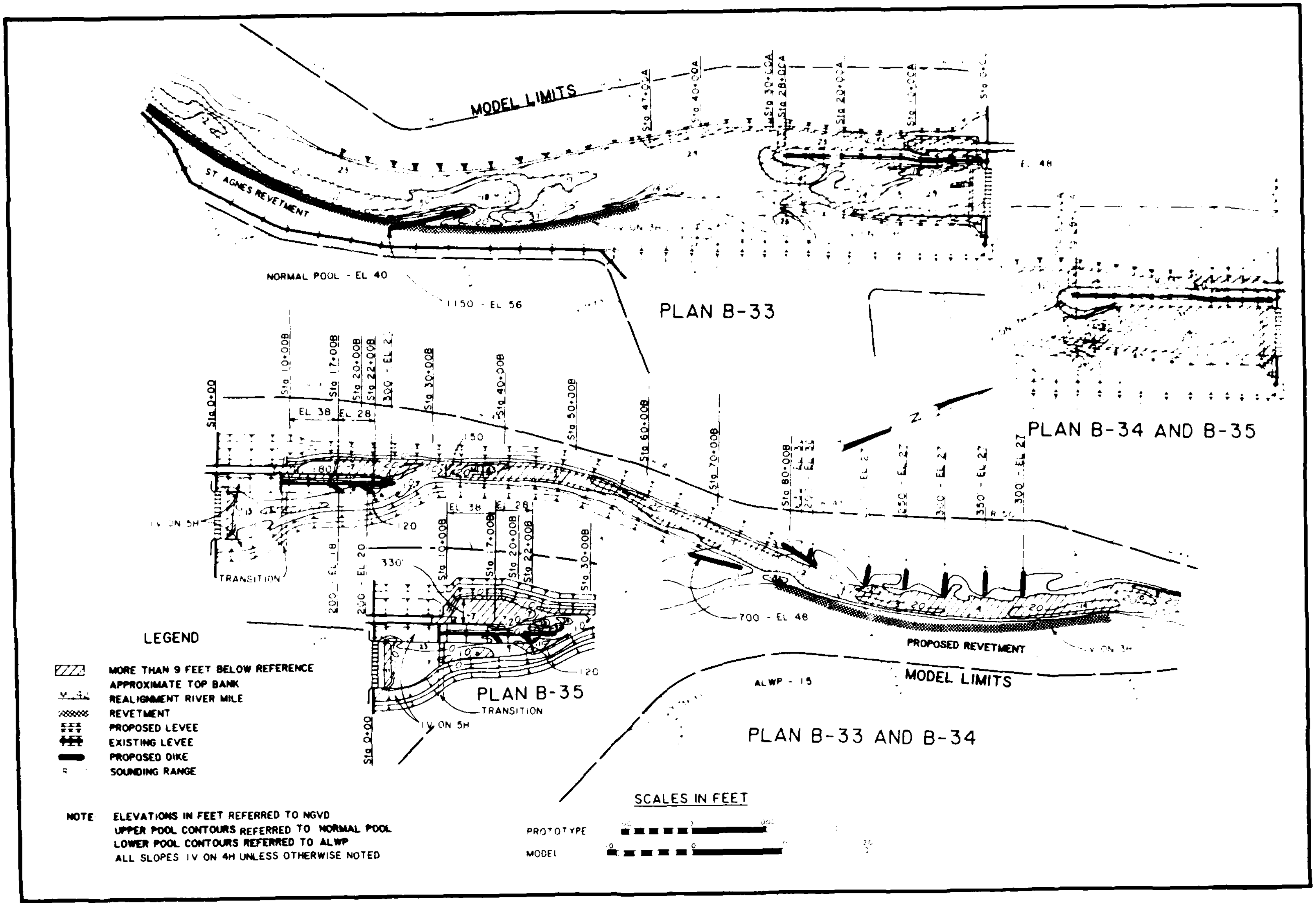


Figure 13. Plans B-33, B-34, and B-35

from the island (Plate 21). Raising the downstream end of the island from el 24 to 28 had little effect on the downstream channel. The deposition above navigation depth in the navigation channel downstream of the island was about 700 ft long and limited the width of the navigation channel to about 125 ft.

Plan B-34

65. Description. The slope of the upstream end and 200 ft down the channel side of the island was changed from 1V on 10H to 1V on 7H (Figure 13). This plan was tested with the average hydrograph (Plate 4), the low-water hydrograph (Plate 5), the high-water hydrograph with a high tailwater (Plate 6), and the high-water hydrograph with a low tailwater (Plate 7).

66. Results. Test results with the average hydrograph (Plate 22) indicated that the change in slope of the head of the island from 1V on 10H to 1V on 7H would slightly increase the size of the scour hole to the right side of the island but the hole would be far enough out in the channel that it would not undermine the island. The developed channel was considered satisfactory for navigation. The bed configurations resulting from tests with the low-water hydrograph (Plate 23) were essentially the same as those resulting from tests with the average hydrograph. The bed configuration resulting from tests with the high-water hydrograph with a high tailwater (Plate 24) were generally the same as those resulting from tests with the average and low-water hydrographs, except for a bar at mile 45.5 and a scour hole at mile 45.1. The bar that extended navigation depth was on the left bank and extended to within 300 ft of the right bank. The scour hole off the end of the upstream longitudinal dike was about 7 ft deeper than with the average hydrograph. Neither the bar nor the hole would be hazardous to navigation. The bed configurations resulting from tests with the high-water hydrograph with a low tailwater (Plate 25) were about the same as those with the high-water hydrograph with a high tailwater except that:

- a. A bar to above navigation depth developed on the right side of the channel at mile 44.5 to within 250 ft of the left bank. This bar should not hinder navigation since tows would normally be running along the left bank to align with the navigation canal.
- b. Two bars would develop to above navigation depth between the island and the left bank. These bars would have to be removed to allow tows to enter or leave the lock.
- c. Three bars would develop to above navigation depth on the right side of the channel downstream of the lock to within 100 ft of

the left bank at miles 43.3, 42.9, and 42.2. These bars would have to be removed to allow tows to pass.

Plan B-35

67. Description. The only modification for Plan B-35 (Figure 13) was the installation of a marine mooring terminal on the left bank just downstream of the lock. The primary purpose of this terminal will be to provide a place to store an extra miter gate, dam bulkhead, and lock culvert bulkhead on barges for use in the repair of damage to locks and dams in the Red River System. The location of the terminal downstream of the entire system will ensure access to any damaged lock and dam even if the pool upstream of the damaged structure is lost. LMN submitted a preliminary drawing showing the terminal to be 600 ft long with the toe of the left bank at the terminal 250 ft from the center line of the lock but preliminary tests with the model tow indicated that an upbound tow could be forced too close to the moored tow for flows of 90,000 cfs and above with a low tailwater. Therefore the left bank at the terminal was cut back an additional 40 ft. The left bank line was tied into the bank line for Plan B-34 about 1,530 ft downstream of the dam. The model was molded to the bed configurations existing in the model at the end of tests of Plan B-34 Run 1. The average hydrograph was repeated four times to determine the accumulated effect on the bed configurations for an extended period.

68. Results. Bed configurations resulting from test of Plan B-35 Run 4 (Plate 26) indicated that the proposed mooring facility would have little effect on sedimentation in the navigation channel downstream of the lock. During the extended testing, a 100-ft-long by 20-ft-wide shoal developed to el 7 in the center of the channel at mile 42.3 (opposite the entrance to the old channel) which is only 8.0 ft below the LWRP. A comparison of results of Plan B-35 Run 4 (Plate 26) with those of Plan B-34 Run 1 (Plate 25) indicates that the navigation channel throughout the test reach would remain essentially the same through four repetitions of the average annual hydrograph. Two shoal areas to el 31 did develop upstream of the lock and dam during these five runs, but since this is 9 ft below normal pool they would not interfere with navigation.

Results of channel development
tests - Plan B series

69. Model results of tests of Plan B indicated that a navigation

channel of adequate width and depth along a satisfactory alignment can be developed for Lock and Dam 1 located at the proposed site with modifications developed in Plan B-34. This plan should require little maintenance dredging of bed load in the approaches to the proposed lock, except when sustained high water occurs with extremely low tailwater. The condition tested has a frequency of occurrence of once in 111 years. Construction of the proposed mooring facility on the left bank just downstream of the lock as shown in Plan B-35 had essentially no effect on the navigation channel.

Navigation Tests - Plans B-34 and B-35

70. Navigation tests were conducted with Plans B-34 and B-35 to determine if the bed configurations developed with these plans would produce flow conditions satisfactory for navigation.

Plan B-34

71. Description. The conditions for this test were the same as those for channel development tests of Plan B-34 (Figure 13) except that the model was changed to an undistorted scale of 1:120 and the model was molded to bed configurations existing at the end of test of Plan B-34 Run 1 (Plate 22). Velocities, current directions and water-surface elevations were obtained and multiexposure photographs of the tow's movement were taken for flows of 145,000 cfs with normal and minimum tailwaters, 96,000 cfs with a normal tailwater, and 31,000 cfs with a normal tailwater. Also, video tapes were taken of the tow's movement for flows of 145,000 cfs with a minimum tailwater and 31,000 cfs with a normal tailwater. Point velocities as shown in Figure 14 were taken at depths of 10, 20, and 30 ft and at the bottom of the channel along the longitudinal dike, along the upstream end of the island separating the lock and dam, just upstream of each gate in the dam, along the right bank downstream of the dam, and along the left bank downstream of the island for a flow of 145,000 cfs with a minimum tailwater.

72. Results. Velocities and current directions are shown in Plates 27-30. The effects of currents on the model tow are shown in Photographs 1-14. These results indicated that this plan would develop satisfactory navigation conditions throughout the test reach. Current directions upstream of the lock with this plan were generally straight and parallel to the left bank from at least 1 mile just upstream of the lock approach canal entrance. The

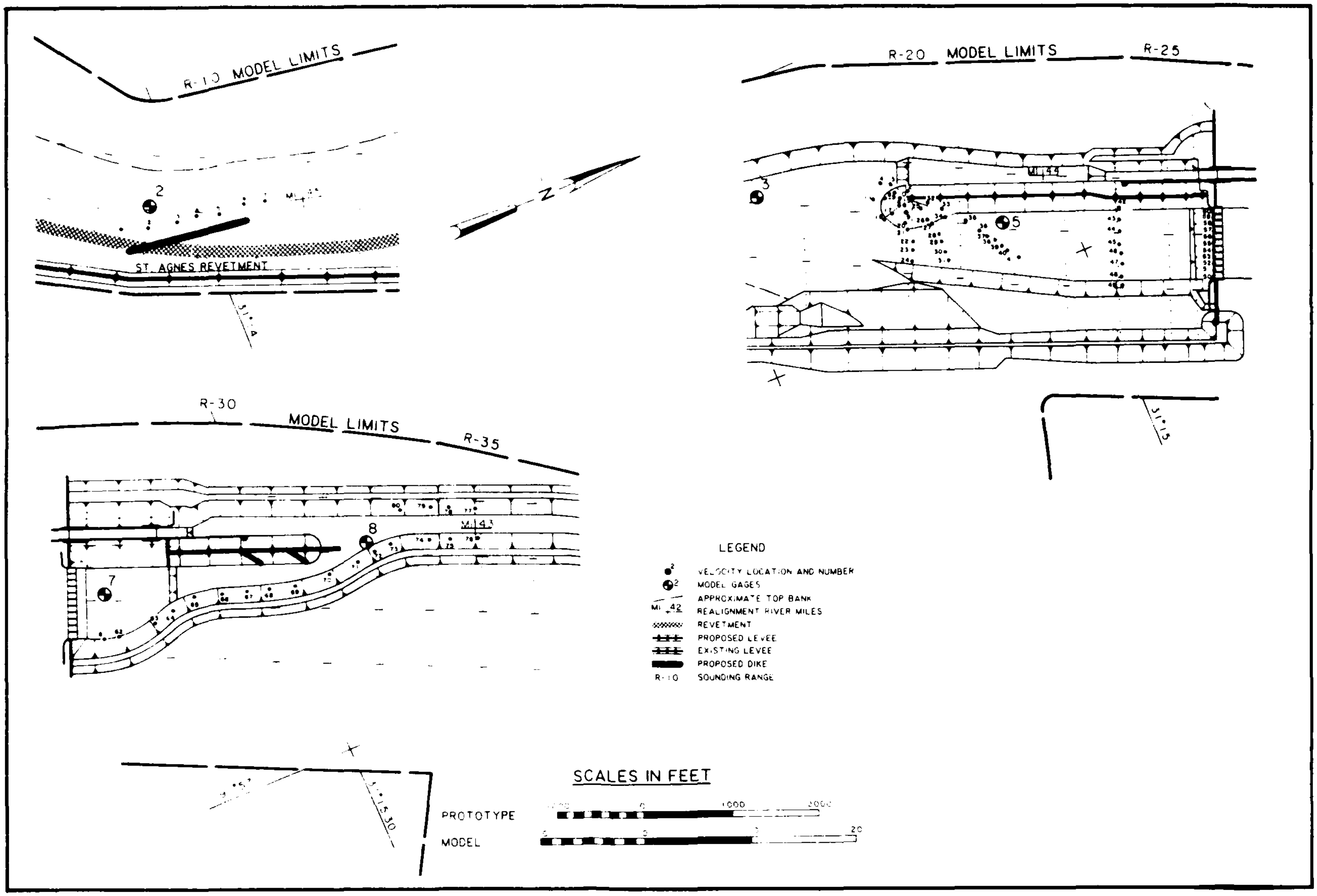


Figure 14. Location of point velocities

maximum velocities in the canal and for at least 1 mile upstream and downstream of the canal (Plates 27-30) were lower than those in the existing channels above and below this reach (Plates 8-10). The maximum velocities in the upstream approach to the canal, which would affect a tow crossing to the left bank upstream of the longitudinal dike, were 9.4 fps at the dike and 8.8 fps at the canal entrance and occurred with a flow of 145,000 cfs with a minimum tailwater (Plate 30). Although high, the velocities were significantly lower than the 10.5 fps measured in the existing channel upstream of the proposed improvements (Plates 10 and 30). Maximum velocities that would affect a tow in the upstream approach to the canal with flows of 145,000 cfs with a normal tailwater, 96,000 cfs, and 31,000 cfs were 7.1 fps, 8.0 fps, and 7.6 fps opposite the longitudinal dike and 6.2 fps, 8.1 fps, and 2.6 fps at the canal entrance, respectively.

73. Current directions in the downstream approach to the lock were generally straight and parallel to the left bank from the end of the island to the existing channel and straight and parallel to the right bank for at least 1 mile in the existing channel downstream. The maximum velocities that would affect a tow in the downstream canal were 10.9 fps at mile 42.7 and 10.4 fps in the entrance to the canal (mile 42.1). These velocities, which occurred with flow at 145,000 cfs with a minimum tailwater (Plate 28), compare with 12.5 fps in the existing channel downstream of proposed improvements (Plate 10). The maximum velocities downstream of the lock for flows of 145,000 cfs with a normal tailwater, 96,000 cfs, and 31,000 cfs were 6.6 fps, 8.9 fps, and 6.2 fps, respectively.

74. In the upper pool there were two trouble spots for navigation--the high currents at the downstream end of the longitudinal dike that could pull the tows toward the dam and the outdraft at the head of the island that could pull the tow into the island. Downbound tows should have no difficulty if they crossed to the left bank upstream of the longitudinal dike (Photo 1), stayed along the left bank, and maintained speed until they were out of the main channels (Photos 2-5). Downbound tows occupied about two-thirds of the channel in the bend just upstream of the longitudinal dike for the 145,000-cfs flow with normal tailwater (Photo 1). This would limit this reach to one-way traffic during high flows. The upbound tow would have no difficulty provided it navigated along the left bank, entered the existing channel at full speed, stayed along the left bank until it passed the longitudinal dike, and crossed

to the right bank (Photos 6-10). In the lower pool neither downbound nor upbound tows would have any trouble except near the downstream end of the guard wall where flows of 96,000 cfs and 145,000 cfs overtopped the island and had a tendency to push the tow to the left bank (Photos 11 and 12). To overcome this the downbound tow would have to angle its nose toward the island as it left the end of the guard wall and the upbound tow would have to angle its nose toward the island as it approached the guard wall. The 31,000-cfs flow did not overtop the island so this tendency to push the tow to the left bank would be shifted to the downstream end of the island and the tows would have to angle toward the island farther downstream (Photos 13 and 14). Downbound tows would occupy most of the channel width through the bend downstream of the island (Photos 11 and 13), limiting this reach to one-way traffic during high flows.

75. The resulting water-surface elevations (Table 3) indicated that with this plan the maximum drop in water surface across the dam (gage 6 versus 7) would be only 0.2 and 0.3 ft for flows of 96,000 and 145,000 cfs. The drop in water surface from the upstream end of the island to the downstream end (gage 4 versus 8) was 2.1, 0.7, and 2.2 ft for flows of 96,000, 145,000 with a normal tailwater, and 145,000 cfs with a minimum tailwater, respectively. This plan increased water-surface elevations upstream of the dam over those of Plan A (Table 3 versus Table 1) by as much as 1.7 ft for a flow of 96,000 cfs where all flow was within banks but only as much as 0.5 ft for flows of 145,000 cfs for this plan were slightly overbank. The downstream water-surface elevations for this plan were as much as 1.3 ft (96,000-cfs flow) and 1.8 ft (145,000-cfs flow) lower than those for Plan A.

76. Point velocities taken at critical locations to evaluate scour protection needed (Figure 14) are listed in Table 4. The velocities in the dam bays indicated that generally the bay farther from the lock would carry more flow. Gates 1-3 averaged about 7.6 percent of the total flow; gates 4-8 averaged about 9.2 percent, and gates 9-11 averaged about 10.4 percent. Table 5 lists the approximate percentage of flow for each gate as determined from the velocities at a depth of 10 ft.

Plan B-35

77. Description. The conditions for this plan were the same as those for the channel development test of Plan B-35 (Figure 13) except that the model was changed to an undistorted scale of 1:120 and the model was molded to

bed configurations existing at the end of test of Plan B-35 Run 4 (Plate 25). Water-surface elevations, velocities, and current directions were obtained and multiexposure photographs were taken of the tows movement in the lower pool only for flows of 145,000 cfs with normal tailwater, 145,000 cfs with minimum tailwater, 96,000 cfs, and 31,000 cfs.

78. Results. Resulting velocities and current directions (Plates 31 and 32) indicated that excavating the mooring area just downstream of the lock would increase the velocities in the eddies at the lock from 1.2 to 2.8 fps for a flow of 145,000 cfs with a normal tailwater, from less than 0.5 to 2.5 fps for a flow of 145,000 cfs with a minimum tailwater, and from less than 0.5 to 1.6 fps for a flow of 96,000 cfs. Eddy velocities at the end of the island increased from less than 0.5 to 1.6 fps for a flow of 31,000 cfs. However, observations of the movement of the tow and from a comparison of multiexposure photographs for Plan B-34 (Photographs 11-14) with those for Plan B-35 (Photographs 15-18) indicated this increase in eddy velocities had little effect on the tow. Photographs 15-18 showed that the proposed mooring area would be large enough for two barges end to end to be tied up without interfering with tows entering or leaving the lock.

PART IV: DISCUSSION OF RESULTS AND CONCLUSIONS

Limitation of Model Results

79. The limitations of the model based on model verification, the hydrograph, and tailwater elevations stipulated based on proposed channel modifications downstream of the test area should be considered in the analysis of the results of this investigation. Since only one recent prototype survey was available to use in the adjustment of the model, the initial conditions molded in the model for adjustment tests may have been different from the prototype conditions at that time. If the model had been molded to the channel configuration at that time, the model results could have been somewhat different. Channel developments during the movable-bed model model tests were based on an average hydrograph in the Red River with corresponding flows in the Black River and Old River Diversion Canal. The channel developed was then tested with a high-flow hydrograph and a low-flow hydrograph. Although the channels developed are considered representative, they might not reflect exactly the channel that would result from this hydrograph in the Red River with different flows in the Black River and Old River Diversion Canal or a different hydrograph in the Red River.

80. In evaluating the results of tests of various plans, consideration should be given to the fact that some tests were continued through several repetitions of the average hydrograph to give time for the channel to fully develop while others had only one repetition of the hydrograph. Also, the model did not reproduce sediment in suspension or the erosion of riverbanks (banks were fixed in the model). The bed-load sediment transport was based on what was needed to produce reasonable results during the model adjustment. No consideration was given to sediment transport changes that may occur after upstream dams are constructed. It is believed that changes which do occur will have more effect on development time rather than final channel development since most bed movement occurs during periods of high water when the dam gates will be fully open and offer little restriction to flow.

81. Analysis of the results of the navigation tests is based primarily on the study of velocities and current directions and the effects the currents had on the model tow.

82. In spite of the limitations mentioned, the adjustment of the model

is considered sufficient to indicate trends in channel development that can be expected under conditions imposed for each plan and the relative effectiveness of such plans. The bed-configurations developed and the velocities and current directions measured in this study are believed to provide sufficient information for design of the basic features of the lock and dam, the cutoff channel, and the channel development structures in the test reach.

Summary of Results and Conclusions

83. The following general results and conclusions were indicated by this model investigation:

a. With the original plan, Plan A, navigation conditions in the upper pool would be difficult and hazardous because of adverse currents in the vicinity of the longitudinal dikes and at the head of the island separating the lock and dam. Navigation in the reach downstream of the lock would present no problems except that as an upbound tow approached the lower guard wall there would be a slight tendency for it to be pushed toward the left bank.

b. Channel development tests of modifications to the original plan were initiated but not completed because of a decision to relocate the lock and dam to another site.

c. The relocated lock and dam, Plan B, produced high velocities in the navigation channel both upstream and downstream of the lock, but the direction of the currents was generally straight and parallel to the bank except for an outdraft at the end of the upstream approach canal. This outdraft would present problems for downbound tows approaching the entrance to the canal.

d. Movable-bed model tests indicated that shoals would develop on the left bank in the upper pool which would force tows to cross to the left bank farther downstream and under more hazardous conditions. A scour hole would develop that could threaten the stability of the head of the island. Deposition in the downstream channel would limit the width of the navigation channel to about 120 ft.

e. A navigation channel of adequate width and depth could be developed with the lock and dam at the new site with the modifications developed in Plan B-34.

f. Little maintenance dredging of bed load would be required with Plan B-34 except when the infrequent combination of sustained high discharge and low tailwater occurs. This condition has a frequency of occurrence of once in 111 years.

g. The navigation channel should remain satisfactory with the construction of the proposed mooring facility downstream of the lock as with Plan B-35.

h. Downbound tows would need to cross to the left side of the channel just upstream of the longitudinal dike, stay along the left side of the channel, and maintain speed until they enter the lock approach canal.

i. Downbound tows would occupy about two-thirds of the upstream existing channel in the bend just upstream of the longitudinal dike and in the downstream existing channel below the lock. This would limit these reaches to one-way traffic.

j. Distribution of flow through the gated spillway would range from 7.6 percent of the total flow through the gate nearest the lock to 10.4 percent through the gate farthest from the lock at 145,000-cfs discharge and minimum tailwater.

k. The difference in water-surface elevation across the dam would be from 0.2 to 0.3 ft for the open-river flows tested.

Table 1

Water-Surface Elevations

Plans A and A-4

	Plan A Flow			Plan A-4 Flow		
Gage	96,000 cfs	With Normal TW 145,000 cfs	With Minimum TW 145,000 cfs	96,000 cfs	With Normal TW 145,000 cfs	With Minimum TW 145,000 cfs
1	43.0	59.5	49.8	43.2	59.6	49.9
2	41.9	59.0	48.2	42.1	59.1	48.3
3	41.4	58.8	47.8	41.4	58.8	47.8
4	41.2	58.8	47.5	41.2	58.8	47.5
5	41.0	58.7	47.2	41.0	58.7	47.2
6	40.8	58.5	46.8	40.8	58.5	46.8
Dam						
7	40.7	58.4	46.7	40.7	58.4	46.7
8	40.7	58.4	46.7	40.7	58.4	46.7
9	40.5	58.3	46.5	40.5	58.3	46.5
10	40.3	58.2	46.0	40.3	58.2	46.0
11	38.7	57.8	44.0	38.7	57.8	44.0
12	37.9*	57.5*	42.9*	37.9*	57.5*	42.9*

* Controlled elevation.

