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HYDRAULICS
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YAZOO BACKWATER PUMPING STATION SUMP WEST-CENTRAL MISSISSIPPI

Hydraulic Model Investigation

by

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Numerical and physical hydraulic model tests were conducted to investigate the hydraulic performance of the Yazoo Backwater Pumping Station approach channel, sump abutments, and sump. The numerical model was used as a tool for evaluating and screening various approach channel designs prior to testing in the physical models. Physical model tests were conducted in a 1:12.5-scale section model and a 1:26-scale comprehensive model. A variety of operating conditions with various water-surface elevations were evaluated. In the section model, tests indicated that the intensity of the floor vortices increased as the suction bell was moved closer to the floor. Various configurations of approach training walls were evaluated in the section model.

In the 1:26-scale model, comprehensive tests were initially conducted to investigate hydraulic performance in a 15-pump, 17,500-cfs-capacity pumping station. Asymmetrical pump operation generated lateral flows in the approach channel, which generated adverse flow

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distribution in the pump bays. Tests indicated that a streamlined pump intake design compensated for adverse flows in the approach.

At the request of the US Army Engineer District, Vicksburg, the capacity of the pumping station was reduced from 17,500 to 10,000 cfs. Hydraulic performance with the 10,000-cfs station was similar to that observed in the 17,500-cfs station. Tests were conducted to refine the design of the streamlined sump by investigating various pump bay widths. Test results indicated that the pump bay widths could be reduced from 28 to 23 ft if vortex suppressor beams were installed in the pump bays. The adopted design developed from the model study should provide satisfactory hydraulic performance for anticipated flow conditions.

PREFACE

The study of the sump for the Yazoo Backwater Pumping Station was authorized by the Headquarters, US Army Corps of Engineers (HQUSACE), on 15 February 1984, at the request of the US Army Engineer District, Vicksburg (LMK).

The study was conducted during the period February 1984 to December 1987 in the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) under the direction of Messrs. H. B. Simmons and F. A. Herrmann, Jr., former and present Chiefs of the Hydraulics Laboratory, and J. L. Grace, Jr., and Glenn A. Pickering, former and present Chiefs of the Hydraulic Structures Division. The tests were conducted by Messrs. Bobby P. Fletcher and James R. Rucker, Jr., Spillways and Channels Branch, under the direct supervision of Mr. Noel R. Oswalt, Chief of the Spillways and Channels Branch. This report was prepared by Mr. Fletcher and edited by Mrs. Marsha C. Gay, Information Technology Laboratory, WES.

During the course of the study, Messrs. Tom Munsey and John S. Robertson, HQUSACE; Glenn C. Miller, Claudy E. Thomas, and Malcolm L. Dove, US Army Engineer Division, Lower Mississippi River; Jim Luther, US Army Engineer District, St. Louis; and Fred Lee, John P. Meador, Johnny G. Sanders, Charles A. McKinnie, and William L. Holman, LMK, visited WES to discuss the program of model tests, observe the model in operation, and correlate test results with concurrent design work.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. 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
acres	4,046.873	square metres
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
feet of water (39.2° F)	2,988.98	pascals
inches	25.4	millimetres
miles (US statute)	1.609347	kilometres
square miles	2.589998	square kilometres

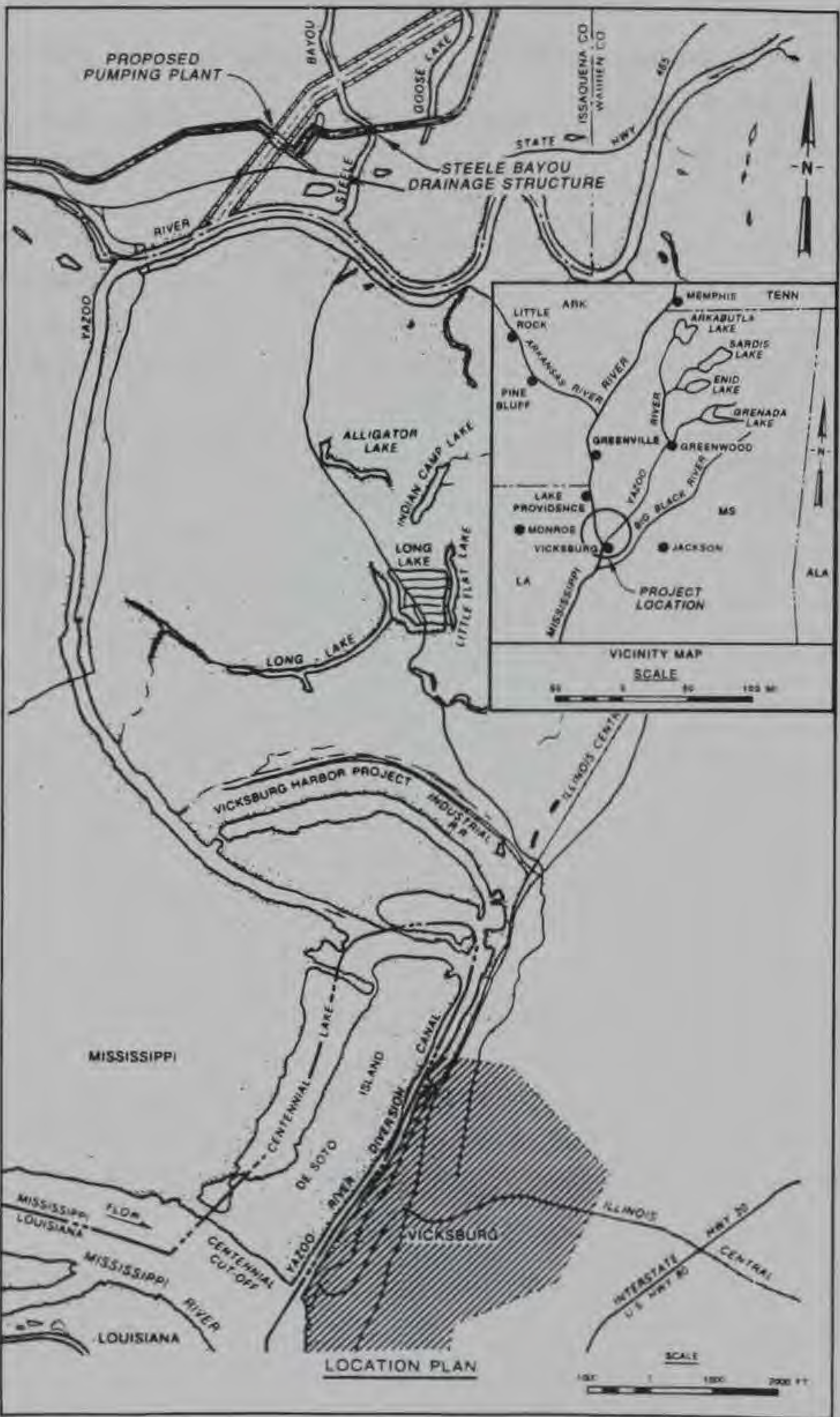

Figure 1. Location and vicinity map

YAZOO BACKWATER PUMPING STATION

WEST-CENTRAL MISSISSIPPI

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The Yazoo Backwater Area, located in west-central Mississippi (Figure 1), contains approximately 1,406 square miles* (Figure 2) protected from backwater flooding and has a drainage area of 4,093 square miles of alluvial land.

2. The project area comprises approximately 539,000 acres in the lower portion of the Yazoo Area, which is subject to inundation by the 100-year flood (Figure 2), and includes parts of Humphreys, Issaquena, Sharkey, Warren, Washington, and Yazoo Counties, Mississippi, and part of Madison Parish, Louisiana. This area is generally triangular in shape and extends northward from Vicksburg some 60 miles to the latitude of Hollandale and Belzoni, Mississippi. Big Sunflower and Little Sunflower Rivers, Deer Creek, and Steele Bayou flow through the area. The Deer Creek ridge, a ridge of higher ground along which US Highway 61 runs, divides the area into two separate ponding areas. Interior drainage in the upper ponding area is evacuated by a drainage structure at the mouth of the Little Sunflower River, while interior drainage in the lower ponding area is evacuated by a drainage structure at the mouth of Steele Bayou.

3. The proposed Yazoo Backwater Pumping Station will be located in the lower ponding area approximately 0.8 mile west of the Steele Bayou drainage structure (Figure 1). At the beginning of this model study, the proposed pump station capacity was 17,500 cfs. During the study, the capacity was reduced to 10,000 cfs. The station will be operated in an attempt to maintain an 80-ft** sump stage from March through November and an 85-ft sump from December

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

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

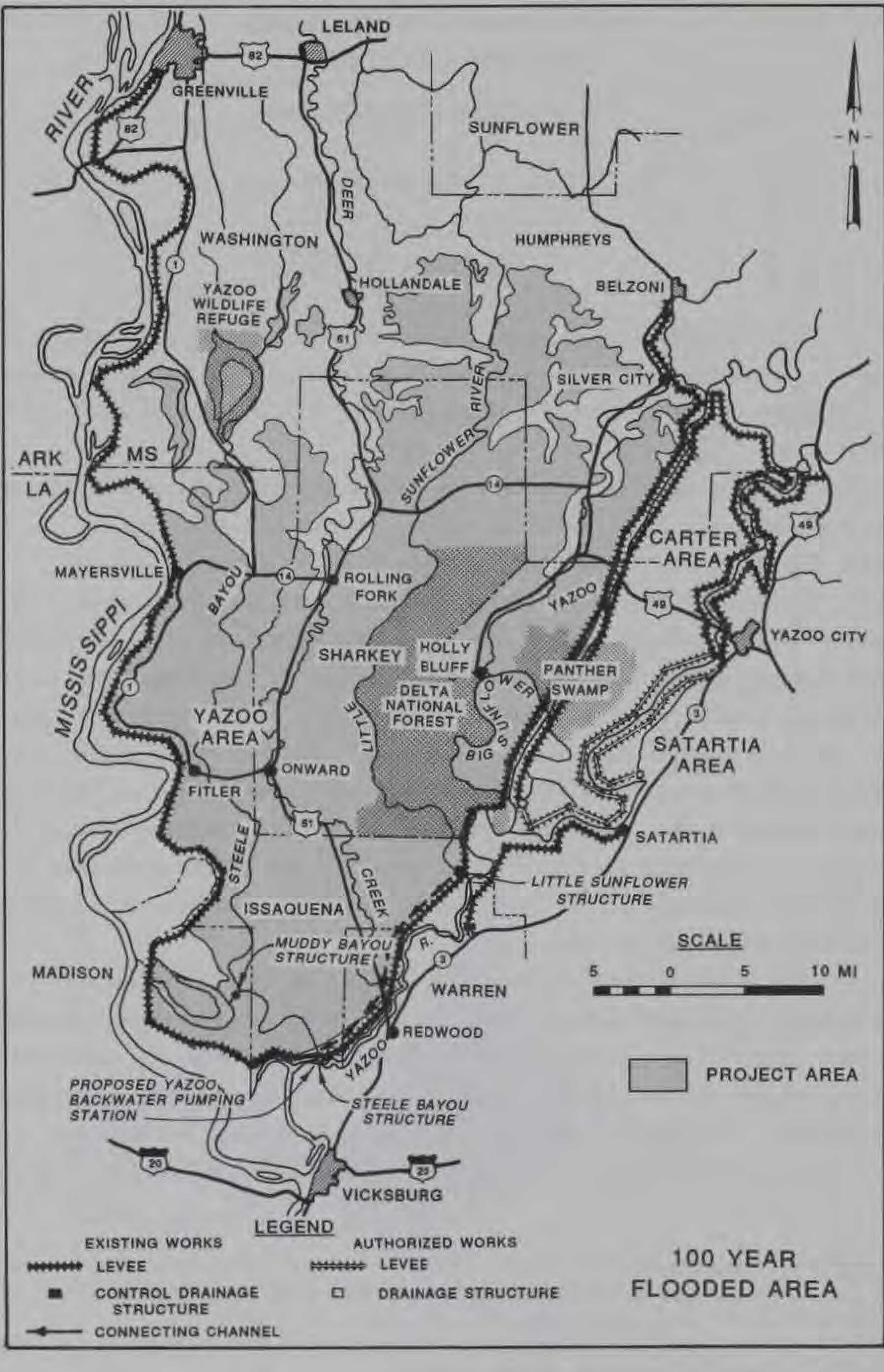

Figure 2. 100-year flood area

through February. Pumping would be initiated when interior ponding reaches el 80, except during the period 1 December-1 March when pumping would be initiated at el 85. The frequency of flooding below el 80 would be unchanged. The full pump capacity of 10,000 cfs will be used only with large floods. The inlet channel will be approximately 4,000 ft long and have a 340-ft bottom width (Plate 1). The depth of the channel will vary from 10 to 30 ft as the lay of the land varies. The inlet channel side slopes will be constructed with a 1V:4H slope.

4. The 10,000-cfs pumping station sump (Plates 2 and 3) will consist of nine bays, each having a 23-ft interior width. The floor of the sump will be located at el 59.0 and remain level throughout its length. Each sump wall will be 80.0 ft in length to provide good approach flow conditions and to provide room for the trash rake machinery, trashracks, and a service bridge. The top of the sump wall will be located at el 105.5. The flow velocity in each sump will be 2.4 fps when at the low sump level of 80.0 ft and a design flow rate of 1,167 cfs.

5. Trashracks will be located just inside the entrance of each pump sump. It is anticipated that the type of trash to be collected on the trashrack will be mainly cotton stalks, soybean stalks, small tree branches, occasional whole trees, and other typical river debris. The racks will be designed for a clear opening between bars of 3.0 in. The velocity through the rack at a sump level of 80.0 ft will be 2.8 fps at the pump's design flow rate. The incline angle of the rack will vary from 60 to 90 deg depending on the final selection of the type of mechanical raker.

6. The suction intake to each pump will be through a watertight concrete conduit connecting the end of the open sump to the eye of the impeller of the pump. The cross section of the intake may change from rectangular to circular such as in a turbine inlet bend, or it may consist of a series of simple geometric shapes to accomplish the required 90-deg bend from horizontal flow to vertical flow. The pump suction intake will be formed in reinforced concrete. Some individual designs may require permanent concrete baffles or splitter walls to direct the flow properly into the pump impeller. The detailed design of the pump suction intake will be determined by the pump supplier.

7. The pump discharge system will consist of a concrete discharge tunnel that transitions from the circular cross-section pump elbow to a

rectangular outlet section and a backflow gate. The ceiling of the discharge exit will be located at el 76.5, which is 2.5 ft below the minimum pumping river el of 79.0. The floor of the discharge outlet will be located at el 68.0, which is the bottom of the outlet channel. To limit the discharge velocity to within the range of 8 to 10 fps at the pump's maximum flow rate, the dimensions of the discharge opening would be approximately 8.5 ft high by 16.5 ft wide. These dimensions will be the basis for the minimum size discharge opening.

8. A backflow gate will be placed at the end of the discharge system. The backflow gate, which will contain multiple shutters or flaps, will prevent reverse flow through the pumping system upon pump start-up and shutdown. Secondly, the backflow gate will be used as a throttling gate during pumping conditions of low and negative static heads. Should the pumps require this mode of operation, the shutter openings in this gate will be sized to provide the necessary additional losses to keep the pump in the safe operating area of its head-discharge curve. If required during low-head pumping, the gate will remain in the fully down position after pump start-up and will not be raised until the static head has increased to a safe level for the pump.

Purpose and Scope of the Model Studies

9. A numerical model was used to ascertain if flows in the approach channel and pump bays displayed any objectionable features. The numerical model was an effective device that complemented and reduced the testing in the physical models.

10. A section model that simulated three pump bays and three pump intakes was used to develop a satisfactory design for the pump bays and pump intakes.

11. A comprehensive model that simulated a portion of the approach channel and the sump was used to evaluate the hydraulic characteristics and develop modifications required for a satisfactory design of the approach channel, transition from the approach channel (abutment training walls) to the sump, and the sump.

12. The models provided information necessary for development of a design that will provide satisfactory hydraulic performance for all anticipated flow conditions.

PART II: THE MODELS

Description

13. The numerical model consisted of a two-dimensional vertically averaged hydrodynamic model WESSEL, which is based on the work of Thompson and Bernard.* The flow field was simulated to the Yazoo Backwater Pumping Station under selected operating conditions. A number of simplifying assumptions were made for the implementation of the two-dimensional numerical model:

a. Small vertical components of velocity relative to total velocity.

b. Vertical channel banks.

c. Constant depth of flow (20 ft).

d. Uniform distribution of outflow at the active pump bay entrances.

e. Uniform distribution of inflow to the approach channel.

f. No flow through channel boundaries other than inlet and outlets.

14. The 1:12.5-scale section model consisted of a ponded approach to three pump bays (Figure 3). Various training wall configurations and pump intake designs were investigated in the section model. The geometry of the various designs investigated could be readily modified and evaluated in the section model. The section model provided only qualitative results because the approach geometry to the model pump bay did not simulate the proposed prototype geometry. The most feasible designs developed in this model were tested in the comprehensive model. A portion of the floor and sidewall was transparent to permit observation of currents and turbulence approaching and entering the suction bell.

15. The 1:26-scale comprehensive model reproduced a 2,500-ft length and 1,000-ft width of approach to the sump, the sump, pump bays, and pump intakes. The model limits are indicated by the dashed lines in Plate 1. The approach channel was contained in a plywood flume and simulated with pea gravel (Figure 4). Pea gravel was used to facilitate modifications to the channel

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* J. F. Thompson and R. S. Bernard. 1985 (Aug). "WESSEL: Code for Numerical Simulation of Two-Dimensional Time-Dependent Width-Averaged Flows with Arbitrary Boundaries," Technical Report E-85-8, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

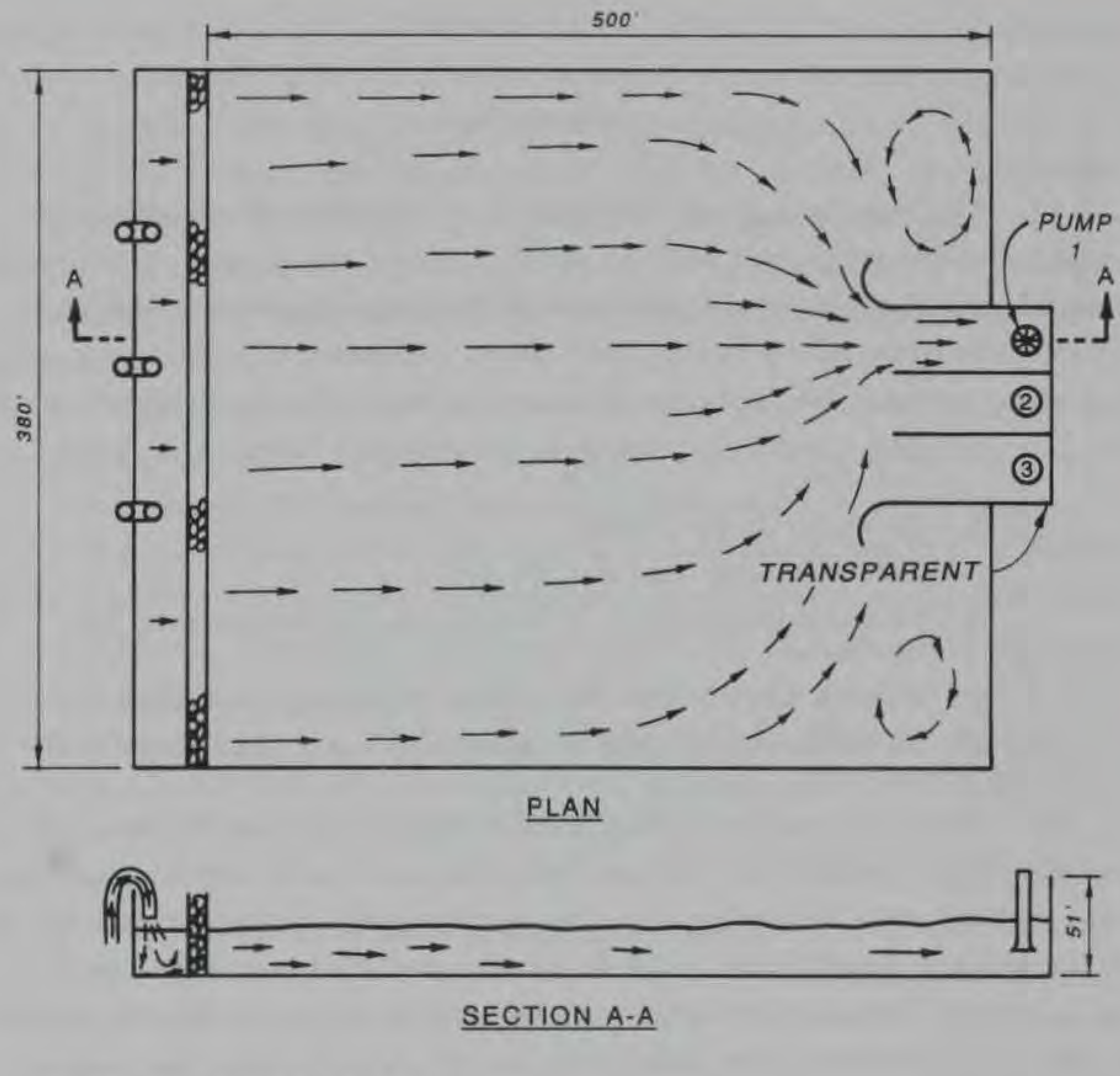
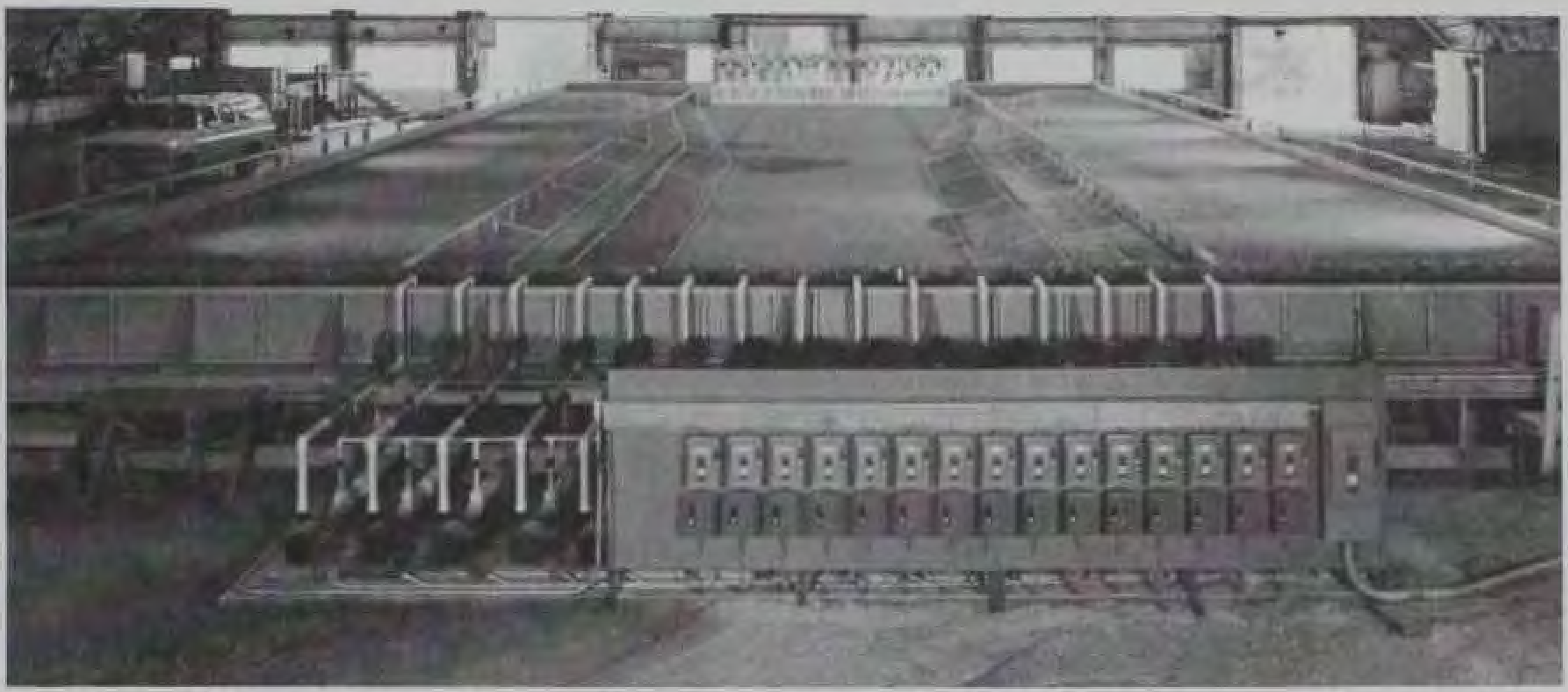


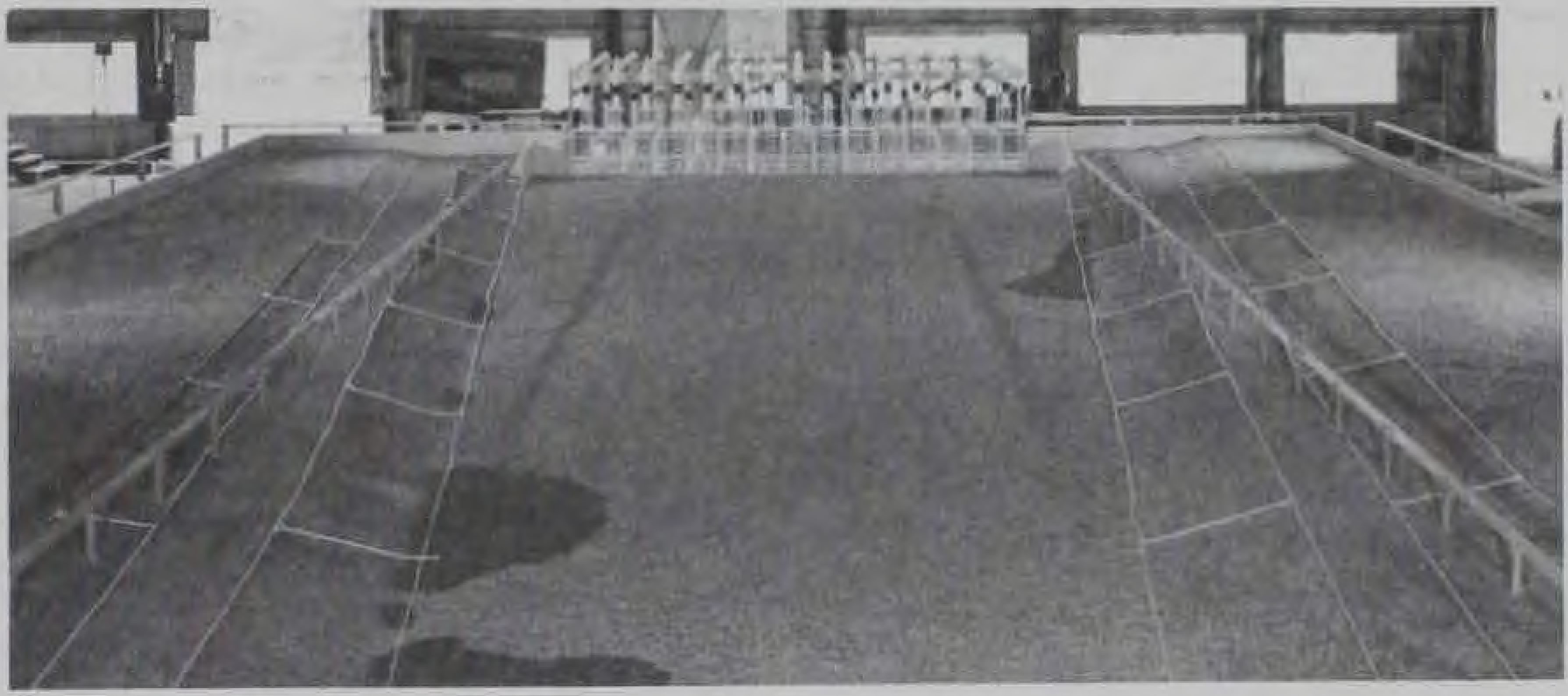
Figure 3. Section model, 1:12.5 scale

geometry in the approach channel. The sides of the sump, pump bays, and pump intakes were constructed of transparent plastic (Figure 4) to permit observation of vortices, turbulence, and subsurface currents. Flow through each pump intake was provided by individual suction pumps that permitted simulation of various flow rates through one or more pump intakes.

16. Water used in the operation of the models was supplied by pumps, and discharges were measured by electromagnetic and turbine flowmeters. Steel rails set to grade along the sides of the flumes provided a reference plane for measuring devices. Water-surface elevations were measured by point gages.



a. General upstream view



b. Approach channel

c. Pump intakes

Figure 4. Comprehensive model, scale 1:26

Evaluation Techniques

17. Techniques used for evaluation of hydraulic performance included the following:

- a. Visual observations were made to detect surface and/or submerged vortices (Figure 5). A design that permits a Stage C surface vortex or submerged vortex with a visible air core is considered unacceptable. Stages of surface vortex development are shown in Figure 5. A typical test consisted of documenting, for a given flow condition, the most severe vortex that occurred in a 10-min (model) time period. Current patterns in the approach channel were determined by dye injected into the water and confetti sprinkled on the water surface.
- b. The magnitude of currents in the approach channel and sump were measured with an electromagnetic velocity probe.
- c. Swirl angle was measured to indicate the strength of swirl entering the pump intake. A swirl angle that exceeds 3 deg is considered unacceptable. Swirl in the pump columns was indicated by a vortimeter (free-wheeling propeller with zero-pitch blades) located inside the pump column (Figure 5). Swirl angle is defined as the ratio of the blade speed V_θ at the tip of the vortimeter blade to the average velocity V_a for the cross section of the pump column. The swirl angle θ is computed from the following formula:

$$\theta = \tan^{-1} \frac{V_\theta}{V_a} \qquad (1)$$

where

$$V_\theta = \pi d n$$

$$V_a = \frac{Q}{A}$$

and

V_θ = tangential velocity at the tip of vortimeter blade, fps

V_a = average pump column axial velocity, fps

d = pump column diameter (used for blade length), ft

n = revolutions per second of the vortimeter

Q = pump discharge, cfs

A = cross-sectional area of the pump column, ft^2

- d. Boundary pressures were measured by piezometers to investigate pressure conditions inside the suction bell and formed suction intake.
- e. Velocity distribution and flow stability in the pump column were measured by impact tubes and piezometers at the approximate location of the pump propeller (Figure 6).

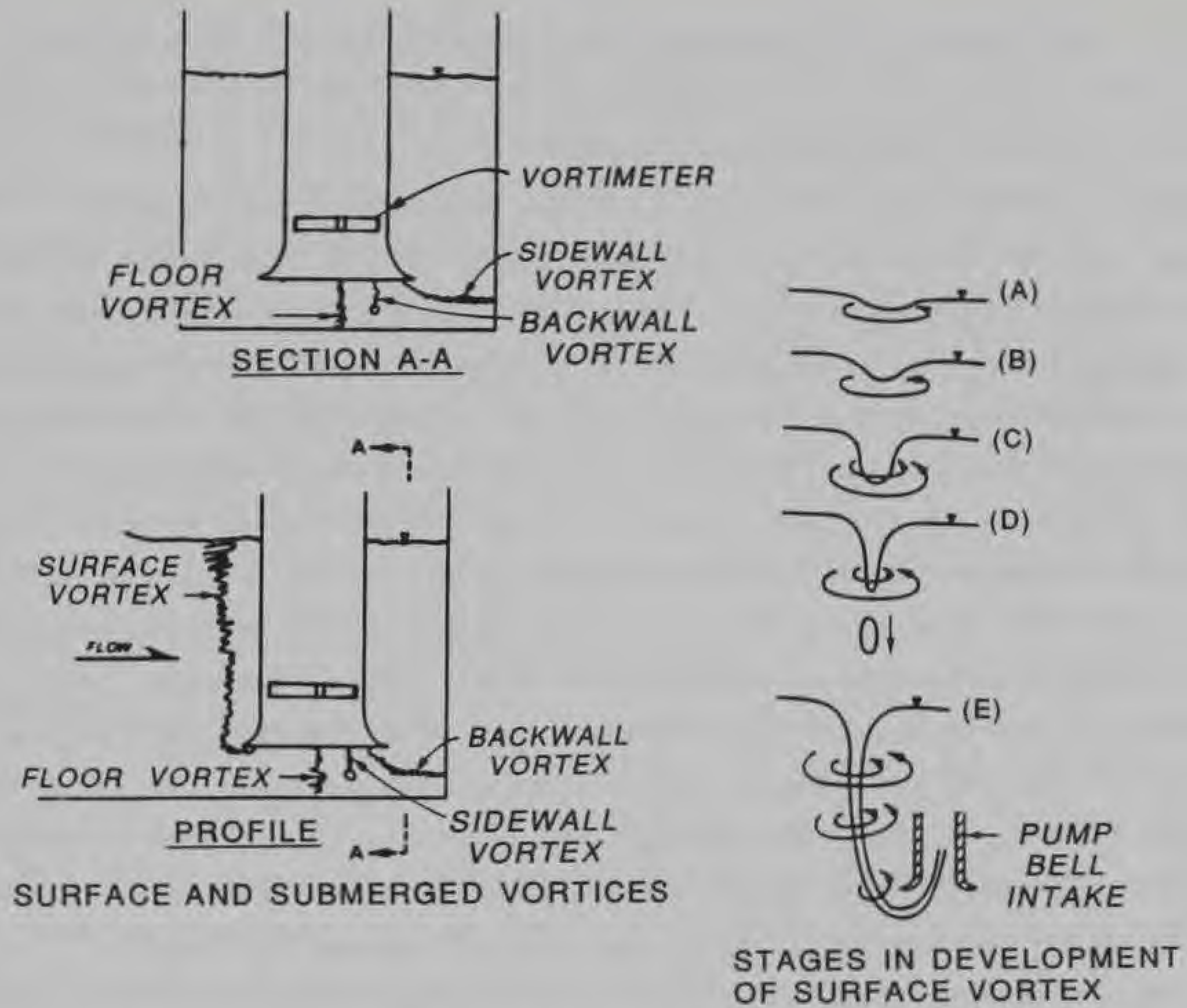


Figure 5. Typical vortices and stages of development

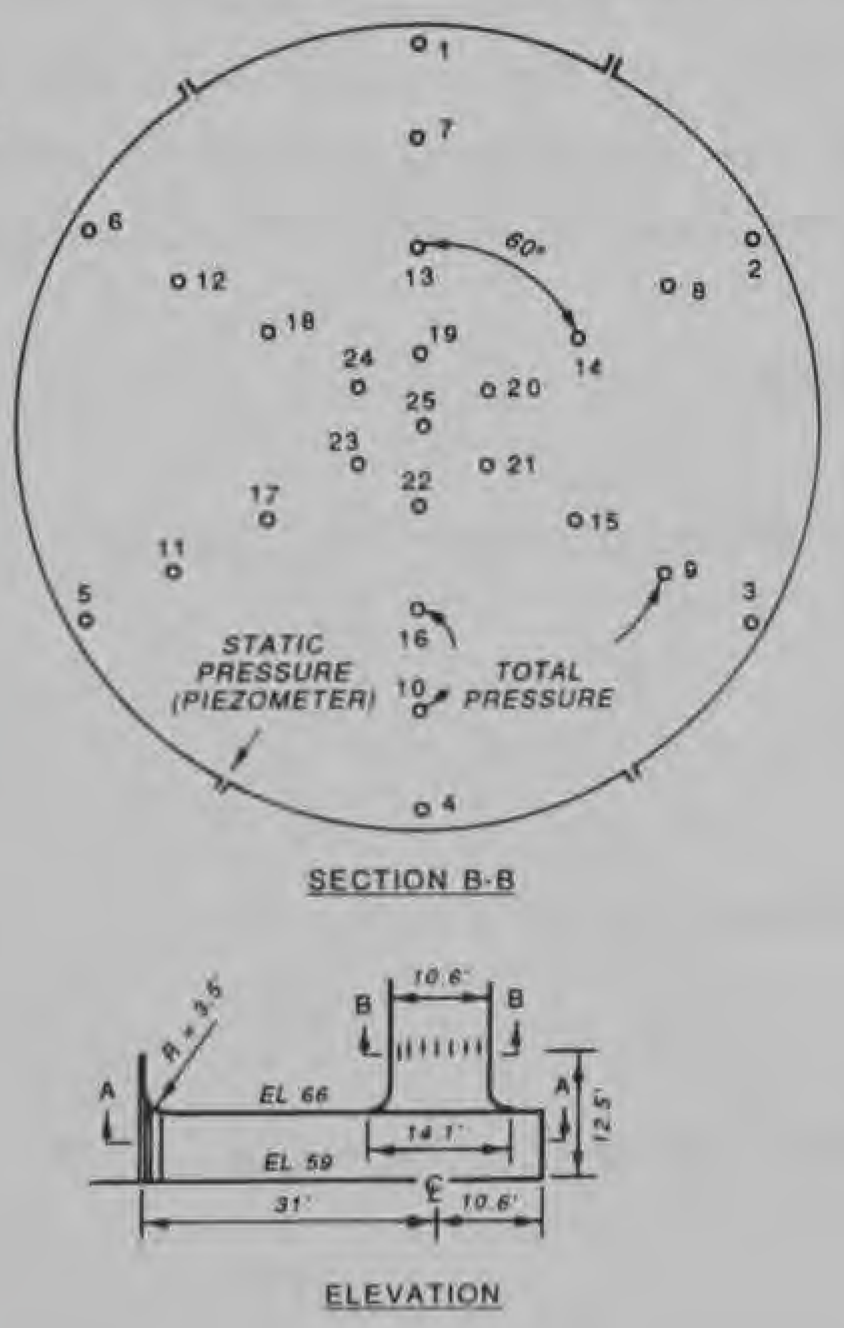


Figure 6. Static and total pressure tubes

f. Pressure fluctuations were measured by a movable probe to determine the stability of flow entering the pump intakes. Pressure fluctuations that exceeded 3 ft of water (prototype) are considered unacceptable.

18. A deviation in the ratio of the average measured velocity to the average computed velocity of 10 percent or greater was considered unacceptable. Four piezometers were located around the periphery of the pump column (Figure 6) to measure an average static pressure at this location. Impact tubes (copper tubes with 1/8-in. ID) were installed with their tips in the same plane as the four piezometers to measure the total pressure at 25 various points (Figure 6) in the pump column. The head differential between the total pressure at each point in the pump column and the average static pressure provides a velocity at each point in the pump column. This velocity was measured by 25 individual electronic differential cells. The differential cells were connected to a data acquisition system capable of collecting data for various lengths of time and sampling at various rates. The data acquisition system was also capable of analyzing the data and providing the minimum, average, maximum, root mean square, and standard deviation of the ratios of the velocities measured at each point to the theoretical average velocity.

19. A typical test consisted of stabilizing the water-surface elevation and flow rate through each pump prior to collecting data. Data were collected for 1 min (model time) and sampled at a rate of 100 samples per second. The velocity detected by each of the 25 impact tubes and the 4 piezometers during the minute of data collection was divided by the theoretical velocity based on continuity. This ratio was plotted as contour lines of equal velocity ratios.

Scale Relations

20. The models were sized so that the Reynolds number R_n defined as

$$R_n = \frac{V_a d}{\nu} \tag{2}$$

where

V_a = average velocity in pump suction column, fps

d = pump column diameter, ft

ν = kinematic viscosity of fluid

was greater than 10^5 to minimize scale effects due to viscous forces.

21. The accepted equations of hydraulic similitude, based upon Froudian criteria, were used to express the mathematical relations between the dimensions and hydraulic quantities of the models and prototype. The general relations expressed in terms of the model scales or length ratios L_r are presented in the following tabulation:

Dimension	Ratio	Scale Relations Model:Prototype Comprehensive	Section
Length	L_r	1:26	1:12.5
Area	$A_r = L_r^2$	1:676	1:156
Velocity	$V_r = L_r^{1/2}$	1:5.1	1:3.54
Discharge	$Q_r = L_r^{5/2}$	1:3,447	1:552
Time	$T_r = L_r^{1/2}$	1:5.1	1:3.54
Pressure	$P_r = L_r$	1:26	1:12.5

22. Measurements of discharge, water-surface elevation, heads, velocities, time, and frequency can be transferred quantitatively from the model to prototype equivalents by means of the scale relations.

PART III: TESTS AND RESULTS

Numerical Model

23. The numerical model was used primarily as a screening tool for development of appropriate approach channel geometries to be further investigated in the physical models. Early in the study it was assumed that asymmetrical operation of the pumps would generate adverse approach flows to the sump. These adverse approach conditions were described by the numerical model and confirmed in the comprehensive model. The numerical model indicated that elaborate divider walls would be needed to channel the approach flow and prevent adverse eddies that were generated by asymmetrical pump operation. The numerical model proved to be a valuable tool for indicating the location and length of the divider walls necessary to provide satisfactory flow to the pump intakes. However, concurrent studies in the section and comprehensive models resulted in the development of a pump intake design that provided satisfactory flow to the pumps with the original proposed approach channel design regardless of the number or combination of pumps operating. Therefore, there was no need for an elaborate, costly approach channel design to provide evenly distributed flow to the pump intakes. Further investigations with the numerical model to develop an approach channel were discontinued.

Section Model

Pump intakes

24. Tests were conducted in a 1:12.5-scale model of three pump bays (Figure 3) to evaluate various pump intake designs. The most feasible design contributed to the development of designs to be further investigated in the comprehensive model (discussed later).

25. The 1.29-ft-diam model pump bell simulated a prototype bell diameter D of 16.17 ft. Each pump bay was 97.0 ft long (6D) and 32.34 ft wide (2D). A pump bell was located inside pump bay 1 as shown in Plate 4. A portion of the floor and sidewall of the pump bay was transparent to permit observation of currents and turbulence approaching and entering the suction bell.

26. Pump intake designs were investigated and evaluated by determining

the critical submergence S_c for surface and submerged vortices for various flow rates and submergences. Critical submergence is defined as the submergence S that generates incipient submerged vortices with visible air cores or Stage C surface vortices. Submergence is measured from the invert of the suction bell to the water surface. Critical submergence was obtained by setting a submergence and varying the discharge to determine the maximum discharge permissible that would not induce surface and/or submerged vortices within a 100-sec (prototype) time frame.

27. Evaluation of the various designs indicated a predominance of floor vortices and negligible development of sidewall and backwall vortices. Critical submergence for floor vortices was used as a basis for comparing the various designs.

28. The type 1 pump intake is shown in Plate 4. For discharges as great as 3,600 cfs and submergences as low as 5 ft, there was no significant development of surface, sidewall, or backwall vortices. A strong floor vortex (maximum diameter 6 in.) induced severe vibration and noise as it formed below the suction bell (Plate 4). Critical submergence for the type 1 pump intake that generated floor vortices is indicated in Plate 5. The type 1 pump intake was considered unacceptable due to severe floor vortices.

29. The type 2 pump intake was similar to the type 1 except a splitter wall was added below the pump intake (Plate 6). The splitter wall, for given discharges, permitted operation without floor vortices at relatively lower submergences (Plate 5). The floor vortices that did occur formed on each side of the splitter wall (Plate 6, Section B-B) and were smaller in diameter (maximum diameter 1.5 in.) and less intense than those observed below the type 1 pump intake.

30. Tests were conducted to investigate how the type 2 pump intake would perform with adverse approach flow. A barrier was placed in the approach to direct flow asymmetrically into the pump bay (Plate 7). A comparison of critical submergence with the type 2 pump intake with different approach conditions indicates that the asymmetric approach flow increases the tendency for floor vortices (Plate 5).

31. The roof was elevated to form the type 3 pump intake (Plate 8). Critical submergence is illustrated in Plate 5. The type 3 pump intake was satisfactory for submergences greater than 11.28 ft, but for lesser submergences (below roof), severe air-entraining Stage E surface vortices occurred.

32. Additional tests were conducted to evaluate hydraulic performance with the splitter wall removed and the ceiling located various distances ℓ from the suction bell (Plate 9). Plate 10 defines conditions of observed incipient floor vortex formation by a plot of the ratio of distance between the suction bell and the ceiling to the diameter of the suction bell versus the critical or minimum value of the discharge parameter. The plot indicates that floor vortices would increase significantly with the ceiling located closer than 0.37D from the suction bell.

33. The ceiling was located 0.37D from the suction bell and various transition radii R (Plate 11) were investigated. Plate 11 illustrates incipient surface vortex formation (Stage C) observed for various submergences as the transition radius was varied relative to discharge. The plot indicates flow improvement for all submergences as the radius was increased to 0.25D. The transition radius was also evaluated by measuring pressure below the pump intake with a movable electronic pressure transducer as shown in Plate 11. Plate 12 indicates less negative pressure was obtained for all submergences with a radius of 0.25D.

34. The ceiling was located flush with the suction bell, the splitter wall was installed, and tests were conducted to evaluate the effect of the transition radius on surface vortices and pressures below the pump intakes for typical submergences of 1.0D, 1.5D, and 2.0D. Plate 13 indicates the improvements in suppression of surface vortices obtained as the ceiling radius was increased above 0.5D. A submergence of 0.5D (Plate 13) showed an increase in surface vortices as the radius was increased above 0.5D. This was due to the water surface being below the point of vertical tangency of the radius. Plate 14 indicates that the transition radius has an insignificant effect on pressure below the pump intake.

35. Based upon tests of pump intake configurations described in paragraphs 32-34, a pump intake (type 4) with the ceiling located flush with the suction bell, a transition radius of 0.25D, and a splitter wall (Plate 15) was considered the most feasible hydraulic design to evaluate further in the comprehensive model. This design was more effective at preventing floor vortices and improving pressure below the pump intake. Although surface vortices did occur in the type 4 design, they can usually be prevented more readily than either floor vortices or excessively low pressures below a pump intake.

Training walls

36. Tests were conducted in the section model to investigate various configurations for the approach training walls. Initially, 15 pumps were proposed for the pumping station; however, observation of approach flows in the general model indicated unsatisfactory flow distribution to the pump intakes due to adverse currents in the approach when certain numbers or combinations of pumps were operating. Initially, training walls located upstream from the pump bays to properly direct the flow into the pump bays were investigated. Testing using a two-dimensional numerical model indicated the approximate length of the training walls needed and that every three pumps should be located between training walls.

37. Sketches of the two designs investigated are shown in Plates 16 and 17. The designs were evaluated by measuring current velocities approaching the pump intakes and observing surface and submerged vortices.

38. Initial tests were conducted with the training walls offset two bell diameters (type 1 training wall) as shown in Plate 16. The operation of pump 1 induced a symmetrical inflow condition in the pump bay. Velocity patterns measured 0.6D from the surface and isovels measured 14 ft from the entrance to the pump bay are shown in Plates 18 and 19, respectively. The operation of pumps 1 and 2 induced an asymmetrical flow condition in each bay (Plates 20 and 21). The operation of pumps 1, 2, and 3 produced symmetrical flow in bay 2 and asymmetrical flow in bays 1 and 3 (Plates 22 and 23).

39. Identical tests were conducted with the splitter walls located flush with the abutments (type 2 training walls) as shown in Plate 17. The operation of pump 1 induced an asymmetrical flow condition at the entrance to the pump bay as lateral flow from the right contracted as it rounded the pier nose (Plates 24 and 25). The operation of pumps 1 and 2 (Plate 26) generated asymmetrical flow at the entrances to the pump bays (Plate 27). The operation of pumps 1, 2, and 3 induced flow contractions at the upstream ends of the splitter walls that concentrated and accelerated flow in the center between the splitter walls (Plate 28). Flow decelerated and was unstable as it entered the pump bays. One suction bell diameter (14 ft) from the bay entrance, flow patterns were symmetrical in bay 2 and asymmetrical in bays 1 and 3 (Plates 28 and 29).

40. A qualitative comparison of the two designs shown in the following tabulation indicates no significant difference in hydraulic performance. It

was decided to evaluate the two designs in the 1:26-scale comprehensive model.

Design Training Wall	Pumps Operating	Flow Distribution		
		Bay 1	Bay 2	Bay 3
Type 1	1	Good		
	1 & 2	Poor	Poor	
	1, 2, & 3	Fair	Good	Fair
Type 2	1	Poor		
	1 & 2	Fair	Fair	
	1, 2, & 3	Fair	Good	Fair

Comprehensive Model

17,500-cfs-capacity pumping station

41. A sketch of the type 1 approach channel, type 1 abutments, and type 1 sump is shown in Plate 30. Abutment and sump details are shown in Plate 31. The typical flow pattern observed with the type 1 abutment is shown in Plate 32. Isovels in the pump bays with all pumps operating are shown in Plates 33 and 34. The eddy that formed in the offset of the type 1 abutment did not create adverse flow conditions at the entrance to the pump bays.

42. In the interest of economy, the width of the downstream end of the approach channel was reduced from 643 to 577 ft (Plate 31) by modifying the abutments as shown in Plates 35 and 36 (type 2 approach and abutments).

43. Hydraulic performance in the pump bays with the type 2 approach and type 2 abutments was similar to that observed with the original design pumping station. The magnitude and direction of approach bottom currents for various flow conditions are shown in Plates 37-40. Surface currents approaching the type 2 abutments and the entrances to the pump bays are indicated by time-lapse photographs of the confetti (Photo 1). The typical flow pattern along the type 2 abutment is shown in Plate 41. The eddy observed with the offset of the type 1 abutment was eliminated with the type 2 abutment. With all pumps operating, flow was well distributed in both the approach channel (Plate 40) and in the entrance to the pump bays (Plates 42 and 43). Some combinations of pumps operating generated asymmetrical flow in the approach channel (Plate 38), which induced asymmetrical flow into the pump bays (pump bay 8, Sections A-A, B-B, Plates 44 and 45, respectively). Performance indicators observed in certain pump intakes are tabulated in Table 1.

44. The pump intake in pump bay 8 was modified to simulate a conventional vertical pump intake in an open pump bay (type 2 sump, Plate 46). Adverse performance occurred in pump bay 8 for certain combinations of pumps operating. Adverse performance is indicated by the isovels in Plates 46 and 47, and by performance indicators in Table 1. Although pumps 1-8 were operating, data were taken for pump 8 only. It is apparent from these data that the more streamlined pump intake improves the distribution of flows entering the pump intake.

45. Model tests were conducted to evaluate hydraulic performance in three sump designs by monitoring flow distribution and stability in the pump column. One of the pump columns was instrumented and a data acquisition system was installed to permit measurement of velocity distribution and flow stability at the approximate location of the pump propeller. The instrumentation and data acquisition system are described in paragraph 17e. The tests were conducted with either all pumps operating (best approach channel flow condition) or with about half the pumps on one side operating (worst approach channel flow condition).

46. Geometric details of the type 1 sump design and plots of equal velocity ratios determined for 8 and 15 pumps operating with water-surface el of 80 are presented in Plate 48. Numerous zones of reduced and adverse flow distribution are indicated. The dashed lines in the plots indicate negative instantaneous velocities.

47. Geometric details and velocity ratios determined with the type 2 sump design are shown in Plate 49. A comparison of the type 2 with the type 1 sump velocity ratio plots indicates that the minimum velocity ratio was more severe with the type 2 design.

48. Additional streamlining was provided by the type 3 design sump to induce a more uniform distribution and acceleration of flow. Geometric details and velocity ratios determined with the type 3 design sump are shown in Plate 50. The test results obtained with the type 3 sump indicate that streamlining the pump intake with a formed suction intake (FSI) provides a significant improvement in flow stability and distribution. The type 3 sump also appears to compensate for adverse flow conditions in the approach channel.

<u>10,000-cfs-capacity pumping station</u>

49. At the request of the US Army Engineer District, Vicksburg, the discharge capacity of the station was reduced from 17,500 cfs to 10,000 cfs

by reducing the number of pumps from 15 to 9. The design discharge capacity per pump remained approximately the same. Details of the sump and approach channel to the 1:26-scale, 10,000-cfs pumping station are shown in Plates 51 and 52. The approach channel is shown in Figure 7.

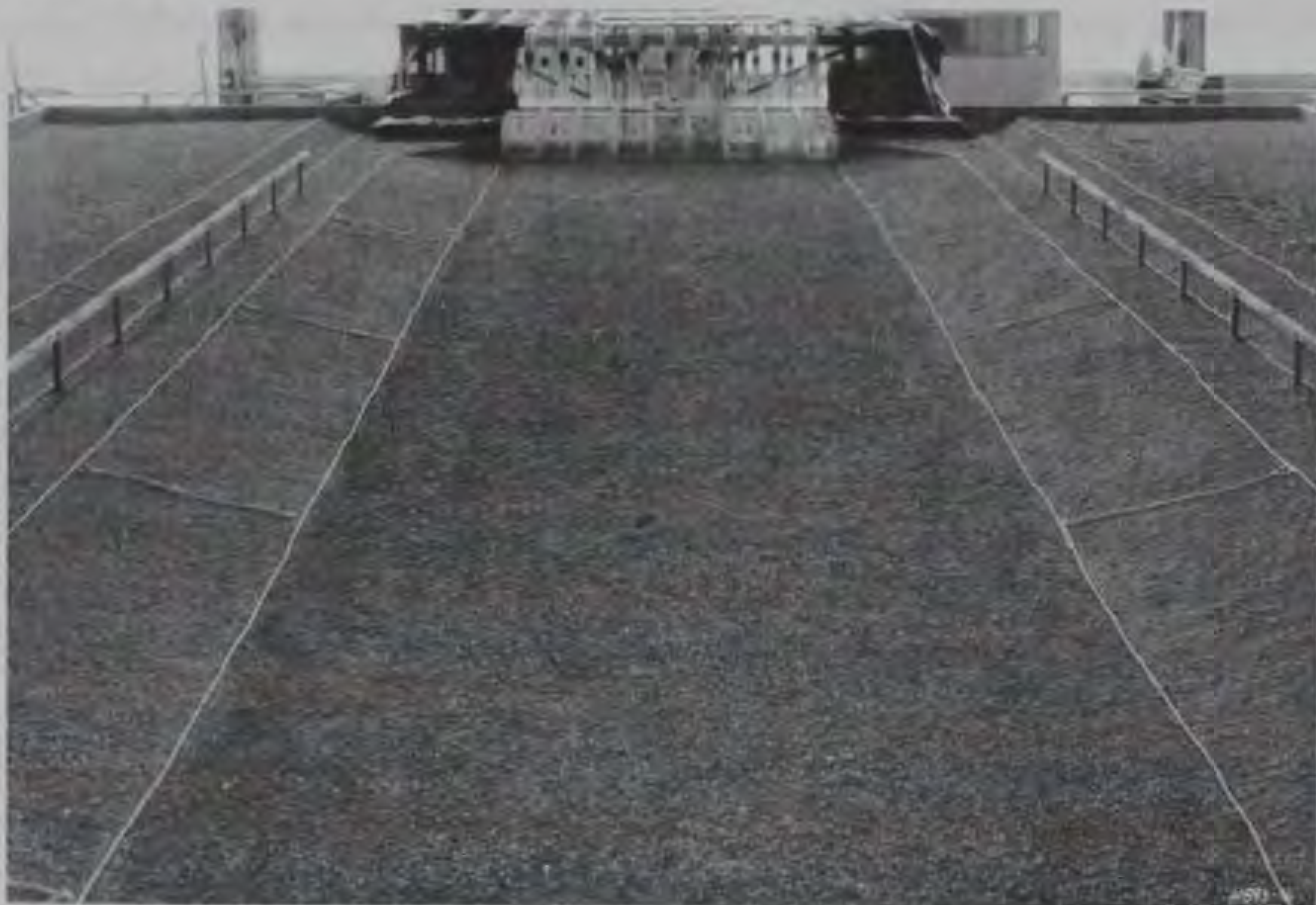


Figure 7. 10,000-cfs-capacity pumping station, type 3 approach channel

50. The magnitude and direction of bottom velocities in the approach channel with all pumps (1-9) and with pumps 1-4 operating are shown in Plates 53 and 54, respectively. Four pumps operating on one side induce lateral approach flow to the entrance of the pump bays (Plate 54). The type 3 sump, which included an FSI (Plate 55), was installed in pump bay 4. Isovels obtained upstream of pump bay 4 at Sections A-A and B-B with all pumps operating indicate satisfactory flow distribution, as shown in Plate 55. With pumps 1-4 operating, the isovels in Plate 56 indicate uneven flow distribution in pump bay 4. The adverse flow distribution is caused by the lateral flow at the entrance of pump bay 4 (Plate 54). Hydraulic performance indicators of flow conditions with all pumps and with only pumps 1-4 operating are tabulated in Table 2. Lines of equal head ratios at the approximate location of the pump propeller (pump 4) are shown in Plate 57. Vortex development in the type 3 design is shown in Plates 58 and 59.

51. The test results indicate that the hydraulic performance of the 10,000-cfs-capacity pumping station equipped with the type 3 sump (FSI) appears satisfactory and similar to that previously reported with the 17,500-cfs capacity pumping station with the type 3 sump.

Pump bay width

52. At the request of the Vicksburg District, additional tests were conducted to refine the design of the type 3 sump by evaluating various pump bay widths ranging from 21.2 to 28 ft.

53. A 21.2-ft-wide pump bay (type 4 sump) is shown in Plate 60. With all pumps operating, flow was evenly distributed in the approach observed in the approach channel and in the pump bays at Section A-A as indicated by the isovels in Plate 60. Flow tended to become more evenly distributed as it passed Section B-B (Plate 60).

54. Hydraulic performance indicators with all pumps and with pumps 1-4 operating are tabulated in Table 2. The flow distribution inside the pump column at the approximate location of the pump propeller is depicted by lines of equal velocity ratios in Plate 61.

55. The splitter wall was removed (type 5 sump, Plate 62) to determine its effect on hydraulic performance. Removal of the splitter wall increased the swirl and had no significant effect on the intensity or location of surface vortices (Table 2). Flow distribution in the pump bay was not significantly affected by removal of the splitter wall (Plate 62). Flow in the pump column with either pumps 1-4 or 1-9 operating was more evenly distributed with the splitter wall removed (Plate 63).

56. A 23-ft-wide pump bay (type 6 sump) is shown in Plate 64, along with flow distribution in pump bay 4 with pumps 1-4 operating. Flow distribution inside the pump column at the approximate location of the pump propeller is depicted by lines of equal velocity ratios in Plate 65. Vortex development in the type 6 sump is shown in Plate 66.

57. A 28-ft-wide pump bay (type 7 sump) is shown in Plate 67, along with flow distribution in pump bay 4. Flow distribution inside the pump column is shown in Plate 68.

58. Hydraulic performance indicators obtained with sump designs 3 through 7 are shown in Table 2. The basic data tabulated in Table 2 were used to plot swirl angle versus bay width (Plate 69) and stage of vortex development versus bay width (Plate 70). Plate 69 indicates an increase in swirl

angle as the bay width decreases. The swirl angle measured in all bay widths was considered acceptable. Plate 70 indicates that surface vortex intensity increases as bay width decreases. Stage C vortices were observed in pump bays with widths equal to or less than 28 ft.

Vortex suppressor beams

59. Tests were conducted to investigate the feasibility of using vortex suppressor beams to eliminate the vortices in the 23-ft-wide pump bay (type 6 sump).

