TECHNICAL REPORT H-69-14

OUTLET WORKS FOR NEW HOPE RESERVOIR CAPE FEAR RIVER BASIN, NORTH CAROLINA

Hydraulic Model Investigation

by

E. S. Melsheimer

N. R. Oswalt

October 1969

Sponsored by

U. S. Army Engineer District
Savannah

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CORPS OF ENGINEERS
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FOREWORD

The model investigation reported herein was authorized by the Office, Chief of Engineers, in 3d indorsement dated 27 June 1966 to a letter from the U. S. Army Engineer District, Savannah, to U. S. Army Engineer District, Wilmington, and was conducted in the Hydraulics Division of the U. S. Army Engineer Waterways Experiment Station during the period September 1966 to June 1968.

During the course of the model investigation Messrs. W. J. Wall, J. B. Harward, and W. C. Lawson of the Savannah District visited the Waterways Experiment Station to discuss results of the tests and to correlate the results with design studies.

The model study was conducted under the general supervision of Mr. E. P. Fortson, Jr., Chief of the Hydraulics Division, and Mr. T. E. Murphy, Chief of the Structures Branch, and under the direct supervision of Mr. J. L. Grace, Jr., Chief of the Spillways and Conduits Section. The engineer in immediate charge of the model was Mr. N. R. Oswalt. This report was prepared by Messrs. E. S. Melsheimer and Oswalt.

Directors of the Waterways Experiment Station during the testing program and preparation and publication of this report were COL John R. Oswalt, Jr., CE, and COL Levi A. Brown, CE. Technical Directors were Messrs. J. B. Tiffany and F. R. Brown.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles	1.609344	kilometers
pounds	0.45359237	kilograms
feet per second	0.3048	meters per second
cubic feet per second	0.0283168	cubic meters per second

SUMMARY

Model investigation of the outlet works for the New Hope Reservoir was initially concerned with verification and improvement of the hydraulic design of the intake structure, conduit, and stilling basin. Subsequent tests involved observations of the effectiveness of the multilevel intakes in providing selective withdrawal of flow from the epilimnion or upper stratum of a stratified reservoir. The study was conducted in a 1:20-scale model of the outlet works which reproduced a portion of the approach area, the intake structure, the outlet conduit, the hydraulic-jump type stilling basin, and approximately 800 ft of exit channel.

The proposed intake structure provided effective regulation of flood-control releases as well as those which are desired to provide quality water downstream during both summer and winter. However, certain operational procedures are necessary to prevent dangerous subatmospheric pressures in the throat section of the water-quality system. Flow conditions in the original conduit intakes, throughout the flood-control facilities, and downstream to the conduit outlet were satisfactory with pressure conditions remaining positive for all discharges with little or no fluctuation. There was no tendency for structural vibration with either flood-control or water-quality flows.

Performance of the original design stilling basin was unacceptable as unstable hydraulic action and eddy formation resulted in very turbulent basin conditions with little or no energy dissipation. Raising the elevation of the basin and lengthening and modifying the transition section (types 2 and 3 basins) resulted in adequate, if not ideal, performance. Single gate operation produced unbalanced flow in the basin; however, as single gate operation is rarely necessary, the types 2 and 3 basins are considered to be acceptable for prototype construction. The elevations of the original basin training walls were sufficient to prevent overtopping.

It was determined that riprap protection is required on both banks of the exit channel.

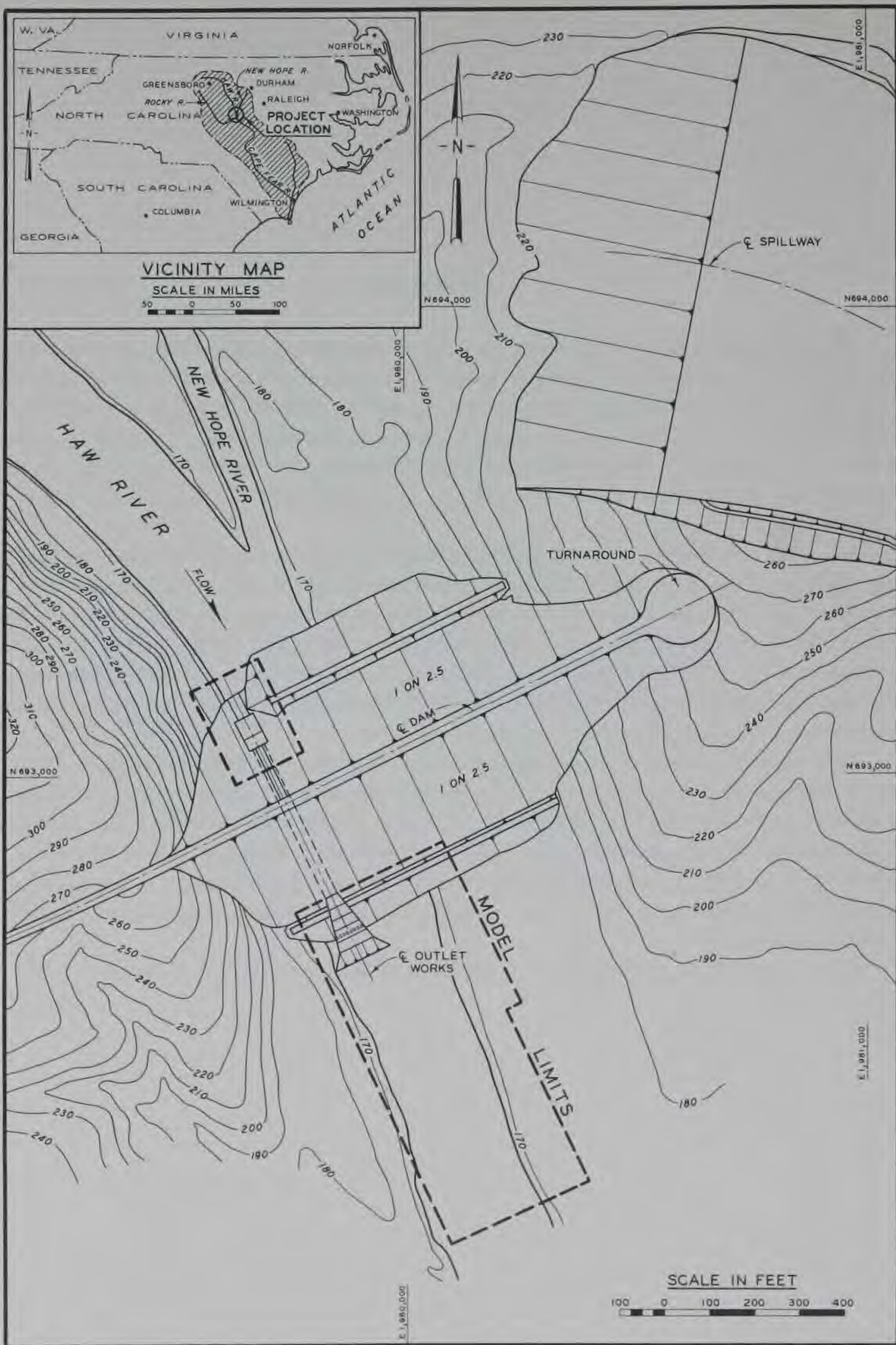

Fig. 1. Location map

OUTLET WORKS FOR NEW HOPE RESERVOIR
CAPE FEAR RIVER BASIN, NORTH CAROLINA

Hydraulic Model Investigation

PART I: INTRODUCTION

THE PROTOTYPE

1. New Hope Reservoir, the largest of three principal reservoirs proposed for construction in the Cape Fear River Basin, is located on the Haw River about 4.2 miles* above its mouth and about 0.3 mile below the mouth of the New Hope River in North Carolina (fig. 1). The overall plan of development would afford a high degree of flood control, water supply for municipal and industrial use, water for additional irrigation, increased flow for water-quality control in conjunction with sewage treatment, and water areas for recreation, fish, and wildlife.

2. The recommended project plan for the reservoir includes the construction of an earth dam, an uncontrolled and unpaved chute spillway, a controlled outlet works, and saddle dikes in the east abutment (fig. 1).

3. Reservoir outflow will be regulated by outlet works consisting of a gated intake tower with two conduit intakes at the base of the structure (el 150**) and eight multilevel intakes at elevations ranging from 179 to 209, emergency and service gates, a rectangular to circular transition section, a 19-ft-diam conduit, and a stilling basin. The outlet works, aligned normal to the axis of the dam, will be located in the present channel of the Haw River, obviating the need for approach and discharge channels. A general plan of the outlet works as originally proposed for model study is shown in plate 1.

4. The outlet works intake recommended for prototype construction permits selective withdrawal from the reservoir ranging from el 150 to 217 by use of two 9- by 19-ft (throat area) flood-control conduit intakes (invert el 150) and two 6- by 6-ft and six 8- by 8-ft multilevel intakes (plate 2). The service gates located downstream of the emergency gates (plate 1) will be used to regulate releases through either the conduit intakes or the multilevel intakes. Selective withdrawals through the multilevel intakes will be discharged into wet wells and through passages provided in the roofs of the conduit intakes between the emergency and service gates. The emergency gates will be closed during selective withdrawal operation.

NEED FOR AND PURPOSE OF MODEL ANALYSIS

5. As adequate guides or background materials were not available for design of the New Hope outlet works, engineers of both the Savannah District and the U. S. Army Engineer Waterways Experiment Station considered a model study necessary to determine the performance of the subject structure in releasing both flood-control and selective withdrawals of quality water downstream. Information desired and obtained required study of overall performance of both the flood-control and selective withdrawal facilities of the outlet works, investigation of flow instabilities and vibration tendencies, pressures, discharge capacities, flow characteristics and pressure conditions in the area of the service gates, stilling basin performance, and protective stone requirements for the side slopes of the exit channel.

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* A table of factors for converting British units of measurement to metric units is presented on page vii.

** All elevations (el) cited herein are in feet referred to mean sea level.

PART II: THE MODEL

DESCRIPTION

6. The model, constructed to an undistorted scale of 1:20, reproduced sufficient area of the reservoir (fig. 2) to obtain natural conditions of approach flow at the intake, the intake structure, the circular conduit, the stilling basin, and 800 ft of the exit channel. The intake structure and conduit were constructed of transparent plastic (fig. 3). The stilling basin chute was fabricated of sheet metal, the sidewalls, basin, and basin elements were made of wood, and the exit channel was molded in cement mortar (fig. 4).

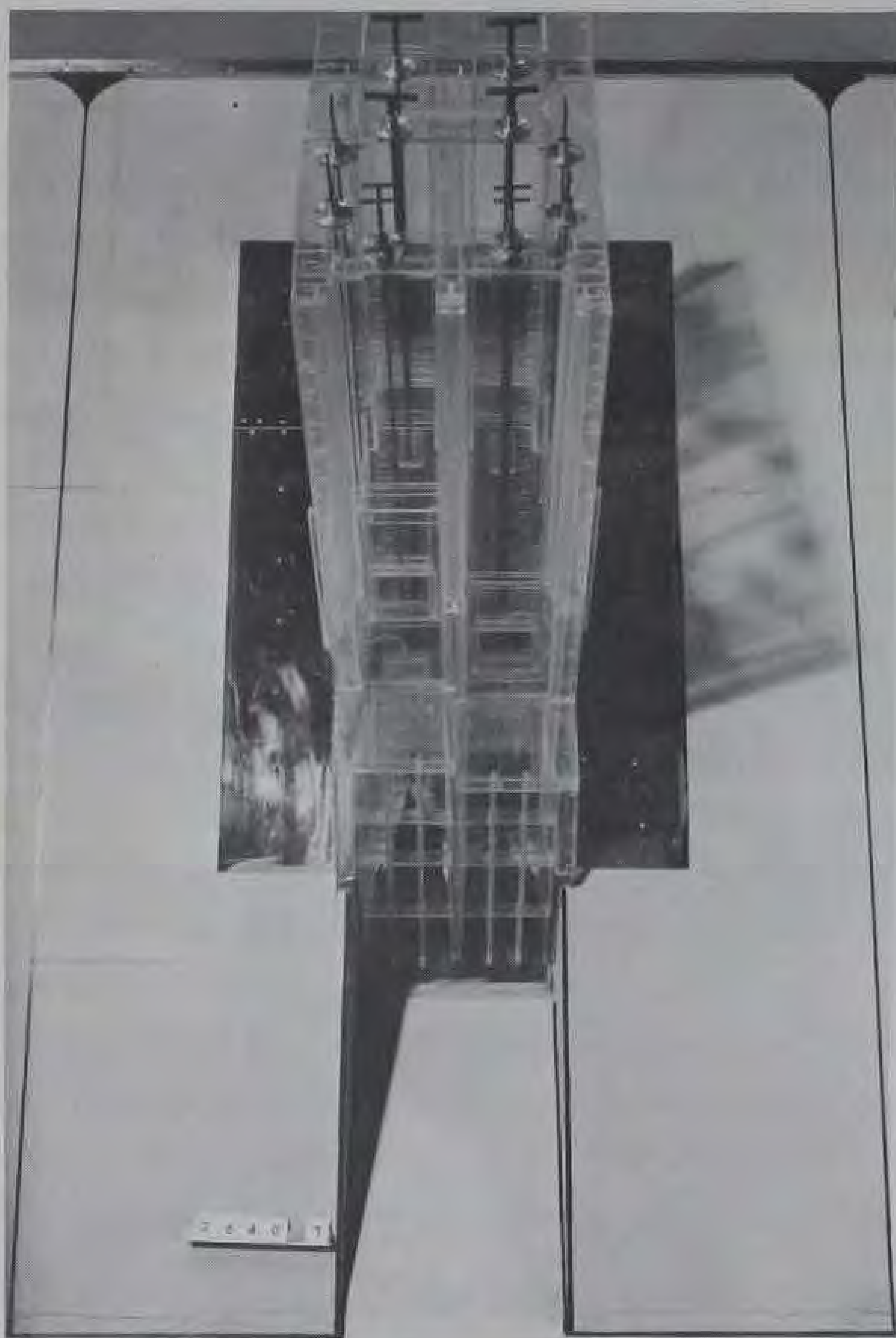


Fig. 2. Reservoir area and intake

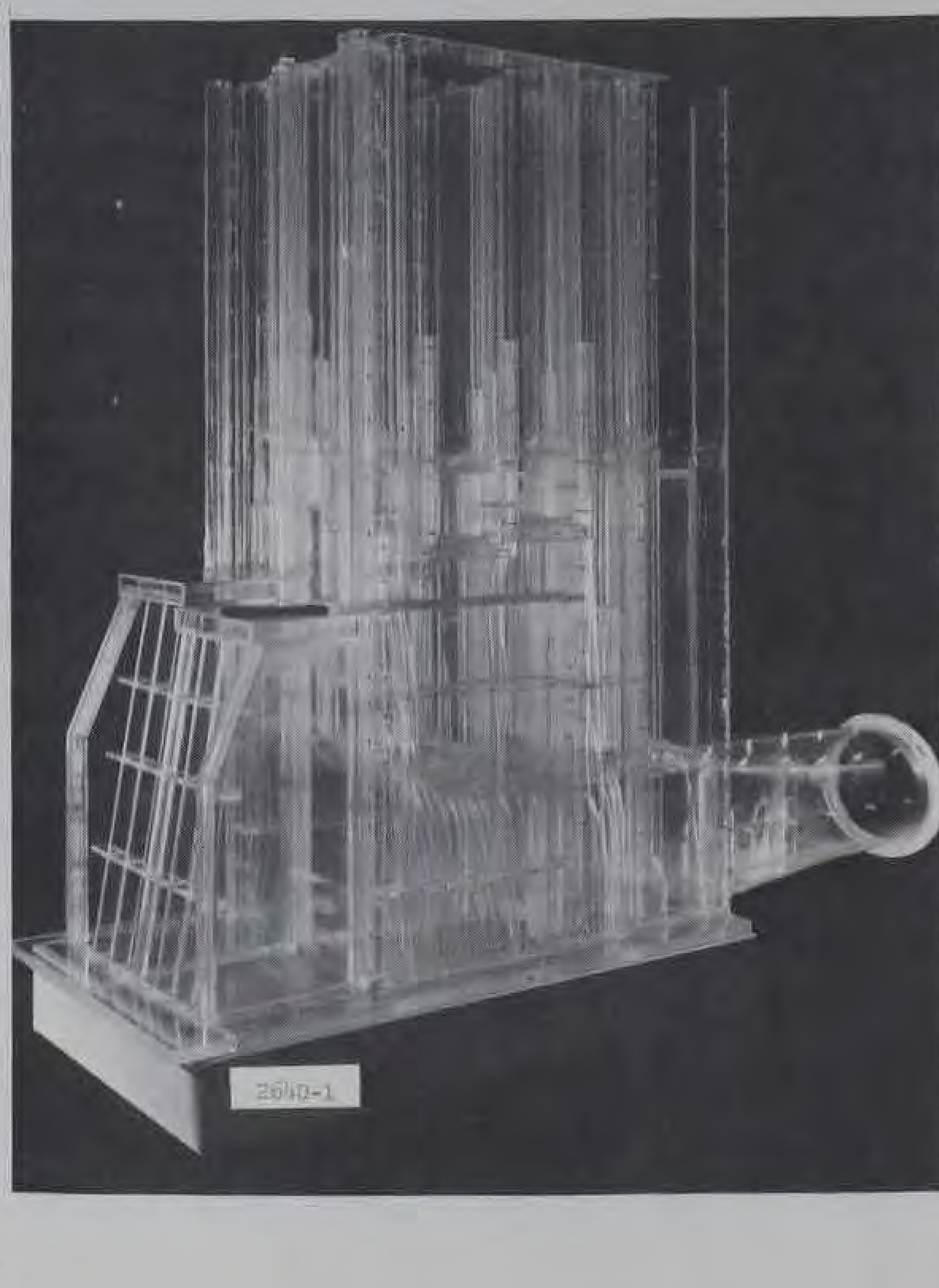


Fig. 3. Original design intake structure

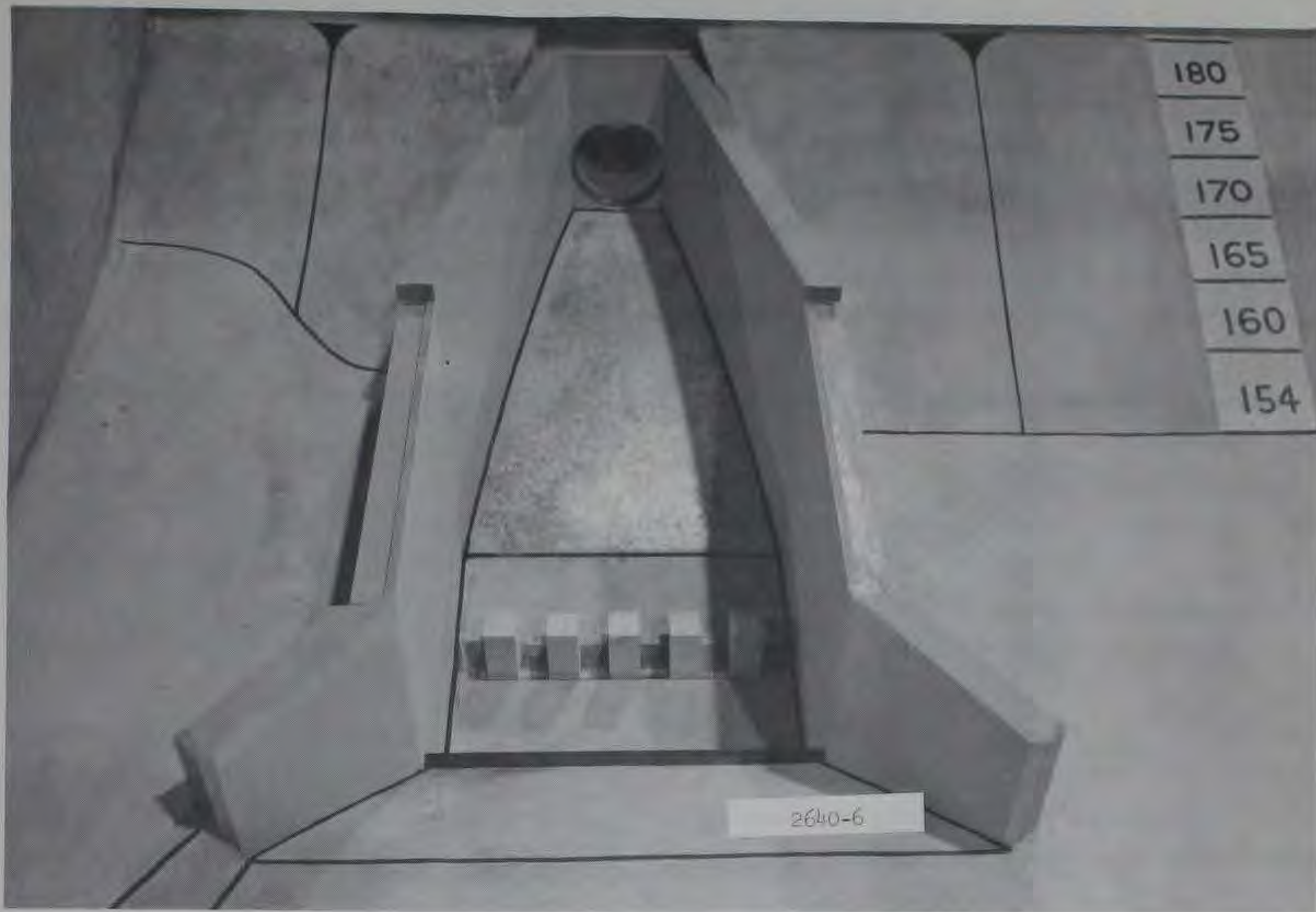


Fig. 4. Original design stilling basin

7. Water used in the operation of the model was supplied by a recirculating system and discharges were measured by means of venturi meters. Water-surface elevations were measured by means of point gages and velocities were measured with a pitot tube. Piezometers were installed throughout the intake structure and conduit for measurement of pressures. Salt water (dyed red) with a density approximately 0.002 g/cc greater than that of the upper layer of fresh water was used to simulate the denser, colder layer of water below the thermocline of the prototype reservoir. Graded limestone was used to simulate prototype stone for investigating riprap requirements for the exit channel side slopes.