Table 2

Water-Surface Elevations

Plans B and B-4

	Plan B Flow			Plan B-4 Flow	
Gage	96,000 cfs	With Normal TW 145,000 cfs	With Minimum TW 145,000 cfs	96,000 cfs	With Minimum TW 145,000 cfs
1	44.4	59.4	49.6	43.9	49.4
2	43.7	58.9	48.7	43.4	48.9
3	41.5	58.3	46.7	41.9	47.2
4	41.3	58.3	46.5	41.6	47.0
5	41.0	58.2	46.1	40.7	45.7
6	41.0	58.2	45.9	40.7	45.7
Dam					
7	40.8	58.1	45.8	40.6	45.6
8	40.5	58.0	45.7	40.4	45.[illegible]
9	40.2	57.9	45.1	40.1	44.9
10	40.0	57.7	44.8	39.9	44.5
11	39.6	57.6	44.3	39.6	44.0
12	38.9*	57.5*	42.9*	38.9*	42.9*

* Controlled elevation.

Table 3

Water-Surface Elevations

Recommended Plan

	Plan B-34			
			With Normal TW	With Minimum TW
Gage	31,000 cfs	96,000 cfs	145,000 cfs	145,000 cfs
1	40.5	43.7	59.3	49.4
2	40.4	43.6	59.1	48.8
3	40.3	42.5	58.9	47.9
4	40.2	42.0	58.8	47.8
5	40.1	41.3	58.7	47.2
6	40.0*	40.9	58.5	46.7
Dam				
7	25.0	40.7	58.2	46.5
8	23.0	39.9	58.1	45.6
9	22.5	39.3	58.0	44.9
10	22.0	39.0	57.9	44.2
11	21.4	38.5	57.7	43.7
12	21.0*	37.9*	57.5*	42.9*

* Controlled elevation.

Table 4

Point Velocities

Plan B-34 - Flow at 145,000 cfs with a Minimum Tailwater

Location No.*	Average Velocity in Feet per Second at Depths of			
	10 ft	20 ft	30 ft	Bottom
1	9.2	8.4	7.5	4.9
2	8.9	8.1	6.7	5.8
3	9.1	9.0	8.5	6.5
4	9.1	9.0	8.5	7.5
5	9.0	8.9	8.6	8.9
6	9.0	8.4	9.1	4.9
7	8.8	8.7	8.7	3.4
8	6.4	4.9		3.5
9	5.4			4.5
10	6.0	4.9		3.4
11	6.9	5.6		3.8
12	4.4	4.1		3.5
13	5.3	4.4		3.1
14	6.2	4.9		3.3
15	8.1			7.2
16	7.7	6.6		5.2
17	7.4	6.7		3.3
18	6.2			3.3
19	9.6	9.2		5.4
20	9.3	8.7	8.3	4.1
21	8.7	7.5		2.5
22	7.7			3.8
23	7.1	5.4		4.8
24	1.2			1.1
25	4.4	2.3		
26	8.6	7.7	5.5	2.6
27	9.5	9.4	9.2	3.3
28	9.0	8.7	7.9	4.8
29	8.7	7.8	6.7	1.6
30	7.2	5.3	4.8	3.1
31				0.7
32	0.9			0.7
33	2.0	2.3		2.9
34	2.4	2.3	2.2	2.2
35	3.4	2.2	1.7	2.1
36	5.1	5.3	5.9	5.8
37	7.4	7.6	7.2	5.8
38	8.0	7.2	7.1	4.1
39	7.6	6.7	6.0	4.8
40	7.8	6.9		6.9

(Continued)

* Figure 14 shows the location where velocities were taken.

Table 4 (Concluded)

Location No.	Average Velocity in Feet per Second at Depths of 10 ft	20 ft	30 ft	Bottom
41	7.8	7.0		3.9
42	4.1	5.3	6.3	5.4
43	8.2	7.5		4.0
44	9.1			6.3
45	8.4			4.8
46	7.8			6.0
47	9.1	7.5		5.0
48	7.6	7.0		5.0
49	6.3			3.7
50	8.0	8.0		5.5
51	8.3	7.8		5.6
52	7.9	7.4		4.9
53	7.0	6.6		4.6
54	6.6	6.2		4.9
55	7.1	6.7		4.8
56	7.5	7.0		5.6
57	7.4	6.6		5.5
58	6.7	7.0		5.5
59	5.8	6.1		4.7
60	5.3	5.4		4.3
61	2.0	2.5	3.9	3.2
62	3.6	5.0		4.5
63	4.1	3.6		2.5
64	6.2	6.4		3.2
65	6.8	7.2	6.3	3.7
66	10.3	9.7	5.6	1.8
67	7.3	6.2		1.7
68	5.8	4.7	3.3	3.2
69	3.2	3.7	3.8	3.0
70	4.5	4.6	3.9	2.2
71	7.0	6.9	6.2	2.6
72	8.9	9.2	6.9	5.0
73	8.6	8.7		6.2
74	10.4	10.2	6.7	4.3
75	7.2	6.7		4.6
76	5.0	4.9		2.6
77	9.0	8.8		5.3
78	9.5	9.2	8.9	6.0
79	8.2	8.2	7.8	4.6
80	7.0	6.7	6.8	4.5

Table 5

Distribution of Flow Through Gated Spillway

Gate* No.	Percent** of Flow
1	6.8
2	7.5
3	8.6
4	9.5
5	9.7
6	9.2
7	8.5
8	9.0
9	10.2
10	10.7
11	10.3

* Gates numbered from lock.

** Percent based on velocities measured at a depth of 10 ft for a flow of 145,000 cfs with a minimum tailwater for Plan B-34. These velocities are presented in Table 4.

Photo 1. Plan B-34, downbound tow crossing to the left bank upstream of the longitudinal dike; discharge 145,000 cfs, tailwater el 57.5 (normal)

Photo 2. Plan B-34, downbound tow approaching the canal and lock from upstream; discharge 145,000 cfs, tailwater el 57.5 (normal)

Photo 3. Plan B-34, downbound tow approaching the canal and lock from upstream; discharge 145,000 cfs, tailwater el 42.9 (minimum)

Photo 4. Plan B-34, downbound tow approaching the canal and lock from upstream; discharge 96,000 cfs, tailwater el 47.? (normal)

Photo 5. Plan B-34, downbound tow approaching the canal and lock from upstream; discharge 31,000 cfs, tailwater el 21.0 (normal)

Photo 6. Plan B-34, upbound tow leaving the lock and canal; discharge 145,000 cfs, tailwater el 57.5 (normal)

Photo 7. Plan B-34, upbound tow crossing to the right bank upstream of the longitudinal dike in the upper pool; discharge 145,000 cfs, tailwater el 57.5 (normal)

Photo 8. Plan B-34, upbound tow leaving the lock and canal; discharge 145,000 cfs, tailwater el 42.9 (minimum)

Photo 9. Plan B-34, upbound tow leaving the lock and canal; discharge 96,000 cfs, tailwater el 37.9 (normal)

Photo [illegible]. Plan B-34, upbound tow leaving the lock and canal; discharge [illegible]1,000 cfs, tailwater el 21.0 (normal)

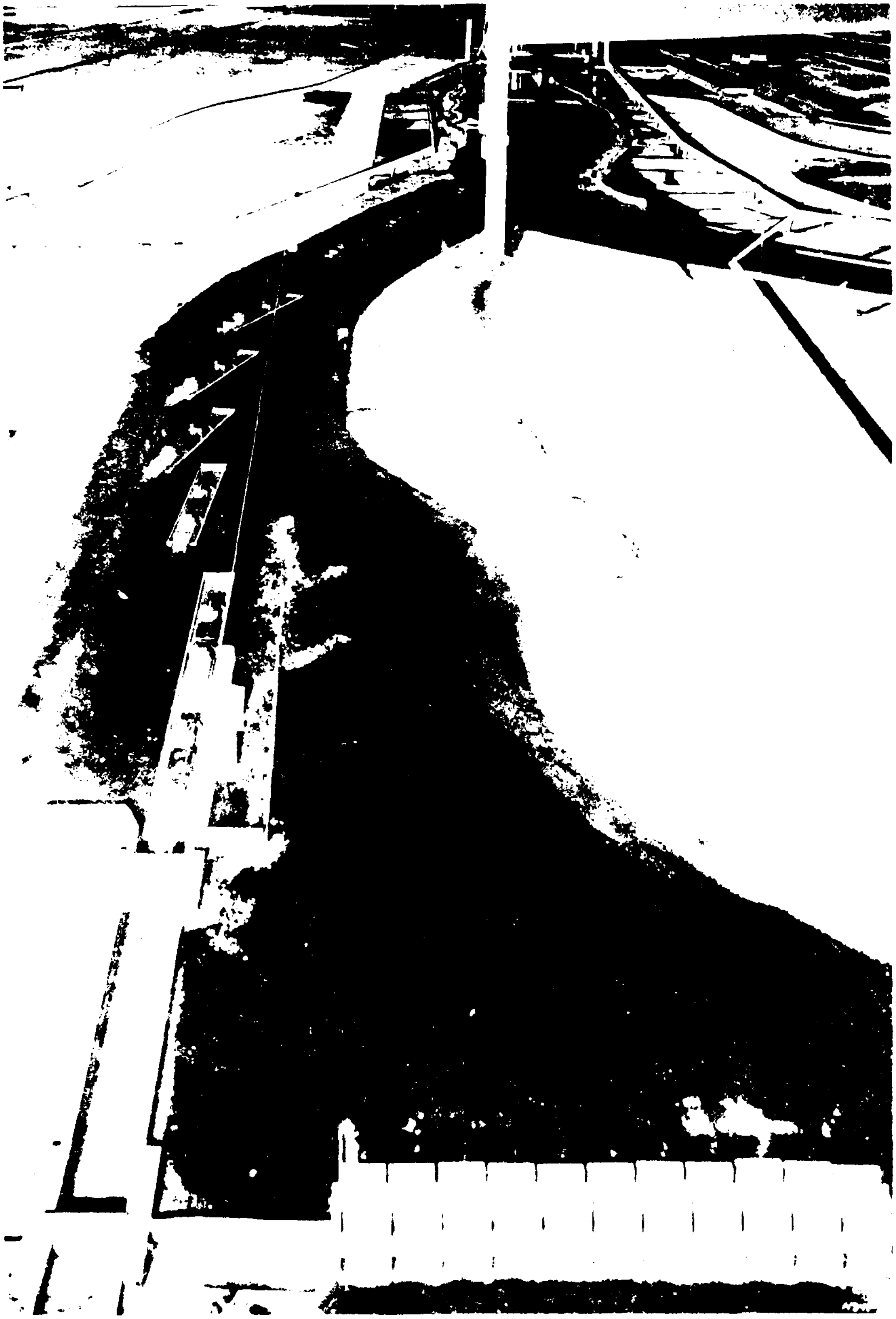


Photo 14. Plan B-34, downbound tow leaving the lock; discharge 145,000 cfs, tailwater el 42.9 (minimum)

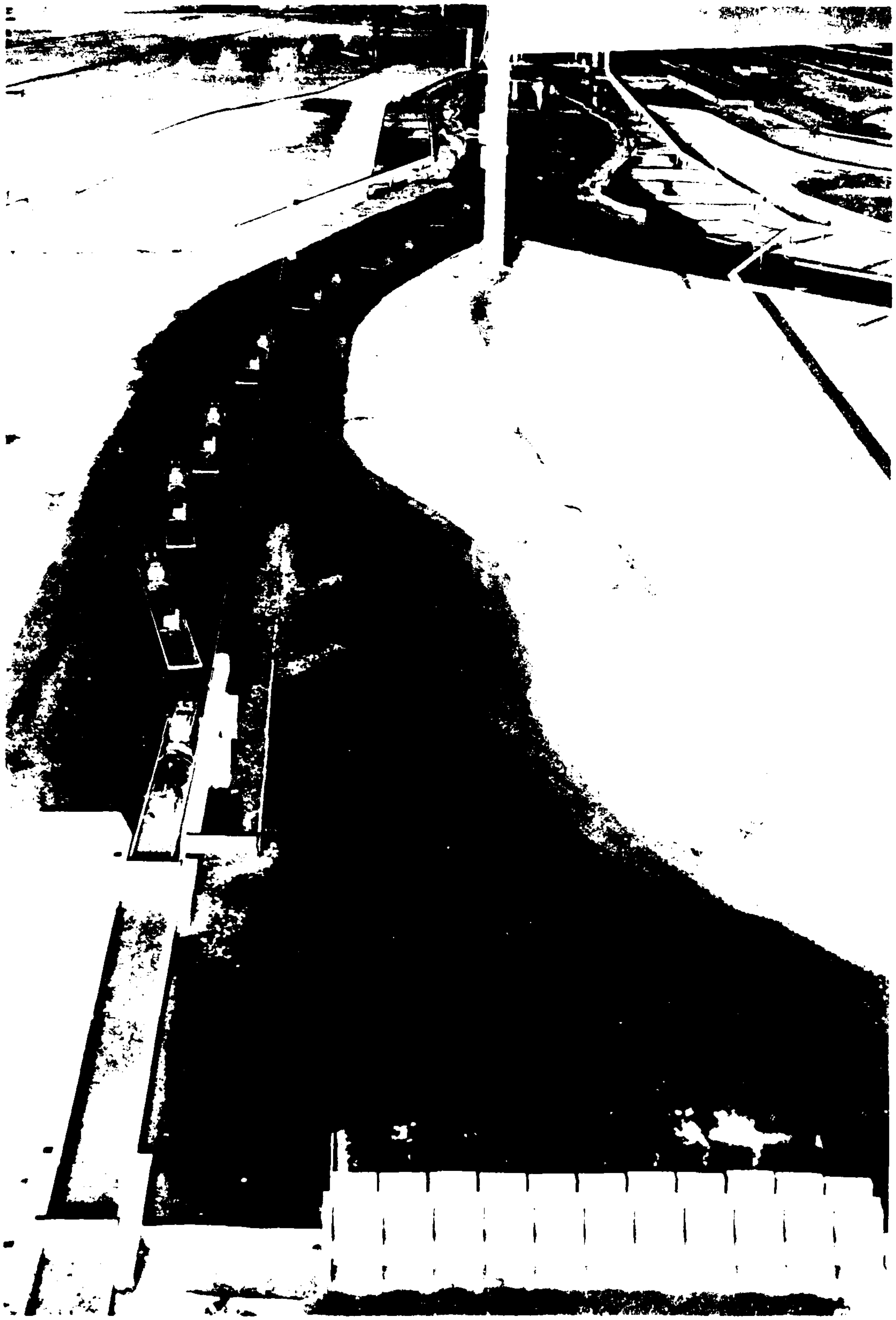


Photo 12. Plan B-34, upbound tow approaching the lock; discharge 145,000 cfs, tailwater el 42.9 (minimum)

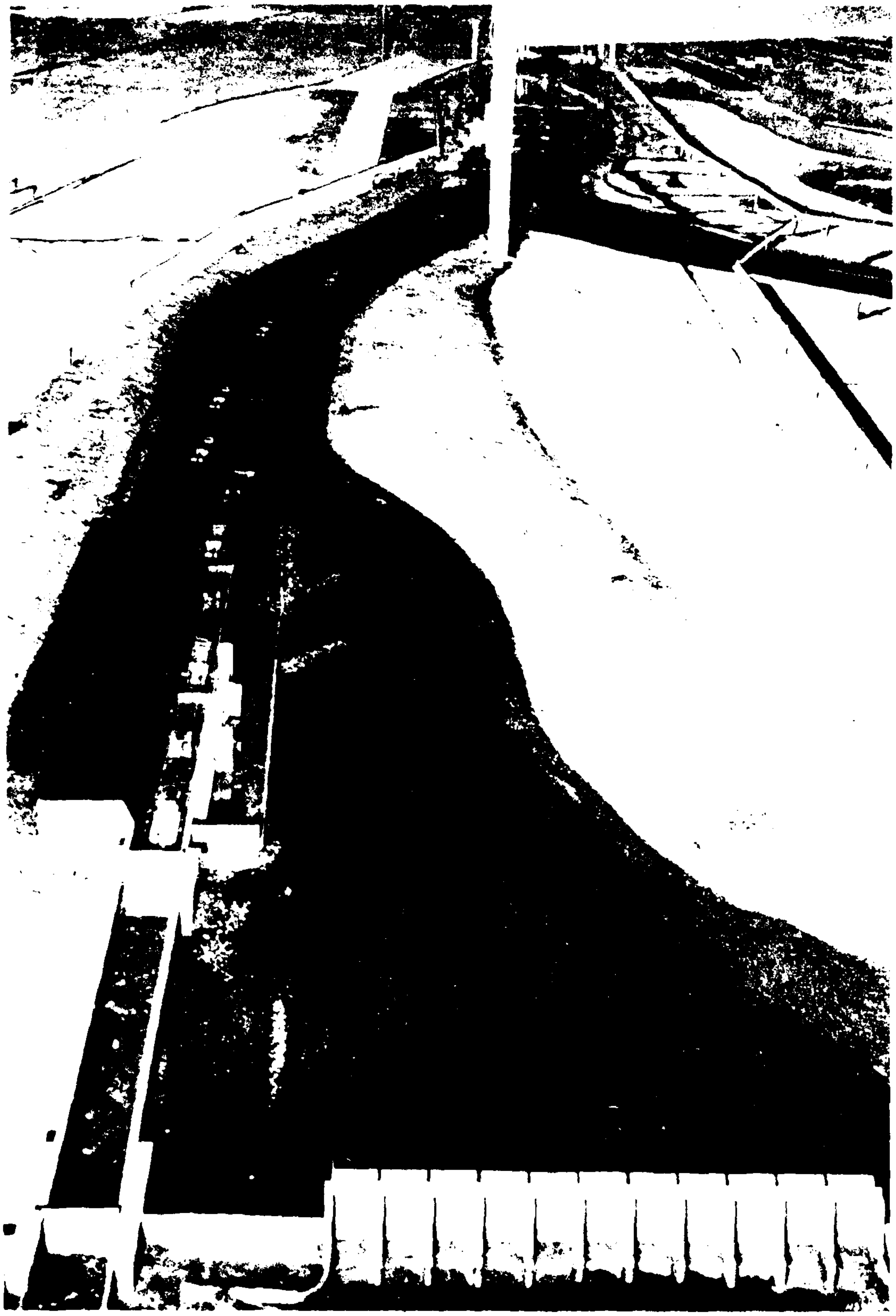


Photo 13. Plan B-34, downbound tow leaving the lock; discharge 31,000 cfs, tailwater el 21.0 (normal)

Photo 14. Plan B-34, upbound tow approaching the lock; discharge 31,000 cfs, tailwater el 21.0 (normal)

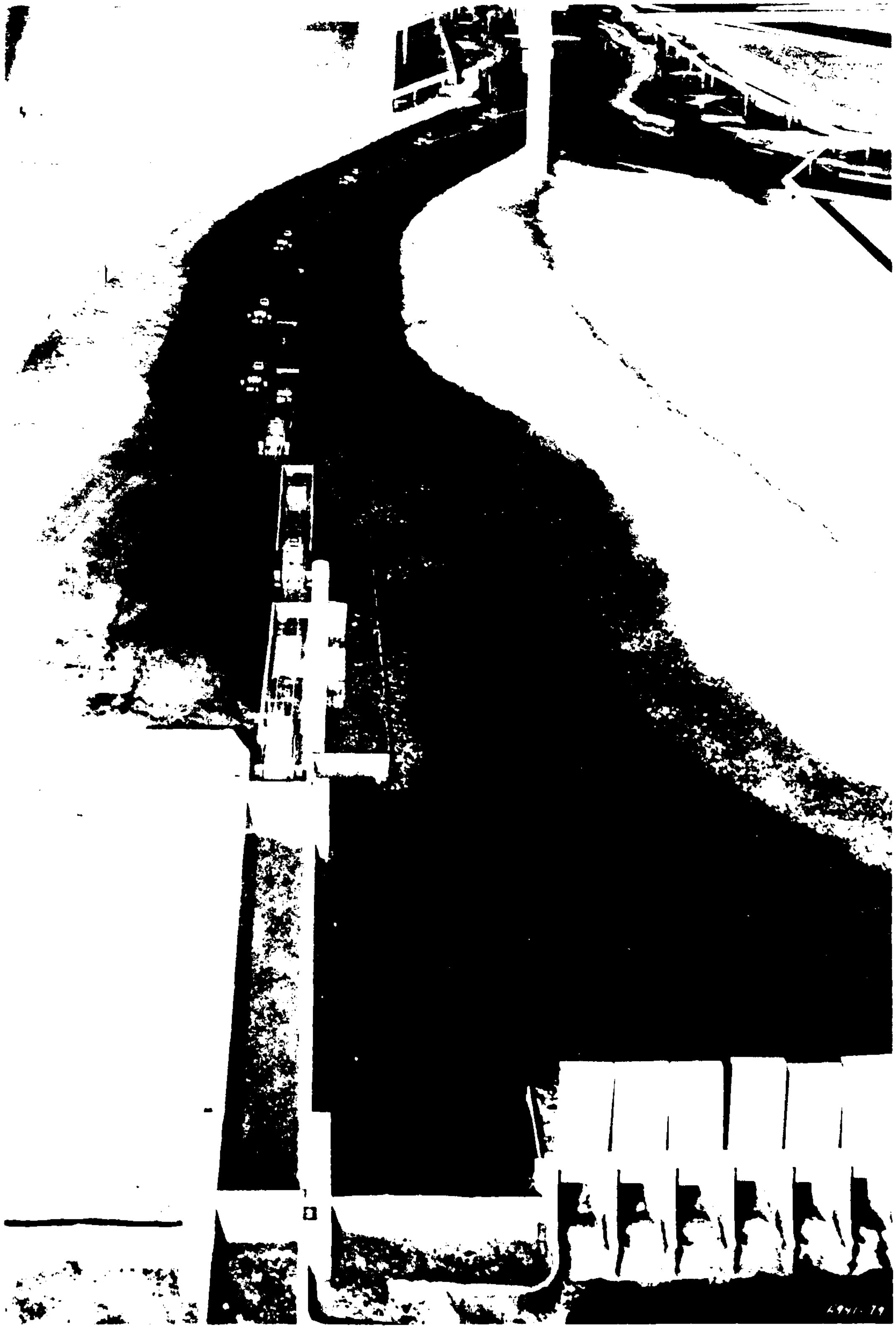


Photo 15. Plan B-35, downbound tow leaving the lock; discharge 145,000 cfs, tailwater el 42.9 (minimum)