60. Various sized vortex suppressor beams were investigated at various locations and angles to determine the most effective design for reducing the tendency for surface vortices. Hydraulic performance of a vortex suppressor beam is related to the height and position of the beam. If the beam is too far from the breast wall, vortices tend to form between the beam and breast wall (Figure 8). If the beam is too close to the breast wall, vortices tend to develop upstream of the beam (Figure 8). If the height of the beam is reduced, there is insufficient surface turbulence to prevent vortices. If the height of the beam is excessive, then head loss is excessive, turbulence

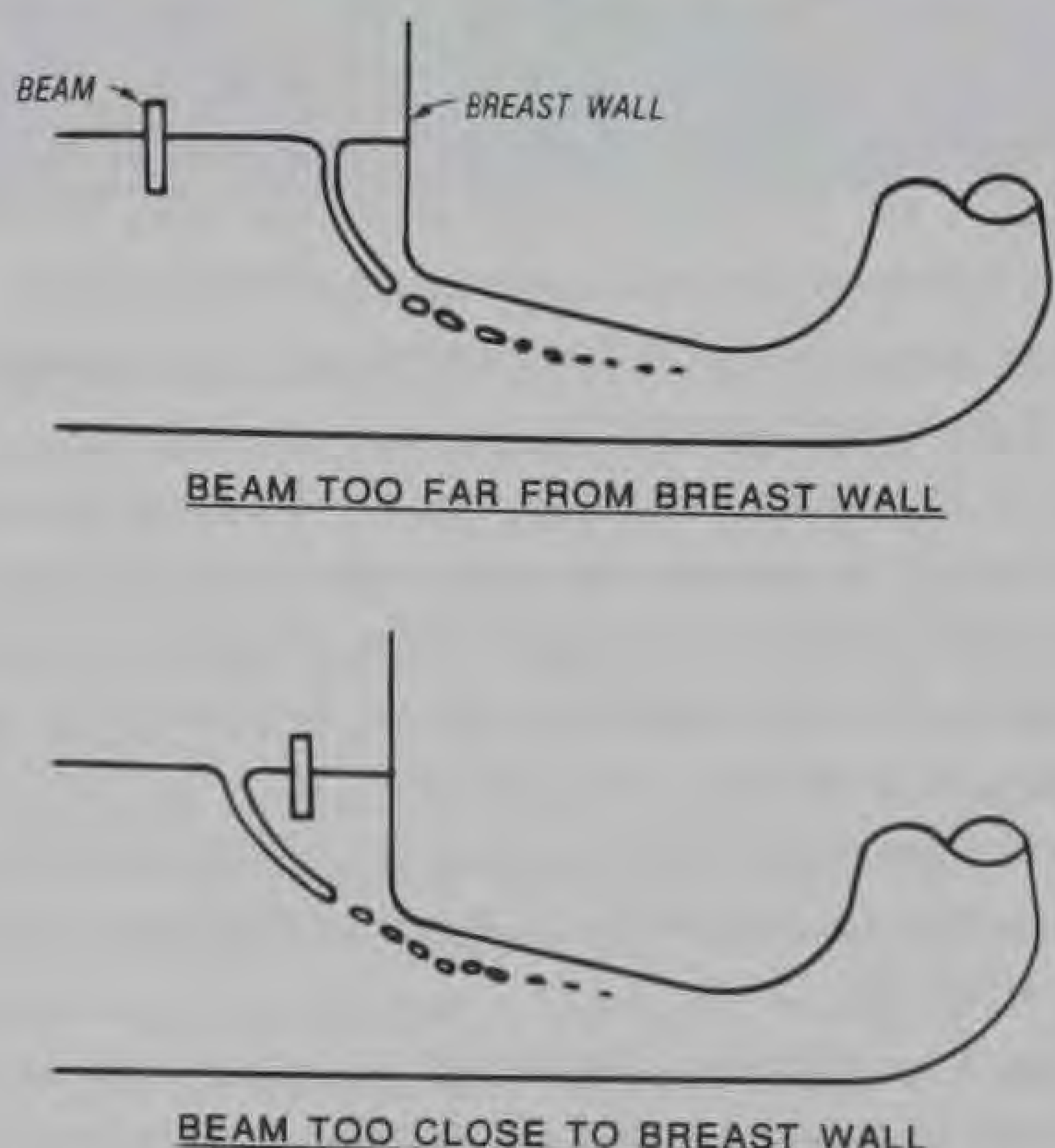


Figure 8. Hydraulic performance of vortex suppressor beam with FSI

downstream from the beam is too severe, and the water level between the beam and breast wall fluctuates excessively. A design was developed that consisted of a single beam that prevented development of undesirable surface vortices at water-surface elevations between 79 and 84. However, at higher water-surface elevations, vortices occurred between the beam and the breast wall. A design (type 8) that consisted of two beams (Plate 71) was successful in eliminating undesirable surface vortices.

61. Flow distribution with the type 8 design in pump bay 4 with pumps 1-4 operating is shown in Plate 72. Flow distribution inside the pump column at the approximate location of the pump propeller is depicted by lines of equal velocity ratios in Plate 73. A plot of water-surface elevation versus vortex development is shown in Plate 74. Vortex development relative to discharge and water-surface elevations is shown in Plate 75. Hydraulic performance indicators are tabulated in Table 2. Evaluation of the plots and tabulated data indicate that the type 8 design will provide satisfactory hydraulic performance for all anticipated flow conditions.

Adopted design

62. The approach channel was modified (type 4) to accommodate the nine 23-ft-wide pump bays (type 8) as shown in Plate 76. The adopted design consists of the type 4 approach channel, type 2 abutments, and the type 8 sump.

63. The type 4 approach channel is shown in Figure 9. The type 8 sump and the type 2 abutments are shown in Plates 76 and 77.

64. The magnitude and direction of bottom velocities in the approach channel are shown in Plates 78 and 79, respectively, with all pumps and pumps 1-4 operating. For various combinations of pumps operating, surface current direction is depicted by time-lapse photographs (Photo 2). Flow in the approach channel and pump bays was evenly distributed with all pumps operating. With asymmetrical pump operation, lateral flow in the approach (Photo 2) caused uneven flow distribution in the pump bays as indicated by the isovels at Section A-A in Plate 80. Flow tended to become more evenly distributed as it passed Section B-B (Plate 80).

65. Flow distribution inside the pump columns at the approximate location of the pump propeller for any combination of pumps operating was satisfactory. Flow distribution with all nine pumps and only pumps 1-4 operating is depicted by lines of equal velocity ratios in Plate 81.

66. Observations to detect surface vortices in the pump bays for

Figure 9. Type 4 approach channel

various water-surface elevations and combinations of pumps operating revealed only an occasional Stage A vortex for the expected range of normal operation. A plot of water-surface elevation versus stage of vortex development shown in Plate 82 indicates that operation at water surfaces below the minimum sump level of el 80 does produce higher stages of vortices. Vortex development relative to discharge and water-surface elevation is shown in Plate 83.

67. Test results indicate that the adopted design will provide satisfactory hydraulic performance for anticipated flow rates, water-surface elevations, and any number of pumps operating.

PART IV: SUMMARY AND DISCUSSION

68. A numerical model was used as a screening tool for development of approach channel geometries that would provide satisfactory flow and warrant further investigation in the physical models. The numerical model indicated that a costly divider wall design would be needed to provide satisfactory approach flow during asymmetric pump operation. However, concurrent studies in the physical model resulted in the development of a pump intake design that provided satisfactory flow to the pumps regardless of the number or combination of pumps operating.

69. Initially, tests were conducted in a 1:12.5-scale section model to screen various pump intake designs to be further investigated in the 1:26-scale comprehensive model. A predominance of floor vortices was observed in the various designs investigated. The intensity of the floor vortices was used as a basis for comparing designs. Tests were conducted with and without the splitter wall and with the suction bell located various distances from the floor. The tests indicated that the frequency and intensity of floor vortices increased as the suction bell was moved closer to the floor.

70. Tests were also conducted to investigate the transition radius on the invert of the breast wall. These test results generally indicated that for typical submergences the surface vortices decreased as the radius was increased.

71. Due to anticipated adverse flow conditions in the sump with asymmetrical pump operation, it was decided to investigate various configurations of approach training walls. Tests in the section model provided guidance for design of training walls to be further evaluated in the comprehensive model.

72. Tests in the 1:26-scale comprehensive model were initially conducted to investigate the flow characteristics in a 15-pump, 17,500-cfs-capacity pumping station. Tests were conducted to refine the design of the transition from the approach channel to the sump. During asymmetrical operation of the pumps, adverse lateral flows in the approach channel were observed. Tests indicated that a streamlined pump intake (type 3) sump design compensated for lateral flows in the approach channel. The streamlined intake provided uniform and stable flow to the pump intake regardless of the adverse flow conditions in the approach channel.

73. At the request of the Vicksburg District, the discharge capacity

was reduced from 17,500 to 10,000 cfs by reducing the number of pumps from 15 to 9. As the number of pumps was reduced, the width of the approach channel was also reduced. The type 4 approach channel (Plate 76) and type 2 abutments which consisted of 45-deg training walls provided satisfactory hydraulic performance for all anticipated flow conditions. Various flow conditions in the approach channel were documented by measurement of the magnitude and direction of bottom velocities and time-lapse photographs of surface confetti.

74. Additional tests were conducted to refine the design of the type 3 sump (formed suction intake). Evaluation of various pump bay widths indicated that the swirl angle increased as the bay width decreased and surface vortex intensity increased as bay width decreased. Surface vortices in the pump bays were observed for bay widths of 28 ft and less.

75. Tests were conducted to investigate the feasibility of using vortex suppressor beams to eliminate the vortices in the 23-ft-wide pump bay. A design that consisted of the formed suction intake and two beams (type 8 sump) was successful in eliminating undesirable surface vortices for anticipated flow conditions.

76. The adopted design consists of the type 4 approach channel, type 2 abutments, and the type 8 sump. The adopted design provided satisfactory hydraulic performance for anticipated flow rates, water-surface elevations, and any combination of pumps operating.

Table 1

Flow Characteristics, 17,500-cfs-Capacity

Pumping Station

Design	Discharge per Pump, cfs	Number of Pumps Operating	Sump El	Pump Intake No.	Swirl Angle, deg*	Pressure Fluctuation ft of water	Surface Vortices**
Type 2 approach channel, type 2 abutments, type 1 sump	1,460	1-15	80	1	1.0+	2	A
				6	1.0-	1	--
				11	1.0-	1	--
		1-8		1	1.0+	2	A
				8	2.0-	2	A
		5-11		5	2.0-	2	A
				6	1.0-	2	A
		1-3		1	1.0+	1	A
				3	2.0-	2	A
		1,2 & 5-7		1	1.0+	1	--
				2	1.0-	1	--
				7	1.0-	2	A
		1-5		1	1.0+	1	A
				2	1.0+	1	--
				5	2.0-	2	A
		1		1	1.0-	2	A
		1-15	85	1	1.0-	2	--
		1-8		8	2.0+	2	A

(Continued)

Note: All magnitudes are expressed in terms of prototype equivalents.
* + indicates clockwise swirl; - indicates counterclockwise swirl.
** -- indicates that no surface vortices were observed. No submerged vortices were observed during testing.

Table 1 (Concluded)

Design	Discharge per Pump, cfs	Number of Pumps Operating	Sump El	Pump Intake No.	Swirl Angle, deg*	Pressure Fluctuation ft of water	Surface Vortices**
Type 2 approach channel, type 2 abutments, type 1 sump (continued)	1,460	1-15	95	1	1.0+	1	--
		1-8		8	1.0+	1	--
	1,167	1-15	80	1	1.0+	2	--
		1-8		8	2.0+	2	--
Type 2 approach channel, type 2 abutments, type 2 sump	1,460	1-15		8	4.0+	3	D
		1-8		8	15.0-	4	E
	1,167	1-15		8	4.0+	2	C
		1-8		8	9.0-	3	D

Table 2

Flow Characteristics, 10,000-cfs-Capacity Pumping Station

Type 3 Approach Channel, Type 2 Abutments

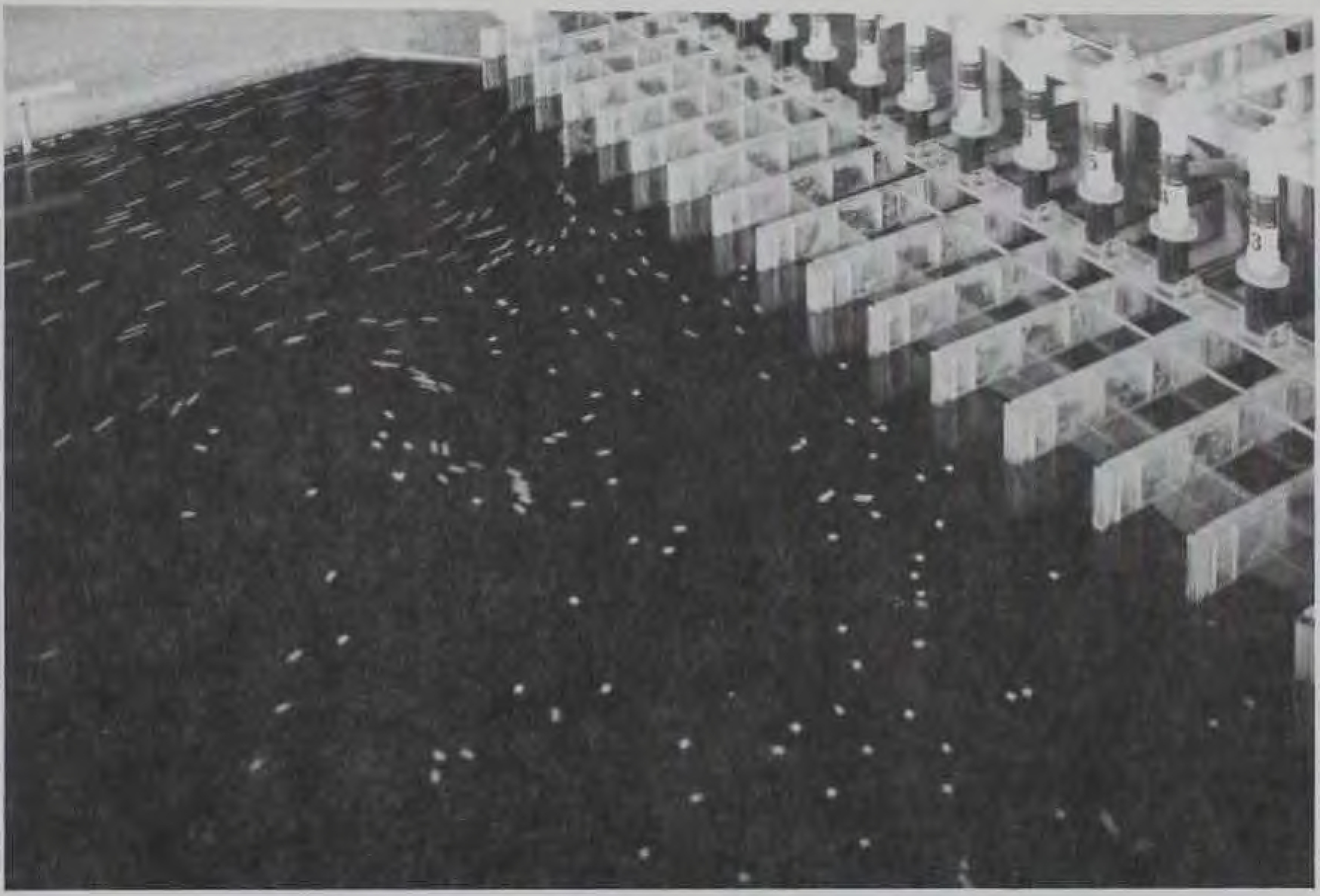
Formed Suction Inlet

Sump Design	Pump Bay Width, ft	Pumps Operating	Swirl Angle, deg*	Stage of Surface Vortices Pump No. 4**	Remarks
Type 3	33	1-9	0.2-	--	
	33	1-4	0.2-	A (intermittent)	
Type 4	21.2	1-9	1.2-	D (intermittent)	
	21.2	1-4	2.0-	D (intermittent)	
Type 5	21.2	1-9	2.6-	D (intermittent)	Splitter wall removed
	21.2	1-4	4.4-	D (intermittent)	
Type 6	23	1-9	1.2-	C (intermittent)	
	23	1-4	1.5-	D (intermittent)	
Type 7	28	1-9	1.0-	A (intermittent)	
	28	1-4	1.0-	C (intermittent)	
Type 8	23	1-9	0.7-	--	Two vortex suppressor beams installed
	23	1-4	1.0-	A (intermittent)	

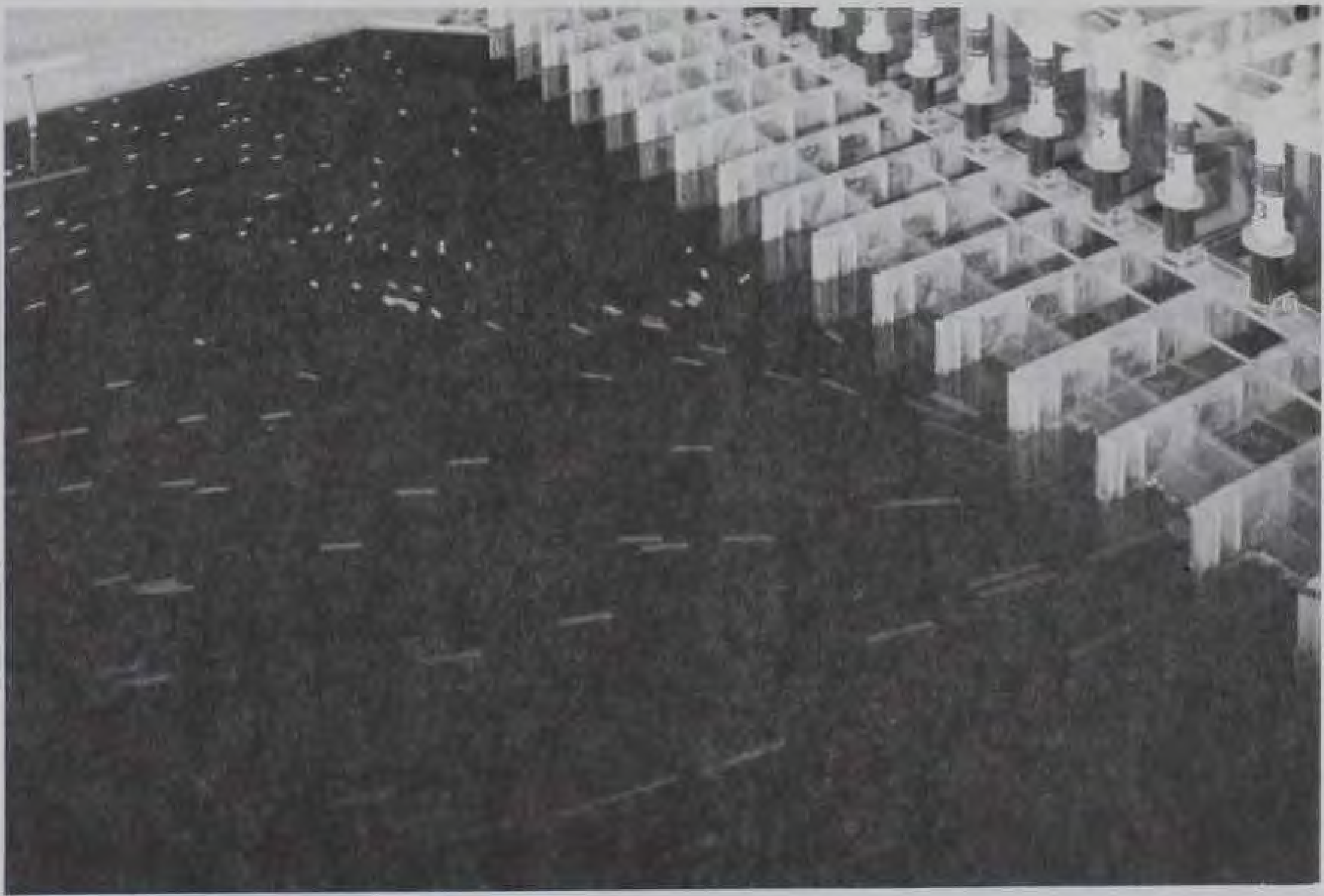
Note: Test conditions: discharge per pump 1,460 cfs; water-surface el 80. All magnitudes are expressed in prototype equivalents.

* - indicates counterclockwise swirl.

** -- indicates no vortex. No submerged vortices were observed during testing.

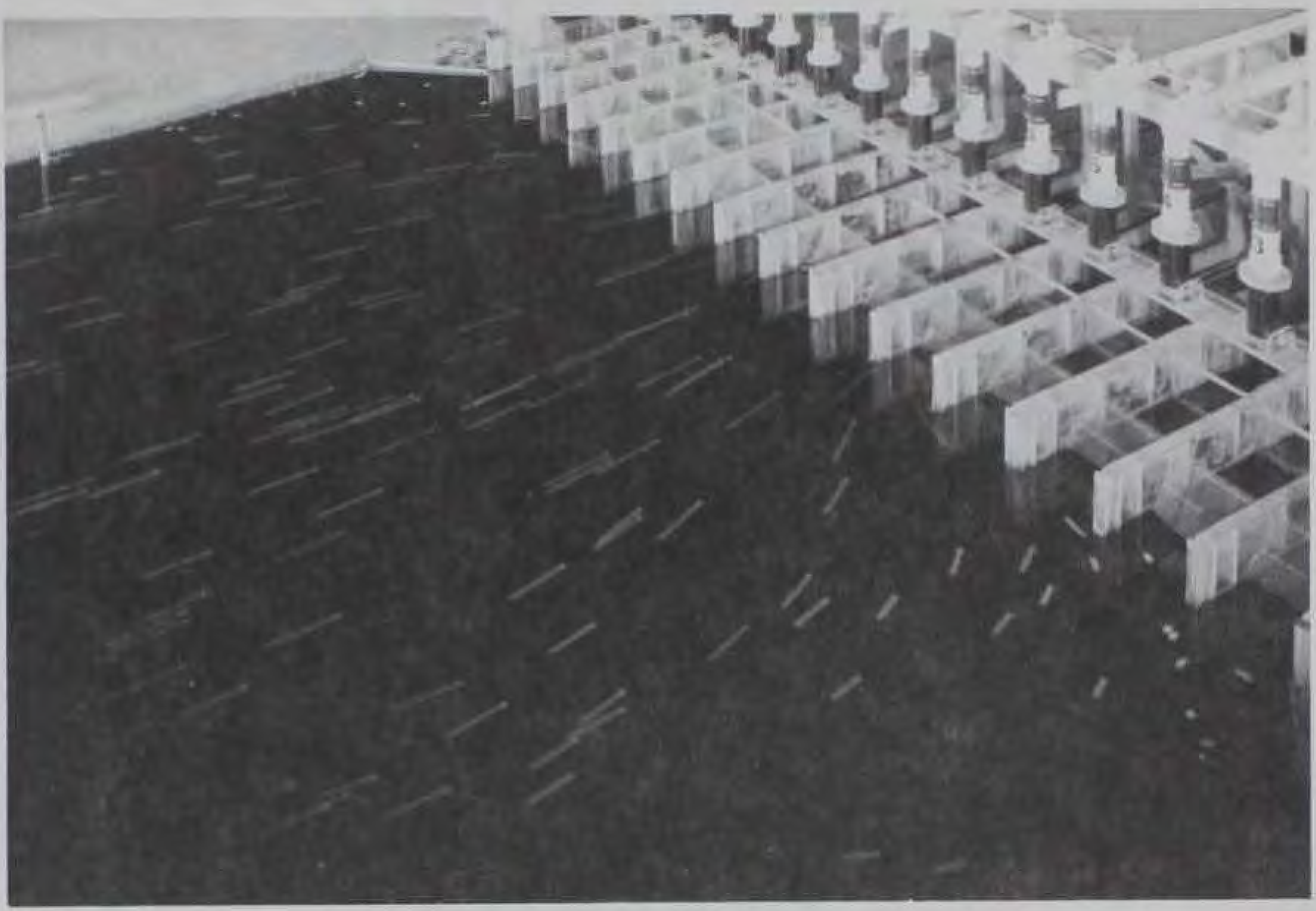


a. Pumps 14-15 operating

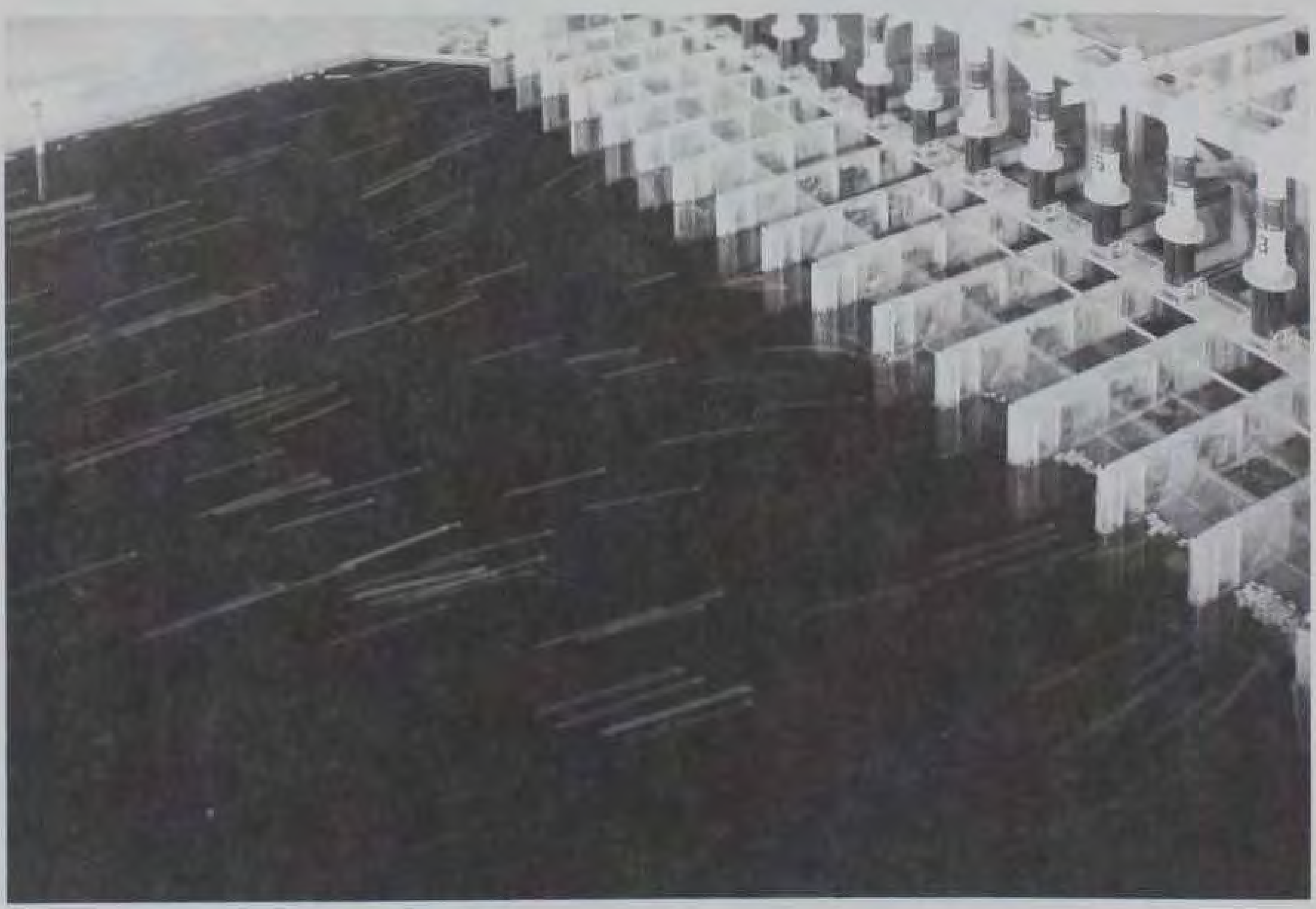


b. Pumps 1-3 operating

Photo 1. Type 2 approach channel, type 2 abutments, type 1 sump, discharge per pump 1,460 cfs, water-surface el 80.0, exposure time 25 sec (prototype) (Sheet 1 of 3)

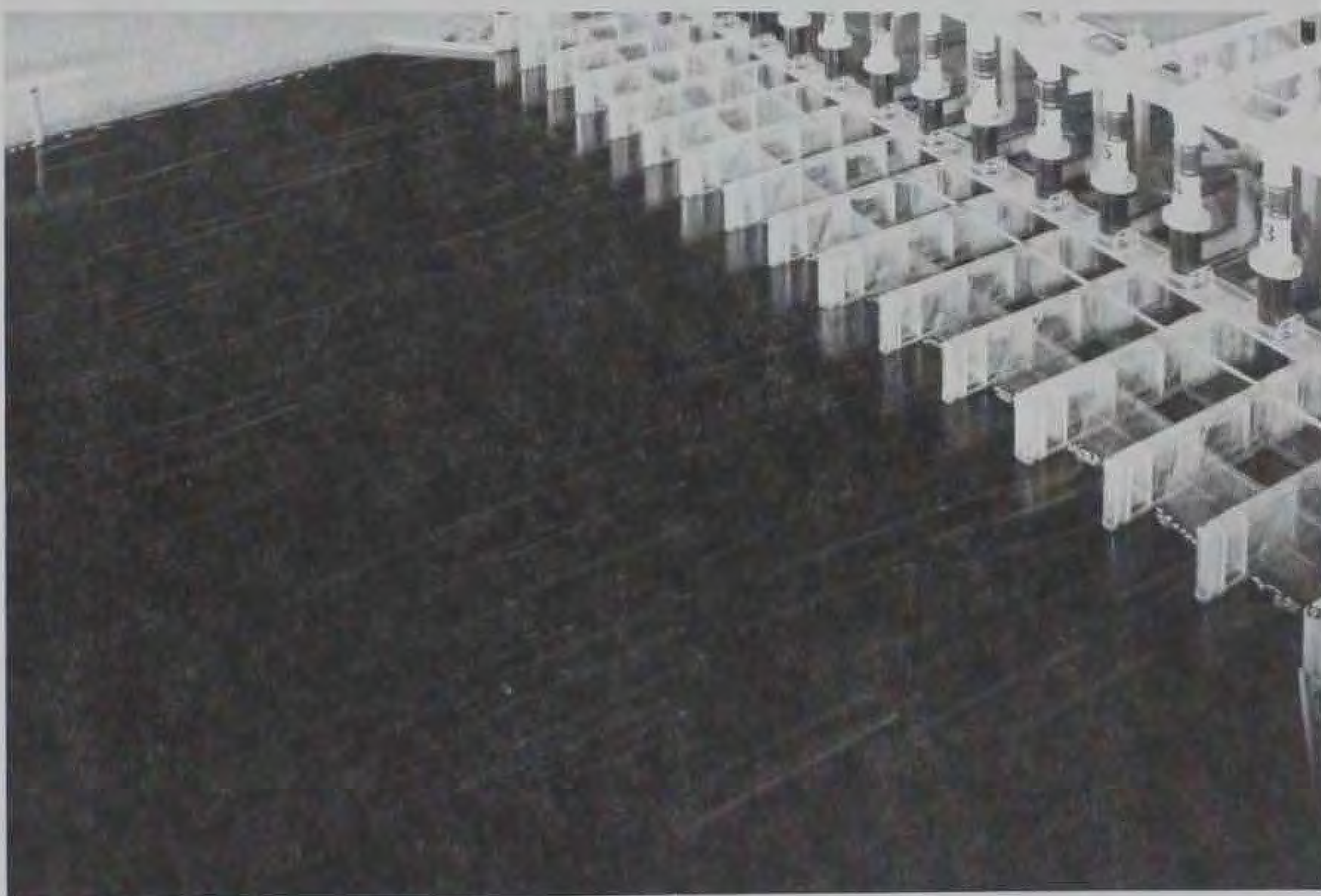


c. Pumps 5-11 operating



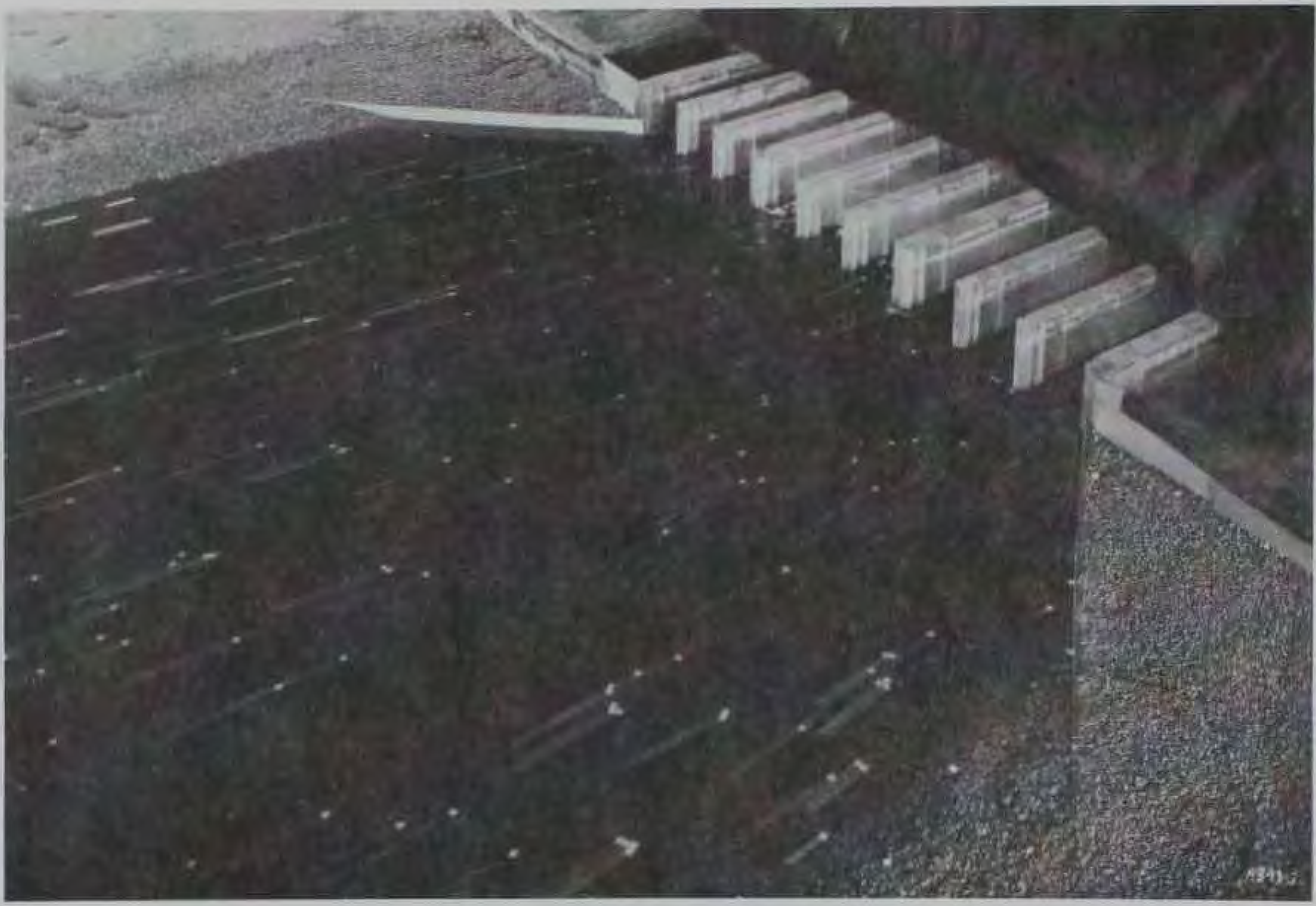
d. Pumps 1-5 and 11-15 operating

Photo 1. (Sheet 2 of 3)

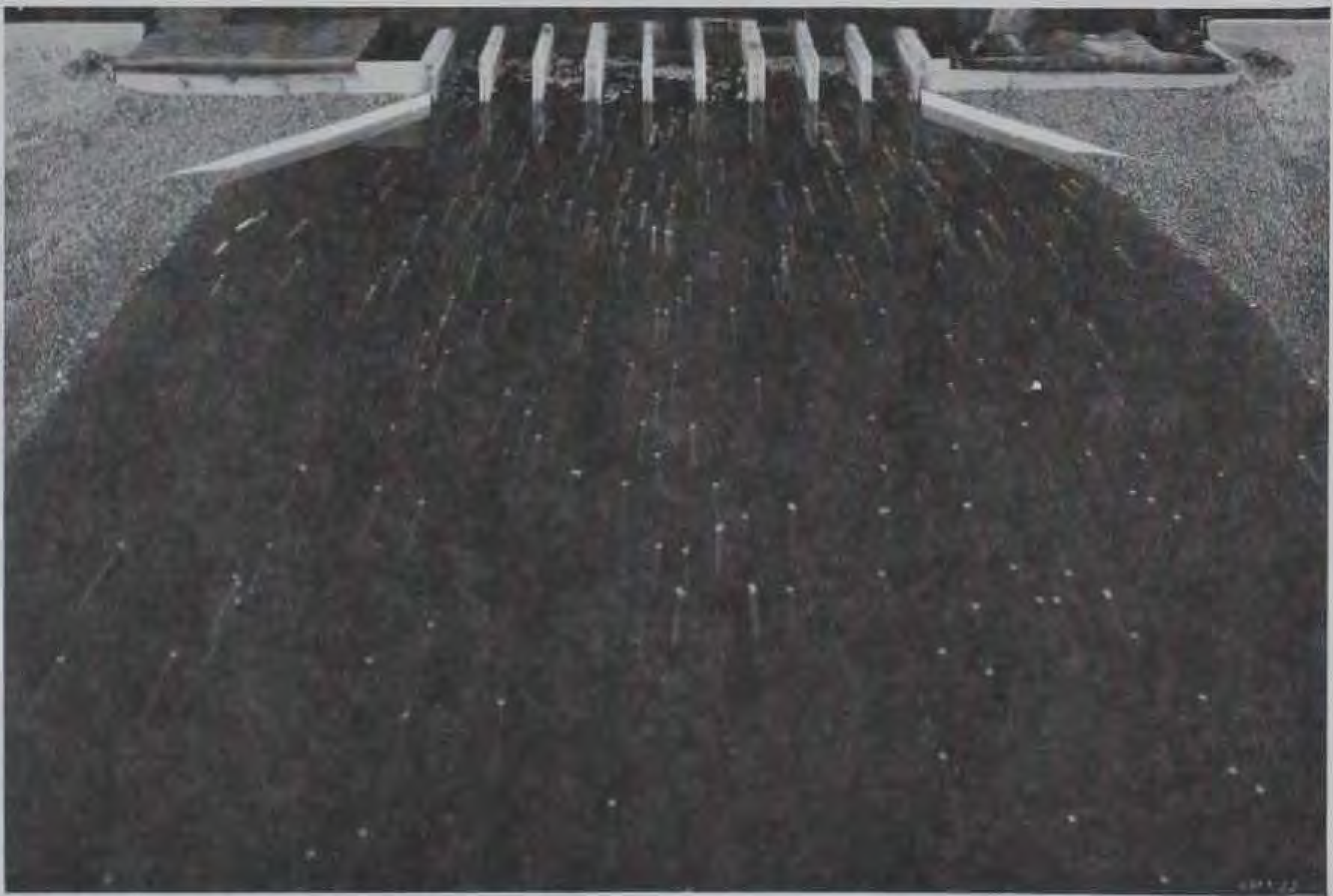


e. Pumps 1-15 operating

Photo 1. (Sheet 3 of 3)

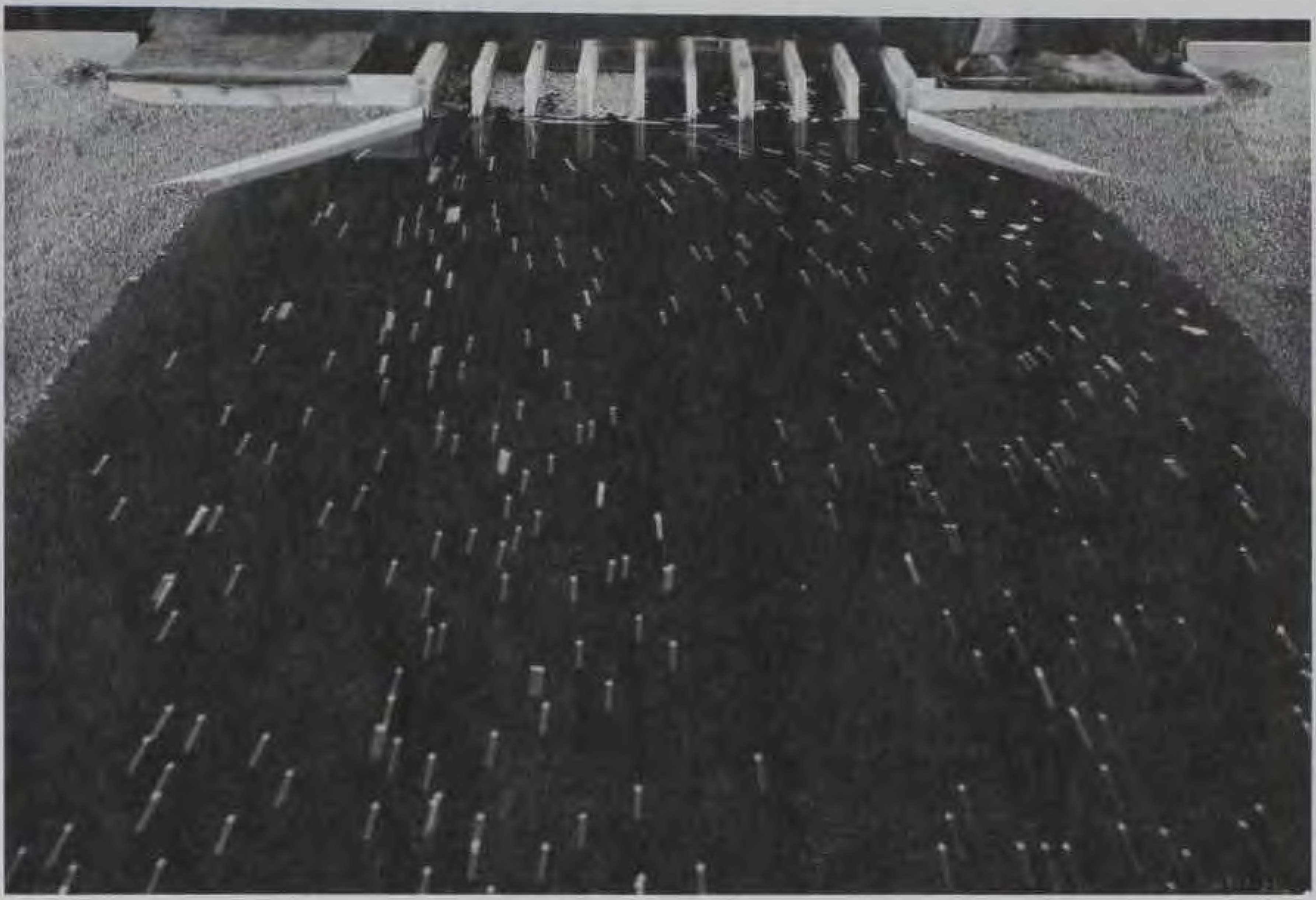


a. Pumps 1-9 operating (side view)

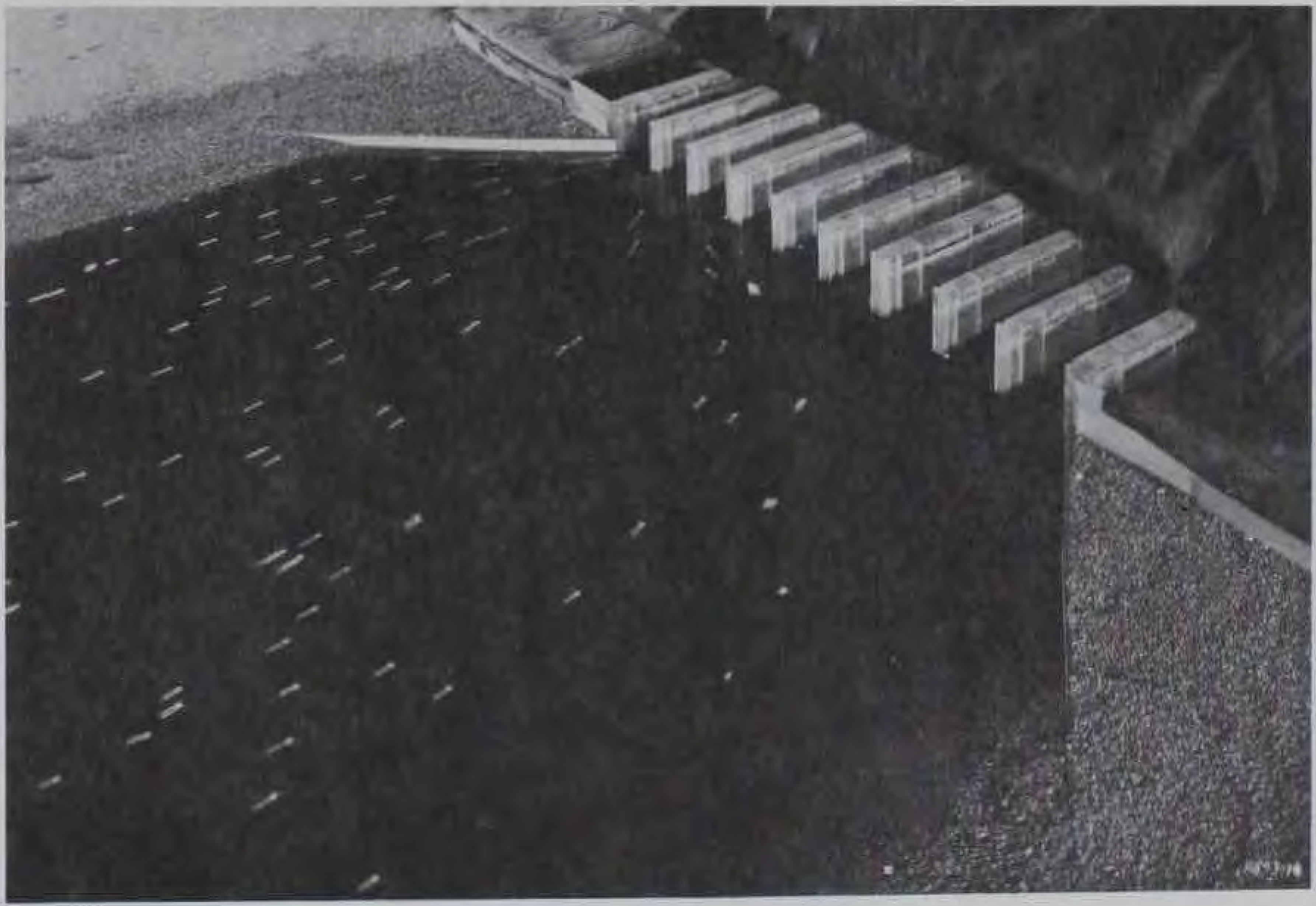


b. Pumps 1-9 operating

Photo 2. Type 4 approach channel, type 2 abutments, type 8 sump, discharge per pump 1,460 cfs, water-surface el 80.0, exposure time 25 sec (prototype) (Sheet 1 of 3)

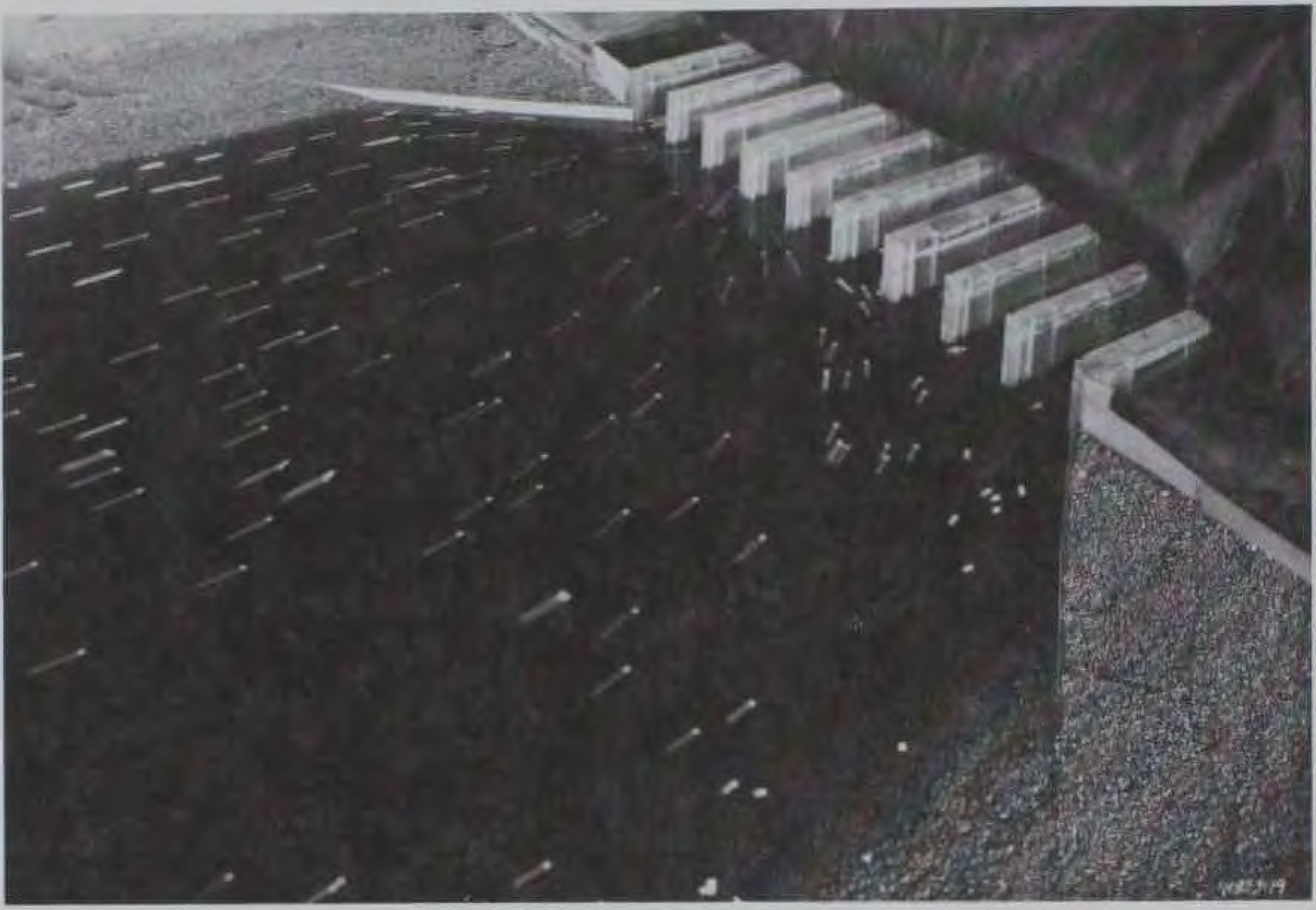


c. Pumps 1 and 2 operating

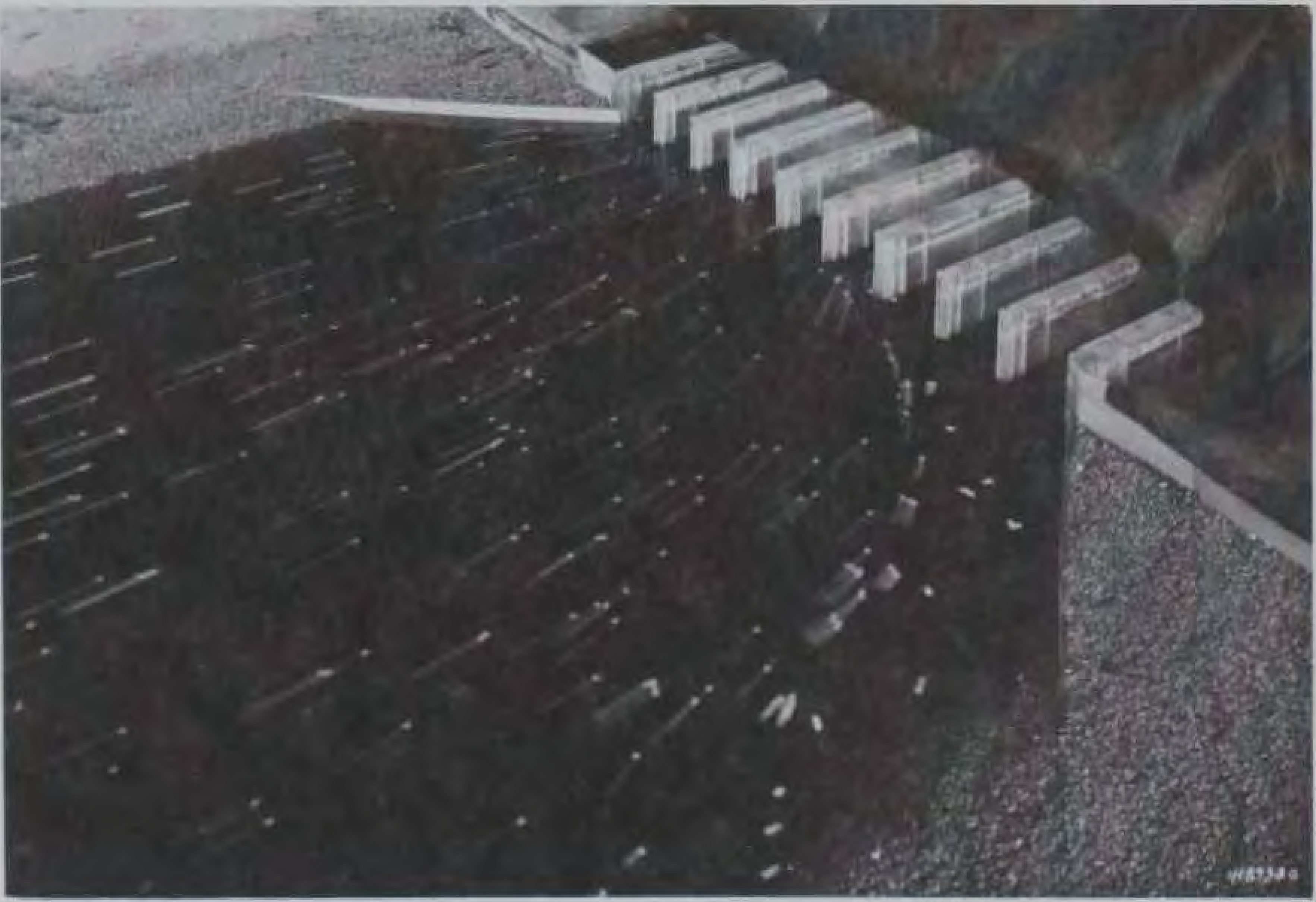


d. Pumps 1 and 2 operating (side view)

Photo 2. (Sheet 2 of 3)

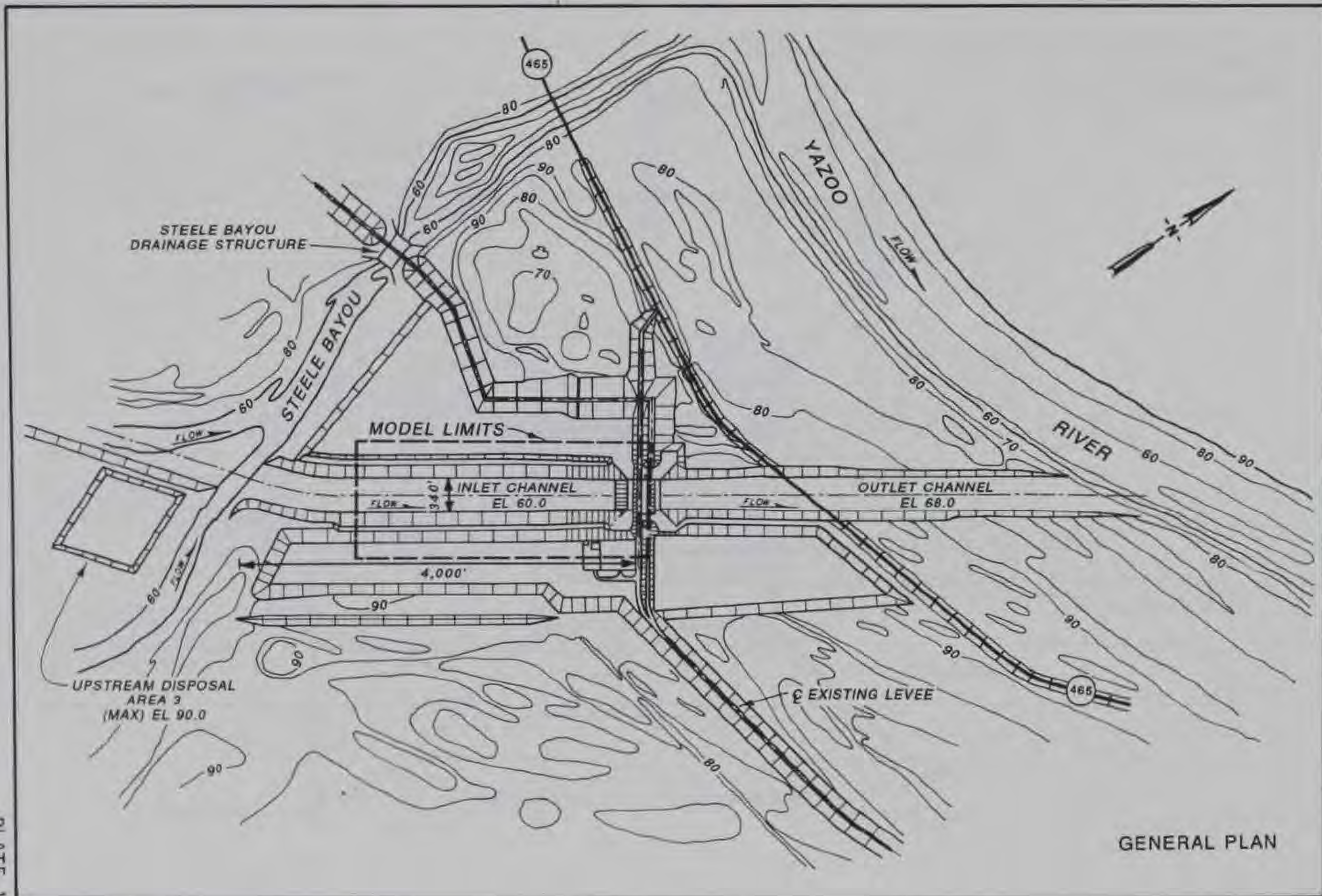


e. Pumps 1-4 operating

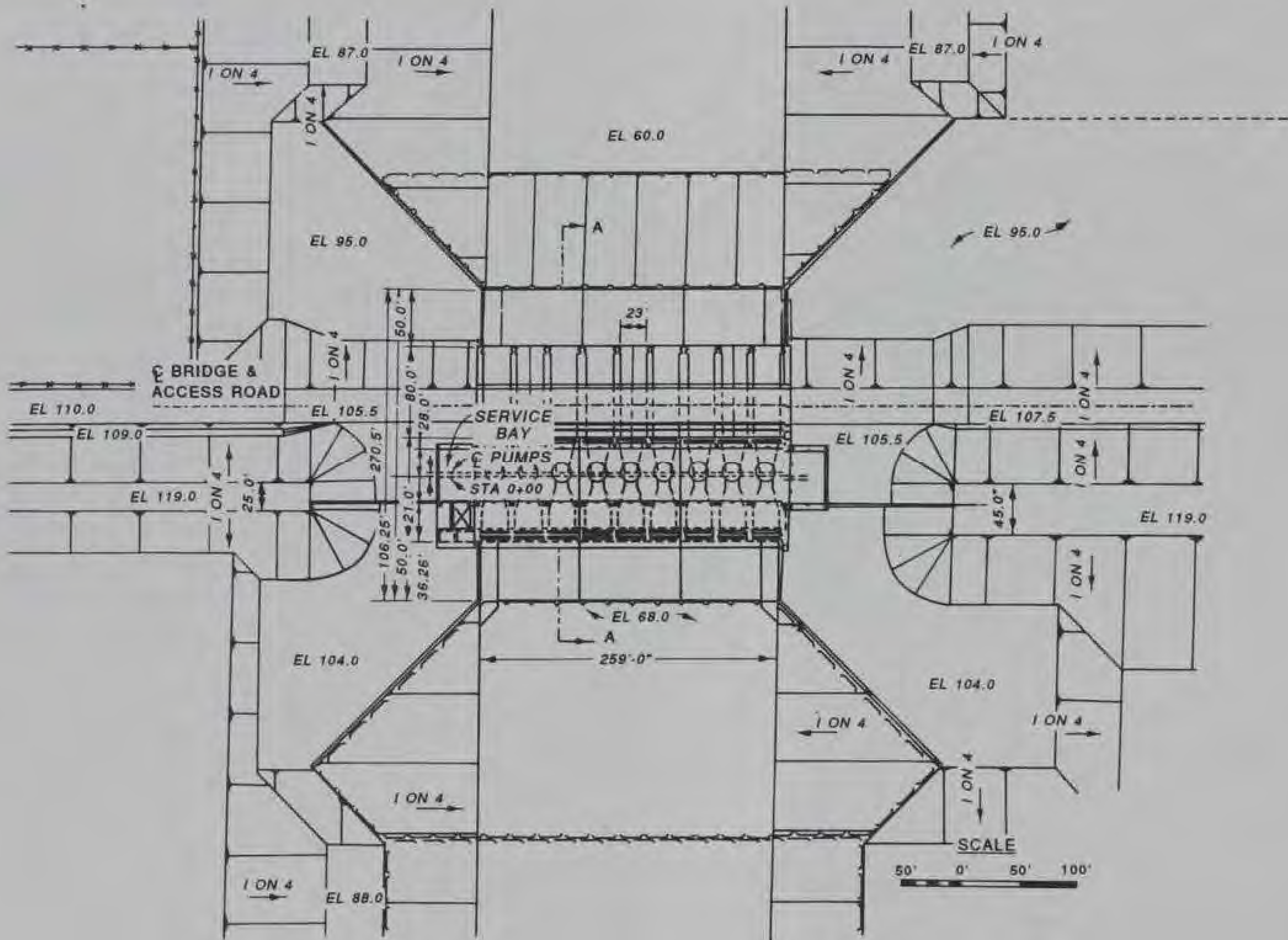


f. Pumps 1-6 operating

Photo 2. (Sheet 3 of 3)