DESIGN CONSIDERATIONS

8. In the design of the model, geometric similitude was preserved between model and prototype by means of an undistorted scale ratio. The accepted equations of hydraulic similitude, based upon the Froudian relation, were used to express the mathematical relation between the dimensional and hydraulic quantities of the model and the prototype.

9. To make a valid study of flow conditions in the outlet works required that the prototype hydraulic grade line be simulated accurately in the model. It is well known that it is not possible to satisfy the requirements of both the Reynolds and Froude criteria for complete similitude by using water in the model if water is the fluid in the prototype. Since hydraulic similitude between the model and prototype was based on Froudian relations, the Reynolds number of the design flow (15,000 cfs) in the

model (11.2×10^5) was lower than that of the prototype (8.3×10^7), with the result that the resistance coefficient of the model (f = 0.127) was disproportionally higher than that of the prototype (f = 0.0085). Therefore, the excess losses in the model conduit were compensated for by constructing only a 10.6-ft (212.0 ft prototype) length of model conduit. This length is based on the relative loss of energy in the model and prototype conduits rather than the theoretical length of 16.5 ft (330.0 ft prototype) based on geometry only.

SCALE RELATIONS

10. General relations for transference of model data to prototype equivalents are presented in the following tabulation.

Dimension	Ratio	Scale Relation
Length	L_r	1:20
Time	$T_r = L_r^{1/2}$	1:4.472
Velocity	$V_r = L_r^{1/2}$	1:4.472
Discharge	$Q_r = L_r^{5/2}$	1:1788
Pressure	$P_r = L_r$	1:20
Roughness (Manning's n)	$N_r = L_r^{1/6}$	1:1.648

11. Quantitative transfer of model data to prototype equivalents by the scale relations listed above was considered reliable except for pressures in the cavitation range in the prototype. Obviously, it is impossible for negative pressures in the prototype to be less than 1 atm (about -34 ft of water). However, in the model, negative pressures equivalent to prototype pressures less than 1 atm are possible. Thus, negative pressures less than 1 atm recorded in model results indicate zones of certain cavitation in the prototype.

PART III: TESTS AND RESULTS

12. Model tests involved the investigation of the overall performance of the outlet works, including discharge characteristics of both the flood-control and selective withdrawal facilities, pressure and flow conditions throughout the structure, the effectiveness of the multilevel intakes in selectively withdrawing water from only the epilimnion of the stratified reservoir, performance of the stilling basin, and determination of protective stone size requirements for exit channel side slopes. Test results pertinent to each component of the structure are presented in order of its position, beginning with the intake structure and proceeding downstream.

MULTILEVEL INTAKE STRUCTURE

Description

13. Details of the multilevel intake structure as tested in the model are shown in plate 2. Although the need for structural changes was not indicated based on these tests, certain operational limitations will be required to prevent the occurrence of cavitation in the openings within the roofs of the conduit intakes upstream of the service gates and withdrawal of hypolimnion water through the multilevel intakes.

Discharge Capacity

14. Discharge characteristics of the flood-control facilities with a single service gate at full and partial openings and with both service gates fully open are shown in plates 3 and 4, respectively. For partial gate openings, the data were obtained with free flow conditions at the outlet portal. For full gate opening conditions, discharge data were obtained for minimum and normal tailwater conditions (both free and submerged flow at the outlet portal). The model indicated the capacity of the structure, at the flood-control pool (el 240) and with both service gates fully open, to be about 18,000 cfs. At the same pool elevation, a discharge of about 10,500 cfs was passed through a single, fully open service gate. The equations presented in plates 3 and 4 are empirical and the best fit of data by the method of least squares. Discharge coefficients for the usual form of the orifice equation are also shown in these plates. Pool elevations resulting from partial openings of a service gate with a constant flood-control flow of 3000 cfs are shown in plate 5.

15. Discharge characteristics of a partially opened service gate with flow through three 8- by 8-ft multilevel intakes of the selective withdrawal facilities are presented in plates 6 and 7. The pressure data, paragraph 19 and plate 10, indicate the existence of negative pressures in the approximately 6- by 9-ft throat section in the roof of the flood-control facilities upstream of the service gate and the need, as expected, to limit service gate openings to a maximum of 6 to 6.5 ft. Restricting the service gate opening to a maximum of 6.5 ft will maintain control by the service gate and prevent the possibility of any instability in flow due to control shifting from the service gate to the throat section.

16. Discharge characteristics of a single 8- by 8-ft multilevel intake are furnished in the following tabulation. Free orifice flow is defined as that condition when the water level inside the tower is equal to or less than the elevation of the top of the multilevel opening. The head on the center of the orifice was used for determination of the free flow discharge coefficient in the usual equation, $Q = C_f A \sqrt{2gH}$. The value of C_f indicated by the data ranged from 0.80 to 0.84 with an average of 0.82. The head differential ΔH between the elevation of the upper pool and the water surface within the tower was used for computation of the submerged orifice flow discharge coefficient in the equation $Q = C_s A \sqrt{2g\Delta H}$. The value of C_s indicated by the data ranged from 0.895 to 0.935 with an average of 0.915.

Free Orifice Flow		Submerged Orifice Flow	
Discharge, cfs	Head on ℄ Orifice, ft	Discharge, cfs	Head Differential, ft
1200	7.7	1200	6.3
1200	8.4	1200	6.8
1200	8.6	1400	8.5
1600	13.5	1400	8.9
2000	21.3	1600	11.0
2000	23.5	2500	26.5
2400	30.6		
2500	36.5		
2700	38.1		

17. Discharge characteristics of a single multilevel intake partially filled with flow such that the opening functions as an unsubmerged weir are tabulated below and satisfied by the equation $Q = 3.5LH^{3/2}$, where L is the length of weir (8 ft) and H is the head on the invert of the opening.

Free Weir Flow	
Discharge, cfs	Head on Invert, ft
300	4.7
400	6.0
500	6.3
500	7.1
600	7.5
600	8.3
700	8.6

Entrance Head Loss

18. Entrance loss coefficients applicable to the flood-control facilities of the intake structure were computed from the calibration data by dividing the head loss by the velocity head within the conduit. The head loss is defined as the difference between the elevations of the upper pool and the energy gradient at the center line of the intake. The elevation of the energy gradient was determined by adding the velocity head to the hydraulic gradient measured between piezometers 110 and 115 (area of uniform flow) and extending the gradient upstream to the center of the intake structure (sta 4+19). Values of the entrance loss coefficient obtained are:

Discharge, cfs	Pool El	Energy Gradient El	Head Loss, H_L Feet of Water	Entrance Loss Coefficient*
12,000	197.4	193.1	4.3	0.147
13,000	204.0	199.3	4.7	0.144
14,000	210.5	205.5	5.0	0.131
15,000	217.2	211.5	5.7	0.132
16,000	224.7	218.6	6.1	0.124
17,900	240.2	232.9	7.3	0.118
			Avg	0.132

* Entrance loss coefficient $E_L = \frac{H_L}{V^2/2g}$; where H_L is head loss in feet and $V^2/2g$ is velocity head within the conduit.

The average entrance loss coefficient of 0.132 would be an accumulation of losses attributed mainly to the trash rack, gate slots, transition constriction, and friction.

Pressures

19. Pressures observed throughout the flood-control facilities were positive for flows ranging from 5000 to 18,000 cfs, pool el 240, and full and partial openings of both service gates (tables 1-4). Piezometer locations are shown in plates 8 and 9. Observation of flow through the water-quality passages revealed negative pressures in the throat section upstream of the service gate. In this area, pressures in the range of -10 to -50 ft of water were recorded at service gate openings of 6 to 14 ft and pool el 211 to 220 (piezometer 20, plate 10). Obviously, it is impossible for negative pressures in the prototype to be less than 1 atm (about -34 ft of water). However, negative pressures in the model equivalent to prototype pressures of less than 1 atm are possible, and model pressures of this magnitude indicate zones of certain cavitation in the prototype. It is the opinion of the Waterways Experiment Station that water-quality withdrawal operation should be limited to those conditions which will result in pressures no lower than -15 ft of water, as average pressures less than this indicate probable cavitation. To satisfy this criterion, the data (plate 10) indicate that, with pool el 212 to 216 and flow through the multilevel intakes, the service gate opening should not exceed 6 to 6.5 ft. This will result in maximum discharges through a single service gate of approximately 2100 and 2200 cfs at pool el 212 and 216, respectively. Service gate openings of 8 to 14 ft will result in serious negative pressures and certain cavitation in the prototype. However, with the service gate fully opened, the throat section becomes vented and a discharge of 2700 cfs can be passed at pool el 216 without the occurrence of negative pressures in the throat section.

SELECTIVE WITHDRAWAL TESTS

20. Investigation of the effectiveness of the multilevel intakes in selectively withdrawing water from the upper and less dense layer of a stratified reservoir was conducted in the model headbay using fresh and salt water. Salt water (dyed red) with a density approximately 0.002 g/cc greater than that of the upper layer of fresh water was used to simulate the denser, colder layer of water below the thermocline of the prototype reservoir. Flow conditions resulting from total releases ranging from 300 to 2700 cfs through various multilevel intakes were observed with the interface located at el 176 and 196 (40 and 20 ft below the normal pool el 216). All flows were controlled by the service gates as rated in plate 6.

21. Selective withdrawal tests indicated that the proposed outlet structure will provide effective regulation for control of both minimum and average water-quality discharges (300 and 800 cfs summer; 300 and 2400 cfs winter). For single intake operation with the thermocline at el 176, flows up to 900 cfs could be passed through each of the front intakes at upper pool el 216 without drawing visible or measurable amounts of the denser saline water below the interface. The average winter flow of 2400 cfs can be released without withdrawing from the hypolimnion, provided intakes on both sides of the structure are utilized and the thermocline is 40 ft below the anticipated pool el 216. Operational releases of 2700 cfs (maximum desired for water-quality release) through only one side of the structure will withdraw quantities as great as 10 and 33 percent from the hypolimnion with the thermocline located 40 and 20 ft below the surface of the upper pool. Velocity distributions indicated by dye particles suggest that the core of the zone of withdrawal coincides essentially with the horizontal axis of the opening and that the majority of the flow is withdrawn from the level of this axis. Tests of a generalized nature to determine the limits of and the velocity distribution within the zone of withdrawal in a randomly stratified

reservoir upstream of an orifice simulating a single 8- by 8-ft multilevel intake of the New Hope structure to scales of 1:50 and 1:100 were conducted in separate facilities and will be discussed in a separate report. Successful means were developed for prediction of the above, provided either the density or temperature gradient within the reservoir is known. Then with known or assumed gradients of pertinent water-quality parameters, the value of each parameter representative of the total release can be estimated by means of weighted averages. As mentioned in paragraph 19, the service gate opening should never exceed 6.5 ft during water-quality operations in order to prevent severe negative pressures in the throat section of the water-quality passage (plate 10). Visual observations also revealed that the geometry of the structure and adjacent topography have a considerable effect on the pattern of flow upstream of the various intakes. Intakes located on the upstream face of the structure were approximately twice as effective in withdrawing water from above the interface (epilimnion) as those located on the sides.

STILLING BASIN

Type 1 (Original) Basin

22. The stilling basin as originally designed consisted of a parabolic drop 76.5 ft long beginning at the outlet portal, a horizontal apron 63.5 ft long and 57.25 ft wide with 10-ft-high by 5-ft-wide baffle piers, a vertical-faced end sill, and 45-deg wing walls (fig. 4, plate 1). The parabolic drop and sidewalls flared uniformly in width from 19 to 57.25 ft over the 76.5-ft length. The inverts of the conduit outlet portal and the stilling basin apron were located at el 148 and 126, respectively. Vertical wing walls flared 45 deg from the downstream end of the parallel training walls for 15 ft. The side slopes of the exit channel downstream from the basin were to be lined with protective stone.

23. Tests with the original stilling basin indicated considerable need for improvement as unstable jump action and eddy formation existed in the stilling basin for all flows observed in the model (photograph 1). Two photographs for each flow are provided to indicate the pulsating condition of basin action.

Type 2 Basin

24. The type 2 stilling basin, designed to provide satisfactory performance for discharges up to 18,000 cfs, was of the hydraulic-jump type with an overall length of 229 ft (plate 11). The basin consisted of a 104-ft-long horizontal approach apron (el 148) with a curved transition section (284-ft radius), bottom quadrant fillets, and flared (1 on 7) sidewalls. With a less elaborate transition section or greater flare of the sidewalls, unbalanced flow occurred, eddies formed in the basin, and flow passed through the basin along one of the sidewalls with little energy dissipation. Intermediate discharges (5000 to 10,000 cfs) were particularly susceptible to this action at the higher tailwater elevations. The horizontal apron, 75 ft long (el 143), was surmounted by a row of 10-ft-high baffle piers and a 5-ft-high end sill. Expected tailwater (plate 12) over the apron provides about 98 percent of the theoretical depth (D_2) required for the formation of a hydraulic jump at the design discharge of 15,000 cfs. This basin, with a length of 2.5 D_2, is as short as considered feasible. A forced jump was formed in the basin with the apron raised to el 148 and severe wave action occurred in the exit channel. Therefore, it was decided that the apron should be placed at el 143.

25. Tests involving observations of basin performance and velocity impinging on various sizes and positions of baffle piers revealed that, while energy dissipation was improved as the baffle piers were moved closer to the toe of the trajectory section, velocities impinging on the face of the baffles increased, reaching a maximum of 54 fps with the baffles at the toe of the trajectory. With the type 2 basin,

velocities against the face of baffle piers were in the range of 45 fps (plate 13). Frequent acceptance of velocities against baffle piers greater than 45 fps is common where the design discharge occurs only rarely; however, because of the anticipated frequency and duration of the design discharge at New Hope, it is recommended that this magnitude not be exceeded. Flow conditions in the type 2 basin for discharges of 5000 to 18,000 cfs are shown in photograph 2; flow characteristics for a discharge of 18,000 cfs are presented in plate 13. As no return flow over the stilling basin training walls should be permitted, the height of the walls should be predicated on the maximum tailwater elevation for conduit flow (el 175). Wing walls downstream of the end sill are not considered necessary.

26. The type 2 basin did not perform in the desired manner when flow was passed through a single control gate. This caused an unequal distribution of flow at the conduit exit portal and resulted in unbalanced flow in the basin with little or no energy dissipation. Satisfactory single gate operation would require a transition section and approach apron several times longer than that proposed. As single gate operation will rarely occur in the prototype, a longer transition section is not considered justified.

Type 3 Basin

27. Prior to completion of the model study, the Office, Chief of Engineers, suggested an oblong-shaped conduit rather than a round conduit for the New Hope outlet. As the stilling basin recommended (type 2) for the circular conduit had its inadequacies, verification of basin action with the new conduit shape was undertaken.

28. The type 3 stilling basin was similar to the type 2 basin with the exception that the approach apron was about 8 ft longer (see plate 11 and fig. 5). Flow conditions in the type 3 basin for discharges up to 18,000 cfs are shown in photographs 3-5. Tailwater elevations for each discharge ranged from expected levels to el 175, that resulting from a total discharge of 18,000 cfs. Observations indicated that basin performance was as satisfactory as that observed in the type 2 basin with the circular conduit. As with the type 2 conduit, single gate operation resulted in unbalanced basin flow, particularly at the lower flows and higher tailwater elevations (photographs 3a, b, c), with little energy dissipation in the basin. However, with both service gates in operation, balanced flow returned to the basin and satisfactory energy dissipation obtained (photograph 3d).

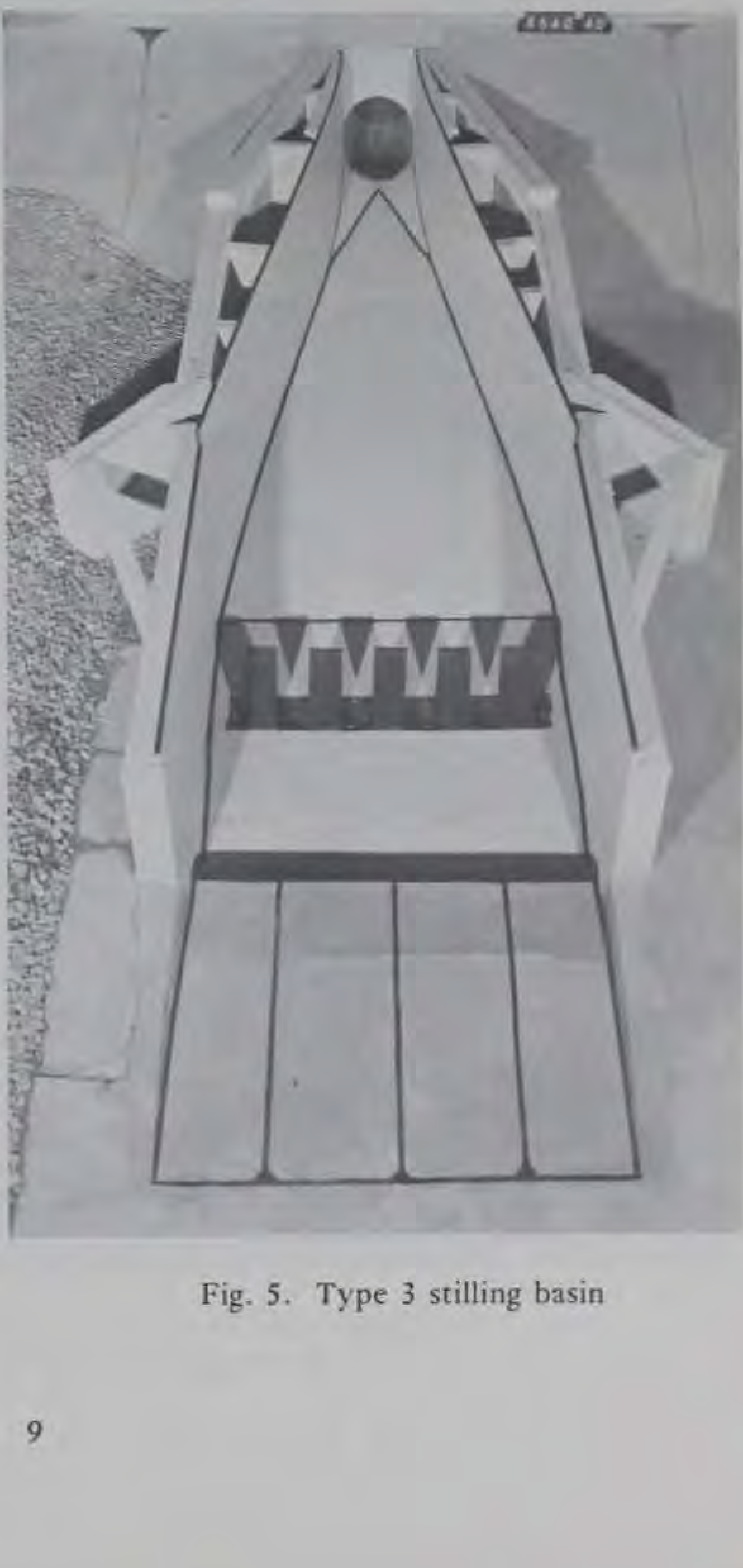


Fig. 5. Type 3 stilling basin

29. Water-surface profiles and velocities for discharges of 5000, 15,000, and 18,000 cfs are shown in plate 14. Velocity distributions were similar to those obtained below the circular

a. Prior to test

b. Riprap displacement along right bank after test of 1-hr duration, discharge 15,000-18,000 cfs (normal tailwater)

Fig. 6. Scour test in exit area downstream of stilling basin

conduit and type 2 basin (plate 13). In summarizing, it is believed that the type 3 basin in conjunction with the oblong conduit performed equally as well as or better than the type 2 basin and the circular conduit.

PROTECTIVE STONE INVESTIGATION

30. Tests were conducted to determine stone-size requirements for protection of the exit channel side slopes. Initial tests of stone placed on the right side slope (fig. 6a), maximum size pieces of 18-in. diameter weighing 265 lb, indicated satisfactory protection except for a 321-ft reach downstream of the stilling basin, sta 2+29 to 5+50 (fig. 6b). Further testing in the 321-ft section indicated that a gradation containing maximum size pieces of 24-in. diameter weighing 675 lb would be sufficient to maintain stability for discharges ranging from 5000 up to 18,000 cfs, even with tailwater elevations lowered 5 ft below the levels anticipated (plate 12) with the various flows.

31. Stone gradation used in these model tests simulated the following gradations of prototype stone:

Gradation of 18-in. Stone			Gradation of 24-in. Stone		
Size, in.	Weight, lb	Percent by Weight	Size, in.	Weight, lb	Percent by Weight
18	265	25	24	675	25
13	120	30	18	265	30
8	32	35	13	120	35
2	0.5	10	8	32	10

Due to existing rock formation, no additional protection was required on the exit channel bottom.

PART IV: DISCUSSION OF RESULTS

32. The results of the model investigation of the New Hope outlet works confirmed the adequacy of certain elements of the structure as designed and the need for modification of other elements. The flood-control facilities of the intake structure as originally designed were satisfactory, having no vibrational tendencies or adverse hydraulic characteristics for all discharge conditions and upper pools ranging from el 190 to 260. No structural changes are suggested; however, certain operational procedures are necessary to reduce the possibility of cavitation damage and the withdrawal of undesirable water through the multilevel intakes.

33. Pressures were positive throughout the model structure for all flood-control flows entering the conduit intakes. However, during water-quality withdrawals, subatmospheric pressures were observed in the throat section of the water-quality system upstream of the service gates (plate 10). For acceptable pressure conditions in this area, it is recommended that all water-quality flows through the multilevel intakes be controlled by service gate openings not to exceed 6.5 ft. However, it was noted that, with the service gate fully opened, the throat section became vented and no negative pressures were evident. Service gate openings and discharges in excess of those discussed in paragraph 19 could be permitted through the selective withdrawal facilities provided the openings in the roofs of the flood-control facilities upstream of the service gates were enlarged to maintain better pressure conditions and greater control of flow by the service gates.

