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PAONIA SPWY & OW

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

WM. E. WAGNER

HYDRAULIC MODEL STUDIES OF PAONIA DAM SPILLWAY AND OUTLET WORKS

Hydraulic Laboratory Report No. Hyd-444

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
DENVER, COLORADO

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UNITED STATES
DEPARTMENT OF THE INTERIOR
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June 19, 1959	Reviewed by: J. W. Ball
	Submitted by: H. M. Martin

Subject: Hydraulic model studies of Paonia Dam spillway and outlet works

SUMMARY

Hydraulic model studies of the Paonia Dam spillway and the outlet works junction with the spillway, Figures 1 through 6, inclusive, were conducted on a 1:36 scale model, Figures 8, 9, 10, and 11, to develop the hydraulic design of the structures.

Data and notes taken on the flow in the model showed the general concept of the preliminary structure to be satisfactory but indicated that certain modifications were desirable. The side channel spillway basin was modified to gain a lower cost basin without sacrificing good hydraulic performance, Figures 12 through 18, inclusive; the left approach wing wall was modified to improve flow conditions in the immediate vicinity, Figures 19 and 20; the chute training walls were extended in height to increase the freeboard, Figures 21 and 22; and the stilling basin was modified to provide a smoother water surface in the discharge channel, Figures 25 through 41. The junction of the spillway and outlet works performed satisfactorily without modification, Figures 23 and 24.

ACKNOWLEDGMENT

The final plans evolved from this study were developed through the cooperation of the staffs of the Spillway and Outlet Works Section and the Hydraulic Laboratory during the period from March 1957 to September 1957.

INTRODUCTION

Paonia Dam, part of the Paonia Project, is located on Muddy Creek, a tributary of the North Fork of the Gunnison River in the west central part of Colorado near Paonia, Figure 1. The dam, Figure 2, is an earthfill structure, approximately 1,000 feet long and 180 feet above the riverbed, with facilities for a spillway and outlet works.

The spillway, Figures 3, 4, 5, and 6, is an open channel chute located near the right abutment. At reservoir elevation 6454, the spillway is designed to discharge 12,600 second-feet over a side channel spillway crest at elevation 6447.5. The approach to the spillway consists of an excavated area at elevation 6444.0 adjacent to the crest. The crest extends across the upstream end and along the left-hand side of the side channel basin. The side channel basin floor is 150 feet long, 20 feet wide at the upstream end, and 30 feet wide at the downstream end. The basin floor is at elevation 6424 at the upstream end and elevation 6423 at the downstream end.

The spillway chute is 547 feet long, measured horizontally, and drops from elevation 6423 at the upstream end to elevation 6243 at the downstream end where it joins the stilling basin apron. The chute is straight and is symmetrical about the center line of the side channel basin. The first 362 feet of the chute is 30 feet wide. The remainder of the chute flares to a 42-foot width at the stilling basin. The upstream portion of the chute is on a 4:1 slope, and the downstream portion is on a 2:1 slope. The two portions are joined by a 100-foot vertical curve. Four chute blocks are placed at the downstream end of the chute, each 4 feet high and 4 feet 9 inches wide.

The stilling basin is 120 feet long, 42 feet wide, and has parallel training walls 48 feet high. Apron elevation 6243 is 43.3 feet below the maximum anticipated tail water elevation for 12,600 second-feet. A dentated end sill having five dentils is located at the downstream end of the basin. Each dentil is 4 feet 9 inches wide by 9 feet high.

The excavated area surrounding the basin is riprapped. Since there are no wing walls at the ends of the basin training walls, the riprapped area slopes upward upstream and to the two sides as well as in a downstream direction. Upstream and to the sides, the riprap slope is 2:1; in the downstream direction, the slope is upward 5:1 to riverbed elevation 6272. The riverbed is in earth.

The outlet works, Figure 3, is located in the right abutment and discharges onto the spillway chute. The maximum discharge is 1,120 second-feet at maximum reservoir elevation; normal discharge is 780 second-feet. The flow is controlled by two 2-foot 9-inch square high pressure slide gates located in a gate chamber in the interior of the dam. The gates discharge into a 10-foot 6-inch wide ventilated tunnel which carries the open channel-type flow 410 feet, on a slope of 0.03713, to an 86-foot vertical curve that becomes tangent to the 2:1 slope of the spillway chute. The details of the outlet works junction with the spillway chute are shown in Figure 6. The minimum anticipated depth of flow in the outlet works junction section, obtained from computations, is shown in Figure 7.

THE MODEL

The model was a 1:36 scale reproduction of the spillway and surrounding area, including a portion of the outlet works tunnel joining the spillway chute, Figures 8, 9, and 10. It was constructed and tested in the Bureau of Reclamation Hydraulic Laboratory in Denver, Colorado.

THE INVESTIGATION

The primary purpose of the investigation was to develop the hydraulic design of the spillway structure, including the junction of the outlet works and spillway structures. In developing the spillway design, it was necessary to study the characteristics of the flow as it approached and passed through the spillway as well as in the downstream river channel. In developing the junction of the outlet works tunnel with the spillway, it was necessary to study the flow conditions when the outlet works and spillway were discharging, both separately and simultaneously.

The model of the preliminary spillway, Figures 8 and 9, was tested for a range of discharges and, in general, was found to perform satisfactorily. Only for discharges near the design flow was the performance inadequate in some respects. For the design flow of 12,600 cfs, the side channel basin at the spillway entrance was not completely utilized and a turbulent disturbance occurred near the left approach training wall; at the downstream end of the spillway chute, the water surface neared the top of the training walls and the spillway basin appeared to be inadequate to contain the hydraulic jump. A high water surface boil produced by the action of the hydraulic jump was observed in the river channel at the downstream end of the basin. The preliminary design of the junction of the spillway and outlet works performed very satisfactorily.

Preliminary Spillway Entrance

The spillway entrance as discussed here includes the approach channel, the spillway crest section, and the side channel basin. The model of the preliminary design is shown in Figures 8 and 9. Flow conditions were satisfactory except for a turbulent area at the left approach training wall for maximum and near maximum flows, as shown in Figures 11A and 12B.

Pressures recorded on the spillway profile, Figure 13, at a section located approximately 19 feet upstream from the left approach wall showed the crest shape to be well designed. The pressures were near atmospheric for the complete discharge range. Pressures at the downstream end of the profile increased as the piezometers became submerged by larger discharges which raised the water level within the basin.

Spillway discharge calibration tests, Figure 14, showed the spillway to discharge the design flow of 12,600 cfs at reservoir elevation 6453.0 which is 0.1 of a foot below the maximum design reservoir elevation. Discharge coefficients were computed from the equation

$$Q = CLH^{3/2}$$

where

- Q = the total discharge
- C = the discharge coefficient
- L = the crest length measured along its axis at elevation 6447.5, and
- H = the difference in elevation between the reservoir and crest

A coefficient of 3.72 for 12,600 cfs was computed from the test data, Figure 14.

The water surface profile along the center line of the side channel basin, Figure 15, appeared to be sufficiently low that the basin floor at its downstream end could be raised to the elevation of the chute floor to eliminate the step up from the basin floor to the chute floor. Elimination of the step would provide a smooth floor which would not trap debris or require draining. In addition, wall heights would thereby be reduced, making the structure more economical to construct.

<u>Spillway Entrance Modifications</u>

In the first modification to eliminate the step, the upstream end of the side channel basin floor was lowered and the downstream end raised so that the entire floor was level at elevation 6421.75, the original elevation of the upstream end of the chute floor. Calibration tests showed that, for the design flow of 12,600 second-feet, the reservoir was at design elevation 6454 and the discharge coefficient was reduced to 3.52. In the side channel basin, the water surface elevation was higher, Figure 15, but in the spillway chute it was lower.

It was considered permissible to exceed the design reservoir elevation 6454 slightly to provide a still more economical structure. Therefore, the basin floor was modified again by raising it 2.25 feet to elevation 6424. Calibration tests showed that the design flow of 12,600 cfs was discharged at reservoir elevation 6454.2 which was considered to be higher than desirable. The coefficient for maximum flow was 3.36. The water surface elevation in the side channel basin was raised about 2 feet and remained about the same as before in the chute.

Recommended Spillway Entrance

The side channel basin floor was modified once again to reduce the reservoir elevation and to provide drainage for the basin floor. The upstream end was placed at elevation 6424 and the downstream end at elevation 6423. This design was adopted for prototype use and is shown in Figure 3. Calibration tests, Figure 14, showed the design flow of 12,600 cfs to be discharged at reservoir elevation 6454.1. The spillway discharge coefficient for the design discharge is 3.53, although the maximum spillway coefficient is 3.63 and occurs just before the crest of the side channel basin becomes submerged at reservoir elevation 6453.7 and a discharge of approximately 11,500 cfs.

Poor flow appearance and excessive turbulence which occurred near the wall in the preliminary design, Figure 16A, was remedied quite effectively by placing rockfill on the dam face upstream from the wall, Figure 16B. However, a more effective and economical method was to reshape the wall, Figure 17. This wall was used in the recommended design. Water surface fluctuations at Point A in Figure 16B were sufficient, however, to make it necessary to raise the wall 4 feet higher than in the preliminary design to prevent overtopping by the flow. Velocity measurements around the upstream curvature of the wall showed the flow velocity to be approximately 7 feet per second. This was considered to be sufficiently low to prevent riprap movement.

The recommended spillway discharging the design flow, Figure 18, provides a full side channel basin discharging smoothly into the spillway chute. The basin also performs well in discharging lesser flows as shown in Figure 19. The lines on the walls in Figure 18 are profiles of the water surfaces for the various modified basins discharging the design flow. The solid black line is the water surface profile for the preliminary design, and the white line is the profile for the recommended design. Water surface profiles along the center line of the side channel basin are shown in Figure 15.