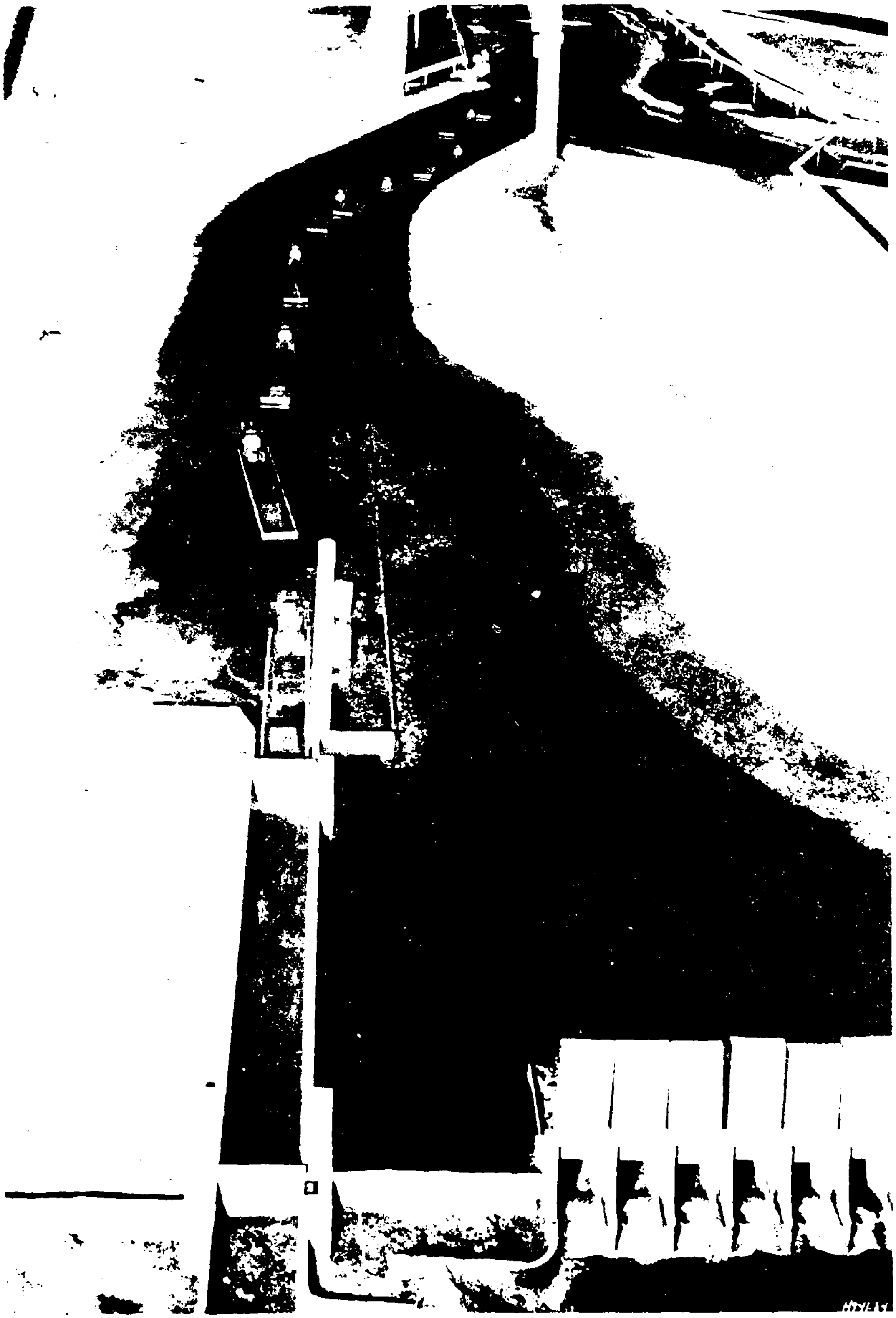


Photo 16. Plan B-35, Upbound tow approaching the lock; discharge 145,000 cfs, tailwater el 42.9 (minimum)

Photo 17. Plan B-35; downbound tow leaving the lock; discharge 31,000 cfs, tailwater el 21.0 (normal)

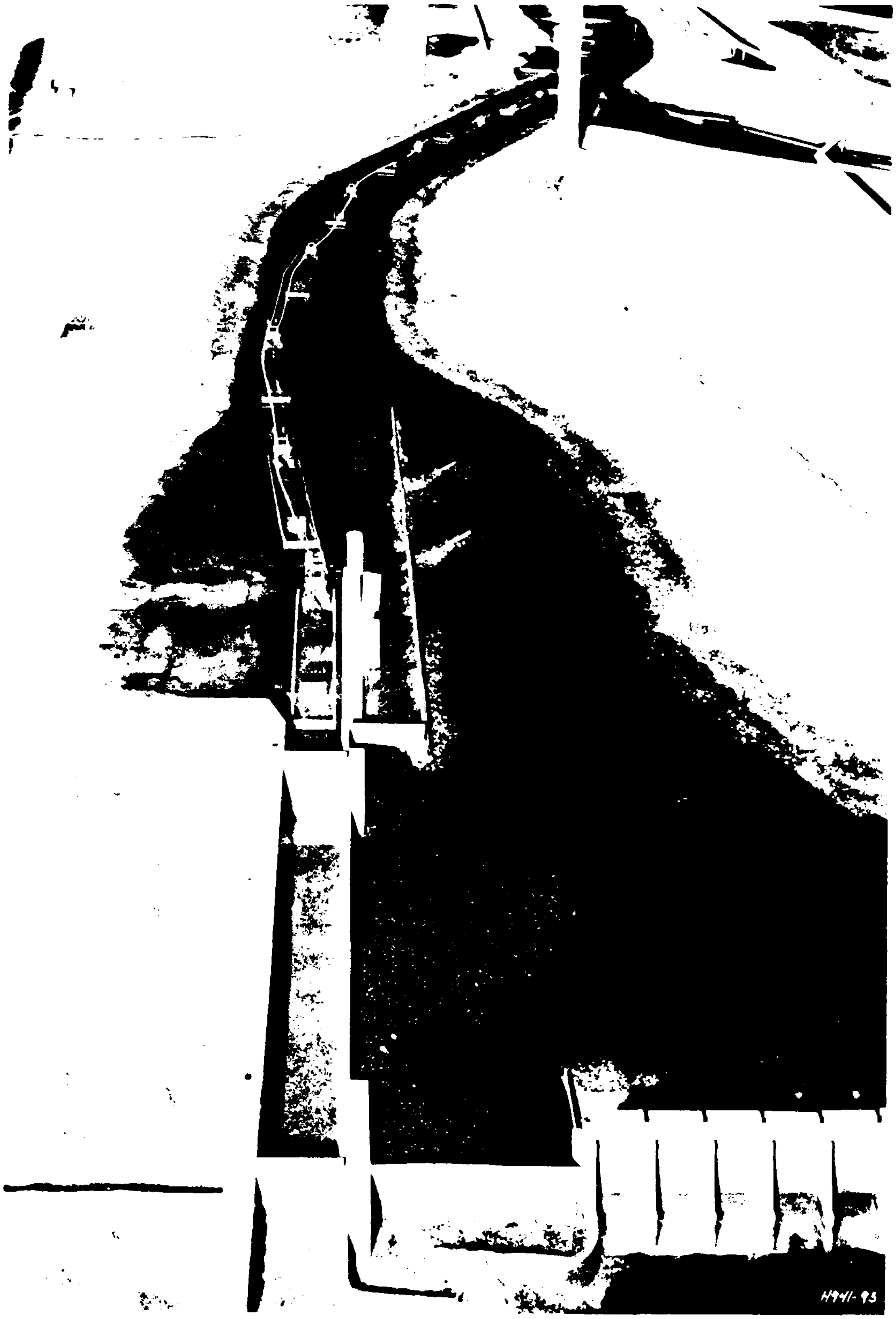
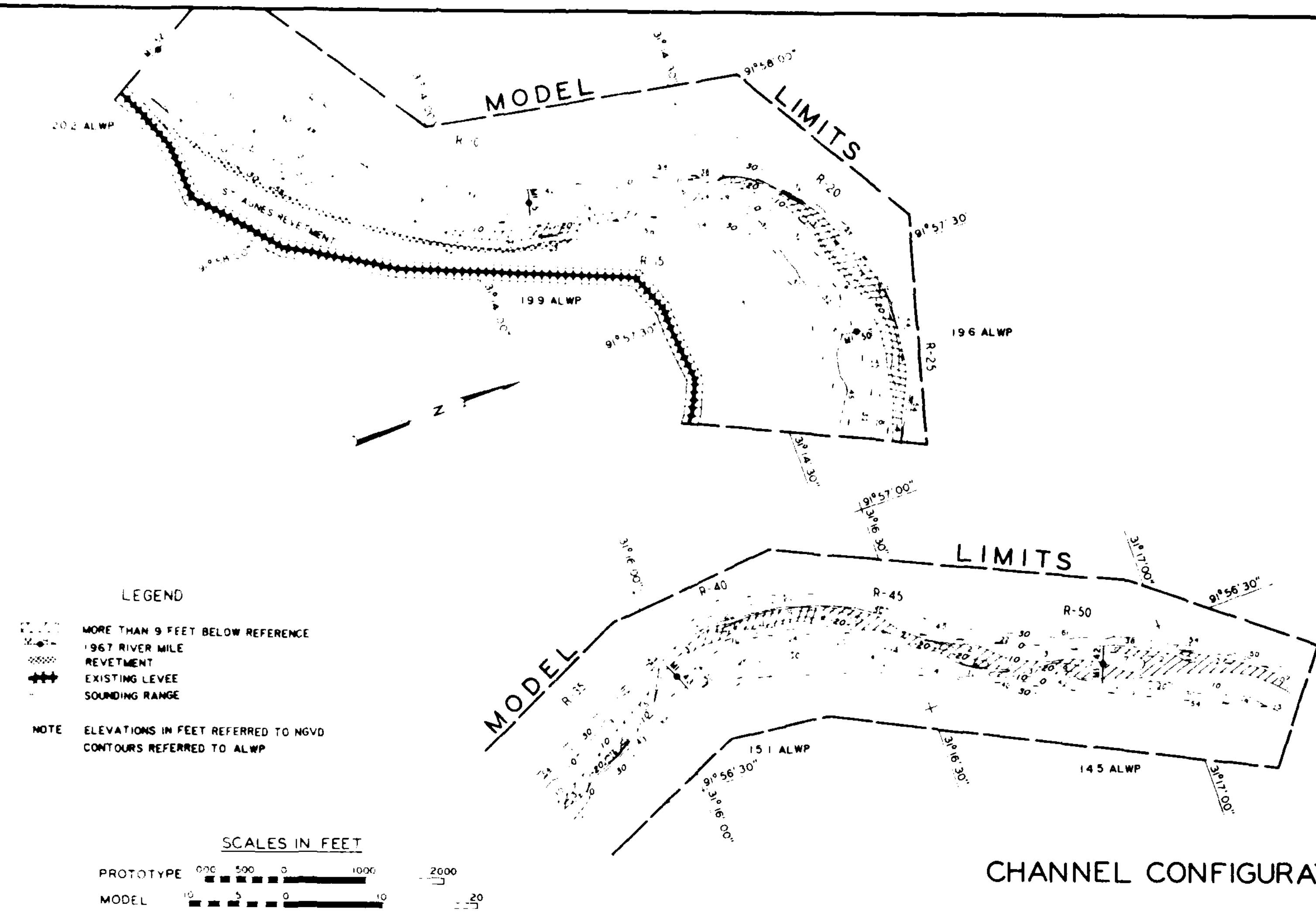
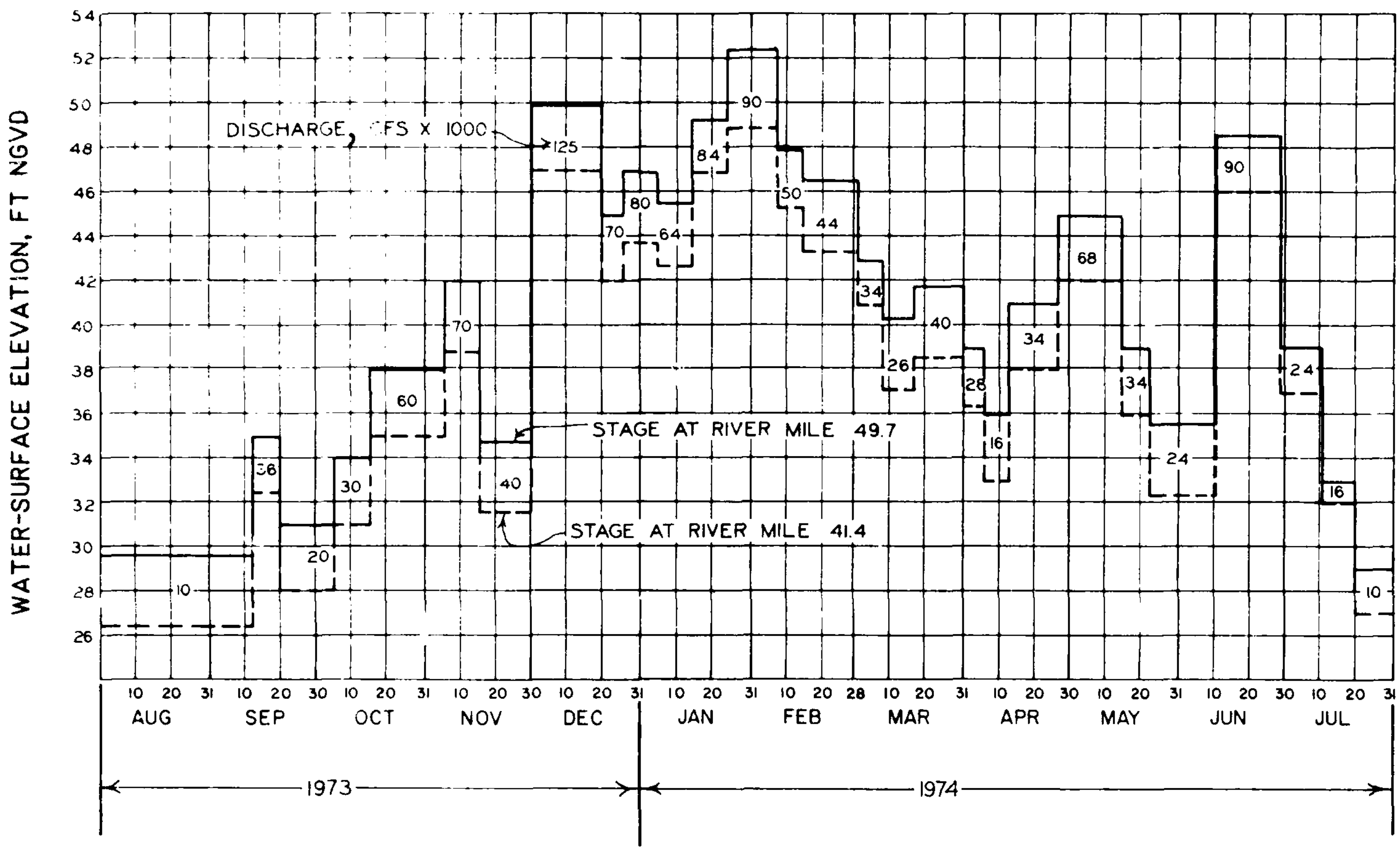


Photo 13. Plan B-36, upbound tow approaching the lock; discharge 31,000 cfs, tailwater el 21.0 (normal)