34. Discharge capacity of the flood-control structure (pool el 240) was about 20 percent greater than anticipated. This capacity increase is attributed to lower-than-expected entrance losses of the structure. Observations of selective withdrawal indicate that the proposed structure will provide effective regulation of quality water during the summer and winter seasons (300-800 cfs and 2400 cfs, respectively). However, the average winter flow of 2400 cfs required withdrawal from both sides of the structure, and the thermocline 40 ft below upper pool el 216.

35. Development of an adequate stilling basin was severely complicated because the elevation of the outlet portal invert with respect to tailwater was so low there was little room to effect spreading of the jet prior to beginning of basin action. Tests of the original design stilling basin revealed unsatisfactory basin action at all flows. Unstable and unbalanced basin action was observed, and excessive wave action extended into the exit area and along the banks of the exit channel at the higher discharges. The stilling basin developed in the model to provide satisfactory performance is shown in plate 11 and modifies the original design by reducing the flare of the sidewalls, raising the basin floor, increasing the basin length, and reducing the height of the end sill. Tests also indicated that this basin is not ideal if single gate operation of the intake structure is permitted. For this condition, unbalanced flow exists at the outlet portal and extends into the basin proper with little or no energy dissipation occurring. However, flow at the outlet portal of the 330-ft-long prototype conduit should be more evenly distributed than it was in the model where, in the interest of friction losses (see paragraph 9), only 212 ft of conduit was reproduced.

36. Tests of the type 3 basin with the oblong conduit installed revealed performance similar to that of the type 2 basin and circular conduit. Basin action was satisfactory with dual gate operation, but less than desirable with single gate operation. Tests also indicated that the height of the basin walls is adequate (el 177) and wing walls are not required downstream of the end sill.

37. Observations of flow conditions below the structure revealed the need for riprap protection along the right bank behind the basin training wall (265-lb stone) and along the right bank of the exit

channel (675-lb stone) downstream of the stilling basin for a distance of 321 ft. An additional 200 ft of 265-lb stone (sta 5+50 to 7+50) along the right bank remained stable for all discharges, even with below-normal tailwater. The left bank of the channel remained stable with 265-lb stone as velocities and wave heights are lower in this area.

Table 1

Pressures Throughout Outlet Structure; Original Design, Both Service Gates Open Full

Pool El 245.0* | Discharge 18,000 cfs | Tailwater El 175.0

Piez No.	Piez Zero	Pressure Reading	Piez No.	Piez Zero	Pressure Reading	Piez No.	Piez Zero	Pressure Reading
1	178.50	218.0	46	150.00	238.0	91	151.90	183.6
2	177.75	226.4	47	150.00	231.3	92	152.20	179.8
3	175.75	221.0	48	150.00	197.5	93	152.60	172.8
4	175.00	219.7	49	150.00	194.8	94	150.00	192.2
5	174.25	219.6	50	217.00	245.0	95	150.00	189.3
6	173.75	218.5	51	208.75	245.0	96	150.00	184.3
7	173.25	218.1	52	209.00	245.0	97	150.00	187.0
8	173.00	216.6	53	194.00	238.6	98	150.00	175.8
9	172.50	216.0	54	194.00	241.7	99	150.00	190.8
10	172.00	214.7	55	184.75	240.2	100	150.00	188.0
11	171.75	214.4	56	188.00	240.2	101	150.00	184.6
12	171.50	212.7	57	188.00	240.5	102	150.00	185.2
13	171.25	211.8	58	213.00	245.0	103	159.50	191.1
14	170.75	210.3	59	209.00	245.0	104	159.50	186.3
15	170.25	208.6	60	209.00	245.0	105	159.50	182.3
16	169.75	207.0	61	215.00	245.0	106	159.50	183.7
17	169.25	204.6	62	211.00	245.0	107	159.40	169.5
18	169.00	202.1	63	211.00	245.0	108	159.30	168.5
19	169.00	199.2	64	183.50	241.2	109	159.20	167.0
20	171.50	194.3	65	201.50	244.7	110	159.10	167.5
21	170.50	209.7	66	170.00	195.8	111	158.90	168.5
22	169.75	208.1	67	180.00	196.0	112	158.80	163.7
23	169.25	200.4	68	190.00	196.6	113	158.70	163.5
24	169.00	197.3	69	200.00	**	114	158.60	163.2
25	169.00	183.7	70	170.00	193.1	115	158.50	160.3
26	159.50	228.6	71	180.00	194.0	116	158.30	159.5
27	159.50	214.4	72	190.00	194.1	117	158.20	157.5
28	159.50	199.2	73	200.00	**	118	149.90	170.5
29	159.50	194.5	74	169.00	190.4	119	149.80	168.5
30	159.50	228.3	75	169.00	188.8	120	149.70	167.0
31	159.50	214.6	76	169.00	184.3	121	149.60	166.8
32	159.50	198.7	77	169.00	185.5	122	149.50	164.8
33	159.50	196.0	78	169.00	176.4	123	149.30	165.0
34	159.50	238.6	79	168.70	195.5	124	149.20	163.8
35	159.50	231.7	80	167.90	191.0	125	149.10	163.6
36	150.00	216.3	81	167.10	184.3	126	149.00	161.7
37	150.00	200.4	82	166.80	175.9	127	148.80	160.8
38	150.00	195.8	83	166.40	174.3			
39	150.00	194.7	84	159.50	195.3			
40	150.00	237.2	85	159.50	191.4			
41	150.00	194.3	86	159.50	180.4			
42	150.00	194.5	87	159.50	178.8			
43	150.00	236.5	88	159.50	178.7			
44	150.00	192.6	89	150.30	195.2			
45	150.00	192.8	90	151.10	191.8			

Note: Piezometer locations are shown in plate 8. Conduit flows full.

* All elevations are in feet referred to mean sea level.

** Piezometer is above water surface.

Table 2

Pressures Throughout Outlet Structure; Original Design, Both Service Gates Open 14.2 ft

Pool El 240.0* | Discharge 15,000 cfs | Tailwater El 172.5

Piez No.	Piez Zero	Pressure Reading	Piez No.	Piez Zero	Pressure Reading	Piez No.	Piez Zero	Pressure Reading
1	178.50	221.5	46	150.00	235.0	91	151.90	162.3
2	177.75	227.2	47	150.00	230.6	92	152.20	162.3
3	175.75	224.8	48	150.00	203.8	93	152.60	161.2
4	175.00	222.4	49	150.00	186.5	94	150.00	165.2
5	174.25	222.4	50	217.00	240.0	95	150.00	164.6
6	173.75	221.8	51	208.75	240.0	96	150.00	163.4
7	173.25	221.0	52	209.00	240.0	97	150.00	171.2
8	173.00	220.3	53	194.00	237.3	98	150.00	164.0
9	172.50	220.0	54	194.00	238.0	99	150.00	165.4
10	172.00	219.1	55	184.75	237.2	100	150.00	163.3
11	171.75	218.6	56	188.00	237.0	101	150.00	163.2
12	171.50	217.5	57	188.00	237.0	102	150.00	165.3
13	171.25	217.0	58	213.00	240.0	103	159.50	162.2
14	170.75	215.8	59	209.00	240.0	104	159.50	160.0
15	170.25	214.6	60	209.00	240.0	105	159.50	161.6
16	169.75	213.7	61	215.00	240.0	106	159.50	164.8
17	169.25	212.0	62	211.00	240.0	107	159.40	165.1
18	169.00	210.5	63	211.00	240.0	108	159.30	165.4
19	169.00	209.6	64	183.50	240.0	109	159.20	165.8
20	171.50	207.5	65	201.50	240.0	110	159.10	167.3
21	170.50	217.0	66	170.00	209.7	111	158.90	169.1
22	169.75	221.0	67	180.00	209.8	112	158.80	165.5
23	169.25	223.0	68	190.00	210.3	113	158.70	165.3
24	169.00	225.0	69	200.00	210.4	114	158.60	165.0
25	169.00	**	70	170.00	208.5	115	158.50	164.1
26	159.50	228.2	71	180.00	209.4	116	158.30	163.7
27	159.50	218.3	72	190.00	209.7	117	158.20	162.0
28	159.50	204.4	73	200.00	209.8	118	149.90	165.0
29	159.50	**	74	169.00	**	119	149.80	166.0
30	159.50	228.0	75	169.00	**	120	149.70	166.1
31	159.50	218.4	76	169.00	**	121	149.60	166.4
32	159.50	204.2	77	169.00	**	122	149.50	167.6
33	159.50	**	78	169.00	**	123	149.30	166.5
34	150.00	235.4	79	168.70	**	124	149.20	165.4
35	150.00	230.7	80	167.90	**	125	149.10	166.2
36	150.00	219.6	81	167.10	**	126	149.00	166.0
37	150.00	205.3	82	166.80	**	127	148.80	164.2
38	150.00	185.8	83	166.40	**			
39	150.00	**	84	159.50	167.3			
40	150.00	234.5	85	159.50	166.5			
41	150.00	207.6	86	159.50	159.3			
42	150.00	187.0	87	159.50	161.3			
43	150.00	234.0	88	159.50	163.4			
44	150.00	208.0	89	150.30	170.0			
45	150.00	187.0	90	151.10	168.6			

Note: Piezometer locations are shown in plate 8. Conduit flows full.

* All elevations are in feet referred to mean sea level.

** Piezometer is above water surface.

Table 3

Pressures Throughout Outlet Structure; Original Design, Both Service Gates Open 9.3 ft

Pool El 240.0* Discharge 10,000 cfs Tailwater El 168.0

Piez No.	Piez Zero	Pressure Reading	Piez No.	Piez Zero	Pressure Reading	Piez No.	Piez Zero	Pressure Reading
1	178.50	231.4	46	150.00	237.0	91	151.90	158.2
2	177.75	233.6	47	150.00	235.0	92	152.20	157.3
3	175.75	232.5	48	150.00	220.6	93	152.60	157.5
4	175.00	232.0	49	150.00	190.1	94	150.00	160.2
5	174.25	232.0	50	217.00	240.0	95	150.00	160.6
6	173.75	231.6	51	208.75	240.0	96	150.00	159.0
7	173.25	231.4	52	209.00	240.0	97	150.00	166.8
8	173.00	231.0	53	194.00	239.0	98	150.00	160.3
9	172.00	230.3	54	194.00	239.6	99	150.00	159.6
10	172.00	230.3	55	184.75	239.0	100	150.00	158.8
11	171.75	230.0	56	188.00	239.0	101	150.00	159.1
12	171.50	229.6	57	188.00	239.0	102	150.00	160.6
13	171.25	229.3	58	213.00	240.0	103	159.50	160.2
14	170.75	228.7	59	209.00	240.0	104	159.50	160.0
15	170.25	228.3	60	209.00	240.0	105	159.50	159.7
16	169.75	227.8	61	215.00	240.0	106	159.50	159.7
17	169.25	227.3	62	211.00	240.0	107	159.40	159.7
18	169.00	226.8	63	211.00	240.0	108	159.30	159.7
19	169.00	227.2	64	183.50	239.4	109	159.20	159.7
20	171.50	227.6	65	201.50	240.0	110	159.10	161.4
21	170.50	228.1	66	170.00	229.2	111	158.90	164.8
22	169.75	229.1	67	180.00	229.7	112	158.80	161.2
23	169.25	230.0	68	190.00	229.7	113	158.70	160.8
24	169.00	232.8	69	200.00	229.7	114	158.60	159.3
25	169.00	**	70	170.00	229.3	115	158.50	158.4
26	159.50	234.2	71	180.00	229.7	116	158.30	158.5
27	159.50	229.7	72	190.00	229.7	117	158.20	159.3
28	159.50	223.0	73	200.00	229.7	118	149.90	161.3
29	159.50	**	74	169.00	**	119	149.80	160.8
30	159.50	234.0	75	169.00	**	120	149.70	161.3
31	159.50	229.6	76	169.00	**	121	149.60	161.3
32	159.50	222.7	77	169.00	**	122	149.50	163.0
33	159.50	**	78	169.00	**	123	149.30	161.5
34	150.00	237.2	79	168.70	**	124	149.20	160.5
35	150.00	235.1	80	167.90	**	125	149.10	160.8
36	150.00	230.1	81	167.10	**	126	149.00	161.2
37	150.00	221.3	82	166.80	**	127	148.80	160.0
38	150.00	189.2	83	166.40	**			
39	150.00	164.8	84	159.50	161.0			
40	150.00	236.5	85	159.50	162.2			
41	150.00	224.7	86	159.50	159.8			
42	150.00	190.0	87	159.50	159.7			
43	150.00	236.4	88	159.50	161.1			
44	150.00	224.9	89	150.30	164.2			
45	150.00	185.4	90	151.10	163.9			

Note: Piezometer locations are shown in plate 8. Conduit flows full.

* All elevations are in feet referred to mean sea level.

** Piezometer is above water surface.

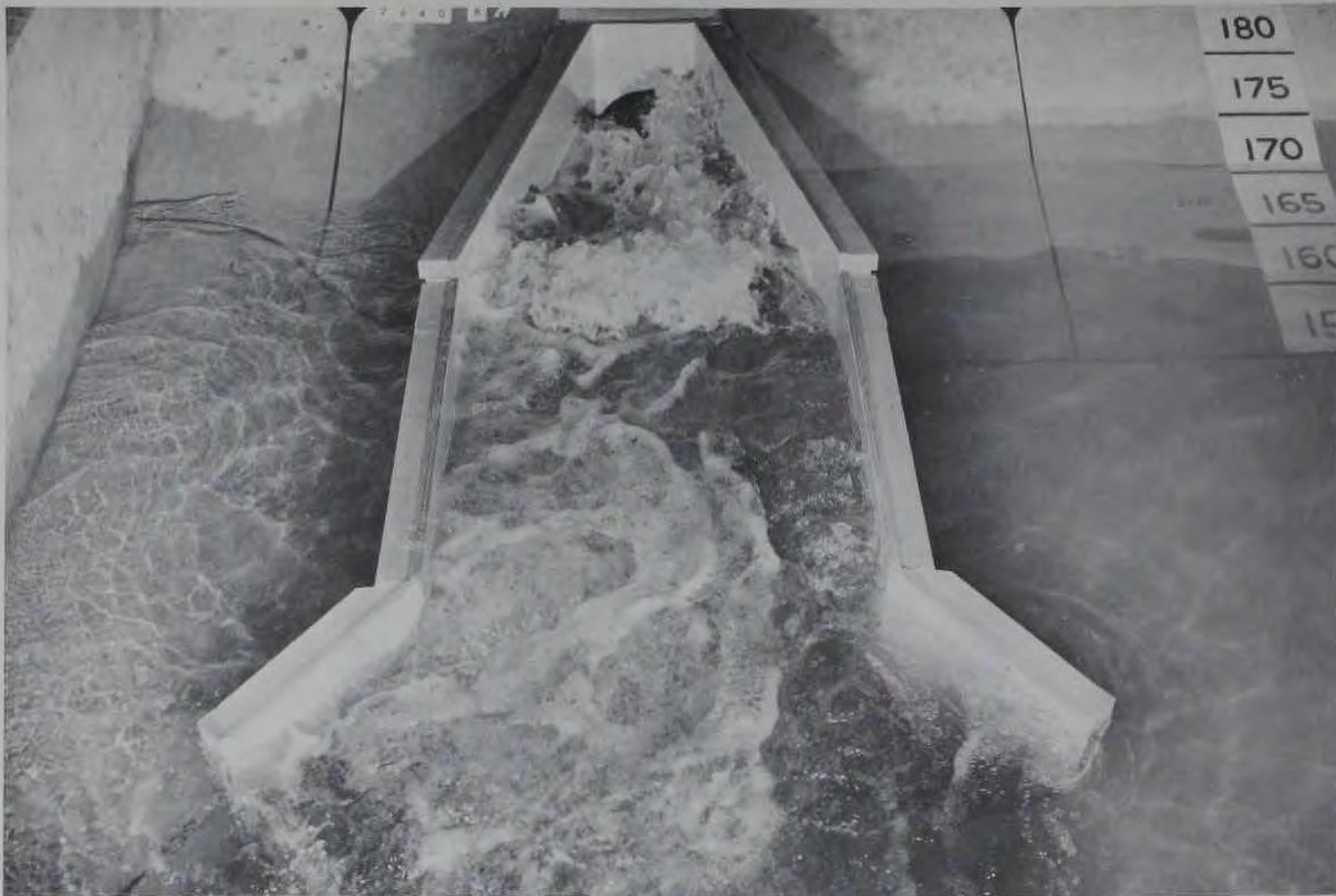
Table 4

Pressures Throughout Outlet Structure; Original Design, Right Service Gate Open 9.3 ft

Pool El 240.0* Discharge 5000 cfs Tailwater El 162.5

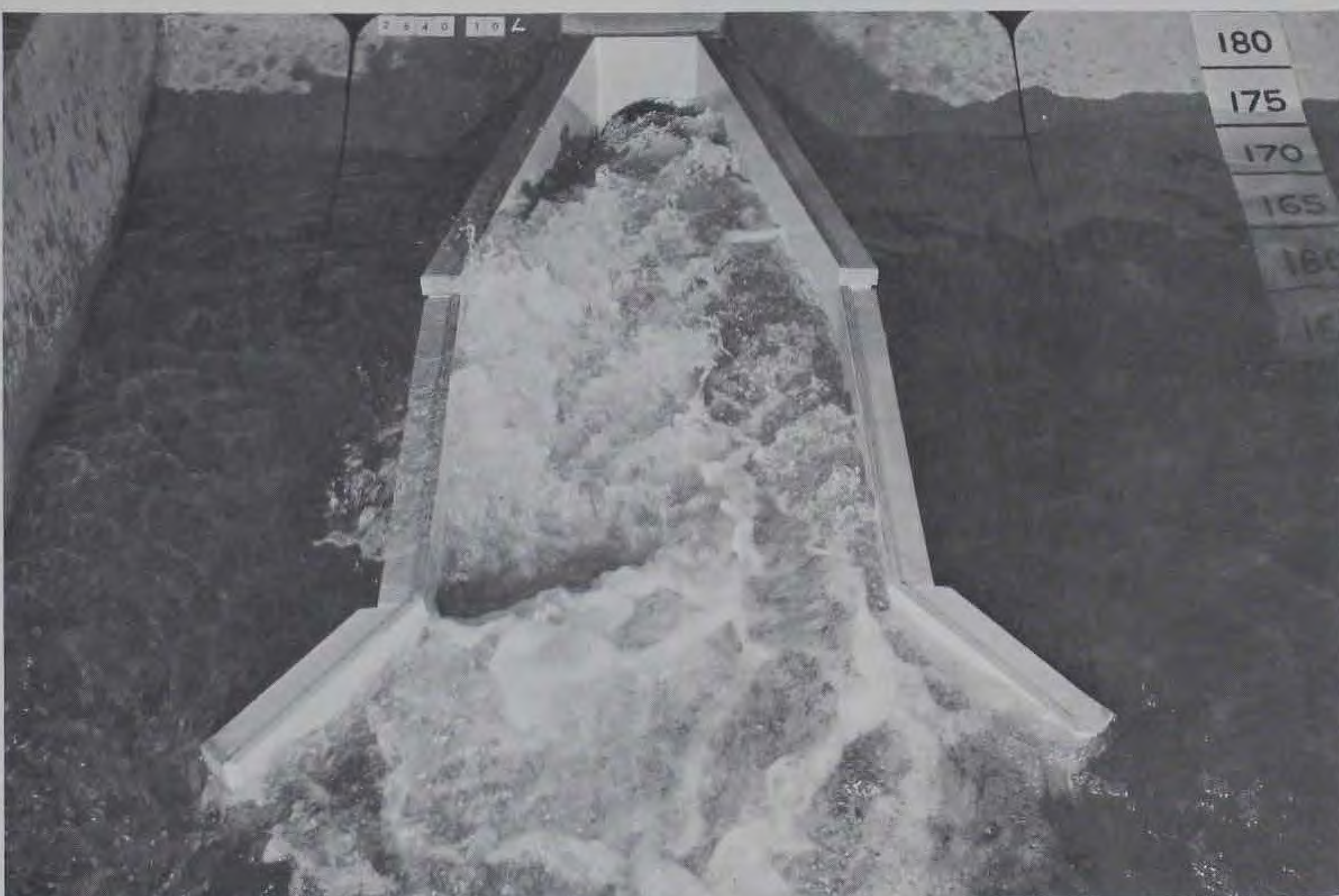
Piez No.	Piez Zero	Pressure Reading	Piez No.	Piez Zero	Pressure Reading	Piez No.	Piez Zero	Pressure Reading
1	178.50	240.0	46	150.00	240.0	91	151.90	156.6
2	177.75	233.2	47	150.00	240.0	92	152.20	153.0
3	175.75	232.5	48	150.00	230.4	93	152.60	156.0
4	175.00	231.9	49	150.00	226.7	94	150.00	160.7
5	174.25	231.8	50	217.00	240.0	95	150.00	160.7
6	173.75	231.5	51	208.75	240.0	96	150.00	155.7
7	173.25	231.2	52	209.00	240.0	97	150.00	154.0
8	173.00	230.7	53	194.00	239.0	98	150.00	157.9
9	172.50	230.5	54	194.00	239.0	99	150.00	160.0
10	172.00	230.1	55	184.75	239.0	100	150.00	158.8
11	171.75	229.8	56	188.00	239.0	101	150.00	155.7
12	171.50	229.3	57	188.00	239.0	102	150.00	151.0
13	171.25	229.0	58	213.00	240.0	103	159.50	**
14	170.75	228.6	59	209.00	240.0	104	159.50	**
15	170.25	228.0	60	209.00	240.0	105	159.50	**
16	169.75	227.6	61	215.00	240.0	106	159.50	**
17	169.25	227.1	62	211.00	240.0	107	159.40	**
18	169.00	226.7	63	211.00	240.0	108	159.30	**
19	169.00	227.3	64	183.50	240.0	109	159.20	**
20	171.50	228.5	65	201.50	240.0	110	159.10	**
21	170.50	227.7	66	170.00	228.3	111	158.90	**
22	169.75	228.6	67	180.00	228.6	112	158.80	**
23	169.25	230.0	68	190.00	228.6	113	158.70	**
24	169.00	233.1	69	200.00	228.6	114	158.60	**
25	169.00	**	70	170.00	230.0	115	158.50	**
26	159.50	234.7	71	180.00	230.0	116	158.30	**
27	159.50	230.0	72	190.00	230.0	117	158.20	**
28	159.50	222.6	73	200.00	230.0	118	149.90	159.5
29	159.50	**	74	169.00	**	119	149.80	158.0
30	159.50	234.3	75	169.00	**	120	149.70	156.4
31	159.50	229.8	76	169.00	**	121	149.60	155.4
32	159.50	222.2	77	169.00	**	122	149.50	157.7
33	159.50	160.0	78	169.00	**	123	149.30	158.2
34	150.00	237.7	79	168.70	**	124	149.20	157.3
35	150.00	235.6	80	167.90	**	125	149.10	156.7
36	150.00	230.4	81	167.10	**	126	149.00	156.8
37	150.00	221.1	82	166.80	**	127	148.80	155.8
38	150.00	189.4	83	166.40	**			
39	150.00	165.5	84	159.50	**			
40	150.00	237.4	85	159.50	**			
41	150.00	224.7	86	159.50	**			
42	150.00	191.2	87	159.50	**			
43	150.00	237.0	88	159.50	**			
44	150.00	224.6	89	150.30	164.5			
45	150.00	186.5	90	151.10	163.8			