Spillway Chute

The flow passed through the preliminary spillway chute in a very satisfactory manner. The water was uniformly distributed across the chute and no high waves occurred, Figure 20. However, water surface fluctuations along the walls occasionally extended to the top. After the recommended side channel basin was installed at the entrance to the chute, the water surface was about 2 to 3 feet lower in the upstream portion of the chute and about 1/2 foot lower in the downstream portion. Nevertheless, it was decided to increase the freeboard as shown in Figure 21.

The Spillway and Outlet Works Junction

The outlet works, Figure 3, is designed to discharge about 800 cfs at reservoir elevation 6370.0 and 1,120 cfs at elevation 6454.1. During the early part of the test program, however, it was contemplated that the outlet works would discharge 1,470 cfs at maximum reservoir elevation 6454.0 and that, normally, its maximum discharge would be 700 cfs; therefore, most of the tests were conducted using these discharges. The tail water curve in Figure 3 and the outlet works rating curve in Figure 7 were used to set the proper flow conditions in the model.

Flows of 700 and 1,470 cfs entered the spillway chute and stilling basin without producing any serious adverse effects, Figures 22A, 23B, and 23C. The relatively large spillway stilling basin was more than adequate to dissipate the energy in the outlet works discharge, and no concentrated flow currents passed over the end sill. There was no erosion of the riverbed produced by the outlet works flow. It seemed desirable, however, to improve the appearance of the outlet works flow as it entered the basin. Flow entering the tail water pool within the basin veered to either the left or the right without spreading and remained on one side or the other until reversed by a flow change such as opening or closing of the valve. Methods of stabilizing the flow in the center of the stilling basin pool were discussed and tried, such as a directional vane placed in the basin. However, no corrective measures were recommended because a simple device could not be found which would not introduce problems when the spillway was discharging. Also, the unstabilized flow in this particular instance caused no harmful effects.

It is possible that the prototype outlet works might continue to discharge when the spillway first begins to operate. Tests showed that the two flows joined together very nicely when the air vent just downstream from the outlet valves was open, Figure 23A. Closing the vent caused a considerable amount of spray where the two flows joined. With the vent open, the spillway flow passed over the outlet works tunnel opening with very little visible disturbance for discharges up to and including the design flow of 12,600 cfs with or without the outlet works discharging, Figures 22B and 22C. It is therefore important that ample air venting be provided and that the vent remain open at all times.

The piezometers located in the junction area, Figures 10 and 24, showed that only small subatmospheric pressures existed at a few of the measuring points for any combination of spillway and outlet works discharges when the air vent was open. However, with the outlet works air vent closed, some of the pressures were considerably below atmospheric, particularly when the spillway was operating either by itself or in conjunction with the outlet works. It was therefore important, from the standpoint of pressures as well as the possibility of flow disturbances occurring, that the outlet works tunnel be vented.

When the spillway is discharging the design flow, the subatmospheric pressures may be slightly lower than shown in the model test data because the velocity of the flow approaching the junction was approximately 10 percent less in the model than was computed for the prototype design flow. The velocity in the model represented a prototype velocity of about 90 feet per second. This velocity occurs for a prototype roughness coefficient in Manning's equation of $n = 0.014$; whereas, the velocity computed using a prototype roughness coefficient of $n = 0.008$ is about 100 feet per second.

Stilling Basin

Preliminary design. The preliminary stilling basin design is shown in Figures 3 and 25. The basin was designed for 12,600 cfs, or 300 cfs per foot of width, entering the basin at a velocity of 109 feet per second and a depth of 2.75 feet at Station 14+09 where the basin width is 42 feet. The toe of the jump occurs upstream, however, where the chute is 38.7 feet wide and the velocity is 102 feet per second. In arriving at these design values, a prototype roughness coefficient of $n = 0.008$ was used in the Manning formula. Since the model flow surfaces were rougher than this, considering the model scale, the velocity at the model basin entrance represented a prototype velocity of only 93 feet per second.

To increase the velocity in the model to that expected in the prototype, a slide gate was installed in the chute at Station 9+35 to raise the reservoir elevation. With the gate placed in the chute to form an orifice 10.2 feet high by 30 feet wide, the reservoir level rose to elevation 6496.8, the top of the model head box. The average depth of flow at the toe of the jump was then measured to be 3.2 feet for the design discharge. Since the chute is 38.7 feet wide at this point, the average velocity is approximately 102 feet per second. This agrees with the design conditions described above.

The Froude number for the adjusted velocity and depth was computed to be 10.0. The conjugate tail water depth D_2 for this condition was computed to be 44 feet for a basin 38.7 feet wide and 40 feet for a basin 42 feet wide. The expected tail water depth for 12,600 cfs taken from the tail water curve, Figure 3, is 43.3 feet. It is possible that the depth may be as low as 42.2 feet. Therefore, the basin is designed for a depth which is slightly in excess of D_2.

The length of a Type II basin for F = 10 should be 4.3 D_2 (4.3 x 40) or 172 feet long.1/ The preliminary basin was shown on the drawings to be 120 feet long. If baffle piers are added to form a Type III basin, the length may be reduced to 2.75 D_2 (2.75 x 40), or 110 feet. Thus, the preliminary basin is too short if baffle piers are not used, and about 10 feet longer than necessary if baffle piers are used.

The preliminary basin discharging the design flow is shown in Figure 26. It is apparent that the basin is too short. A water surface boil about 6 feet high and a generally rough water surface occurred downstream from the basin. Waves near the right bank were 5.5 feet high from maximum crest to minimum trough. However, a 1-hour model erosion test produced very little scour. At the basin corners, the sand bed was eroded 2 feet below the original elevation. No riprap was used in the model since it was desired to show erosion tendencies. In the prototype, the proposed riprap at the end of the basin would provide ample protection. The stilling basin tests were continued to improve the appearance of the action and to reduce the boil and wave heights.

Stilling Basin Modification No. 1

Four streamlined baffles of the type shown in Figure 27 were placed at Station 14+43, approximately 0.8 D_2 or 34 feet from the upstream end of the apron. The basin discharging the design flow is shown in Figure 28. The improvement in water surface roughness downstream from the basin was minor, and the erosion pattern appeared to be identical to that for the preliminary basin.

Stilling Basin Modification No. 2

Modification No. 2, which was quite similar to a Type III basin,2/ utilized a row of square-edged baffle piers, 3 full width and 2 half width piers of the type shown in Figure 27. The upstream faces were first placed 27 feet from the upstream end of the apron and later the distance was increased to 41 feet 3 inches. These two positions bracket the recommended 0.8 D_2 position of 32 feet.

The basin with the baffles located 27 feet downstream from the upstream end of the chute and a discharge of 12,600 cfs is shown in Figure 29. The water surface boil and waves downstream from the basin were greatly reduced from those occurring for the preliminary design. The erosion pattern was not much different than before.

1/,2/Hyd-399, "Progress Report II Research Study on Stilling Basins, Energy Dissipators, and Associated Appurtenances," by J. N. Bradley and A. J. Peterka, June 1, 1955.

It was suspected that cavitation might occur on the top and sides of the square-edged baffles because of the high velocity flow. Therefore, the center baffle was constructed with piezometers located as shown in Figure 27. Pressures were recorded for discharges of 2,500, 7,500, 10,000, and 12,600 cfs with the tail water set in accordance with the tail water curve in Figure 3. All pressures were above atmospheric for discharges ranging up to about 8,500 cfs, as shown by the solid lines in Figure 30. As the discharge was increased above 8,500 cfs, Piezometer 4 on the side of the baffle became more and more subatmospheric until, at about 10,500 second-feet, the pressure was equal to the vapor pressure of water. Pressures on top of the pier did not become subatmospheric until the discharge reached about 11,500 cfs; for 12,600 cfs, the pressures reached about 7 feet of water below atmospheric.

To improve the pressures, the baffle piers were relocated farther downstream (41 feet 3 inches downstream from the upstream end of the apron). However, the improvement was small as shown by the difference between the solid and dashed lines in Figure 30; at the same time, the effectiveness of the baffle piers was greatly reduced.

Stilling Basin Modification No. 3

The square-edged baffles were replaced with an equal number of streamlined baffles shaped similarly to those developed by the U. S. Engineers Waterways Experiment Station 3/ for use at Bluestone Dam and tested again by the U. S. Army Corps of Engineers' Bonneville Hydraulic Laboratory 4/ for use at Chief Joseph Dam, Figure 31. The upstream faces of the baffles were placed 34 feet from the upstream end of the apron. Several piezometers were located on the side of one baffle pier constructed of sheet metal, Figure 31. The piezometers nearest the bottom of the pier showed subatmospheric pressures equal to the vapor pressure of water, Figure 32; therefore, the baffles were unsatisfactory.

If the pressures had been satisfactory, the basin performance would have been acceptable. The performance was better than for streamlined baffles of Modification No. 1, but not as good as for the square-edged baffles of Modification No. 2.

3/Technical Memorandum No. 2-243, "A Laboratory Development of Cavitation-free Baffle Piers, Bluestone Dam, New River, West Virginia."

4/Report No. 34-1, "Spillway and Stilling Basin for Chief Joseph Dam, Columbia River, Washington, Hydraulic Model Investigation."