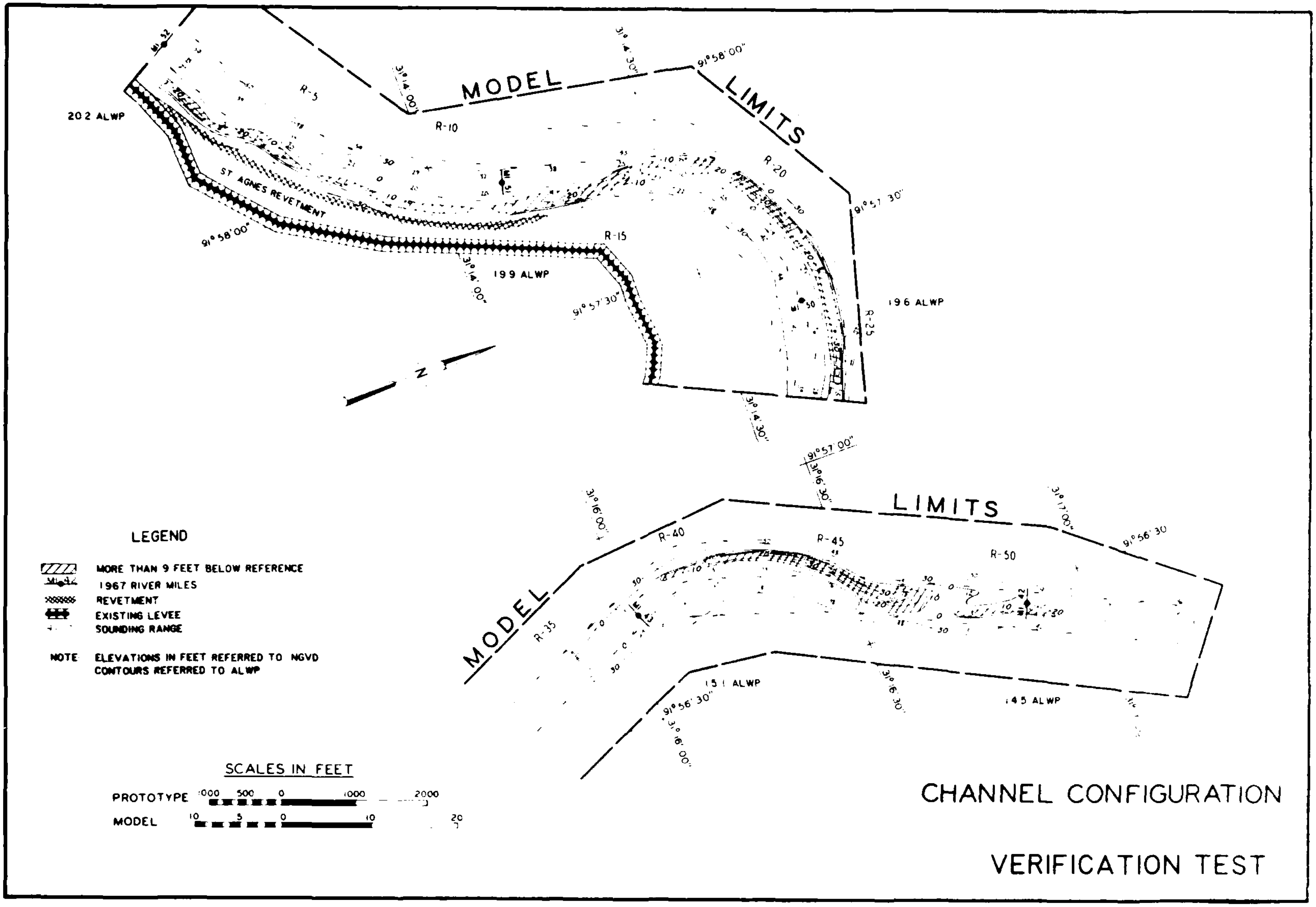


CHANNEL CONFIGURATION

1974 PROTOTYPE SURVEY



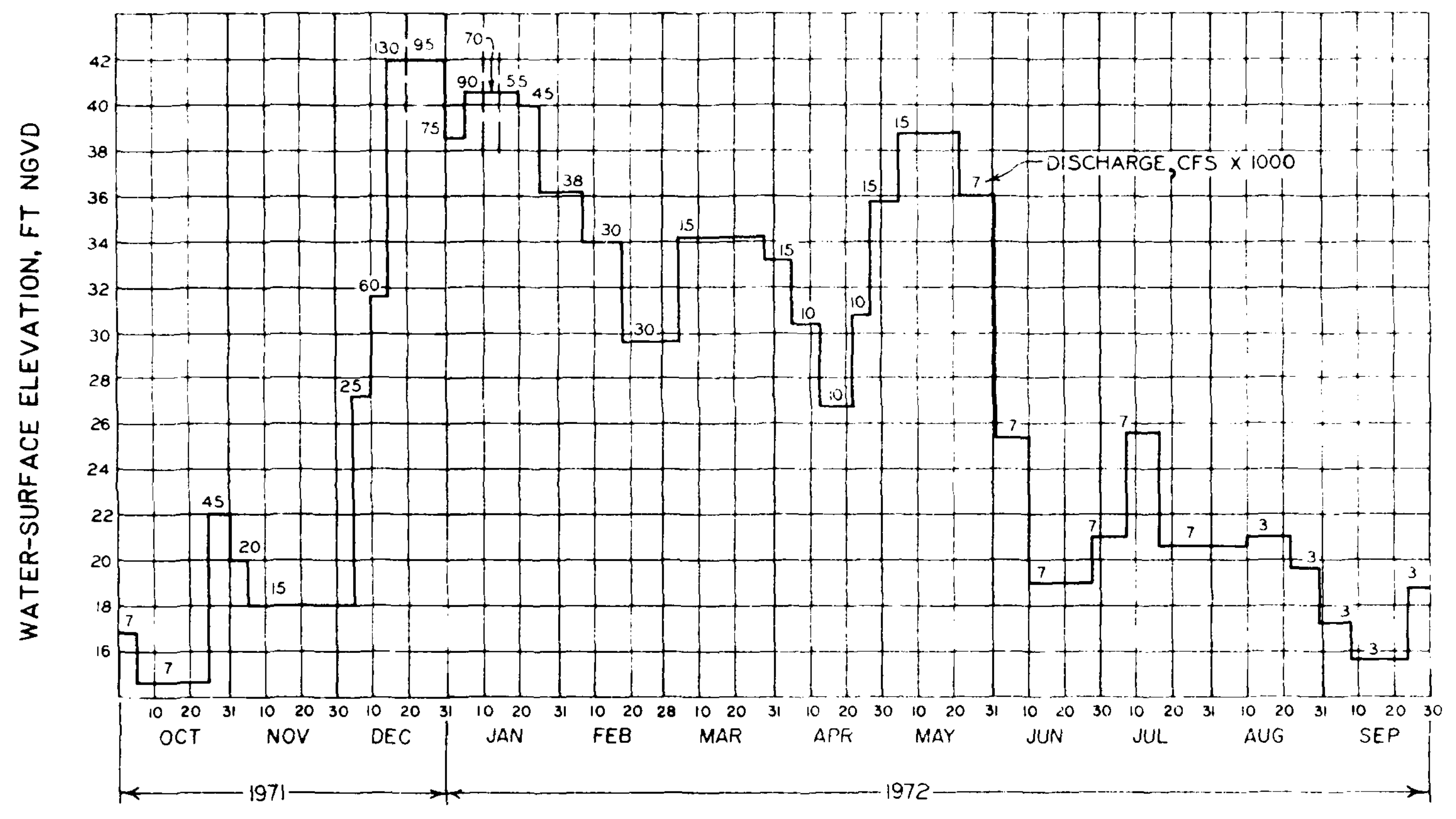
ADJUSTMENT HYDROGRAPH



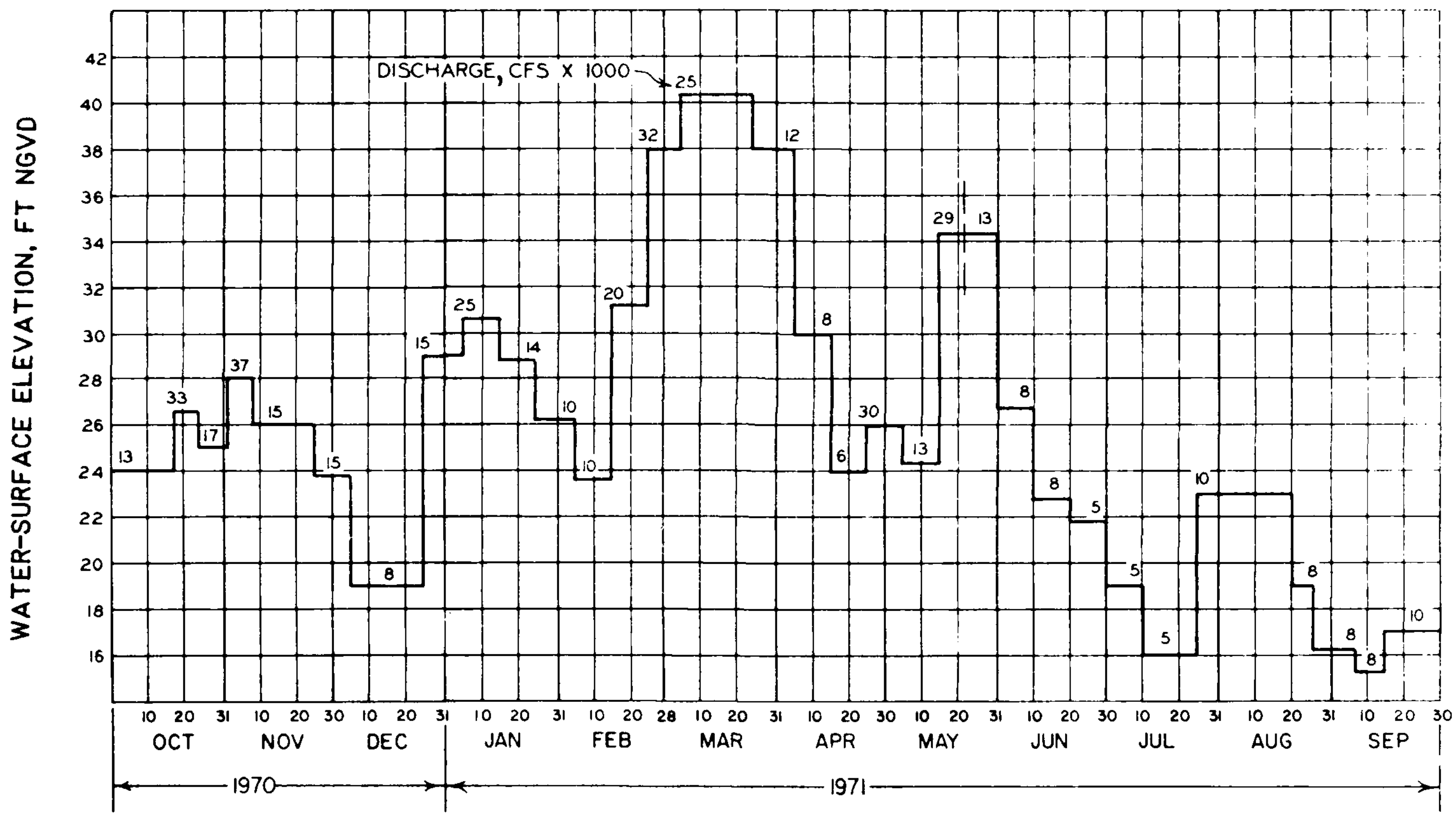
CHANNEL CONFIGURATION

VERIFICATION TEST

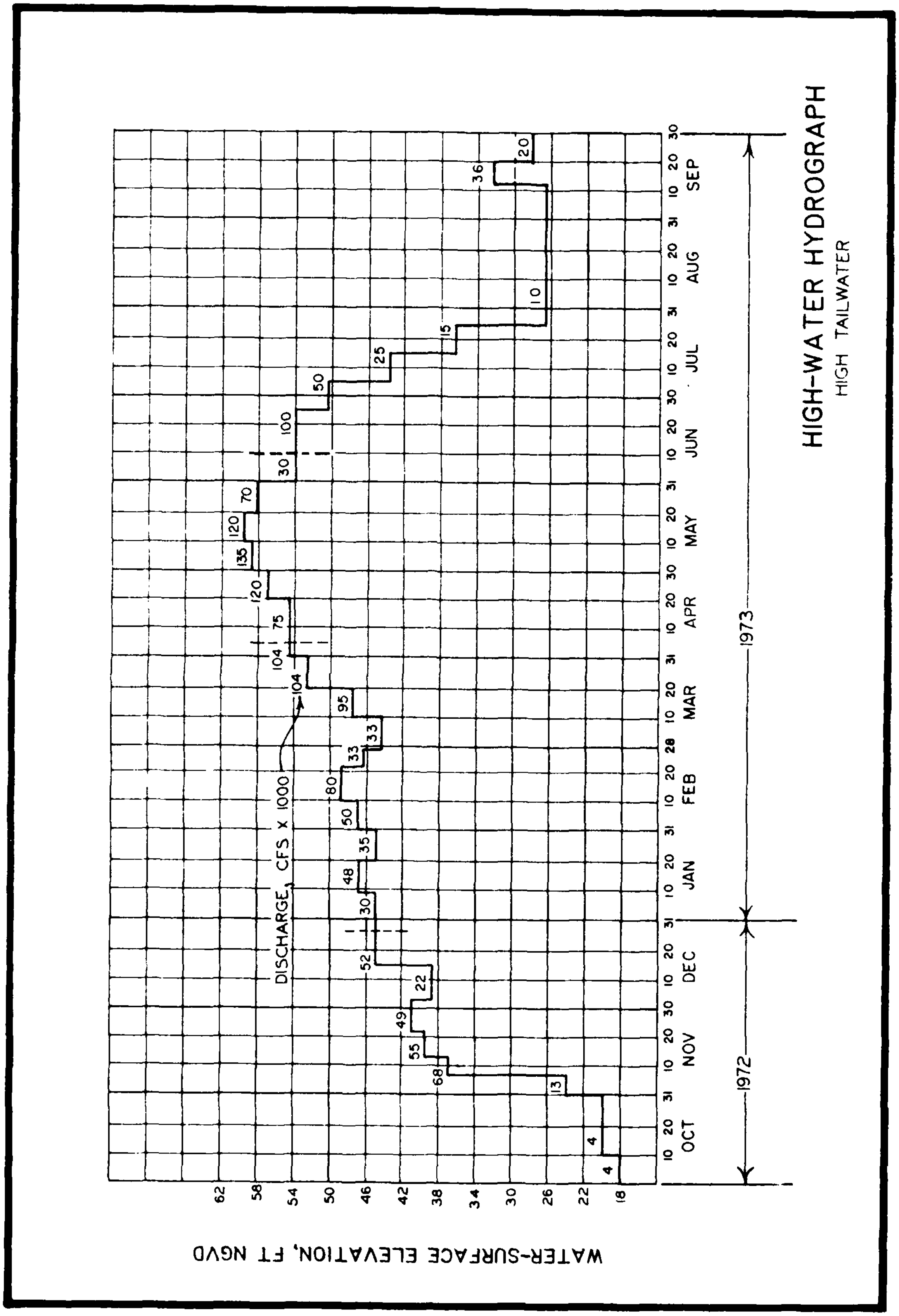
PLATE 3



AVERAGE HYDROGRAPH



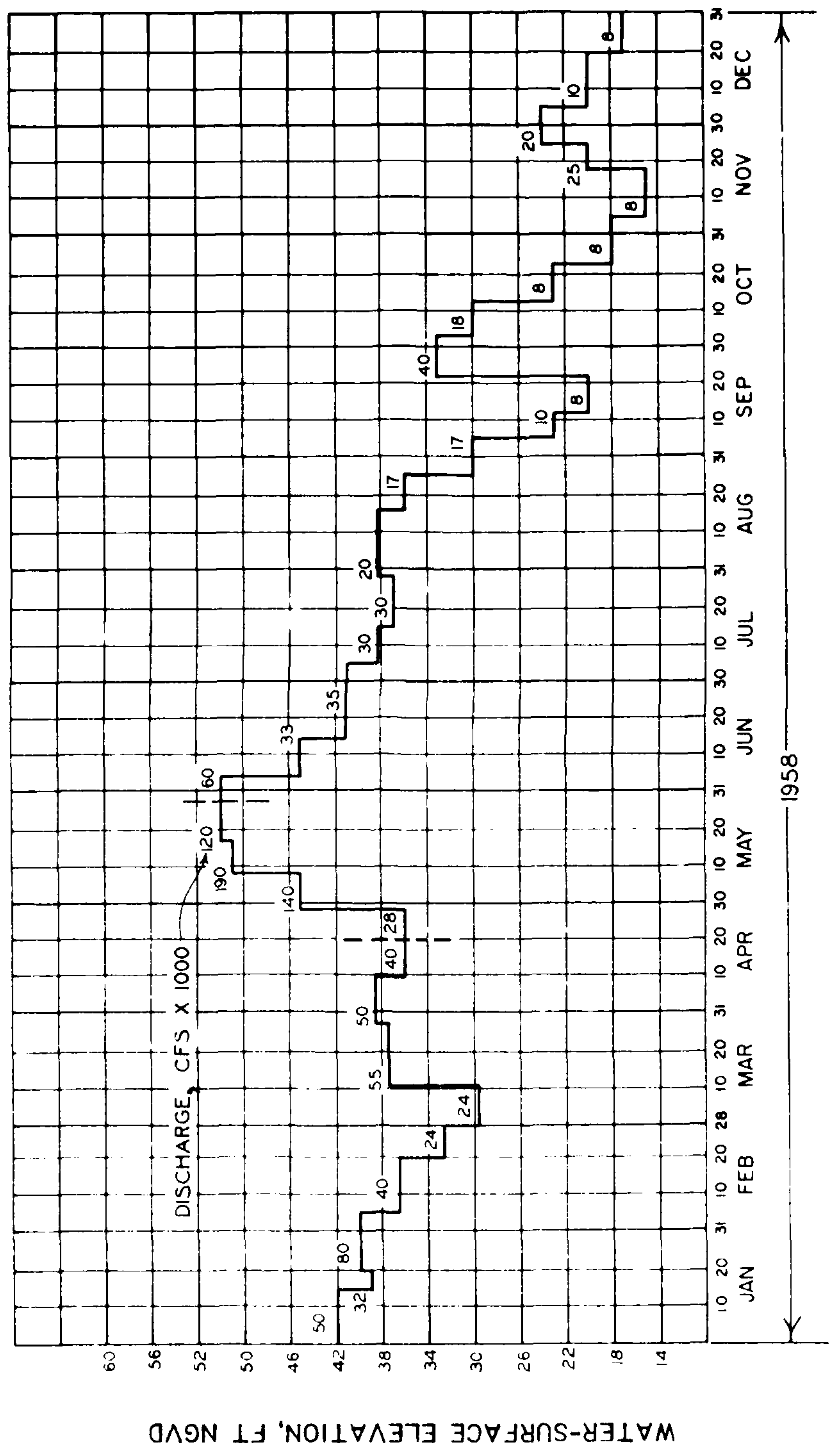
LOW-WATER HYDROGRAPH



HIGH-WATER HYDROGRAPH

HIGH TAILWATER

PLATE 6



HIGH-WATER HYDROGRAPH
LOW TAILWATER

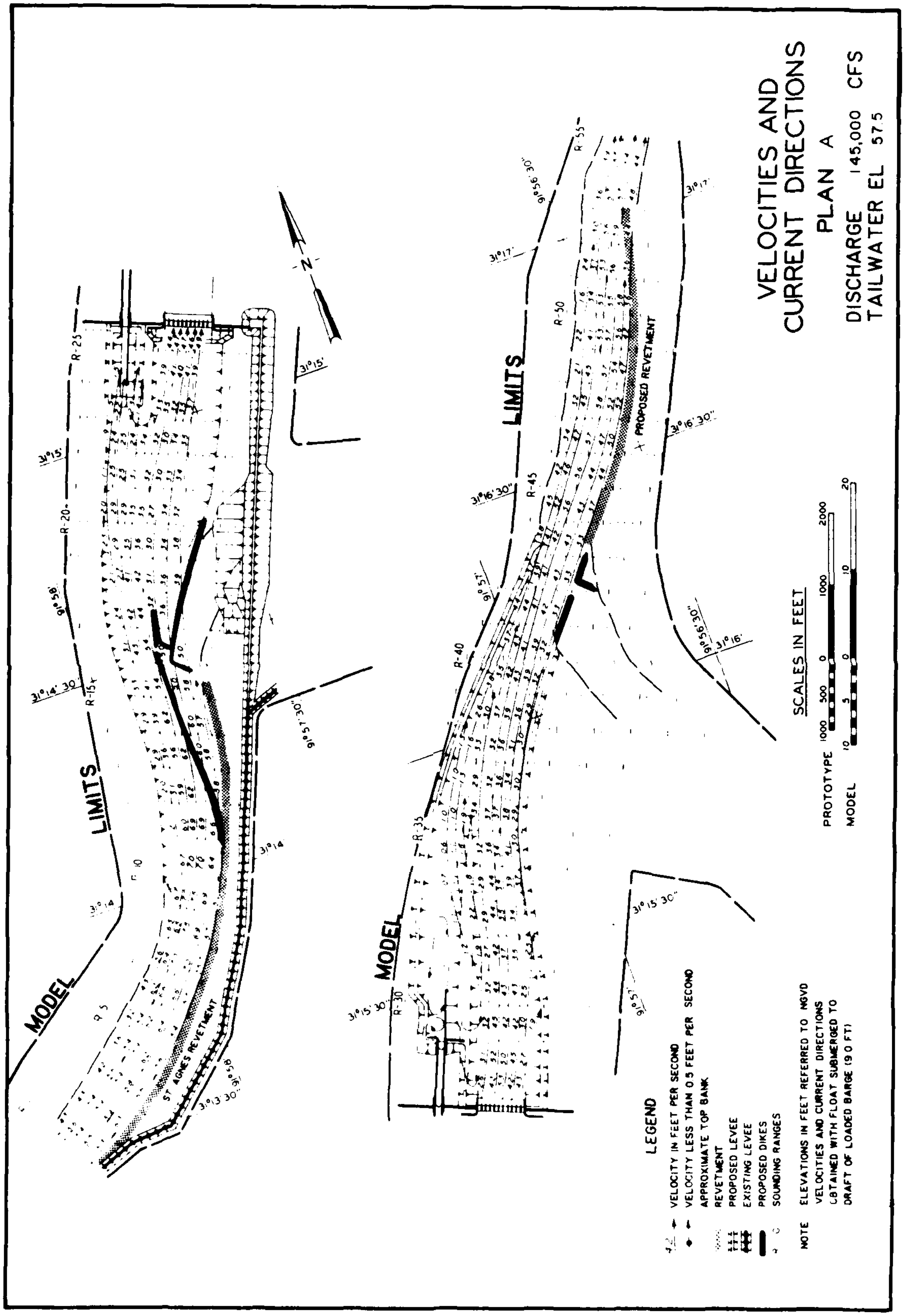
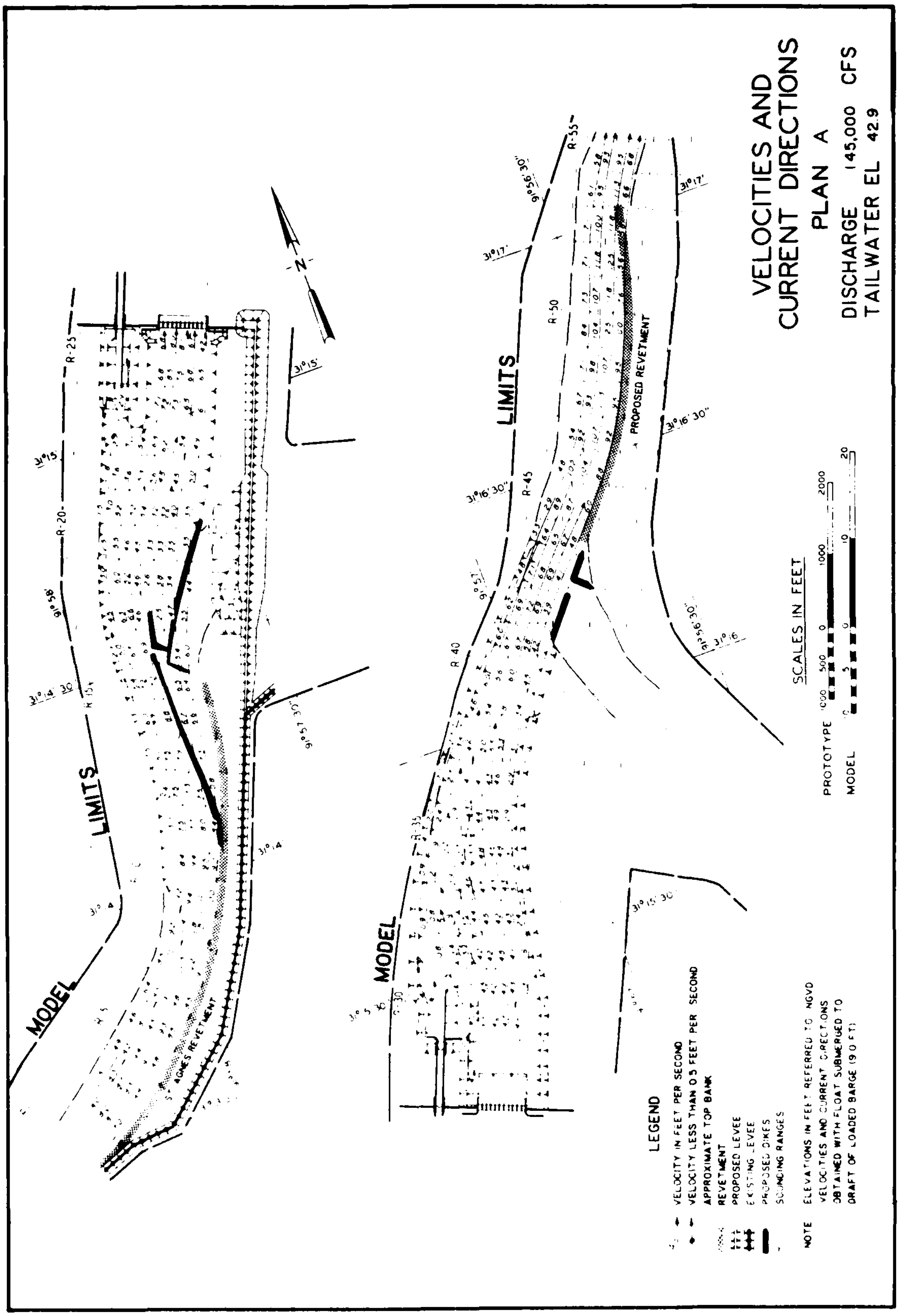
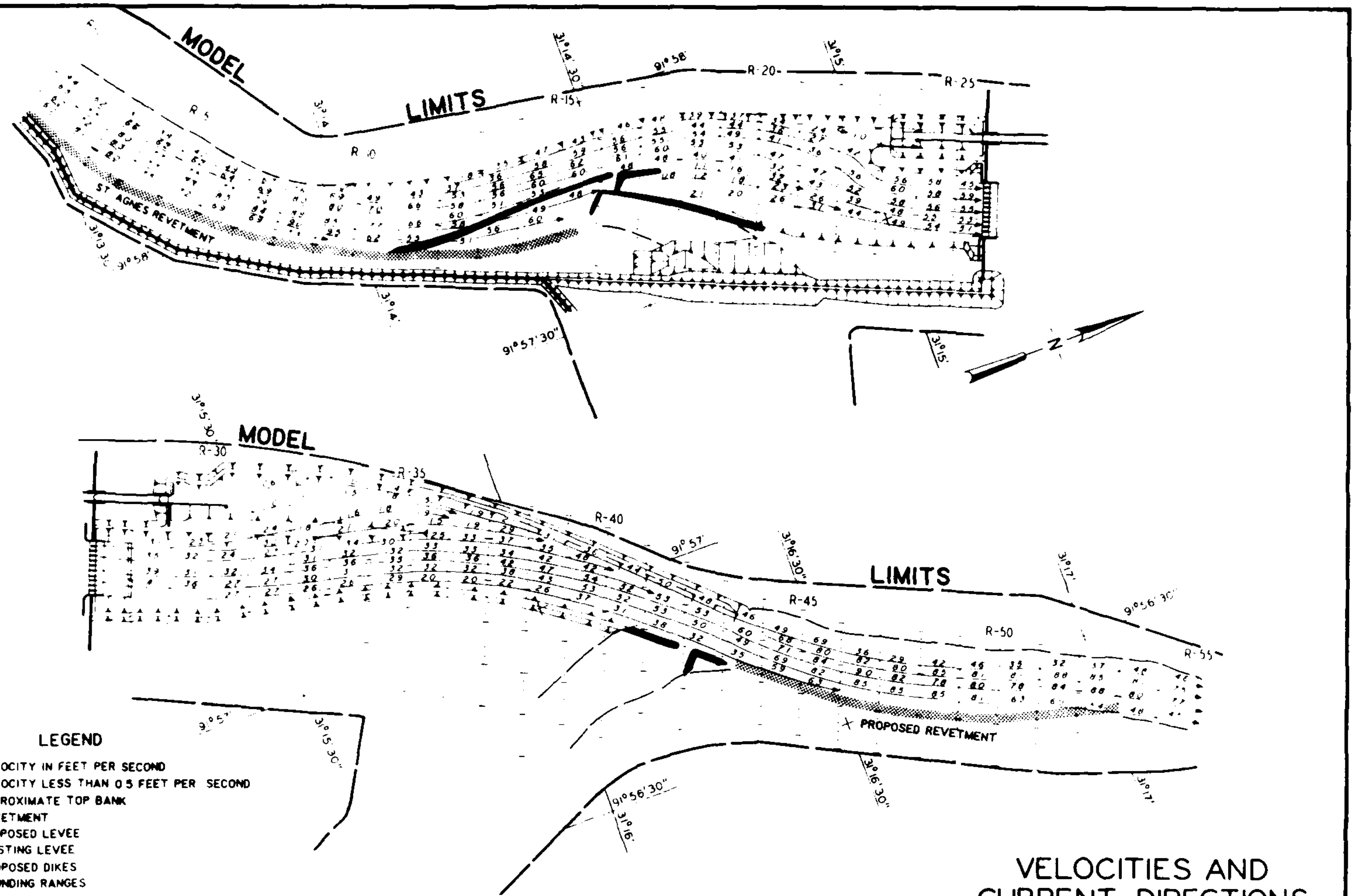

VELOCITIES AND CURRENT DIRECTIONS
PLAN A
DISCHARGE 145,000 CFS
TAILWATER EL 57.5
SCALES IN FEET
PROTOTYPE 1000 500 0 1000 2000
MODEL 10 5 0 10 20
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
APPROXIMATE TOP BANK
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKES
SOUNDING RANGES
NOTE ELEVATIONS IN FEET REFERRED TO NGVD
VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
MODEL LIMITS
PROPOSED REVETMENT
ST AGNES REVETMENT
N

PLATE 8


VELOCITIES AND CURRENT DIRECTIONS
PLAN A
DISCHARGE 145,000 CFS
TAILWATER EL 42.9
SCALES IN FEET
PROTOTYPE
MODEL
MODEL LIMITS
PROPOSED REVETMENT
AGNES REVETMENT
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
APPROXIMATE TOP BANK
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKES
SOUNDING RANGES
NOTE ELEVATIONS IN FEET REFERRED TO NGVD
VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)



LEGEND

- 4.2 → VELOCITY IN FEET PER SECOND
- → VELOCITY LESS THAN 0.5 FEET PER SECOND
- APPROXIMATE TOP BANK
- REVETMENT
- PROPOSED LEVEE
- EXISTING LEVEE
- PROPOSED DIKES
- SOUNDING RANGES

NOTE ELEVATIONS IN FEET REFERRED TO NGVD
VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)