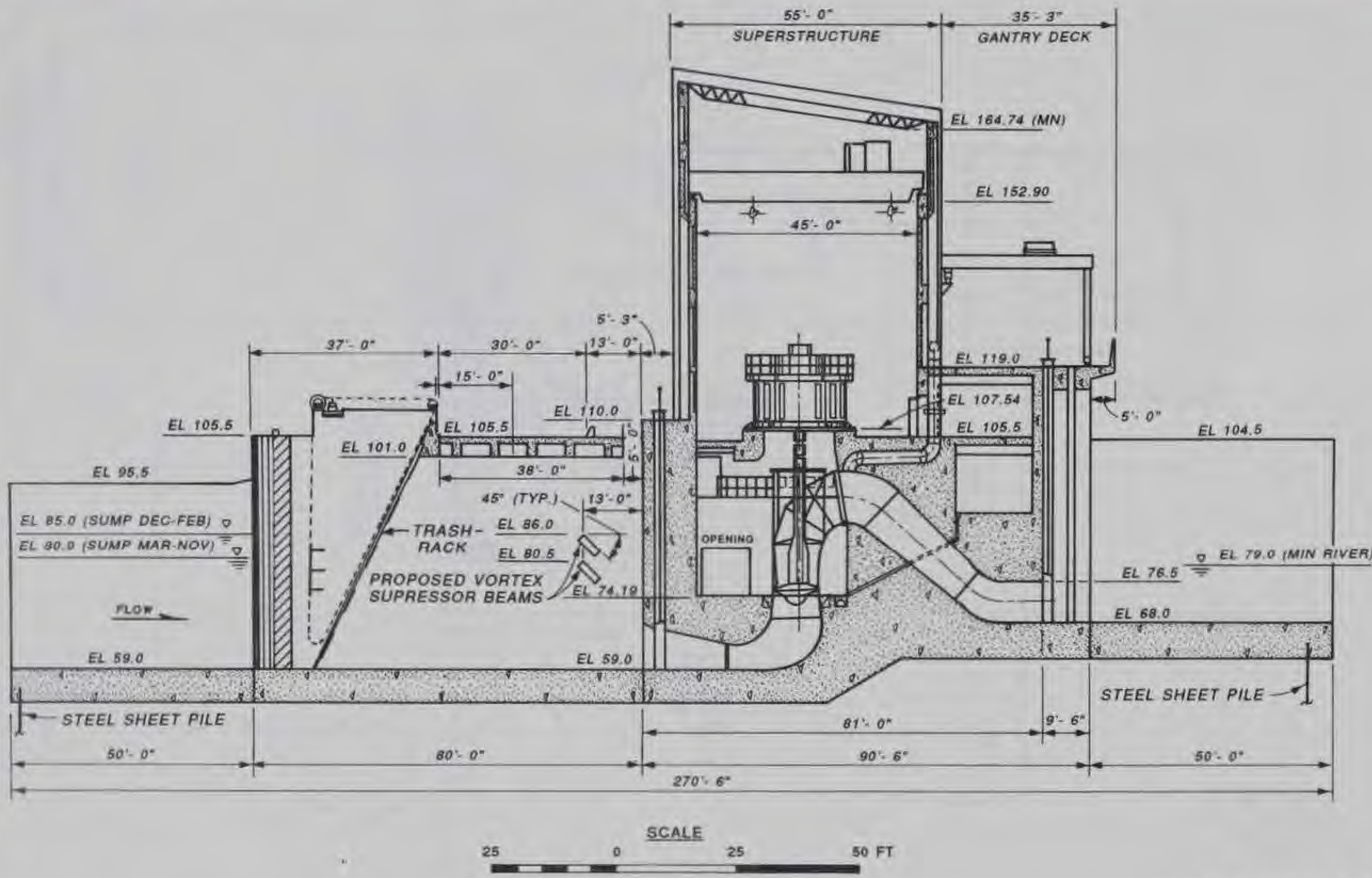


GENERAL PLAN



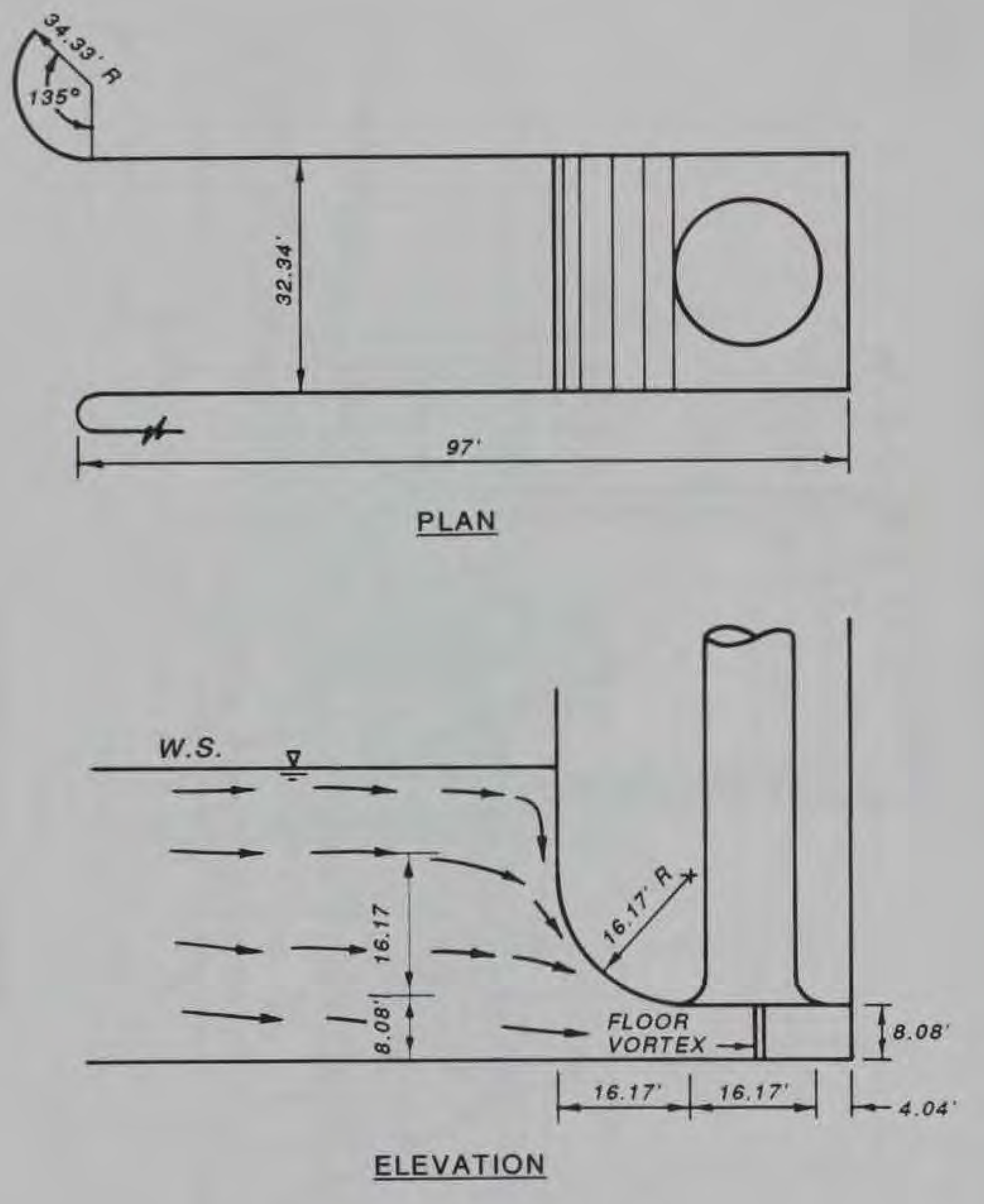
NOTE: SEE PLATE 3
FOR SECTION A-A

STRUCTURE
PLAN

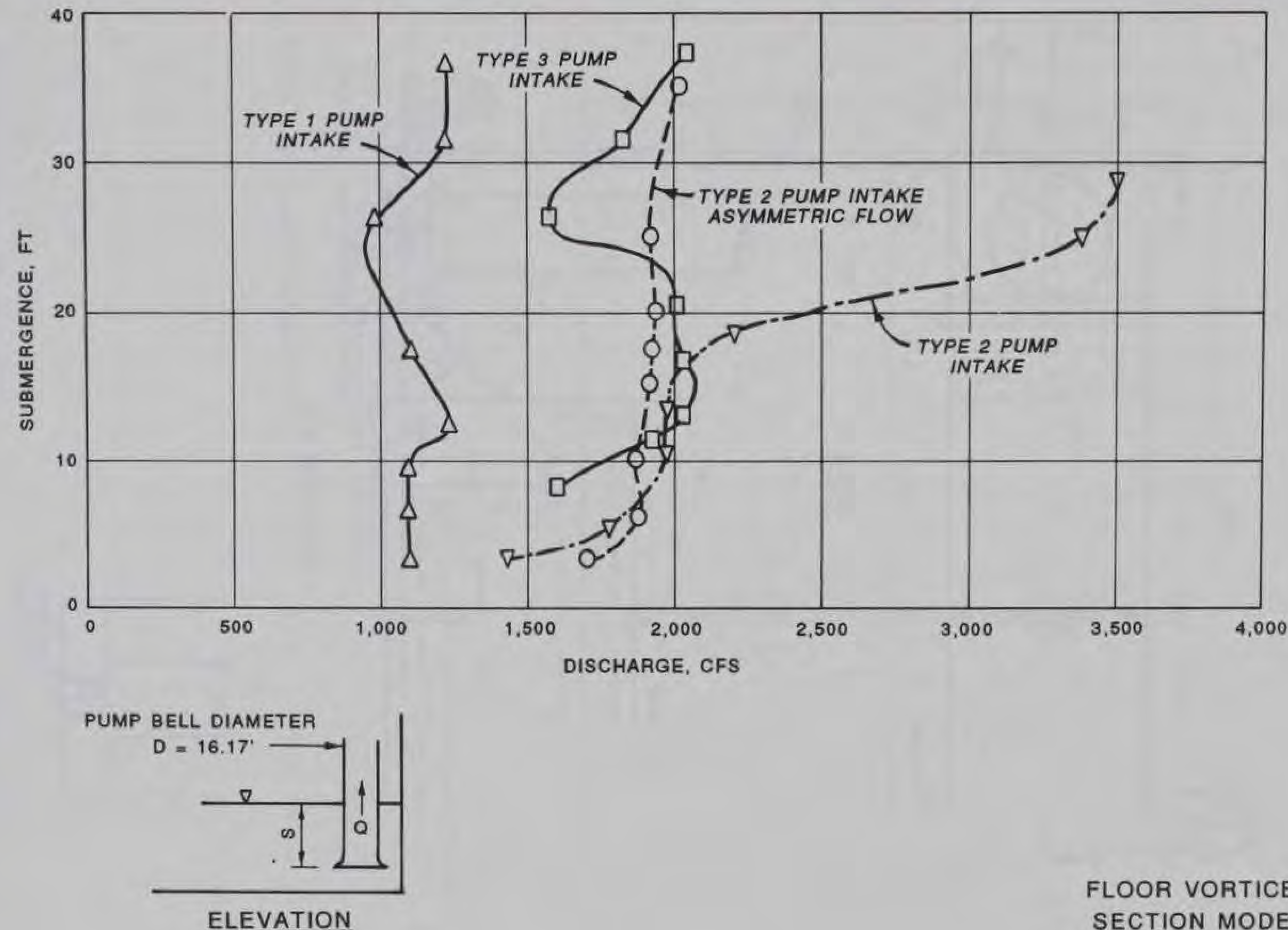


SECTION A-A

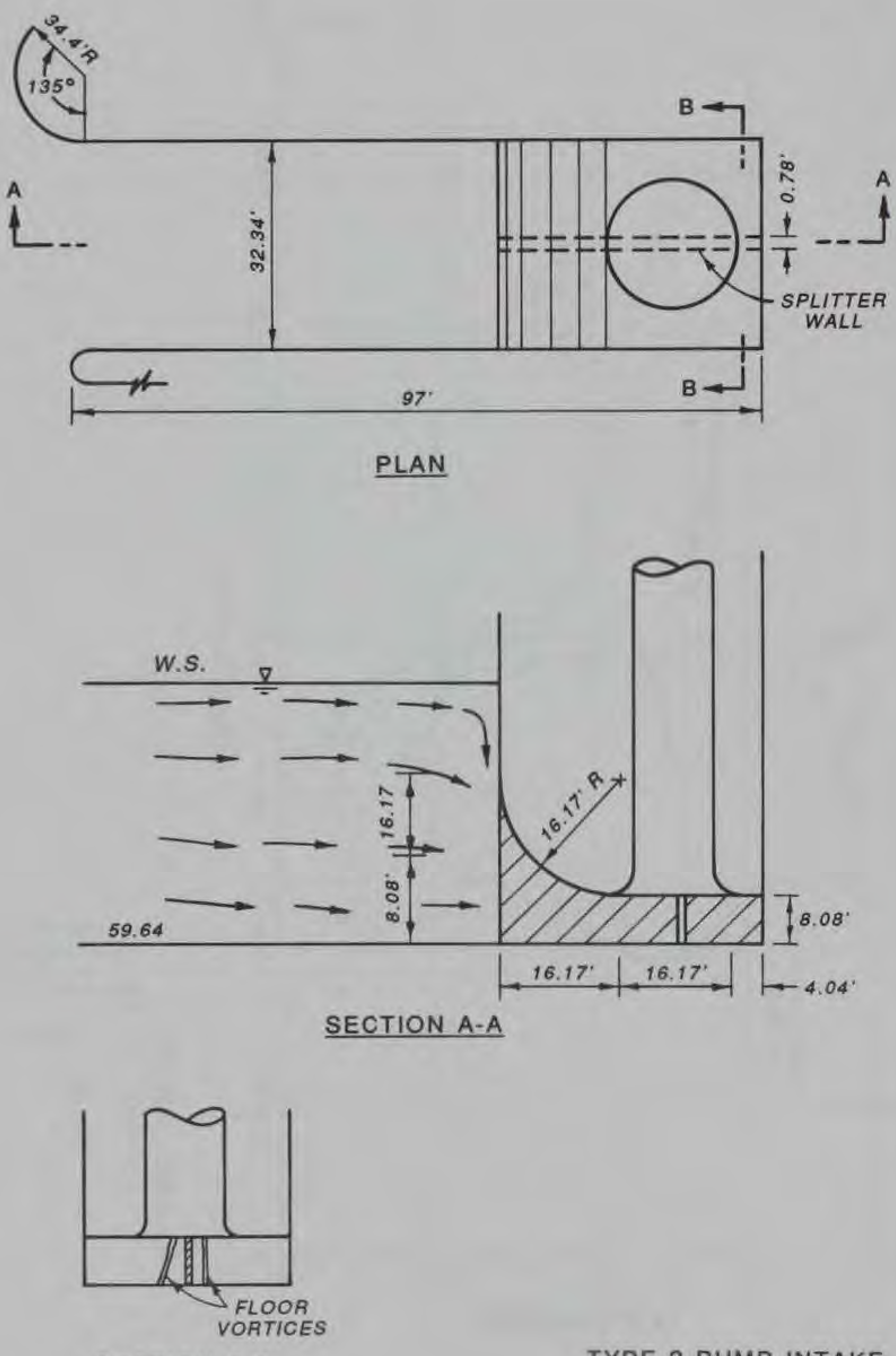
PLATE 3



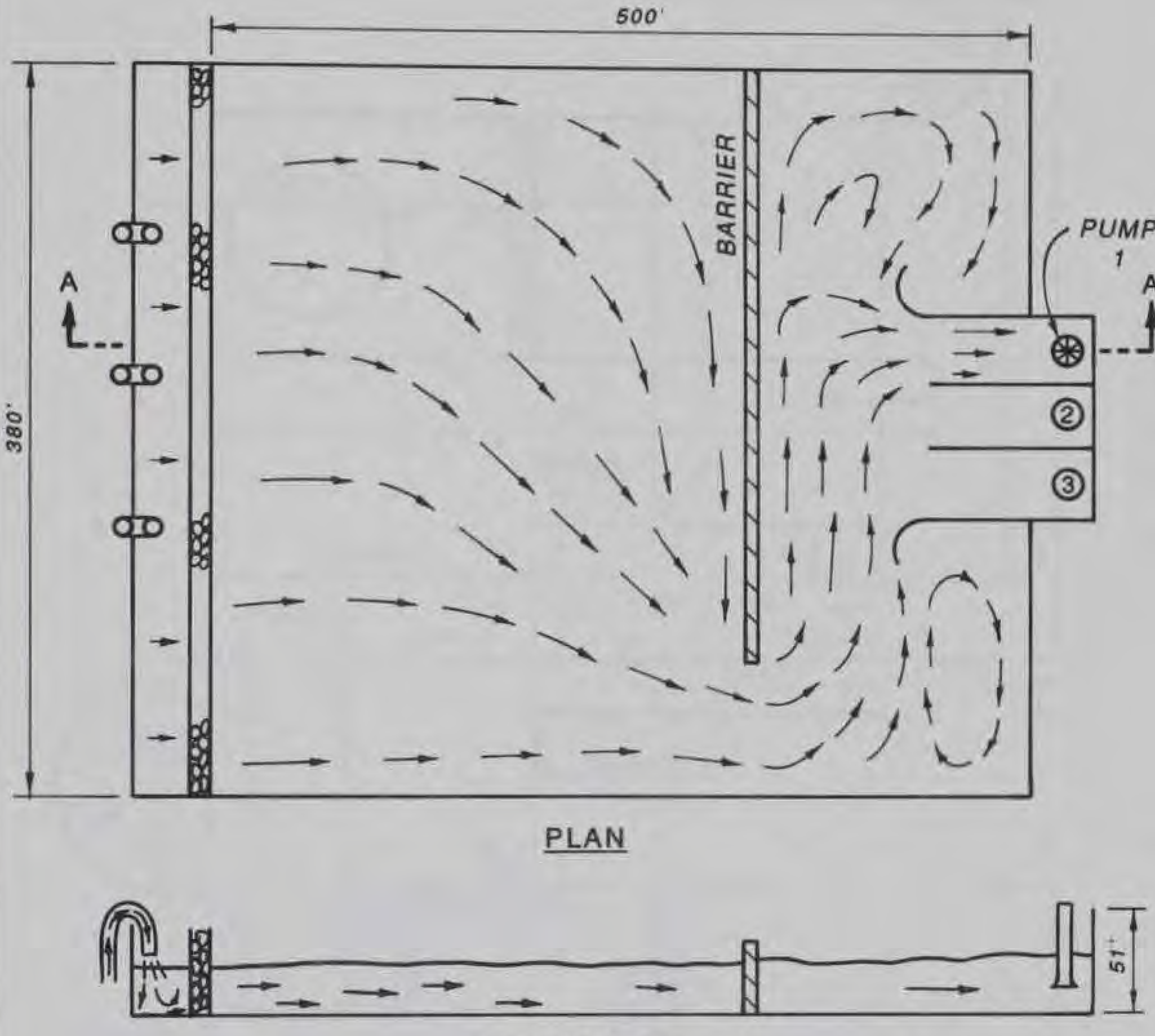
TYPE 1 PUMP INTAKE
SECTION MODEL



FLOOR VORTICES
SECTION MODEL



TYPE 2 PUMP INTAKE SECTION MODEL

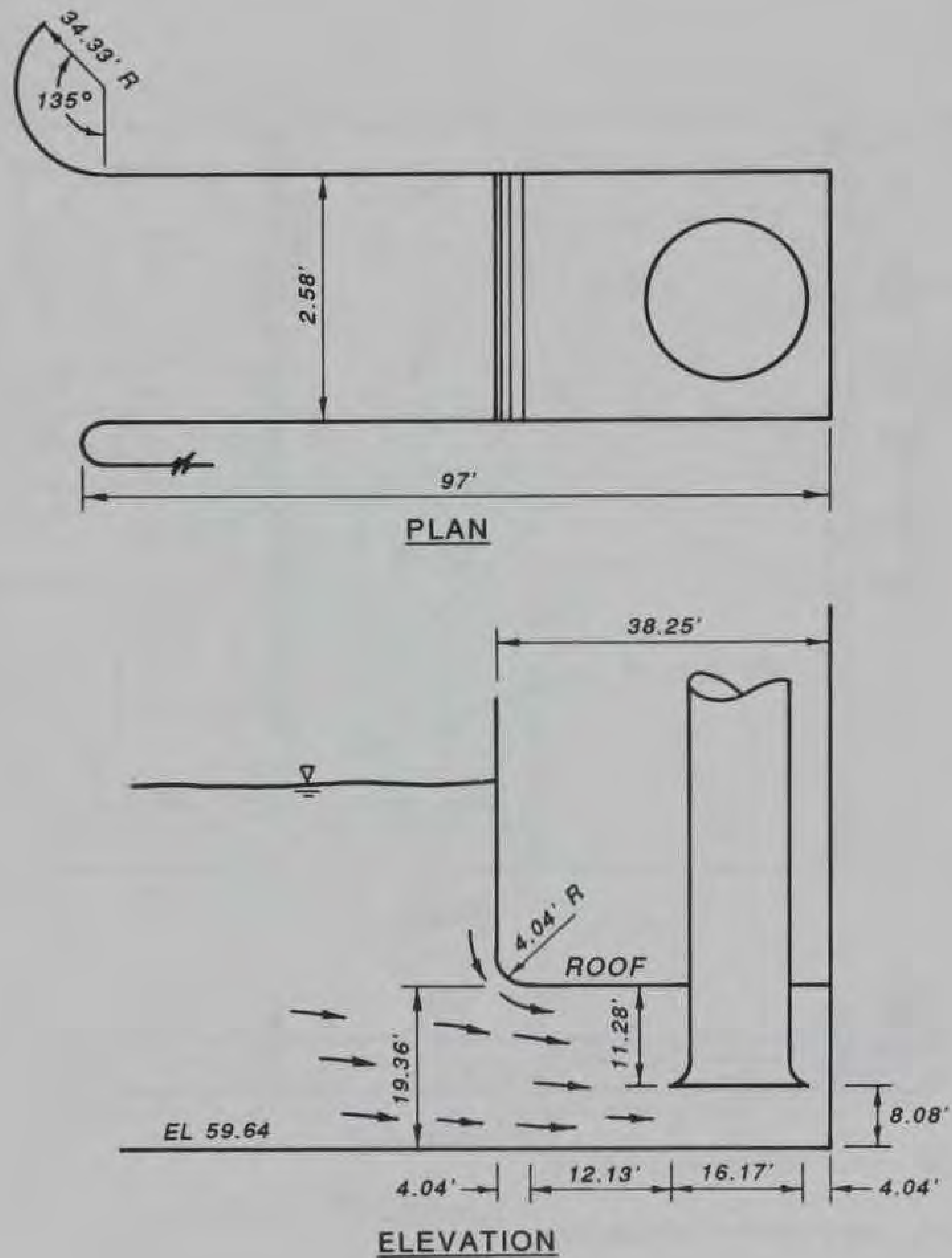


PLAN

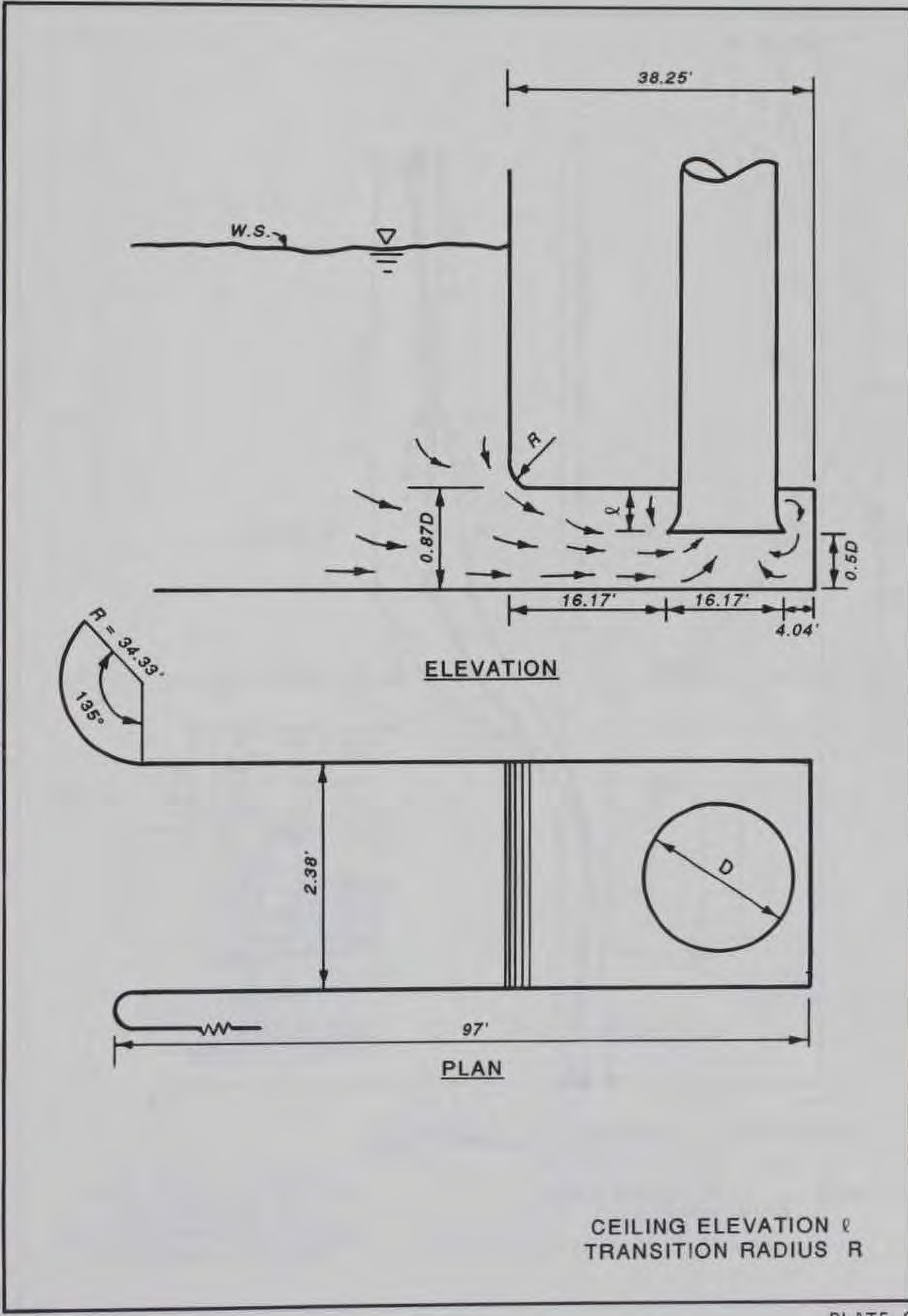
SECTION A-A

NOTE: ONLY PUMP 1 OPERATING

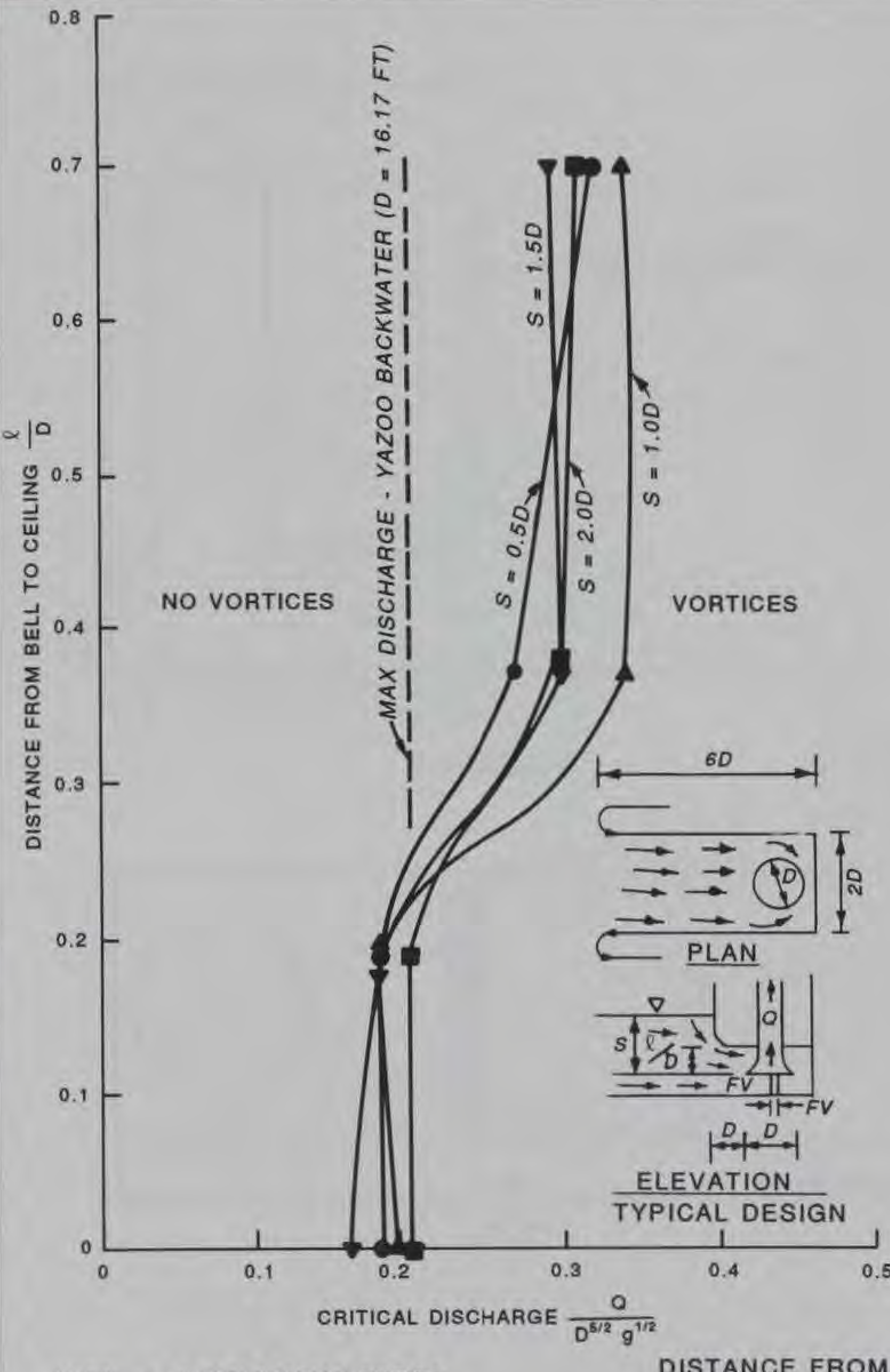
TYPE 2 APPROACH
ASYMMETRIC FLOW
SECTION MODEL



TYPE 3 PUMP INTAKE
SECTION MODEL

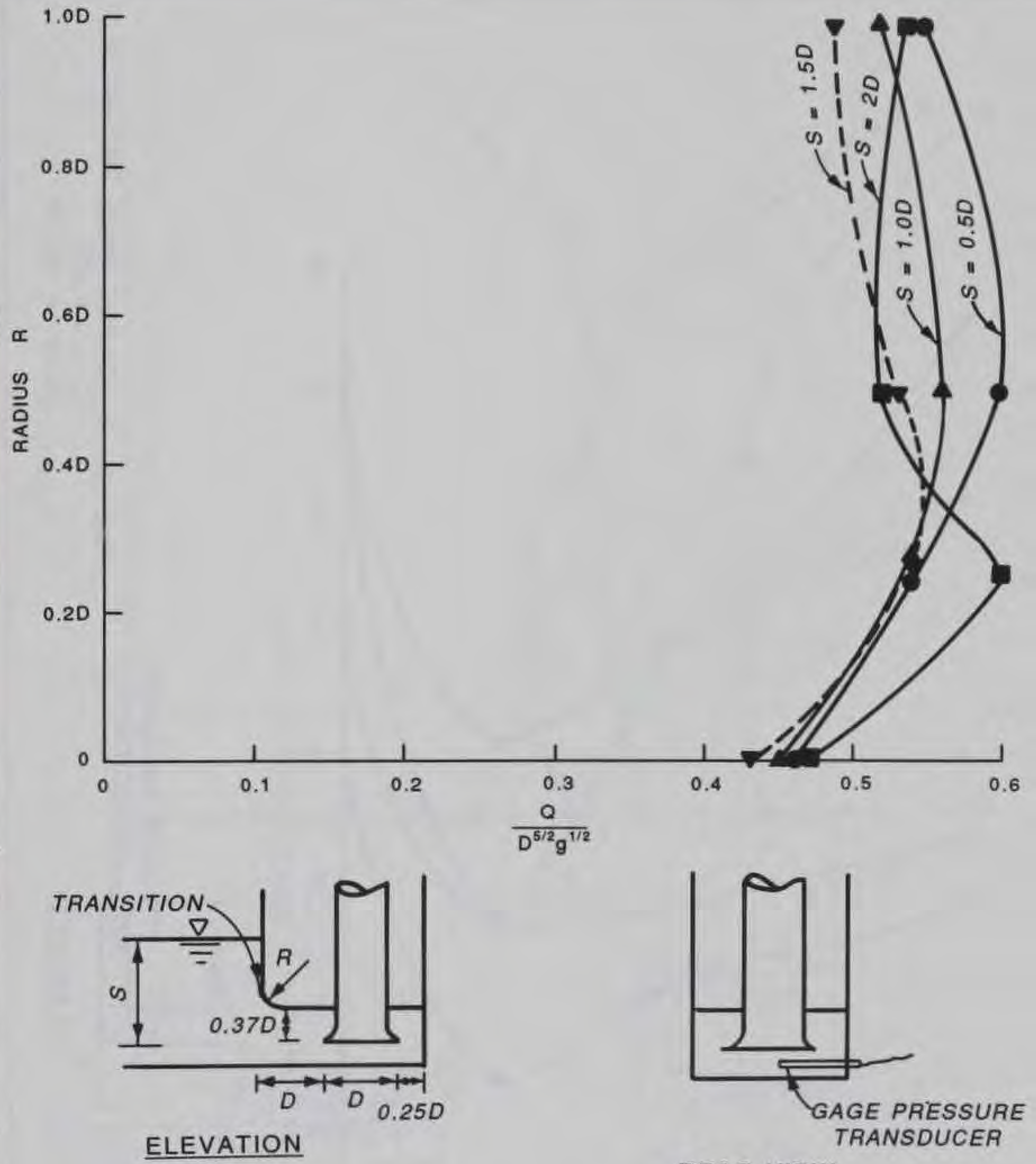


38.25'
W.S.
R
0.87D
ℓ
0.5D
16.17'
16.17'
4.04'
R = 34.33'
135°
ELEVATION
2.38'
D
97'
PLAN
CEILING ELEVATION ℓ
TRANSITION RADIUS R



NOTE: g - ACCELERATION DUE TO GRAVITY IN FT/SEC^2

DISTANCE FROM BELL TO CEILING ℓ/D VERSUS DISCHARGE FOR FLOOR VORTEX FV

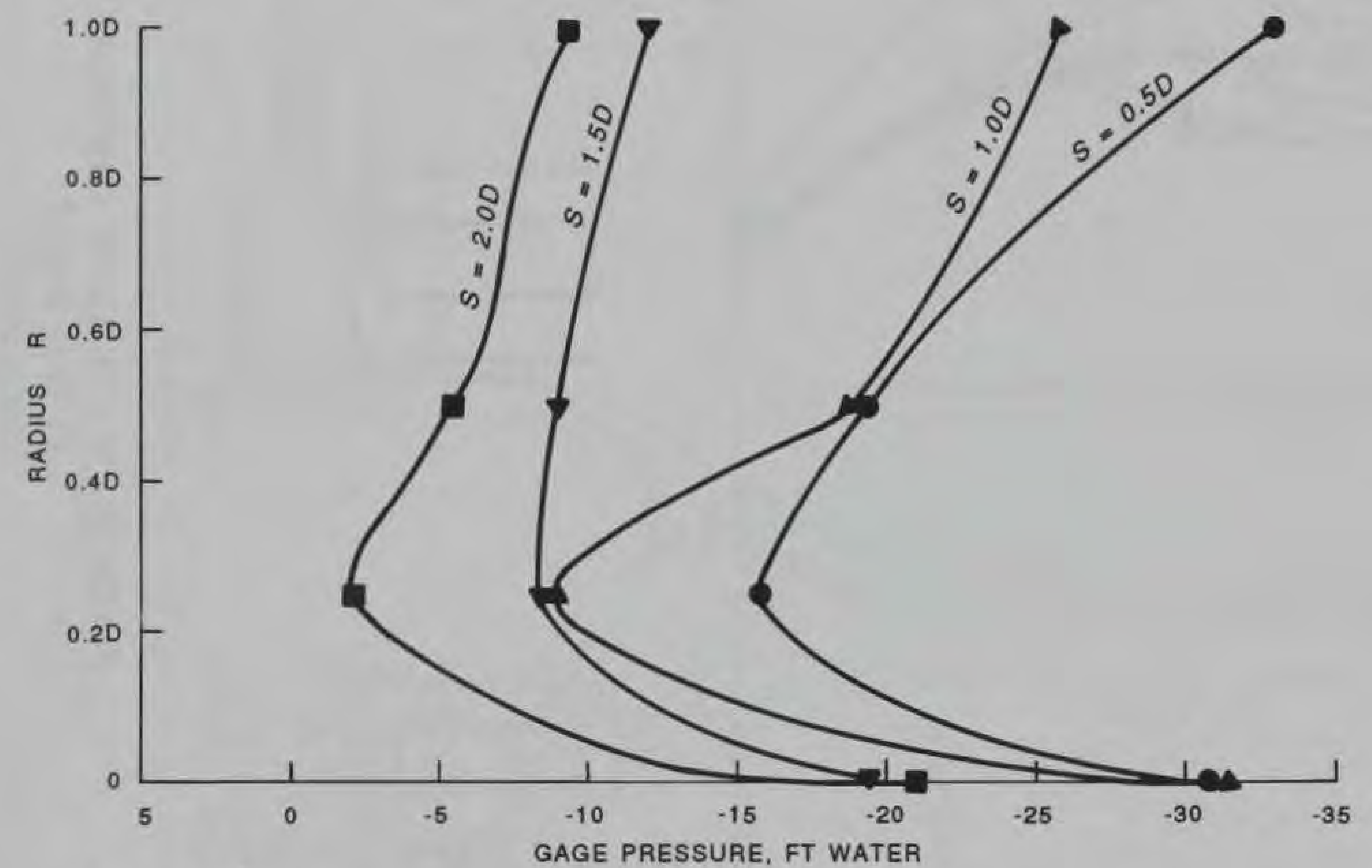


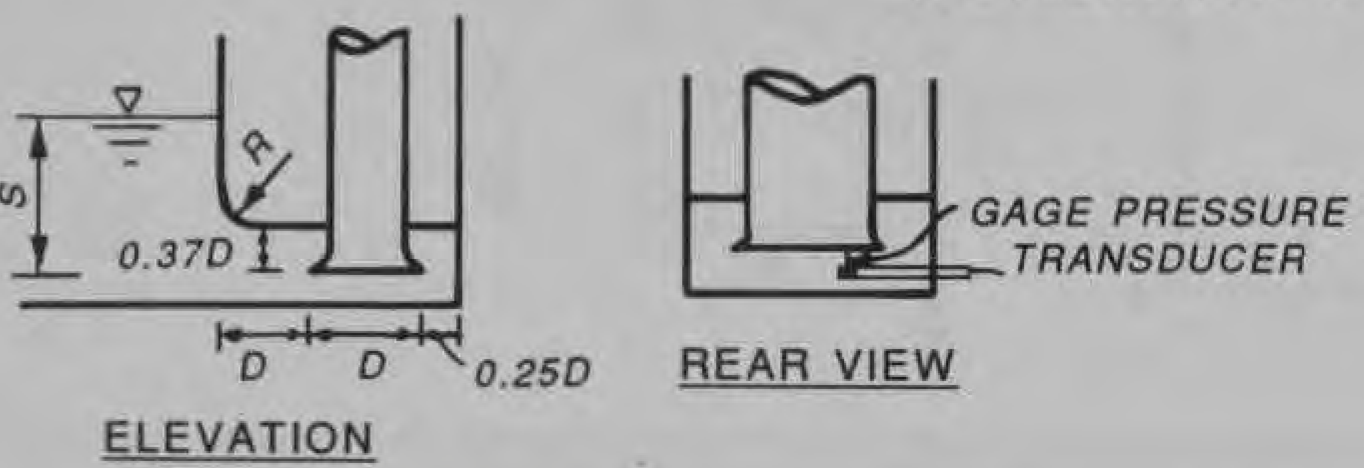
RADIUS R VERSUS CRITICAL FLOW RATE

ℓ/D = 0.37D

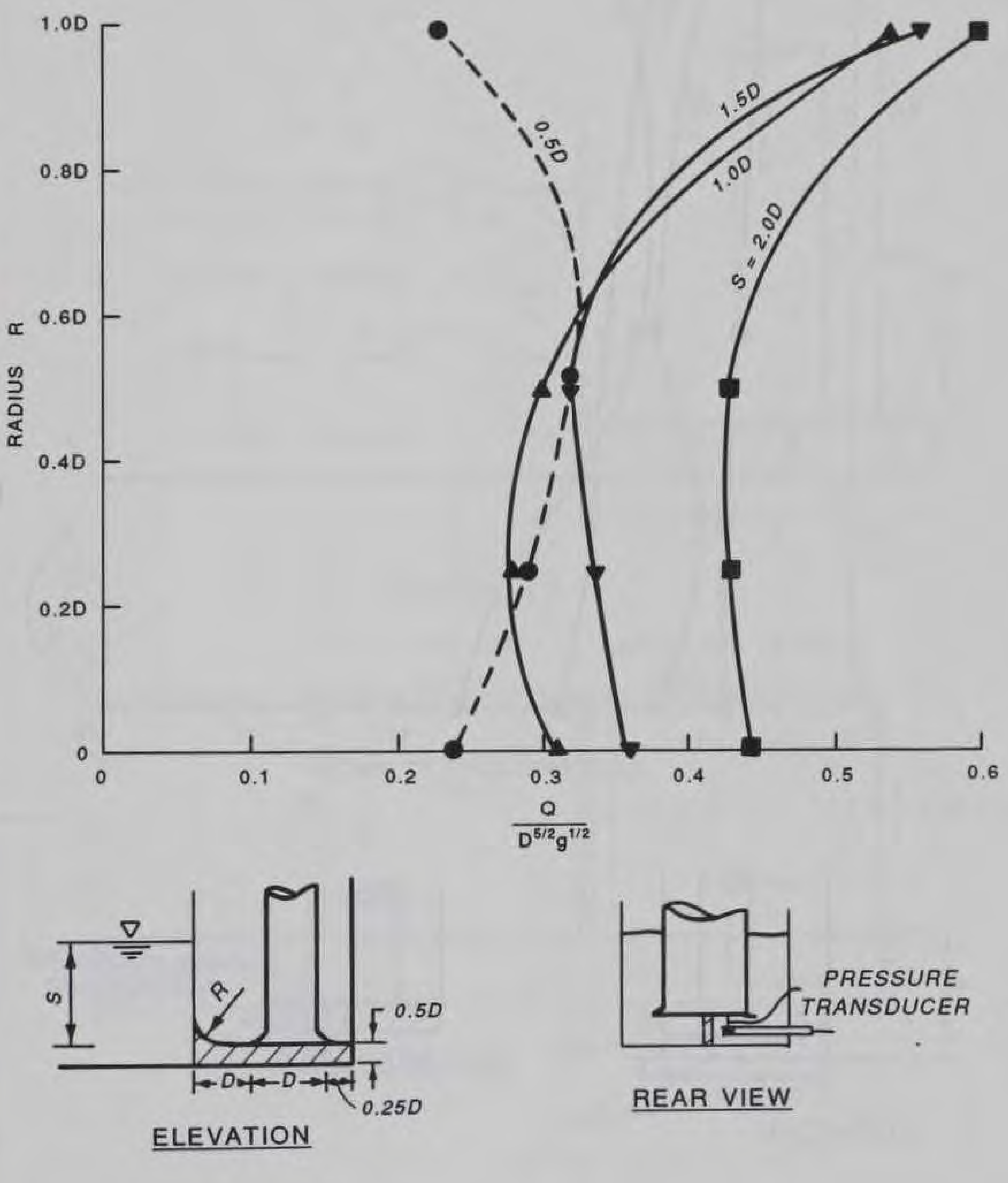
SECTION MODEL

SURFACE VORTICES (STAGE C)

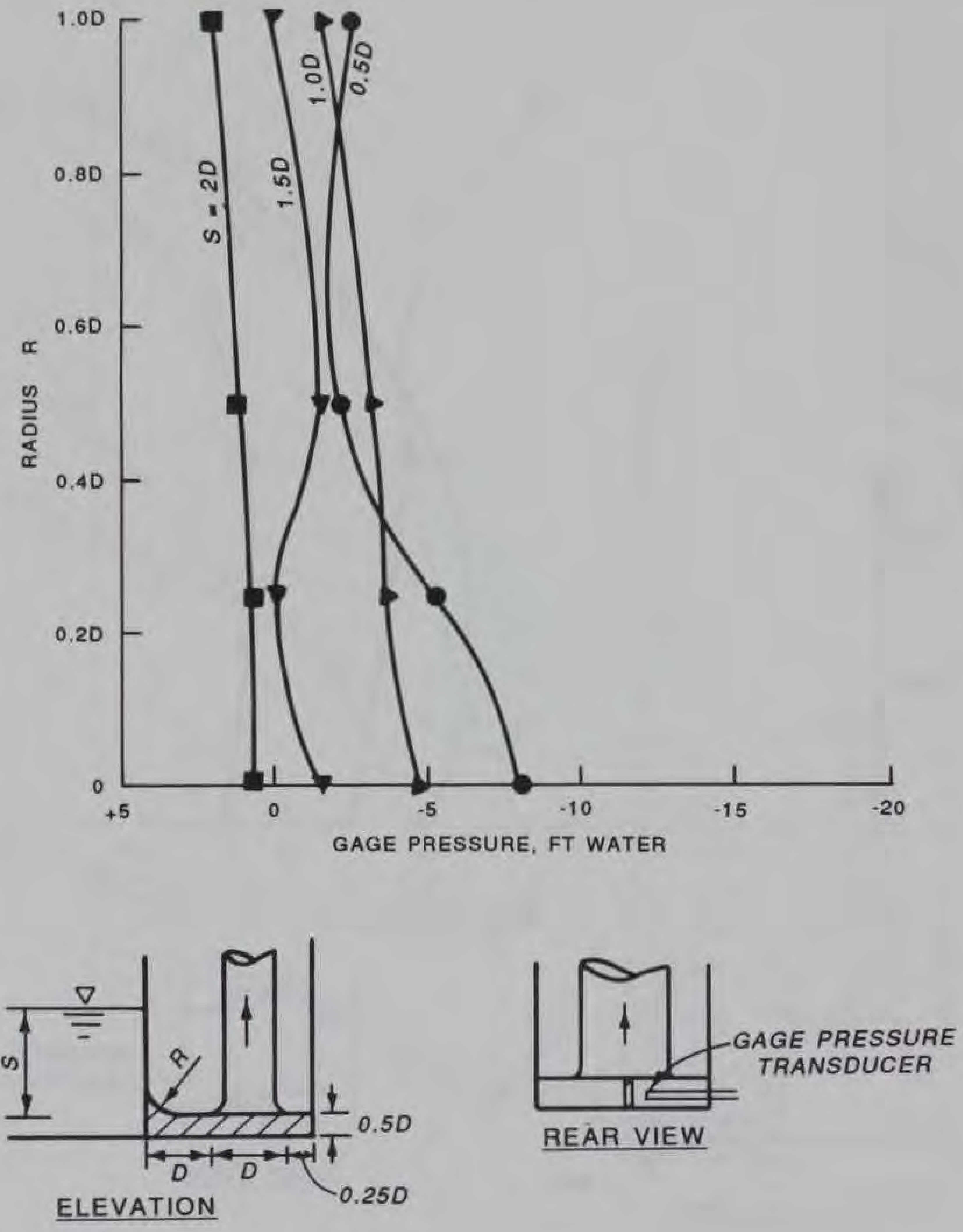




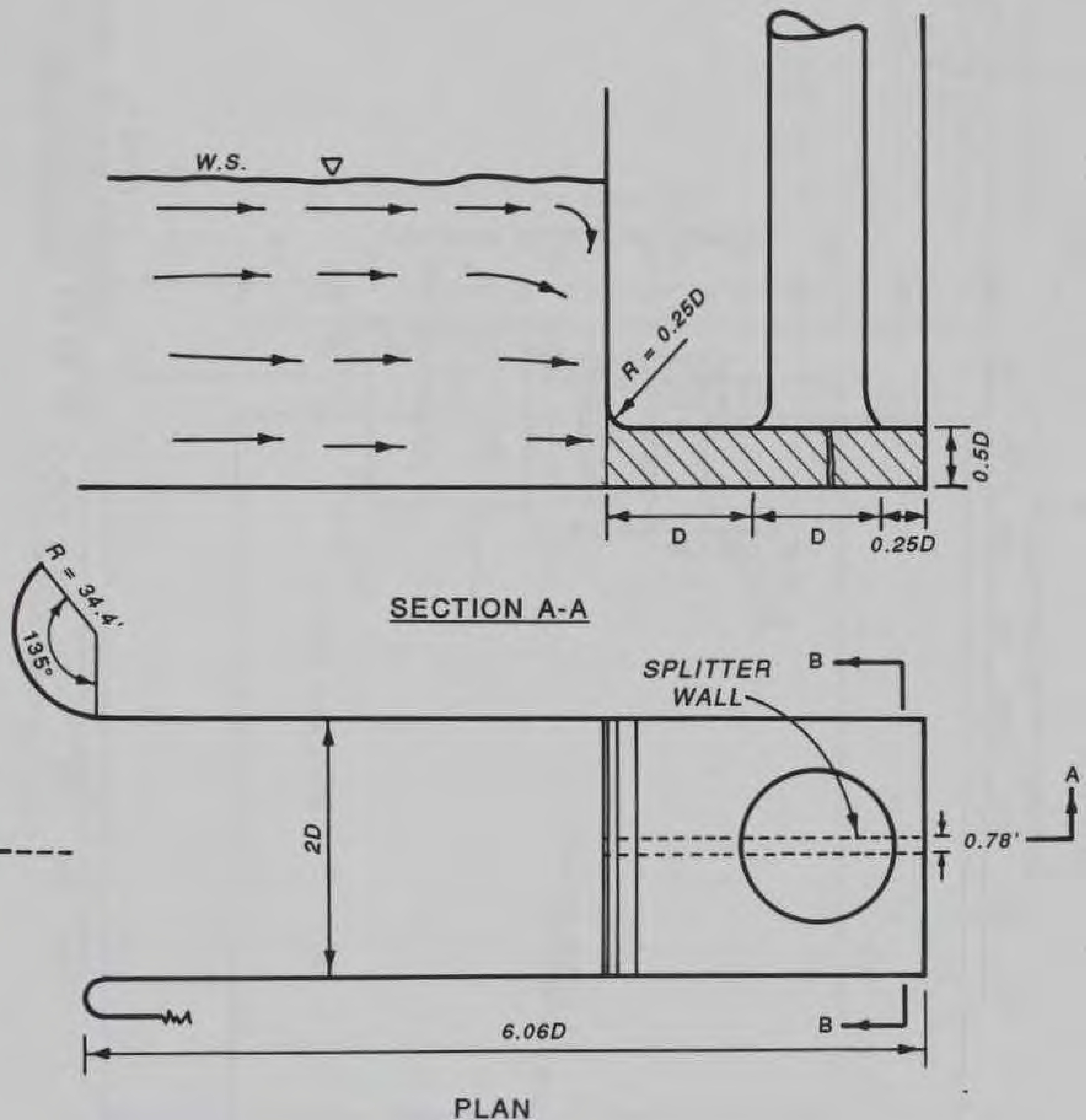
RADIUS R VERSUS GAGE PRESSURE
ℓ = 0.37D
SECTION MODEL



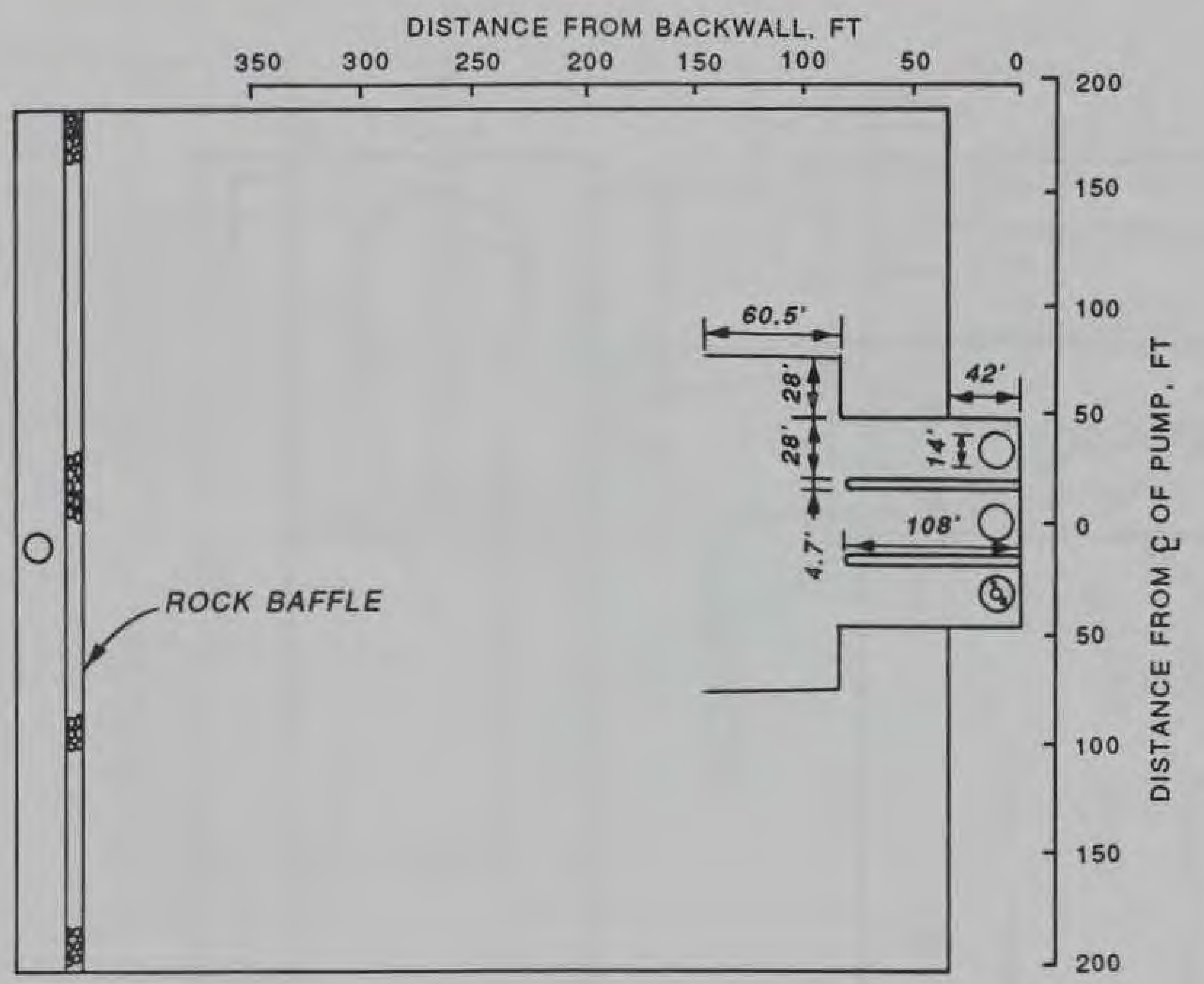
RADIUS R VERSUS CRITICAL FLOW RATE
SPLITTER WALL
SECTION MODEL
SURFACE VORTICES (STAGE C)



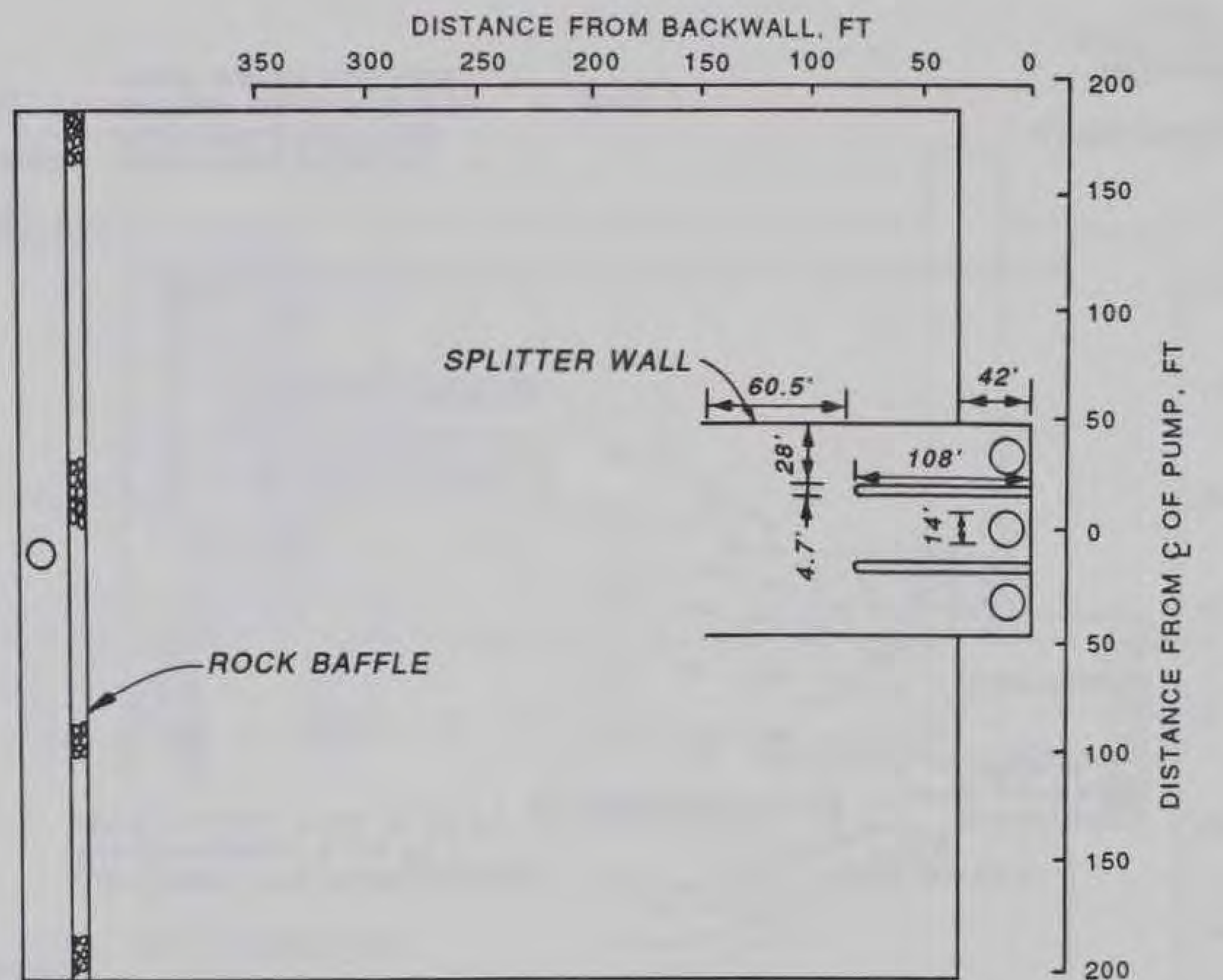
RADIUS R VERSUS GAGE PRESSURE
SPLITTER WALL
SECTION MODEL



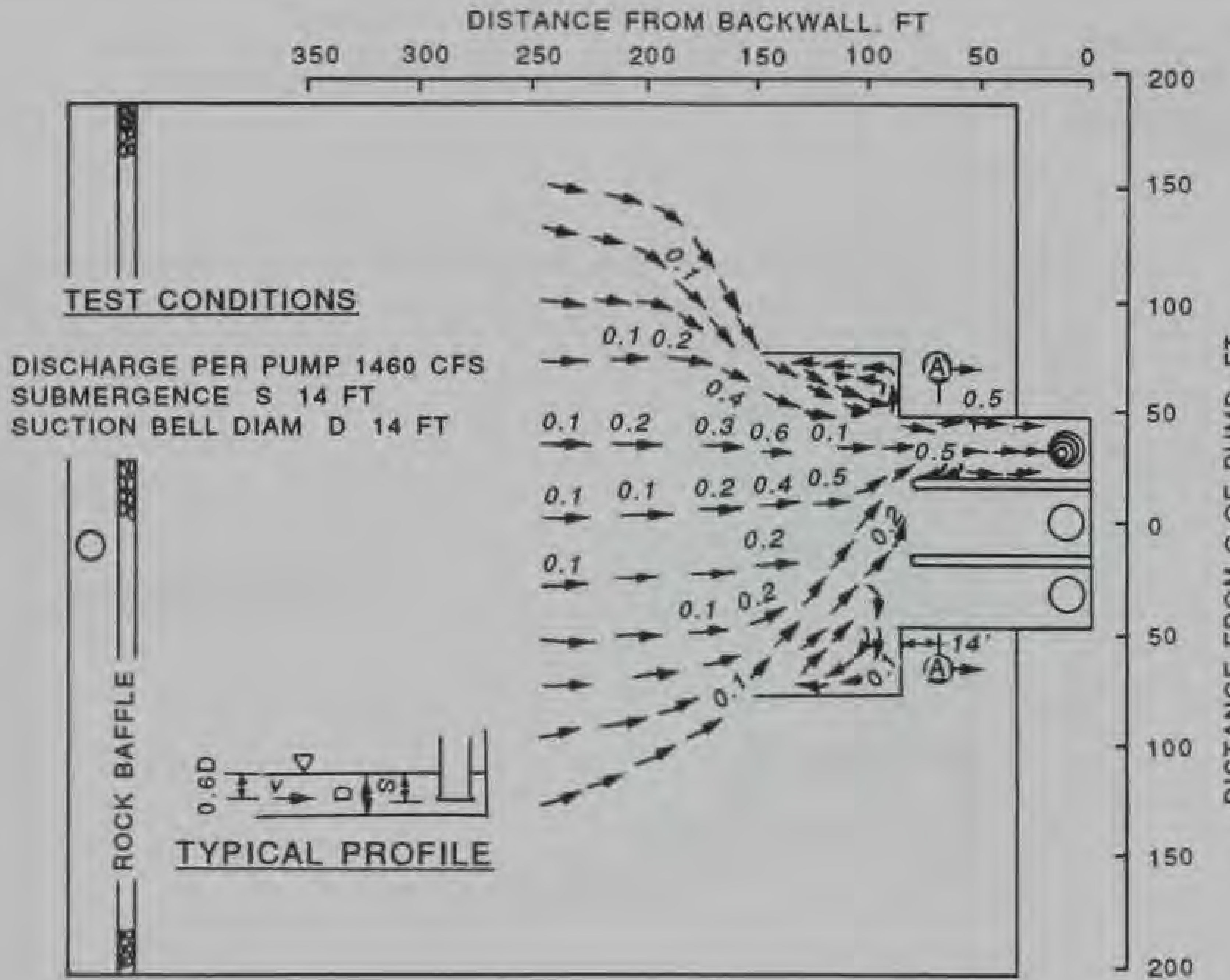
TYPE 4 PUMP INTAKE



TYPE 1
TRAINING WALLS OFFSET
28 FT (2D) FROM ABUTMENTS
SECTION MODEL

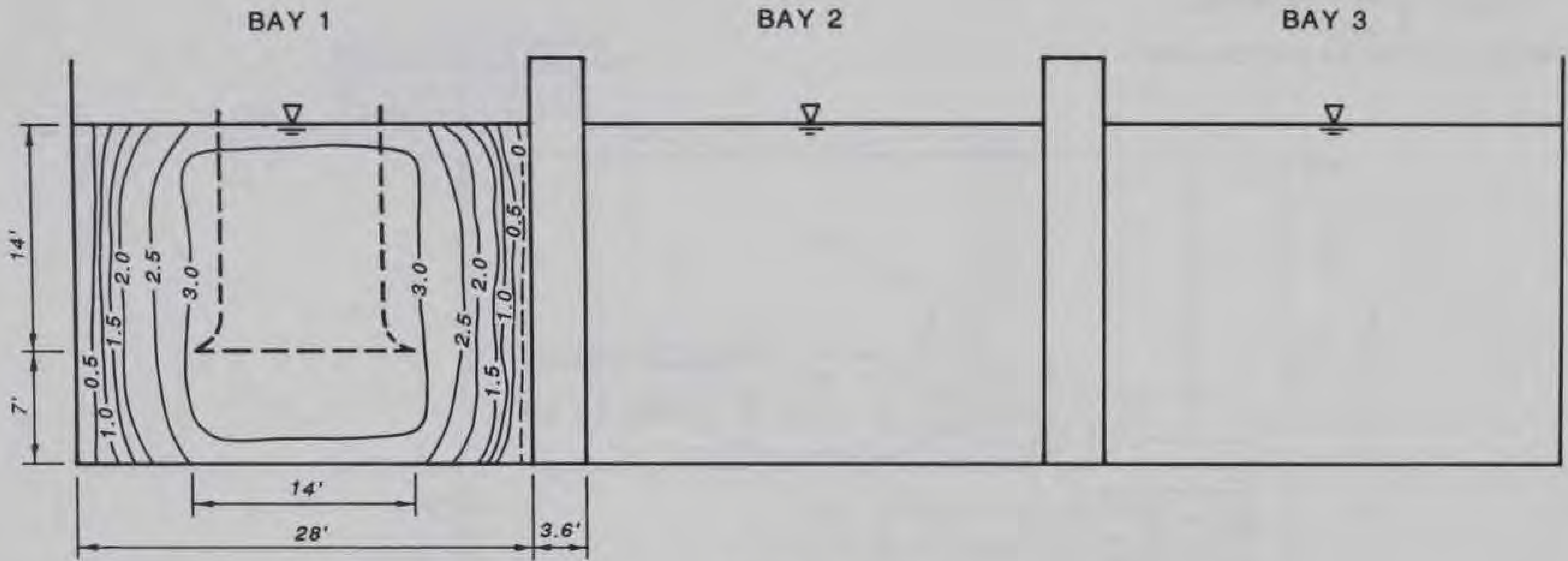


TYPE 2
TRAINING WALLS
FLUSH WITH ABUTMENTS
SECTION MODEL



NOTE: VELOCITIES V ARE IN PROTOTYPE FEET PER SECOND MEASURED 0.6D FROM WATER SURFACE.