Recommended Stilling Basin

The recommended basin design made use of 5 baffles 9 feet high placed 41 feet downstream from the upstream end of the apron, Figure 33. These streamlined baffles were shaped according to the baffle piers developed for the outlet works stilling basin at Adaminaby Dam.5/

The baffles were also similar to those used in Modification No. 1; however, one additional pier was placed in the row, and the baffle piers were 9 feet high rather than 7 feet high. The upstream face of the baffle pier, or the impact area, was thereby increased about 45 percent.

For the design flow of 12,600 cfs, the performance of the recommended basin was satisfactory, Figure 34. The water surface downstream from the basin in the river channel was not as smooth as when square-edged baffles were used, but it was considered to be satisfactory. However, various attempts were made to smooth the water surface without moving the baffles upstream. A second row of baffles 9 feet high placed downstream and staggered with respect to the first provided only slight improvement. In another test, the slots in the end sill were filled level with the top of the sill, the boil height in the basin was reduced, and the water surface was smoother. However, the erosion pattern was not good; much bed material was carried into the basin which, in a prototype structure, might cause abrasion to concrete surfaces. Therefore, these modifications were not adopted.

The water surface profile within the recommended basin for the design discharge is recorded in Figure 35 along with the water surface profiles for other basin modifications. The preliminary design had the lowest profile, but the water surface boil which occurred downstream from the end of the basin produced high waves in the discharge channel. For the recommended design having the 9-foot high baffles, the boil formed upstream from the end sill and produced a higher water surface in the upstream portion of the basin. This resulted in a smoother water surface downstream. The square-edged baffles were most effective in filling the upstream portion of the basin and smoothing out the flow, but were not recommended for prototype construction because of the subatmospheric pressures produced by the square edges.

Wave heights were recorded near the right bank of the discharge channel at a point 93 feet downstream from the stilling basin and 57 feet to the right, Figure 36. For the design flow the waves were 3 feet high,

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5/Hyd-397, "Hydraulic Model Studies of Outlet Works Adaminaby Dam for Australian Snowy Mountains Authority," by J. C. Schuster, September 9, 1954.

measured from maximum crest to minimum trough over an observation period of 1 minute or more. This compares with 5.4 feet in the preliminary design and 2.4 feet for the square-edged baffles.

Pressure measurements made on one of the recommended baffles, Figures 37 and 38, showed the baffle pier design to be satisfactory for prototype use. For the design flow, 12,600 cfs, 11 feet of water below atmospheric pressure was observed in the lowermost row of piezometers. However, it was possible to discharge 11,300 cfs before the pressure dropped to atmospheric. It is therefore improbable that cavitation will occur in the prototype except, perhaps, at near maximum discharges.

To better understand the relation between velocity at the baffle piers and pressures on the piers, the total head and the hydrostatic head were measured in the flow at a point 11 feet upstream from the baffle pier face and 2 feet above the apron, Figure 39. For the design flow, the velocity was about 80 feet per second at this point. The velocity of the flow at the toe of the jump was 102 feet per second, and the velocity of the flow striking the baffles is estimated to be 65 or 70 feet per second. Usually, 50 to 60 feet per second is considered to be the upper limiting velocity for use of square-edged piers.

The lowest pressure on a square-edged pier was found at Piezometer 4, Figure 30. This pressure becomes atmospheric at a spillway discharge of about 8,200 cfs. The velocity for 8,200 cfs is about 50 feet per second, Figure 39. For 10,000 cfs, a pressure of minus 18 for Piezometer 4, and a velocity of about 60 feet per second are indicated.

The tail water elevation at which the hydraulic jump would sweep out of the basin was determined; but first, it was necessary to lower the level of the discharge channel by removing some of the movable bed. The tail water was lowered until the hydraulic jump roller ceased to roll back into the basin to form the jump. The tail water elevation at which this action first occurred was recorded for a range of discharges as the sweep-out tail water elevation, Figure 40. The difference between the sweep-out elevation and the expected tail water elevation is the margin of safety against the occurrence of this phenomenon in the prototype. For instance, the margin of safety for the design flow was approximately 10 feet of tail water or about 3 feet more than provided by the preliminary design.

After the conclusion of the model study, a decision was made to construct the preliminary design rather than the recommended design because of the possibility of low pressures and cavitation occurring on the baffle piers. To further reduce the possibility of cavitation in the basin, the chute blocks and the dentils on the end sill were streamlined to a greater degree than shown in the preliminary design drawings. Since these modifications were made after the model had been dismantled, they were not tested.

FIGURE 1
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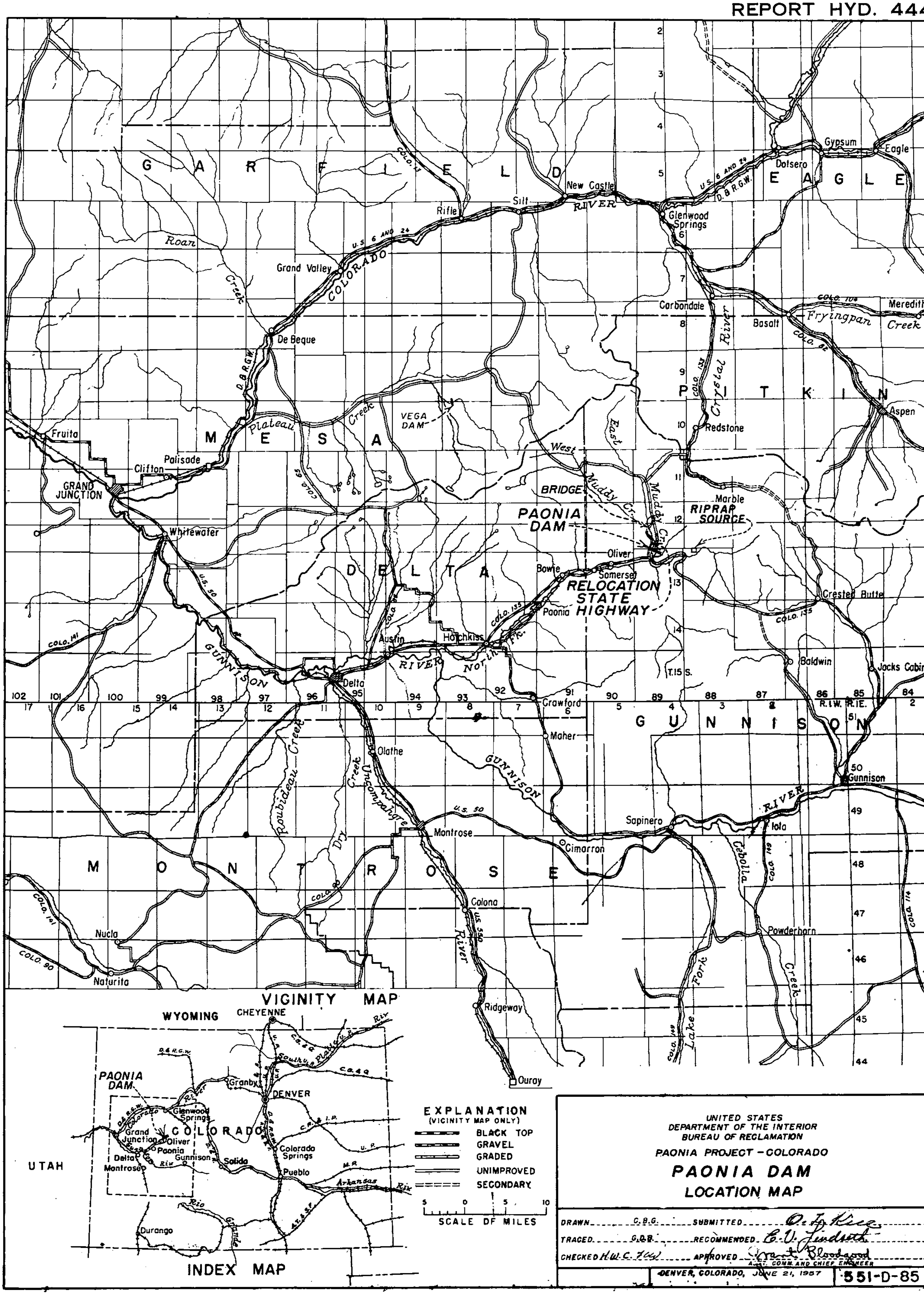
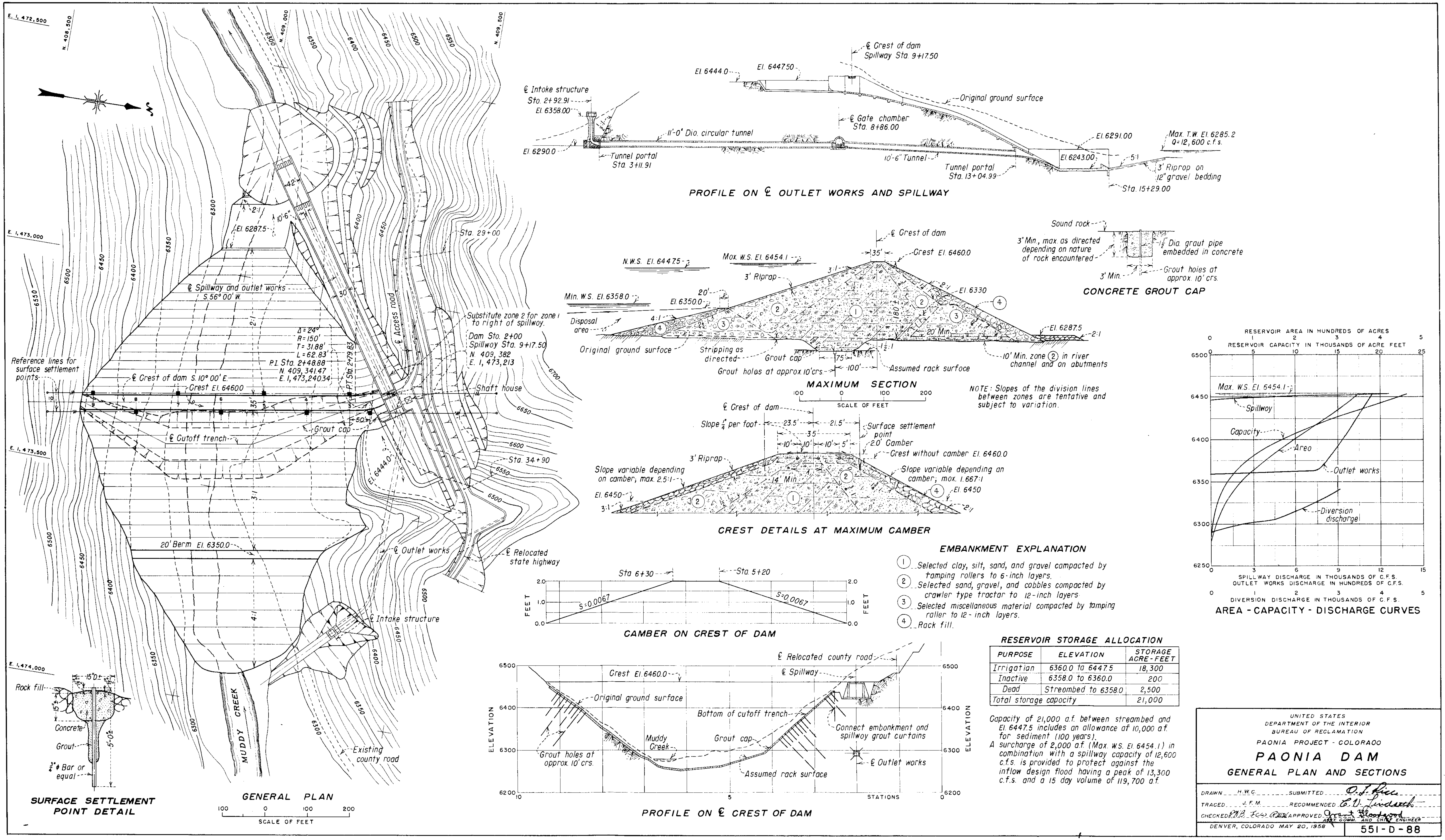