Note: Piezometer locations are shown in plate 8. Conduit flows full.
* All elevations are in feet referred to mean sea level.
** Piezometer is above water surface.



a. Discharge 14,000 cfs; tailwater el 172.0; both service gates open 14.2 ft

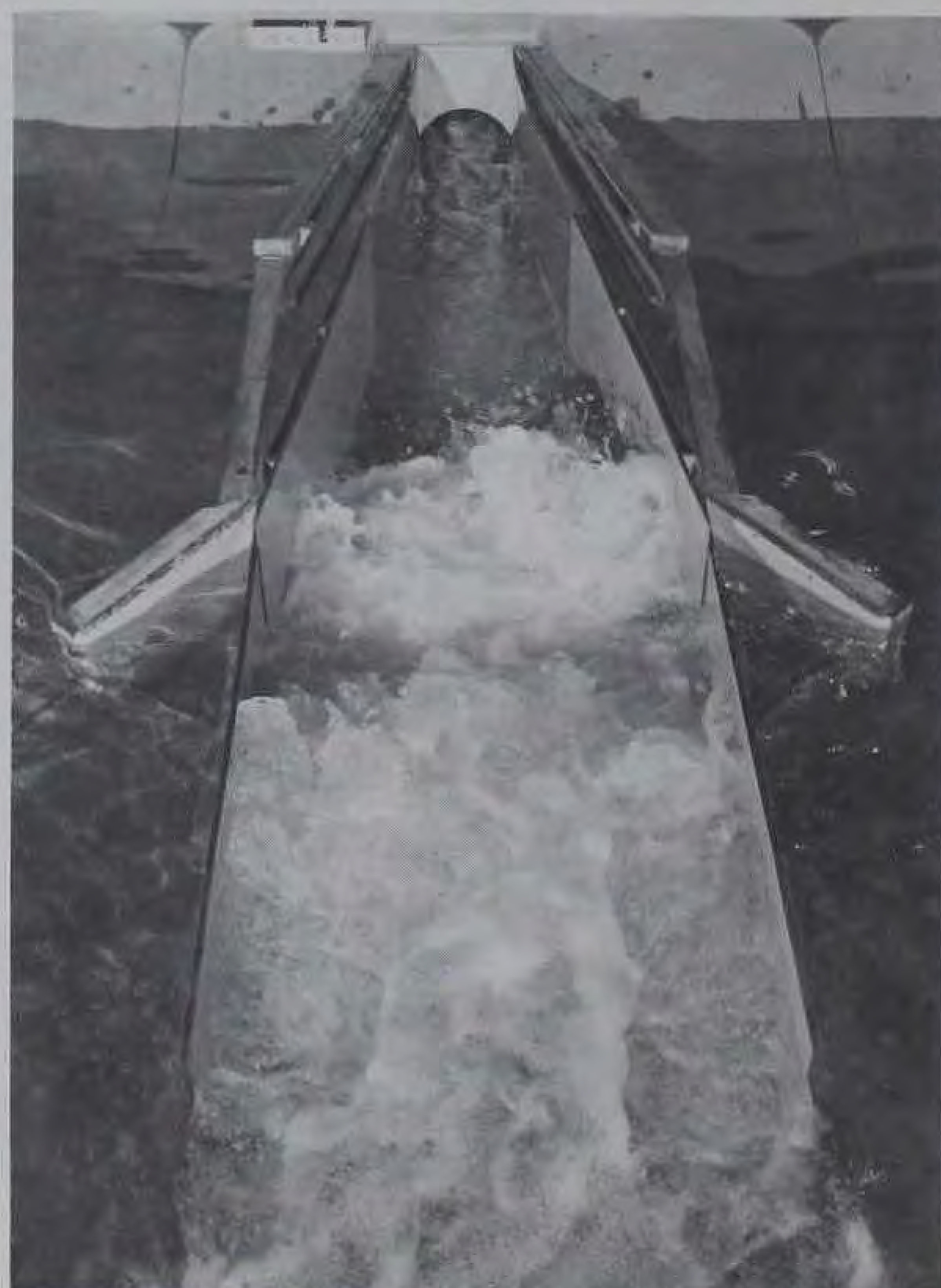
Photograph 1. Flow conditions in the type 1 (original) design basin for discharges of 14,000 and 18,000 cfs (sheet 1 of 2)



b. Discharge 18,000 cfs; tailwater el 175.0; both service gates open full

Photograph 1 (sheet 2 of 2)

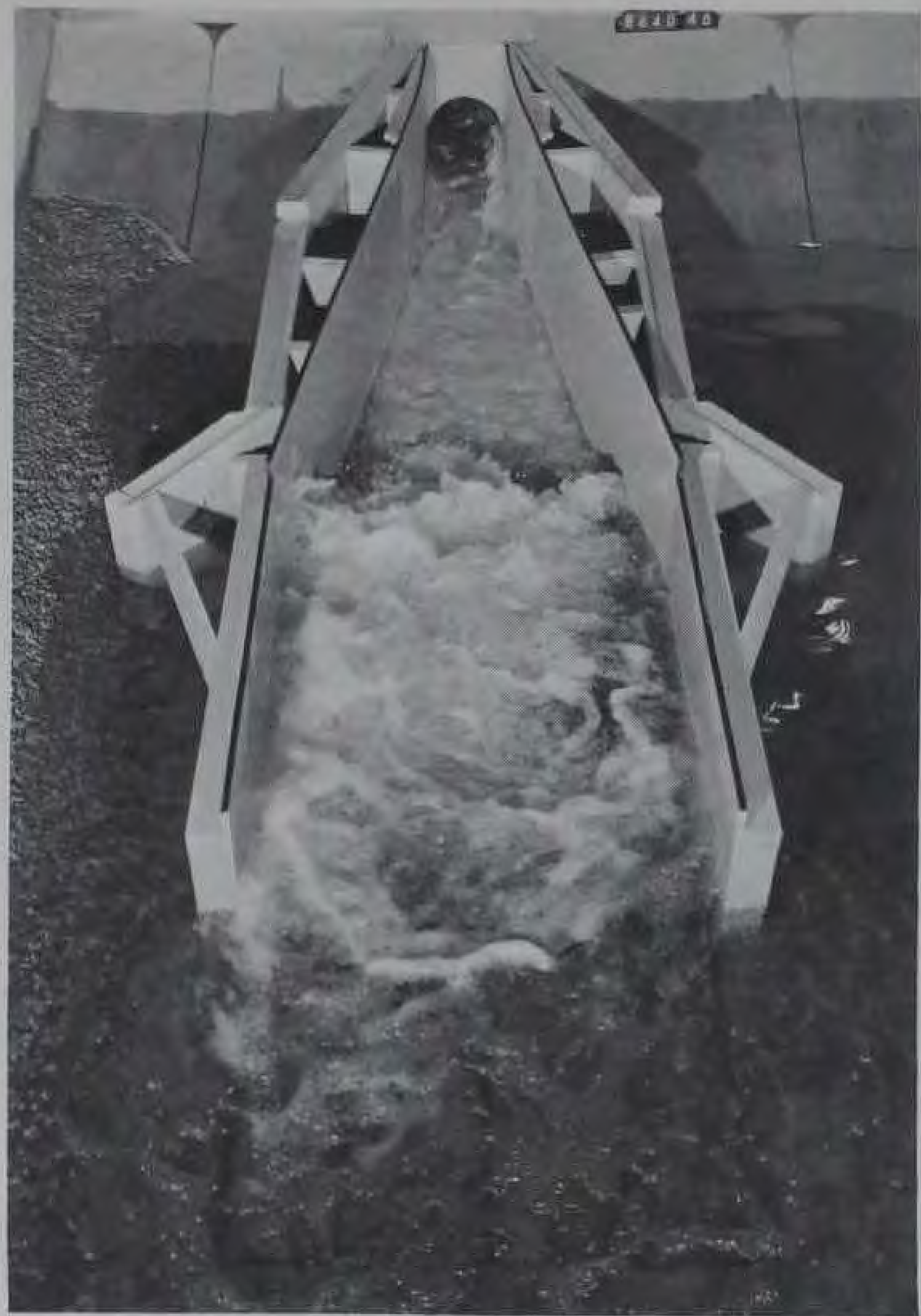
a. Discharge 5000 cfs; tailwater el 162.5; one service gate open 9.6 ft



b. Discharge 15,000 cfs; tailwater el 172.5; both service gates open 14.2 ft

Photograph 2. Flow conditions in the type 2 basin for discharges of 5000, 15,000, and 18,000 cfs (sheet 1 of 2)

c. Discharge 18,000 cfs; tailwater el 175.0; both service gates open full

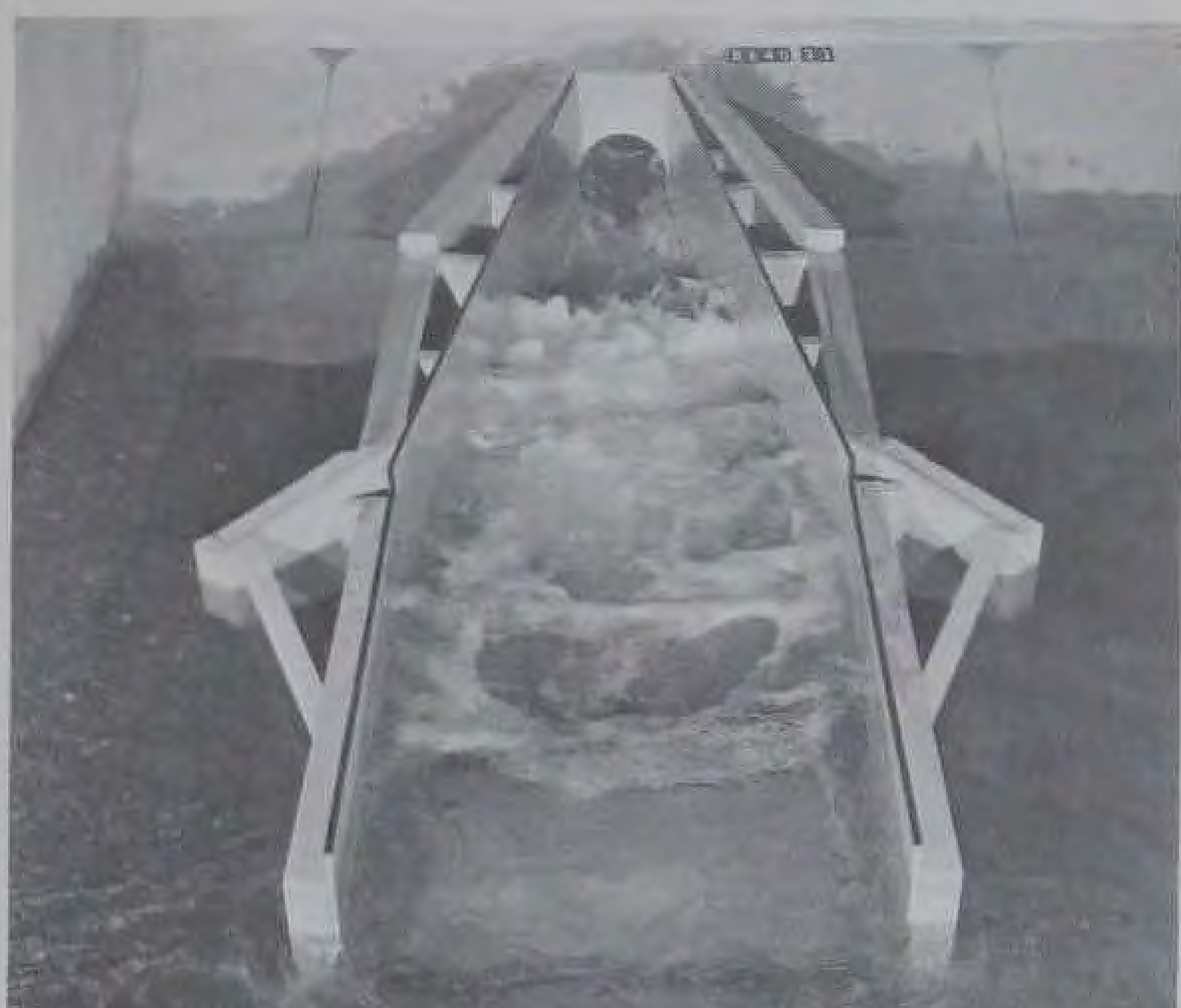


a. Tailwater el 162.5; one service gate open 9.6 ft

b. Tailwater el 168.5; one service gate open 9.6 ft

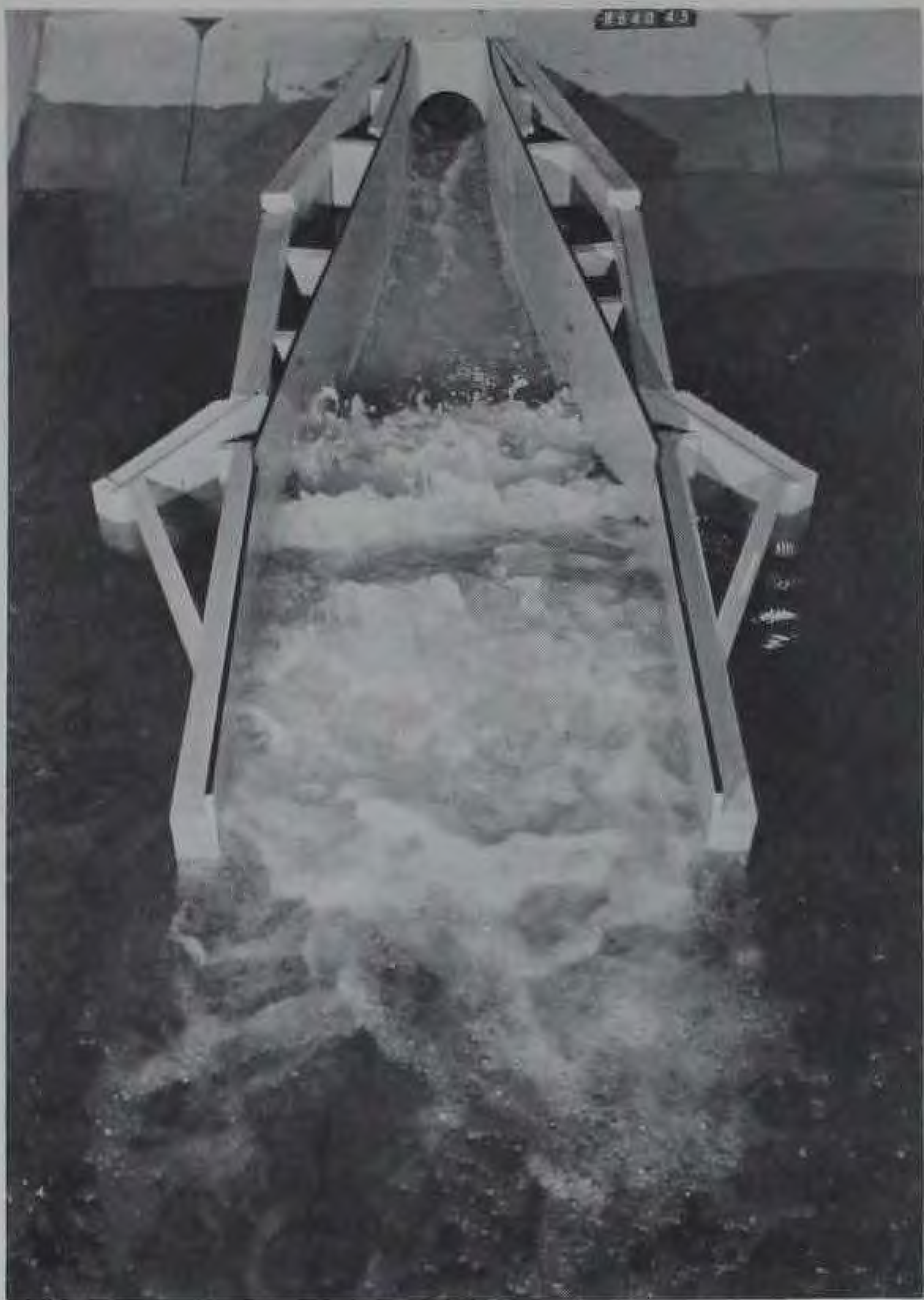
Photograph 3. Flow conditions in the type 3 basin for a discharge of 5000 cfs (sheet 1 of 2)

c. Tailwater el 175.0; one service gate open 9.6 ft



d. Tailwater el 168.5; both service gates open 4.8 ft

Photograph 3 (sheet 2 of 2)



a. Tailwater el 168.5

b. Tailwater el 175.0

Photograph 4. Flow conditions in the type 3 basin for a discharge of 10,000 cfs and both service gates open 9.6 ft

a. Discharge 15,000 cfs; tailwater el 172.5; both service gates open 14.2 ft

b. Discharge 15,000 cfs; tailwater el 175.0; both service gates open 14.2 ft

Photograph 5. Flow conditions in the type 3 basin for discharges of 15,000 and 18,000 cfs (sheet 1 of 2)