SCALES IN FEET

PROTOTYPE 1000 500 0 1000 2000

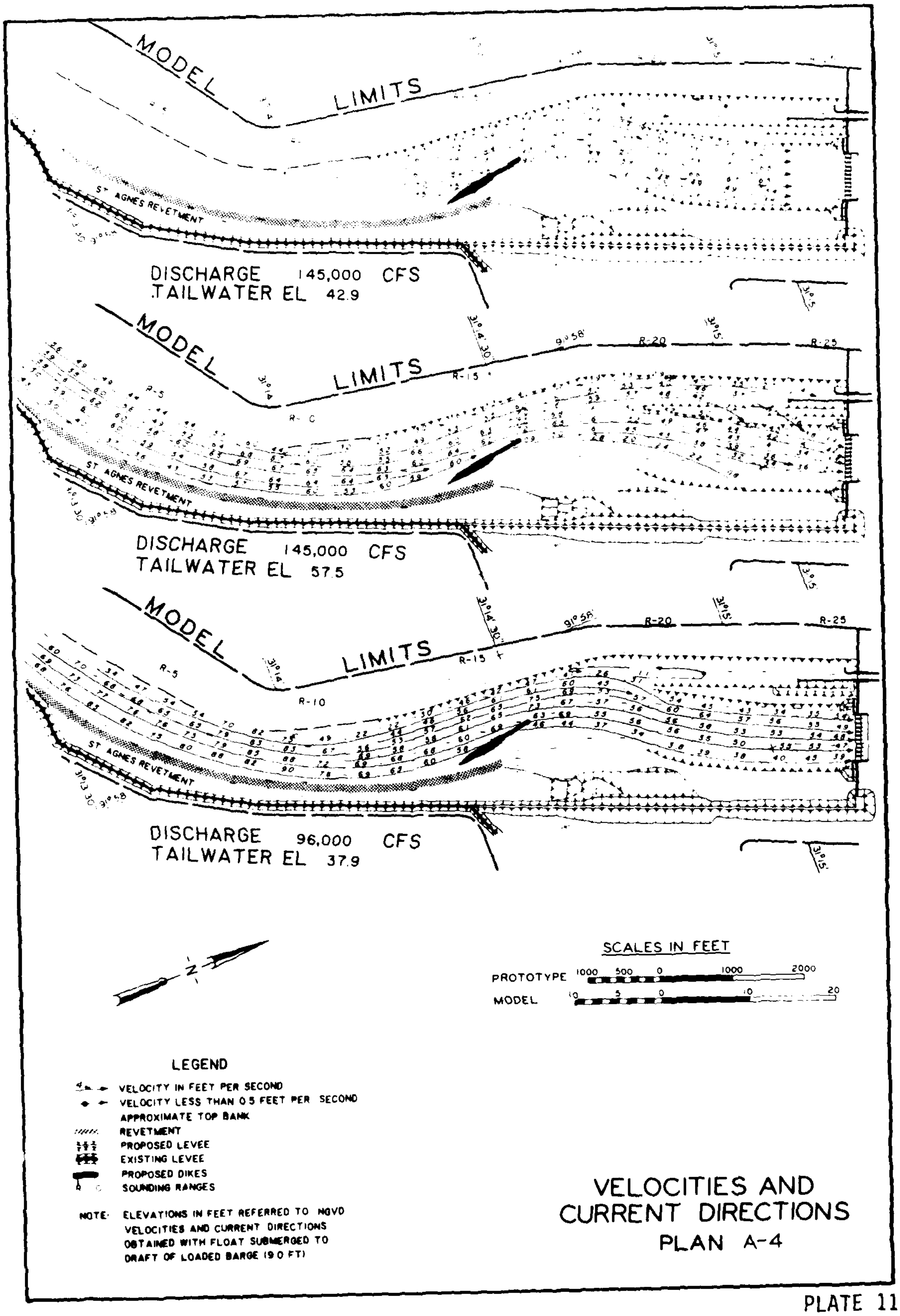
MODEL 10 5 0 10 20

VELOCITIES AND CURRENT DIRECTIONS

PLAN A

DISCHARGE 96,000 CFS

TAILWATER EL 37.9



VELOCITIES AND CURRENT DIRECTIONS
PLAN A-4

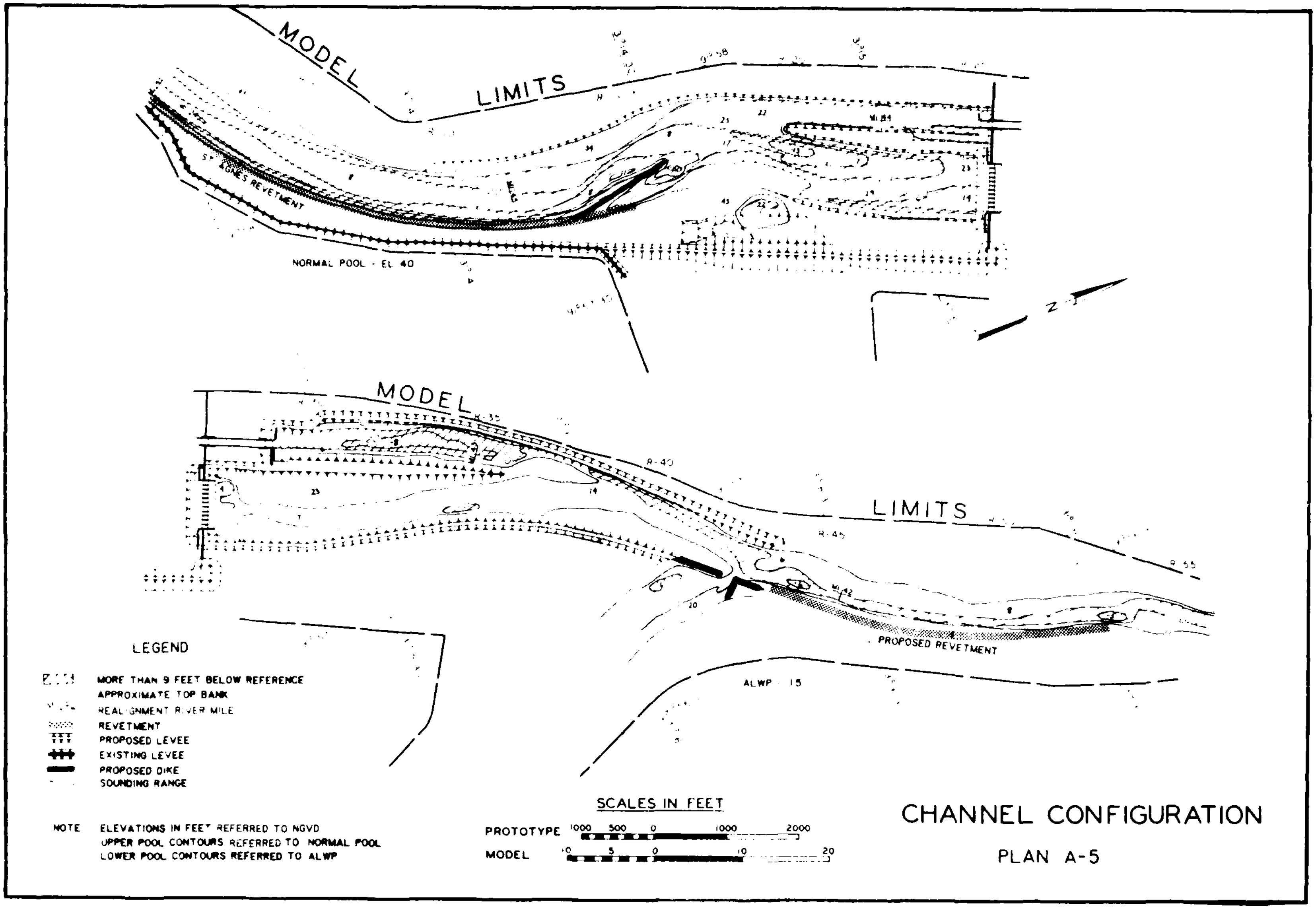

MODEL LIMITS
NORMAL POOL - EL 40
ST AGNES REVETMENT
N
MODEL LIMITS
PROPOSED REVETMENT
ALWP 15
LEGEND
MORE THAN 9 FEET BELOW REFERENCE
APPROXIMATE TOP BANK
REALIGNMENT RIVER MILE
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKE
SOUNDING RANGE
NOTE ELEVATIONS IN FEET REFERRED TO NGVD
UPPER POOL CONTOURS REFERRED TO NORMAL POOL
LOWER POOL CONTOURS REFERRED TO ALWP
SCALES IN FEET
PROTOTYPE 1000 500 0 1000 2000
MODEL 10 5 0 10 20
CHANNEL CONFIGURATION
PLAN A-5

PLATE 12

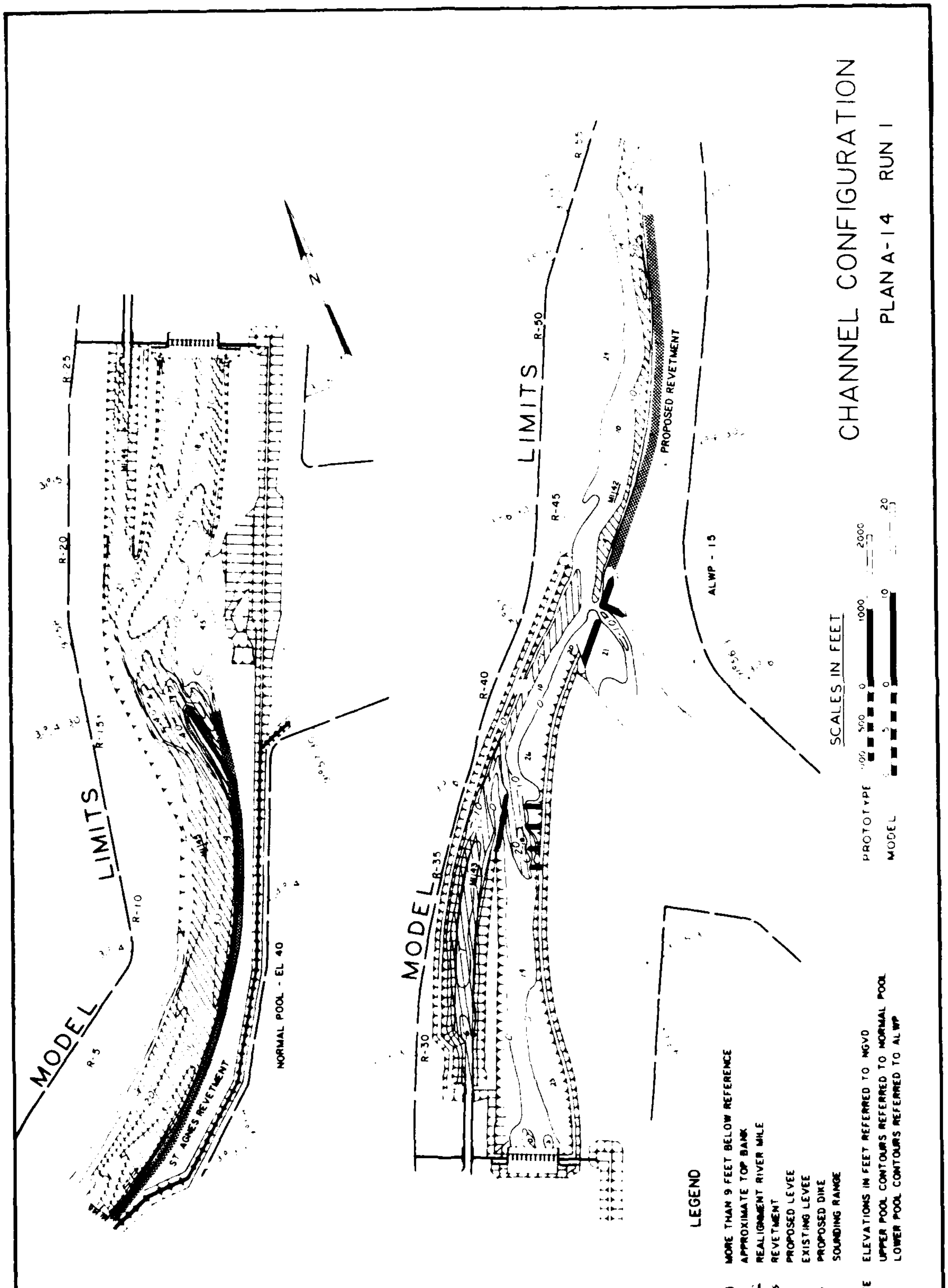

CHANNEL CONFIGURATION
PLAN A-14 RUN 1
MODEL LIMITS
MODEL LIMITS
ST AGNES REVETMENT
NORMAL POOL - EL 40
PROPOSED REVETMENT
ALWP - 15
N
R-5
R-10
R-15
R-20
R-25
R-30
R-35
R-40
R-45
R-50
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
MORE THAN 9 FEET BELOW REFERENCE
APPROXIMATE TOP BANK
REALIGNMENT RIVER MILE
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKE
SOUNDING RANGE
NOTE
ELEVATIONS IN FEET REFERRED TO NGVD
UPPER POOL CONTOURS REFERRED TO NORMAL POOL
LOWER POOL CONTOURS REFERRED TO ALWP

PLATE 13

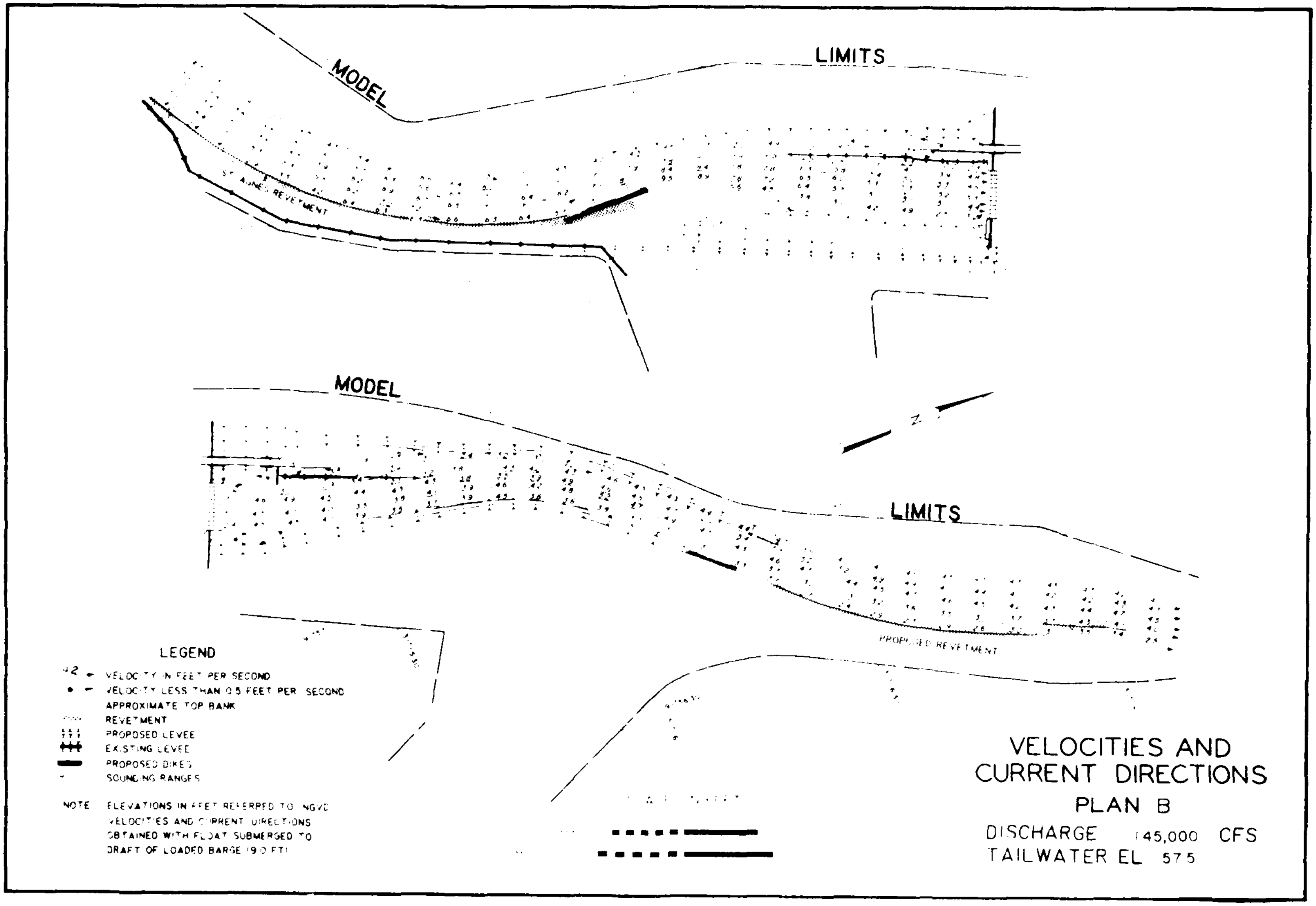
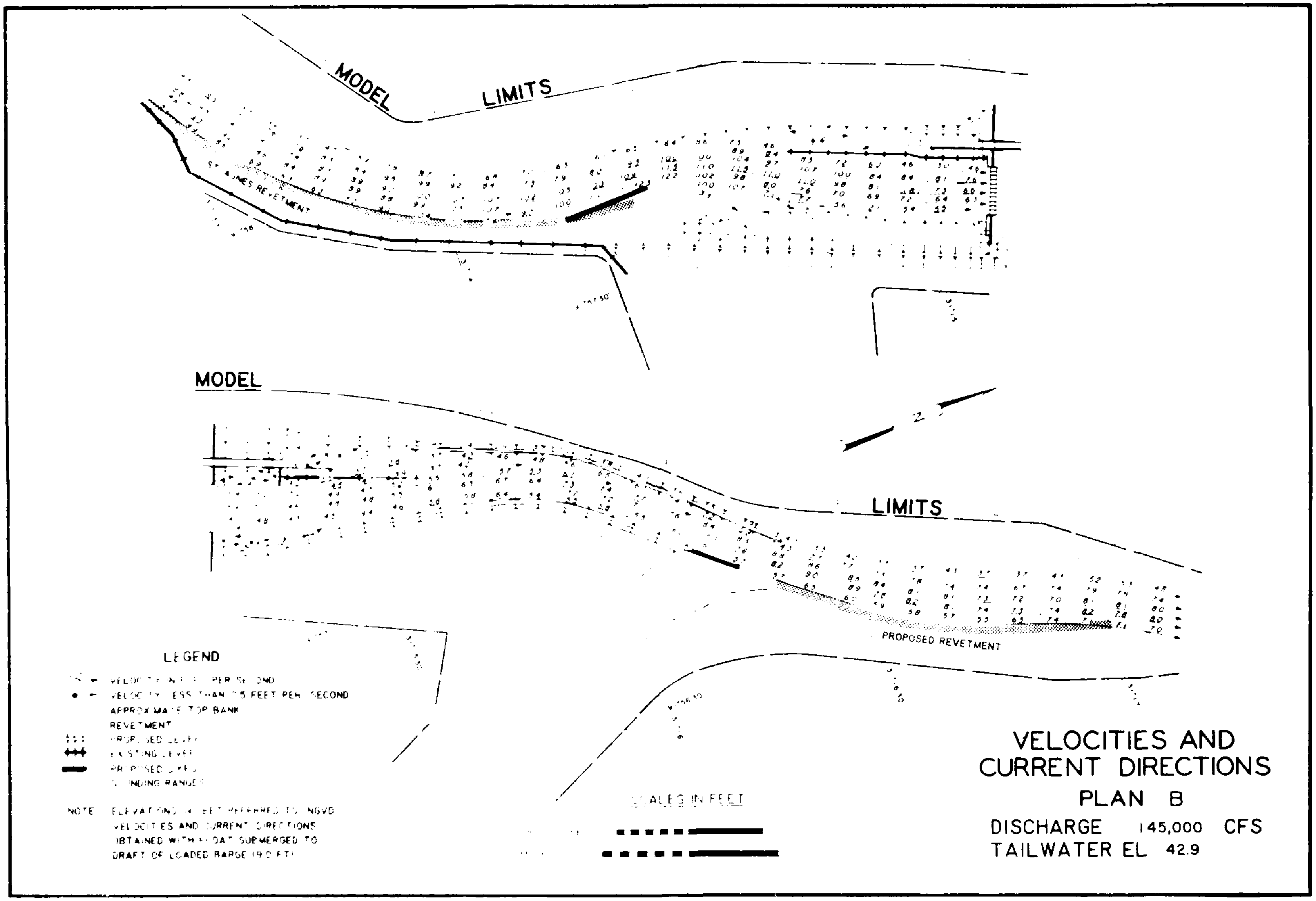
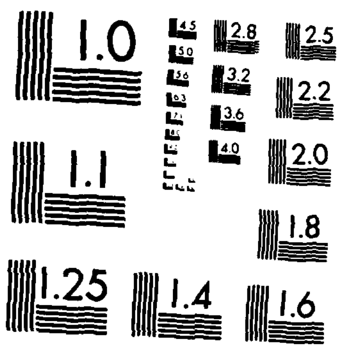

MODEL
LIMITS
ST. AGNES REVETMENT
MODEL
LIMITS
PROPOSED REVETMENT
N
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
APPROXIMATE TOP BANK
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKES
SOUNDING RANGES
NOTE ELEVATIONS IN FEET REFERRED TO NGVD
VELOCITIES AND CURRENT DIRECTIONS
OBTAINED WITH FLOAT SUBMERGED TO
DRAFT OF LOADED BARGE (9.0 FT)
VELOCITIES AND
CURRENT DIRECTIONS
PLAN B
DISCHARGE 145,000 CFS
TAILWATER EL 57.5

PLATE 14


MODEL LIMITS
MODEL LIMITS
ST JAMES REVETMENT
PROPOSED REVETMENT
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 1.5 FEET PER SECOND
APPROXIMATE TOP BANK
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKES
SOUNDING RANGES
NOTE ELEVATIONS IN FEET REFERRED TO NGVD
VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (9.0 FT)
SCALES IN FEET
VELOCITIES AND CURRENT DIRECTIONS
PLAN B
DISCHARGE 145,000 CFS
TAILWATER EL 42.9

AD-A171 594 LOCK AND DAM 1 RED RIVER WATERWAY; HYDRAULIC MODEL INVESTIGATION(U) ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG MS HYDRAULICS LAB J E FOSTER ET AL. JUN 86 WES/TR/HL-86-6 2/2