RESERVOIR STORAGE ALLOCATION

PURPOSE	ELEVATION	STORAGE ACRE-FEET
Irrigation	6360.0 to 6447.5	18,300
Inactive	6358.0 to 6360.0	200
Dead	Streambed to 6358.0	2,500
Total storage capacity		21,000

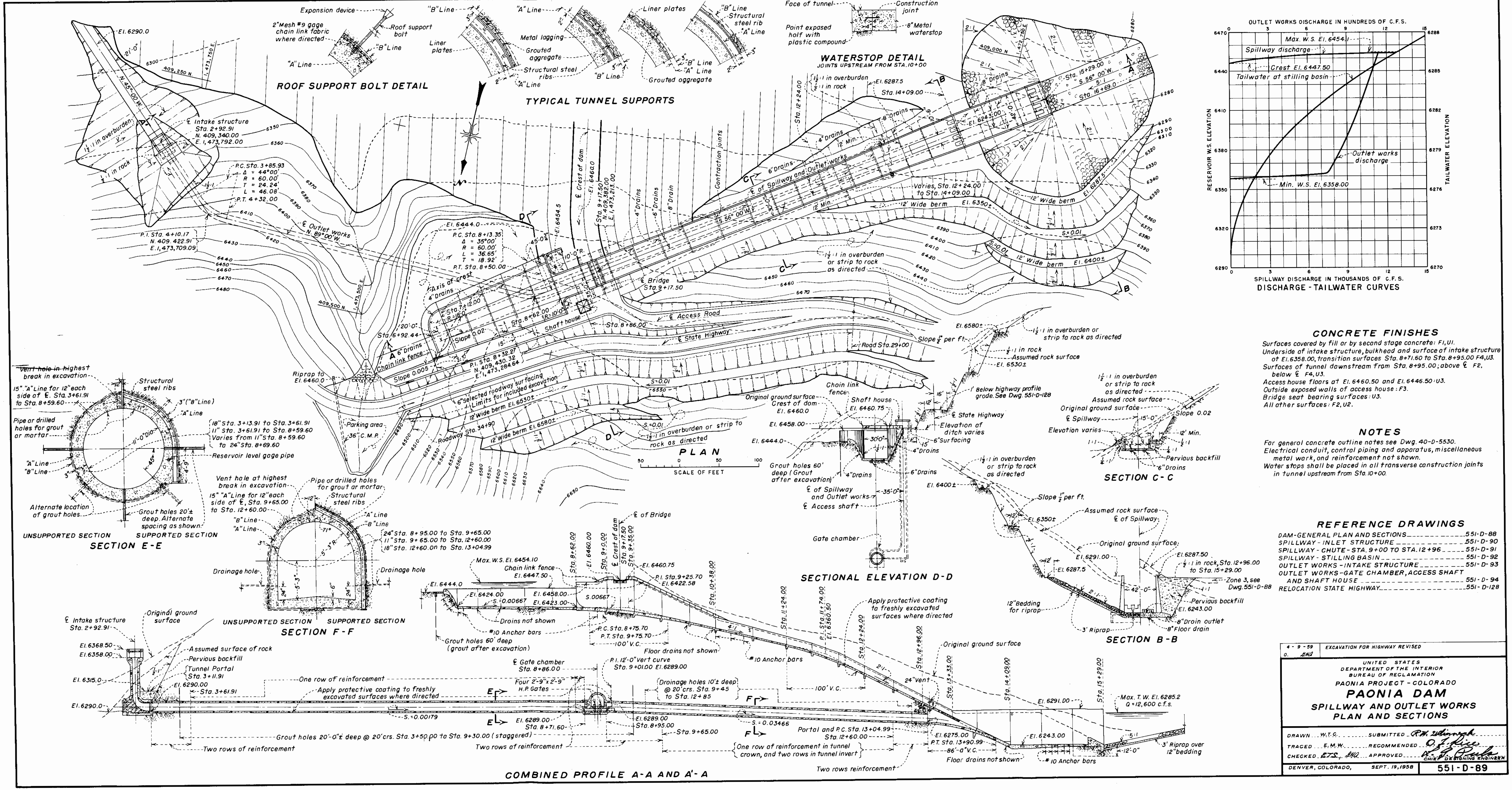
Capacity of 21,000 a.f. between streambed and El. 6447.5 includes an allowance of 10,000 a.f. for sediment (100 years).
A surcharge of 2,000 a.f. (Max. W.S. El. 6454.1) in combination with a spillway capacity of 12,600 c.f.s. is provided to protect against the inflow design flood having a peak of 13,300 c.f.s. and a 15 day volume of 119,700 a.f.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PAONIA PROJECT - COLORADO

PAONIA DAM

GENERAL PLAN AND SECTIONS

DRAWN H.W.C. SUBMITTED O. L. Rice
TRACED J.F.M. RECOMMENDED C. V. Lindseth
CHECKED APPROVED Grant Bloodgood, ASST. COMM. AND CHIEF ENGINEER
DENVER, COLORADO MAY 20, 1958 551-D-88


ROOF SUPPORT BOLT DETAIL
TYPICAL TUNNEL SUPPORTS
WATERSTOP DETAIL
JOINTS UPSTREAM FROM STA. 10+00
PLAN
SCALE OF FEET
DISCHARGE - TAILWATER CURVES
OUTLET WORKS DISCHARGE IN HUNDREDS OF C.F.S.
SPILLWAY DISCHARGE IN THOUSANDS OF C.F.S.
RESERVOIR W.S. ELEVATION
TAILWATER ELEVATION
Max. W.S. El. 6454.1
Spillway discharge
Crest El. 6447.50
Tailwater at stilling basin
Outlet works discharge
Min. W.S. El. 6358.00
CONCRETE FINISHES
Surfaces covered by fill or by second stage concrete: F1, U1.
Underside of intake structure, bulkhead and surface of intake structure at El. 6358.00, transition surfaces Sta. 8+71.60 to Sta. 8+95.00 F4, U3.
Surfaces of tunnel downstream from Sta. 8+95.00; above ℄ F2, below ℄ F4, U3.
Access house floors at El. 6460.50 and El. 6446.50: U3.
Outside exposed walls of access house: F3.
Bridge seat bearing surfaces: U3.
All other surfaces: F2, U2.
NOTES
For general concrete outline notes see Dwg. 40-D-5530.
Electrical conduit, control piping and apparatus, miscellaneous metal work, and reinforcement not shown.
Water stops shall be placed in all transverse construction joints in tunnel upstream from Sta. 10+00.
SECTION C-C
SECTION E-E
UNSUPPORTED SECTION
SUPPORTED SECTION
SECTION F-F
SECTIONAL ELEVATION D-D
SECTION B-B
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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PAONIA PROJECT - COLORADO
PAONIA DAM
SPILLWAY AND OUTLET WORKS
PLAN AND SECTIONS
DRAWN W.T.C. SUBMITTED
TRACED E.M.W. RECOMMENDED
CHECKED E.T.S. APPROVED
CHIEF DESIGNING ENGINEER
DENVER, COLORADO, SEPT. 19, 1958
551-D-89