APPROACH FLOW PATTERNS
TYPE 1
TRAINING WALLS OFFSET
28 FT (2D) FROM ABUTMENTS
PUMP 1 OPERATING



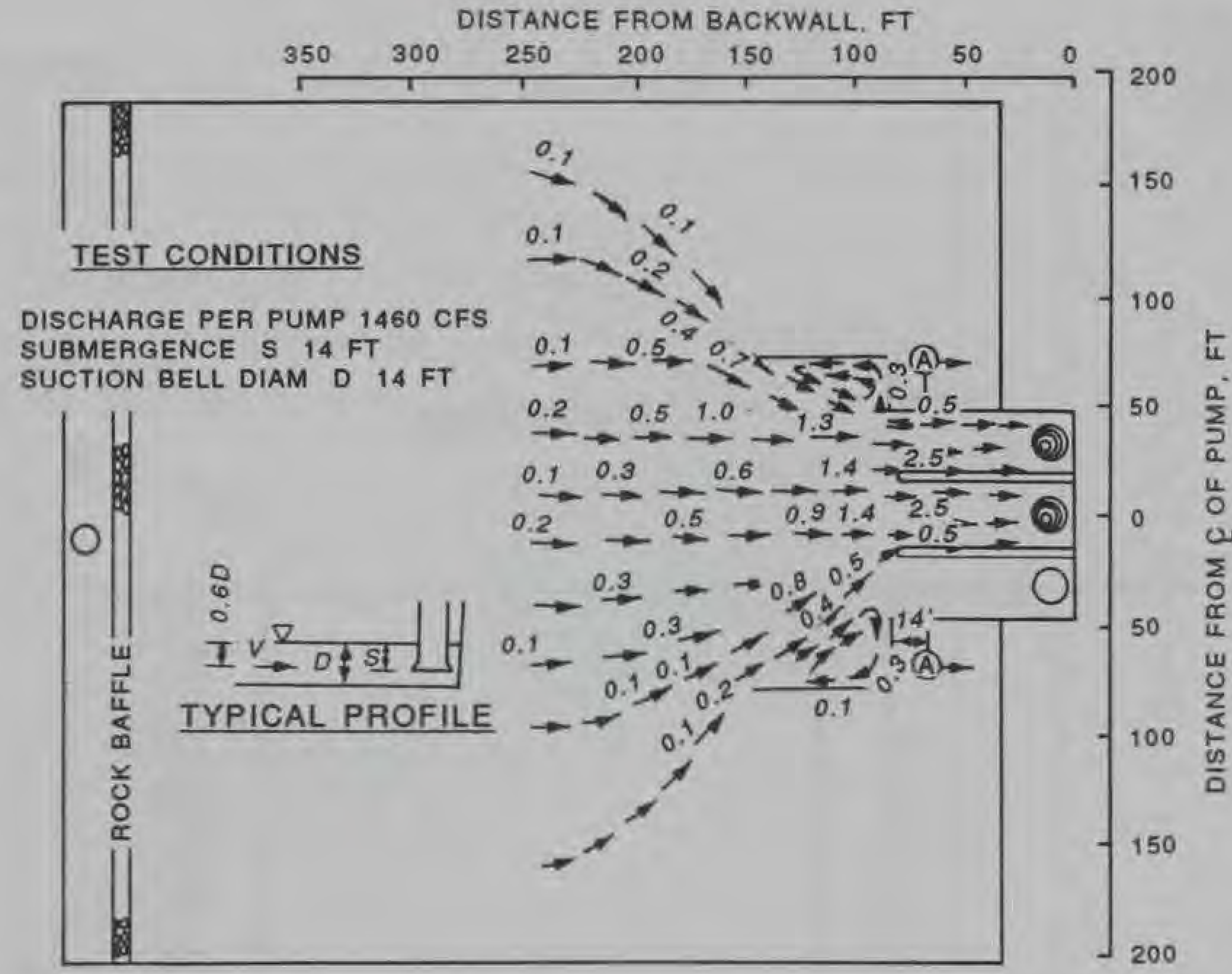
SECTION A-A

TEST CONDITIONS

PUMP OPERATING 1
DISCHARGE PER PUMP 1460 CFS
SUBMERGENCE S 14 FT
SUCTION BELL DIAM D 14 FT

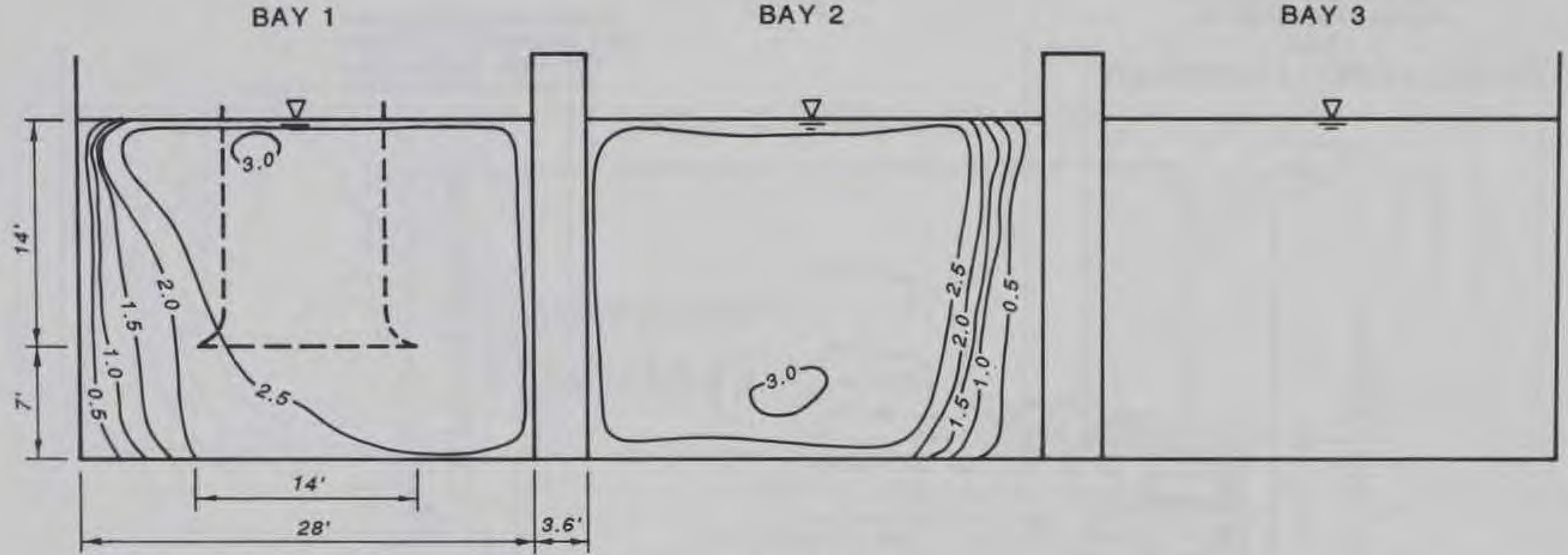
NOTE: ISOVELS ARE IN PROTOTYPE FEET PER SECOND.

ISOVELS
TYPE 1
TRAINING WALLS
OFFSET 28 FT (2D)
FROM ABUTMENTS
PUMP 1 OPERATING



NOTE: VELOCITIES V ARE IN PROTOTYPE FEET PER SECOND MEASURED 0.6D FROM WATER SURFACE.

APPROACH FLOW PATTERNS
TYPE 1
TRAINING WALLS OFFSET
28 FT (2D) FROM ABUTMENTS
PUMPS 1 & 2 OPERATING



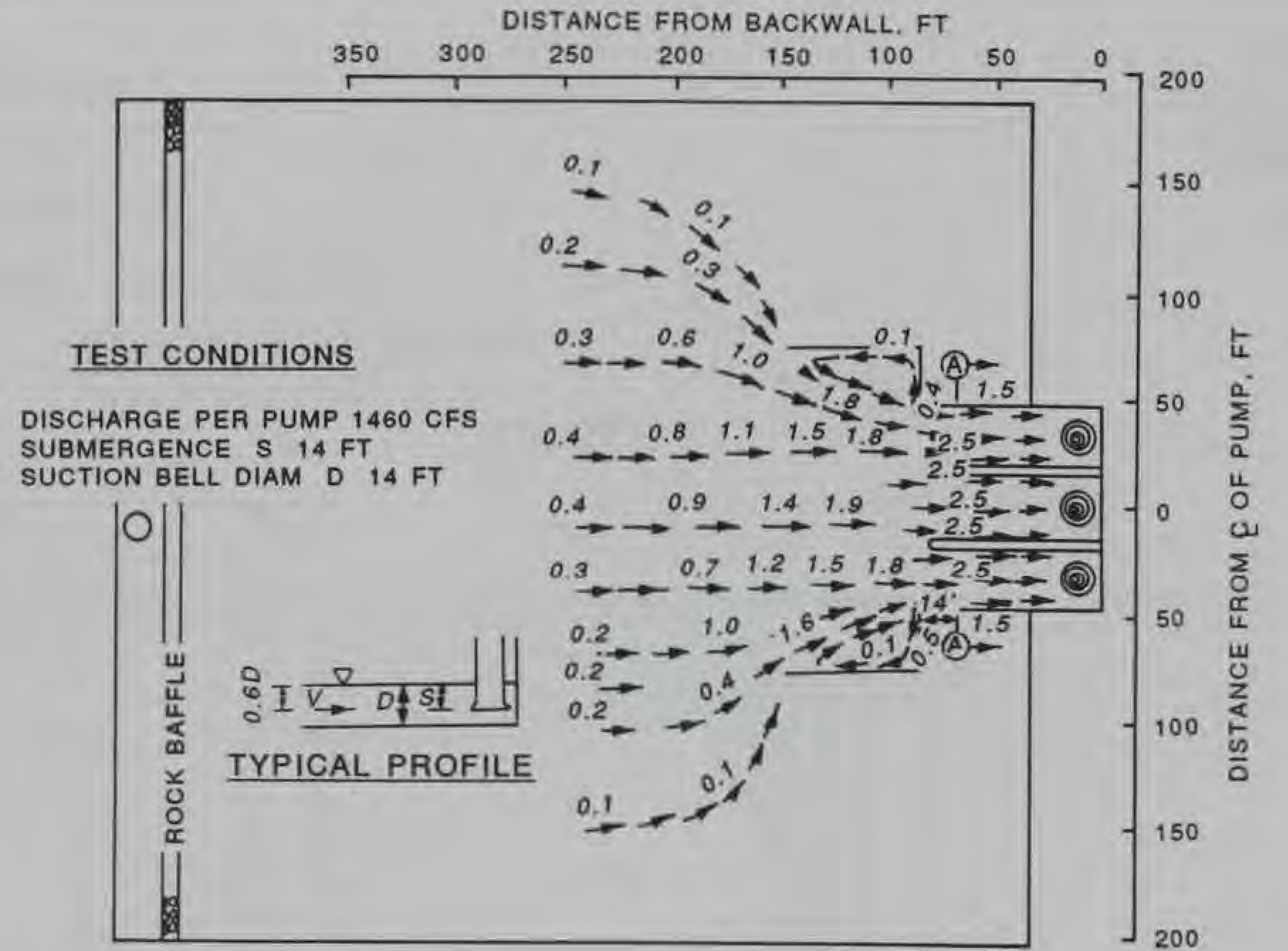
SECTION A-A

TEST CONDITIONS

PUMPS OPERATING 1 & 2
DISCHARGE PER PUMP 1460 CFS
SUBMERGENCE S 14 FT
SUCTION BELL DIAM D 14 FT

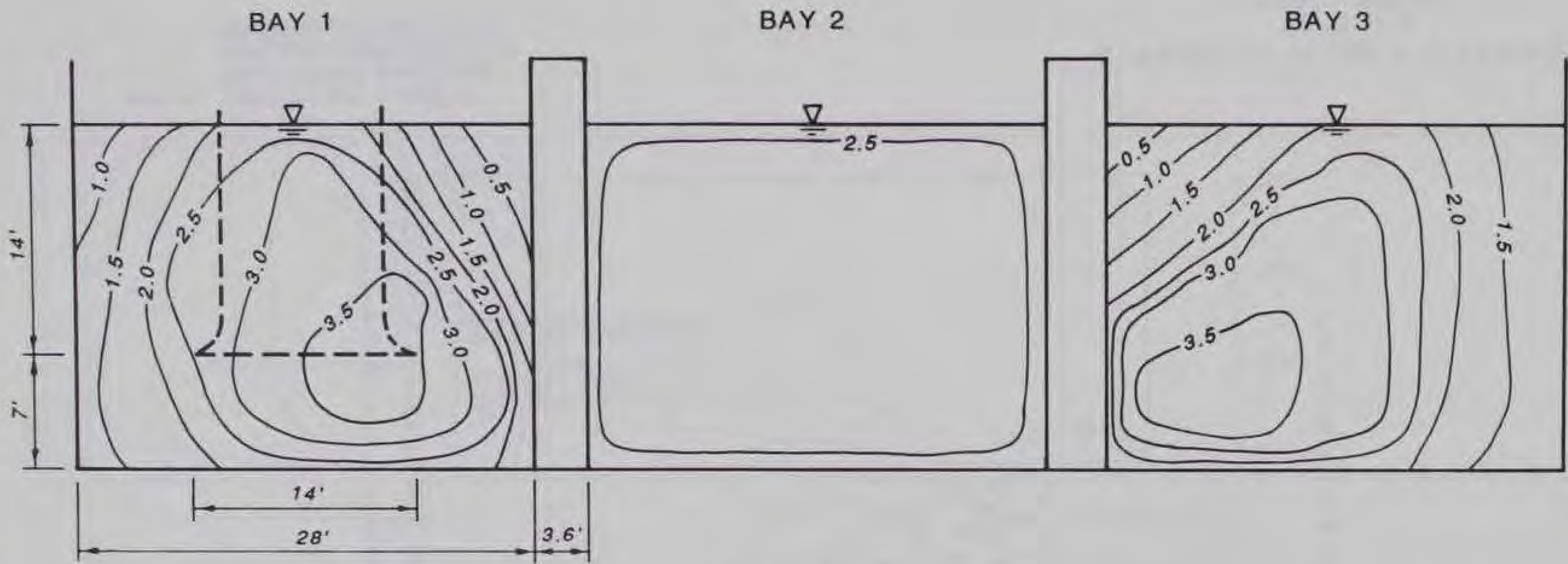
NOTE: ISOVELS ARE IN PROTOTYPE FEET PER SECOND.

ISOVELS
TYPE 1
TRAINING WALLS
OFFSET 28 FT (2D)
FROM ABUTMENTS
PUMPS 1 & 2
OPERATING



NOTE: VELOCITIES V ARE IN PROTOTYPE FEET PER SECOND MEASURED 0.6D FROM WATER SURFACE.

APPROACH FLOW PATTERNS
TYPE 1
TRAINING WALLS OFFSET
28 FT (2D) FROM ABUTMENTS
PUMPS 1, 2, & 3 OPERATING



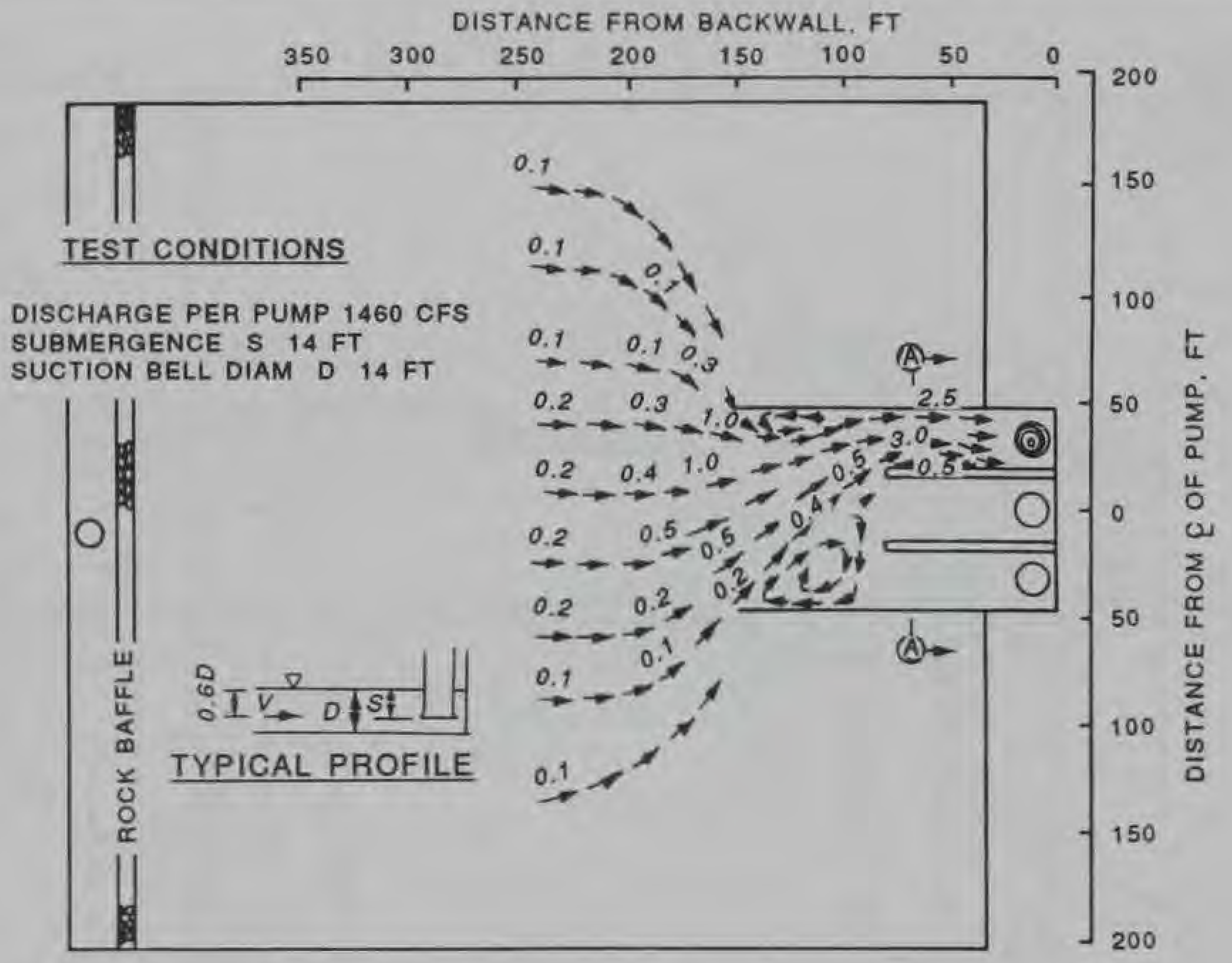
SECTION A-A

TEST CONDITIONS

PUMPS OPERATING 1, 2, & 3
DISCHARGE PER PUMP 1460 CFS
SUBMERGENCE S 14 FT
SUCTION BELL DIAM D 14 FT

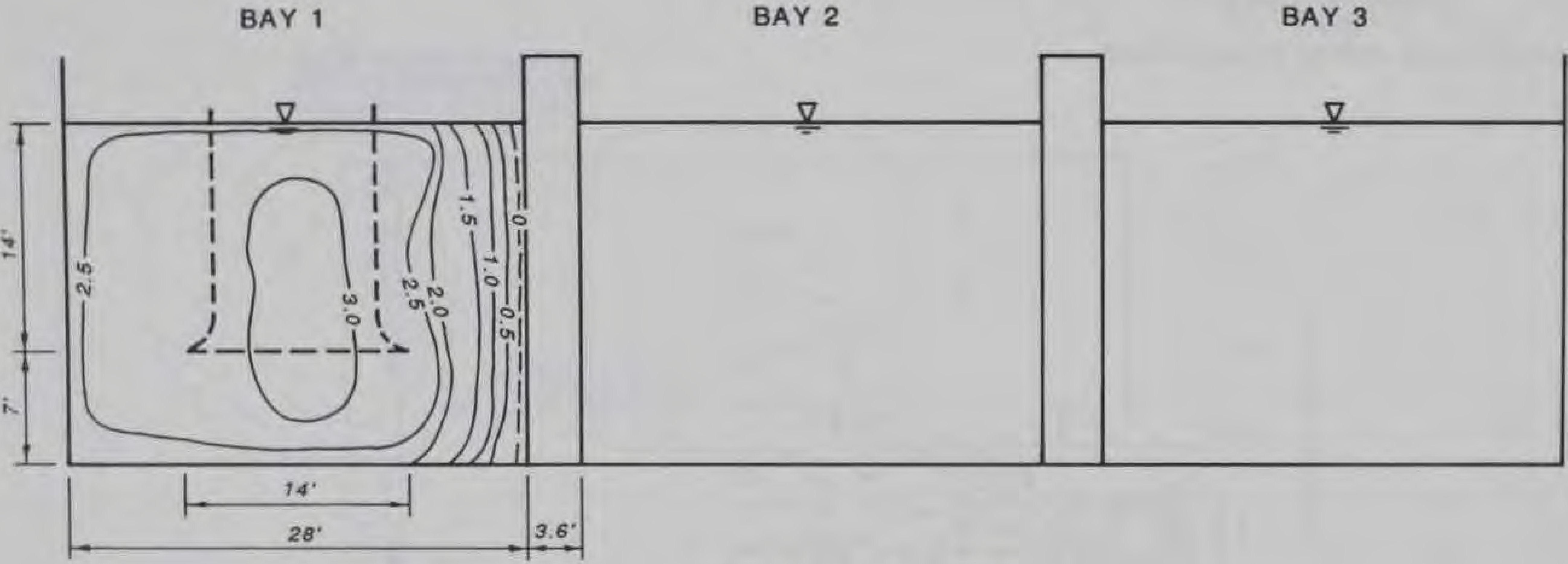
NOTE: ISOVELS ARE IN PROTOTYPE FEET PER SECOND.

ISOVELS
TYPE 2
TRAINING WALLS
FLUSH WITH ABUTMENTS
PUMPS 1, 2, AND 3
OPERATING



NOTE: VELOCITIES V ARE IN PROTOTYPE FEET PER SECOND MEASURED 0.6D FROM WATER SURFACE.

APPROACH FLOW PATTERNS
TYPE 2
TRAINING WALLS
FLUSH WITH ABUTMENTS
PUMP 1 OPERATING



SECTION A-A

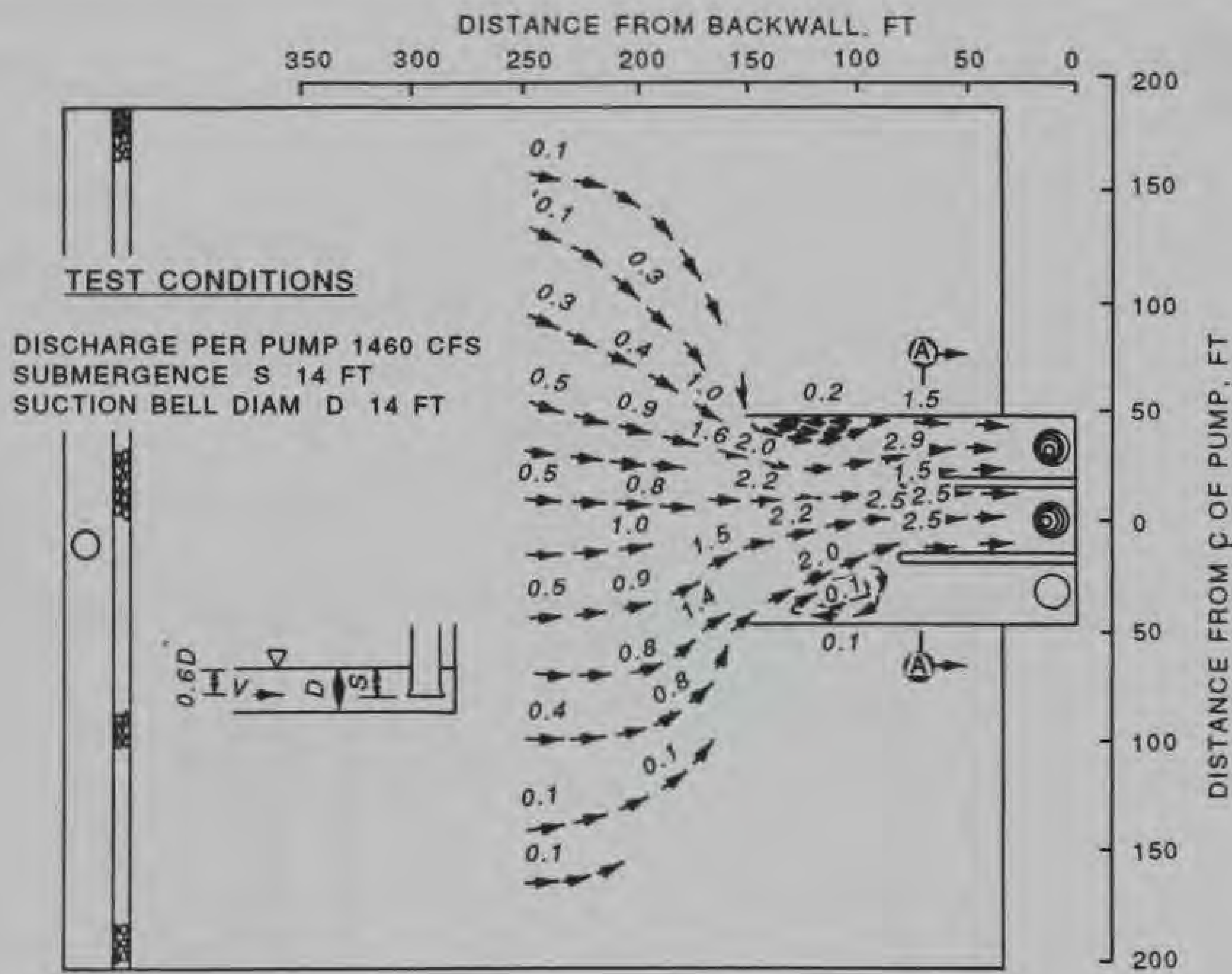
TEST CONDITIONS

PUMP OPERATING 1
DISCHARGE PER PUMP 1460 CFS
SUBMERGENCE S 14 FT
SUCTION BELL DIAM D 14 FT

NOTE: ISOVELS ARE IN PROTOTYPE
FEET PER SECOND.

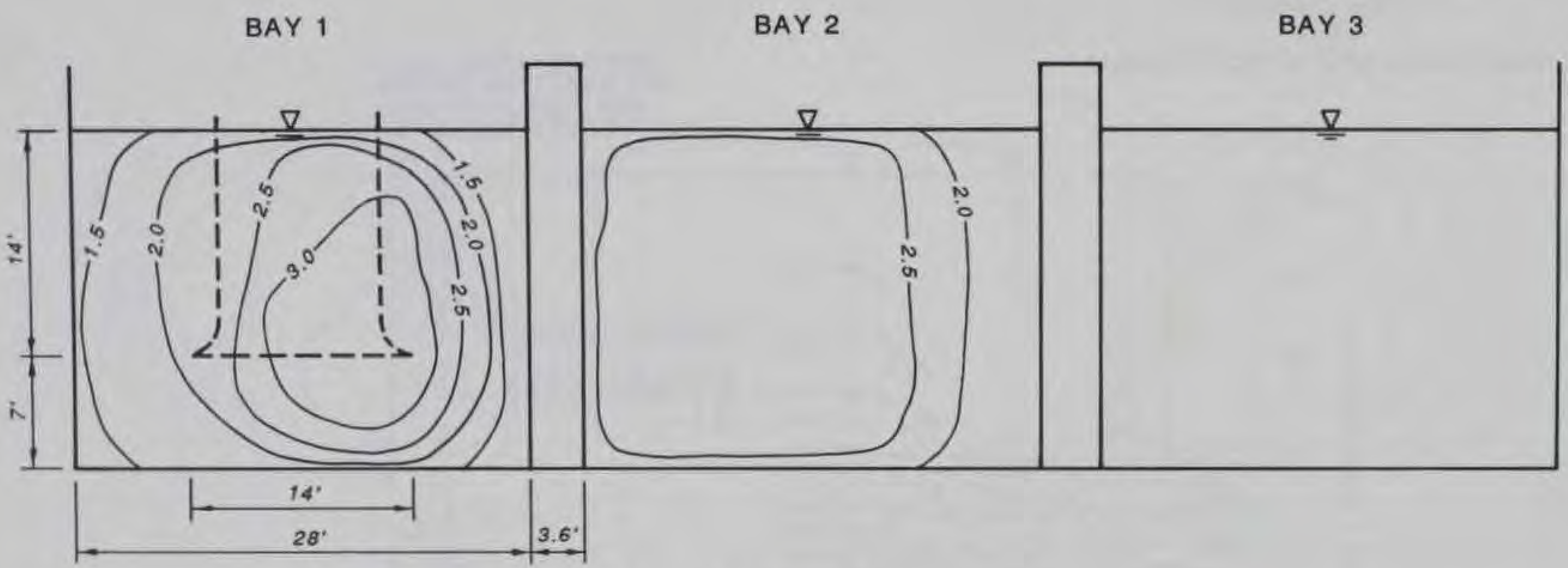
--- FLOW IN UPSTREAM DIRECTION

ISOVELS
TYPE 2
TRAINING WALLS
FLUSH WITH ABUTMENTS
PUMP 1 OPERATING



NOTE: VELOCITIES V ARE IN PROTOTYPE FEET PER SECOND MEASURED 0.6D FROM WATER SURFACE.

APPROACH FLOW PATTERNS
TYPE 2
TRAINING WALLS
FLUSH WITH ABUTMENTS
PUMPS 1 & 2 OPERATING



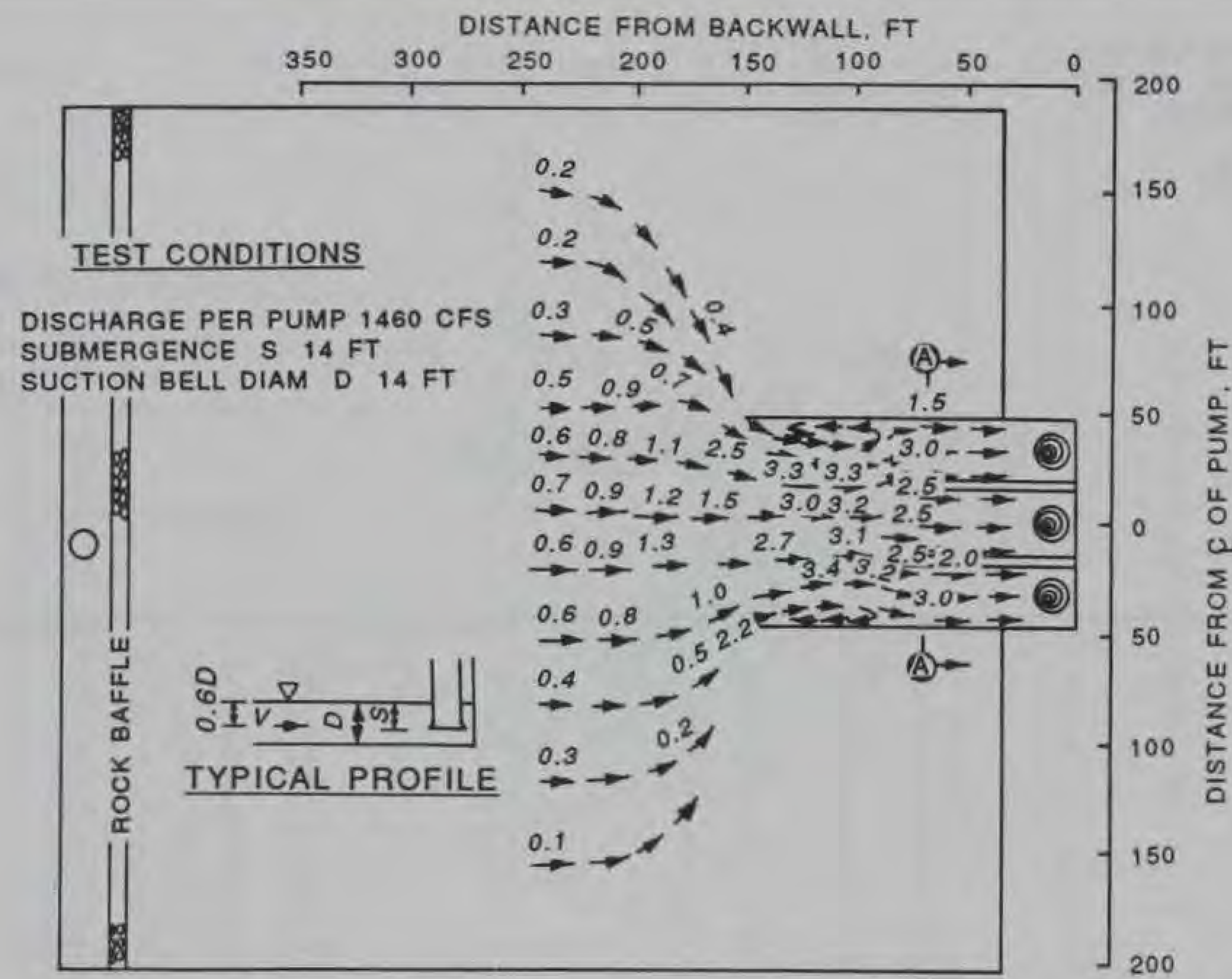
SECTION A-A

TEST CONDITIONS

PUMPS OPERATING 1 & 2
DISCHARGE PER PUMP 1460 CFS
SUBMERGENCE S 14 FT
SUCTION BELL DIAM D 14 FT

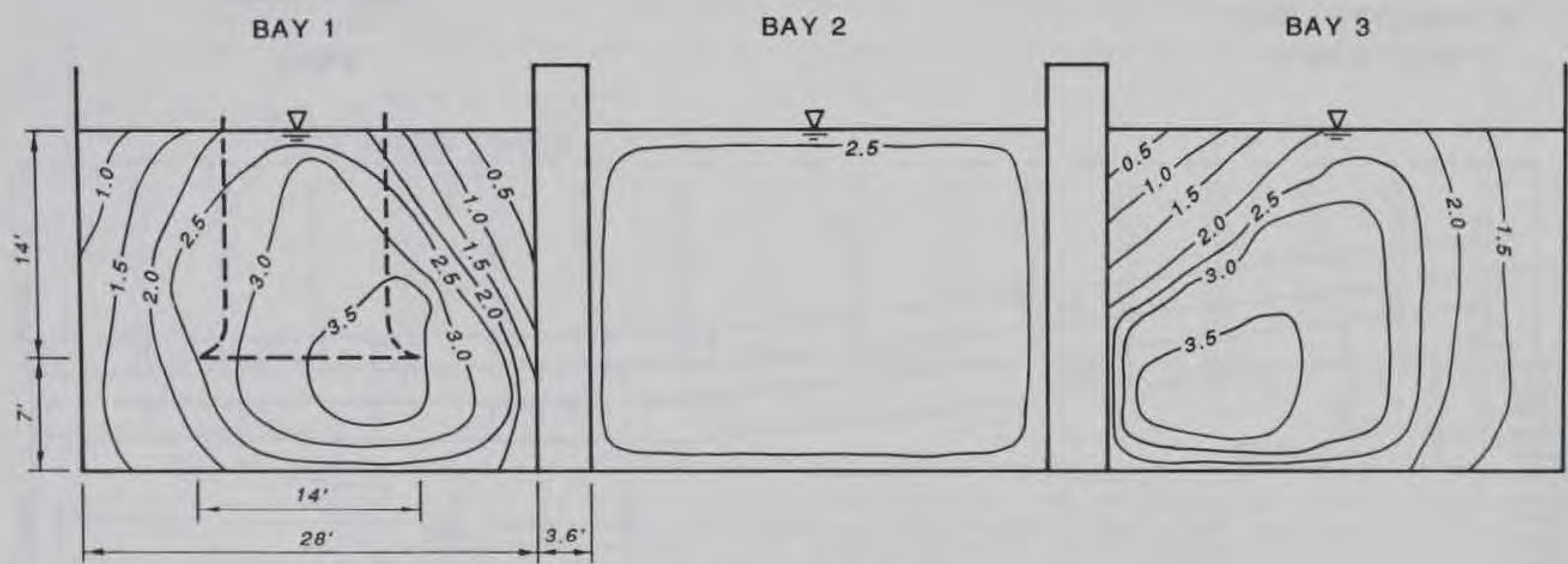
NOTE: ISOVELS ARE IN PROTOTYPE FEET PER SECOND.

ISOVELS
TYPE 2
TRAINING WALLS
FLUSH WITH ABUTMENTS
PUMPS 1 & 2 OPERATING



NOTE: VELOCITIES V ARE IN PROTOTYPE FEET PER SECOND MEASURED 0.6D FROM WATER SURFACE.

APPROACH FLOW PATTERNS
TYPE 2
TRAINING WALLS
FLUSH WITH ABUTMENTS
PUMPS 1, 2, & 3 OPERATING



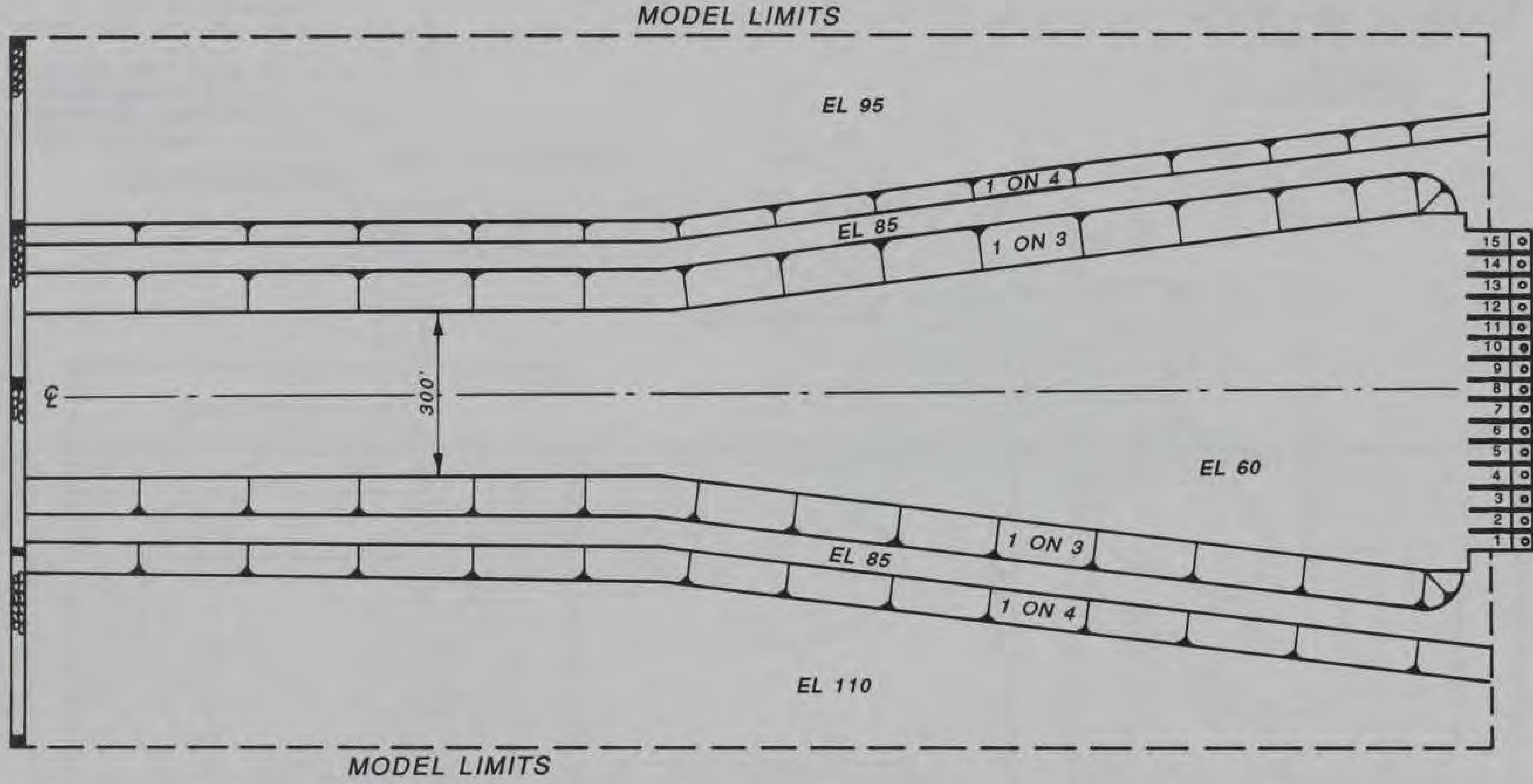
SECTION A-A

TEST CONDITIONS

PUMP OPERATING 1, 2, & 3
DISCHARGE PER PUMP 1460 CFS
SUBMERGENCE S 14 FT
SUCTION BELL DIAM D 14 FT

NOTE: ISOVELS ARE IN PROTOTYPE FEET PER SECOND.

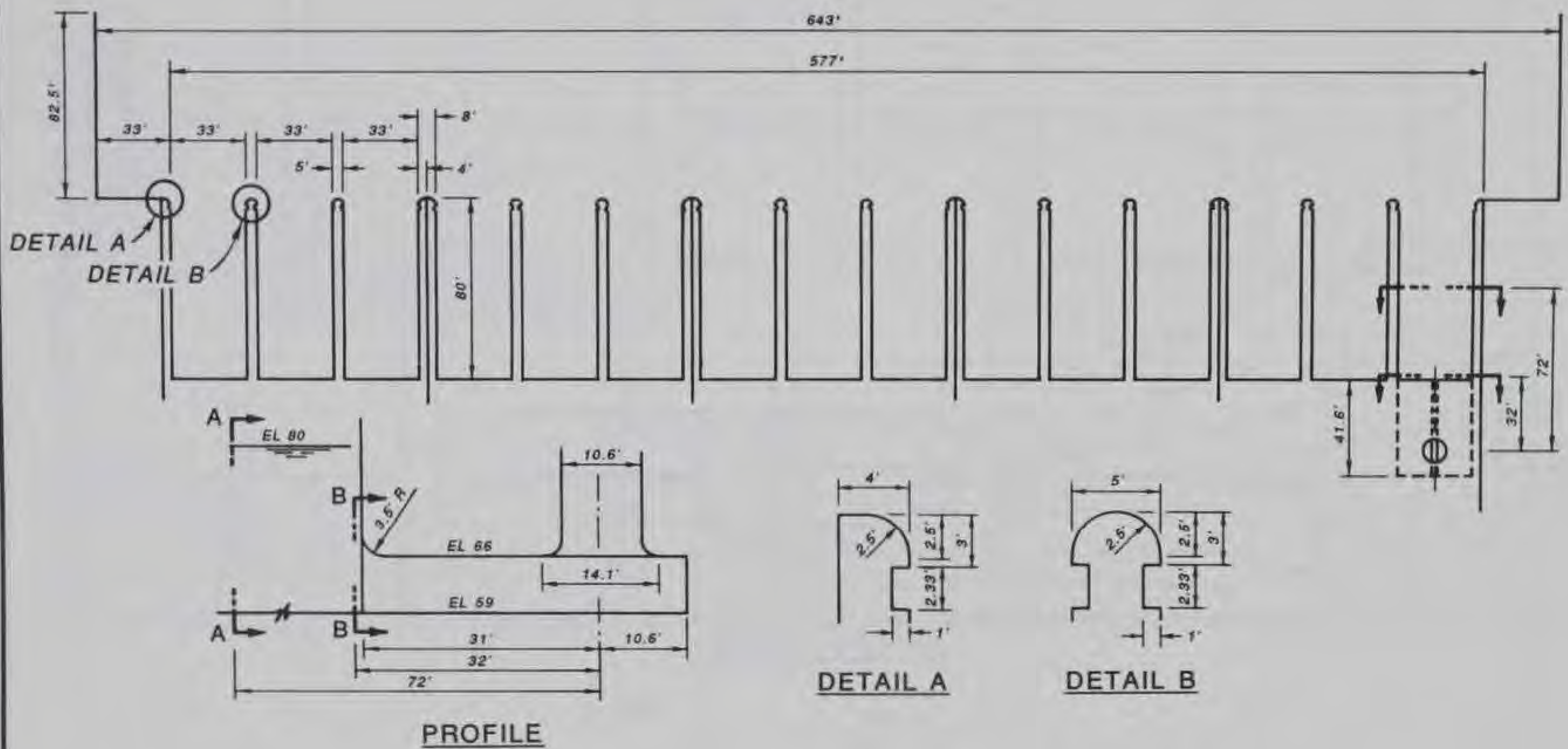
ISOVELS
TYPE 2
TRAINING WALLS
FLUSH WITH ABUTMENTS
PUMPS 1, 2, & 3 OPERATING



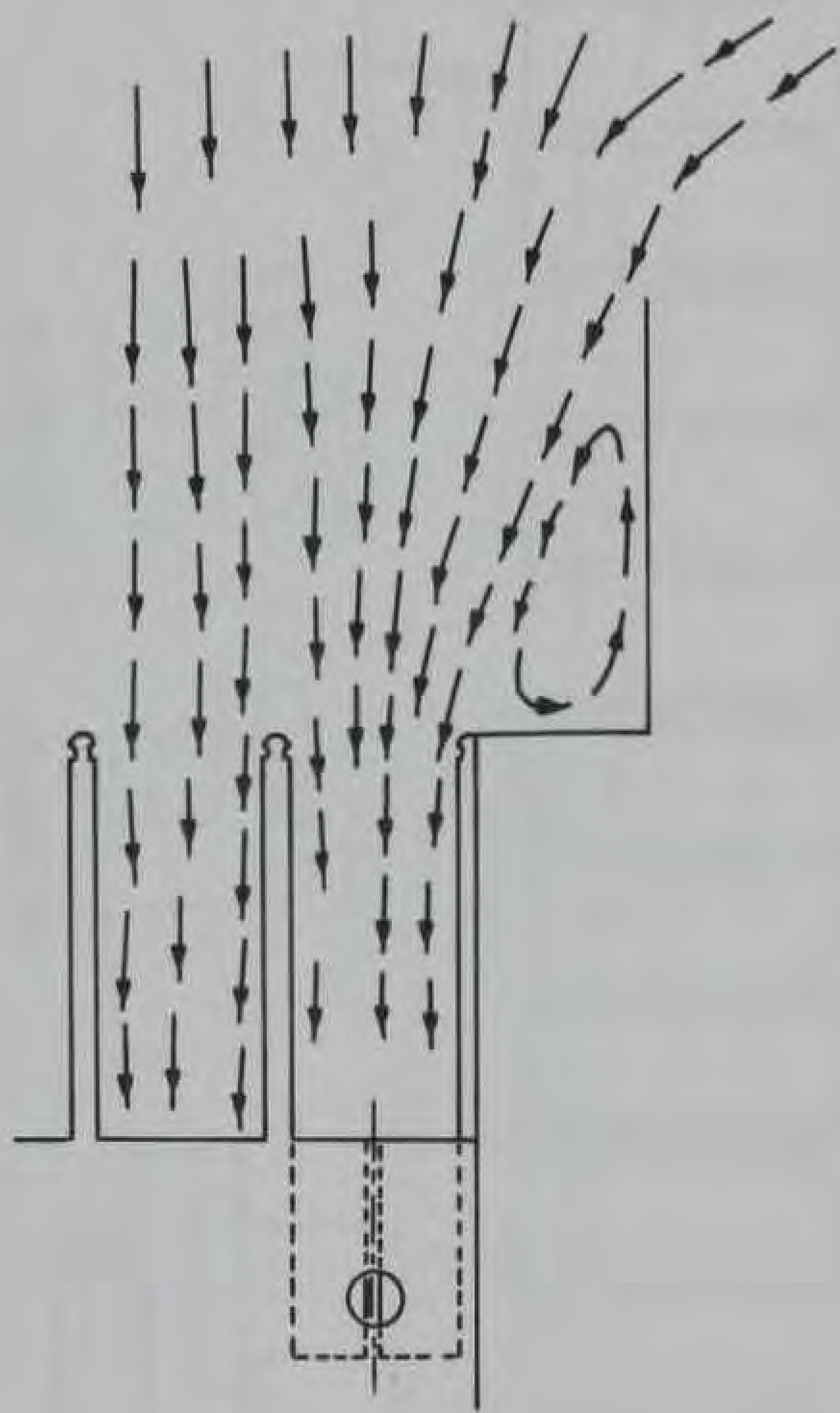
SCALE

100 0 100 200 FT

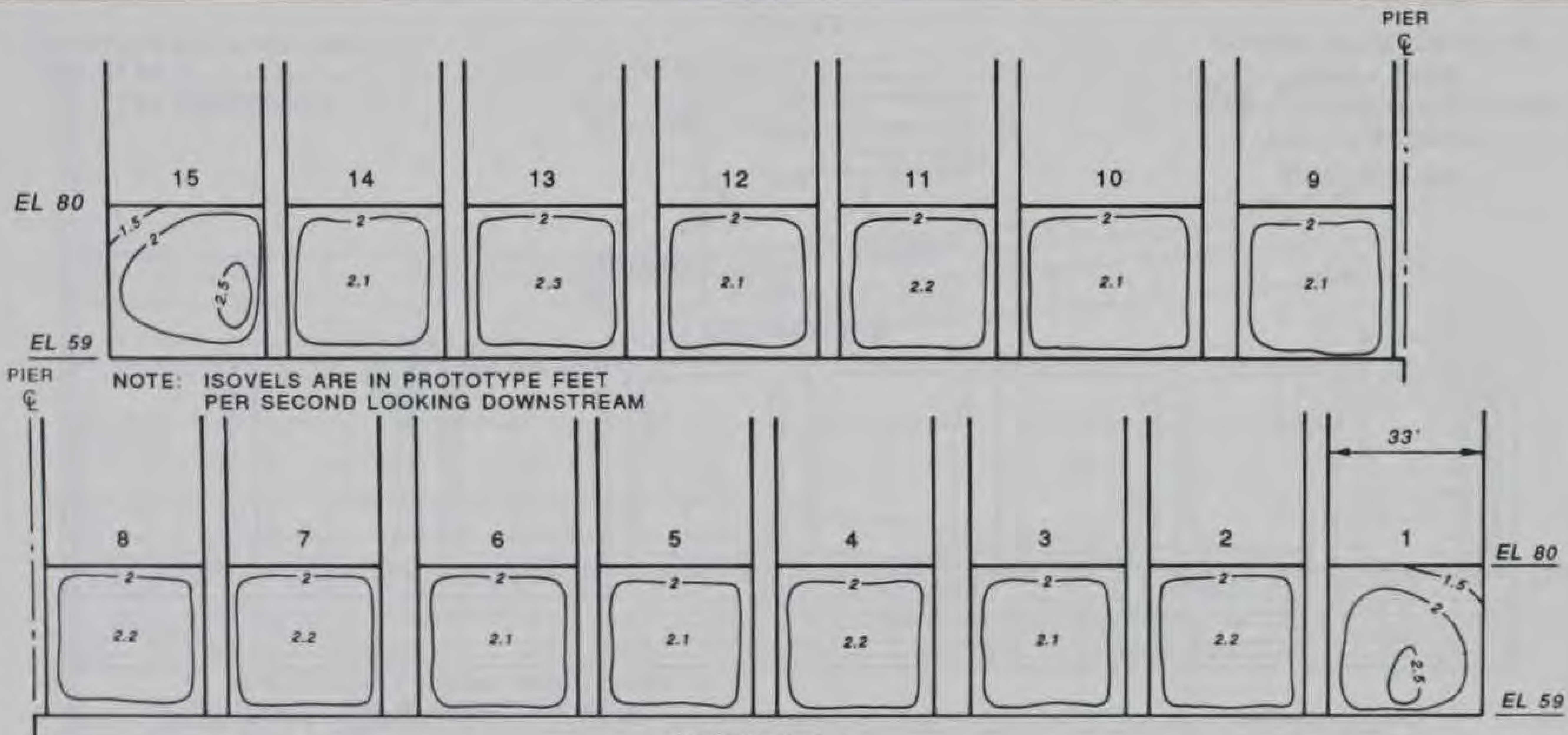
TYPE 1 SUMP
TYPE 1 ABUTMENTS
TYPE 1 APPROACH CHANNEL
COMPREHENSIVE MODEL



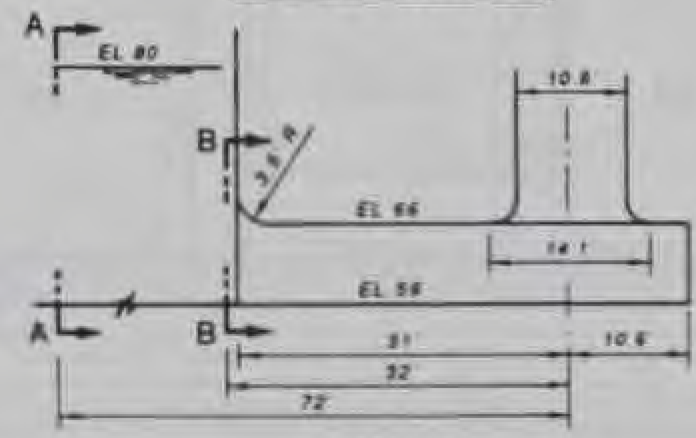
TYPE 1 ABUTMENTS
TYPE 1 SUMP



FLOW PATTERN
TYPE 1 ABUTMENT
COMPREHENSIVE MODEL



SECTION A-A

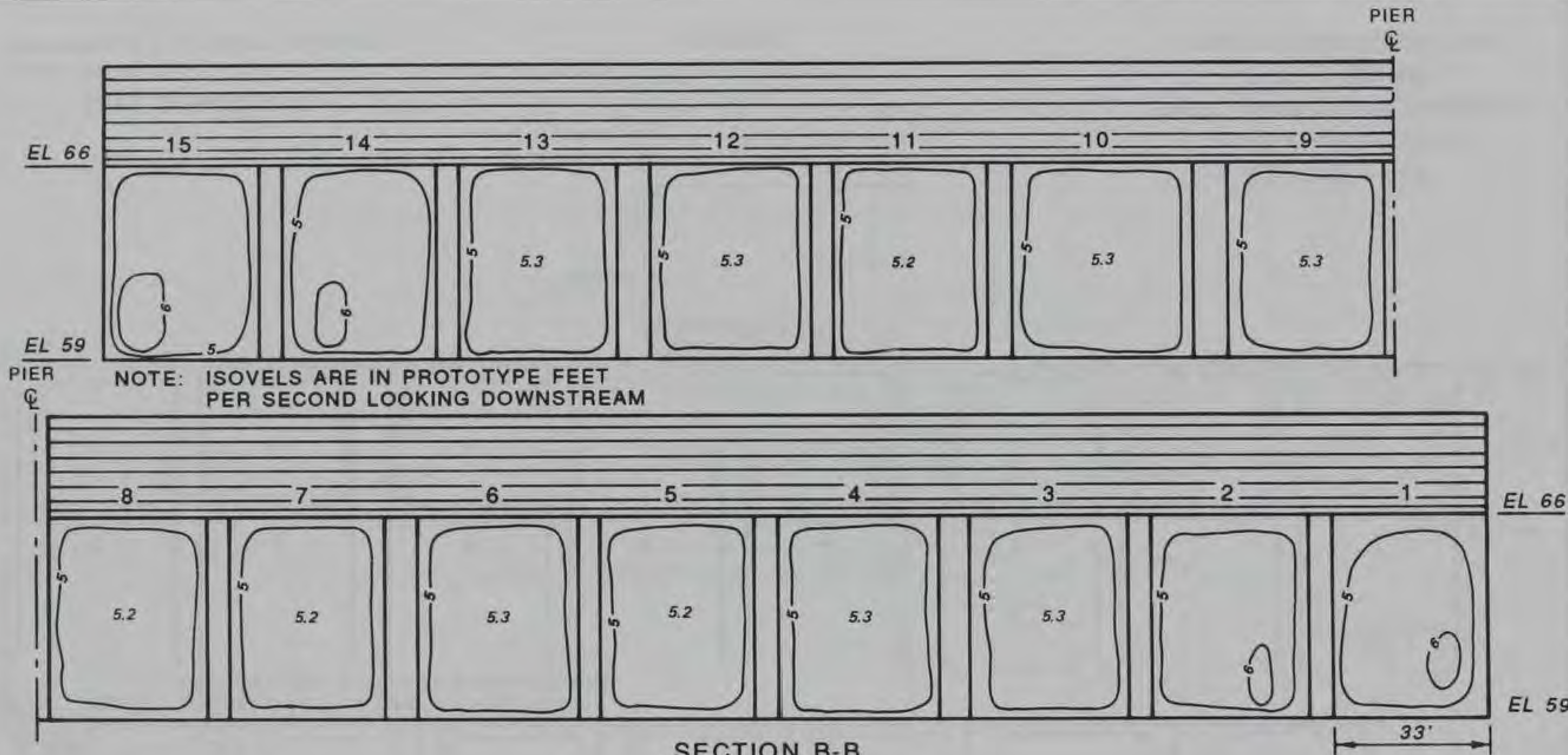


PROFILE

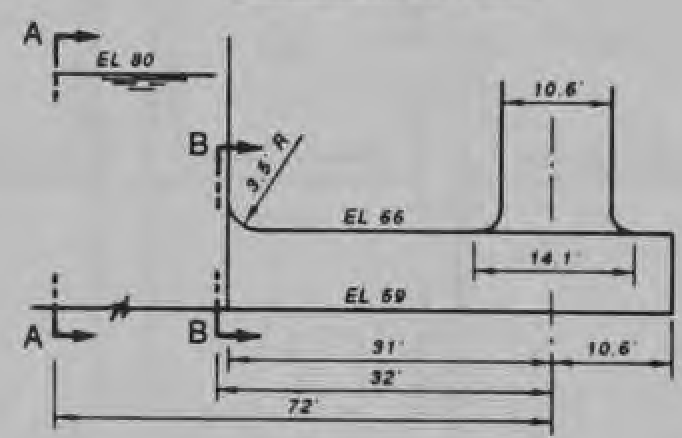
TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