UNCLASSIFIED F/G 13/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

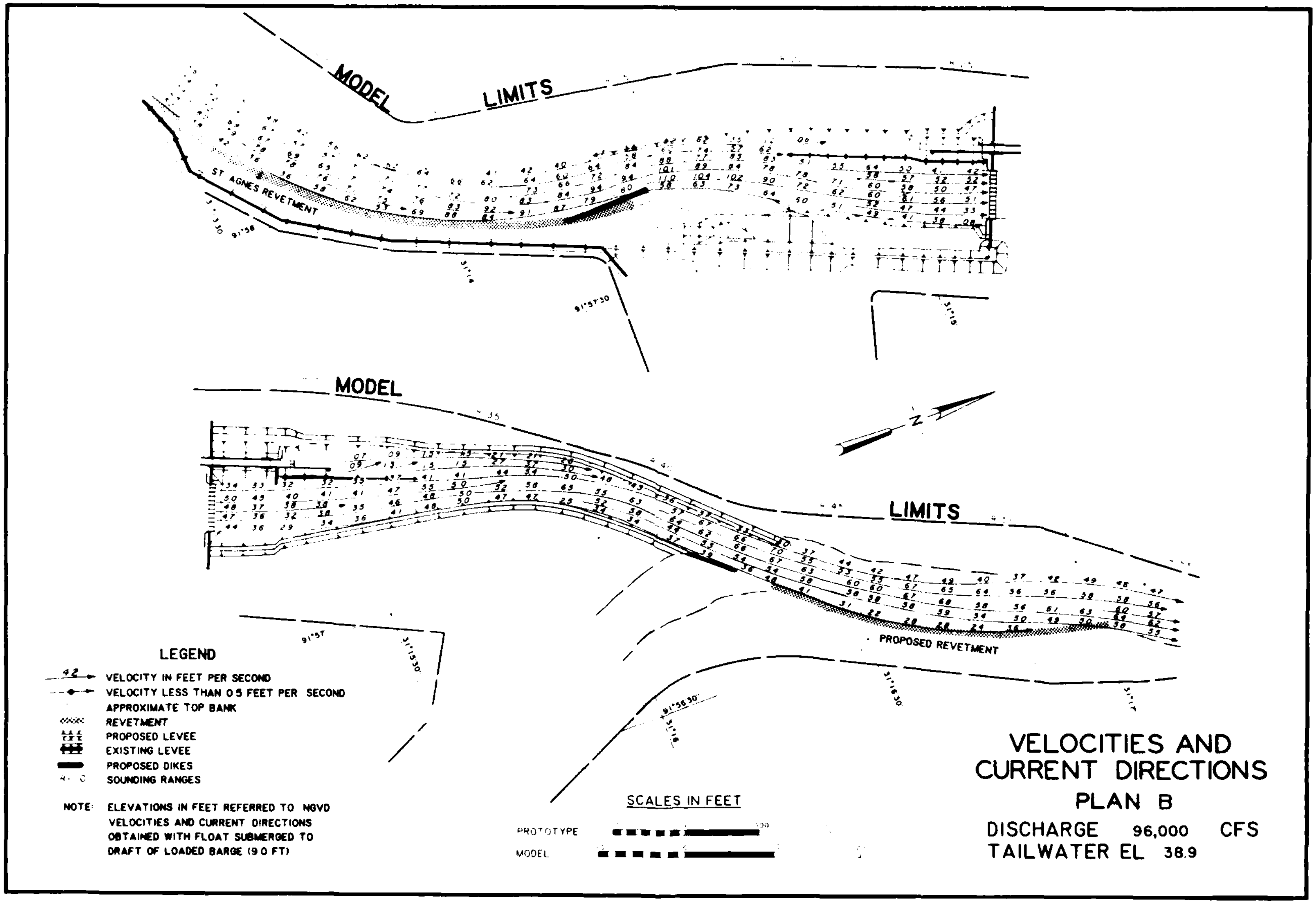
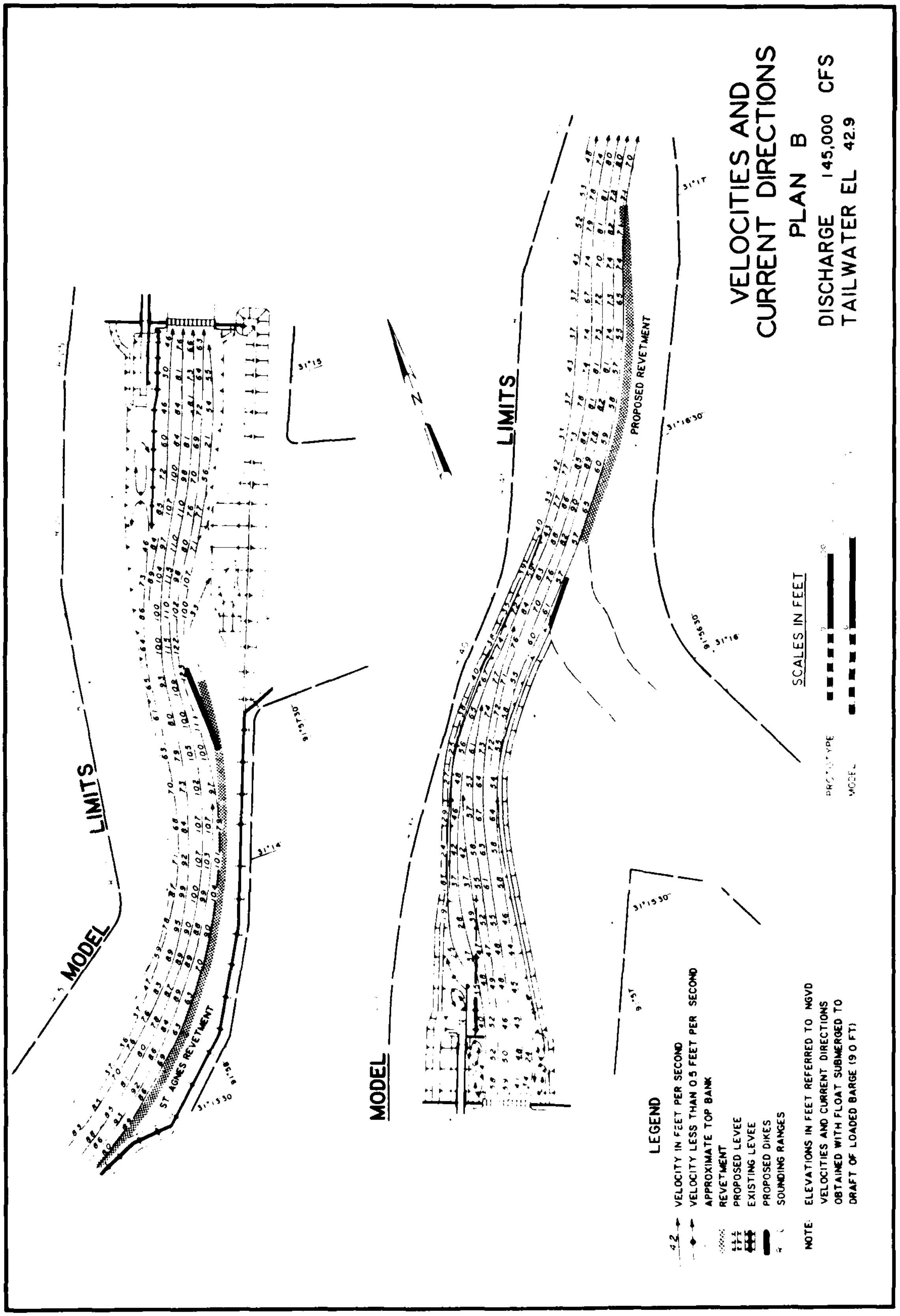
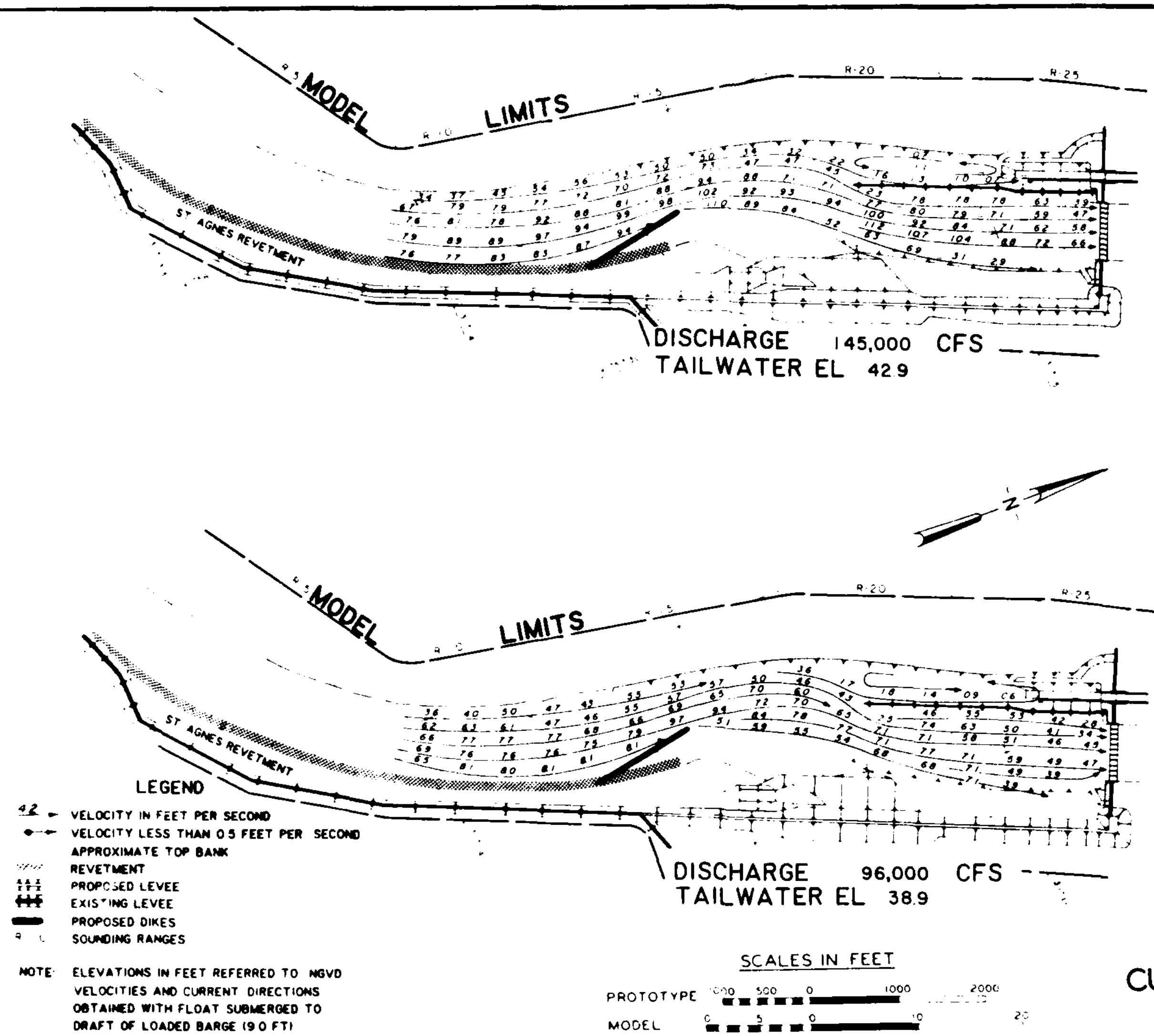
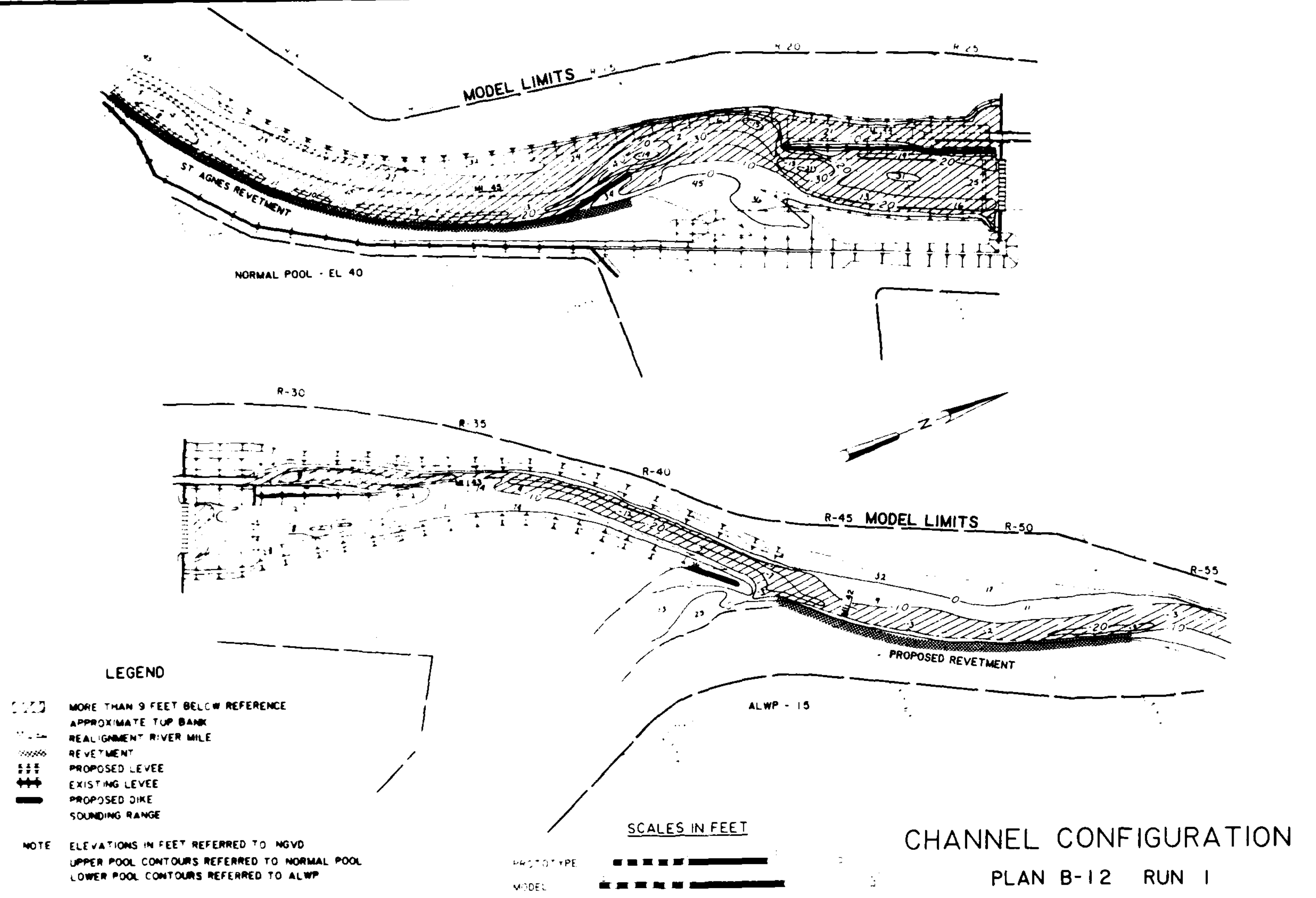

MODEL LIMITS
ST AGNES REVETMENT
MODEL LIMITS
PROPOSED REVETMENT
N
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
APPROXIMATE TOP BANK
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKES
SOUNDING RANGES
NOTE: ELEVATIONS IN FEET REFERRED TO NGVD
VELOCITIES AND CURRENT DIRECTIONS
OBTAINED WITH FLOAT SUBMERGED TO
DRAFT OF LOADED BARGE (9.0 FT)
SCALES IN FEET
PROTOTYPE
MODEL
VELOCITIES AND
CURRENT DIRECTIONS
PLAN B
DISCHARGE 96,000 CFS
TAILWATER EL 38.9

PLATE 16


VELOCITIES AND
CURRENT DIRECTIONS
PLAN B
DISCHARGE 145,000 CFS
TAILWATER EL 42.9
MODEL LIMITS
MODEL LIMITS
ST AGNES REVETMENT
PROPOSED REVETMENT
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
APPROXIMATE TOP BANK
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKES
SOUNDING RANGES
NOTE: ELEVATIONS IN FEET REFERRED TO NGVD
VELOCITIES AND CURRENT DIRECTIONS
OBTAINED WITH FLOAT SUBMERGED TO
DRAFT OF LOADED BARGE (9.0 FT)

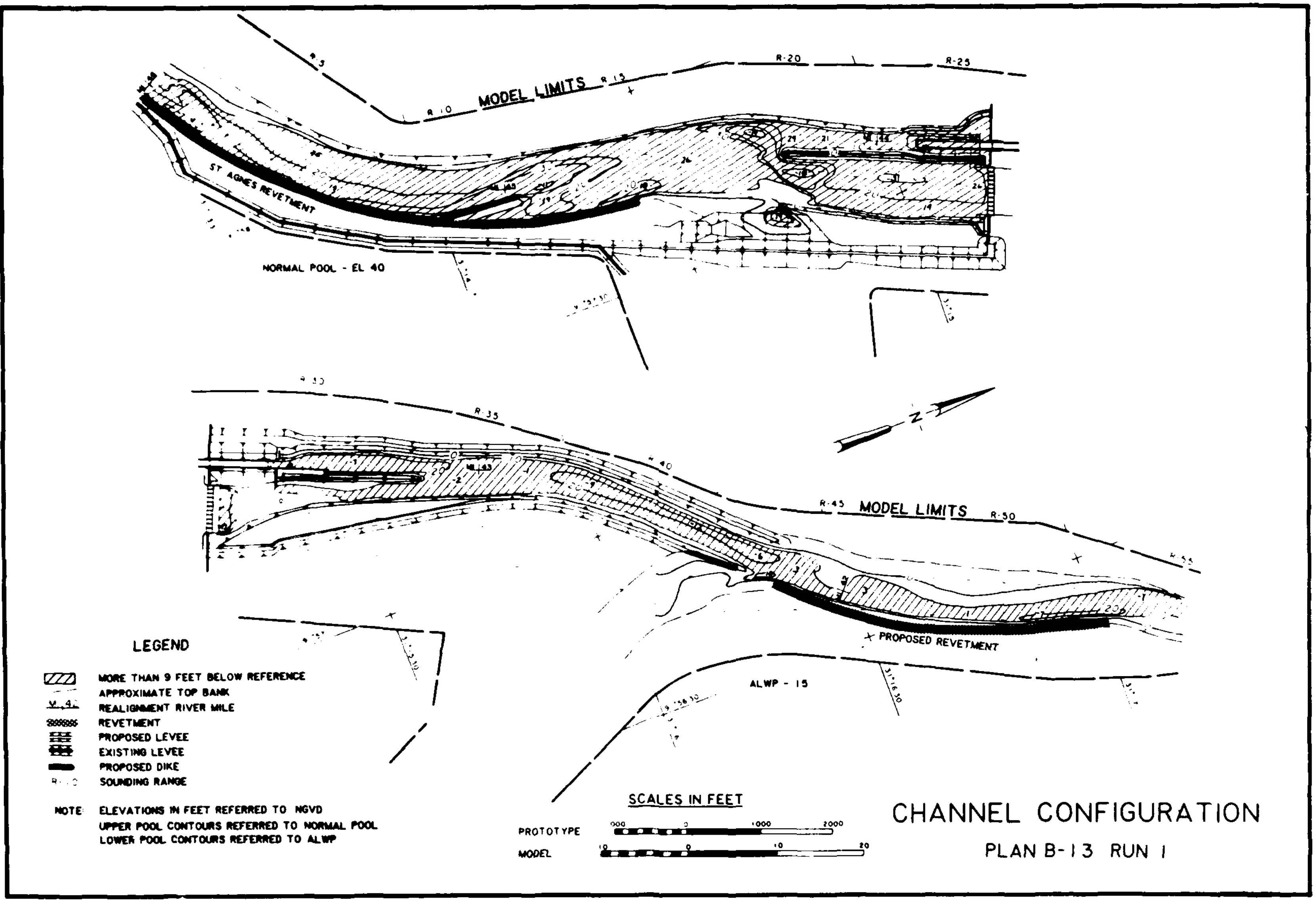


VELOCITIES AND CURRENT DIRECTIONS
PLAN B-4



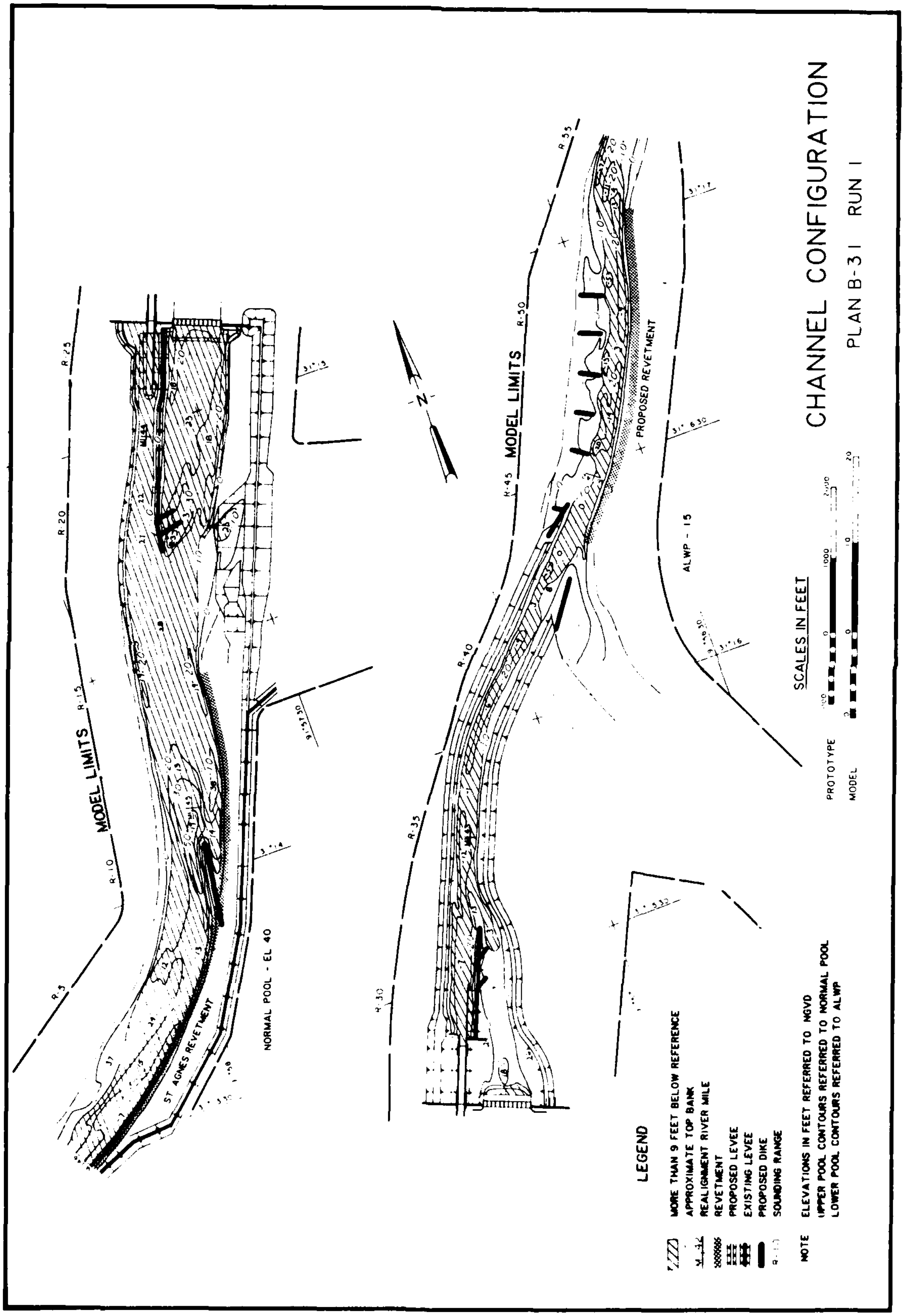
CHANNEL CONFIGURATION

PLAN B-12 RUN 1



CHANNEL CONFIGURATION

PLAN B-13 RUN 1


CHANNEL CONFIGURATION
PLAN B-31 RUN 1
MODEL LIMITS
MODEL LIMITS
ST AGNES REVETMENT
NORMAL POOL - EL 40
PROPOSED REVETMENT
ALWP - 15
N
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
MORE THAN 9 FEET BELOW REFERENCE
APPROXIMATE TOP BANK
REALIGNMENT RIVER MILE
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKE
SOUNDING RANGE
NOTE
ELEVATIONS IN FEET REFERRED TO NGVD
UPPER POOL CONTOURS REFERRED TO NORMAL POOL
LOWER POOL CONTOURS REFERRED TO ALWP