FIGURE 4
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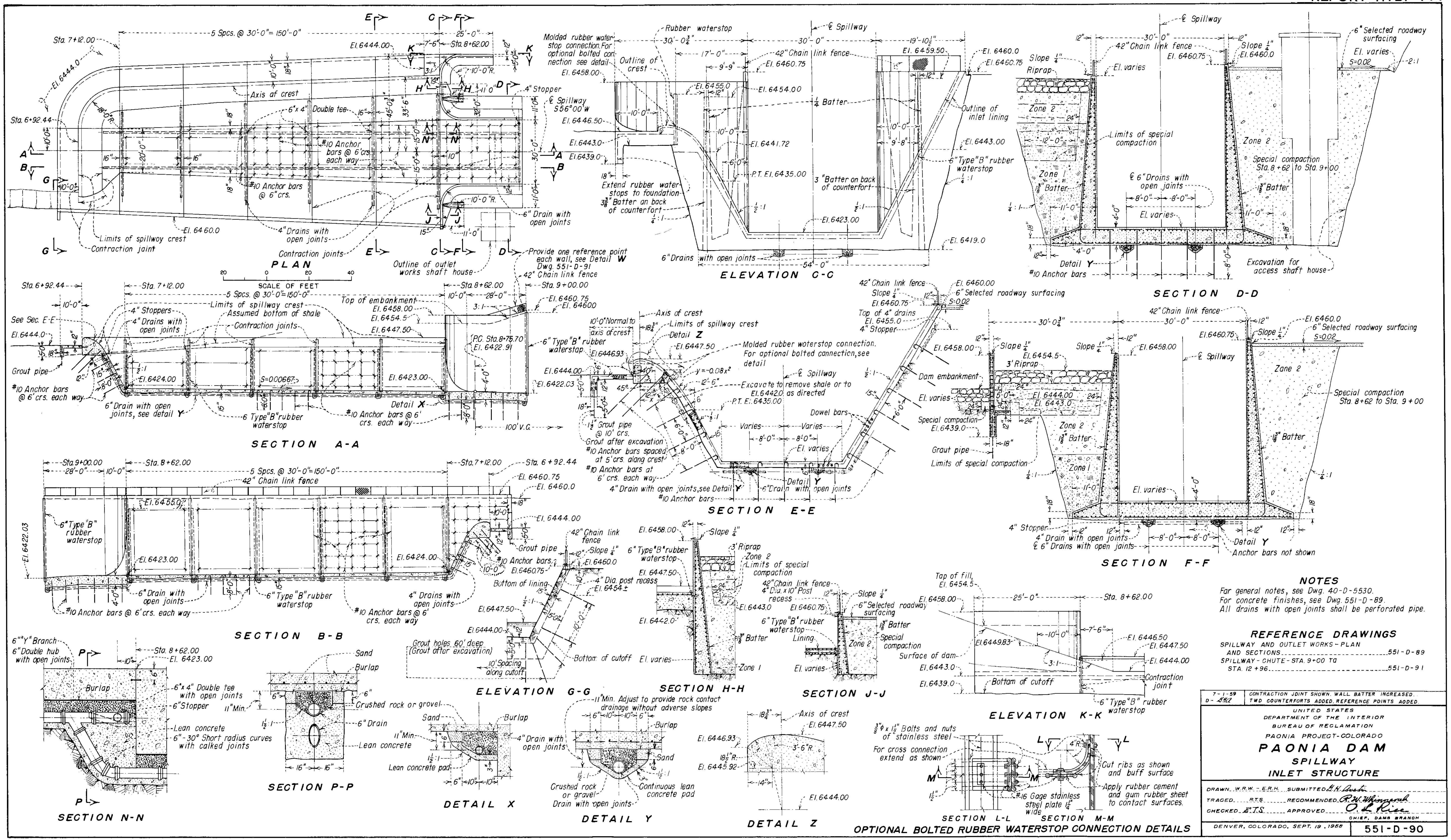