c. Discharge 18,000 cfs; tailwater el 175.0; both service gates open full

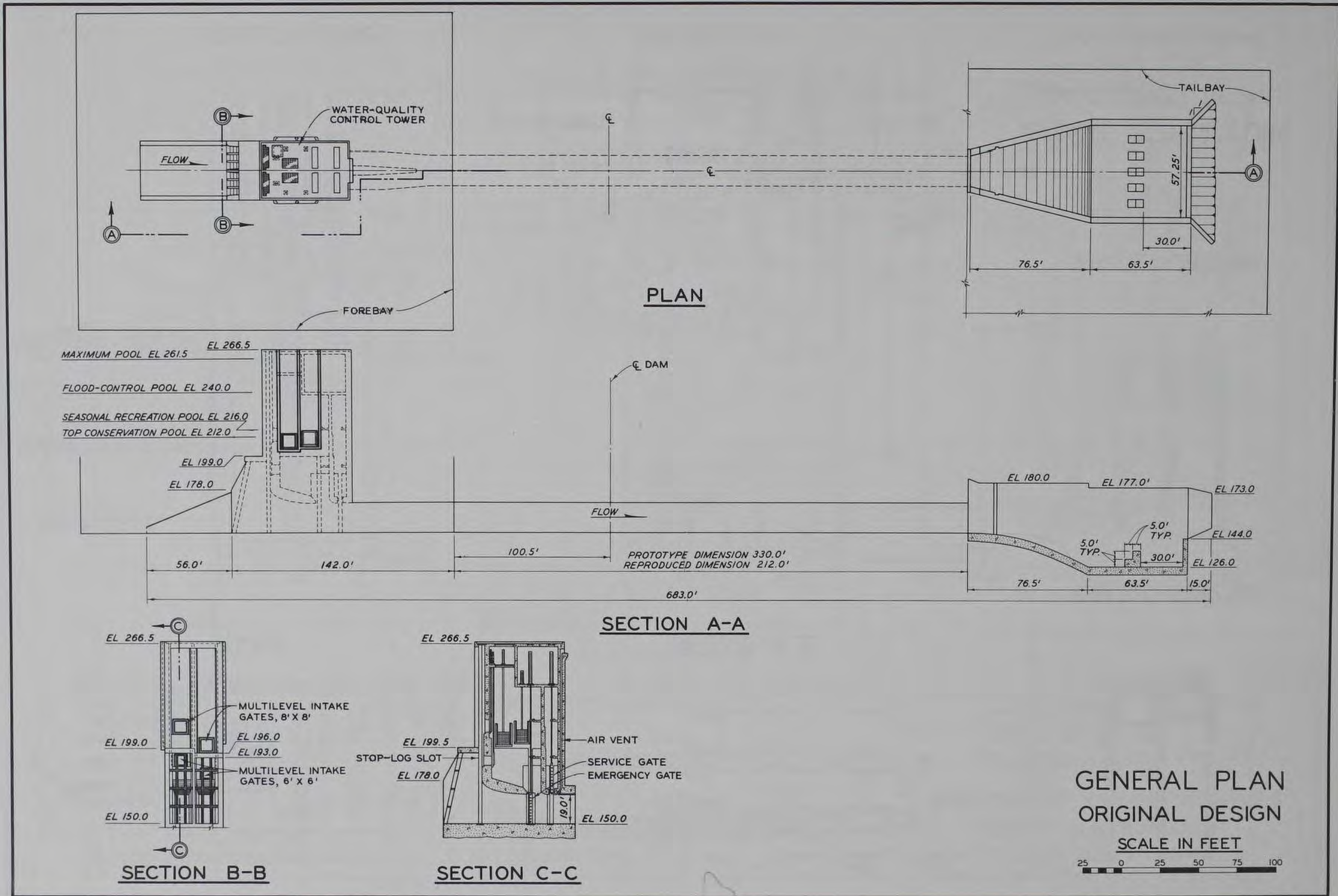
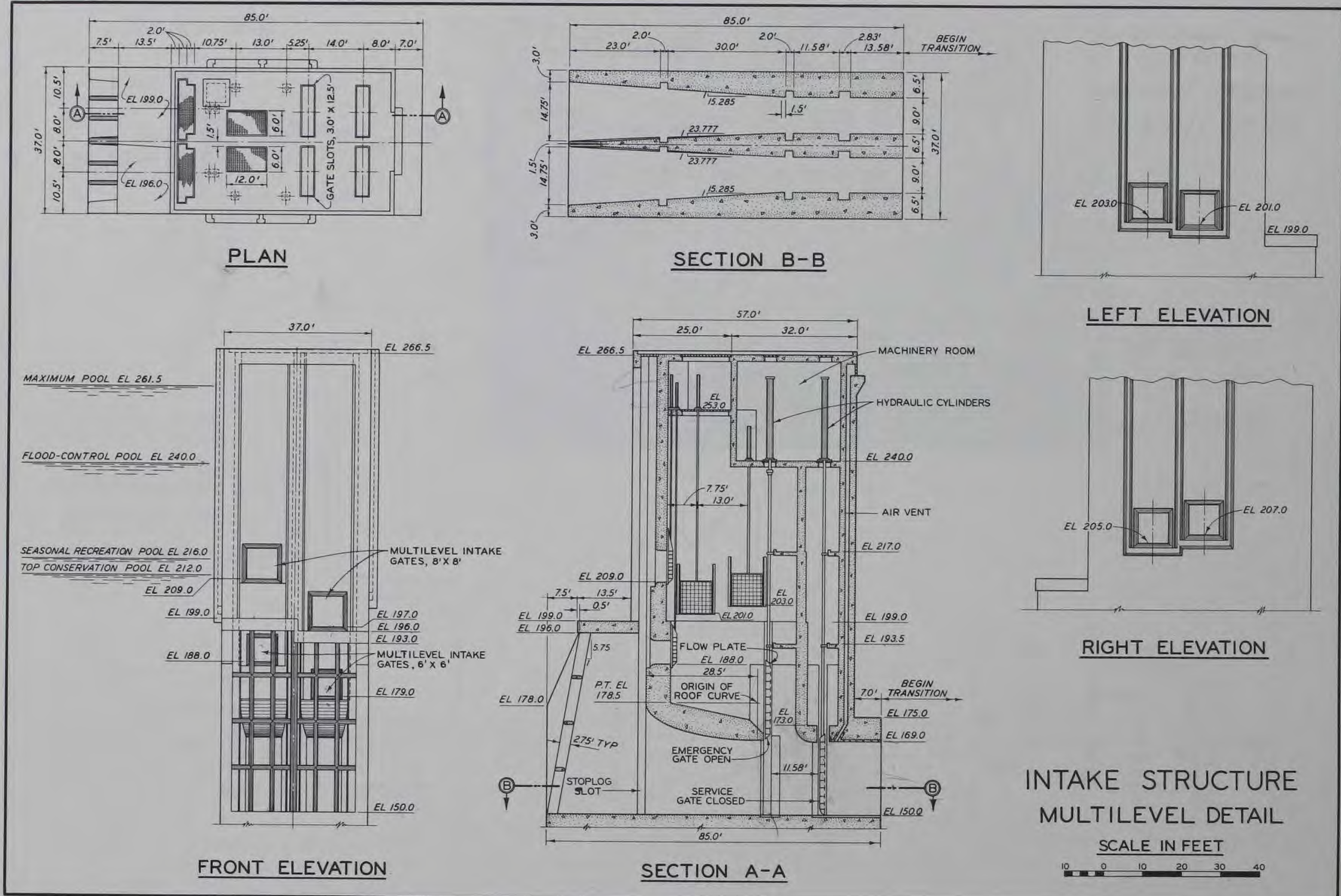
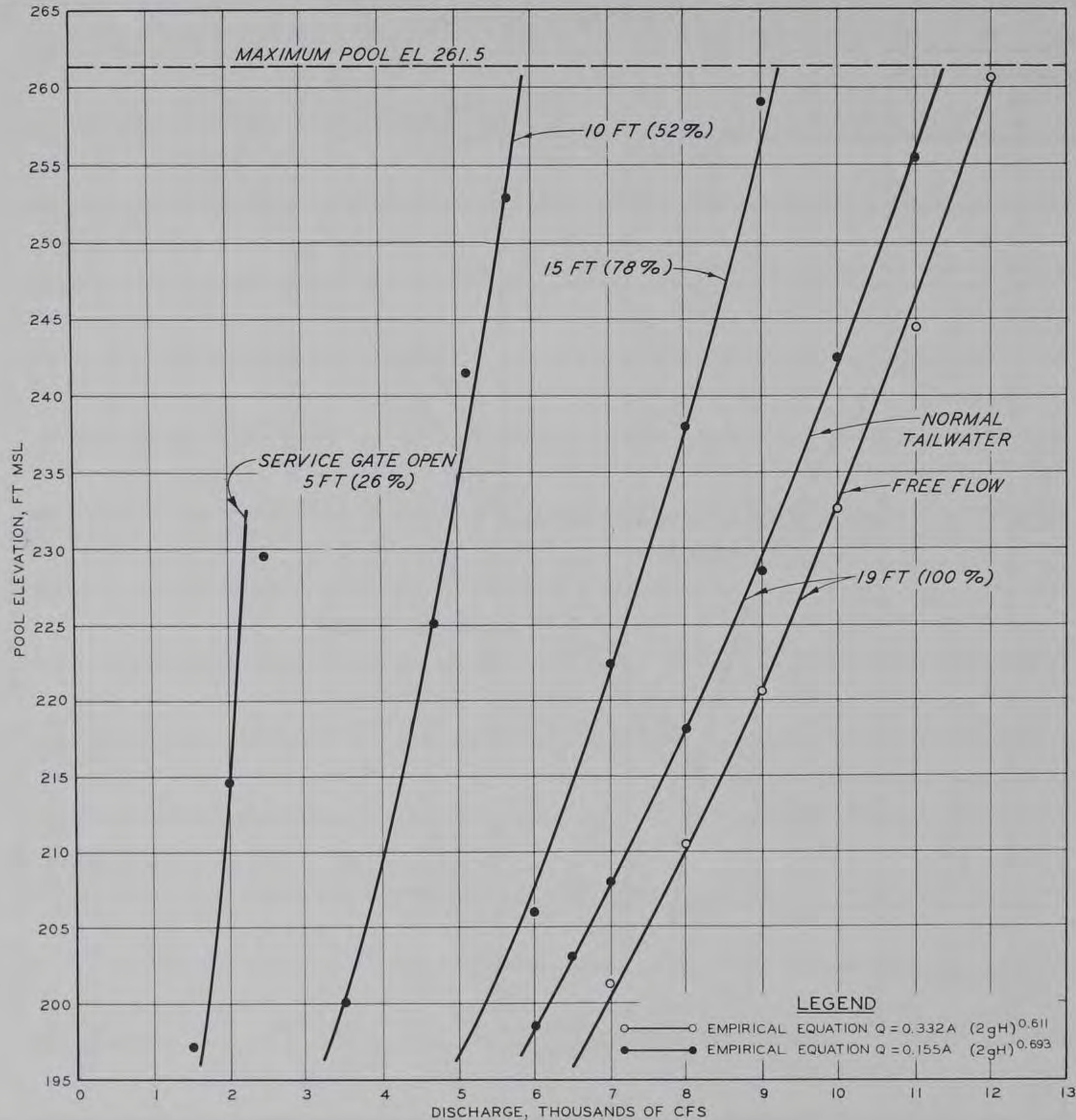

WATER-QUALITY CONTROL TOWER
FLOW
FOREBAY
TAILBAY
PLAN
57.25'
30.0'
76.5'
63.5'
MAXIMUM POOL EL 261.5
EL 266.5
FLOOD-CONTROL POOL EL 240.0
SEASONAL RECREATION POOL EL 216.0
TOP CONSERVATION POOL EL 212.0
EL 199.0
EL 178.0
℄ DAM
FLOW
EL 180.0
EL 177.0'
EL 173.0
EL 144.0
5.0' TYP.
5.0' TYP.
30.0'
EL 126.0
56.0'
142.0'
100.5'
PROTOTYPE DIMENSION 330.0'
REPRODUCED DIMENSION 212.0'
76.5'
63.5'
15.0'
683.0'
SECTION A-A
EL 266.5
MULTILEVEL INTAKE GATES, 8' X 8'
EL 199.0
EL 196.0
EL 193.0
MULTILEVEL INTAKE GATES, 6' X 6'
EL 150.0
SECTION B-B
EL 266.5
EL 199.5
STOP-LOG SLOT
EL 178.0
AIR VENT
SERVICE GATE
EMERGENCY GATE
19.0'
EL 150.0
SECTION C-C
GENERAL PLAN
ORIGINAL DESIGN
SCALE IN FEET
25 0 25 50 75 100

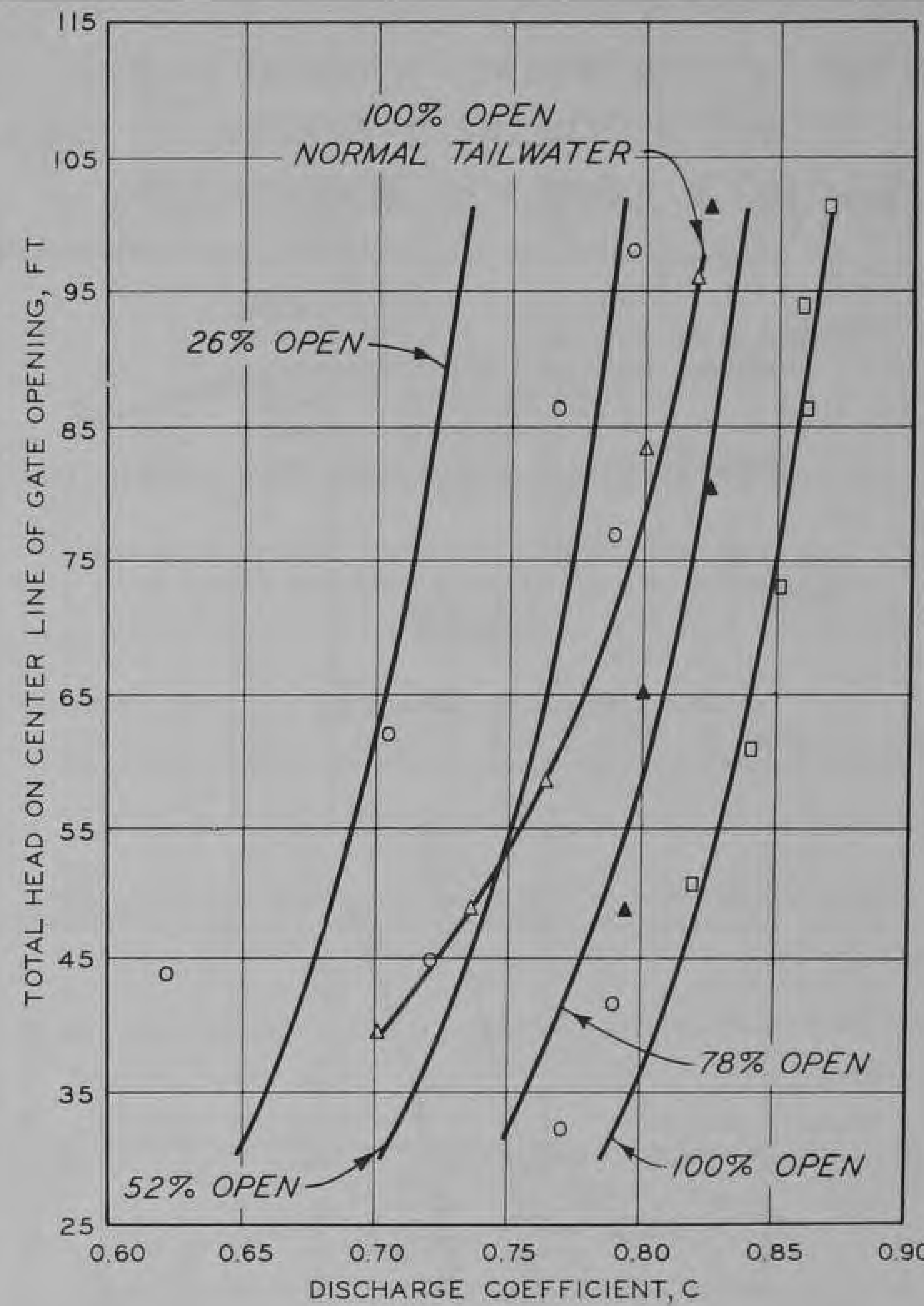
PLATE 1

PLATE 2



PLAN
GATE SLOTS, 3.0' X 12.5'
EL 199.0
EL 196.0
SECTION B-B
BEGIN TRANSITION
LEFT ELEVATION
EL 203.0
EL 201.0
EL 199.0
RIGHT ELEVATION
EL 205.0
EL 207.0
FRONT ELEVATION
MAXIMUM POOL EL 261.5
FLOOD-CONTROL POOL EL 240.0
SEASONAL RECREATION POOL EL 216.0
TOP CONSERVATION POOL EL 212.0
MULTILEVEL INTAKE GATES, 8' X 8'
MULTILEVEL INTAKE GATES, 6' X 6'
EL 266.5
EL 209.0
EL 197.0
EL 196.0
EL 193.0
EL 188.0
EL 179.0
EL 150.0
SECTION A-A
MACHINERY ROOM
HYDRAULIC CYLINDERS
AIR VENT
FLOW PLATE
ORIGIN OF ROOF CURVE
EMERGENCY GATE OPEN
SERVICE GATE CLOSED
STOPLOG SLOT
P.T. EL 178.5
EL 253.0
EL 240.0
EL 217.0
EL 199.0
EL 193.5
EL 175.0
EL 169.0
EL 178.0
EL 150.0
85.0'
57.0'
37.0'
INTAKE STRUCTURE
MULTILEVEL DETAIL
SCALE IN FEET
10 0 10 20 30 40