SECTION A-A
TYPE 1 ABUTMENTS
TYPE 1 APPROACH CHANNEL
TYPE 1 SUMP
PUMPS OPERATING 1-15



SECTION B-B

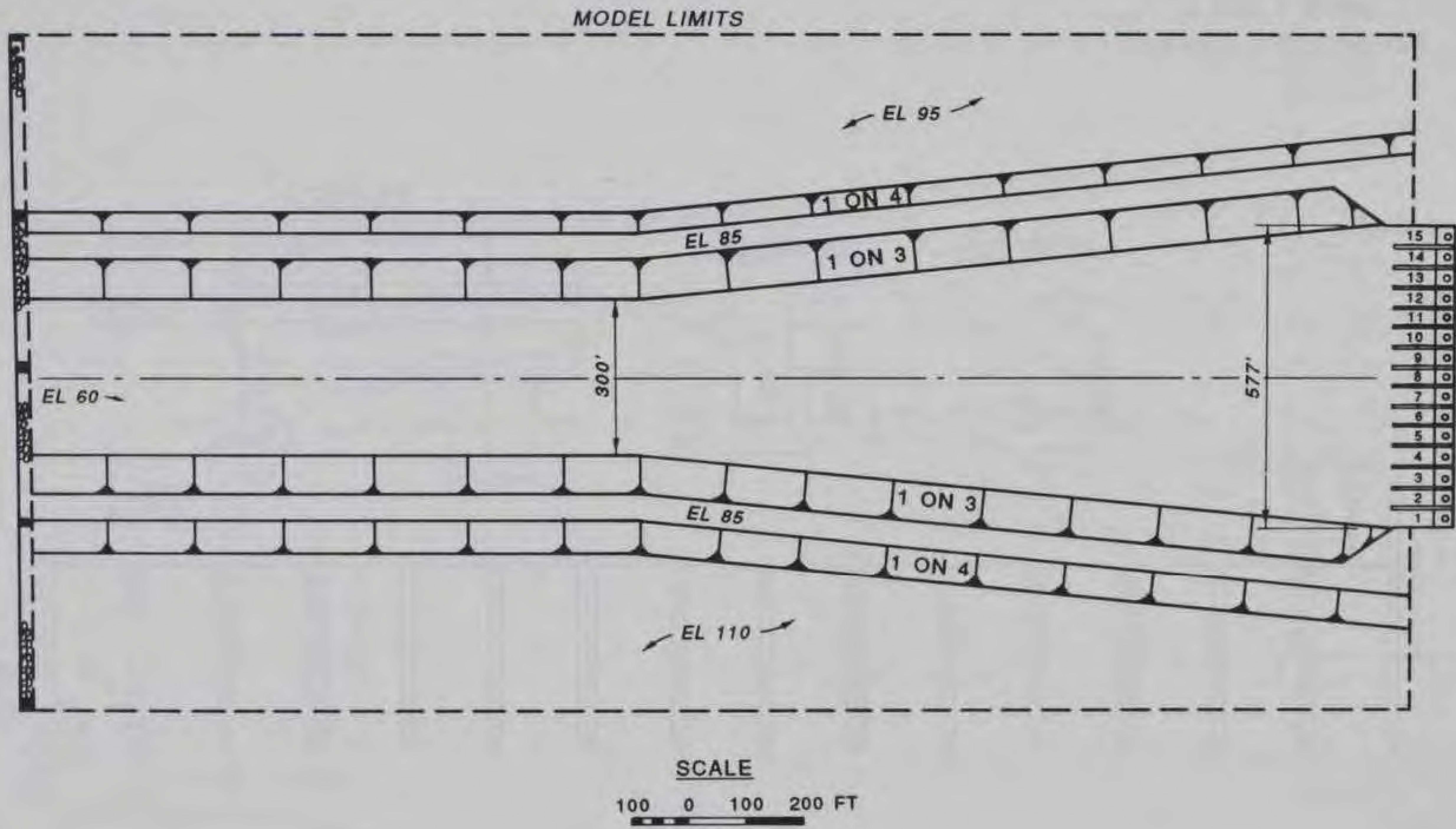


PROFILE

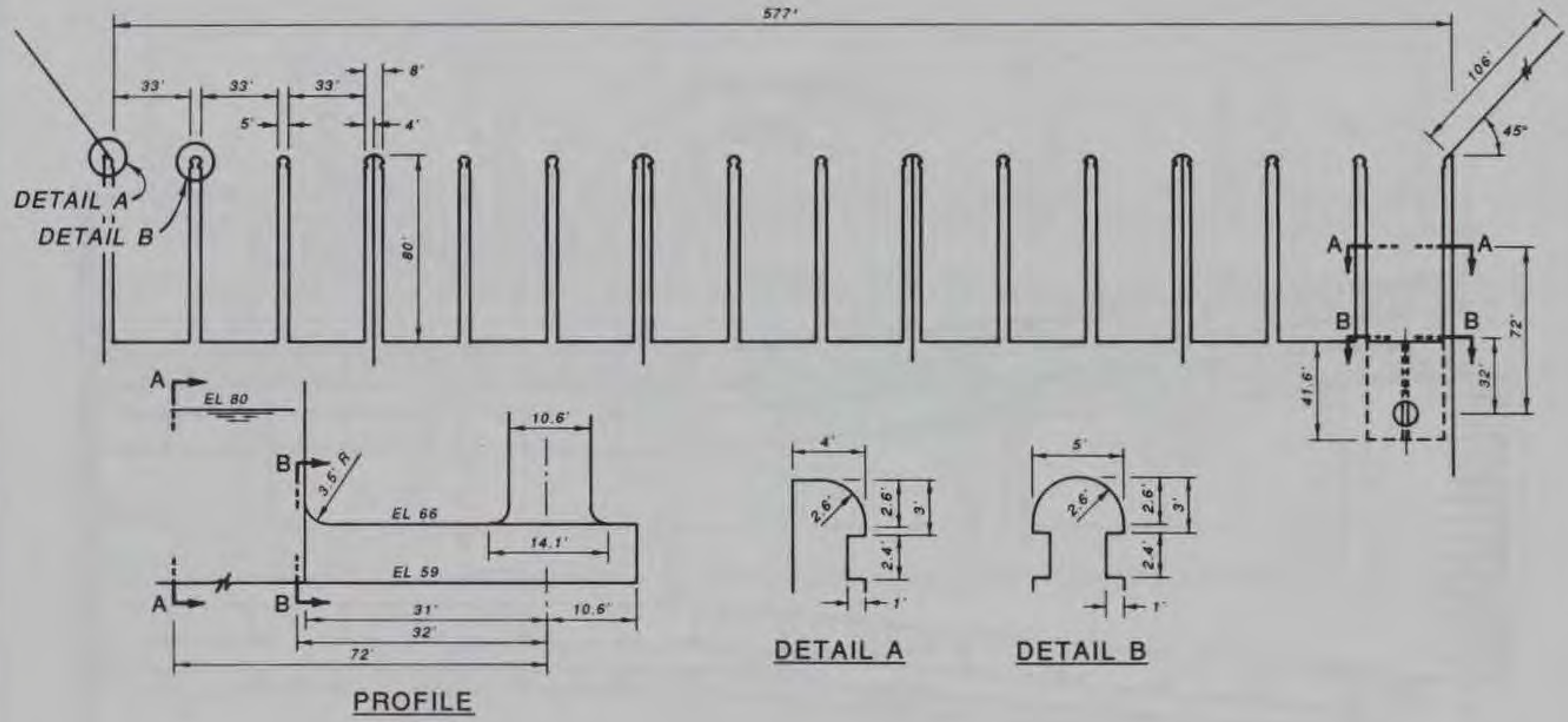
TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

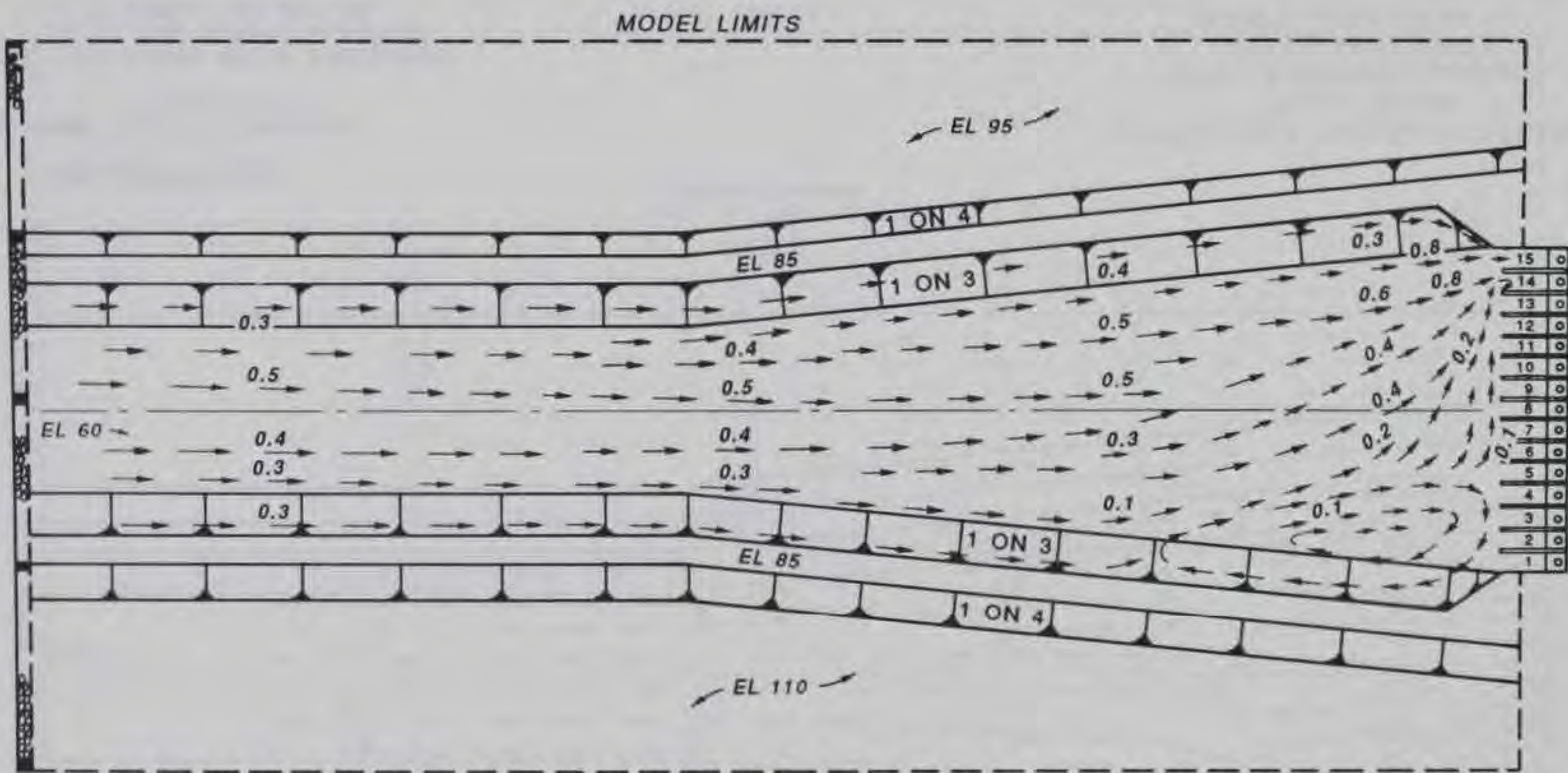
SECTION B-B
TYPE 1 ABUTMENTS
TYPE 1 APPROACH CHANNEL
TYPE 1 SUMP
PUMPS OPERATING 1-15



TYPE 1 SUMP
TYPE 2 ABUTMENTS
TYPE 2 APPROACH CHANNEL



TYPE 2 ABUTMENTS
TYPE 1 SUMP



SCALE

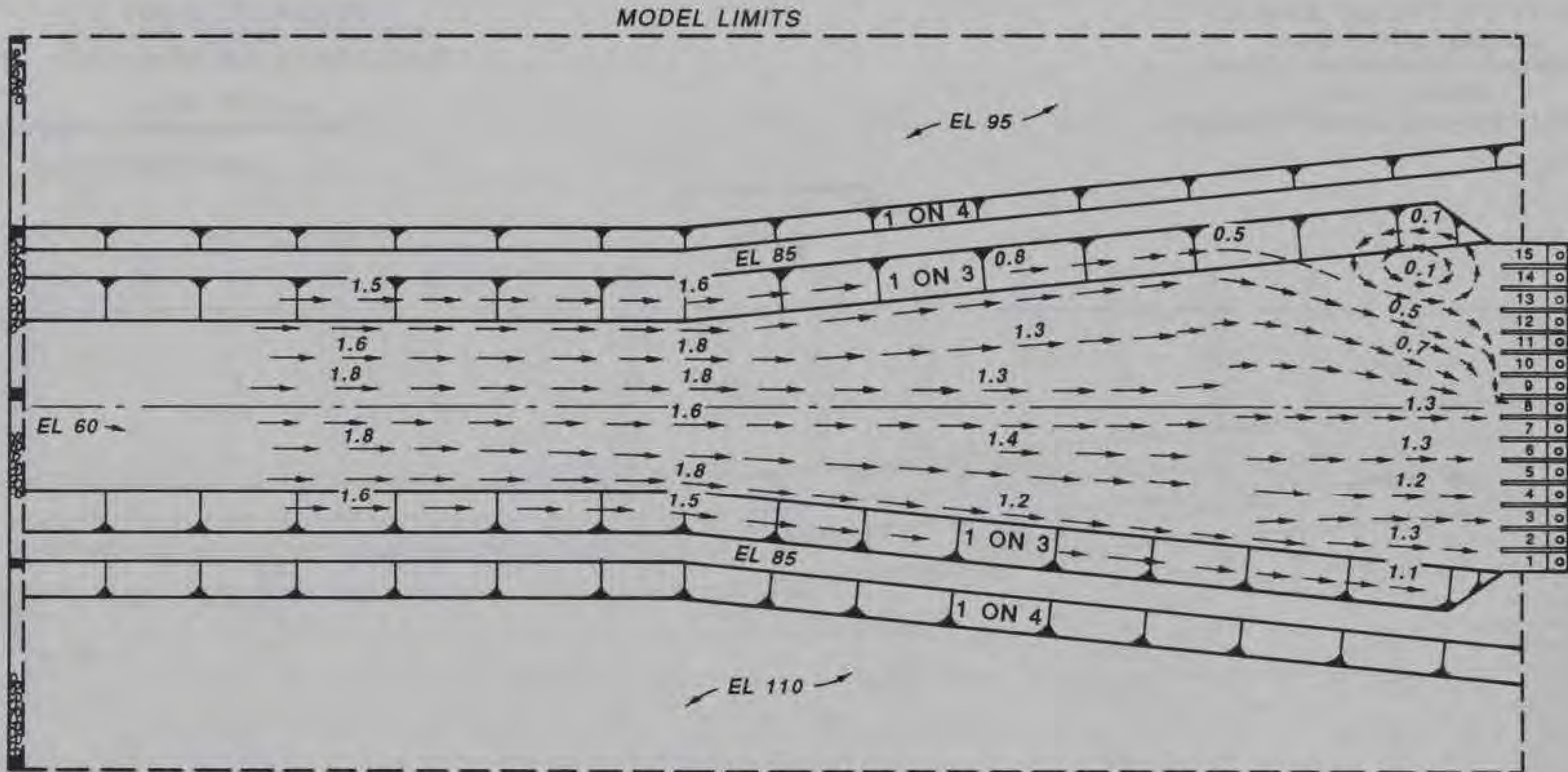
100 0 100 200 FT

TEST CONDITIONS

DISCHARGE PER PUMP 1460 CFS
POOL EL 80 FT

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 2 FT ABOVE THE BOTTOM

APPROACH FLOW PATTERNS
TYPE 1 SUMP
TYPE 2 APPROACH CHANNEL
TYPE 2 ABUTMENTS
PUMPS OPERATING 14-15



SCALE

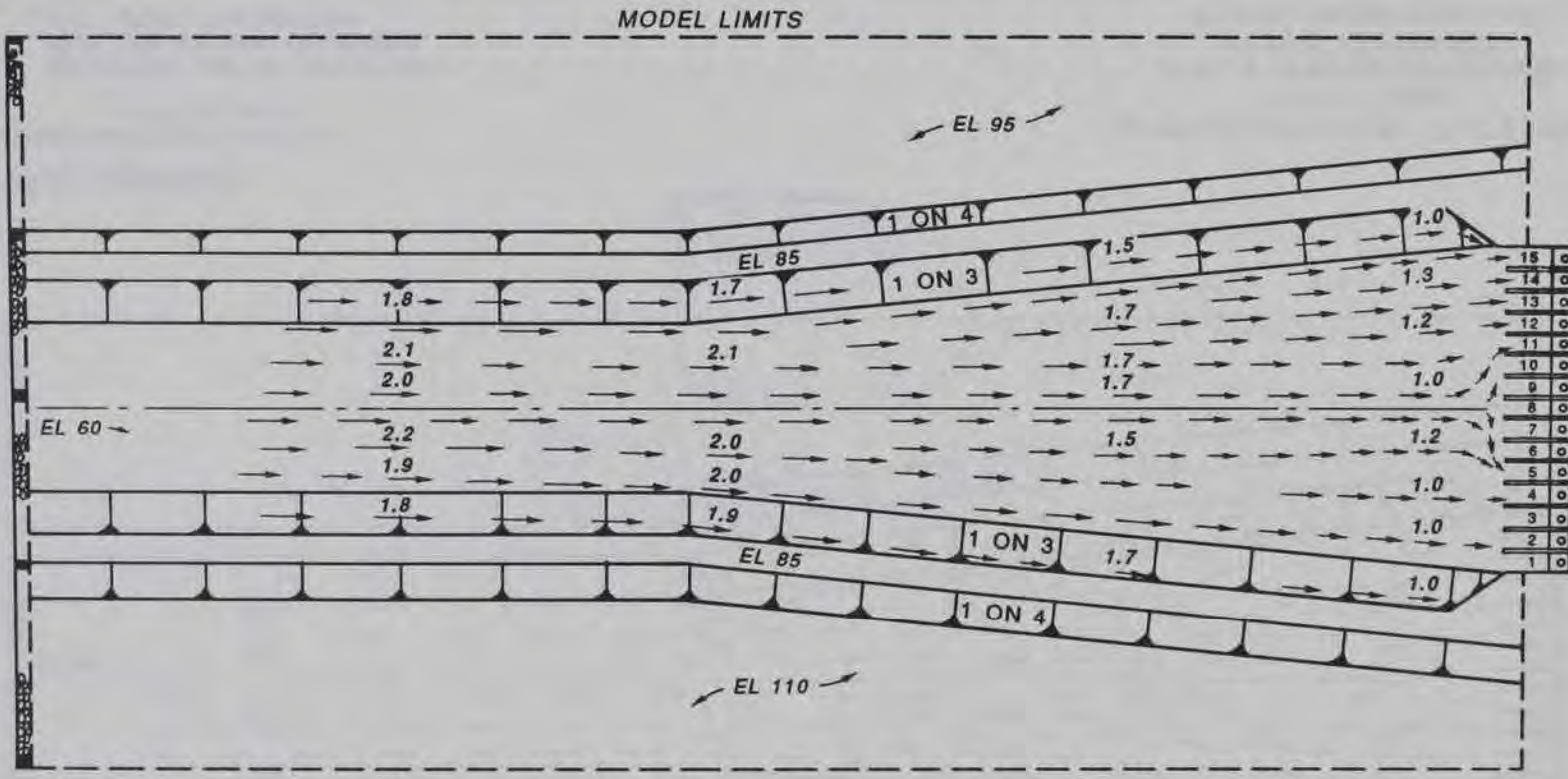
100 0 100 200 FT

TEST CONDITIONS

DISCHARGE PER PUMP 1460 CFS
POOL EL 80 FT

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 2 FT ABOVE THE BOTTOM

APPROACH FLOW PATTERNS
TYPE 1 SUMP
TYPE 2 APPROACH CHANNEL
TYPE 2 ABUTMENTS
PUMPS OPERATING 1-8



SCALE

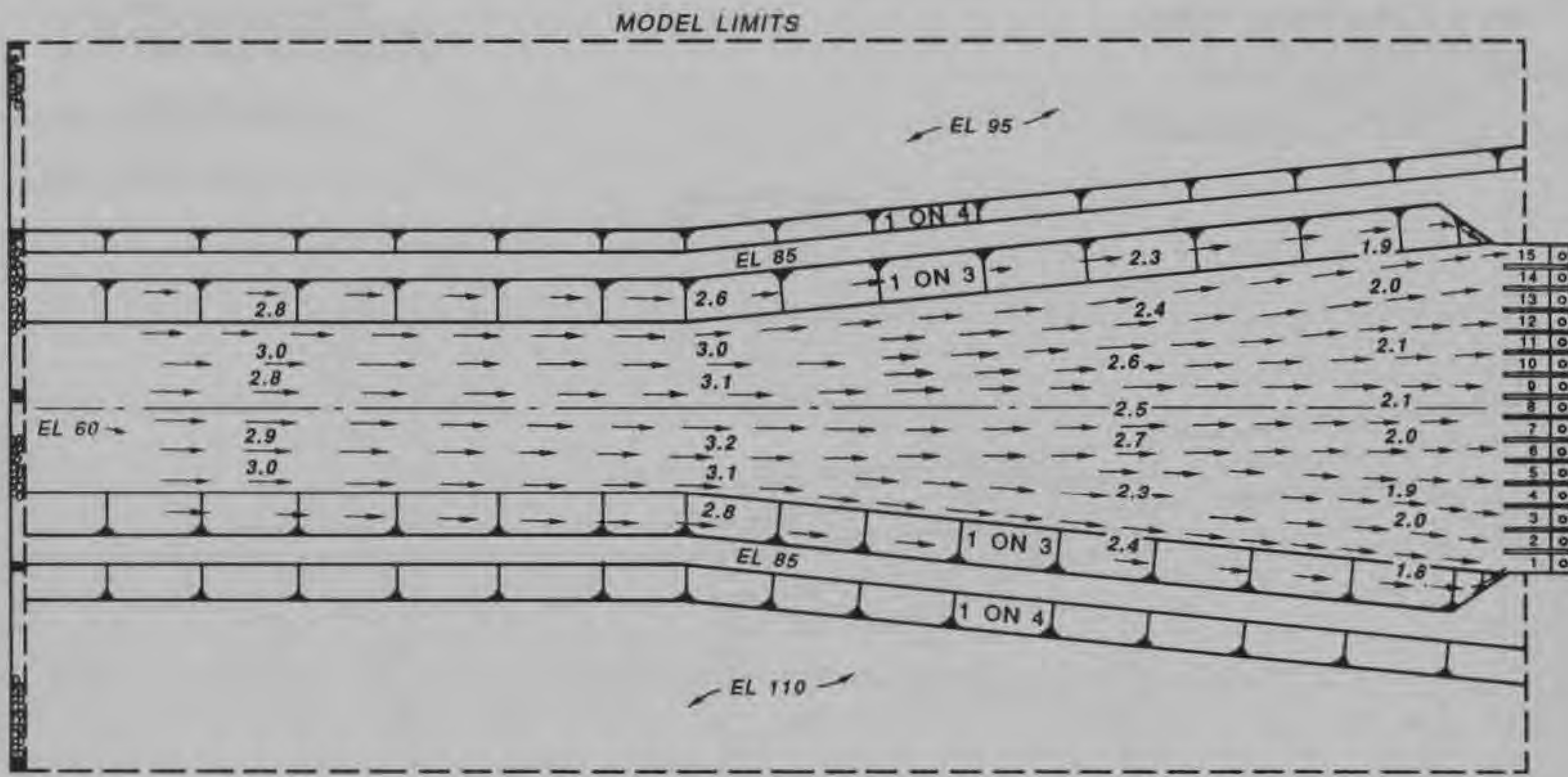
100 0 100 200 FT

TEST CONDITIONS

DISCHARGE PER PUMP 1460 CFS
POOL EL 80 FT

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 2 FT ABOVE THE BOTTOM

APPROACH FLOW PATTERNS
TYPE 1 SUMP
TYPE 2 APPROACH CHANNEL
TYPE 2 ABUTMENTS
PUMPS OPERATING 1-5 AND 11-15



SCALE

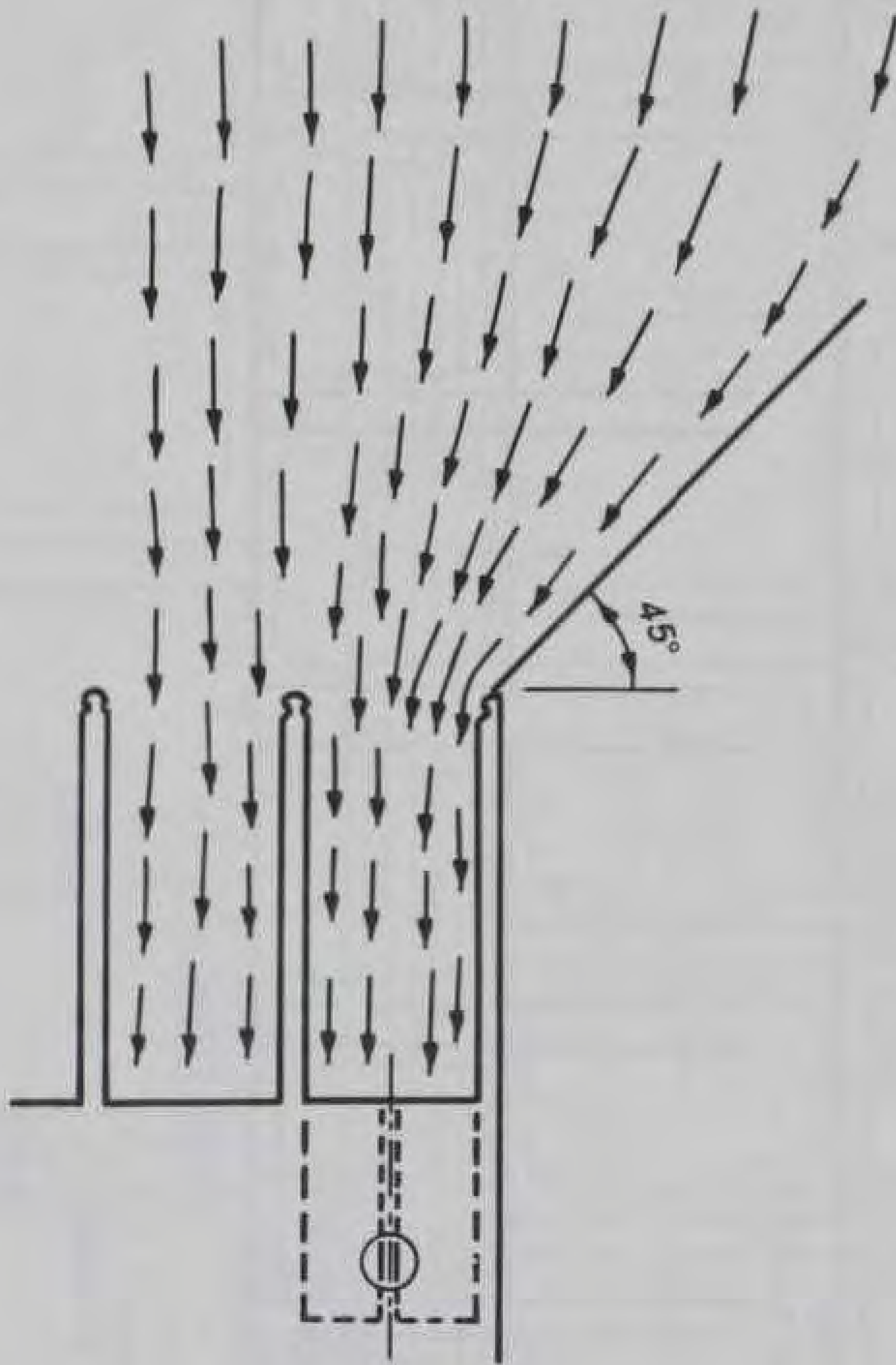
100 0 100 200 FT

TEST CONDITIONS

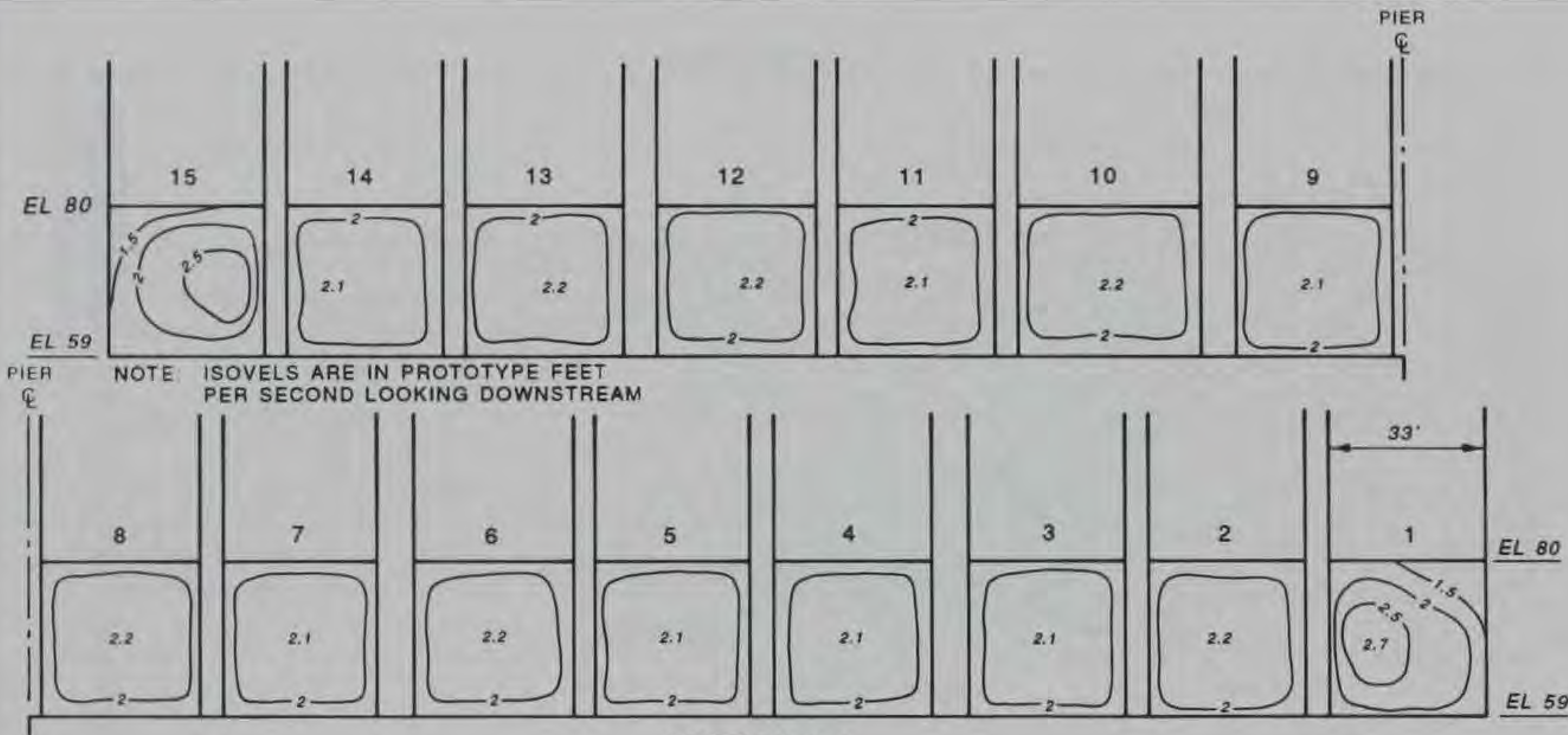
DISCHARGE PER PUMP 1460 CFS
POOL EL 80 FT

NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 2 FT ABOVE THE BOTTOM

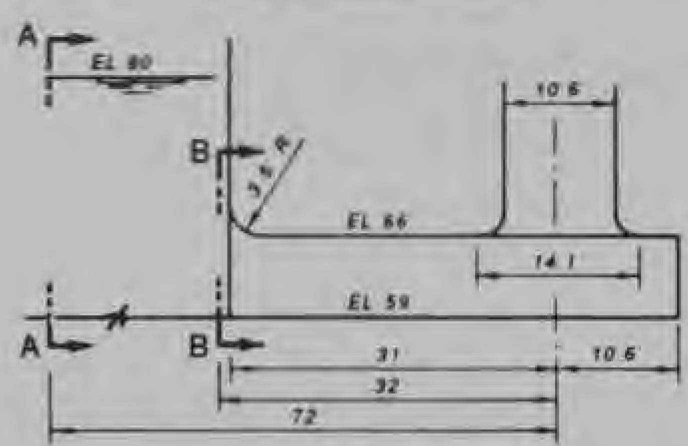
APPROACH FLOW PATTERNS
TYPE 1 SUMP
TYPE 2 APPROACH CHANNEL
TYPE 2 ABUTMENTS
PUMPS OPERATING 1-15



FLOW PATTERN
TYPE 2 ABUTMENT
COMPREHENSIVE MODEL



SECTION A-A

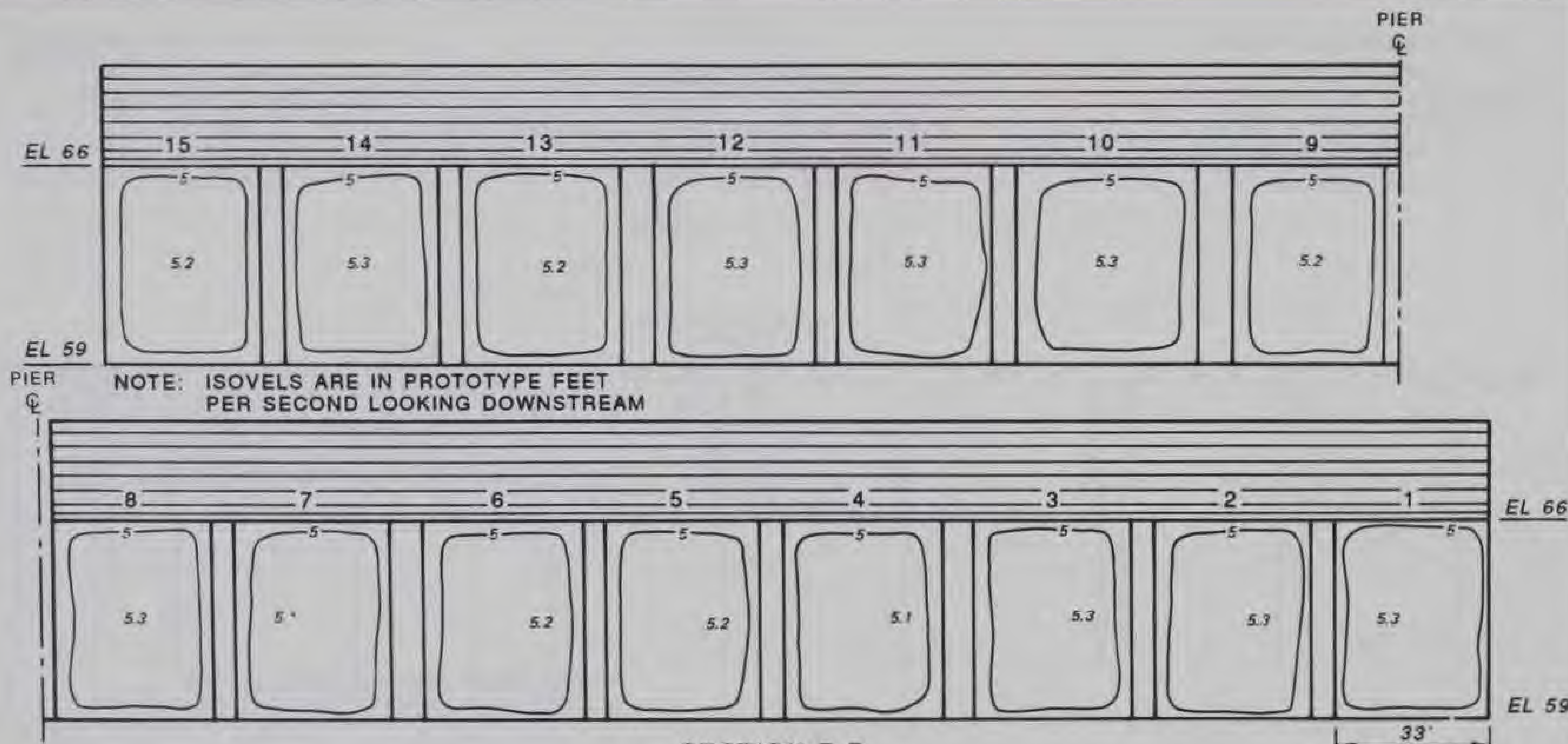


PROFILE

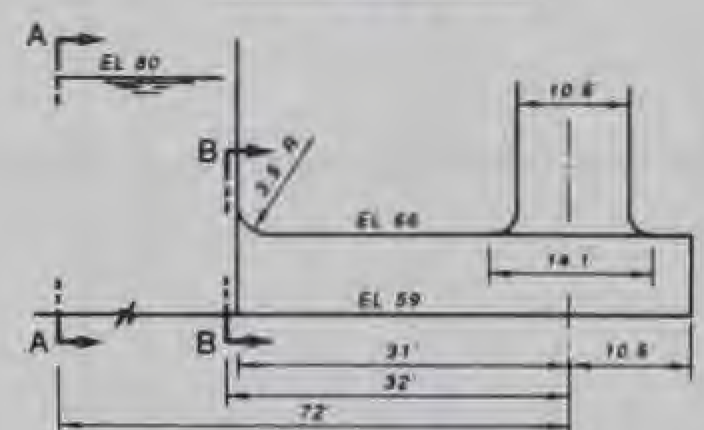
TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

ISOVELS
SECTION A-A
TYPE 2 ABUTMENTS
TYPE 2 APPROACH CHANNEL
TYPE 1 SUMP
PUMPS OPERATING 1-15



SECTION B-B

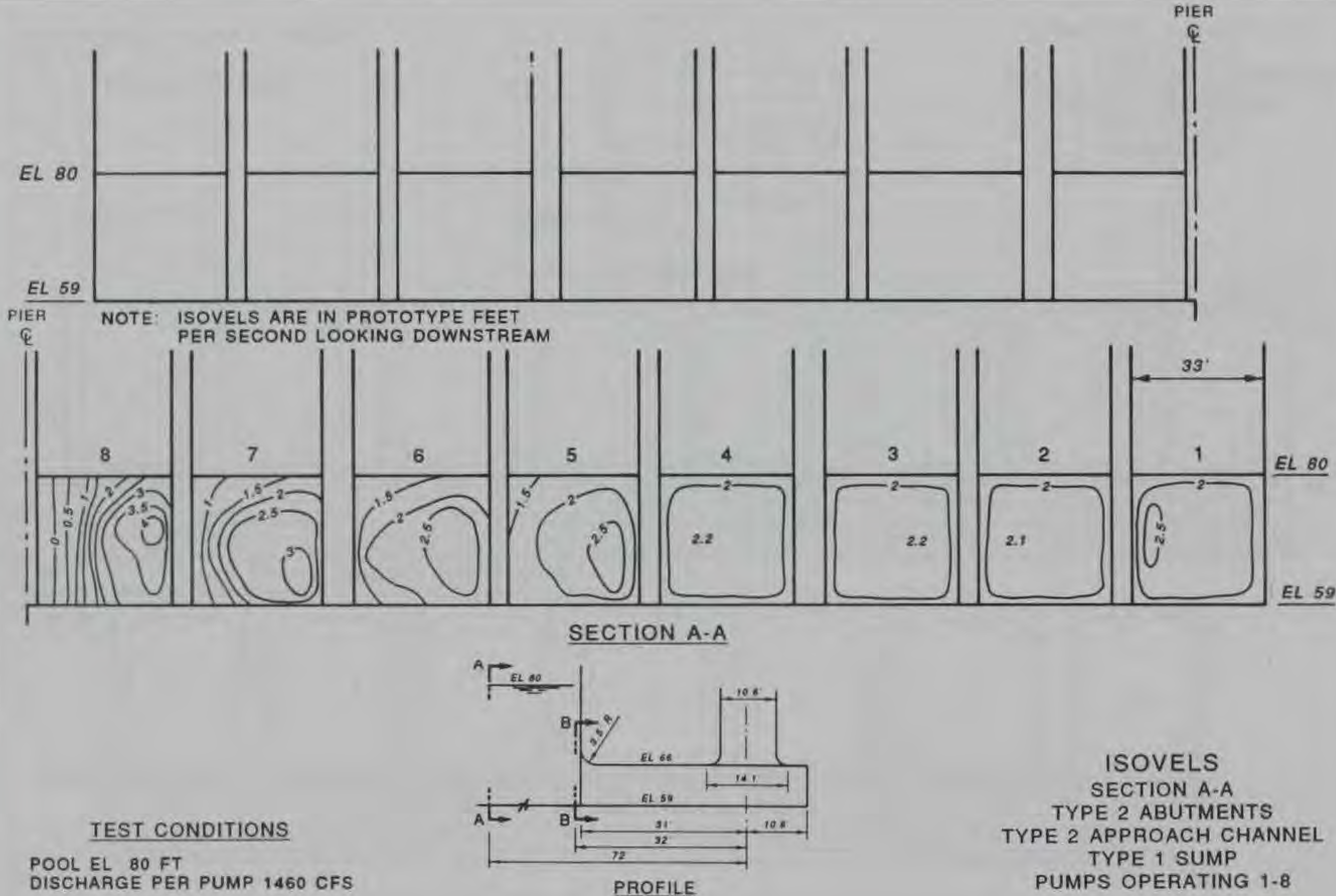


PROFILE

TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

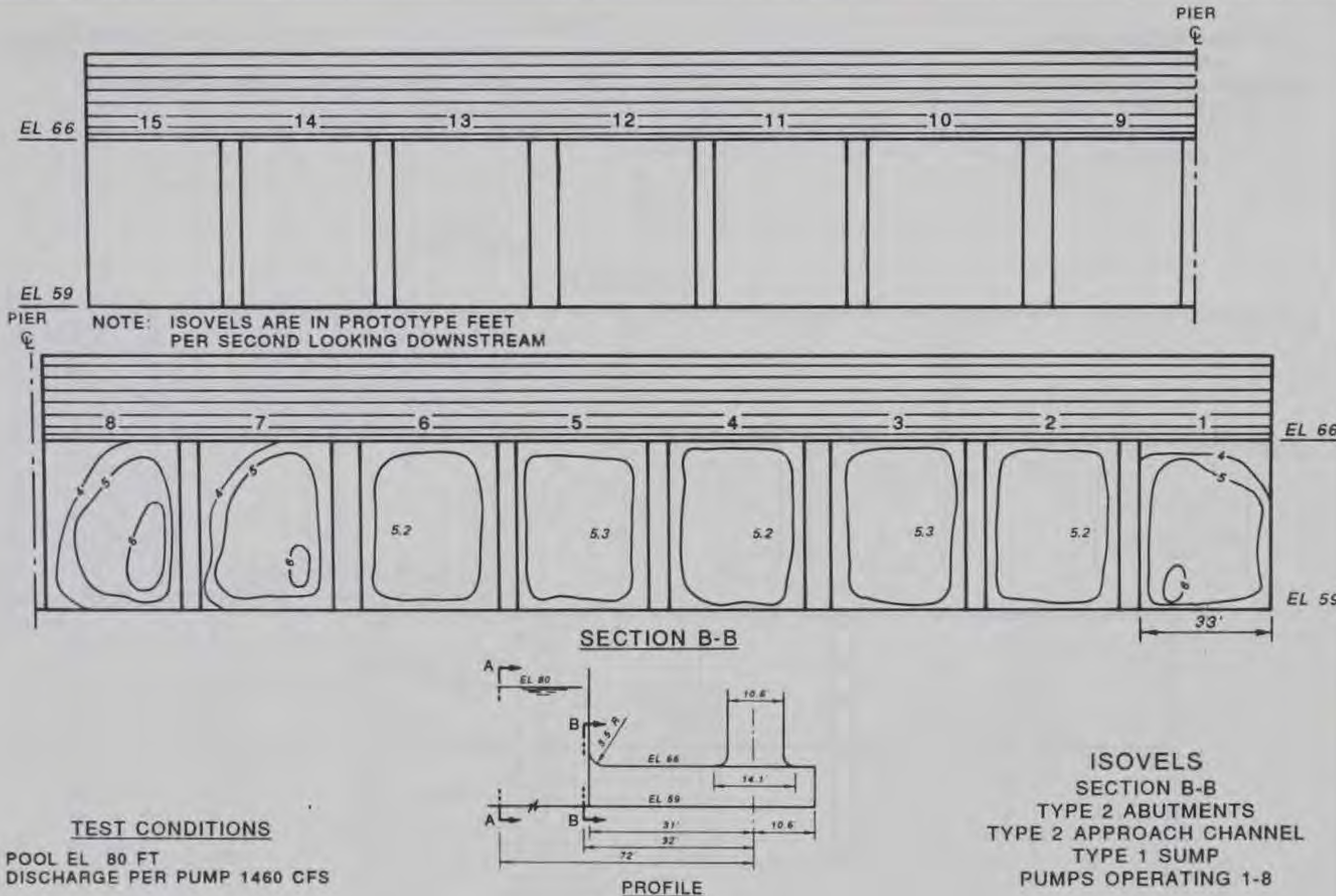
ISOVELS
SECTION B-B
TYPE 2 ABUTMENTS
TYPE 2 APPROACH CHANNEL
TYPE 1 SUMP
PUMPS OPERATING 1-15



TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

ISOVELS
SECTION A-A
TYPE 2 ABUTMENTS
TYPE 2 APPROACH CHANNEL
TYPE 1 SUMP
PUMPS OPERATING 1-8

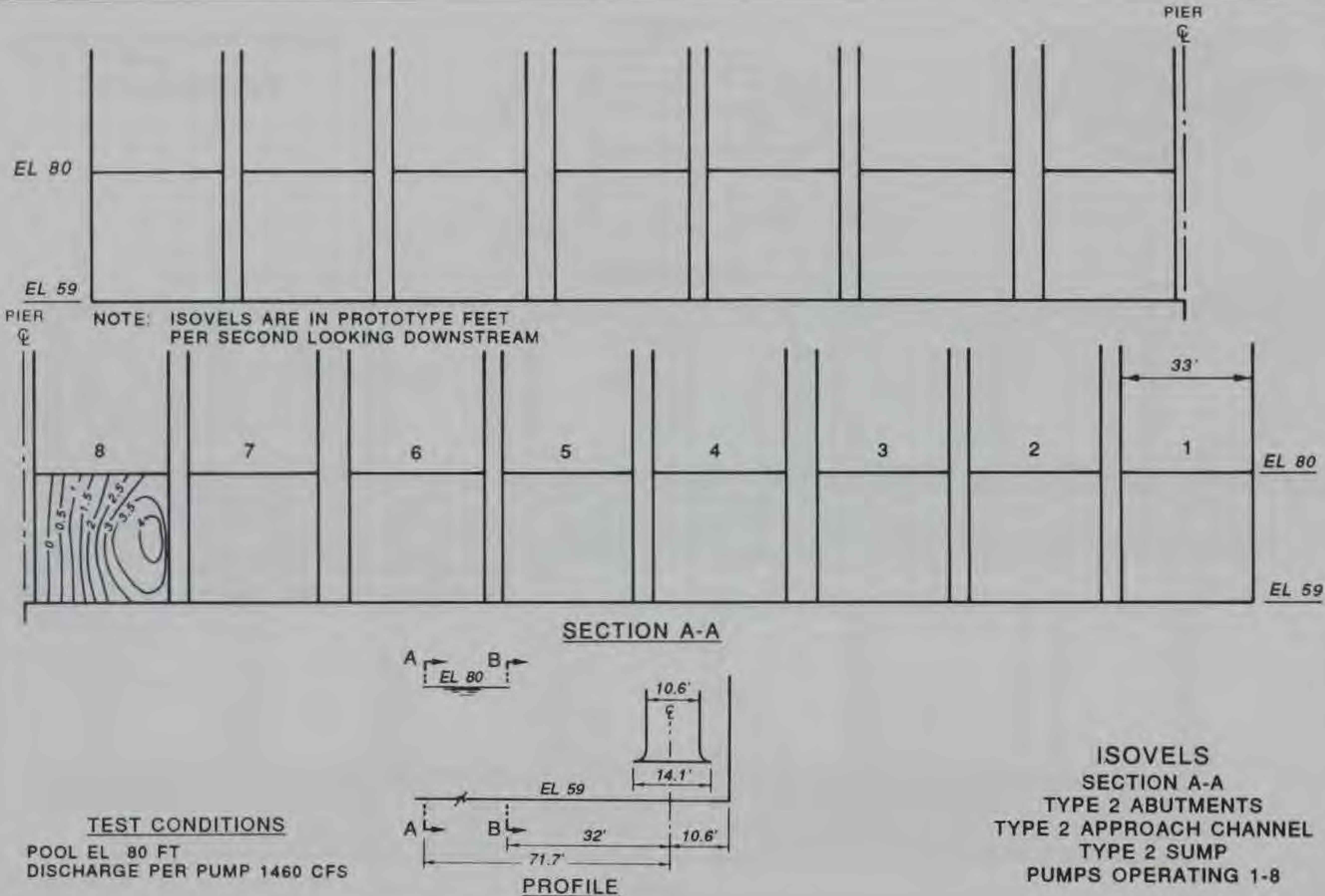


TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

ISOVELS

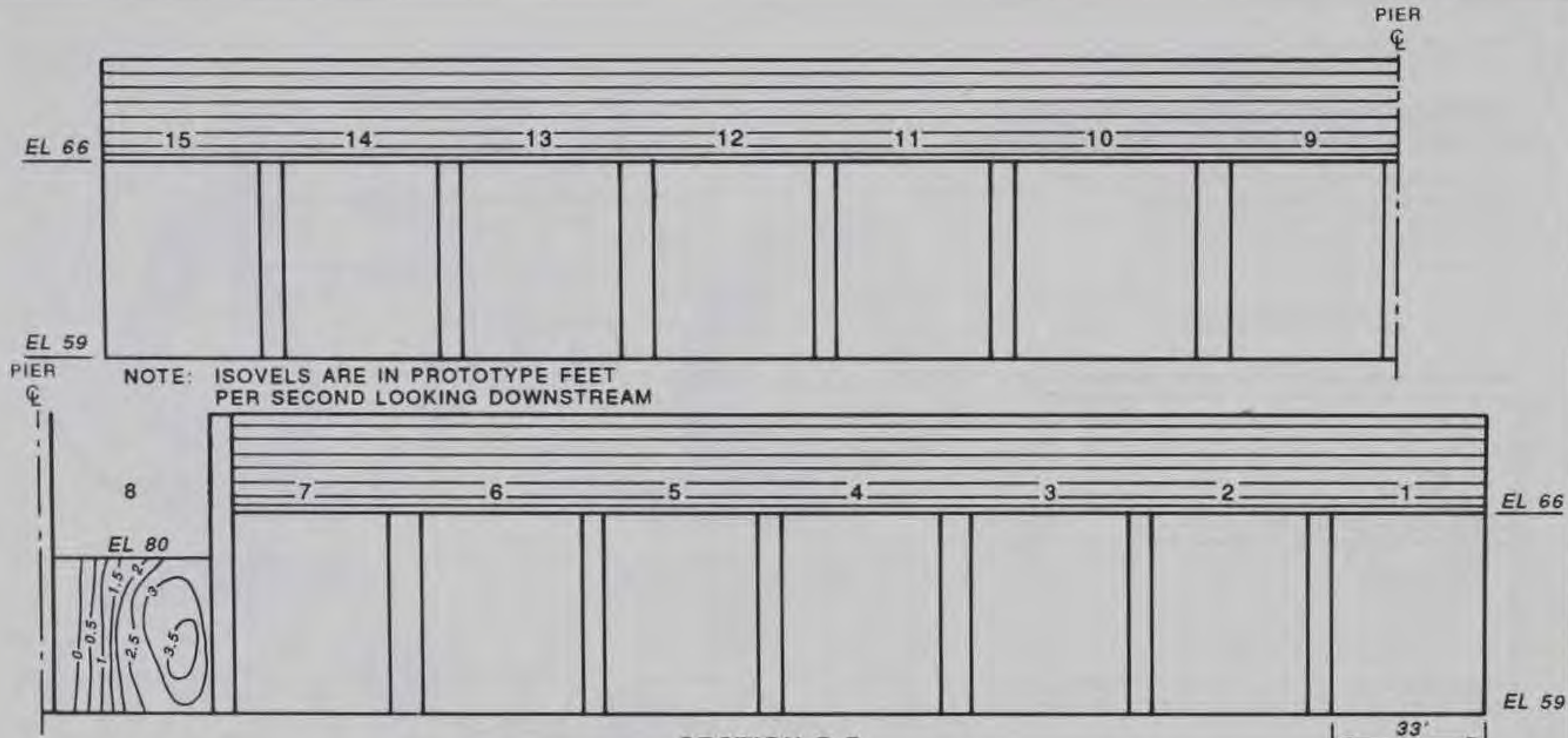
SECTION B-B
TYPE 2 ABUTMENTS
TYPE 2 APPROACH CHANNEL
TYPE 1 SUMP
PUMPS OPERATING 1-8



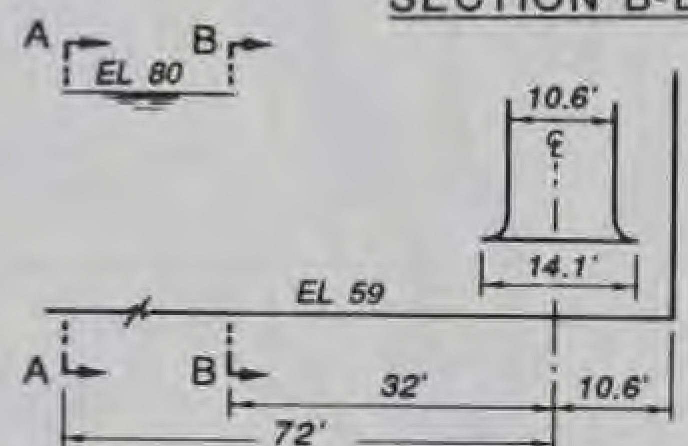
TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

ISOVELS
SECTION A-A
TYPE 2 ABUTMENTS
TYPE 2 APPROACH CHANNEL
TYPE 2 SUMP
PUMPS OPERATING 1-8



SECTION B-B

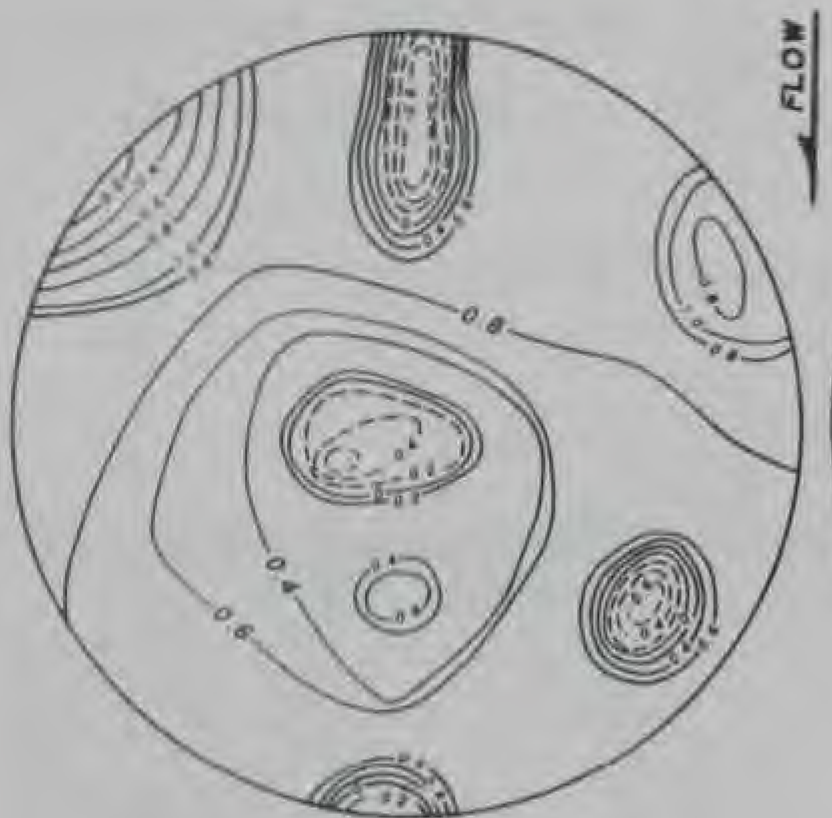


PROFILE

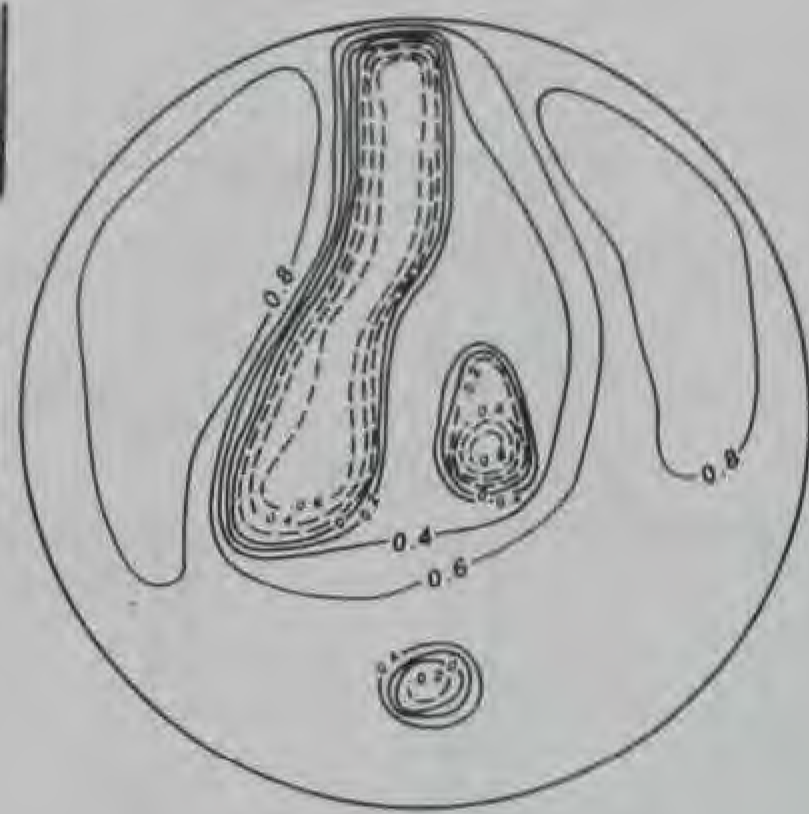
TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

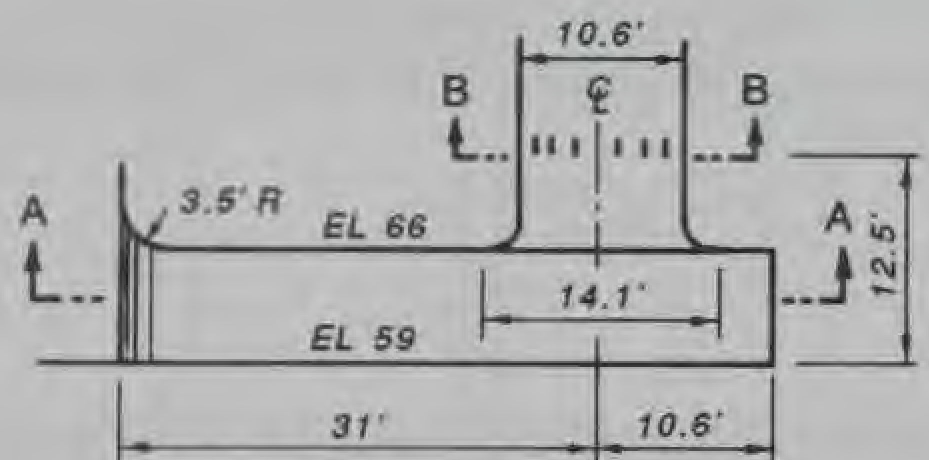
ISOVELS
SECTION B-B
TYPE 2 ABUTMENTS
TYPE 2 APPROACH CHANNEL
TYPE 2 SUMP
PUMPS OPERATING 1-8



SECTION B-B
(PUMPS OPERATING 1-15)



SECTION B-B
(PUMPS OPERATING 1-8)

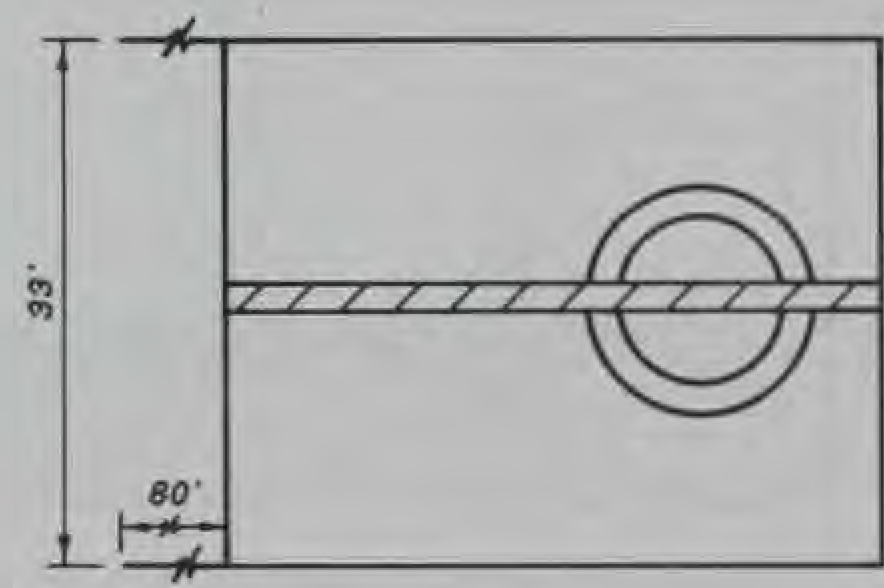


ELEVATION

TEST CONDITIONS

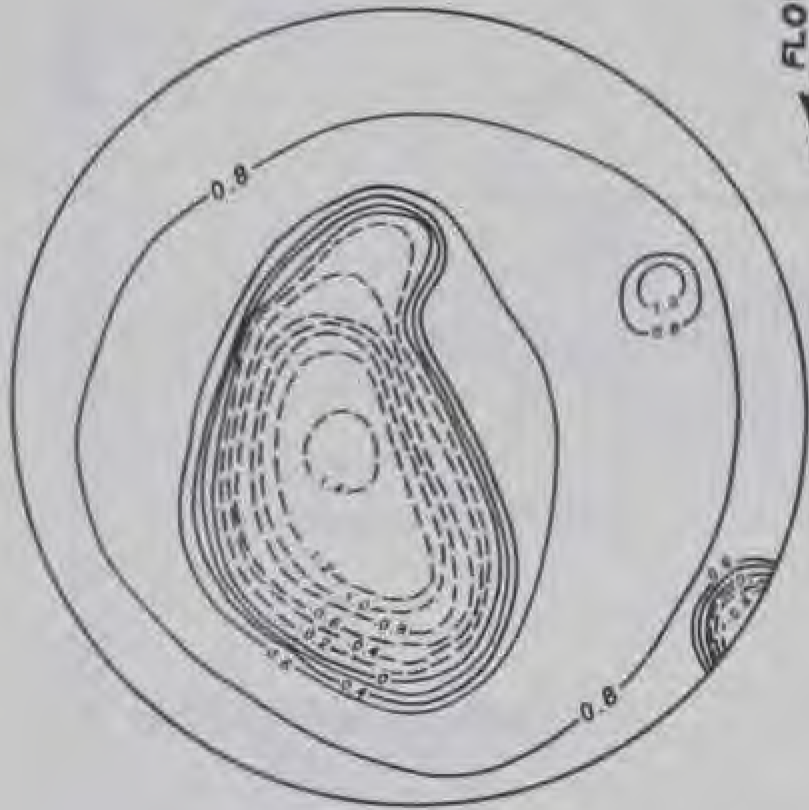
WATER-SURFACE EL 80 FT
DISCHARGE PER PUMP 1460 CFS

NOTE: SOLID CONTOUR LINES INDICATE THE MINIMUM MEASURED INSTANTANEOUS VELOCITY DIVIDED BY THE THEORETICAL VELOCITY. DASHED CONTOUR LINES INDICATE NEGATIVE VELOCITY RATIO.