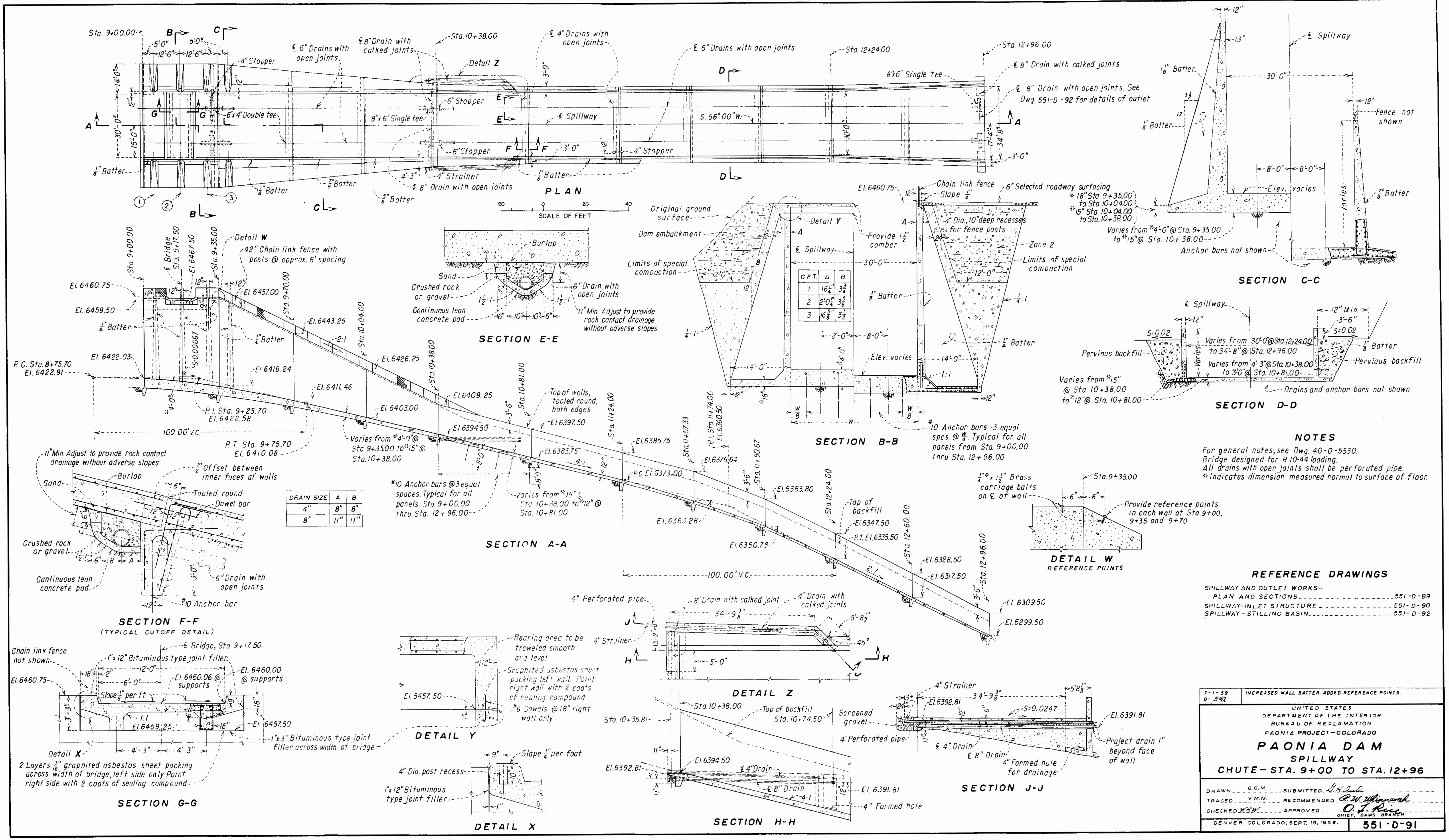
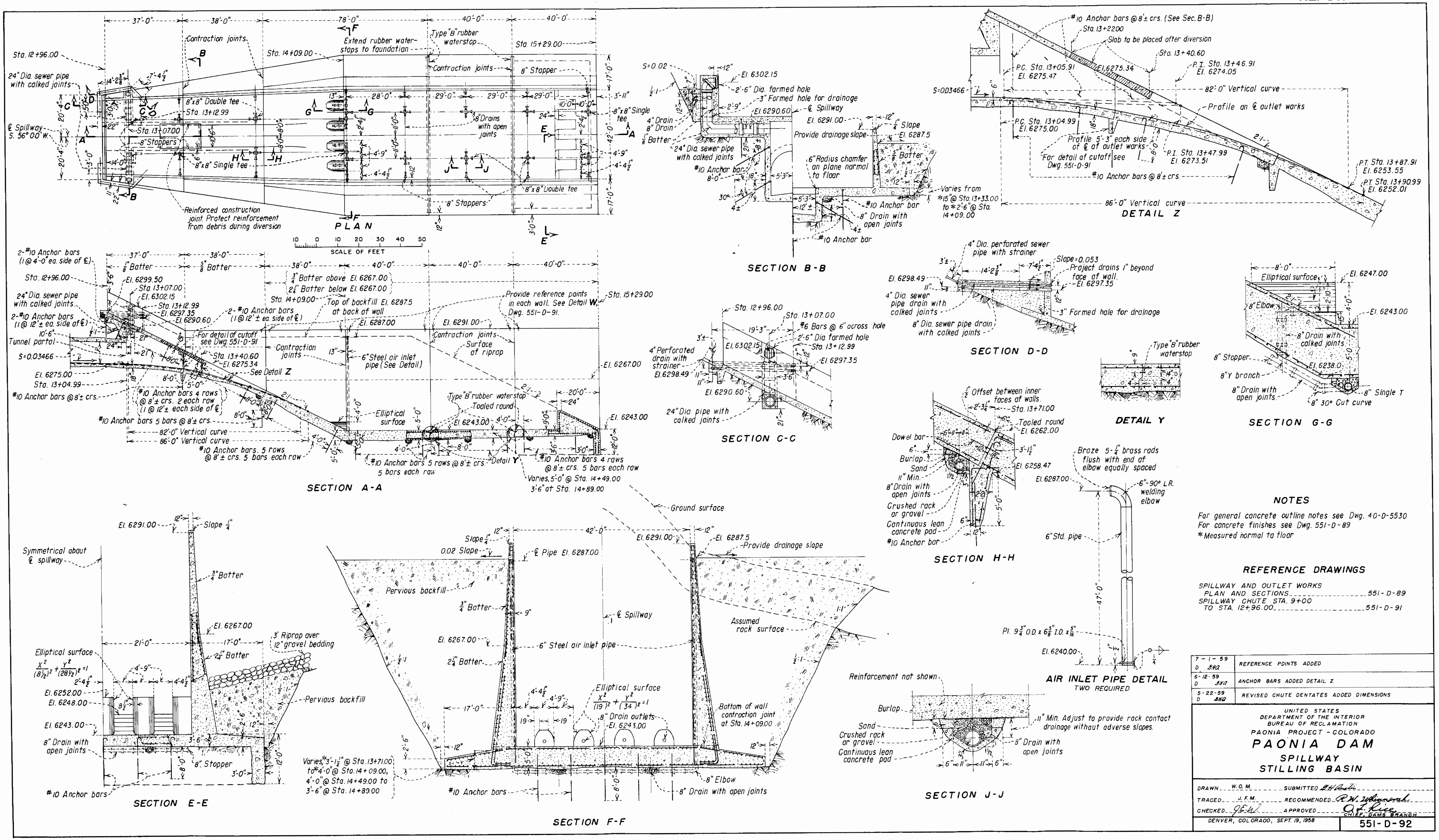
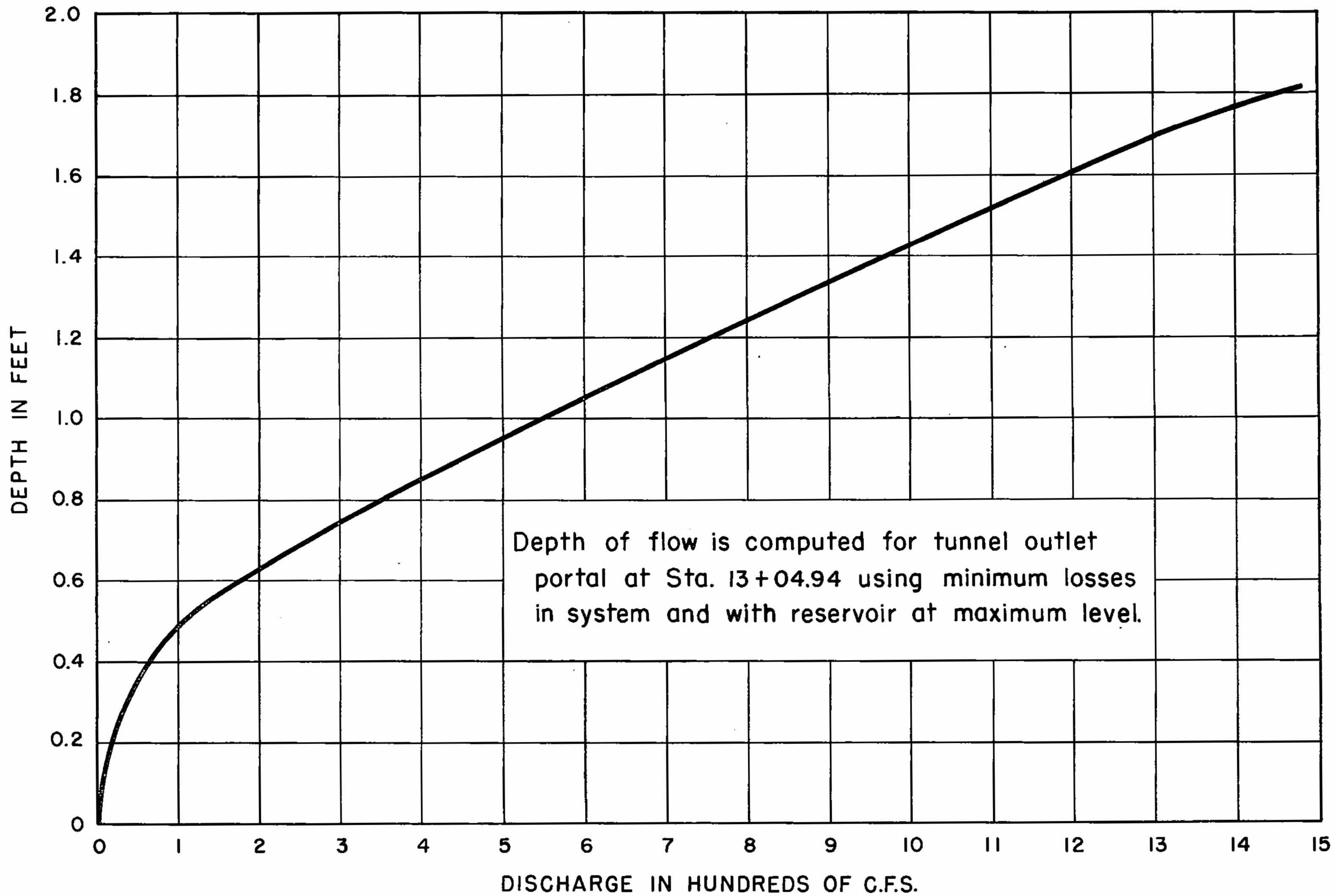