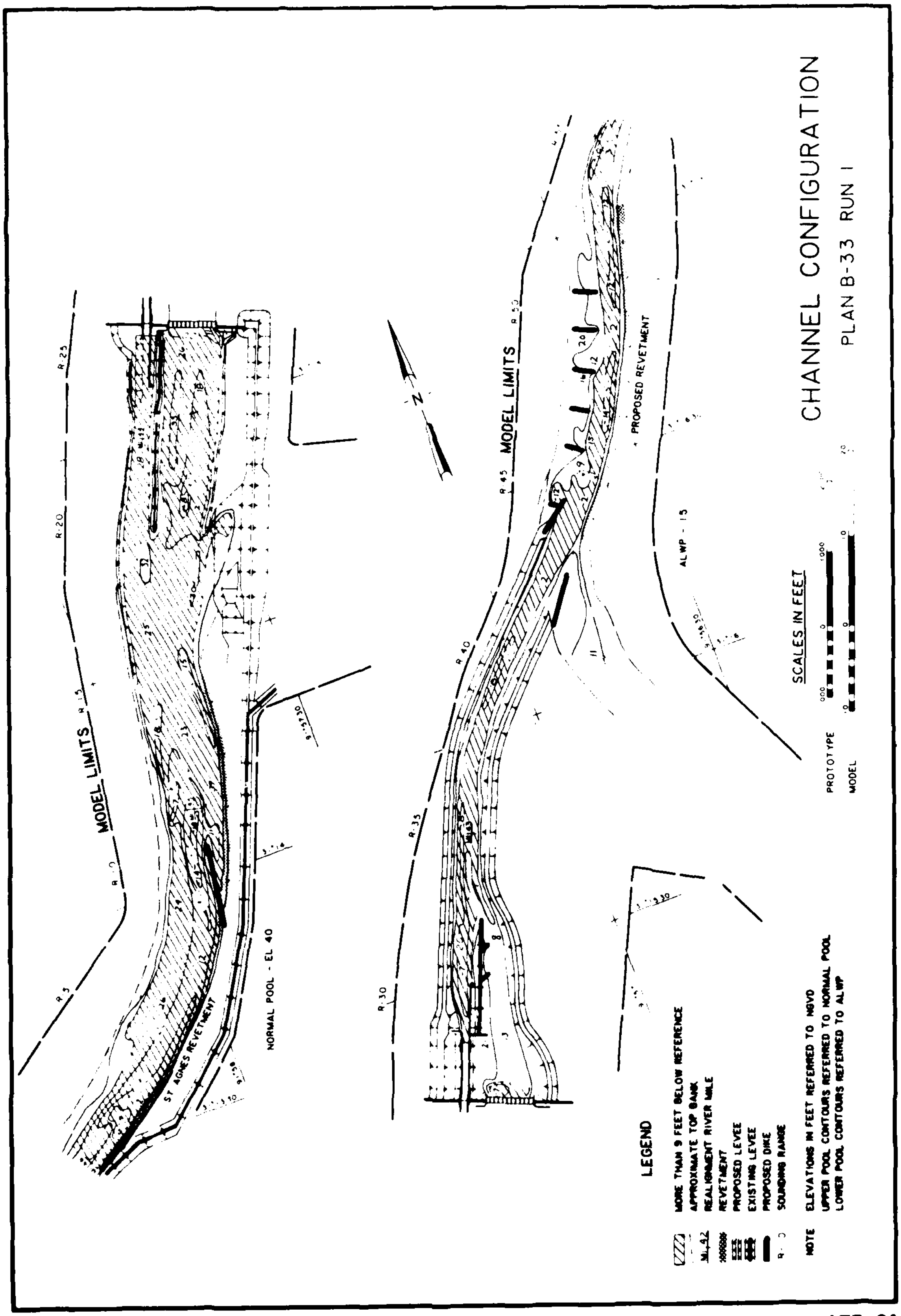
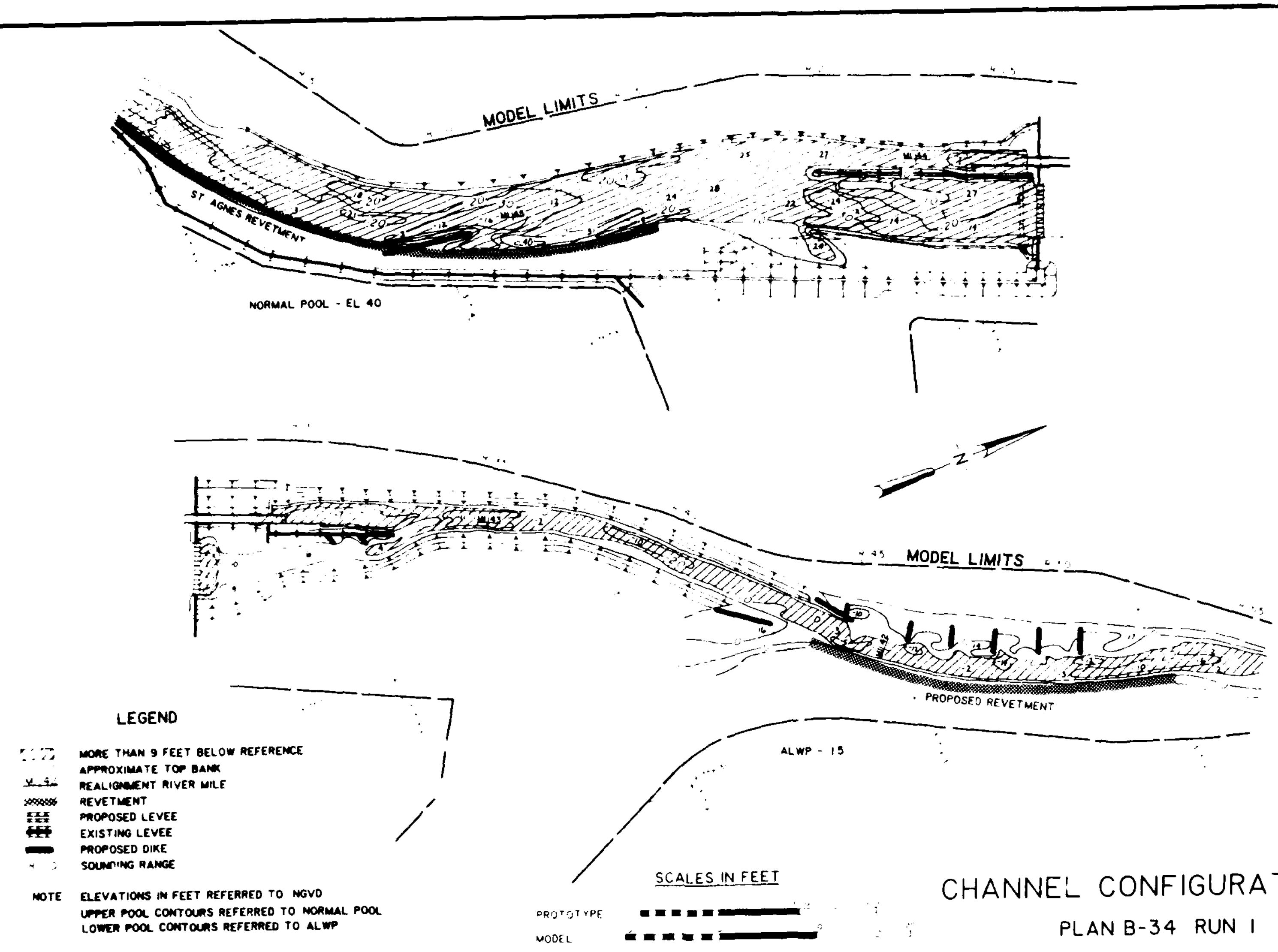

CHANNEL CONFIGURATION
PLAN B-33 RUN 1
MODEL LIMITS
MODEL LIMITS
ST AGNES REVETMENT
NORMAL POOL - EL 40
PROPOSED REVETMENT
ALWP - 15
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
MORE THAN 9 FEET BELOW REFERENCE
APPROXIMATE TOP BANK
REALIGNMENT RIVER MILE
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKE
SOUNDING RANGE
NOTE
ELEVATIONS IN FEET REFERRED TO NGVD
UPPER POOL CONTOURS REFERRED TO NORMAL POOL
LOWER POOL CONTOURS REFERRED TO ALWP

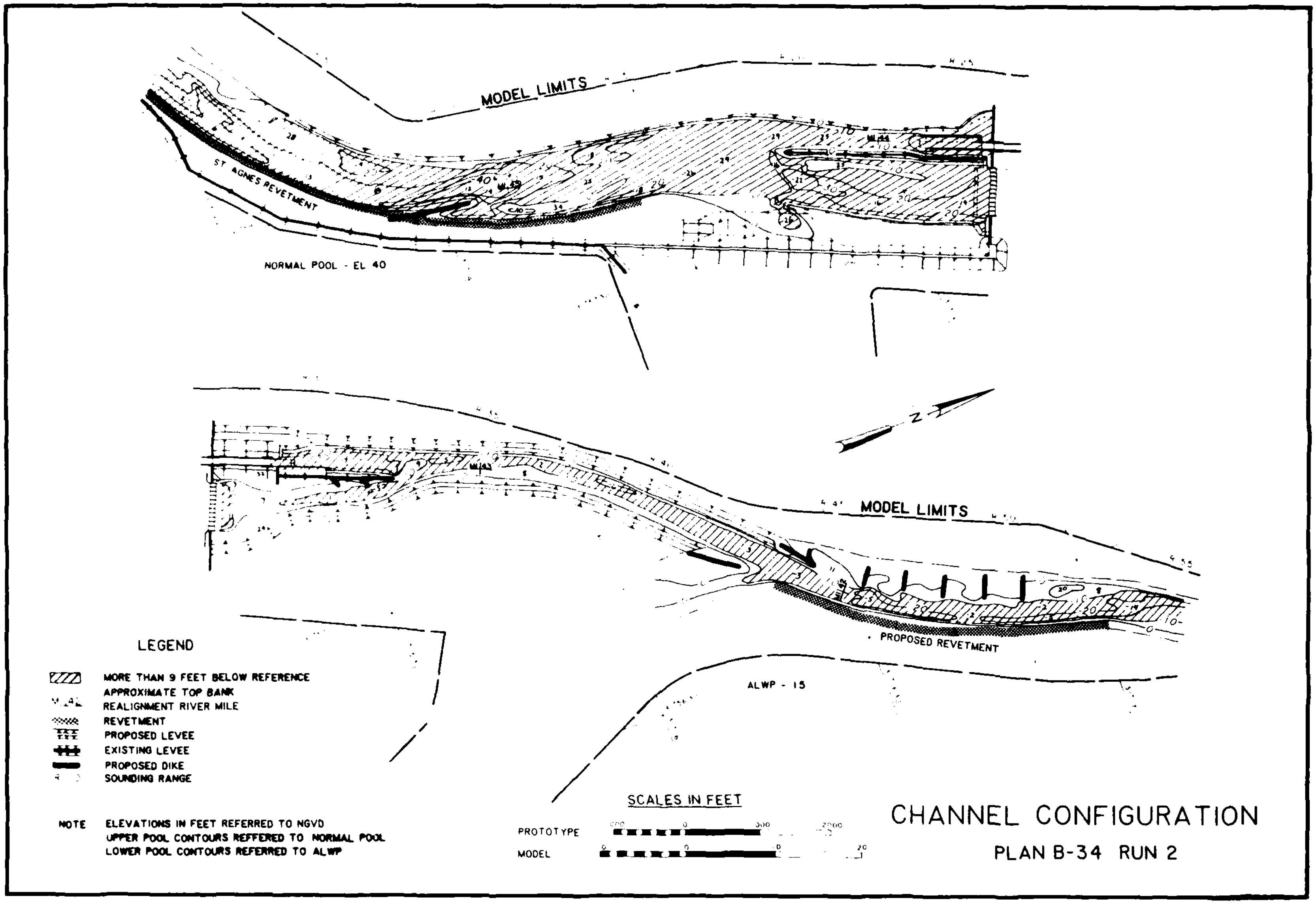
PLATE 21



CHANNEL CONFIGURATION

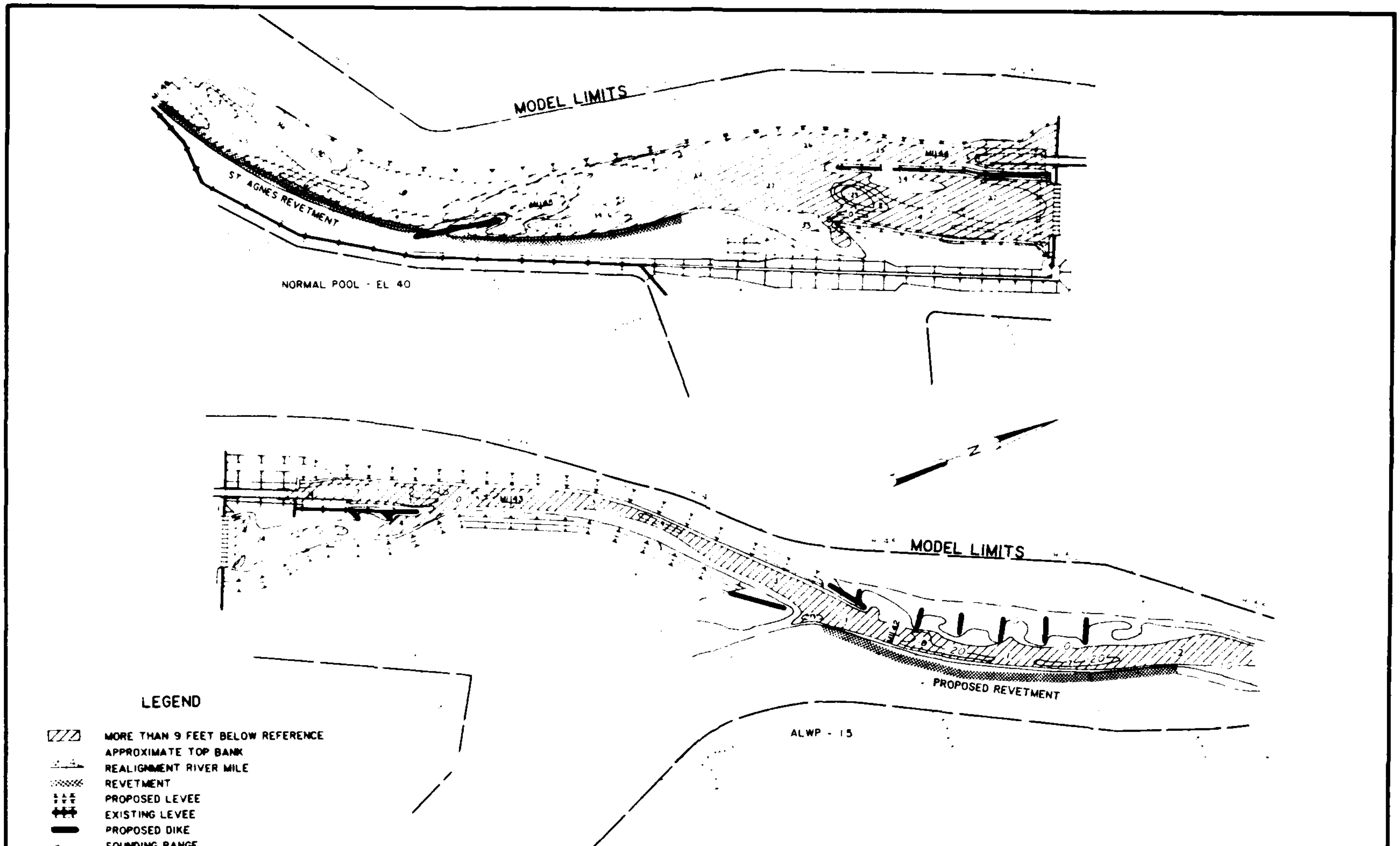
PLAN B-34 RUN I

PLATE 22



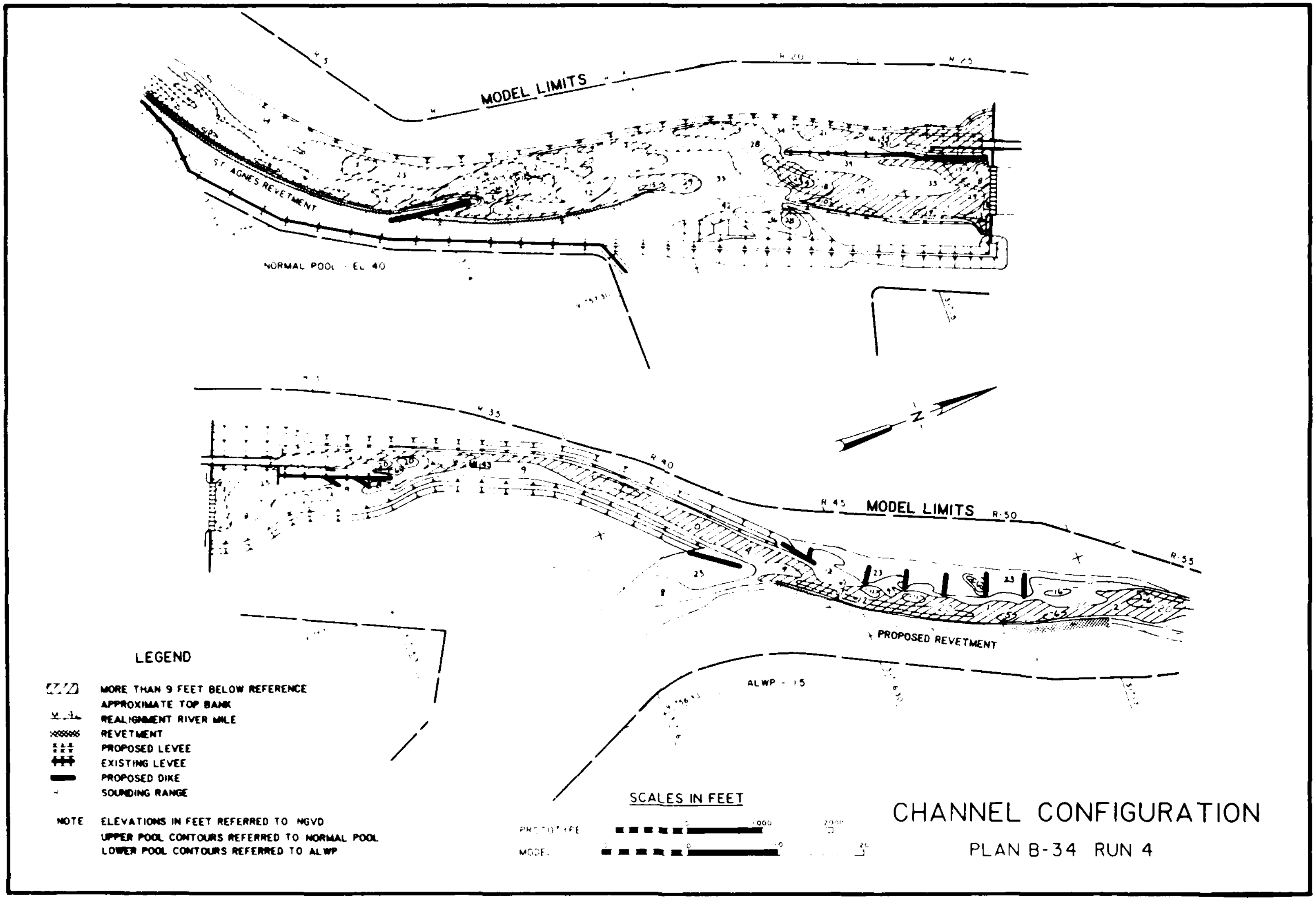
CHANNEL CONFIGURATION

PLAN B-34 RUN 2



CHANNEL CONFIGURATION

PLAN B-34 RUN 3


MODEL LIMITS
ST AGNES REVETMENT
NORMAL POOL - EL 40
MODEL LIMITS
R 35
R 40
R 45
R 50
R 55
N
PROPOSED REVETMENT
ALWP - 15
LEGEND
MORE THAN 9 FEET BELOW REFERENCE
APPROXIMATE TOP BANK
REALIGNMENT RIVER MILE
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKE
SOUNDING RANGE
NOTE
ELEVATIONS IN FEET REFERRED TO NGVD
UPPER POOL CONTOURS REFERRED TO NORMAL POOL
LOWER POOL CONTOURS REFERRED TO ALWP
SCALES IN FEET
PROTOTYPE
MODEL
CHANNEL CONFIGURATION
PLAN B-34 RUN 4

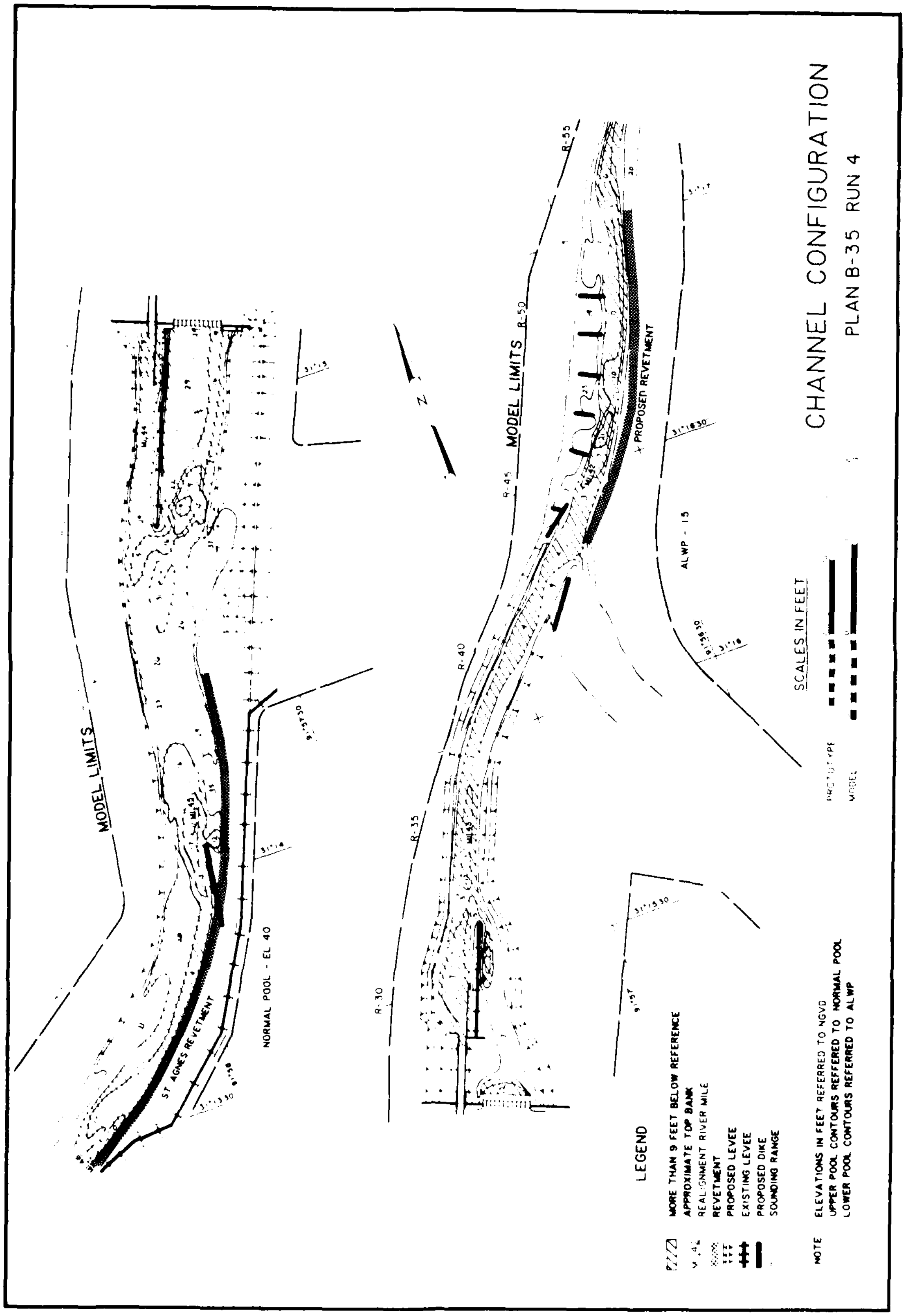
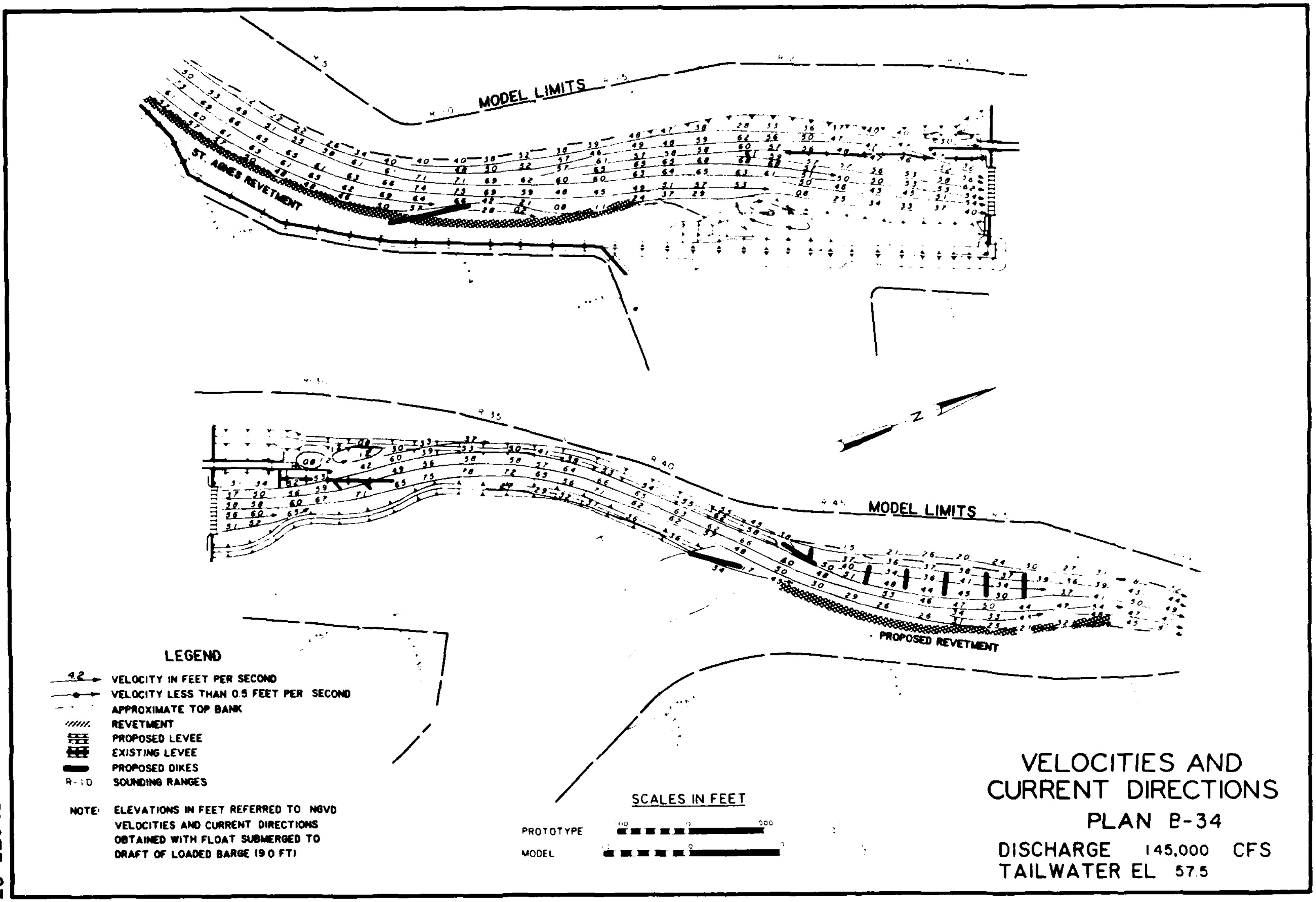