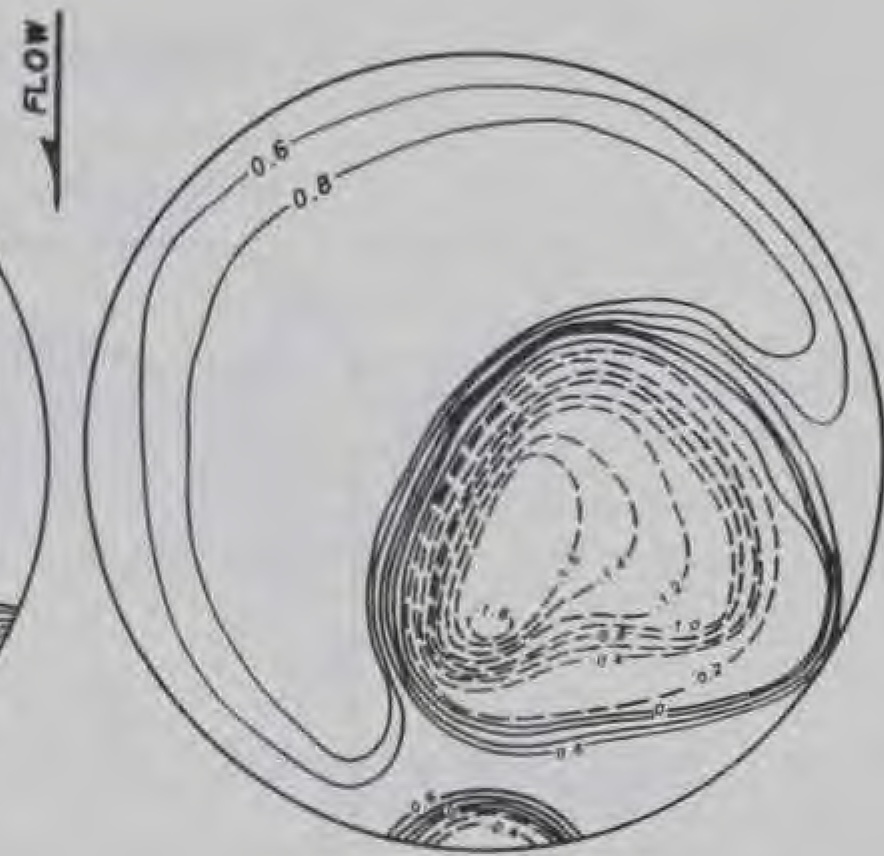


SECTION A-A

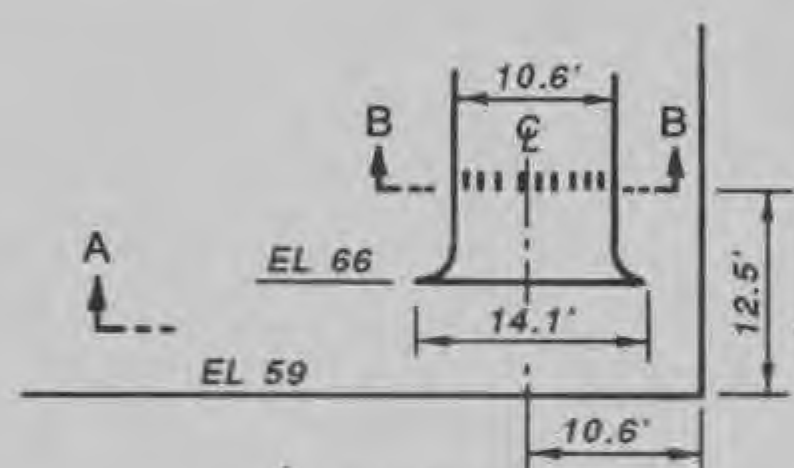
LINES OF EQUAL VELOCITY RATIOS
17,500-CFS-CAPACITY PUMPING STATION
PUMP 8
TYPE 1 SUMP



SECTION B-B
(PUMPS OPERATING 1-15)



SECTION B-B
(PUMPS OPERATING 1-8)

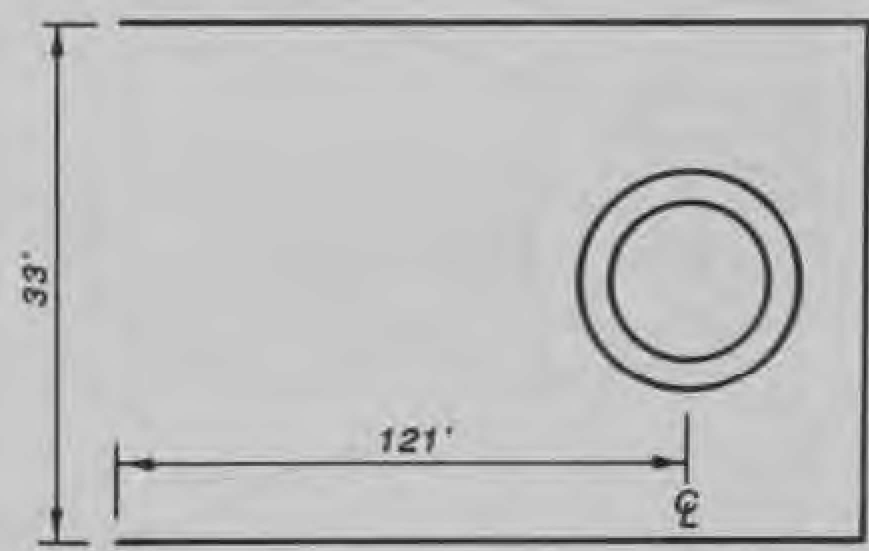


ELEVATION

TEST CONDITIONS

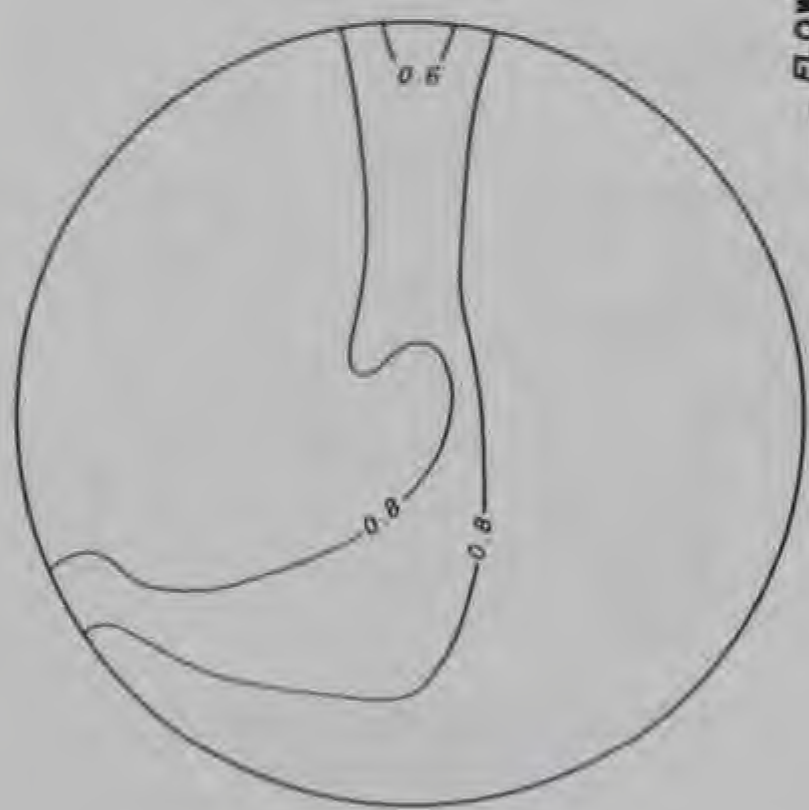
WATER-SURFACE EL 80 FT
DISCHARGE PER PUMP 1460 CFS

NOTE: SOLID CONTOUR LINES INDICATE THE MINIMUM MEASURED INSTANTANEOUS VELOCITY DIVIDED BY THE THEORETICAL VELOCITY. DASHED CONTOUR LINES INDICATE NEGATIVE VELOCITY RATIO.

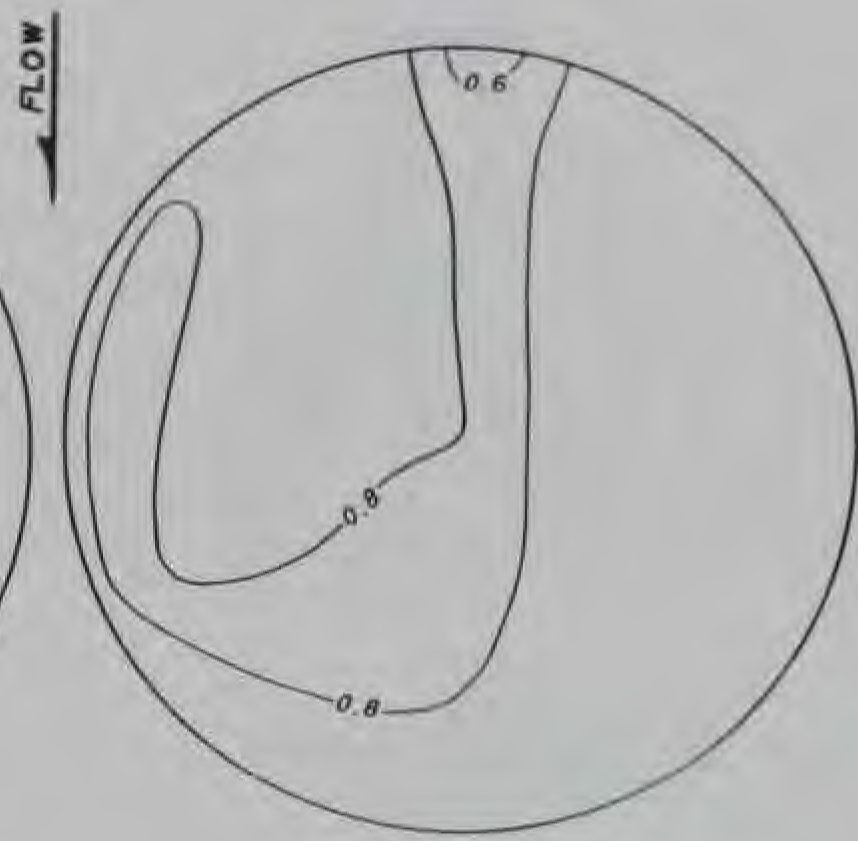


SECTION A-A

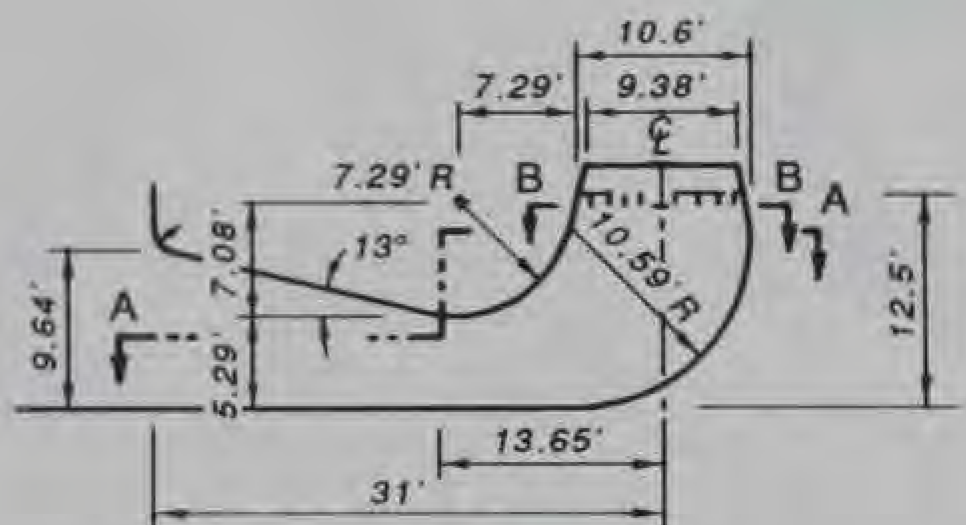
LINES OF EQUAL VELOCITY RATIOS
17,500-CFS-CAPACITY PUMPING STATION
PUMP 8
TYPE 2 SUMP



SECTION B-B
(PUMPS OPERATING 1-15)



SECTION B-B
(PUMPS OPERATING 1-8)

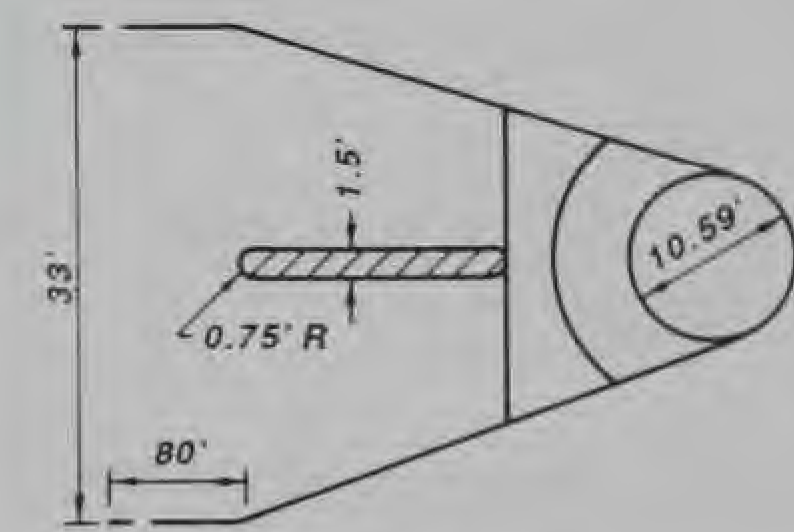


ELEVATION

TEST CONDITIONS

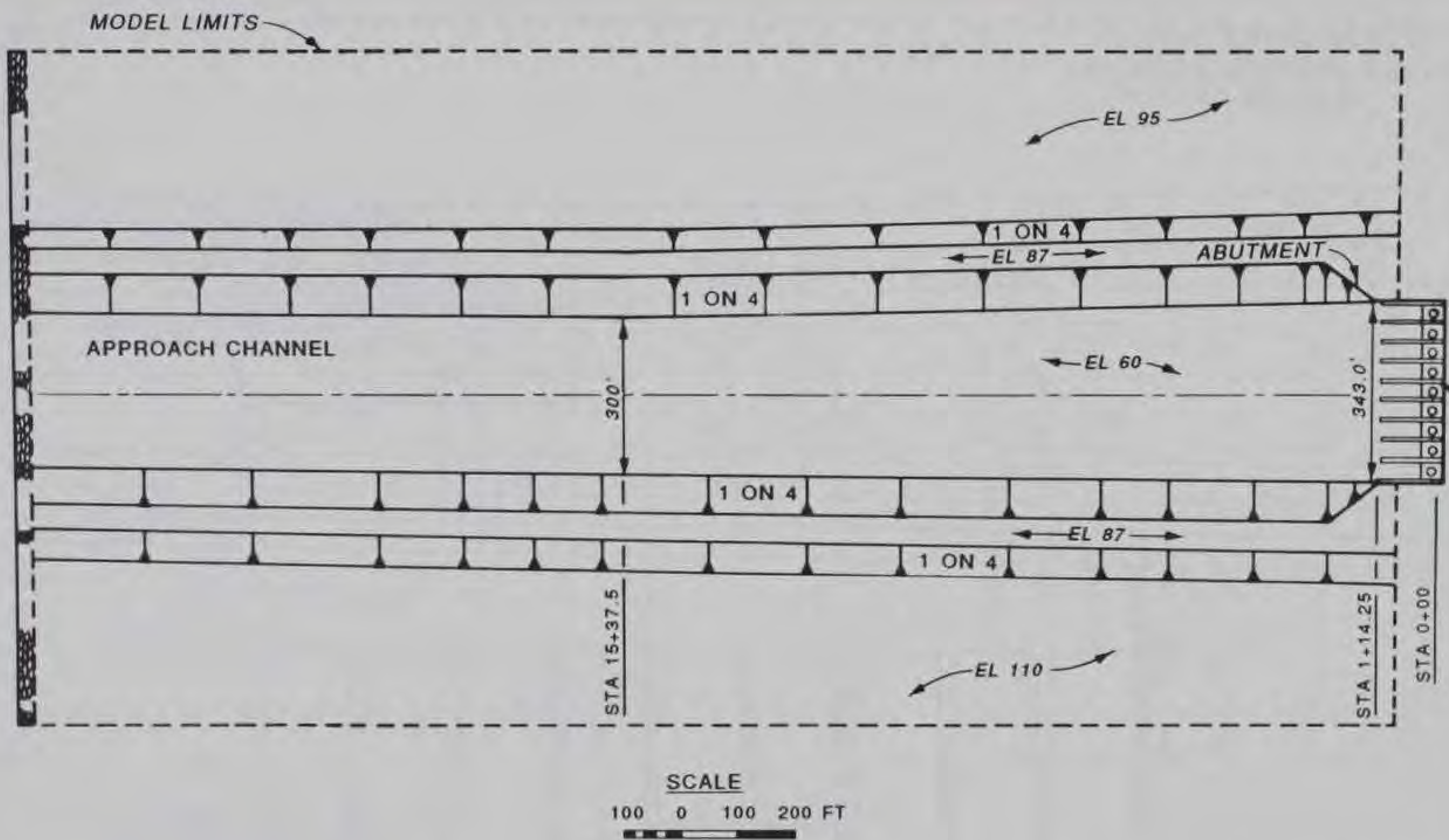
WATER-SURFACE EL 80 FT
DISCHARGE PER PUMP 1460 CFS

NOTE: SOLID CONTOUR LINES INDICATE THE MINIMUM MEASURED INSTANTANEOUS VELOCITY DIVIDED BY THE THEORETICAL VELOCITY. DASHED CONTOUR LINES INDICATE NEGATIVE VELOCITY RATIO.



SECTION A-A

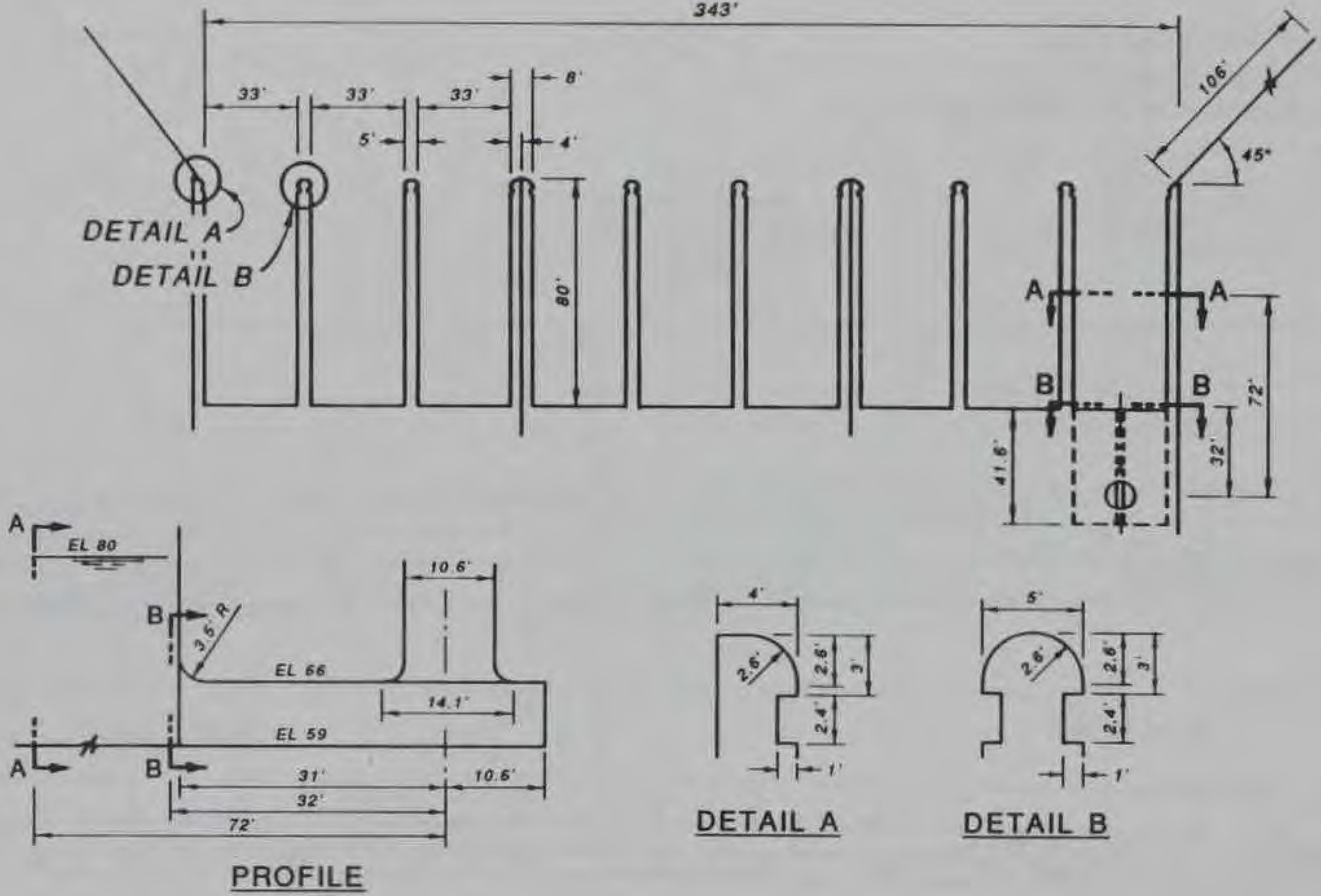
LINES OF EQUAL VELOCITY RATIOS
17,500-CFS-CAPACITY PUMPING STATION
PUMP 8
TYPE 3 SUMP



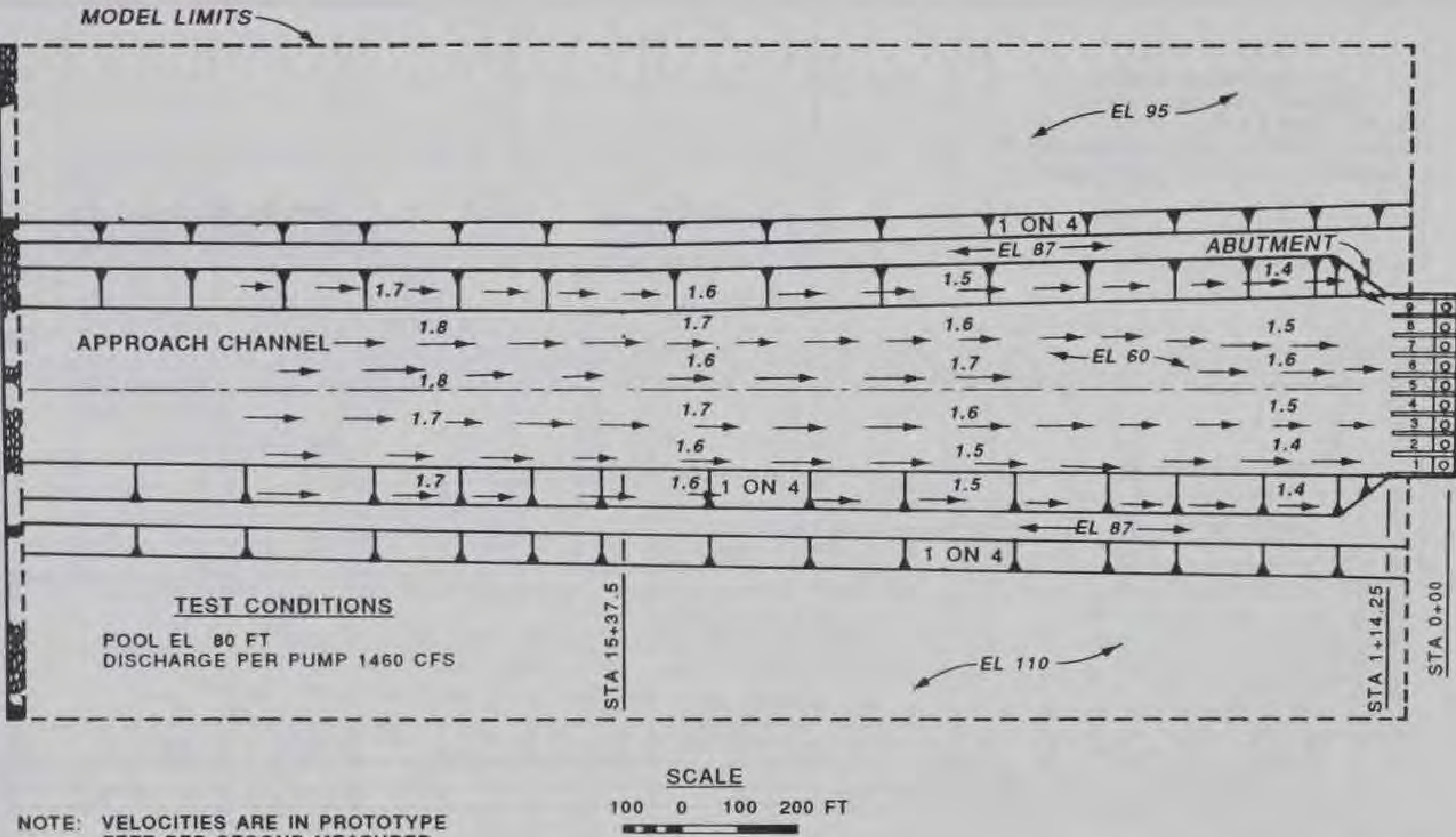
10,000-CFS-CAPACITY PUMPING STATION

TYPE 3 SUMP - TYPE 2 ABUTMENTS

TYPE 3 APPROACH CHANNEL



10,000-CFS-
CAPACITY PUMPING STATION
TYPE 2 ABUTMENTS

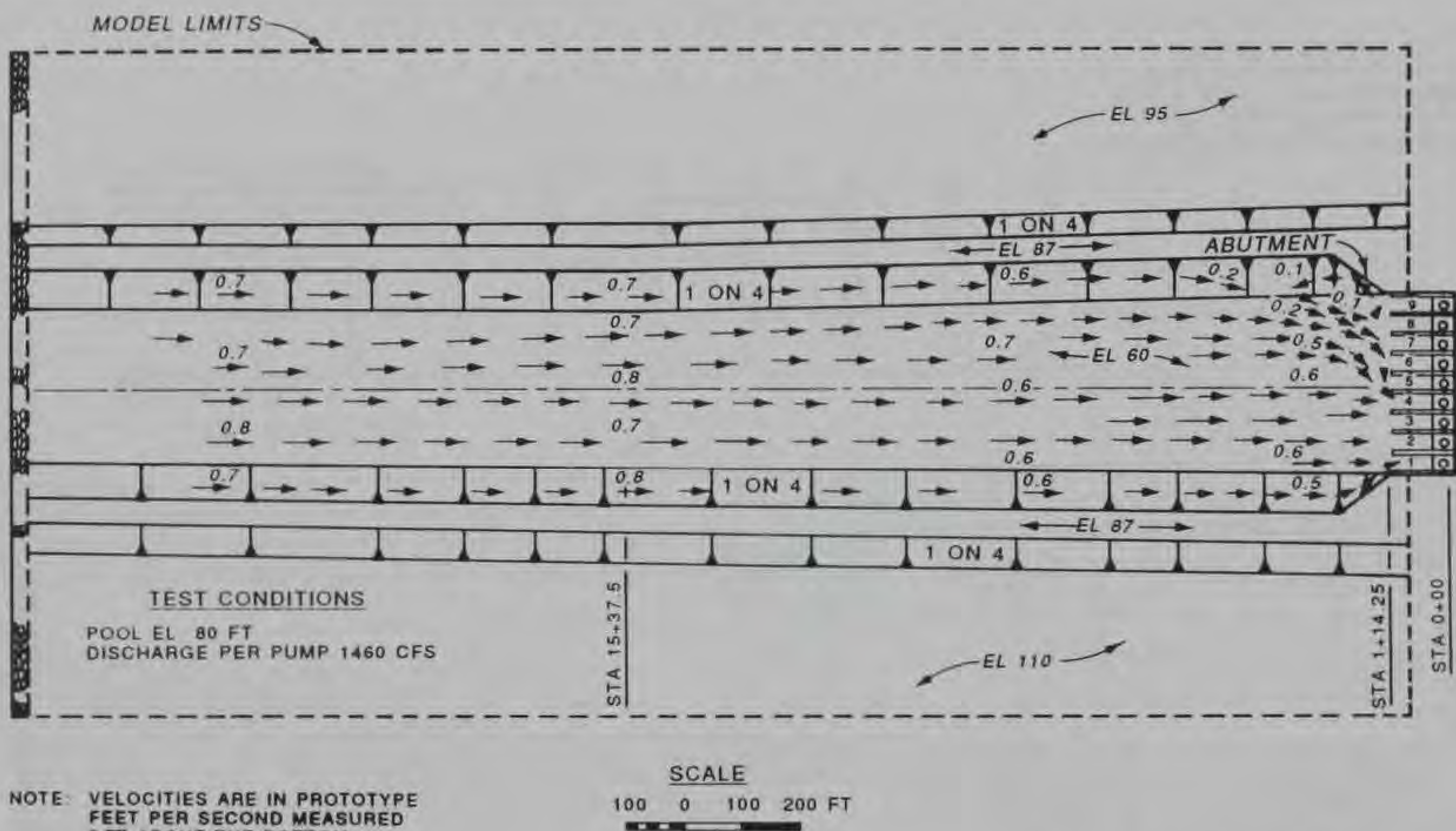


TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

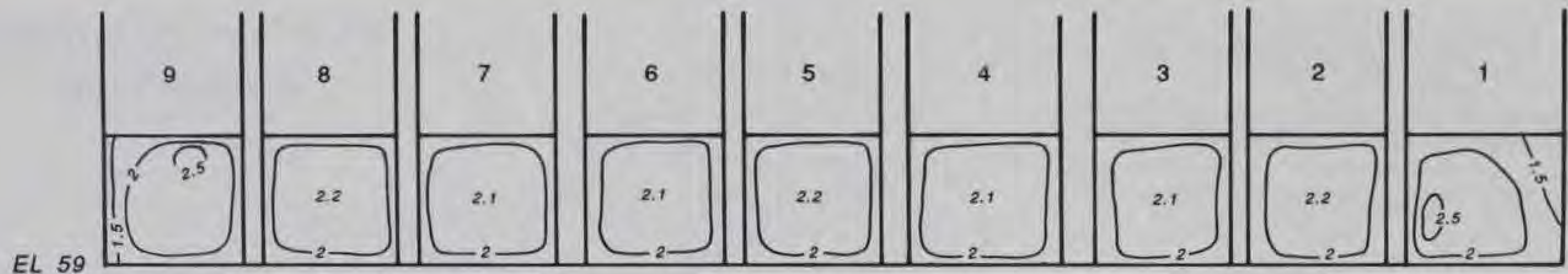
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 2 FT ABOVE THE BOTTOM

APPROACH FLOW PATTERNS
10,000-CFS-CAPACITY PUMPING STATION
TYPE 3 SUMP - TYPE 2 ABUTMENTS
TYPE 3 APPROACH CHANNEL
PUMPS OPERATING 1-9



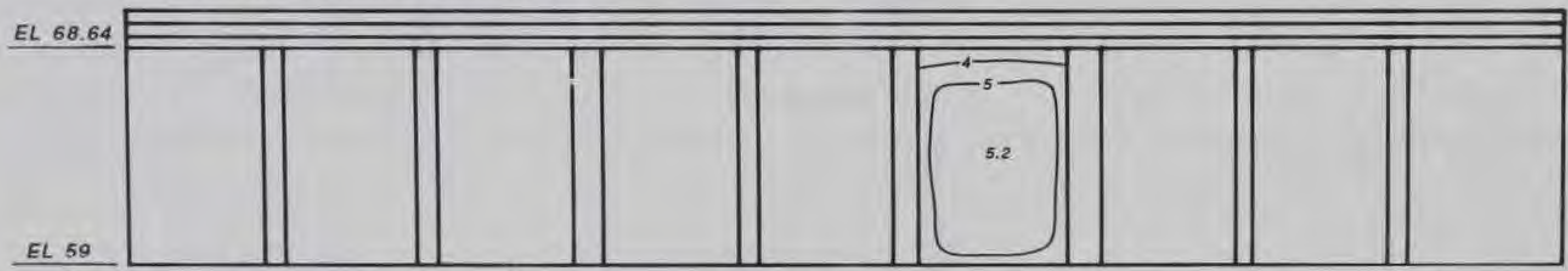
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 2 FT ABOVE THE BOTTOM

APPROACH FLOW PATTERNS
10,000-CFS-CAPACITY PUMPING STATION
TYPE 3 SUMP - TYPE 2 ABUTMENTS
TYPE 3 APPROACH CHANNEL
PUMPS OPERATING 1-4

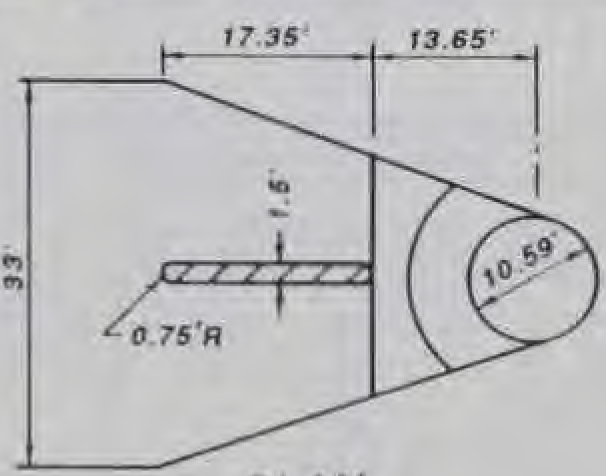


NOTE: ISOVELS ARE IN PROTOTYPE FEET PER SECOND LOOKING DOWNSTREAM

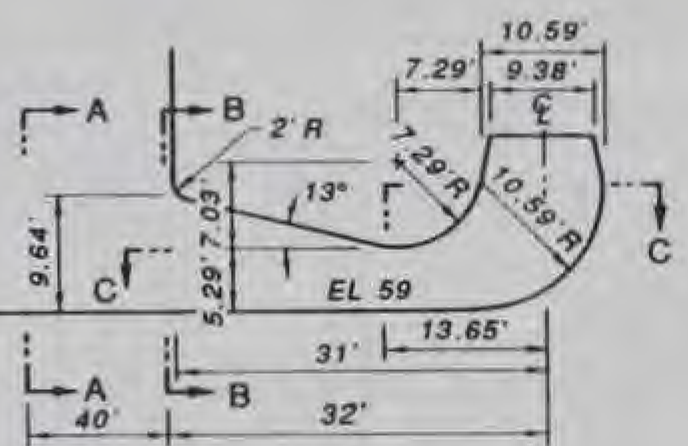
SECTION A-A



SECTION B-B



PLAN

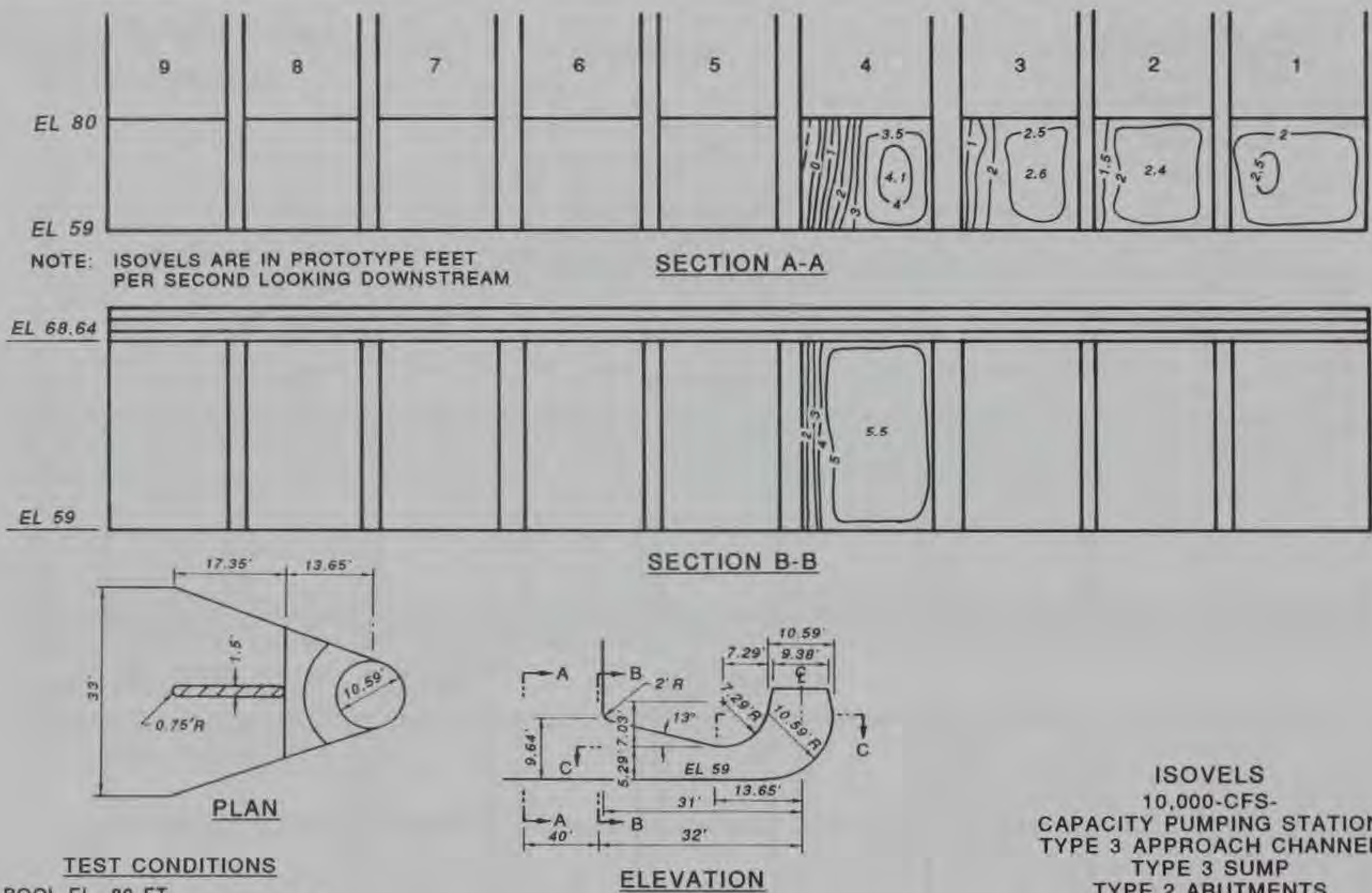


ELEVATION

TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

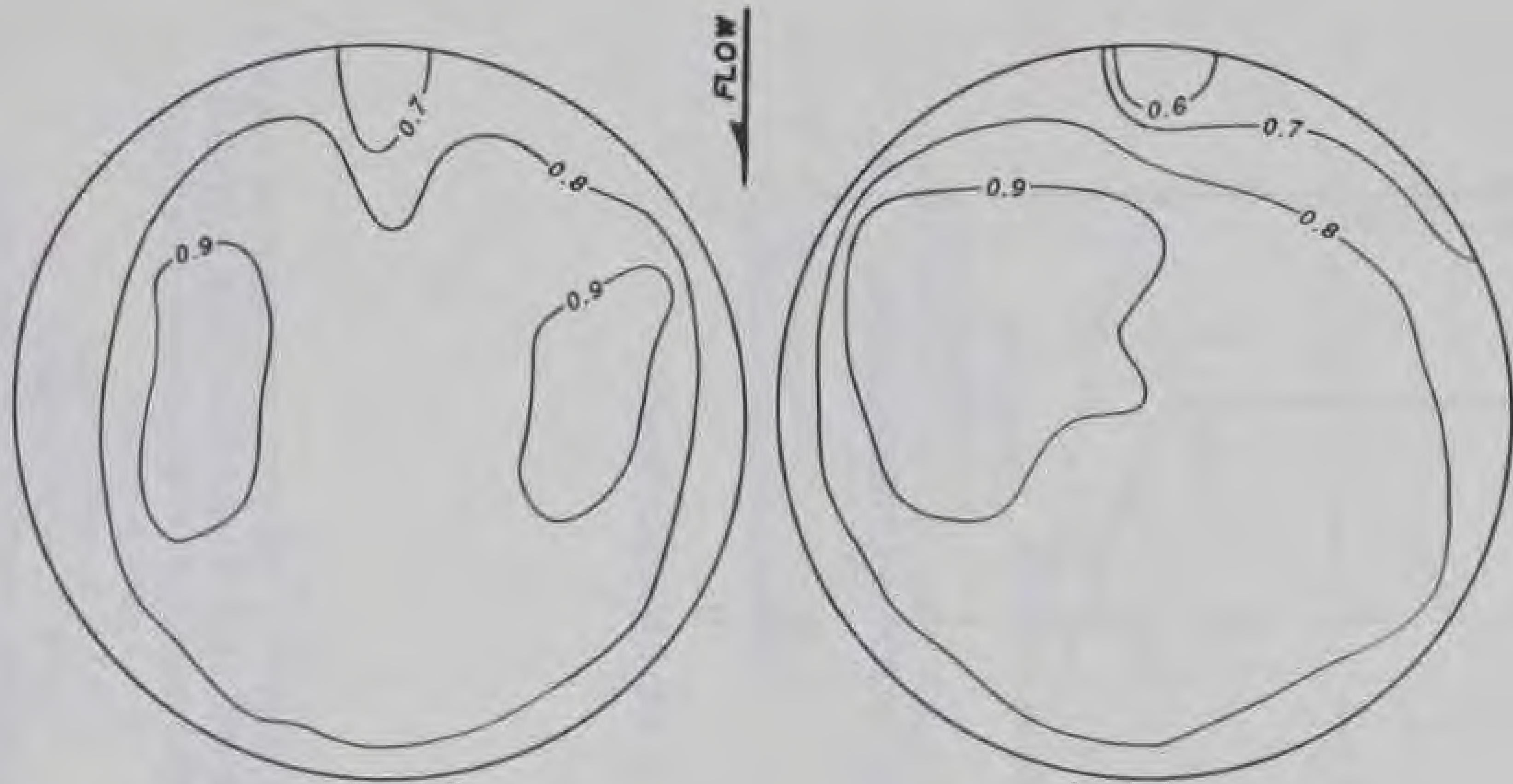
ISOVELS
10,000-CFS-
CAPACITY PUMPING STATION
TYPE 3 APPROACH CHANNEL
TYPE 3 SUMP
TYPE 2 ABUTMENTS
PUMPS OPERATING 1-9



TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

ISOVELS
10,000-CFS-
CAPACITY PUMPING STATION
TYPE 3 APPROACH CHANNEL
TYPE 3 SUMP
TYPE 2 ABUTMENTS
PUMPS OPERATING 1-4



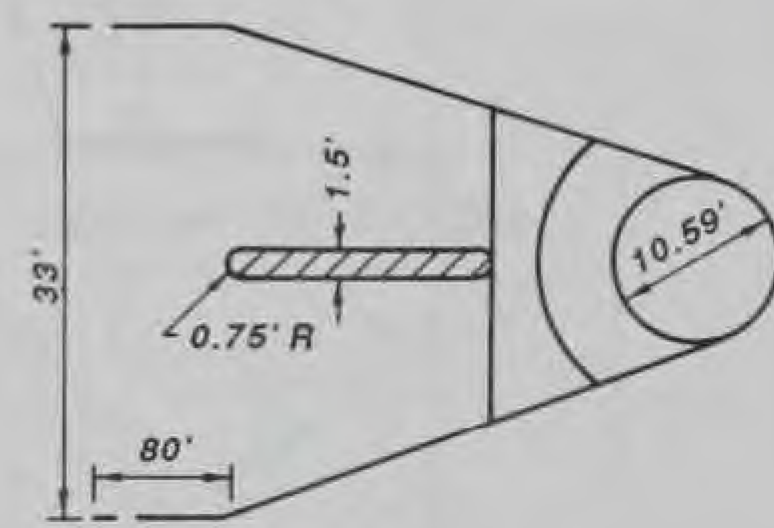
SECTION B-B
(PUMPS OPERATING 1-9)

SECTION B-B
(PUMPS OPERATING 1-4)

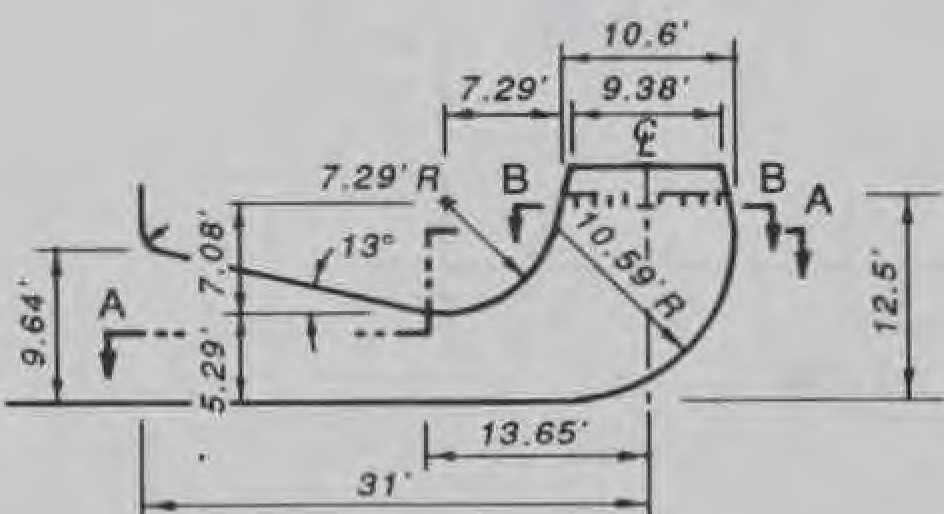
TEST CONDITIONS

WATER-SURFACE EL 80 FT
DISCHARGE PER PUMP 1460 CFS

NOTE: SOLID CONTOUR LINES INDICATE THE MINIMUM MEASURED INSTANTANEOUS VELOCITY DIVIDED BY THE THEORETICAL VELOCITY. DASHED CONTOUR LINES INDICATE NEGATIVE VELOCITY RATIO.