NOTE: MODEL COEFFICIENT DETERMINED FROM EQUATION $Q = CA\sqrt{2gH}$

A = AREA OF GATE OPENING

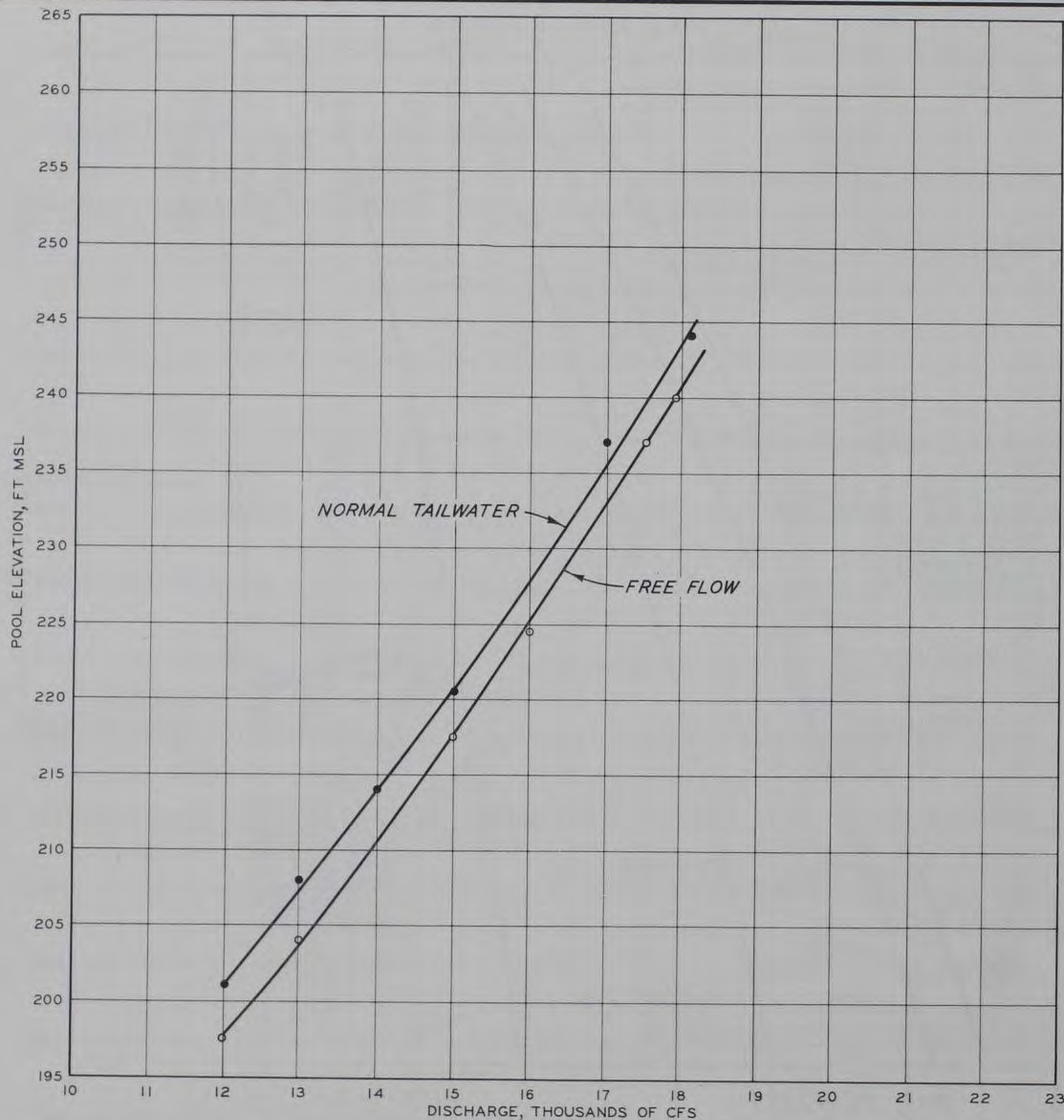
H = HEAD TO CENTER OF GATE OPENING

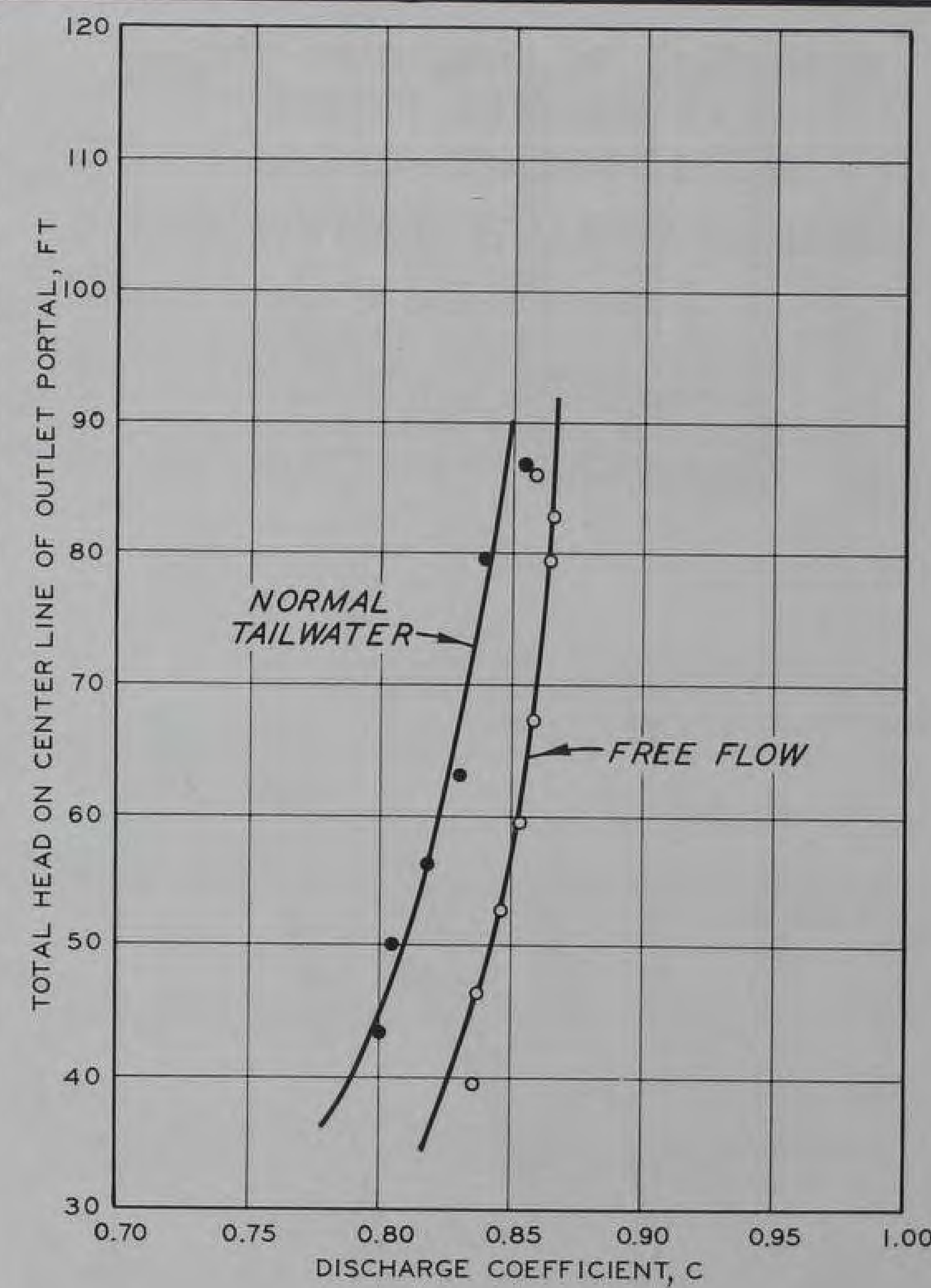
SERVICE GATE IS 19 FT HIGH BY 9 FT WIDE

INVERT OF GATE AT EL 150

DISCHARGE RATING CURVES

FLOOD-CONTROL FLOW
SINGLE SERVICE GATE
FULL AND PARTIAL OPENINGS



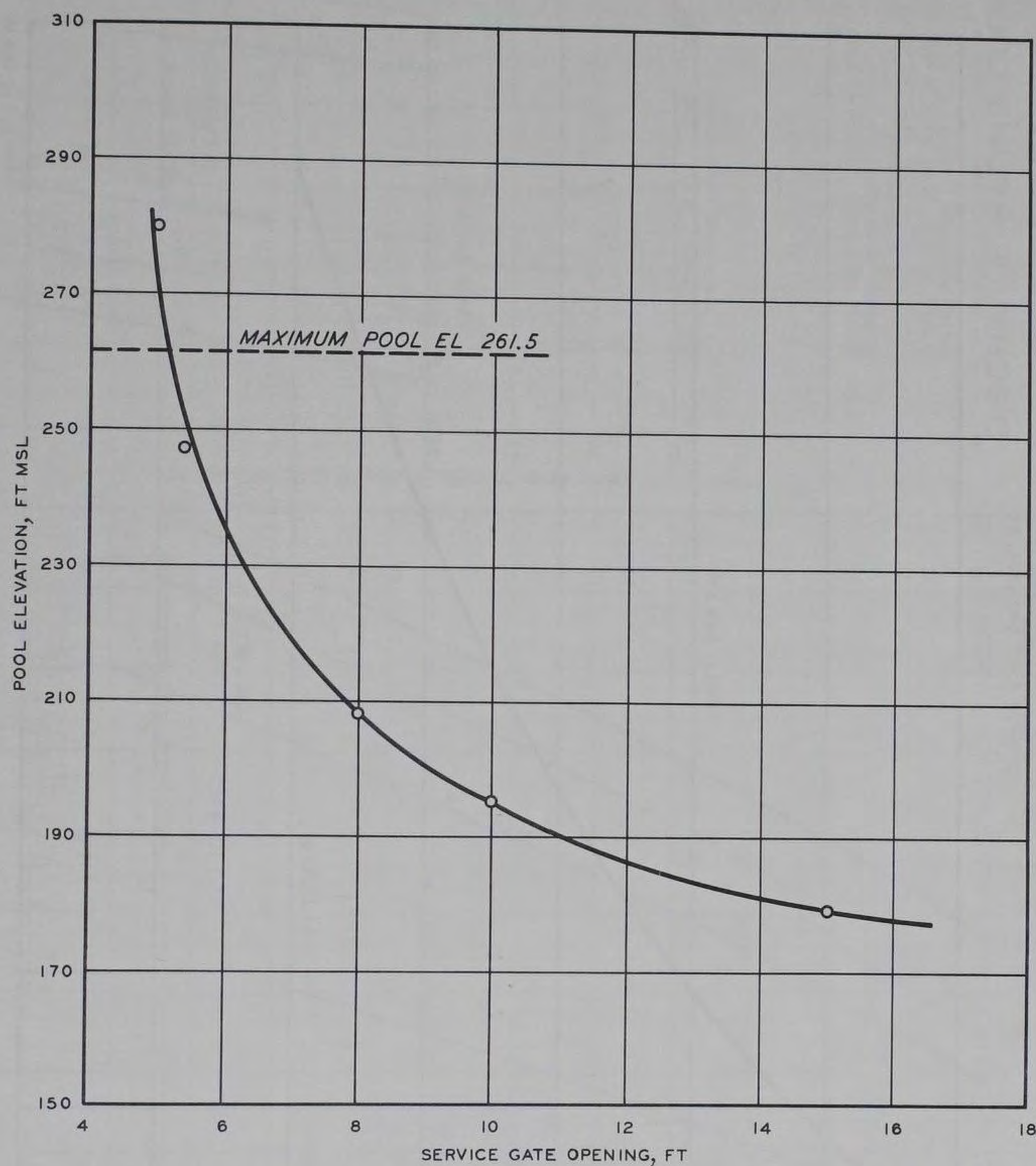


LEGEND

○—○ EMPIRICAL EQUATION $Q = 0.577A\ (2gH)^{0.547}$
●—● EMPIRICAL EQUATION $Q = 0.464A\ (2gH)^{0.569}$

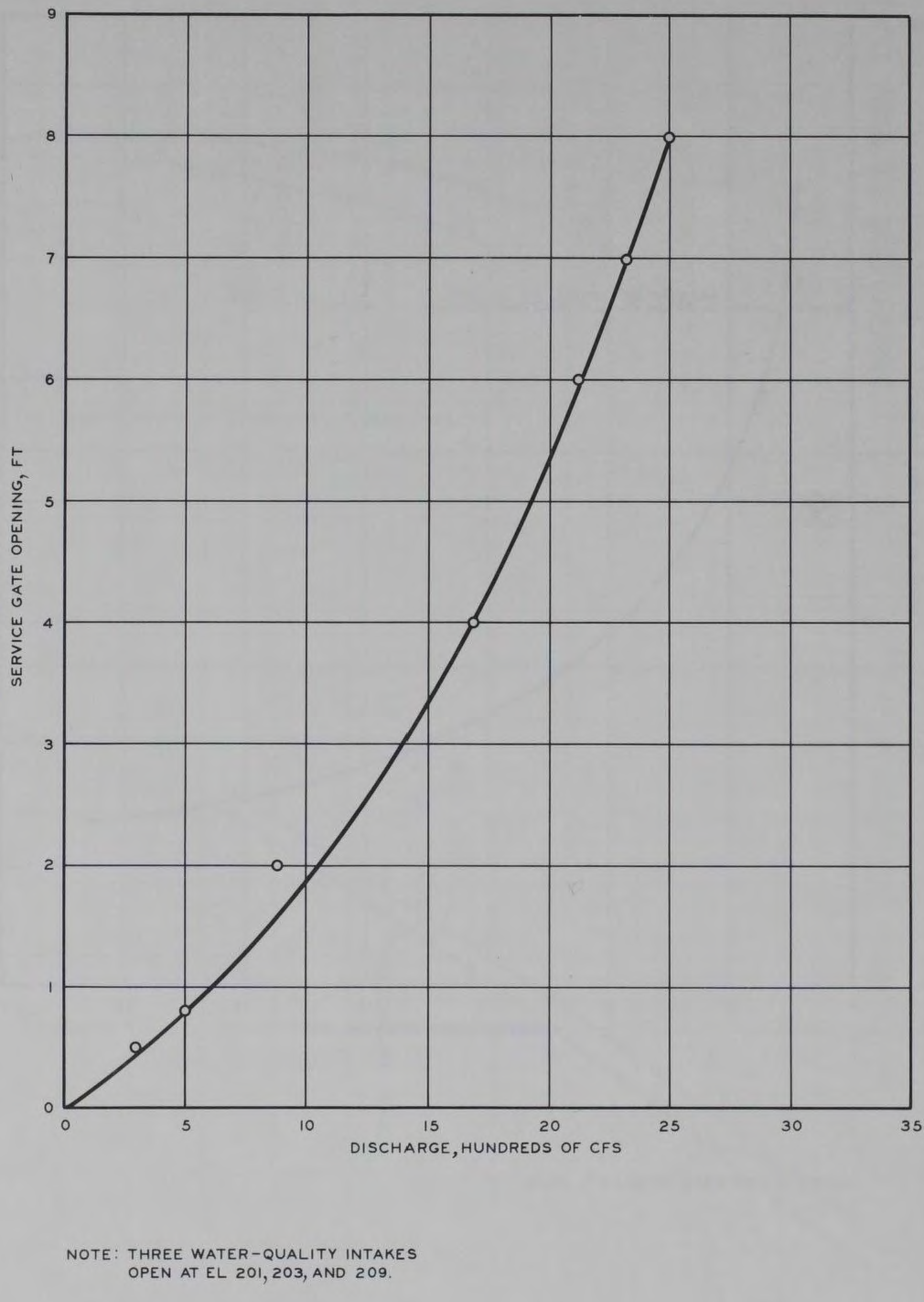
NOTE: MODEL COEFFICIENT DETERMINED FROM EQUATION $Q = CA\sqrt{2gH}$
A=AREA OF GATE OPENING
H=HEAD TO CENTER OF GATE OPENING
SERVICE GATE IS 19 FT HIGH BY 9FT WIDE
INVERT OF GATE AT EL 150

DISCHARGE RATING CURVES
FLOOD-CONTROL FLOW
BOTH SERVICE GATES FULLY OPEN

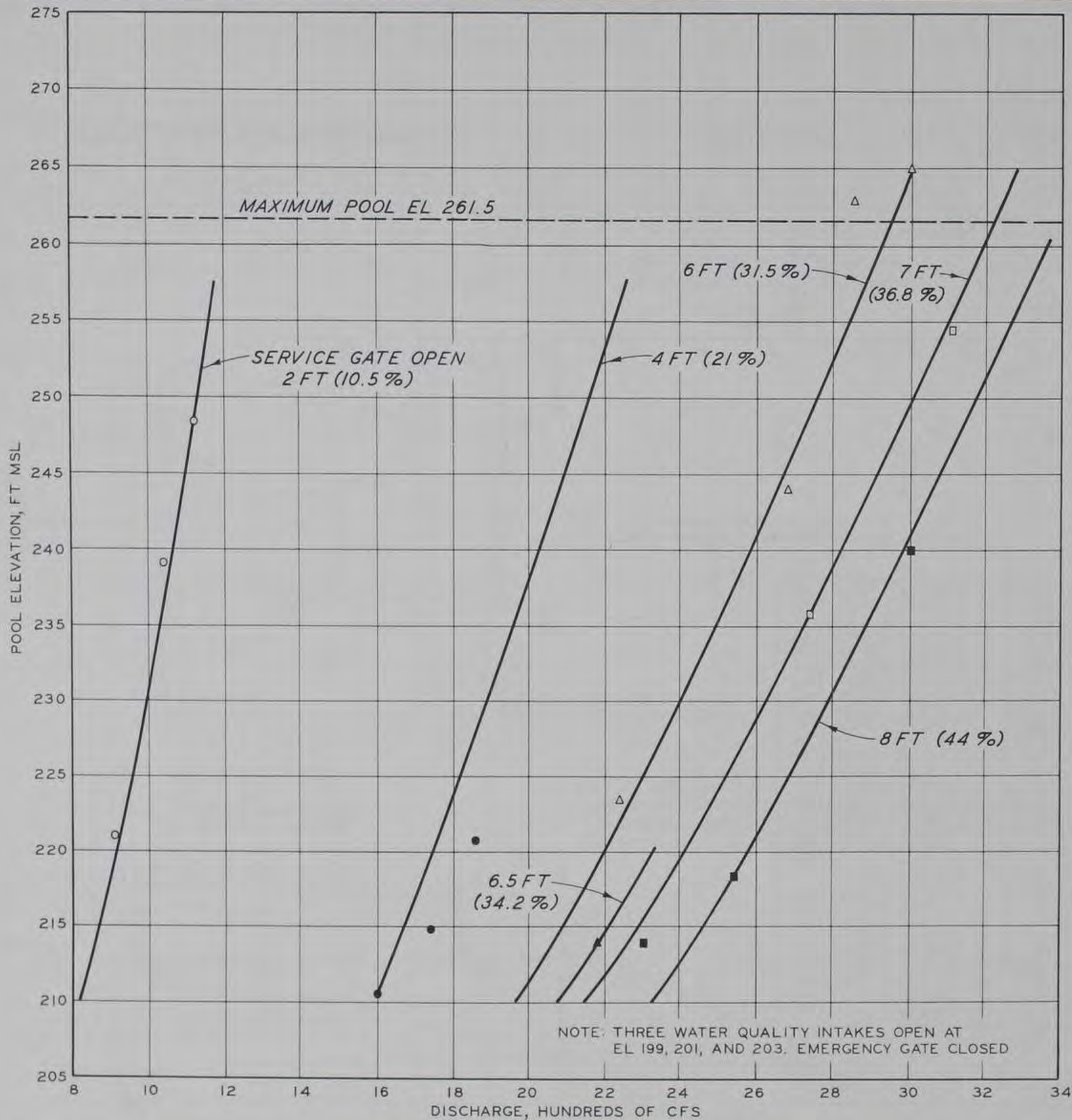


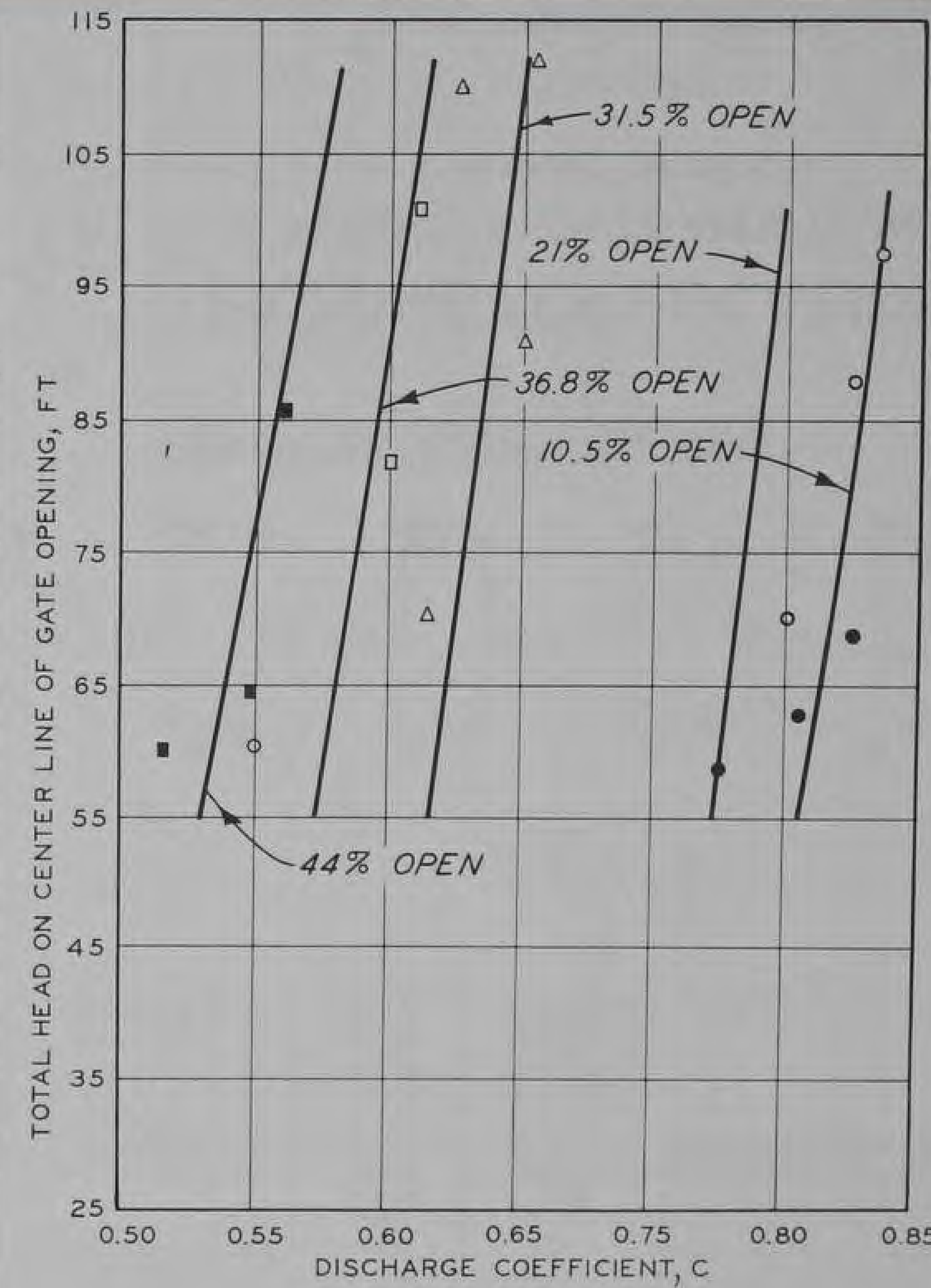
NOTE: MULTILEVEL INTAKES CLOSED.

SERVICE GATE RATING
FLOOD-CONTROL FLOW
SINGLE SERVICE GATE
DISCHARGE 3000 CFS



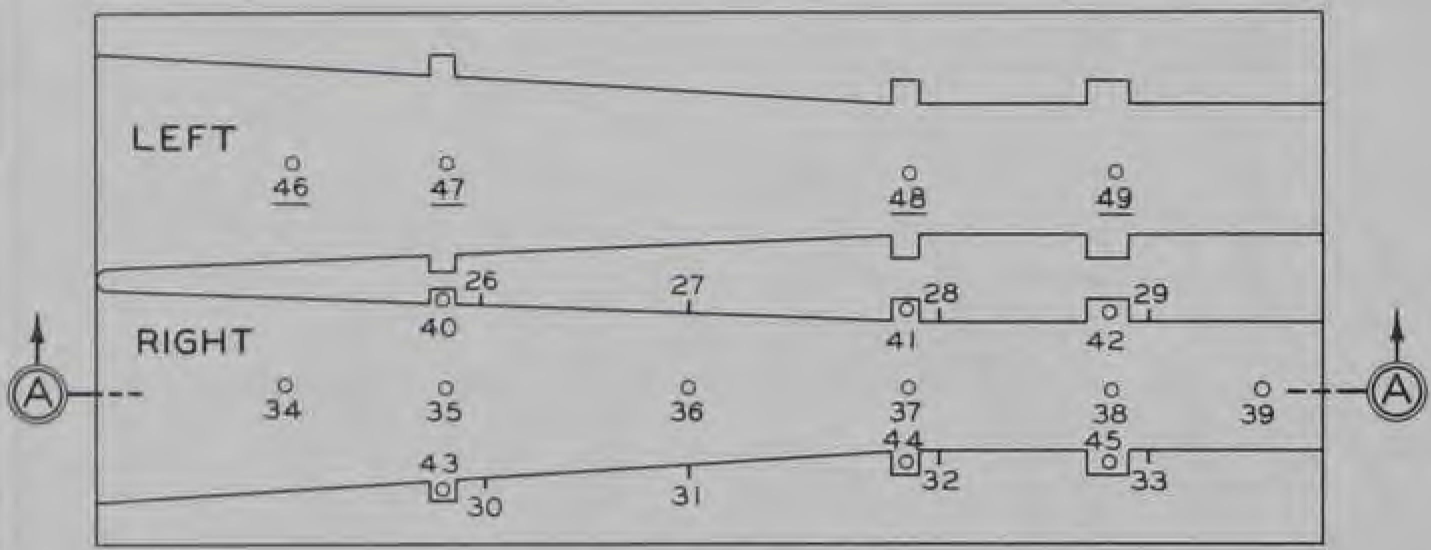
DISCHARGE RATING CURVE
WATER-QUALITY FLOW
SINGLE SERVICE GATE
POOL ELEVATION 216





NOTE: MODEL COEFFICIENT DETERMINED FROM EQUATION $Q = CA\sqrt{2gH}$
A=AREA OF GATE OPENING
H=HEAD TO CENTER OF GATE OPENING
SERVICE GATE IS 19 FT HIGH BY 9 FT WIDE
MULTILEVEL INTAKE 8 X 8 FT

DISCHARGE RATING CURVES
WATER-QUALITY FLOW
SINGLE SERVICE GATE
PARTIAL OPENING



INTAKE PLAN

CONDUIT INTAKE		
PIEZ NO.	EL	STA
1	178.50	4+47.2
2	177.75	4+46.6
3	175.75	4+45.4
4	175.00	4+44.6
5	174.25	4+43.8
6	173.75	4+42.9
7	173.25	4+42.0
8	173.00	4+41.0
9	172.50	4+40.1
10	172.00	4+39.1
11	171.75	4+38.2
12	171.50	4+37.3
13	171.25	4+36.3
14	170.75	4+34.3
15	170.25	4+32.3
16	169.75	4+30.4
17	169.25	4+26.4
18	169.00	4+22.4
19	169.00	4+18.4
20	171.50	4+08.8
21	170.50	4+08.4
22	169.75	4+07.6
23	169.25	4+06.5
24	169.00	4+04.5
25	169.00	3+91.0
26	159.50	4+45.4
27	159.50	4+16.0
28	159.50	4+12.0
29	159.50	3+87.5
30	159.50	4+45.4

CONDUIT INTAKE (CONT)		
PIEZ NO.	EL	STA
31	159.50	4+16.0
32	159.50	4+12.0
33	159.50	3+87.5
34	150.00	4+60.5
35	150.00	4+48.4
36	150.00	4+16.0
37	150.00	4+14.0
38	150.00	4+00.0
39	150.00	3+91.0
40	150.00	4+48.4
41	150.00	4+14.0
42	150.00	4+00.0
43	150.00	4+48.4
44	150.00	4+14.0
45	150.00	4+00.0
46	150.00	4+60.5
47	150.00	4+48.4
48	150.00	4+14.0
49	150.00	4+00.0