PLAN
SCALE OF FEET
SECTION A-A
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
(TYPICAL CUTOFF DETAIL)
SECTION G-G
SECTION H-H
SECTION J-J
DETAIL W
REFERENCE POINTS
DETAIL X
DETAIL Y
DETAIL Z
NOTES
For general notes, see Dwg. 40-D-5530.
Bridge designed for H 10-44 loading.
All drains with open joints shall be perforated pipe.
* Indicates dimension measured normal to surface of floor.
REFERENCE DRAWINGS
SPILLWAY AND OUTLET WORKS- PLAN AND SECTIONS 551-D-89
SPILLWAY-INLET STRUCTURE 551-D-90
SPILLWAY-STILLING BASIN 551-D-92
7-1-59 INCREASED WALL BATTER. ADDED REFERENCE POINTS
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PAONIA PROJECT-COLORADO
PAONIA DAM
SPILLWAY
CHUTE - STA. 9+00 TO STA. 12+96
DRAWN G.C.M. SUBMITTED
TRACED V.M.N. RECOMMENDED
CHECKED APPROVED
CHIEF, DAMS BRANCH
DENVER, COLORADO, SEPT. 19, 1958.
551-D-91

FIGURE 6
REPORT HYD. 444





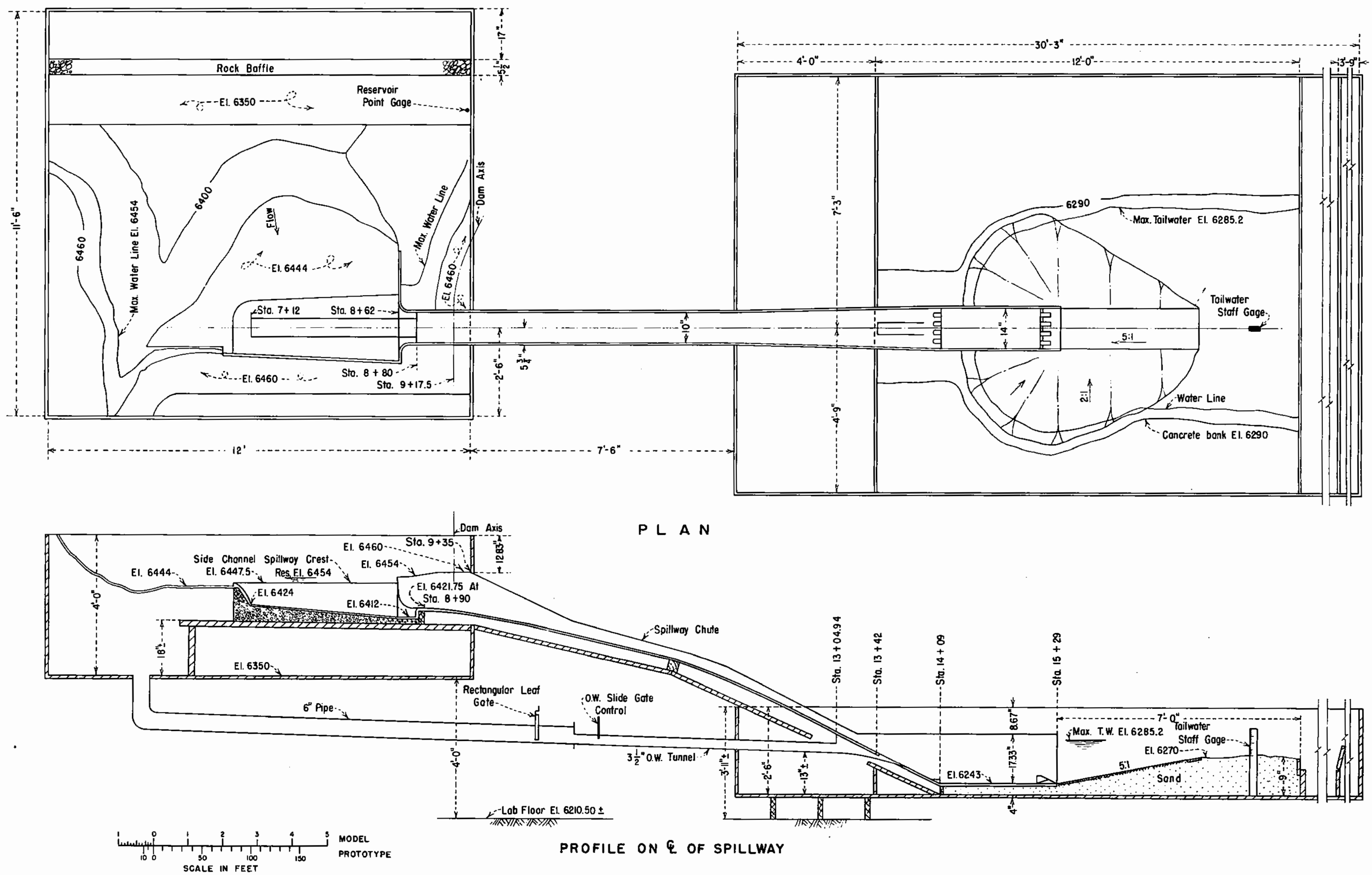
PAONIA DAM SPILLWAY

OUTLET WORKS RATING CURVE – PRELIMINARY

1:36 SCALE MODEL

FIGURE 7
REPORT HYD. 444

600



PROFILE ON ℄ OF SPILLWAY

PAONIA DAM SPILLWAY AND OUTLET WORKS

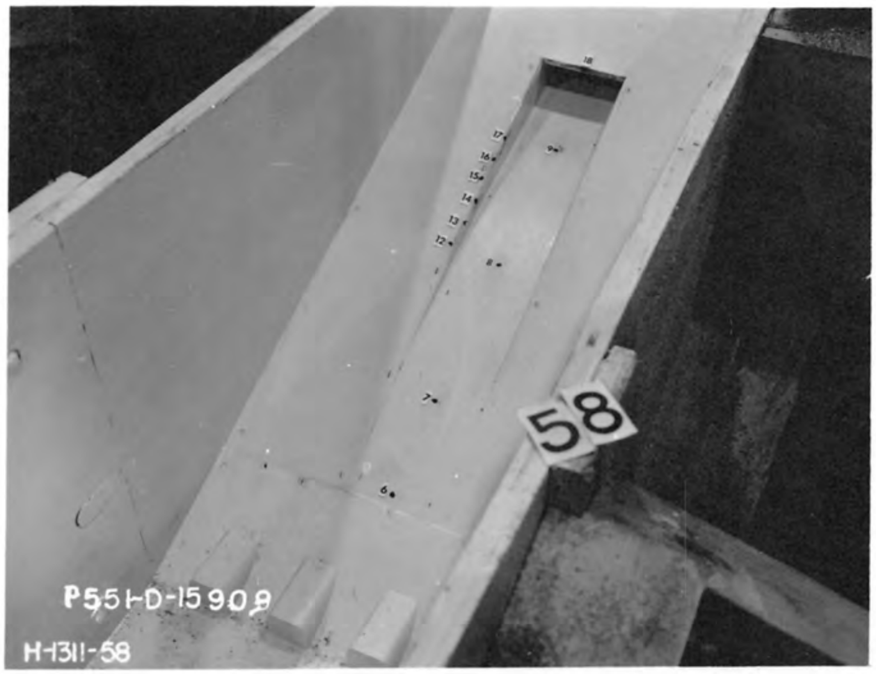
MODEL LAYOUT—PRELIMINARY SPILLWAY

1:36 SCALE MODEL

A. Side channel spillway entrance. Note step up from side channel basin floor to chute floor.

B. Spillway chute, outlet works junction, stilling basin, and discharge channel.

PAONIA DAM SPILLWAY
PRELIMINARY SPILLWAY DESIGN MODEL
1:36 SCALE MODEL



Numbers designate piezometer locations.

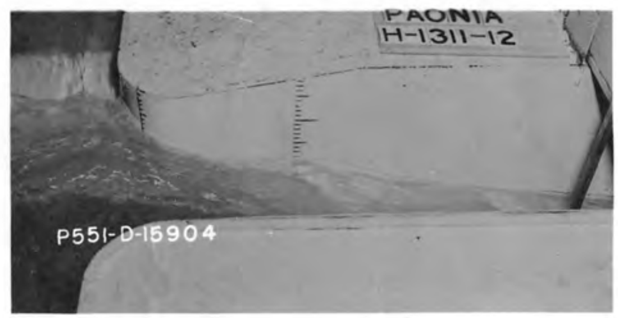
PAONIA DAM SPILLWAY & OUTLET WORKS
OUTLET WORKS AND SPILLWAY JUNCTION MODEL
1:36 SCALE MODEL

PAONIA DAM SPILLWAY
PRELIMINARY SPILLWAY--12,600 CFS
1:36 SCALE MODEL

A. Basin is not fully utilized.

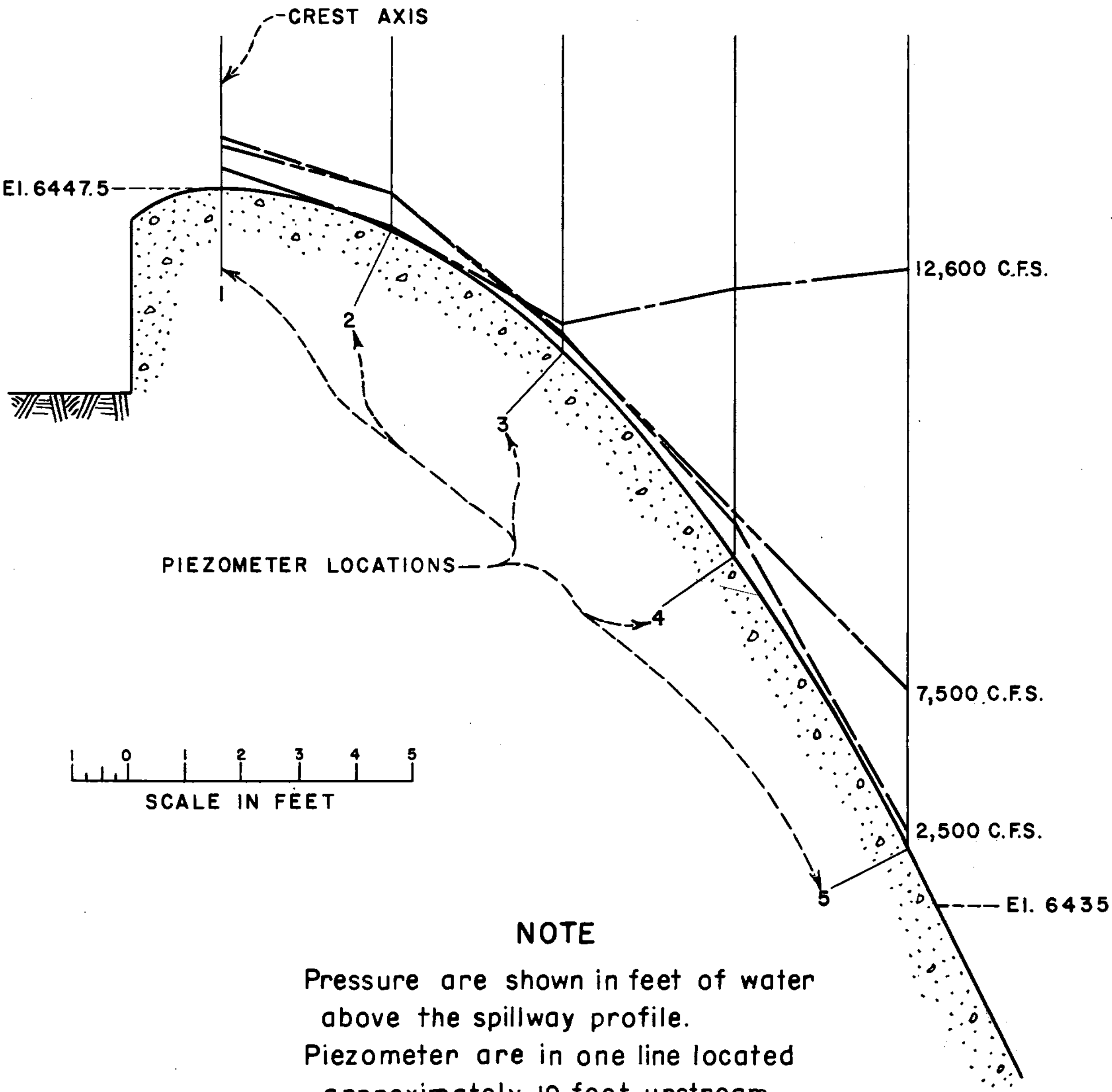
B. **Turbulence occurs at left approach wall.**