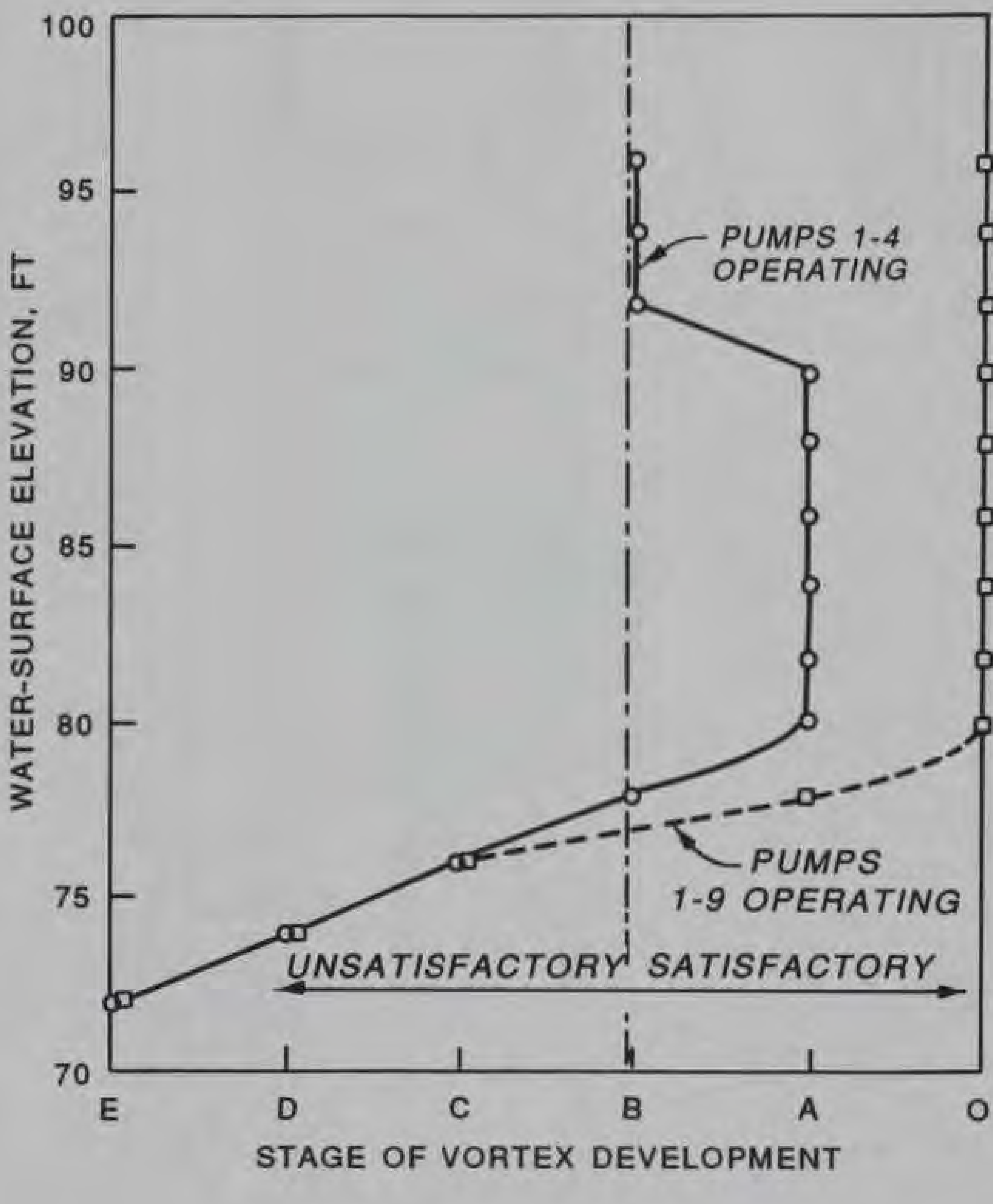
SECTION A-A



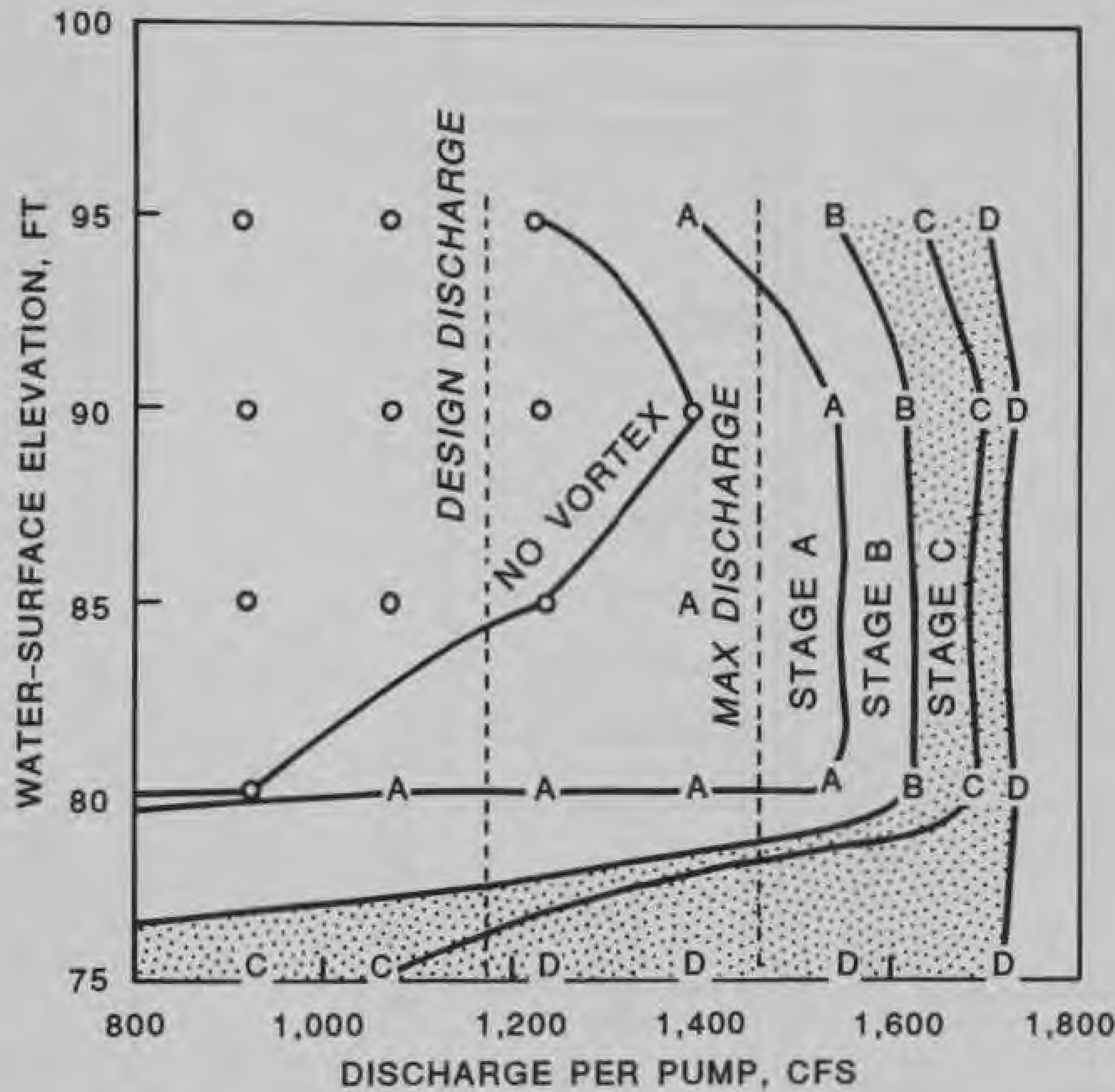
ELEVATION

LINES OF EQUAL VELOCITY RATIOS

10,000-CFS-CAPACITY PUMPING STATION
PUMP 4
TYPE 3 SUMP



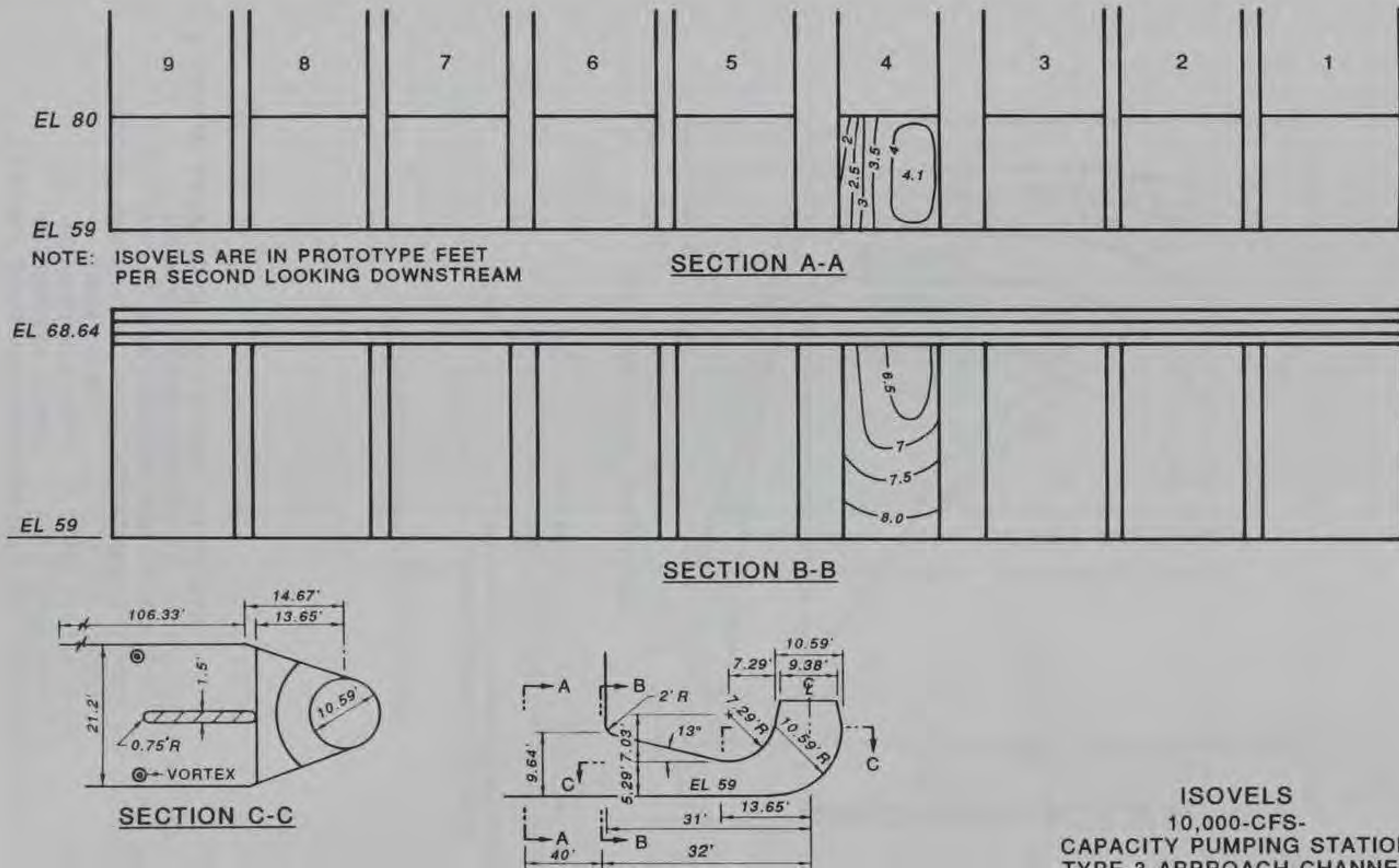
STAGE OF VORTEX DEVELOPMENT IN BAY 4
VERSUS WATER-SURFACE ELEVATION
10,000-CFS-CAPACITY PUMPING STATION
TYPE 3 SUMP
TYPE 3 APPROACH
TYPE 2 ABUTMENTS
DISCHARGE PER PUMP 1460 CFS



UNSATISFACTORY PERFORMANCE DUE TO SURFACE VORTICES

NOTE: SYMBOLS ON PLOT INDICATE STAGE OF DEVELOPMENT

STAGE OF VORTEX DEVELOPMENT IN BAY 4
DISCHARGE VERSUS
WATER-SURFACE ELEVATION
10,000-CFS-CAPACITY PUMPING STATION
TYPE 3 SUMP
TYPE 3 APPROACH
TYPE 2 ABUTMENTS
DISCHARGE PER PUMP 1460 CFS



NOTE: ISOVELS ARE IN PROTOTYPE FEET PER SECOND LOOKING DOWNSTREAM

SECTION A-A

SECTION B-B

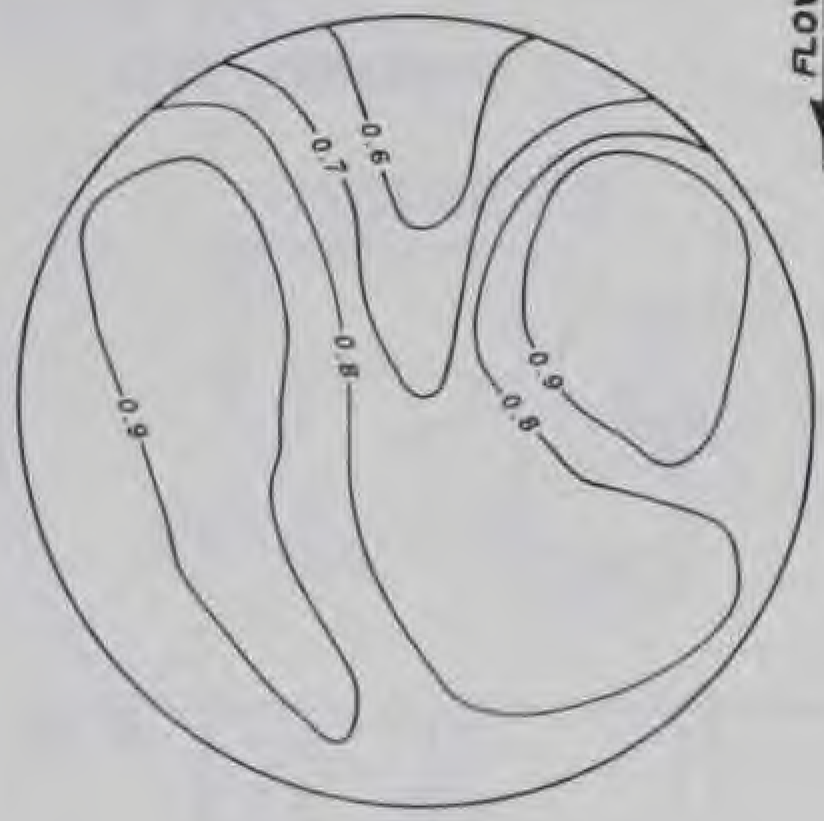
SECTION C-C

ELEVATION

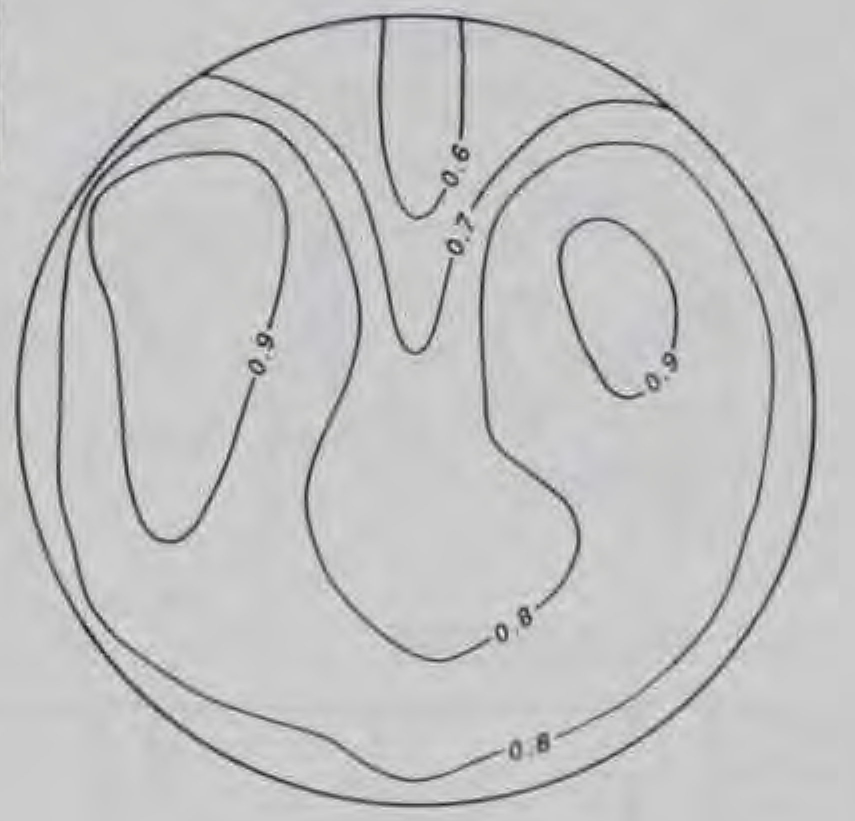
TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

ISOVELS
10,000-CFS-
CAPACITY PUMPING STATION
TYPE 3 APPROACH CHANNEL
TYPE 4 SUMP
TYPE 2 ABUTMENTS
PUMPS OPERATING 1-4



SECTION B-B
(PUMPS OPERATING 1-9)

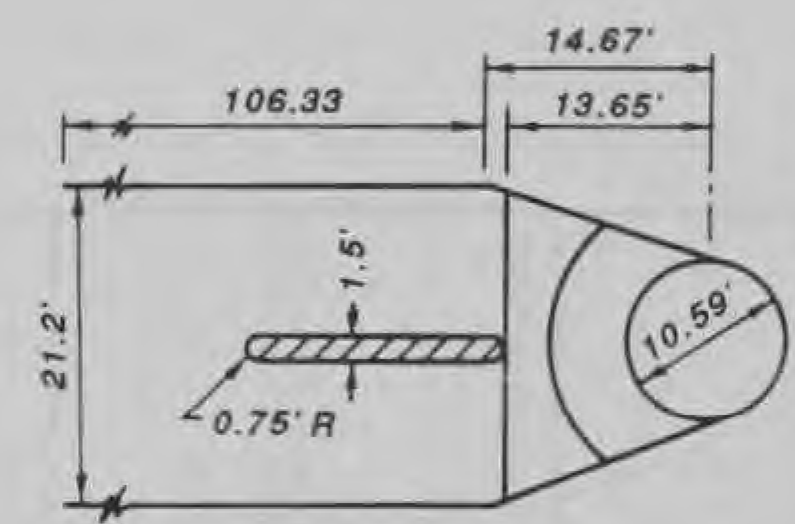


SECTION B-B
(PUMPS OPERATING 1-4)

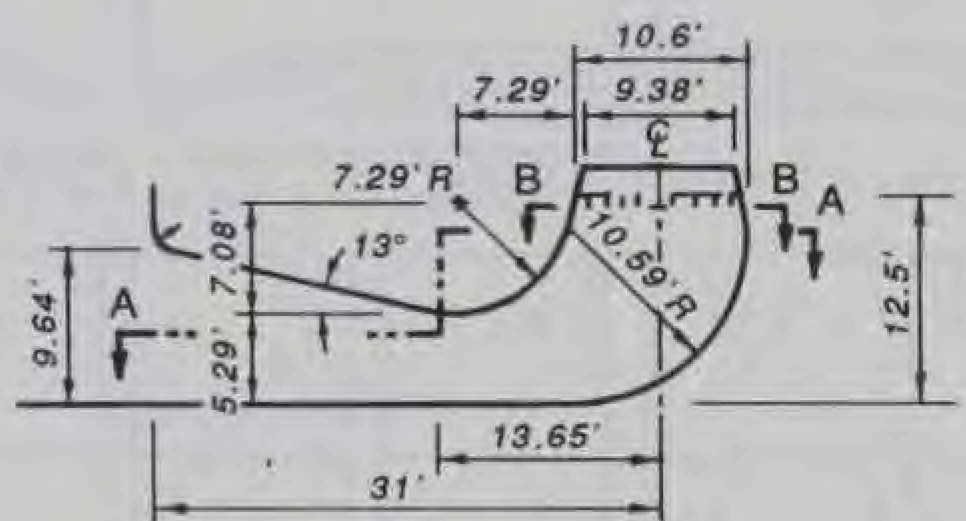
TEST CONDITIONS

WATER-SURFACE EL 80 FT
DISCHARGE PER PUMP 1460 CFS

NOTE: SOLID CONTOUR LINES INDICATE THE MINIMUM MEASURED INSTANTANEOUS VELOCITY DIVIDED BY THE THEORETICAL VELOCITY. DASHED CONTOUR LINES INDICATE NEGATIVE VELOCITY RATIO.

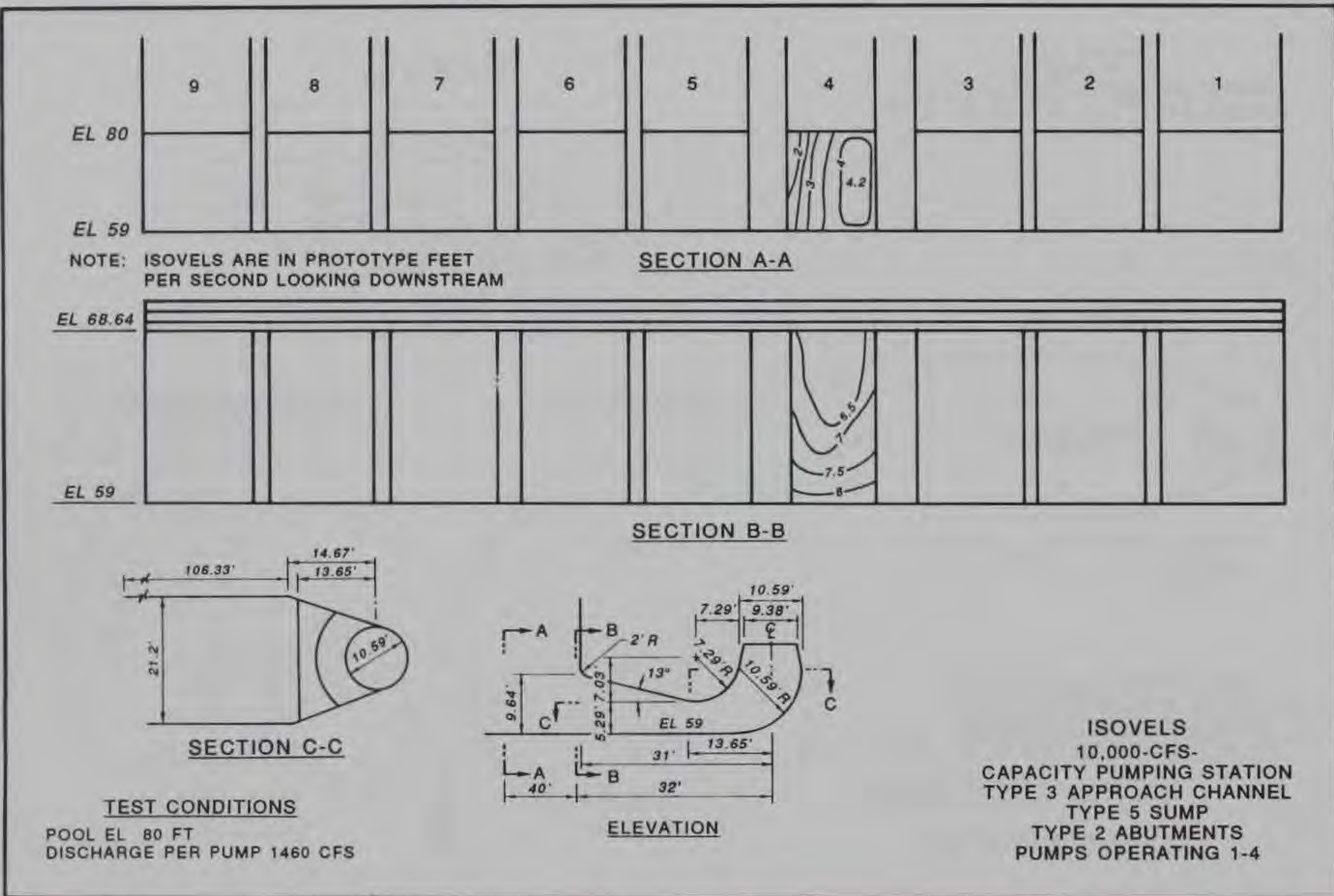


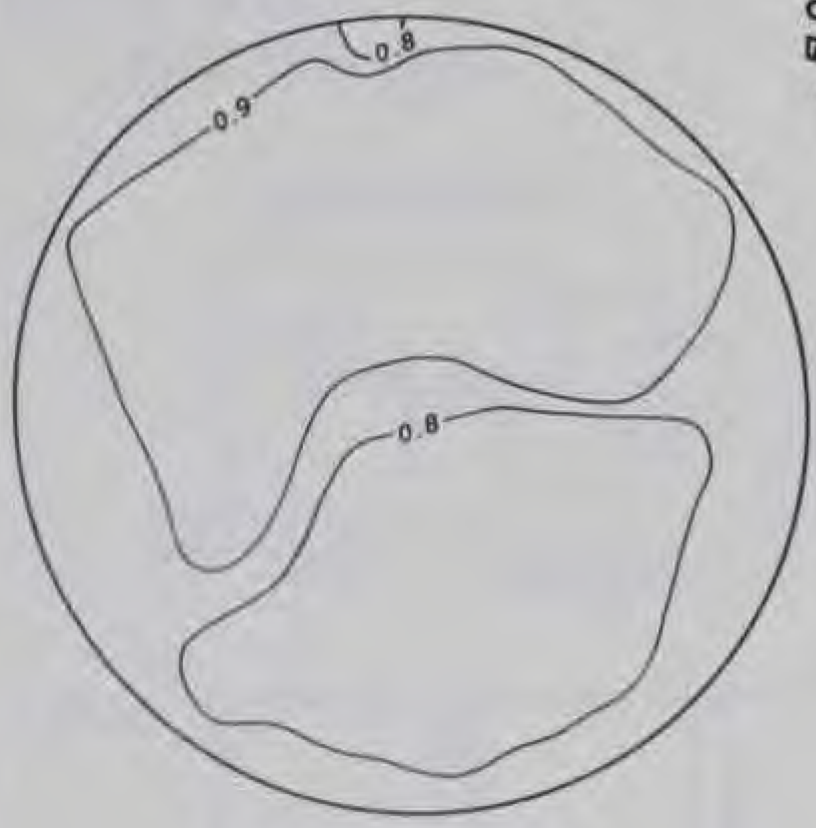
SECTION A-A



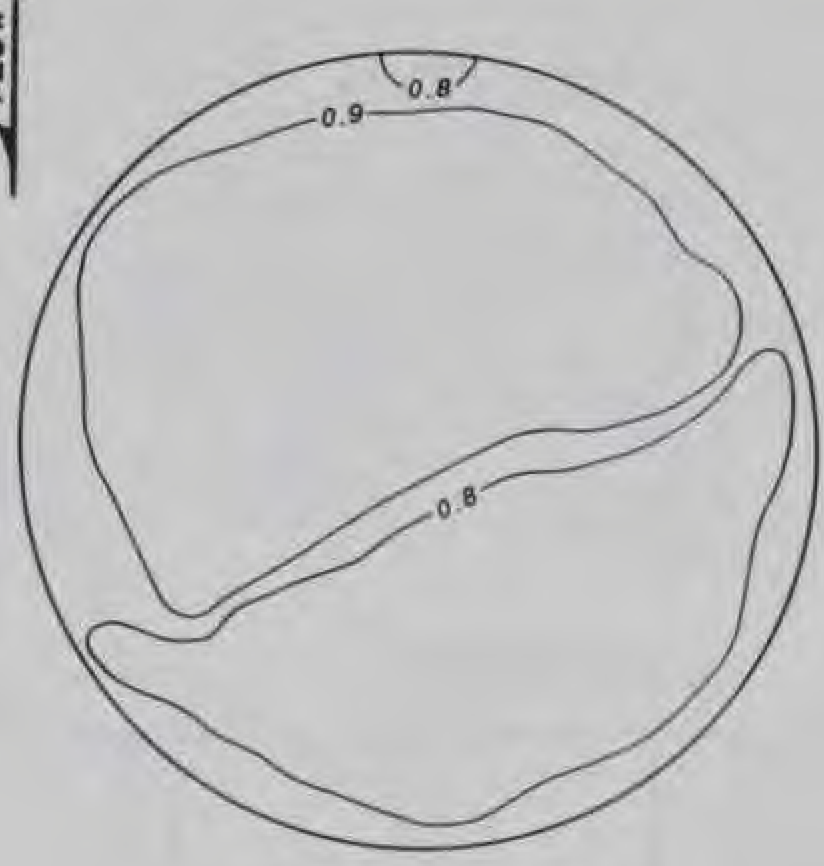
ELEVATION

LINES OF EQUAL VELOCITY RATIOS
10,000-CFS-CAPACITY PUMPING STATION
PUMP 4
TYPE 4 SUMP


9
8
7
6
5
4
3
2
1
EL 80
EL 59
2
3
4
4.2
NOTE: ISOVELS ARE IN PROTOTYPE FEET PER SECOND LOOKING DOWNSTREAM
SECTION A-A
EL 68.64
EL 59
6.5
7
7.5
8
SECTION B-B
106.33'
14.67'
13.65'
21.2'
10.59'
SECTION C-C
TEST CONDITIONS
POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS
10.59'
7.29'
9.38'
A
B
2' R
7.29' R
10.59' R
13°
9.64'
7.03'
5.29'
C
EL 59
13.65'
31'
40'
32'
ELEVATION
ISOVELS
10,000-CFS-
CAPACITY PUMPING STATION
TYPE 3 APPROACH CHANNEL
TYPE 5 SUMP
TYPE 2 ABUTMENTS
PUMPS OPERATING 1-4



SECTION B-B
(PUMPS OPERATING 1-9)

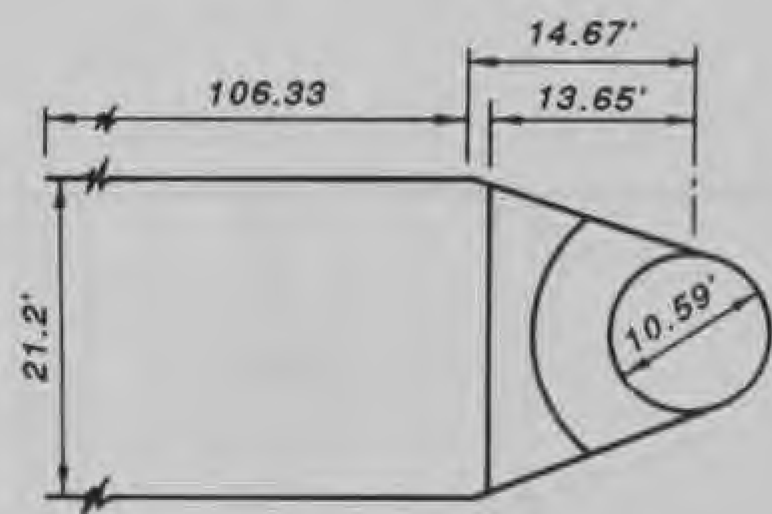


SECTION B-B
(PUMPS OPERATING 1-4)

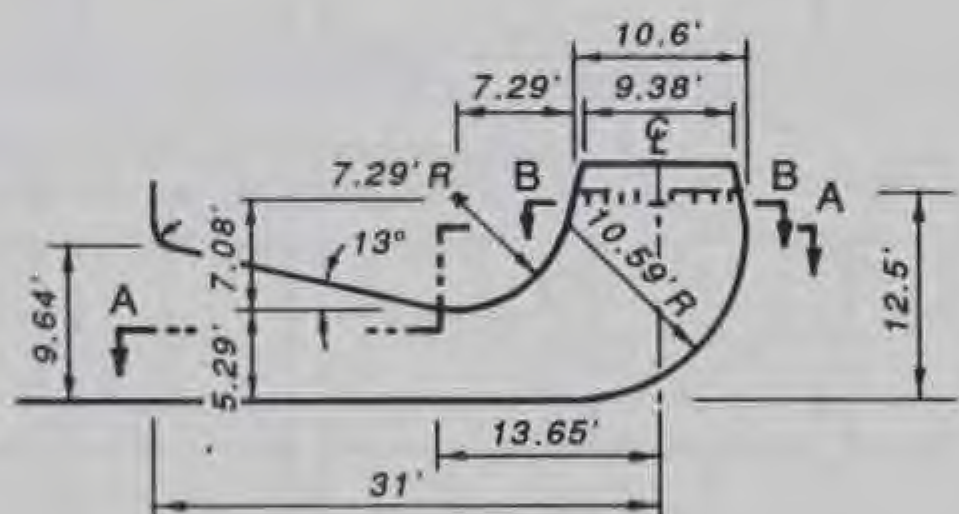
TEST CONDITIONS

WATER-SURFACE EL 80 FT
DISCHARGE PER PUMP 1460 CFS

NOTE: SOLID CONTOUR LINES INDICATE THE MINIMUM MEASURED INSTANTANEOUS VELOCITY DIVIDED BY THE THEORETICAL VELOCITY. DASHED CONTOUR LINES INDICATE NEGATIVE VELOCITY RATIO.



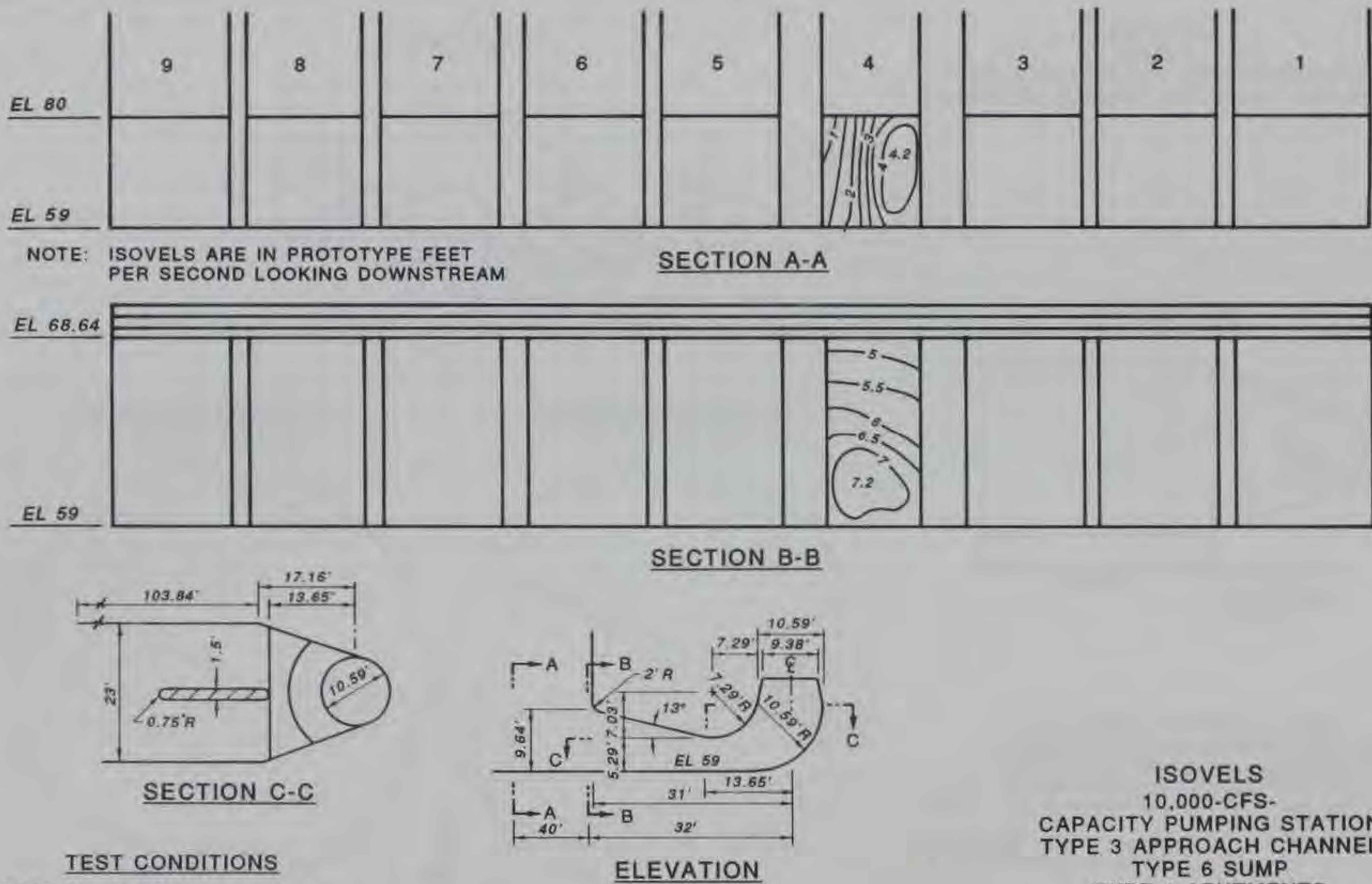
SECTION A-A



ELEVATION

LINES OF EQUAL VELOCITY RATIOS
10,000-CFS-CAPACITY PUMPING STATION
PUMP 4
TYPE 5 SUMP

PLATE 64

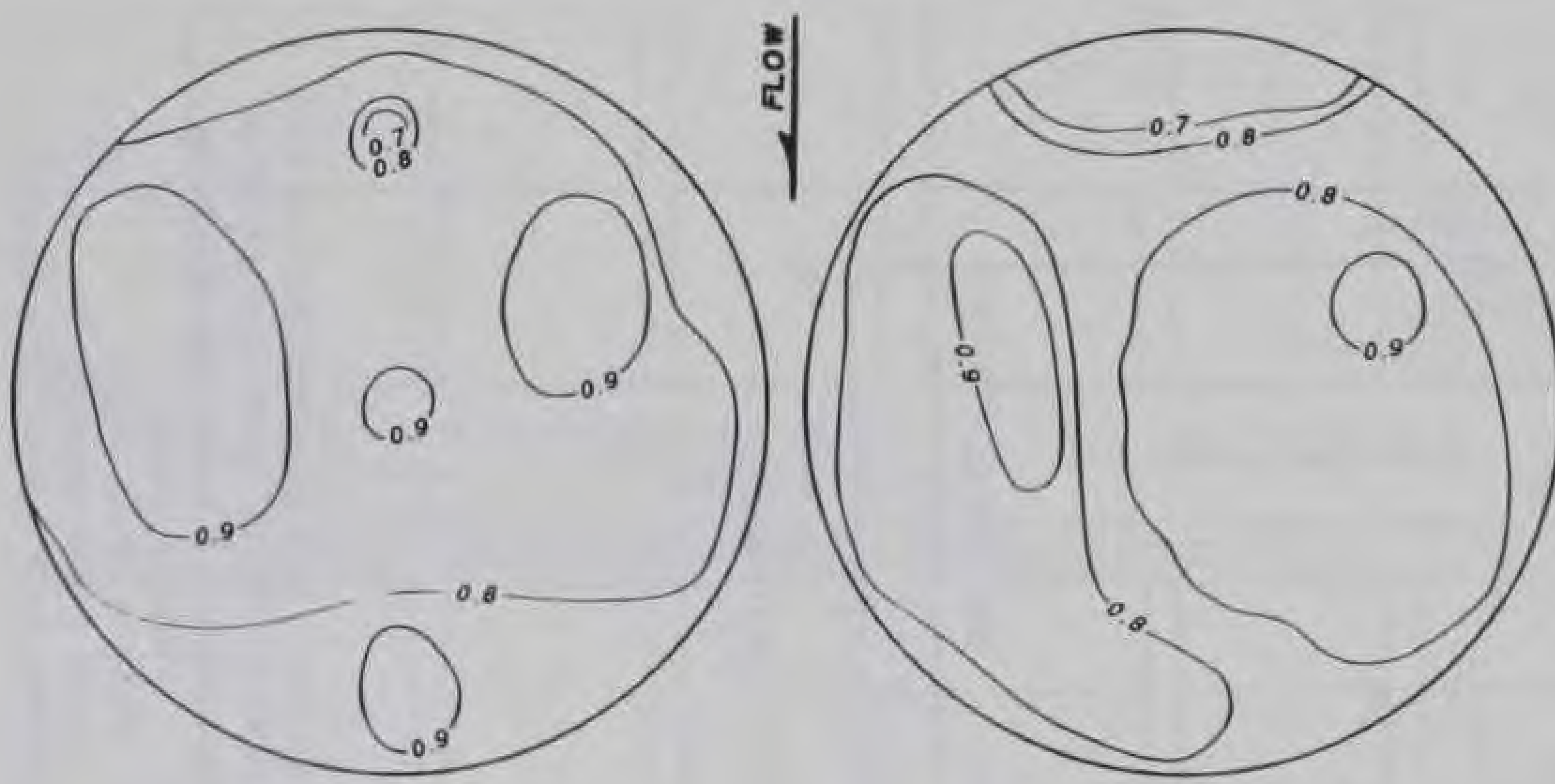


NOTE: ISOVELS ARE IN PROTOTYPE FEET PER SECOND LOOKING DOWNSTREAM

TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

ISOVELS
10,000-CFS-
CAPACITY PUMPING STATION
TYPE 3 APPROACH CHANNEL
TYPE 6 SUMP
TYPE 2 ABUTMENTS
PUMPS OPERATING 1-4



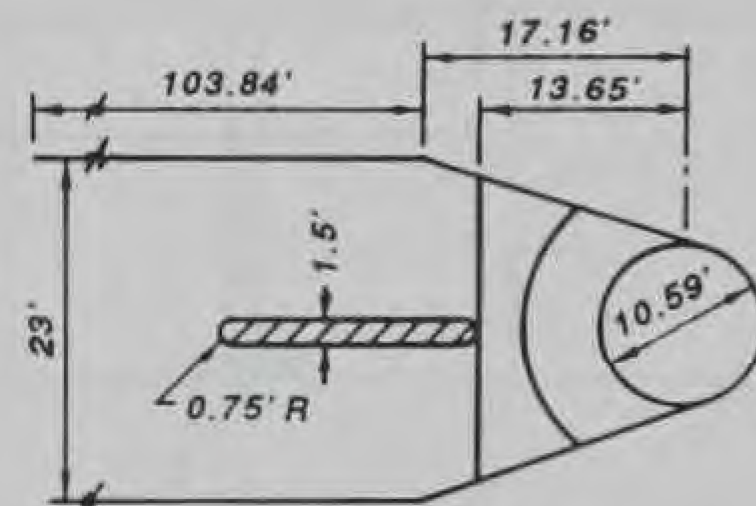
SECTION B-B
(PUMPS OPERATING 1-9)

SECTION B-B
(PUMPS OPERATING 1-4)

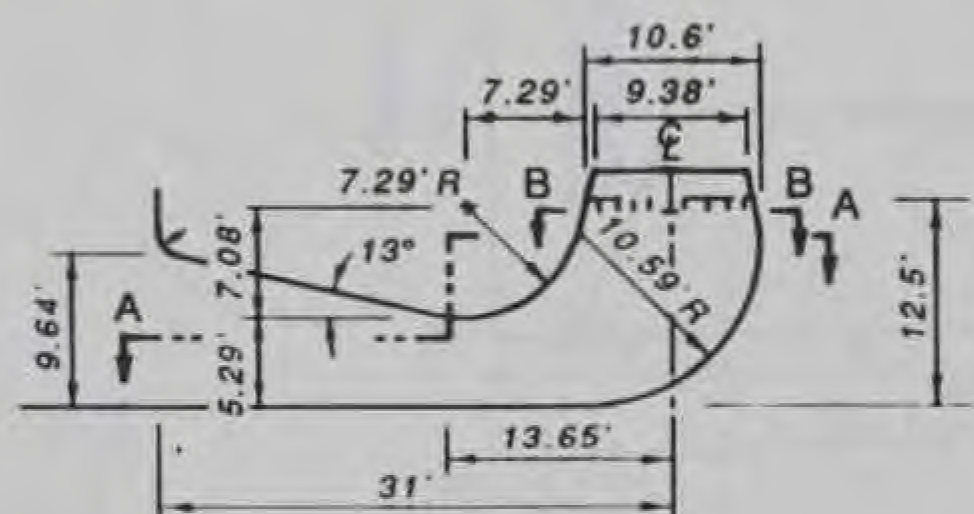
TEST CONDITIONS

WATER-SURFACE EL 80 FT
DISCHARGE PER PUMP 1460 CFS

NOTE: SOLID CONTOUR LINES INDICATE THE MINIMUM MEASURED INSTANTANEOUS VELOCITY DIVIDED BY THE THEORETICAL VELOCITY. DASHED CONTOUR LINES INDICATE NEGATIVE VELOCITY RATIO.

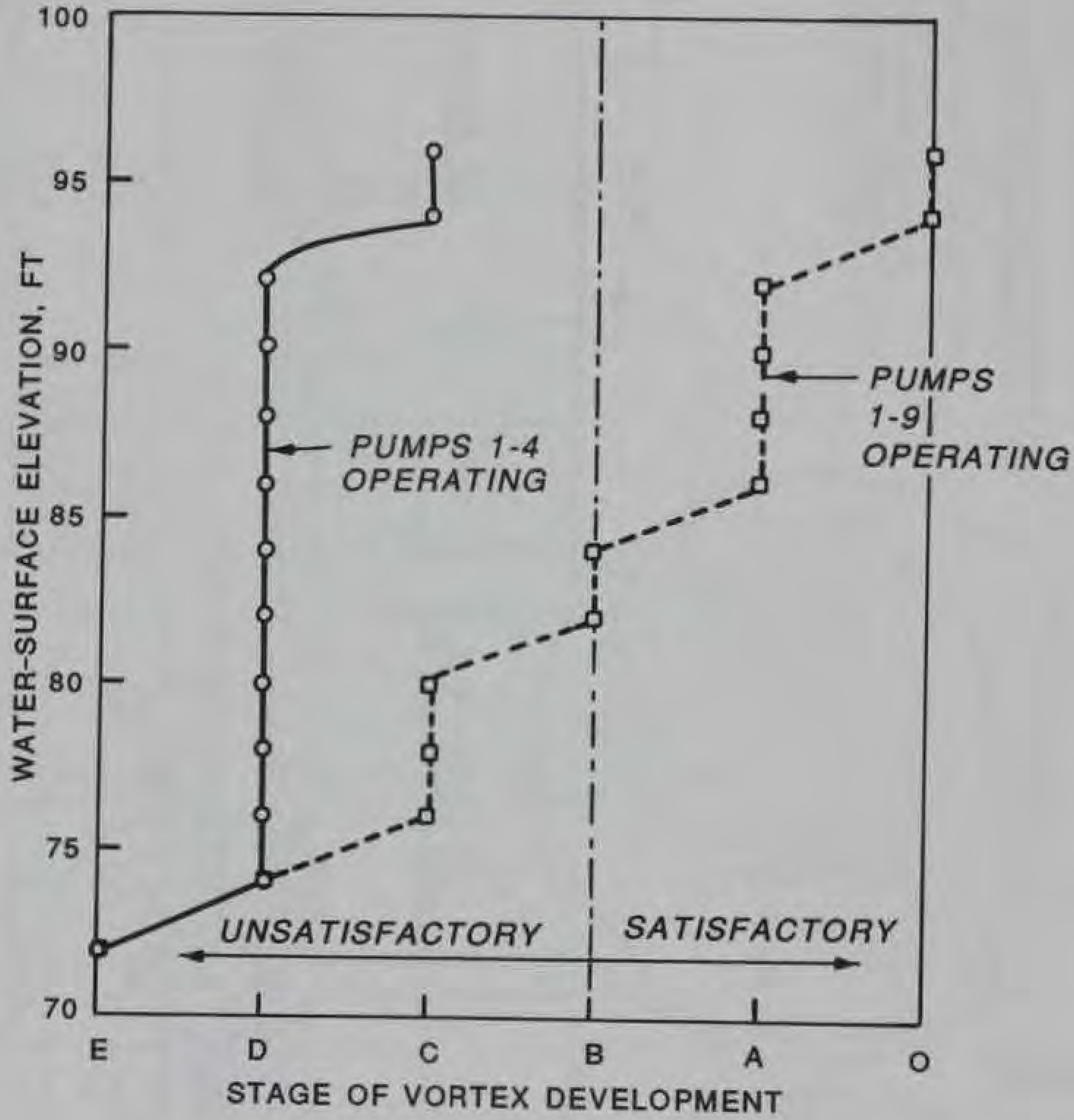


SECTION A-A



ELEVATION

LINES OF EQUAL VELOCITY RATIOS
10,000-CFS-CAPACITY PUMPING STATION
PUMP 4
TYPE 6 SUMP

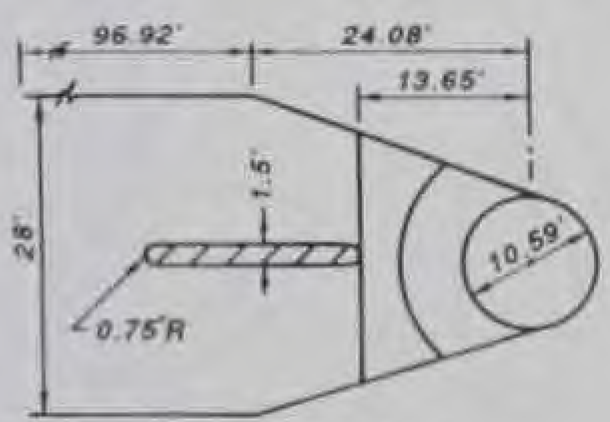


STAGE OF VORTEX DEVELOPMENT IN BAY 4
VERSUS WATER-SURFACE ELEVATION
10,000-CFS-CAPACITY PUMPING STATION
TYPE 6 SUMP
TYPE 3 APPROACH
TYPE 2 ABUTMENTS
DISCHARGE PER PUMP 1460 CFS

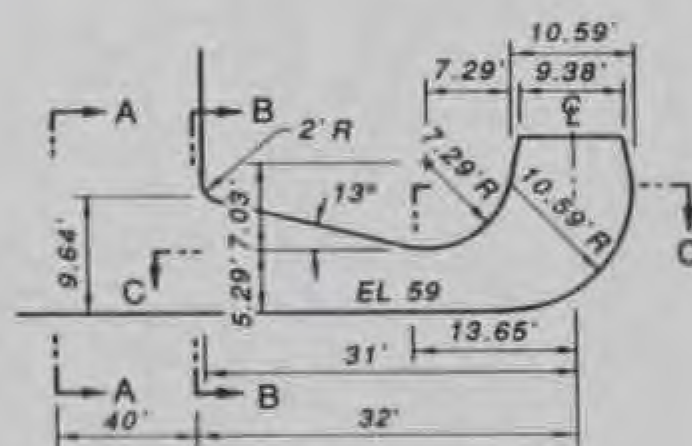
NOTE: ISOVELS ARE IN PROTOTYPE FEET
PER SECOND LOOKING DOWNSTREAM

SECTION A-A

SECTION B-B



SECTION C-C

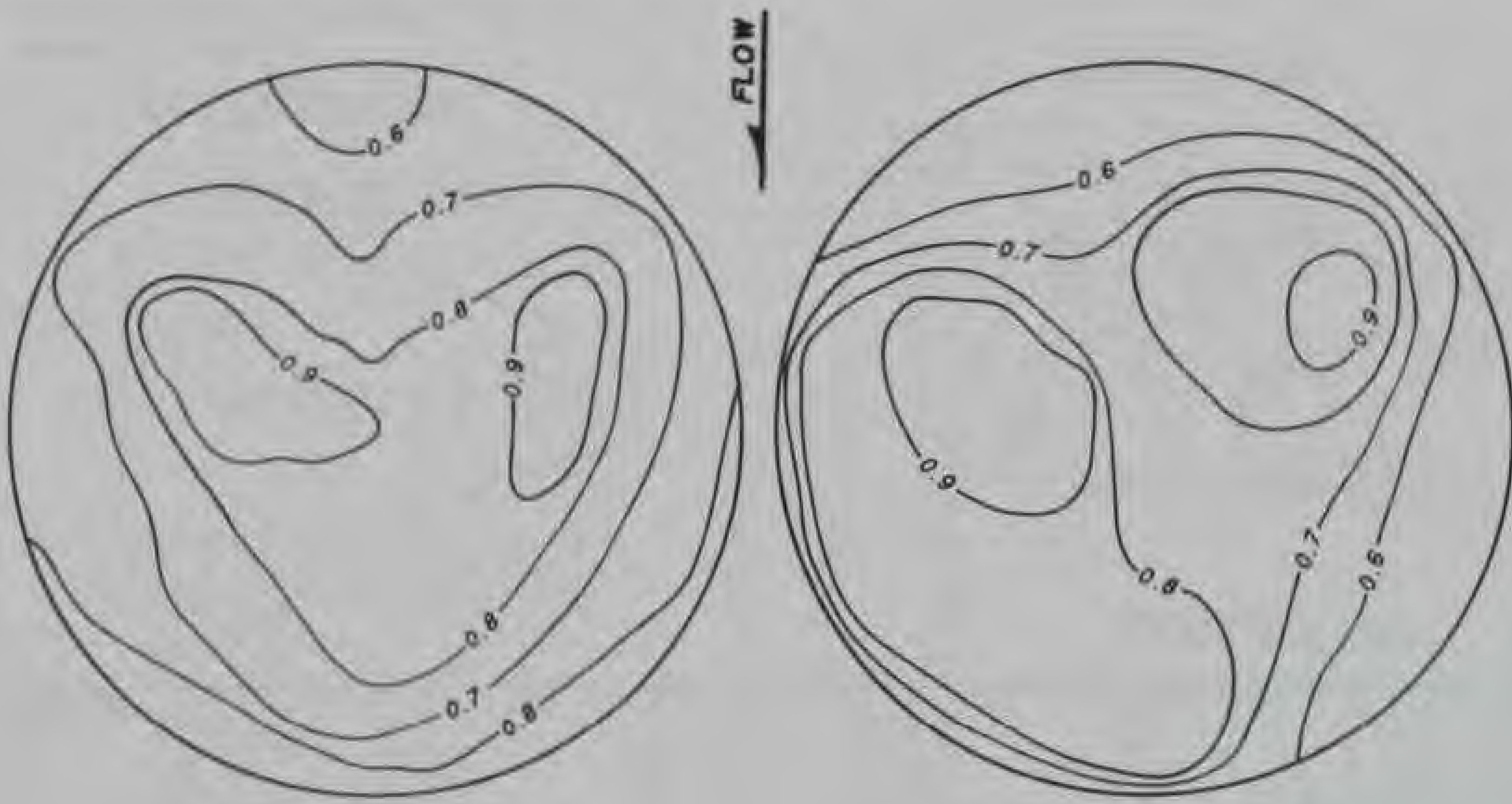


ELEVATION

TEST CONDITIONS

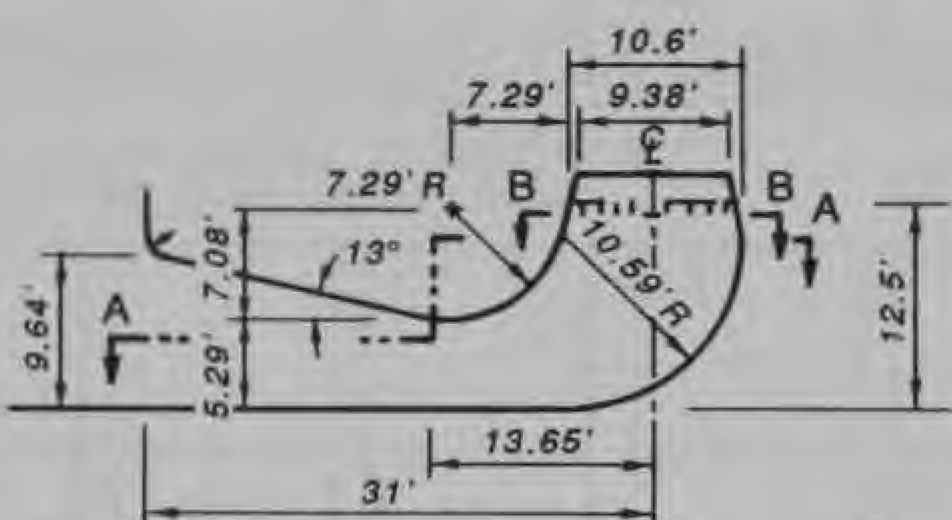
POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

ISOVELS
10,000-CFS-
CAPACITY PUMPING STATION
TYPE 3 APPROACH CHANNEL
TYPE 7 SUMP
TYPE 2 ABUTMENTS
PUMPS OPERATING 1-4



SECTION B-B
(PUMPS OPERATING 1-9)

SECTION B-B
(PUMPS OPERATING 1-4)

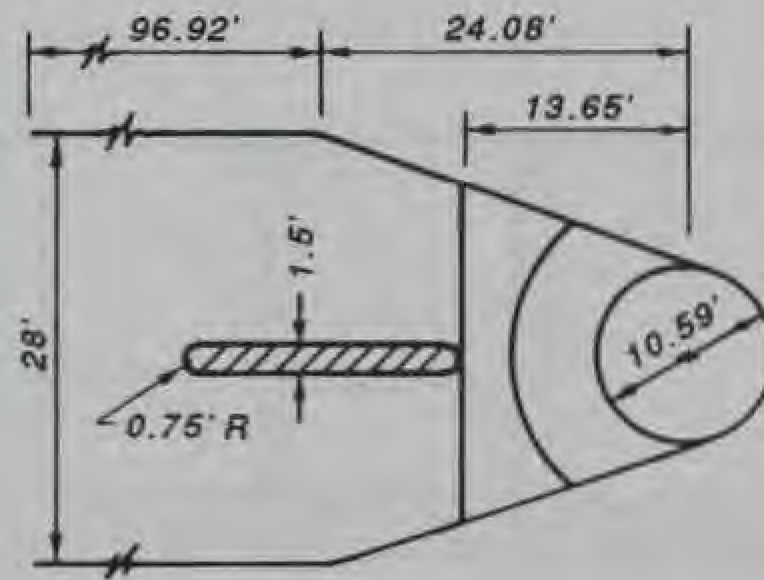


ELEVATION

TEST CONDITIONS

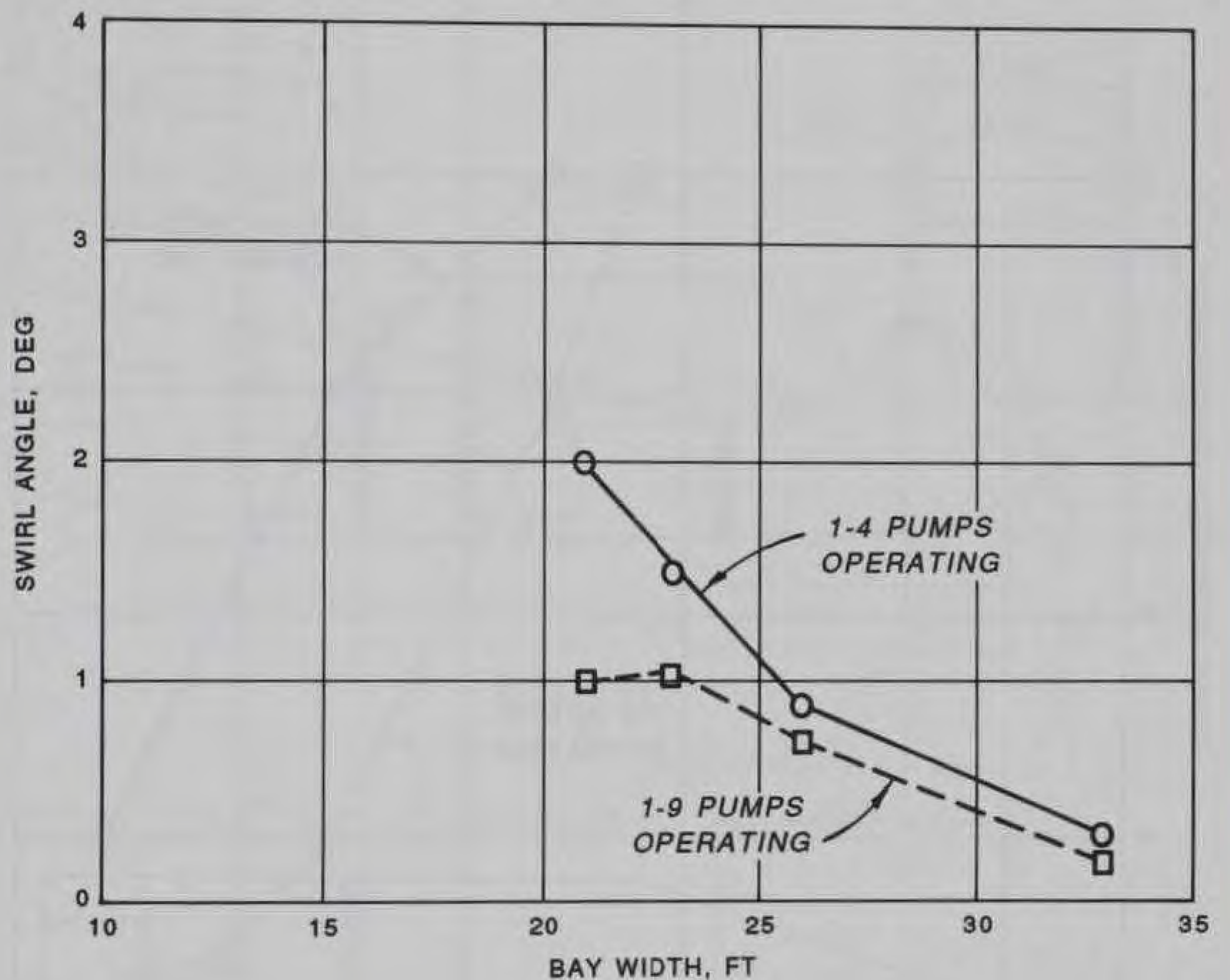
WATER-SURFACE EL 80 FT
DISCHARGE PER PUMP 1460 CFS

NOTE: SOLID CONTOUR LINES INDICATE THE MINIMUM MEASURED INSTANTANEOUS VELOCITY DIVIDED BY THE THEORETICAL VELOCITY. DASHED CONTOUR LINES INDICATE NEGATIVE VELOCITY RATIO.