CHANNEL CONFIGURATION
PLAN B-35 RUN 4
MODEL LIMITS
MODEL LIMITS
ST AGNES REVETMENT
NORMAL POOL - EL 40
PROPOSED REVETMENT
ALWP - 15
R-30
R-35
R-40
R-45
R-50
R-55
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
MORE THAN 9 FEET BELOW REFERENCE
APPROXIMATE TOP BANK
REALIGNMENT RIVER MILE
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKE
SOUNDING RANGE
NOTE
ELEVATIONS IN FEET REFERRED TO NGVD
UPPER POOL CONTOURS REFERRED TO NORMAL POOL
LOWER POOL CONTOURS REFERRED TO ALWP

PLATE 26


MODEL LIMITS
ST. AGNES REVETMENT
MODEL LIMITS
PROPOSED REVETMENT
N
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
APPROXIMATE TOP BANK
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKES
SOUNDING RANGES
NOTE: ELEVATIONS IN FEET REFERRED TO NGVD
VELOCITIES AND CURRENT DIRECTIONS
OBTAINED WITH FLOAT SUBMERGED TO
DRAFT OF LOADED BARGE (9.0 FT)
SCALES IN FEET
PROTOTYPE
MODEL
VELOCITIES AND
CURRENT DIRECTIONS
PLAN B-34
DISCHARGE 145,000 CFS
TAILWATER EL 57.5

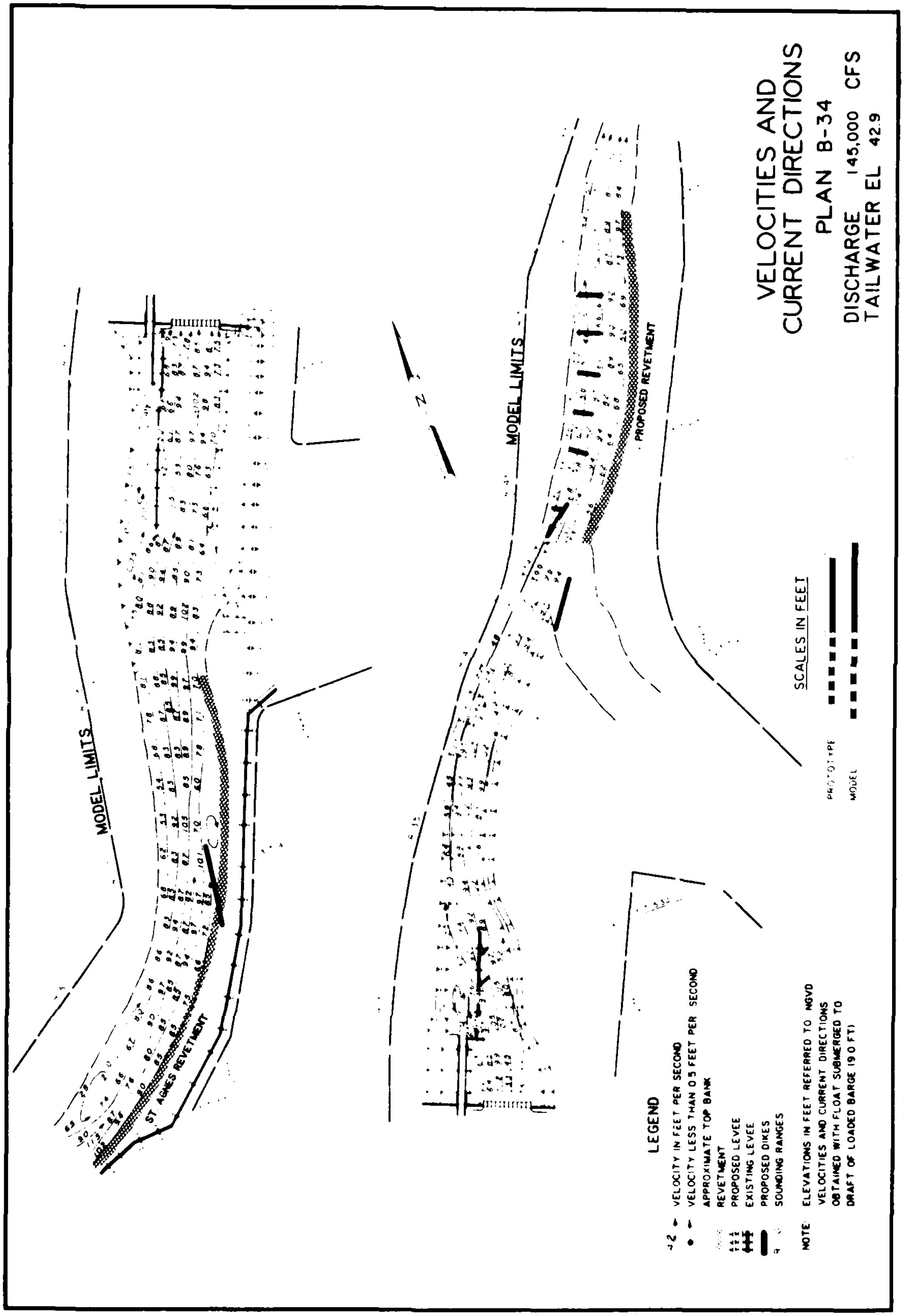
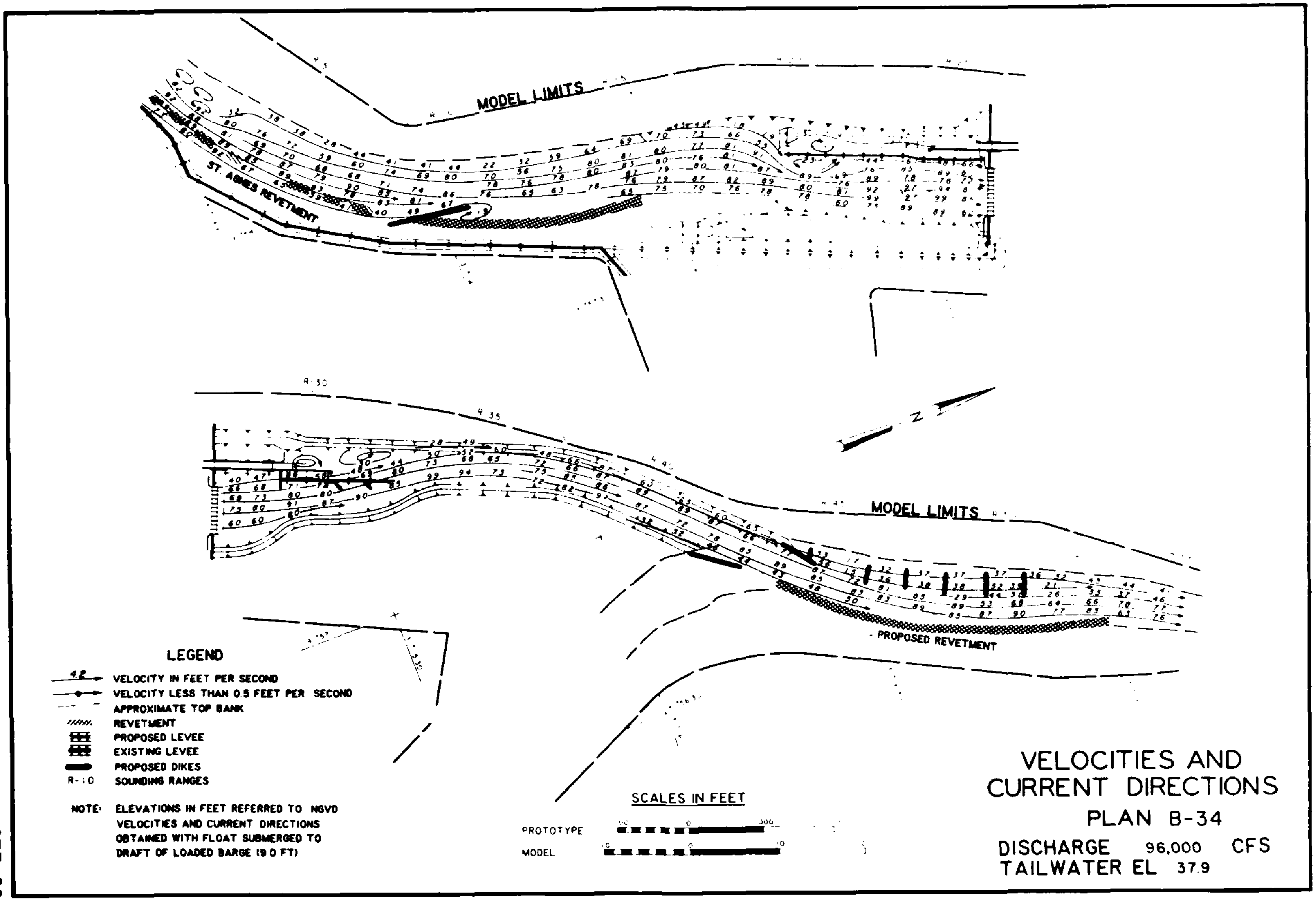

VELOCITIES AND
CURRENT DIRECTIONS
PLAN B-34
DISCHARGE 145,000 CFS
TAILWATER EL 42.9
MODEL LIMITS
MODEL LIMITS
ST AGNES REVETMENT
PROPOSED REVETMENT
N
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
4.2 VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
APPROXIMATE TOP BANK
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKES
SOUNDING RANGES
NOTE: ELEVATIONS IN FEET REFERRED TO NGVD
VELOCITIES AND CURRENT DIRECTIONS OBTAINED WITH FLOAT SUBMERGED TO DRAFT OF LOADED BARGE (19.0 FT)

PLATE 28



VELOCITIES AND CURRENT DIRECTIONS

PLAN B-34

DISCHARGE 96,000 CFS

TAILWATER EL 37.9

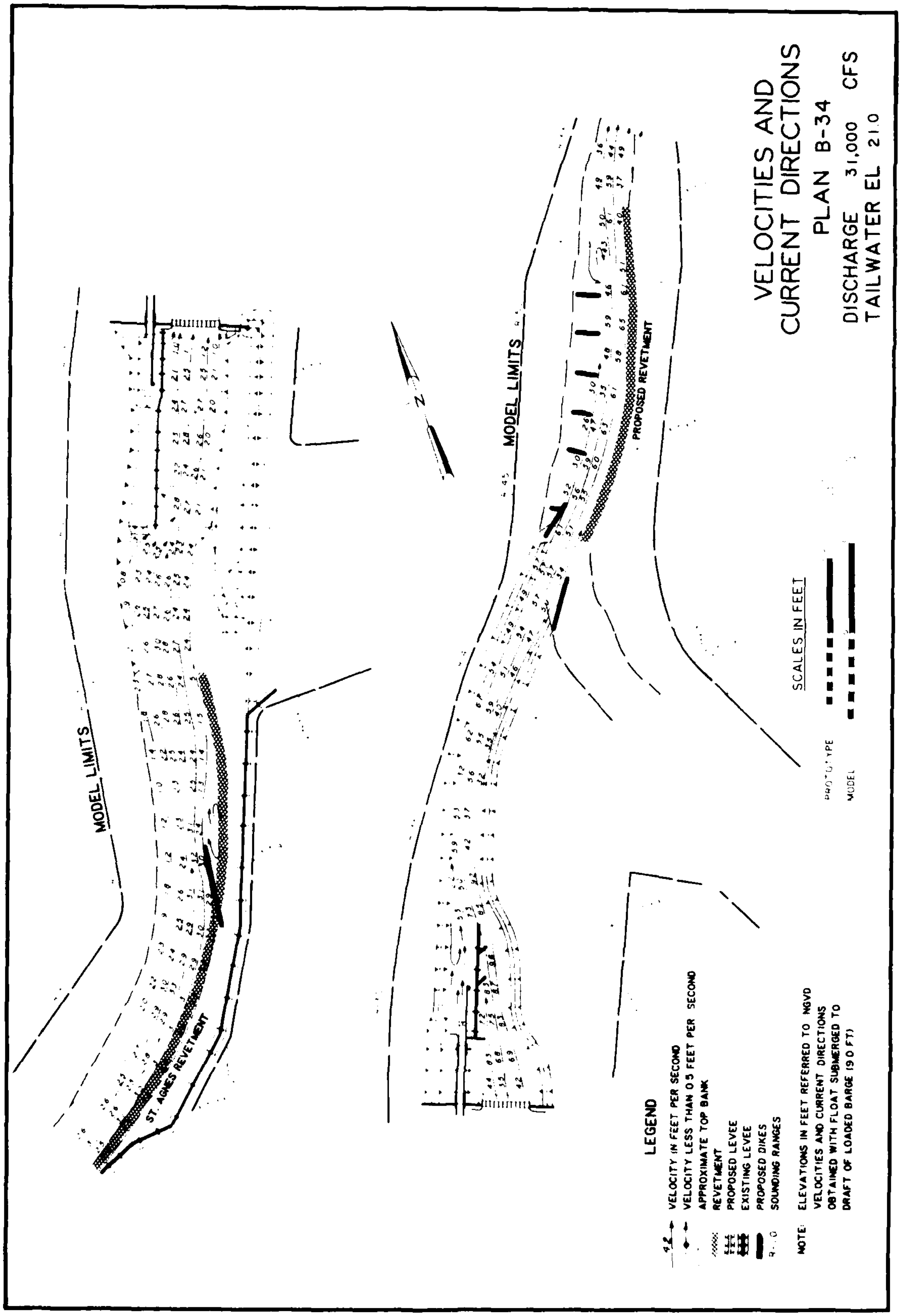
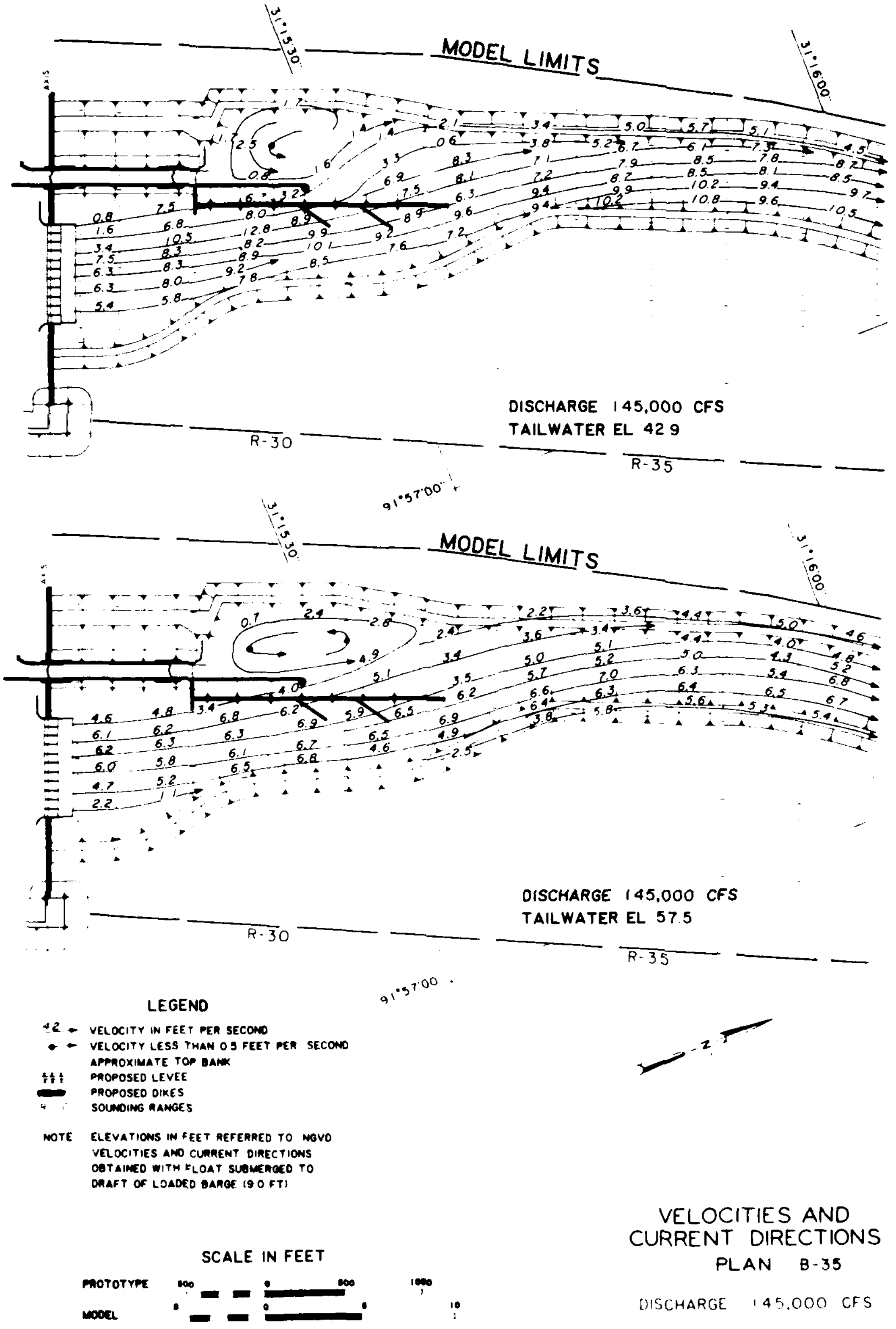
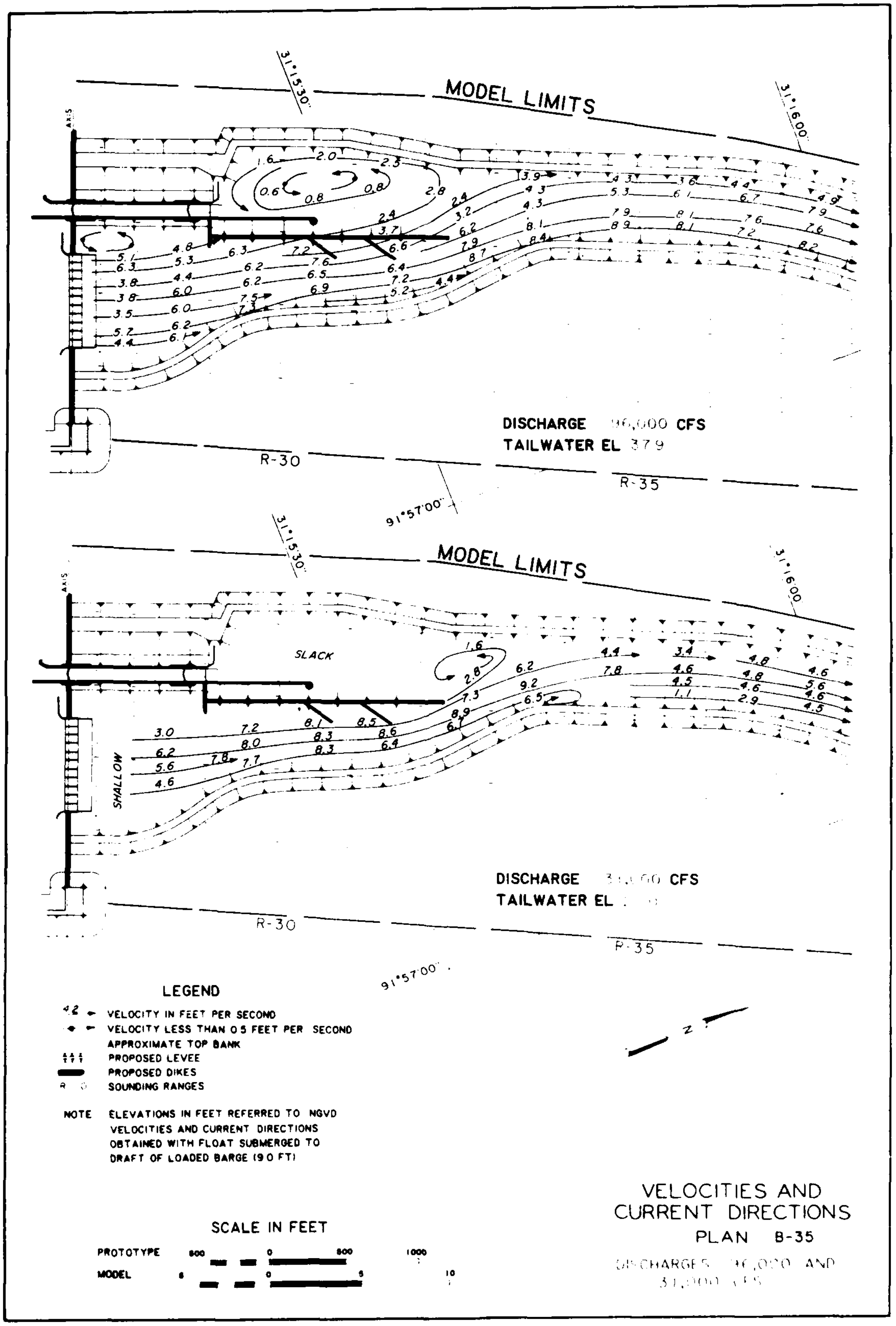

VELOCITIES AND
CURRENT DIRECTIONS
PLAN B-34
DISCHARGE 31,000 CFS
TAILWATER EL 21.0
MODEL LIMITS
MODEL LIMITS
PROPOSED REVETMENT
ST. AGNES REVETMENT
N
SCALES IN FEET
PROTOTYPE
MODEL
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
APPROXIMATE TOP BANK
REVETMENT
PROPOSED LEVEE
EXISTING LEVEE
PROPOSED DIKES
SOUNDING RANGES
NOTE: ELEVATIONS IN FEET REFERRED TO NGVD
VELOCITIES AND CURRENT DIRECTIONS
OBTAINED WITH FLOAT SUBMERGED TO
DRAFT OF LOADED BARGE (9.0 FT)

PLATE 30



VELOCITIES AND CURRENT DIRECTIONS
PLAN B-35
DISCHARGE 145,000 CFS


MODEL LIMITS
31°15'30"
31°16'00"
DISCHARGE 96,000 CFS
TAILWATER EL
R-30
R-35
91°57'00"
SLACK
SHALLOW
DISCHARGE CFS
TAILWATER EL
LEGEND
VELOCITY IN FEET PER SECOND
VELOCITY LESS THAN 0.5 FEET PER SECOND
APPROXIMATE TOP BANK
PROPOSED LEVEE
PROPOSED DIKES
SOUNDING RANGES
NOTE ELEVATIONS IN FEET REFERRED TO NGVD
VELOCITIES AND CURRENT DIRECTIONS
OBTAINED WITH FLOAT SUBMERGED TO
DRAFT OF LOADED BARGE (9.0 FT)
SCALE IN FEET
PROTOTYPE 500 0 500 1000
MODEL 5 0 5 10
VELOCITIES AND
CURRENT DIRECTIONS
PLAN B-35
DISCHARGES 96,000 AND

END
DTIC
10-86

END

10-86

DTIC