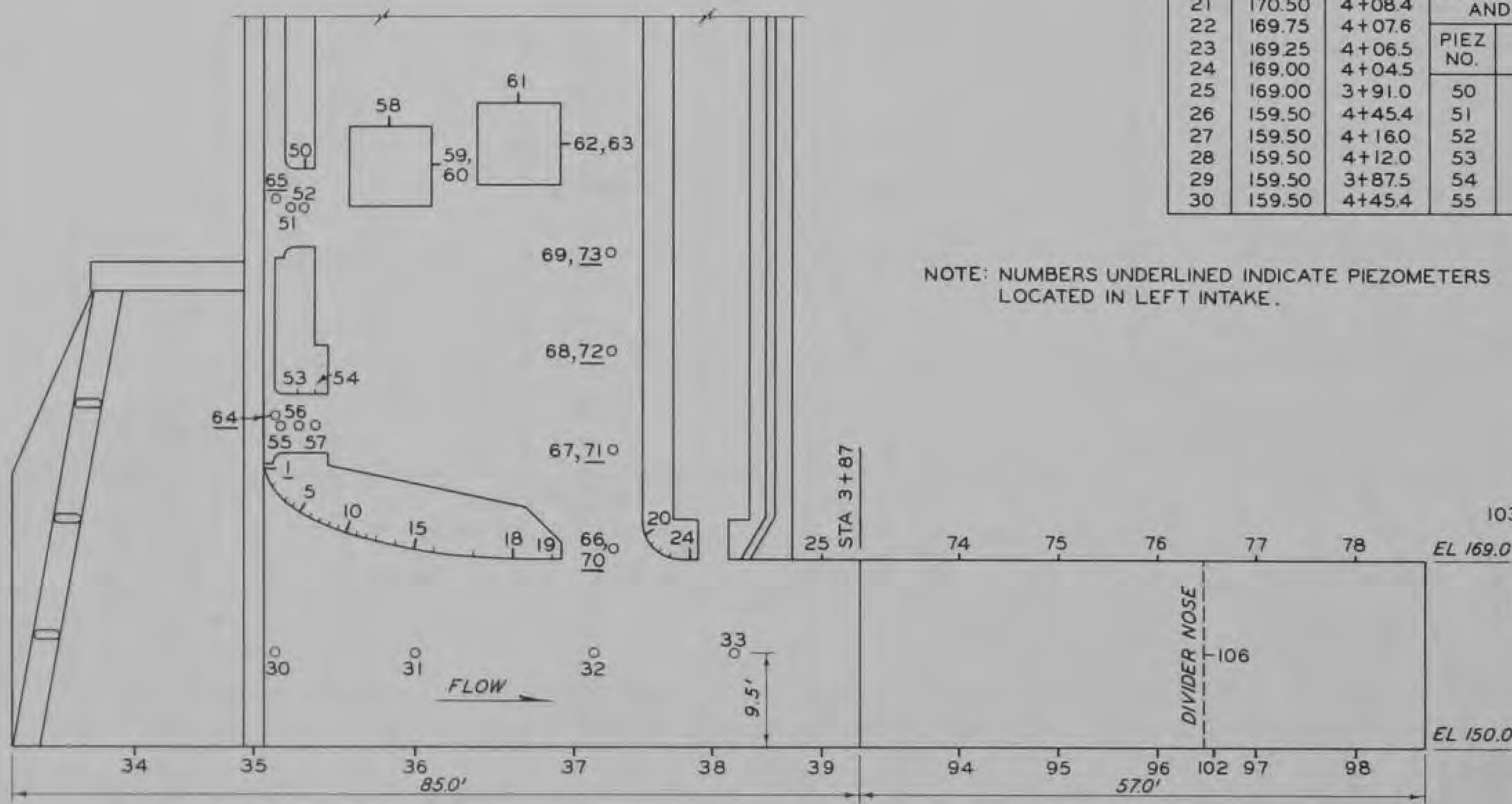
MULTILEVEL GATE ENTRANCE AND INTERIOR OF TOWER		
PIEZ NO.	EL	STA
50	217.00	4+43.0
51	208.75	4+45.0
52	209.00	4+43.0
53	194.00	4+44.8
54	194.00	4+42.8
55	184.75	4+46.8

MULTILEVEL GATE ENTRANCE AND INTERIOR OF TOWER (CONT)		
PIEZ NO.	EL	STA
56	188.00	4+44.8
57	188.00	4+42.8
58	213.00	4+34.5
59	209.00	4+30.5
60	209.00	4+30.5
61	215.00	4+21.5
62	211.00	4+17.5
63	211.00	4+17.5
64	183.50	4+47.4
65	201.50	4+47.4
66	170.00	4+12.0
67	180.00	4+12.0
68	190.00	4+12.0
69	200.00	4+12.0
70	170.00	4+12.0
71	180.00	4+12.0
72	190.00	4+12.0
73	200.00	4+12.0

TRANSITION		
PIEZ NO.	EL	STA
74	169.00	3+77.0
75	169.00	3+67.0
76	169.00	3+57.0
77	169.00	3+47.0
78	169.00	3+37.0
79	168.70	3+77.0
80	167.90	3+67.0
81	167.10	3+57.0

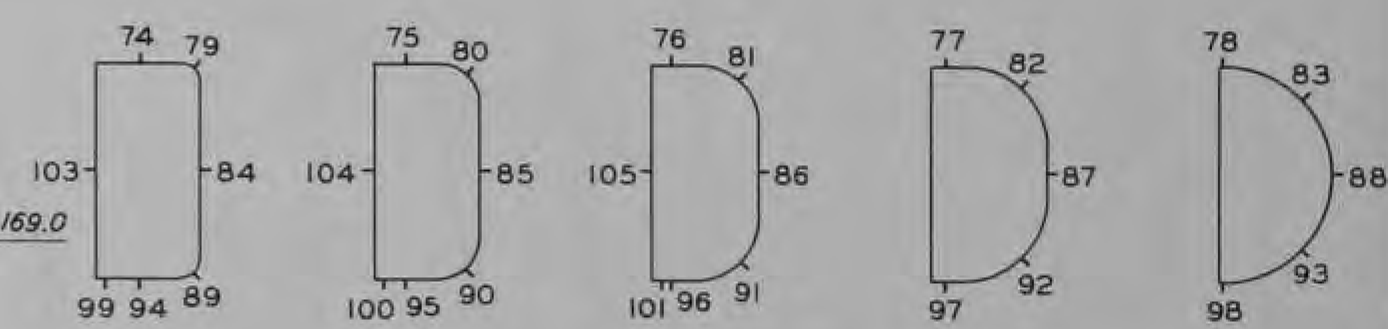
TRANSITION (CONT)		
PIEZ NO.	EL	STA
82	166.80	3+47.0
83	166.40	3+37.0
84	159.50	3+77.0
85	159.50	3+67.0
86	159.50	3+57.0
87	159.50	3+47.0
88	159.50	3+37.0
89	150.30	3+77.0
90	151.10	3+67.0
91	151.90	3+57.0
92	152.20	3+47.0
93	152.60	3+37.0
94	150.00	3+77.0
95	150.00	3+67.0
96	150.00	3+57.0
97	150.00	3+47.0
98	150.00	3+37.0
99	150.00	3+77.0
100	150.00	3+67.0
101	150.00	3+57.0
102	150.00	3+48.3
103	159.50	3+77.0
104	159.50	3+67.0
105	159.50	3+57.0
106	159.50	3+49.3

NOTE: NUMBERS UNDERLINED INDICATE PIEZOMETERS LOCATED IN LEFT INTAKE.



INTAKE ELEVATION SECTION A-A

TRANSITION



TRANSITION HALF-SECTIONS

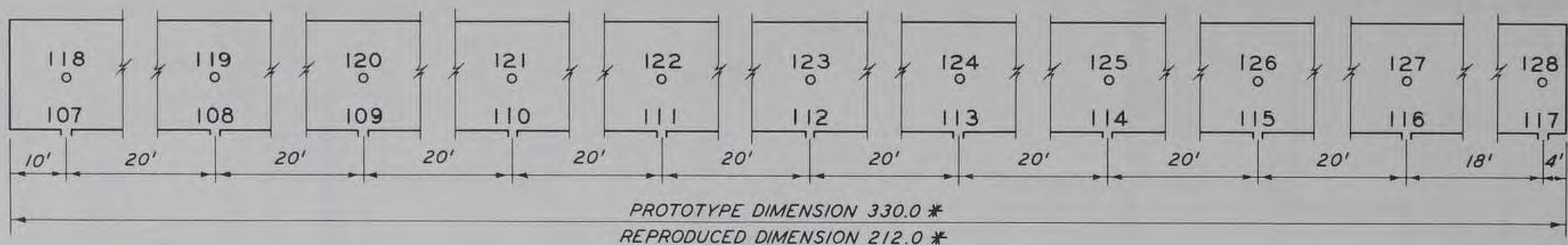
PIEZOMETER LOCATIONS

INTAKE AND TRANSITION

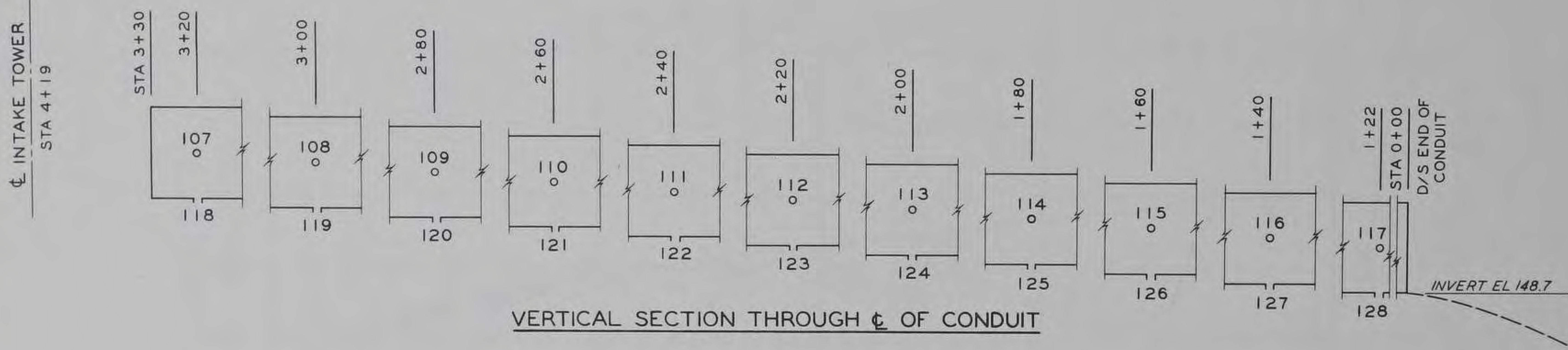
ORIGINAL DESIGN

SCALE IN FEET

10 0 10 20 30



PLAN



VERTICAL SECTION THROUGH ℄ OF CONDUIT

PIEZ NO.	PIEZ EL	PIEZ NO.	PIEZ EL
107	159.4	118	149.9
108	159.3	119	149.8
109	159.2	120	149.7
110	159.1	121	149.6
111	158.9	122	149.5
112	158.8	123	149.3
113	158.7	124	149.2
114	158.6	125	149.1
115	158.5	126	149.0
116	158.3	127	148.8
117	158.2	128	148.7

* AS FRICTION LOSSES IN THE PLASTIC MODEL WERE GREATER THAN PROTOTYPE LOSSES, IT WAS NECESSARY TO SHORTEN THE MODEL CONDUIT AS SHOWN TO SIMULATE ACCURATELY THE HYDRAULIC GRADE LINE AT THE INTAKE.