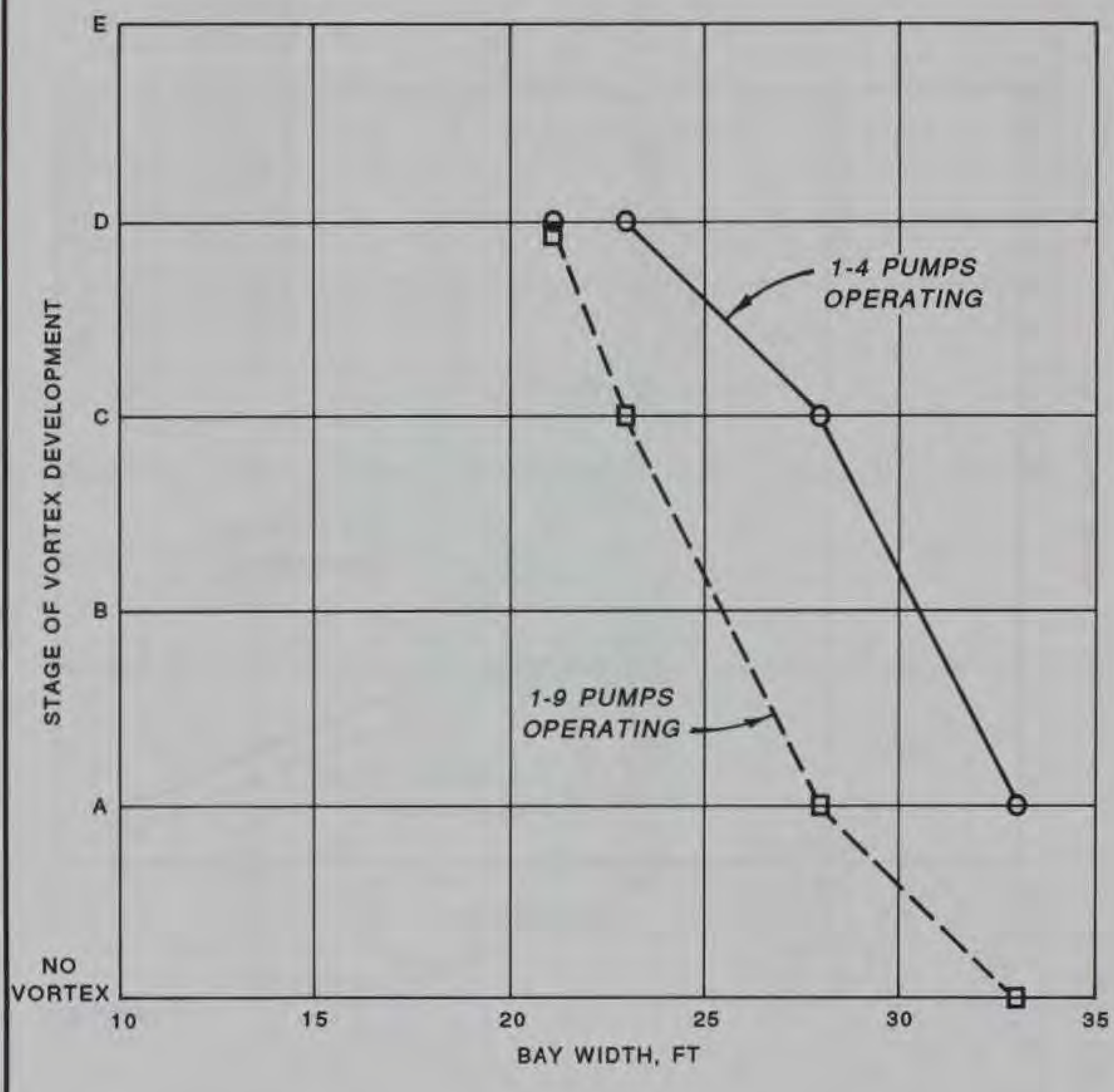


SECTION A-A

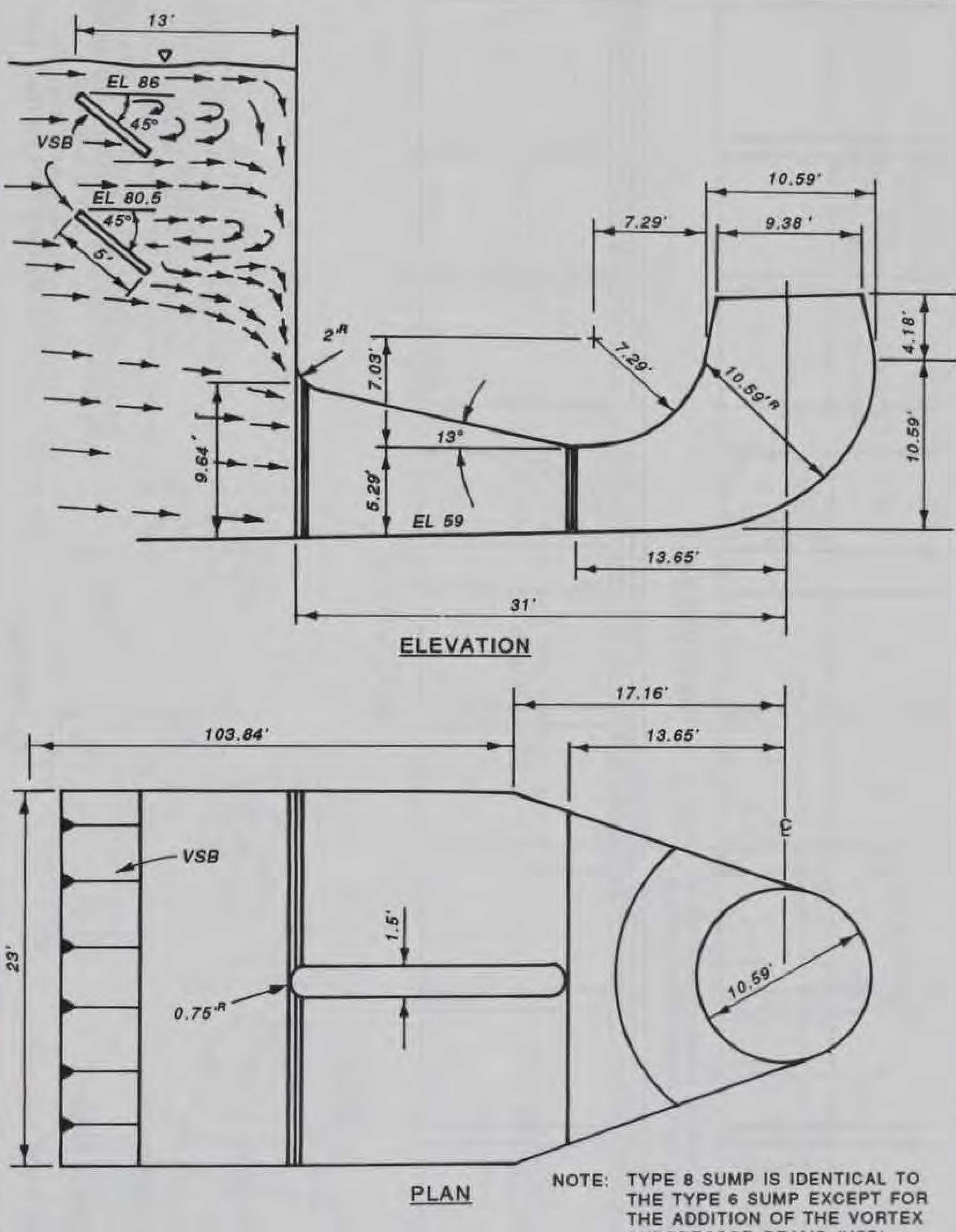
LINES OF EQUAL VELOCITY RATIOS
10,000-CFS-CAPACITY PUMPING STATION
PUMP 4
TYPE 7 SUMP



SWIRL ANGLE VS BAY WIDTH
10,000-CFS-CAPACITY PUMPING STATION
TYPE 3 APPROACH
TYPE 2 ABUTMENTS
DISCHARGE PER PUMP 1460 CFS
WATER-SURFACE (SUMP) EL 80 FT

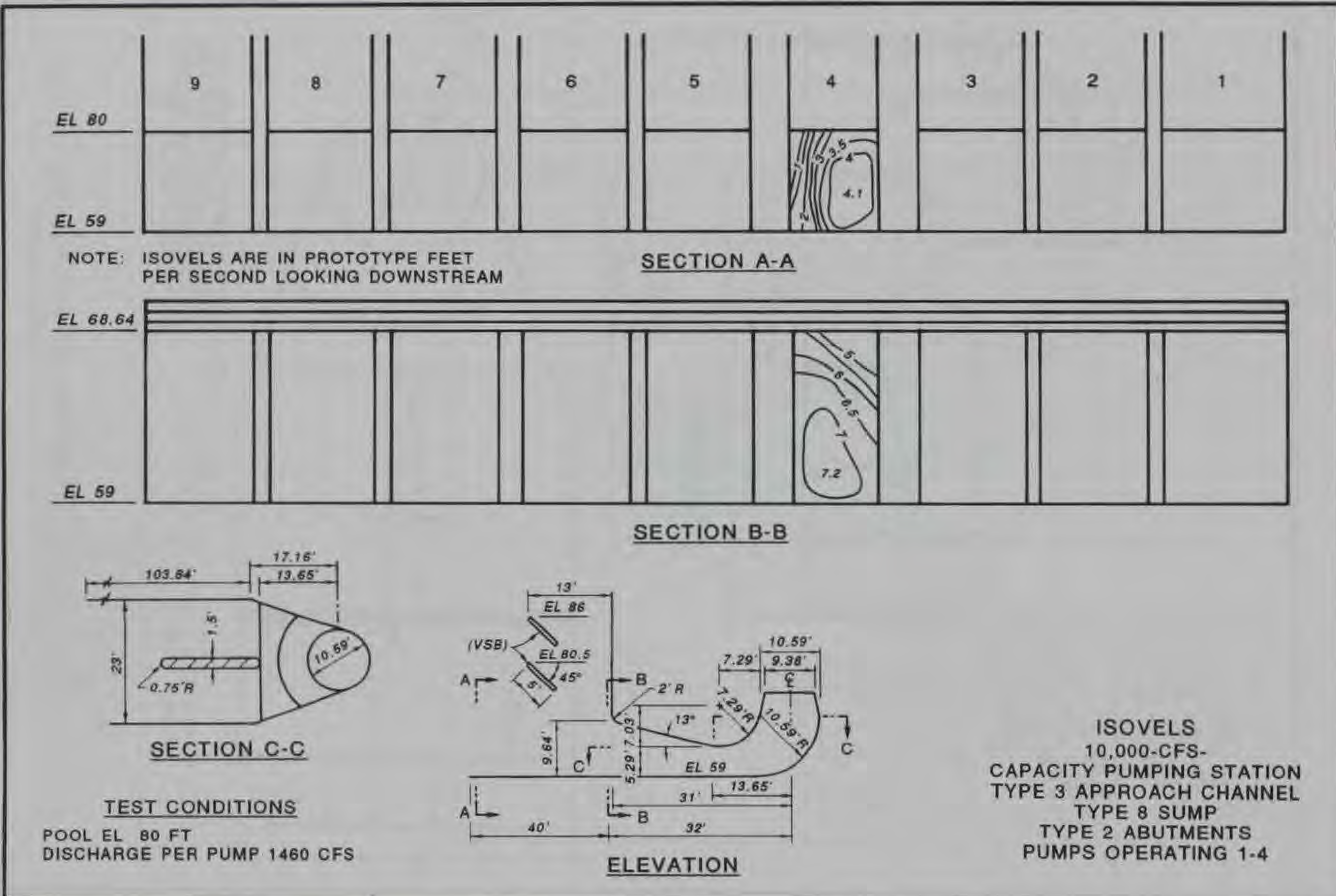


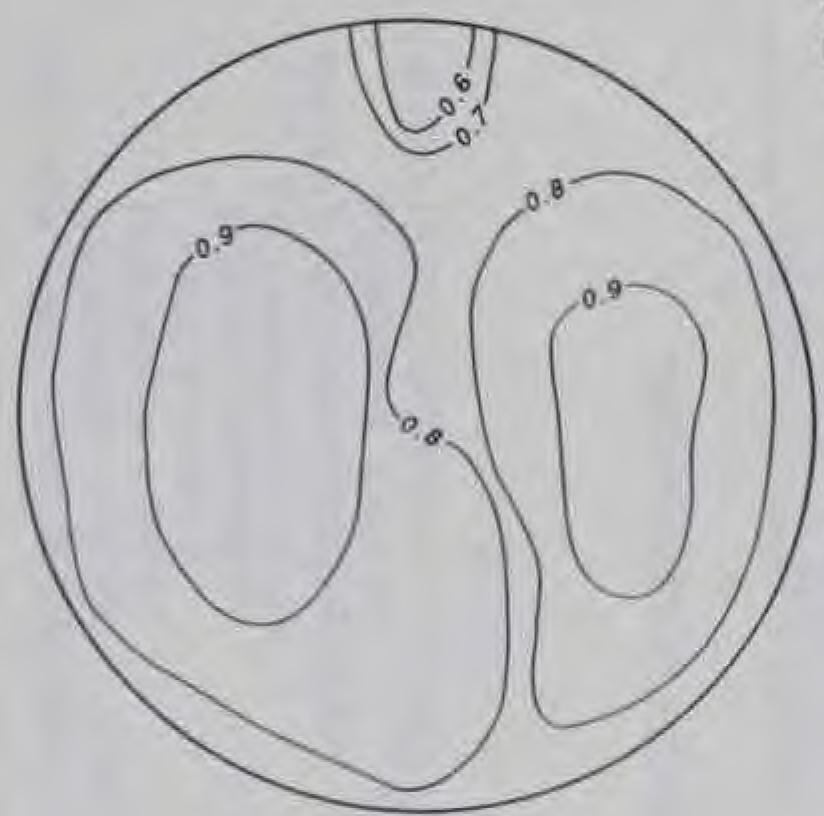
STAGE OF VORTEX DEVELOPMENT
VERSUS BAY WIDTH
10,000-CFS-CAPACITY PUMPING STATION
TYPE 3 APPROACH
TYPE 2 ABUTMENTS
DISCHARGE PER PUMP 1460 CFS
WATER-SURFACE (SUMP) EL 80 FT



NOTE: TYPE 8 SUMP IS IDENTICAL TO THE TYPE 6 SUMP EXCEPT FOR THE ADDITION OF THE VORTEX SUPPRESSOR BEAMS (VSB)

10,000-CFS-CAPACITY PUMPING STATION
TYPE 8 SUMP


9
8
7
6
5
4
3
2
1
EL 80
EL 59
3.5
3
4
4.1
2
NOTE: ISOVELS ARE IN PROTOTYPE FEET PER SECOND LOOKING DOWNSTREAM
SECTION A-A
EL 68.64
EL 59
5
6
6.5
7
7.2
SECTION B-B
103.84'
17.16'
13.65'
1.5'
23'
0.75'R
10.59'
SECTION C-C
TEST CONDITIONS
POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS
13'
EL 86
(VSB)
EL 80.5
45°
5'
2' R
13°
10.59'
7.29'
9.38'
7.29'R
10.59'R
9.64'
7.03'
5.29'
EL 59
31'
13.65'
40'
32'
ELEVATION
ISOVELS
10,000-CFS-
CAPACITY PUMPING STATION
TYPE 3 APPROACH CHANNEL
TYPE 8 SUMP
TYPE 2 ABUTMENTS
PUMPS OPERATING 1-4



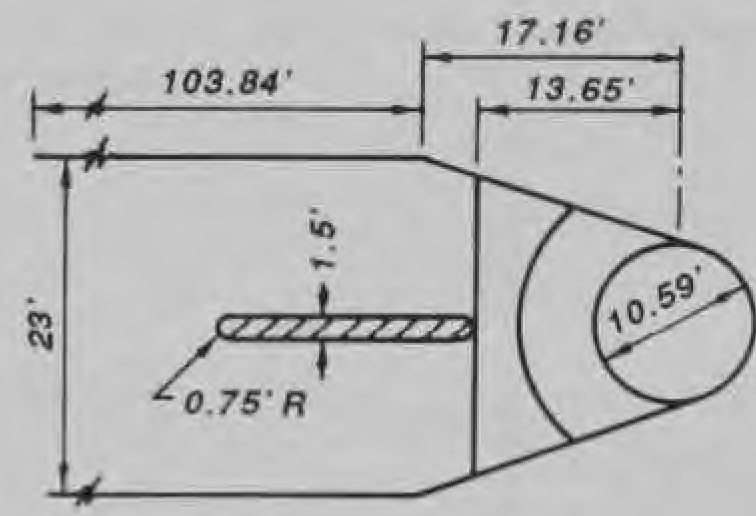
SECTION B-B
(PUMPS OPERATING 1-9)

SECTION B-B
(PUMPS OPERATING 1-4)

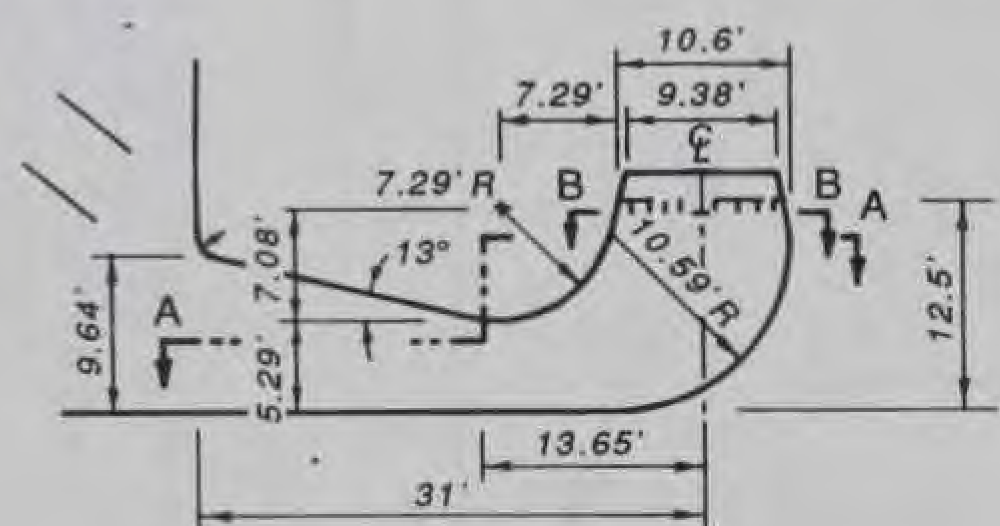
TEST CONDITIONS

WATER-SURFACE EL 80 FT
DISCHARGE PER PUMP 1460 CFS

NOTE: SOLID CONTOUR LINES INDICATE THE MINIMUM MEASURED INSTANTANEOUS VELOCITY DIVIDED BY THE THEORETICAL VELOCITY. DASHED CONTOUR LINES INDICATE NEGATIVE VELOCITY RATIO.

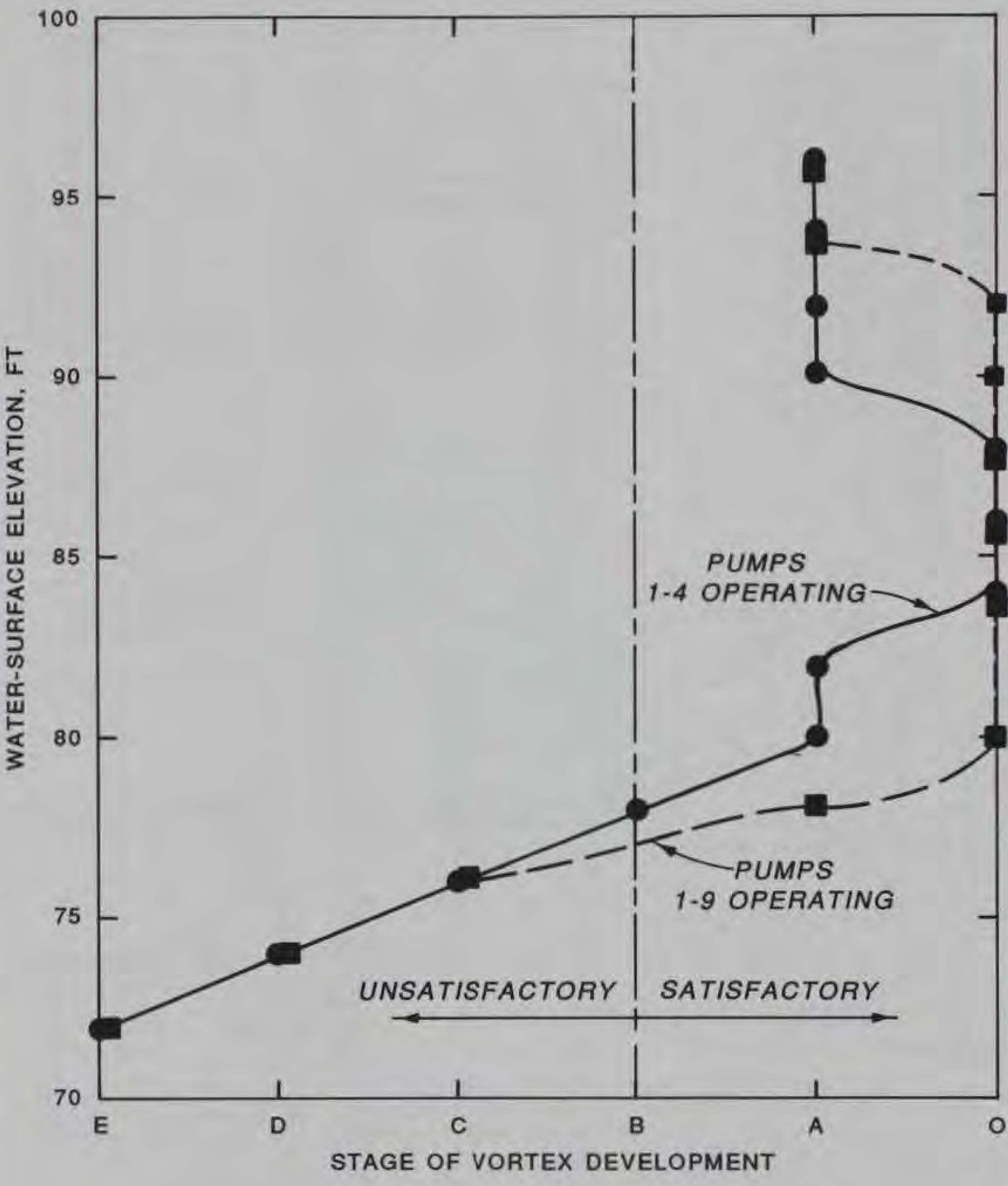


SECTION A-A

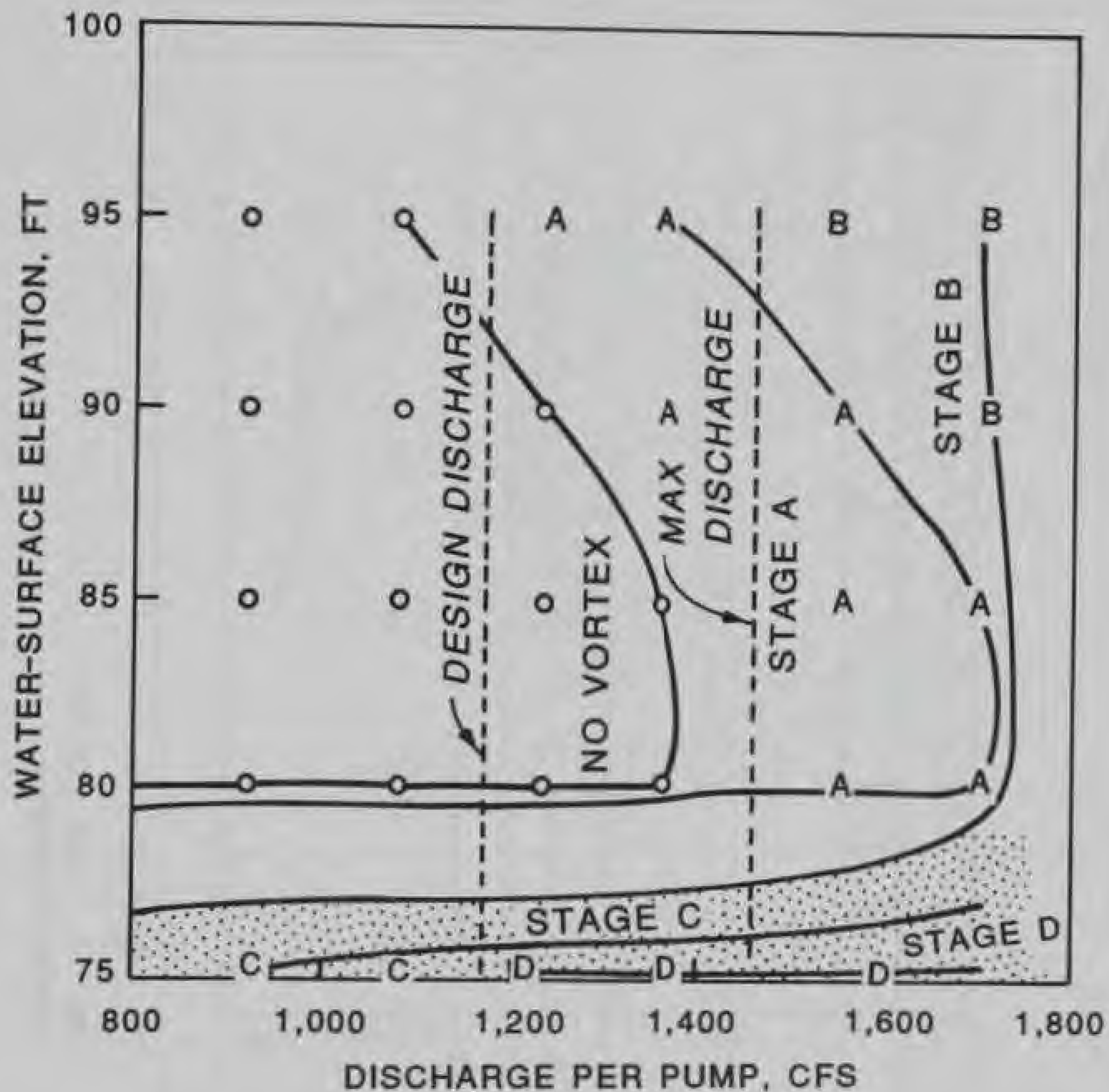


ELEVATION

LINES OF EQUAL VELOCITY RATIOS
10,000-CFS-CAPACITY PUMPING STATION
PUMP 4
TYPE 8 SUMP



STAGE OF VORTEX DEVELOPMENT
IN BAY 4 VERSUS
WATER-SURFACE ELEVATION
10,000-CFS-CAPACITY
PUMPING STATION
TYPE 8 SUMP
TYPE 3 APPROACH
TYPE 2 ABUTMENTS
DISCHARGE PER PUMP 1460 CFS

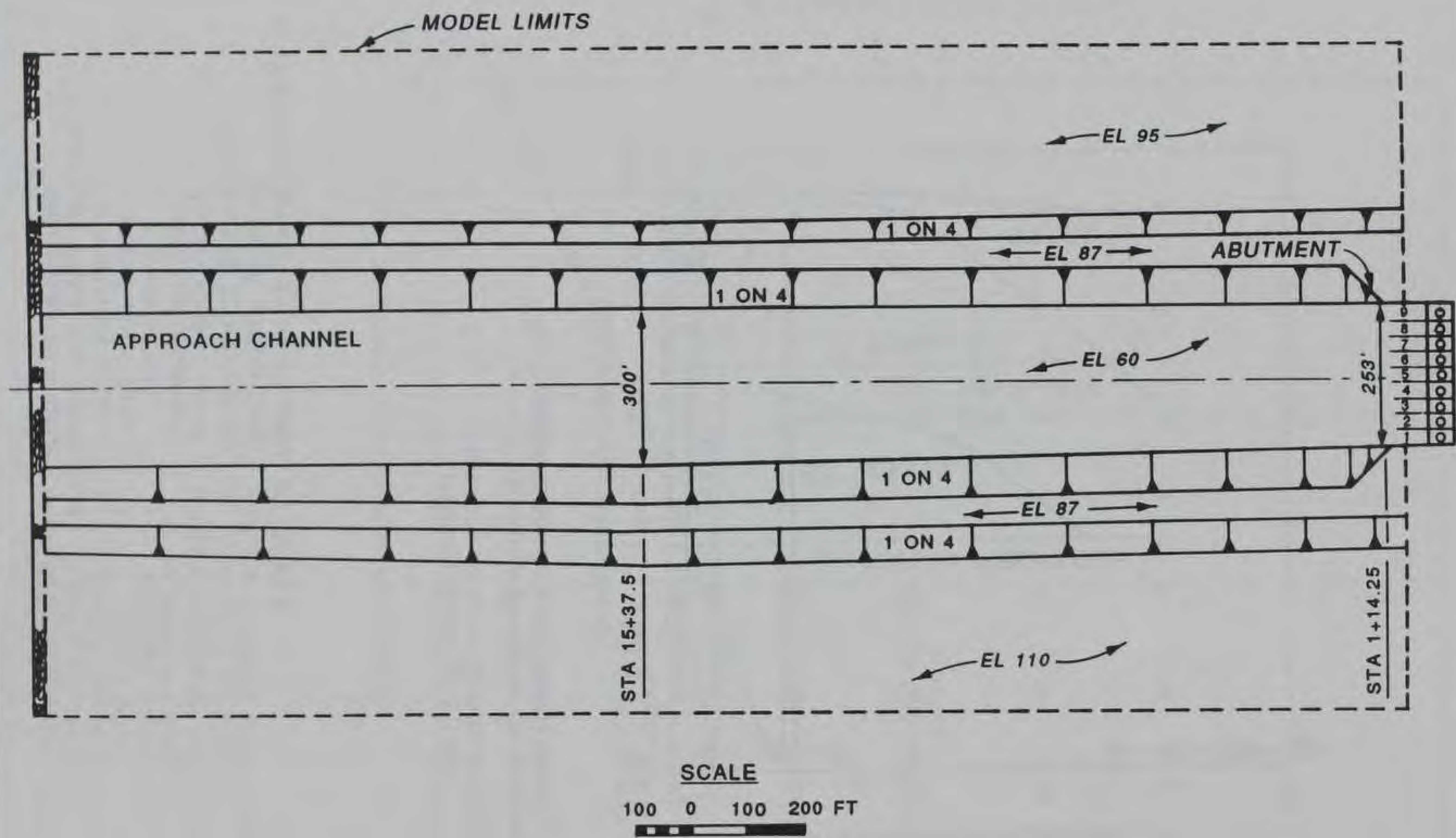


UNSATISFACTORY PERFORMANCE DUE TO SURFACE VORTICES

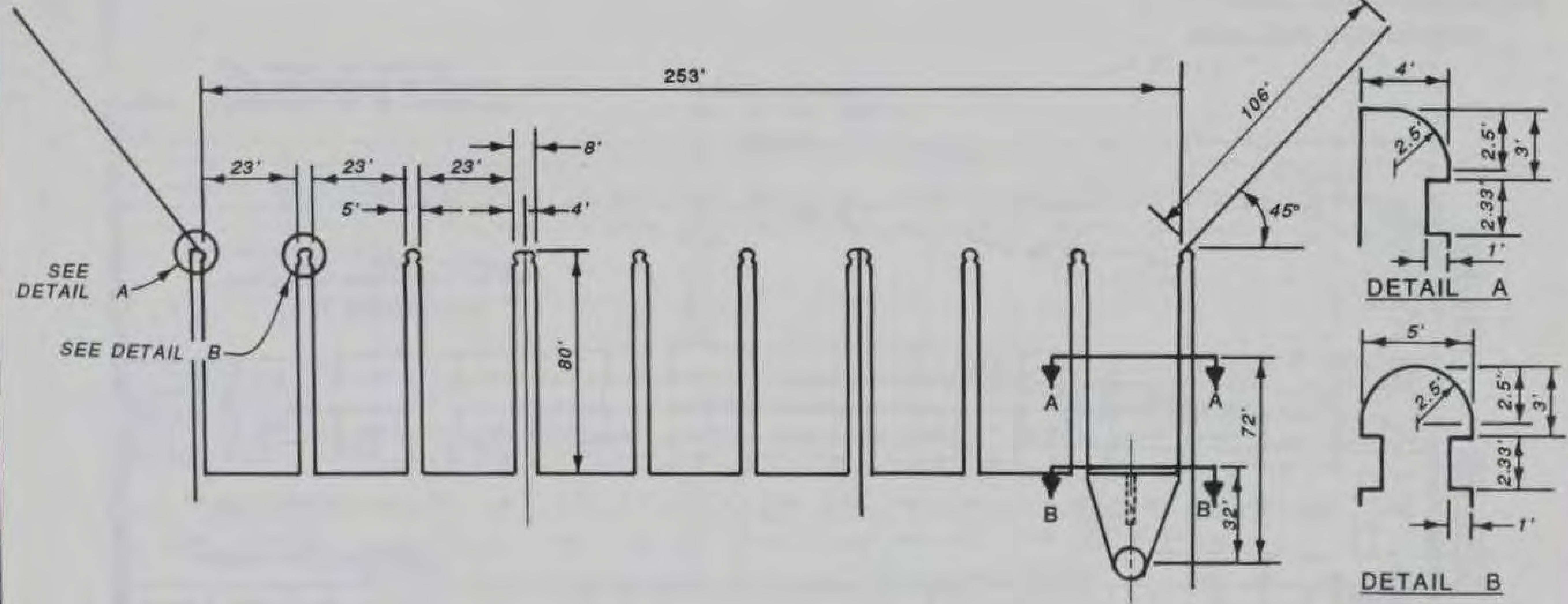
NOTE: SYMBOLS ON PLOT INDICATE STAGE OF DEVELOPMENT

STAGE OF VORTEX DEVELOPMENT IN BAY 4
DISCHARGE VERSUS
WATER-SURFACE ELEVATION
10,000-CFS-CAPACITY
PUMPING STATION
TYPE 8 SUMP
TYPE 3 APPROACH
TYPE 2 ABUTMENTS
DISCHARGE PER PUMP 1460 CFS
PUMPS 1-4 OPERATING

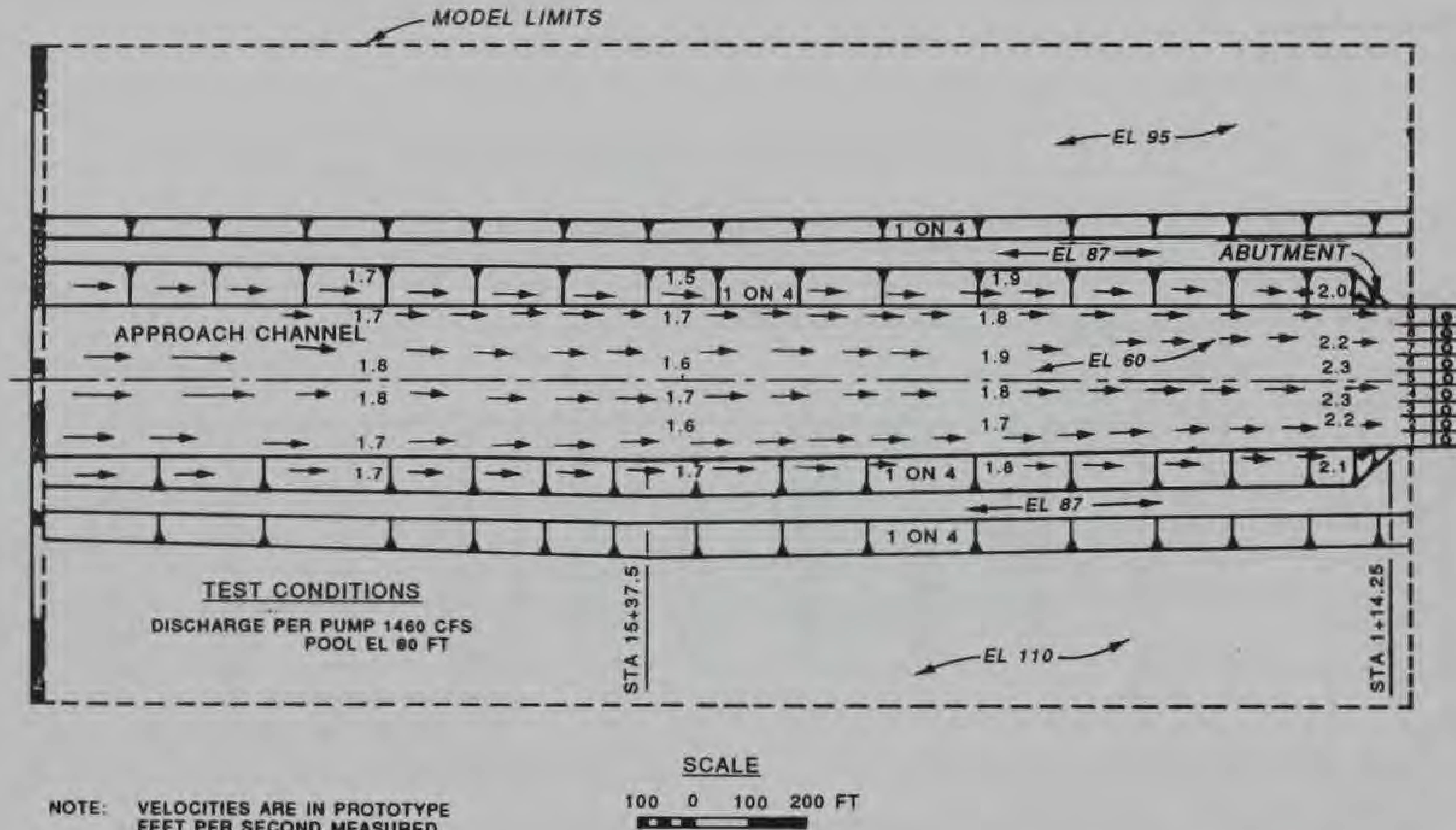
PLATE 76



TYPE 4 APPROACH CHANNEL
TYPE 8 SUMP - TYPE 2 ABUTMENTS



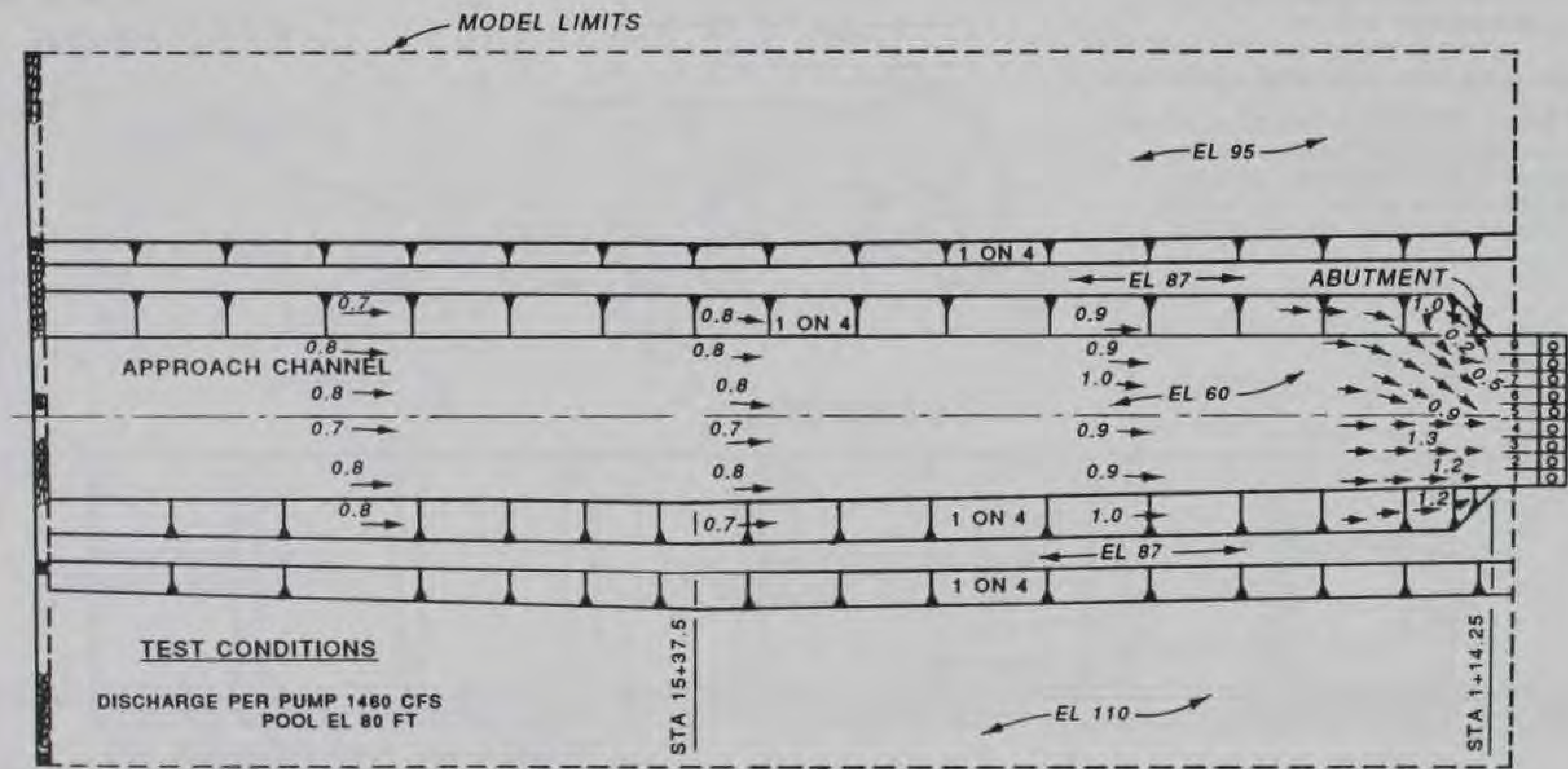
TYPE 2 ABUTMENTS
TYPE 8 SUMP



NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 2 FT ABOVE THE BOTTOM

BOTTOM VELOCITIES

TYPE 8 SUMP - TYPE 2 ABUTMENTS
TYPE 4 APPROACH CHANNEL
PUMPS OPERATING 1-9



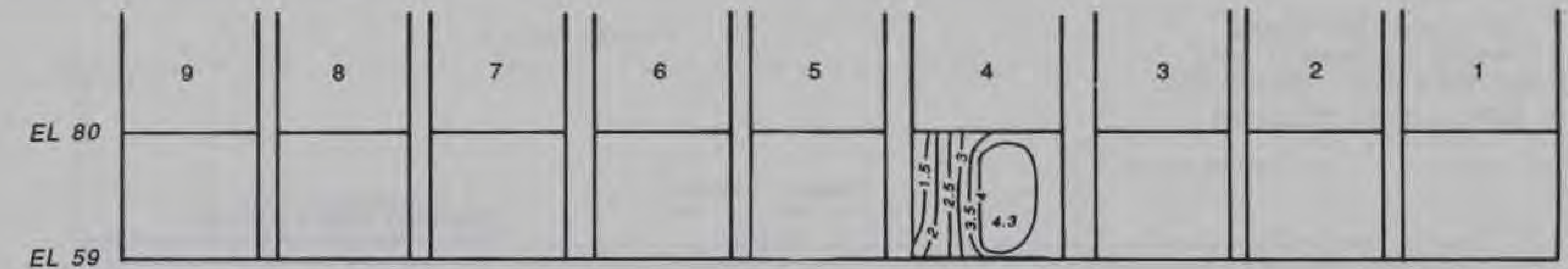
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND MEASURED 2 FT ABOVE THE BOTTOM

SCALE

100 0 100 200 FT

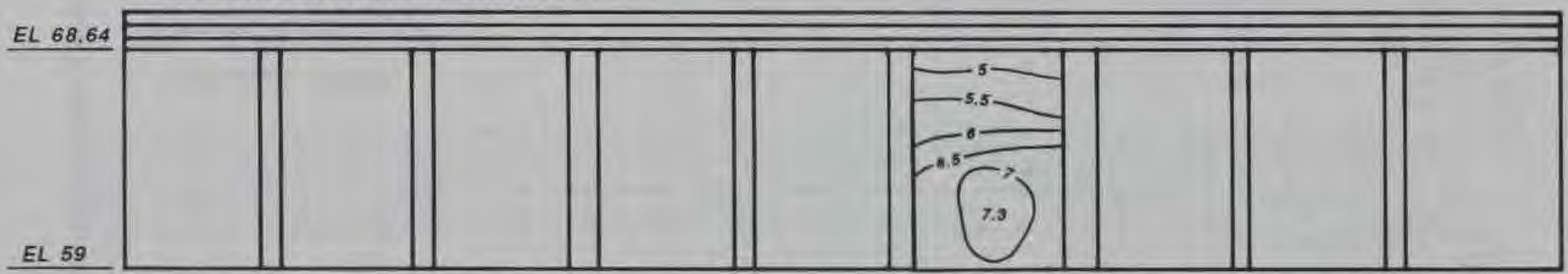
BOTTOM VELOCITIES

TYPE 8 SUMP - TYPE 2 ABUTMENTS
TYPE 4 APPROACH CHANNEL
PUMPS OPERATING 1-4

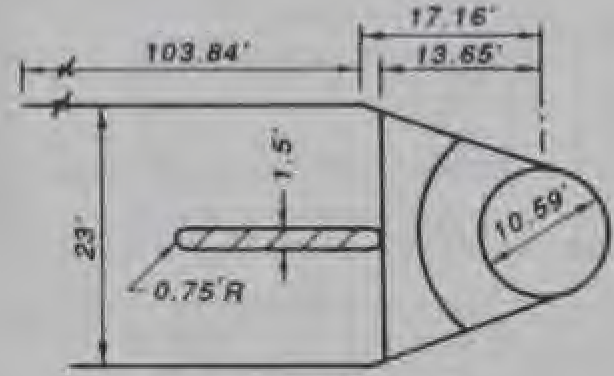


NOTE: ISOVELS ARE IN PROTOTYPE FEET PER SECOND LOOKING DOWNSTREAM

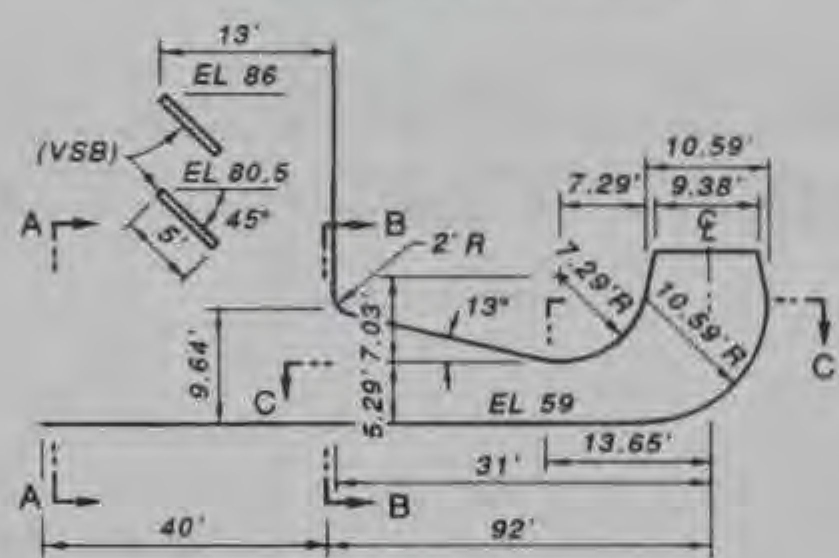
SECTION A-A



SECTION B-B



SECTION C-C

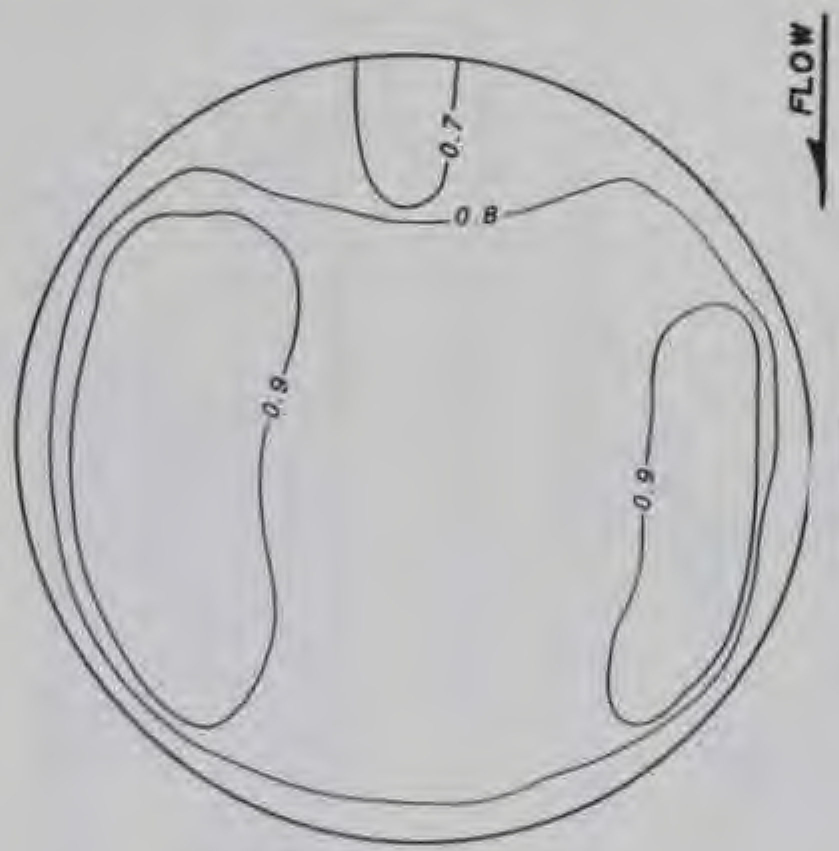


ELEVATION

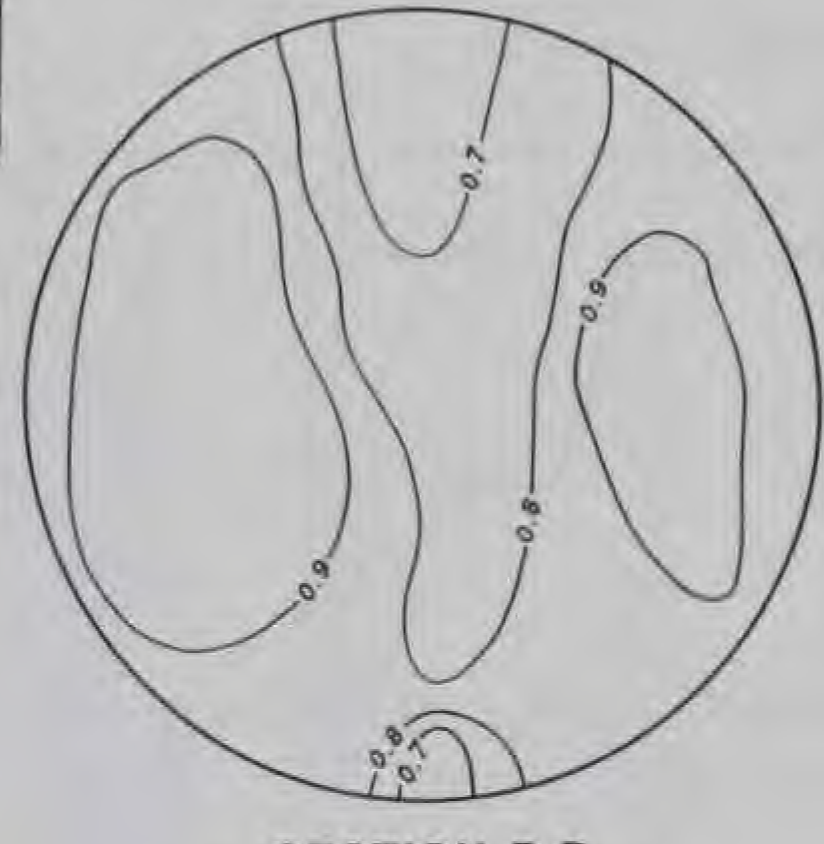
TEST CONDITIONS

POOL EL 80 FT
DISCHARGE PER PUMP 1460 CFS

ISOVELS
10,000-CFS-
CAPACITY PUMPING STATION
TYPE 4 APPROACH CHANNEL
TYPE 8 SUMP
TYPE 2 ABUTMENTS
PUMPS OPERATING 1-4



SECTION B-B
(PUMPS OPERATING 1-9)

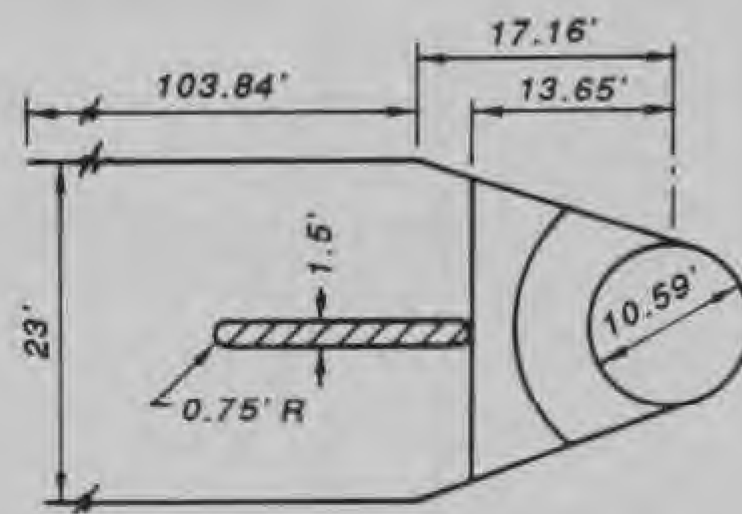


SECTION B-B
(PUMPS OPERATING 1-4)

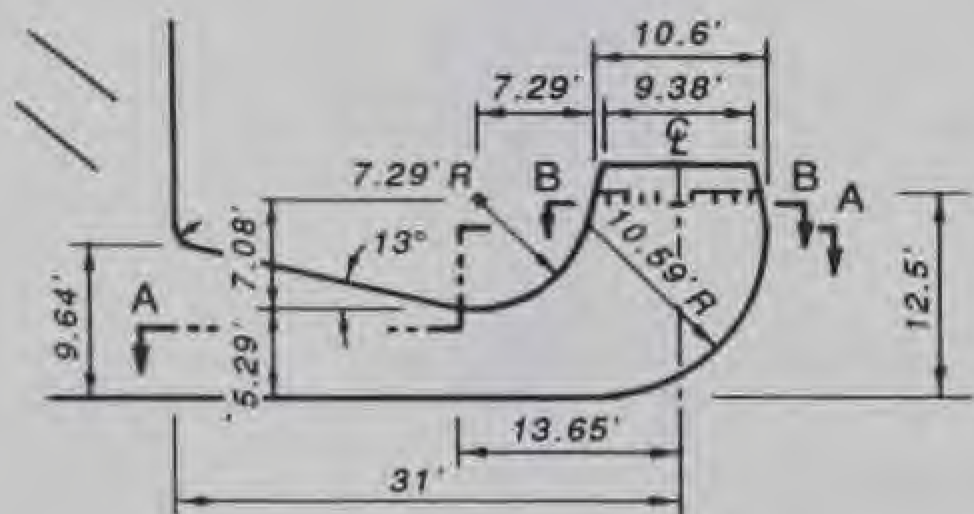
TEST CONDITIONS

WATER-SURFACE EL 80 FT
DISCHARGE PER PUMP 1460 CFS

NOTE: SOLID CONTOUR LINES INDICATE THE MINIMUM MEASURED INSTANTANEOUS VELOCITY DIVIDED BY THE THEORETICAL VELOCITY. DASHED CONTOUR LINES INDICATE NEGATIVE VELOCITY RATIO.

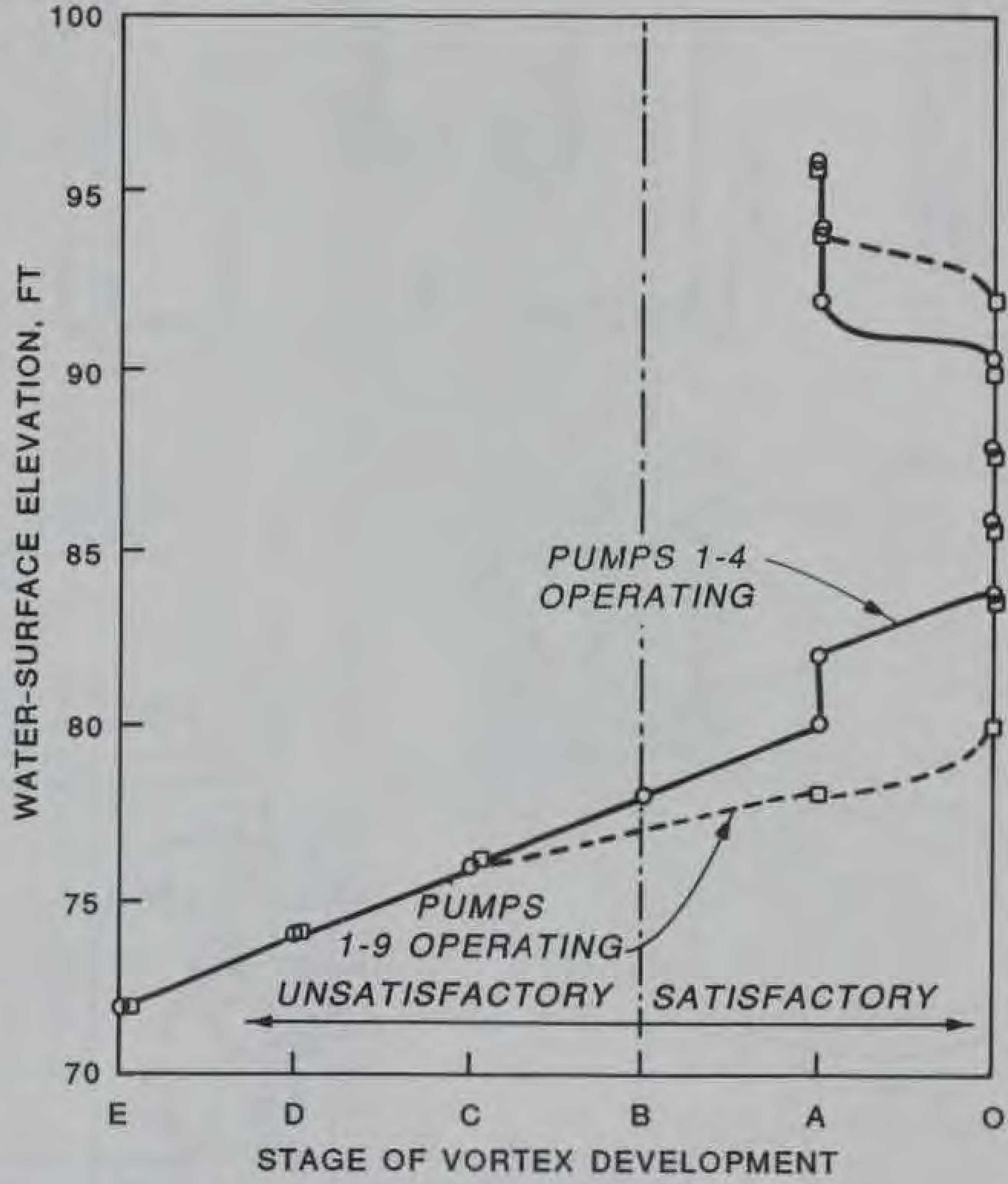


SECTION A-A

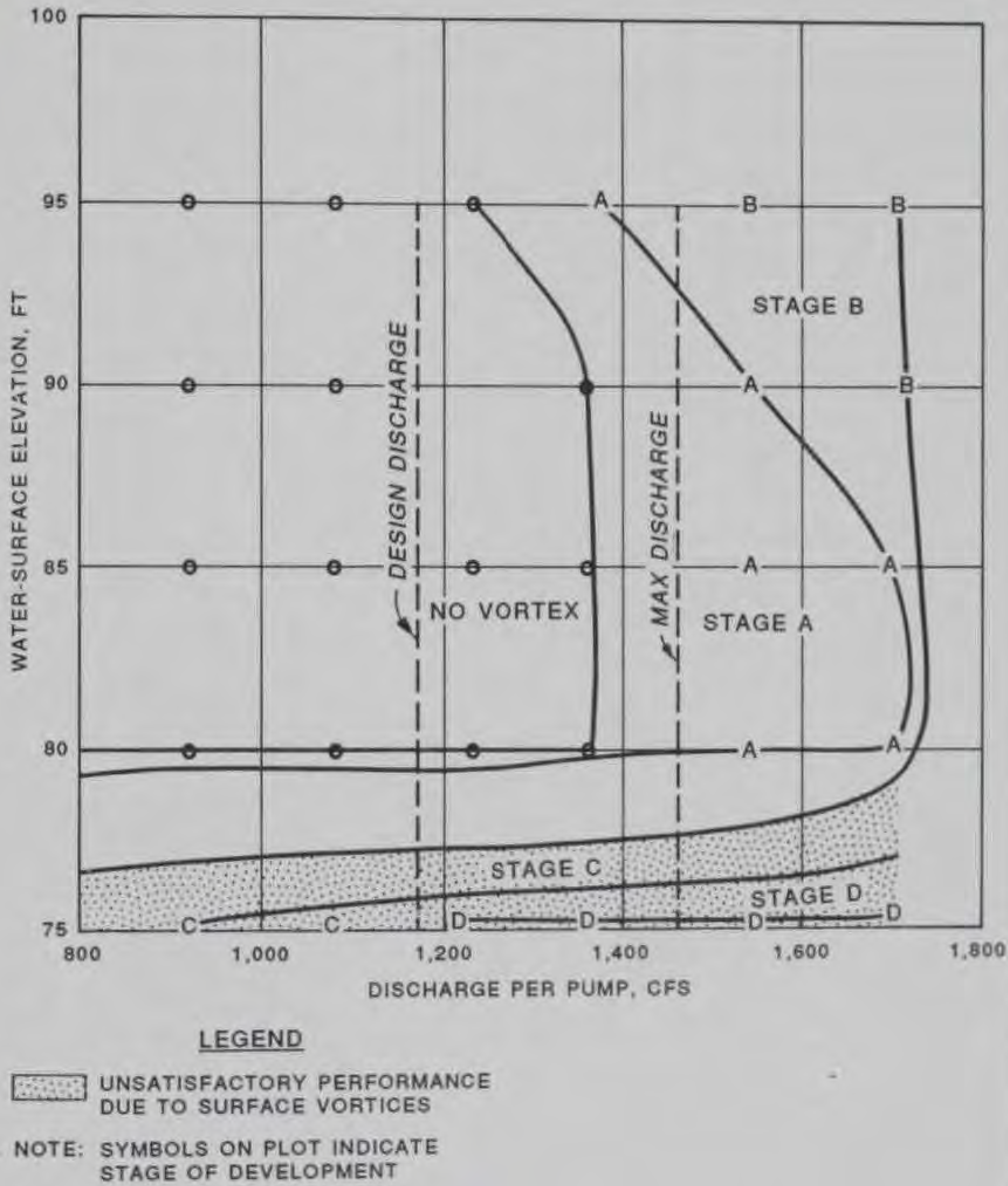


ELEVATION

LINES OF EQUAL VELOCITY RATIOS
10,000-CFS-CAPACITY PUMPING STATION
PUMP 4
TYPE 8 SUMP
TYPE 2 ABUTMENTS
TYPE 4 APPROACH CHANNEL



STAGE OF VORTEX DEVELOPMENT IN BAY 4
VERSUS WATER-SURFACE ELEVATION
10,000-CFS-CAPACITY PUMPING STATION
TYPE 8 SUMP
TYPE 4 APPROACH
TYPE 2 ABUTMENTS
DISCHARGE PER PUMP 1460 CFS



VORTEX DEVELOPMENT IN BAY 4
10,000-CFS-CAPACITY PUMPING STATION
TYPE 4 APPROACH
TYPE 2 ABUTMENTS
TYPE 8 SUMP
PUMPS OPERATING 1-4