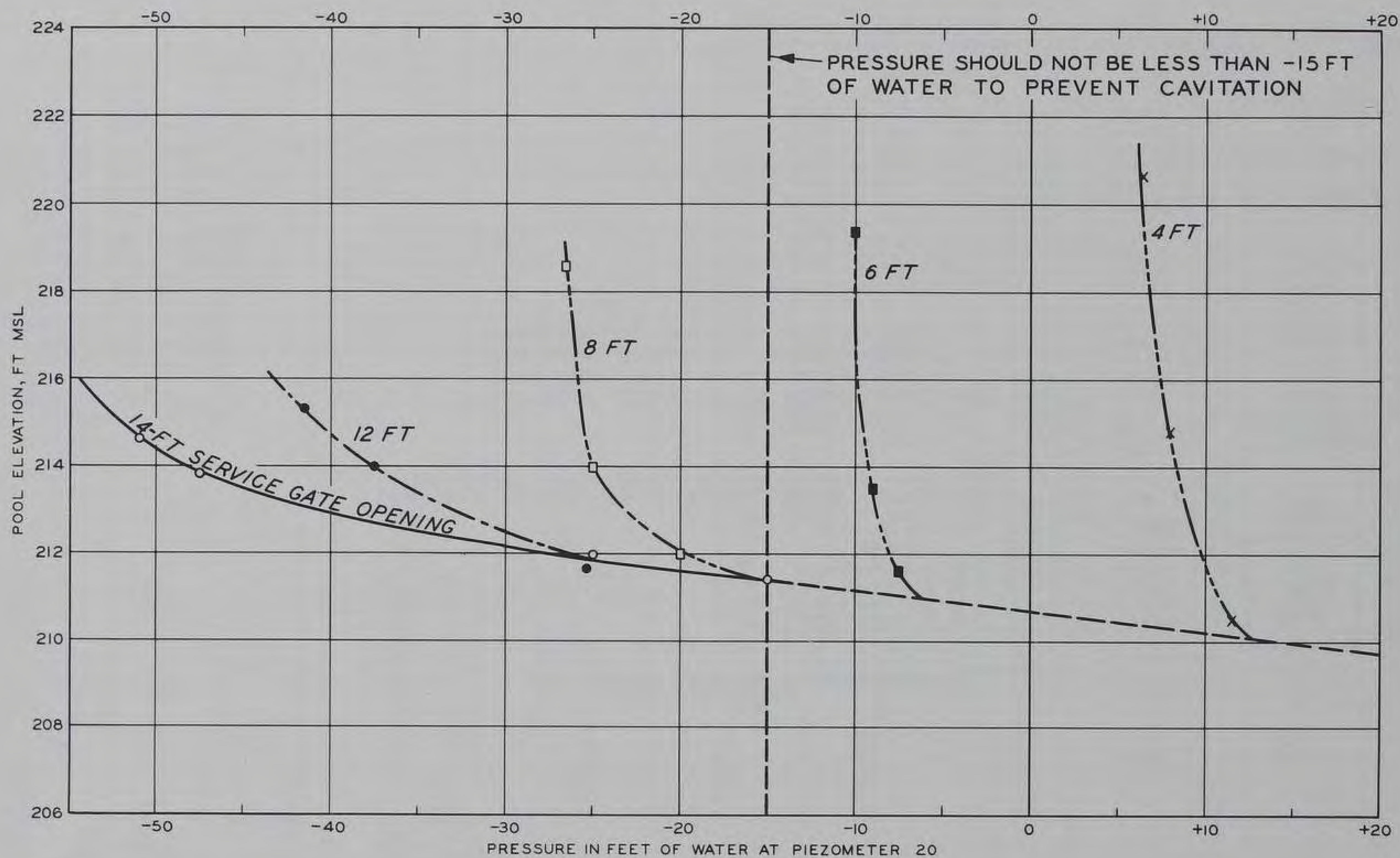
PIEZOMETER (CONDUIT) LOCATIONS

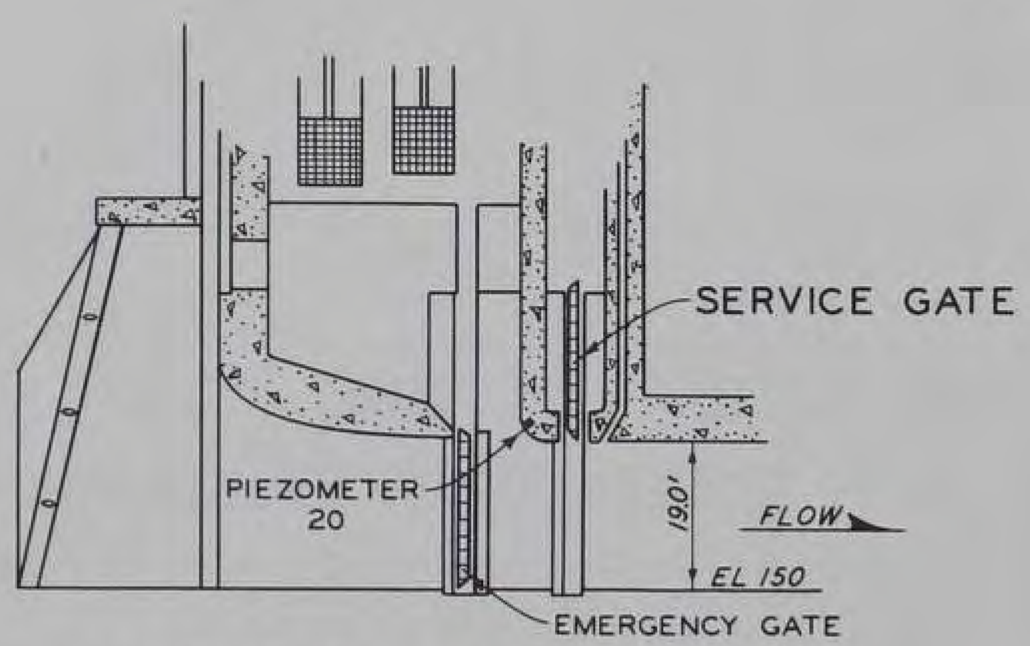
TYPE I (ORIGINAL) DESIGN

SCALE IN FEET

10 0 10 20

PLATE 10

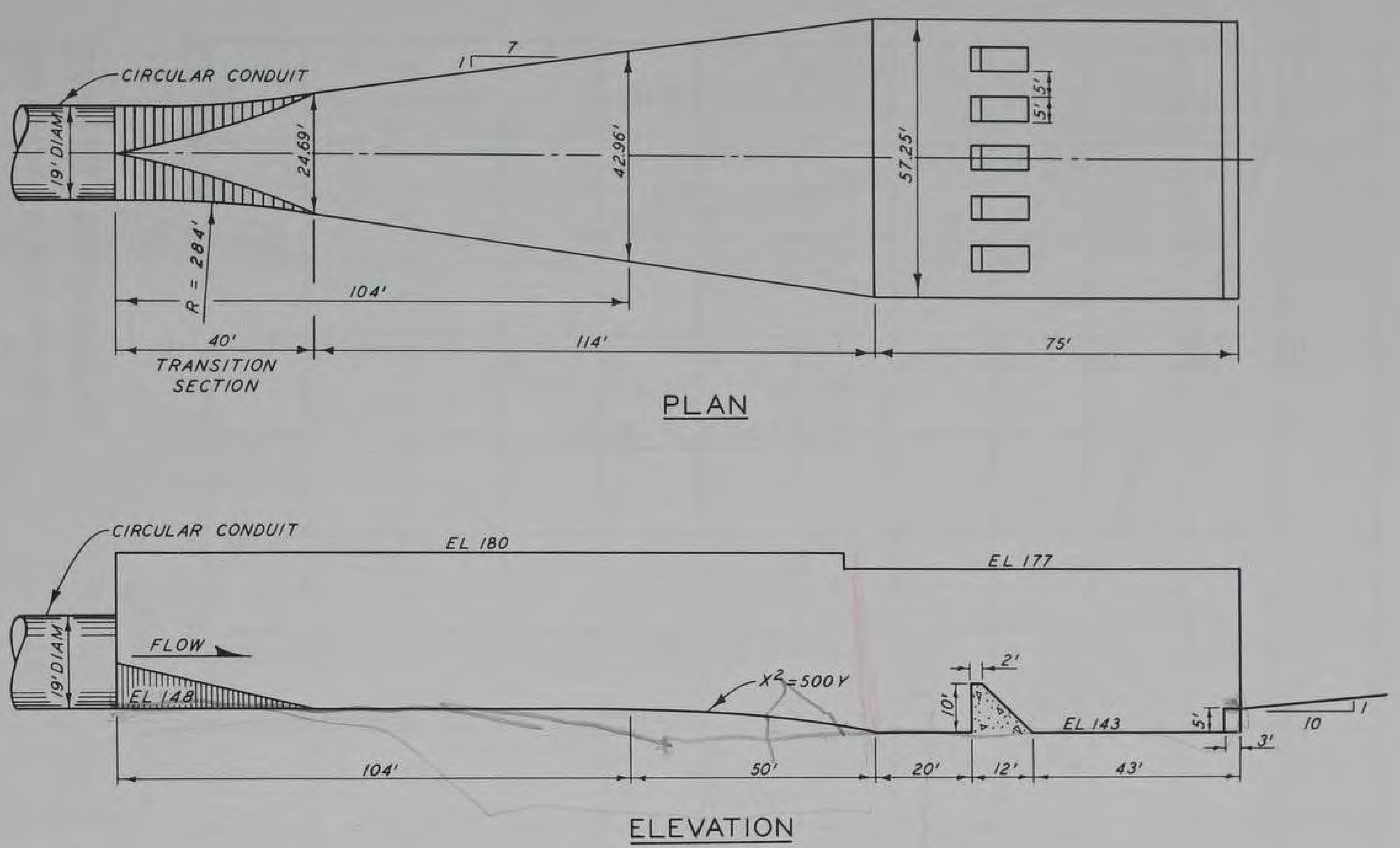




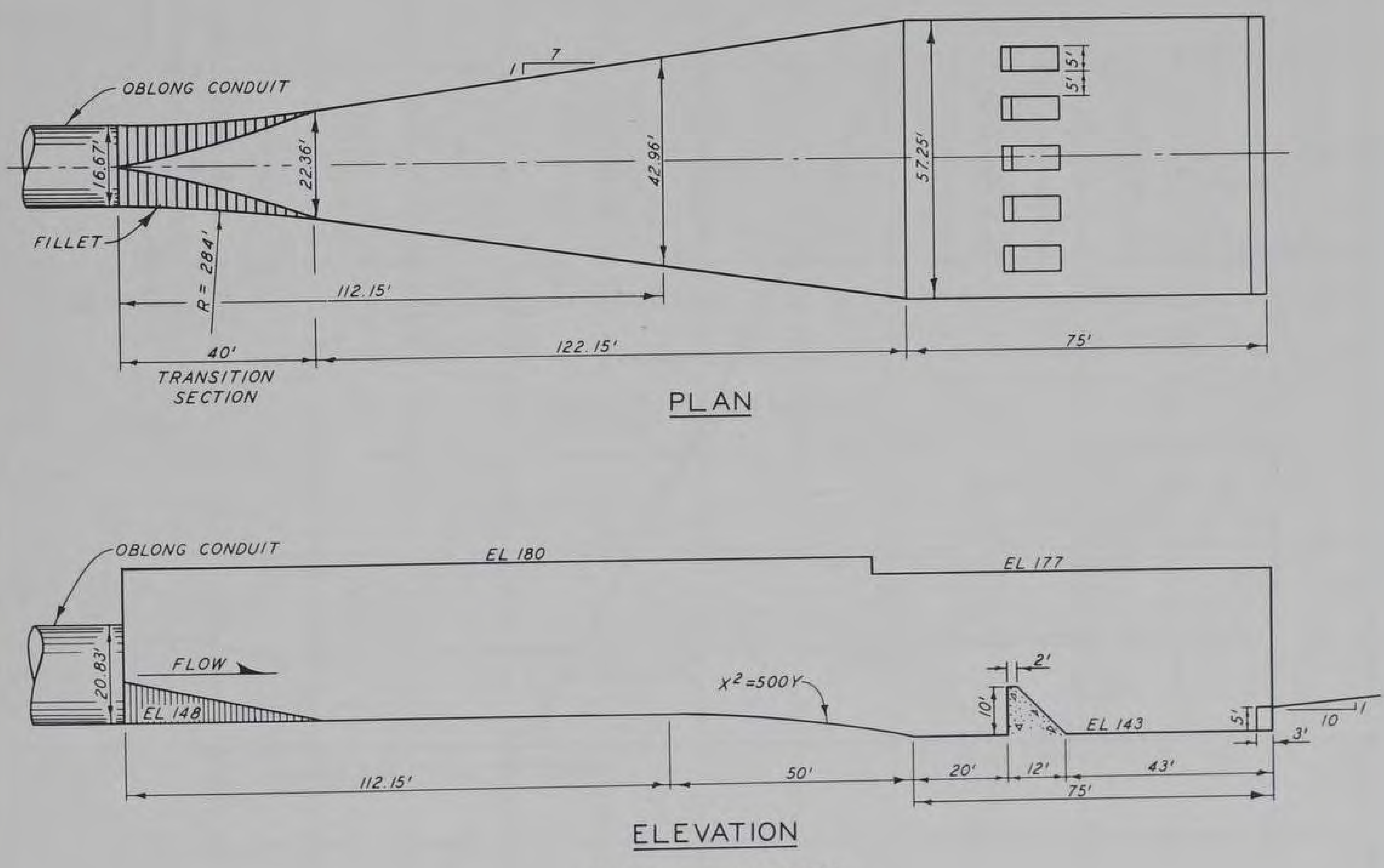
MULTILEVEL THROAT SECTION

NOTE: THREE 8- X 8-FT MULTILEVEL INTAKES OPEN FULL AND EMERGENCY GATE CLOSED

MINIMUM PRESSURES IN MULTILEVEL THROAT SECTION



TYPE 2 BASIN



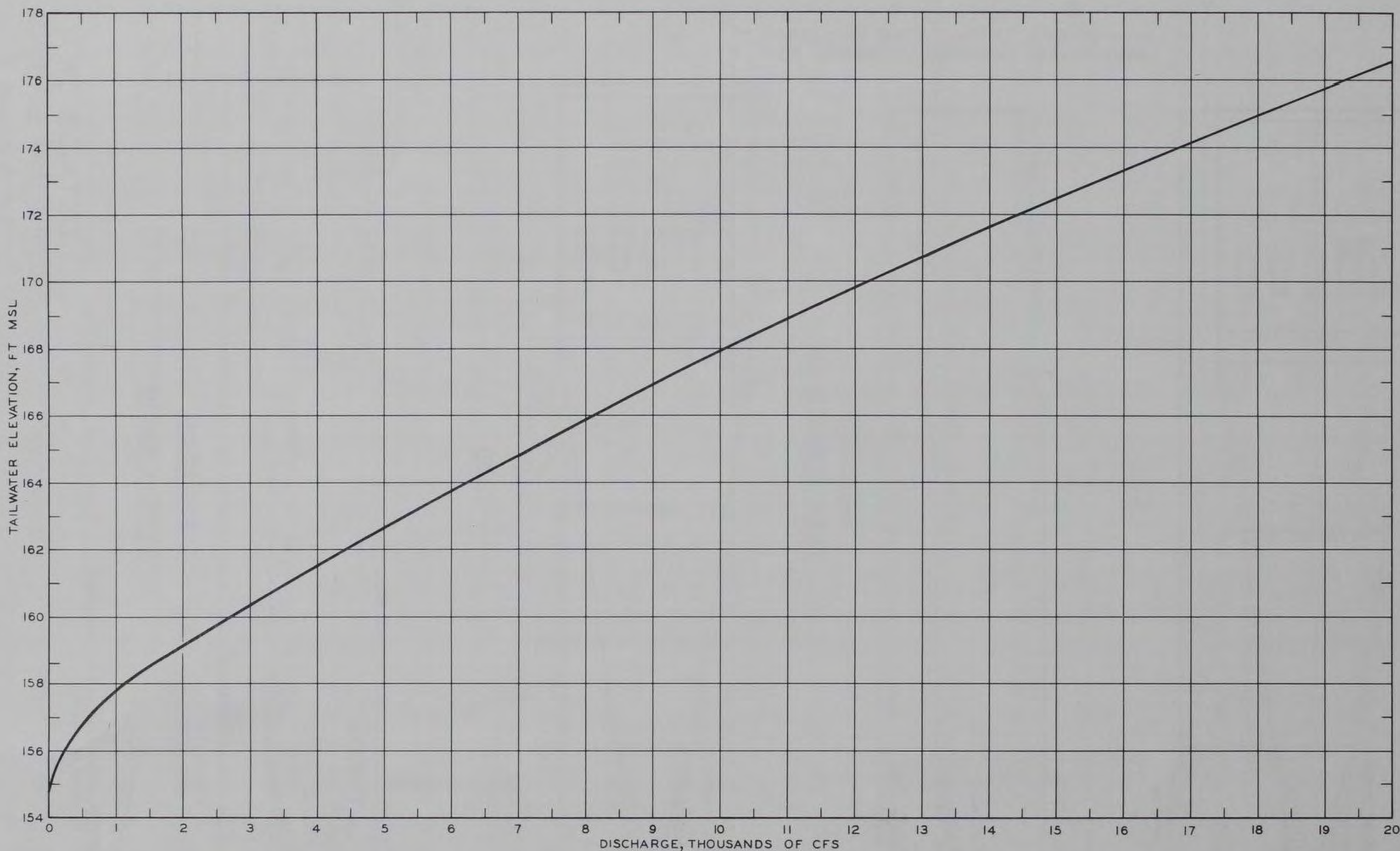
TYPE 3 BASIN

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

DETAILS OF STILLING BASINS

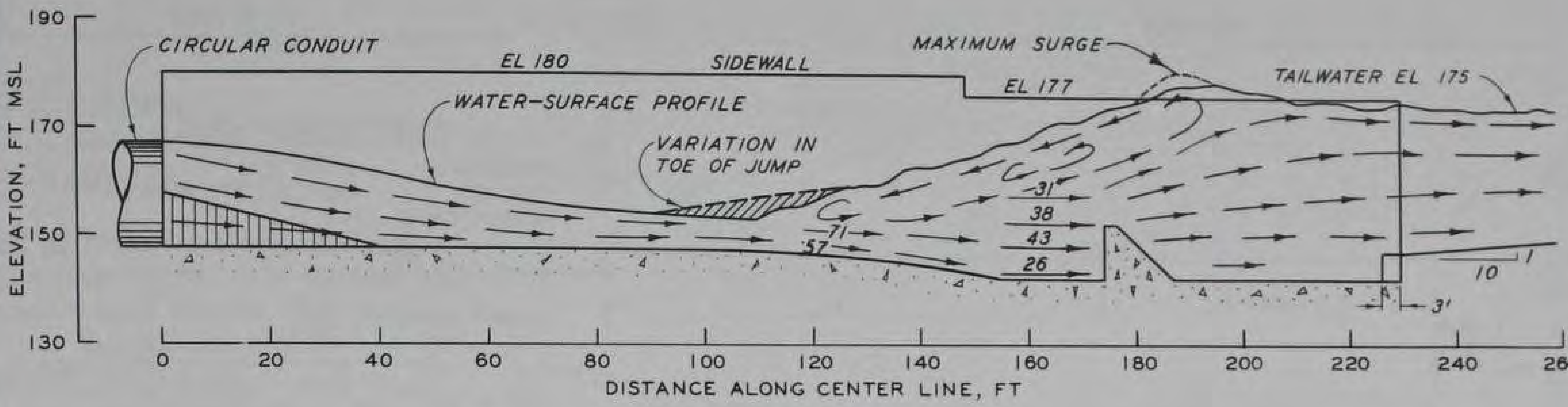
TYPES 2 AND 3

PLATE 12

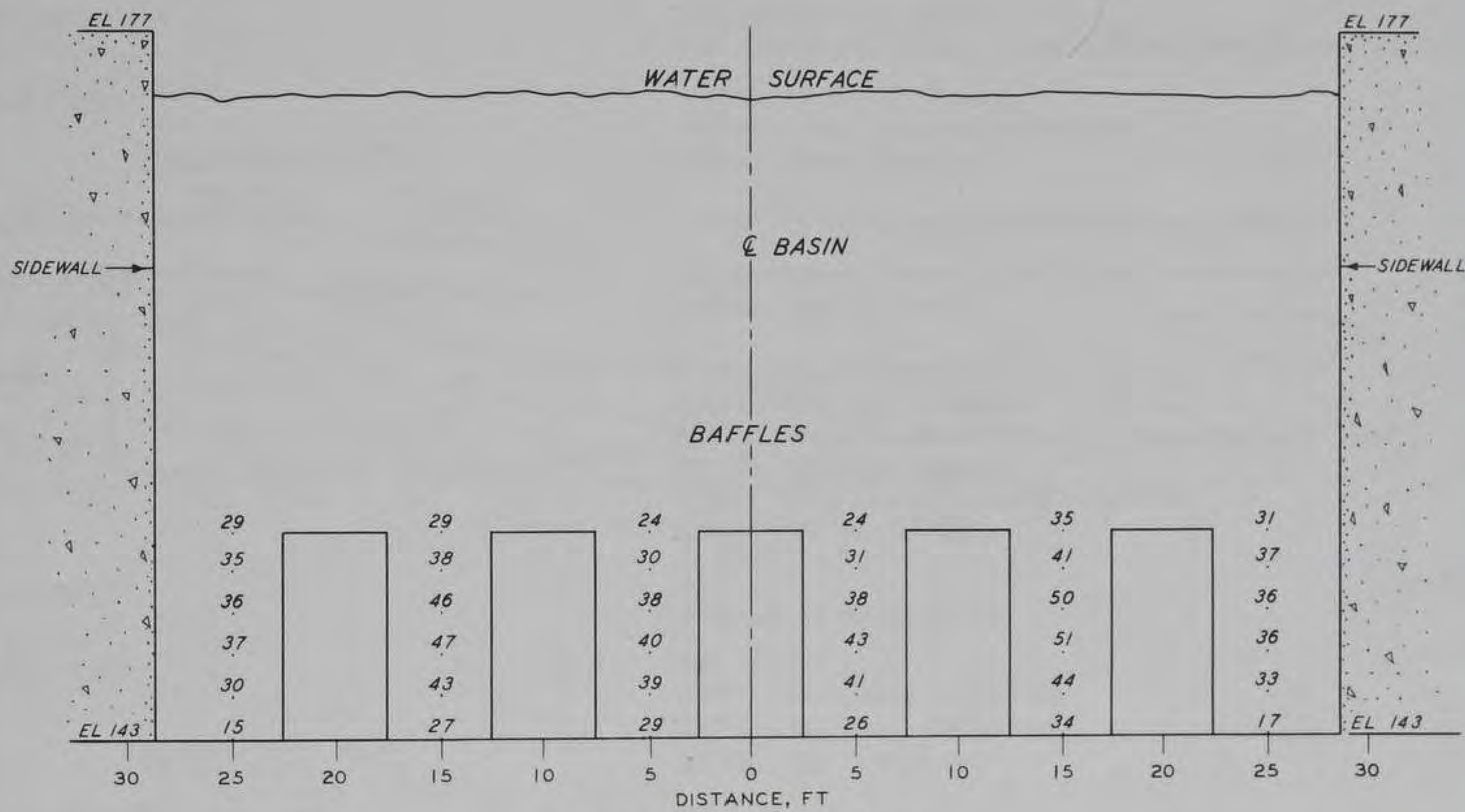


TAILWATER CURVE

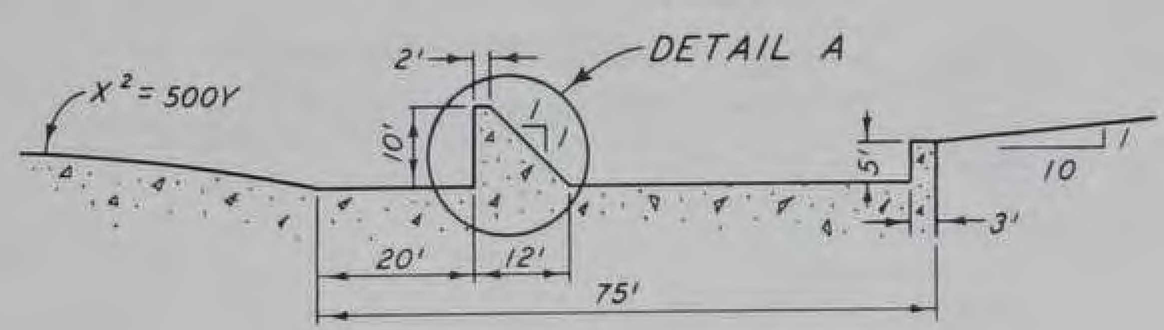
LOW-FLOW DISCHARGE



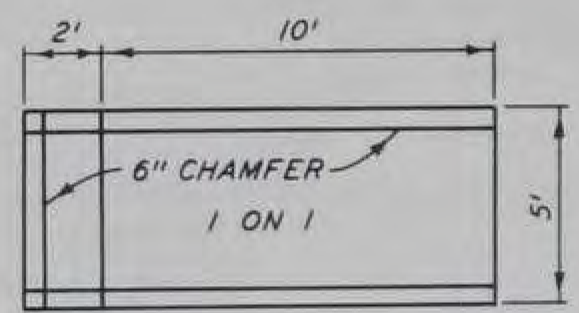
SIDE ELEVATION



FRONT ELEVATION



BAFFLE LOCATION



PLAN

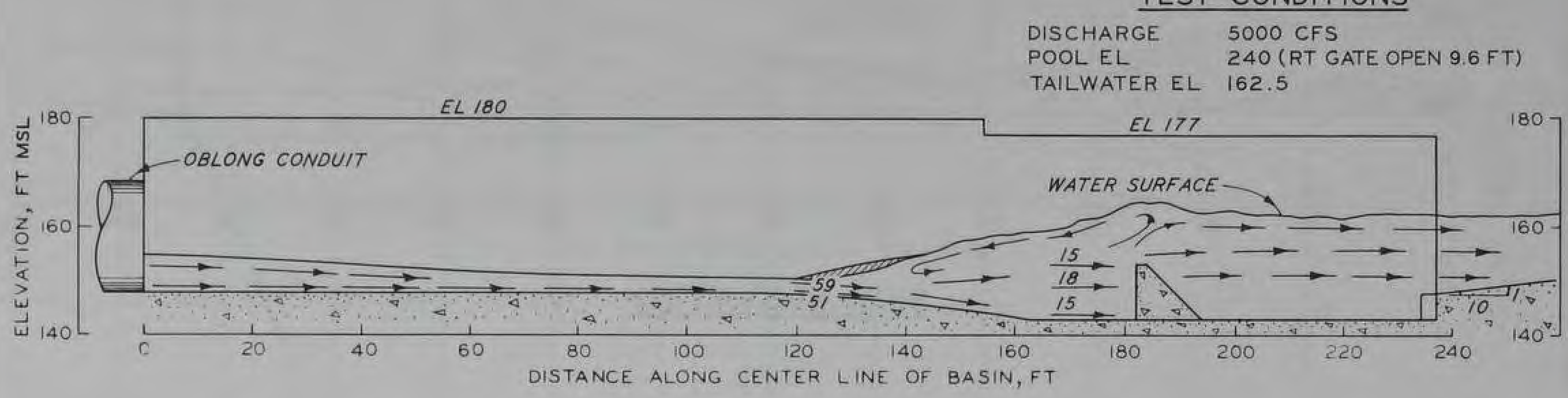
DETAIL A

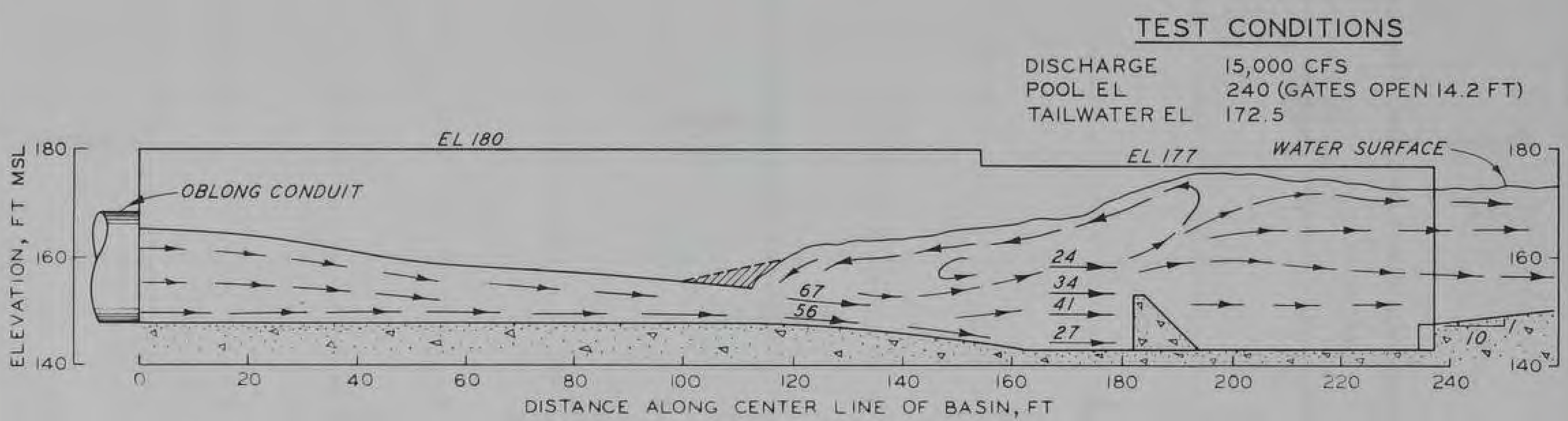
NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND

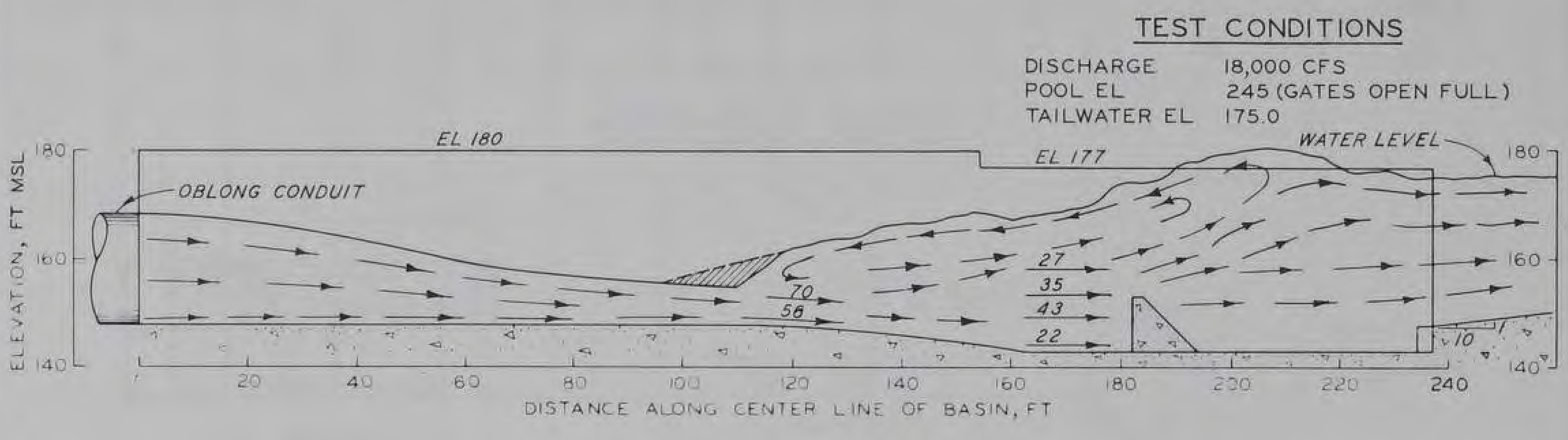
WATER-SURFACE PROFILE AND FLOW CHARACTERISTICS

TYPE 2 STILLING BASIN

DISCHARGE 18,000 CFS







NOTE: VELOCITIES ARE IN PROTOTYPE FEET PER SECOND.

WATER-SURFACE PROFILES AND FLOW CHARACTERISTICS
TYPE 3 STILLING BASIN
DISCHARGES 5000, 15,000, AND 18,000 CFS

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4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	U. S. Army Engineer District Savannah, Georgia

13. ABSTRACT

Model investigation of the outlet works for the New Hope Reservoir was initially concerned with verification and improvement of the hydraulic design of the intake structure, conduit, and stilling basin. Subsequent tests involved observations of the effectiveness of the multilevel intakes in providing selective withdrawal of flow from the epilimnion or upper stratum of a stratified reservoir. The study was conducted in a 1:20-scale model of the outlet works which reproduced a portion of the approach area, the intake structure, the outlet conduit, the hydraulic-jump type stilling basin, and approximately 800 ft of exit channel. The proposed intake structure provided effective regulation of flood-control releases as well as those which are desired to provide quality water downstream during both summer and winter. However, certain operational procedures are necessary to prevent dangerous subatmospheric pressures in the throat section of the water-quality system. Flow conditions in the original conduit intakes, throughout the flood-control facilities, and downstream to the conduit outlet were satisfactory with pressure conditions remaining positive for all discharges with little or no fluctuation. There was no tendency for structural vibration with either flood-control or water-quality flows. Performance of the original design stilling basin was unacceptable as unstable hydraulic action and eddy formation resulted in very turbulent basin conditions with little or no energy dissipation. Raising the elevation of the basin and lengthening and modifying the transition section (types 2 and 3 basins) resulted in adequate, if not ideal, performance. Single gate operation produced unbalanced flow in the basin; however, as single gate operation is rarely necessary, types 2 and 3 basins are considered acceptable for prototype construction. It was determined that riprap protection is required on both banks of the exit channel.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Hydraulic models						
New Hope Reservoir						
Outlet works						
Stilling basins						
Water flow						