C. **Flow from the basin into the chute.**



D. **Wall scales show prototype feet.**

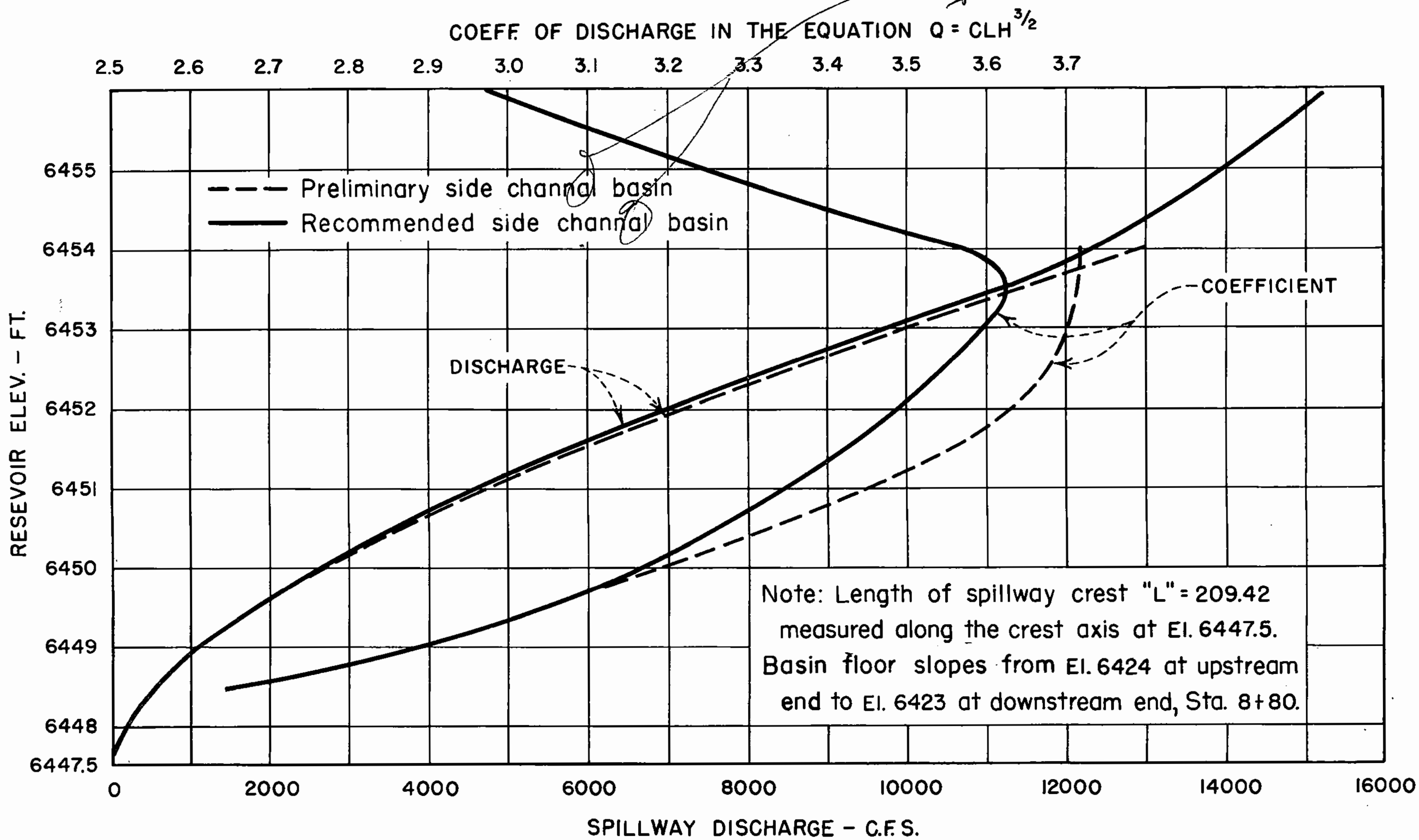
PAONIA DAM SPILLWAY
PRELIMINARY SIDE CHANNEL BASIN--12,600 CFS
1:36 SCALE MODEL



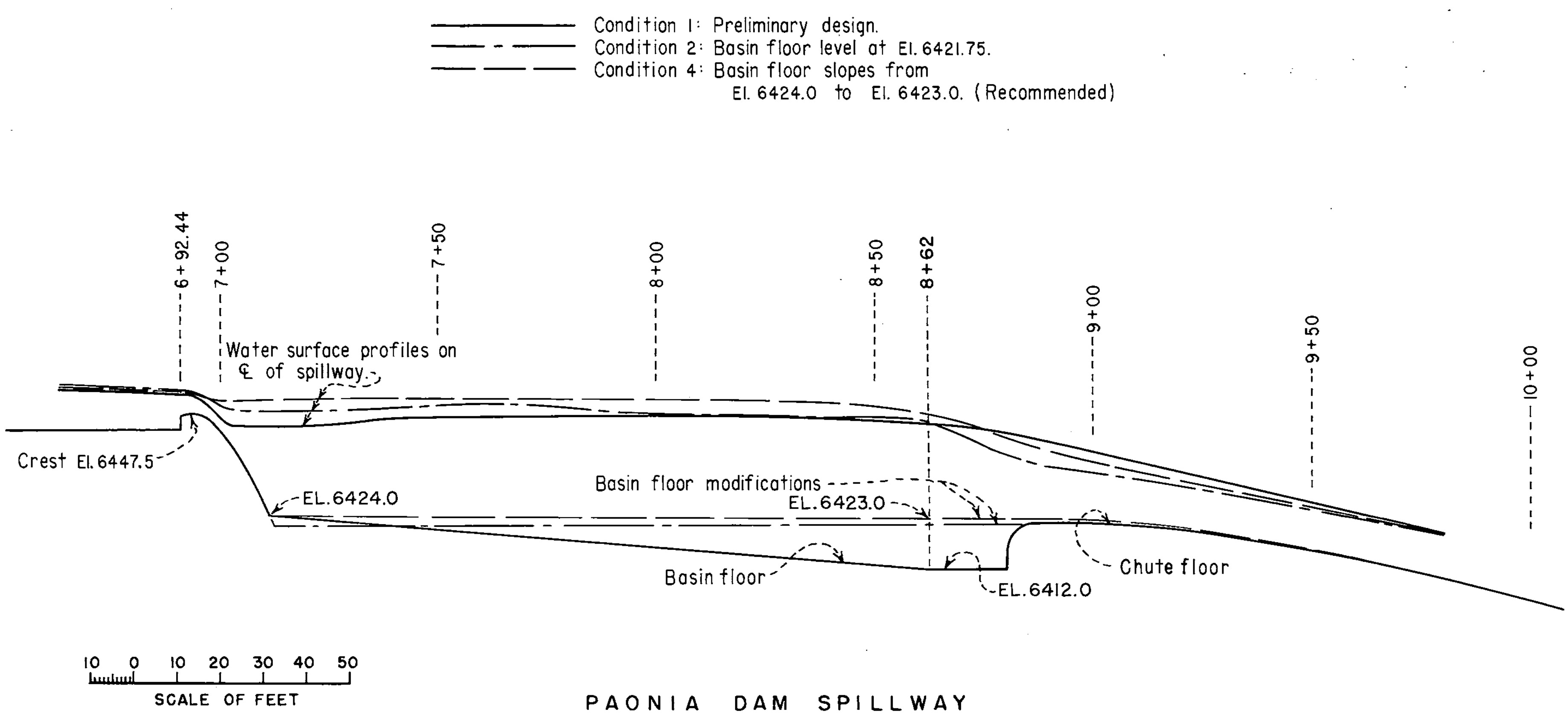
NOTE

Pressure are shown in feet of water above the spillway profile.
Piezometer are in one line located approximately 19 feet upstream from left approach wall.

PAONIA DAM SPILLWAY
CREST PRESSURES
1:36 SCALE MODEL

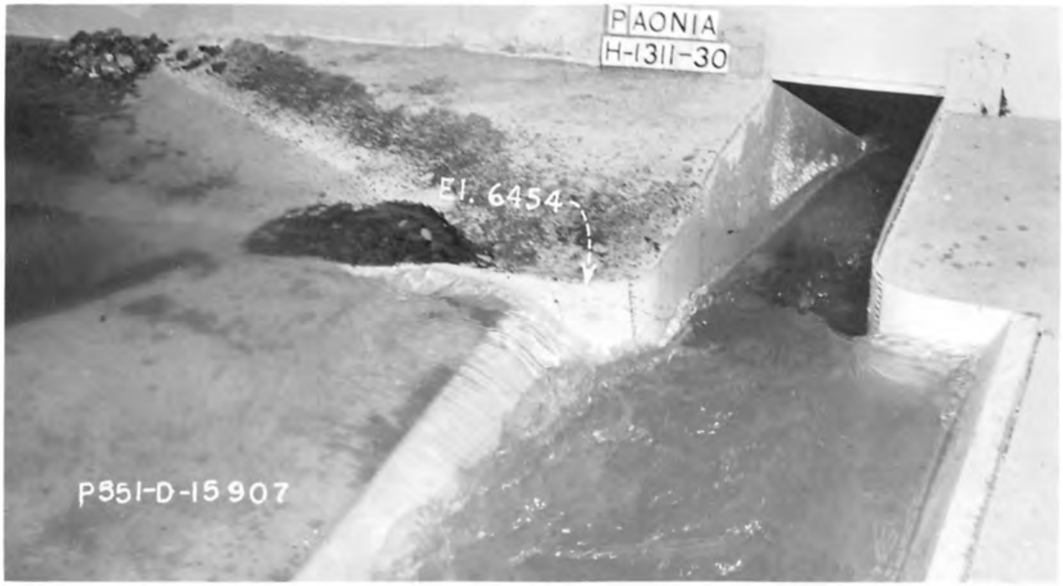


PAONIA DAM SPILLWAY
DISCHARGE AND COEFFICIENT OF DISCHARGE CURVES
FOR PRELIMINARY AND RECOMMENDED DESIGN
1:36 SCALE MODEL



PAONIA DAM SPILLWAY
WATER SURFACE PROFILES IN SIDE CHANNEL BASINS-12,600 CFS
1:36 SCALE MODEL

FIGURE 15
REPORT HYD. 444



A. Preliminary left approach wall.

B. Rock fill was effective in reducing turbulence near left wall but flow fluctuations sometimes overtopped the wall.

PAONIA DAM SPILLWAY
PRELIMINARY LEFT APPROACH WALL--12,600 CFS
1:36 SCALE MODEL

Velocity near the upstream end of the left wall is 7 feet per second. The flow is smooth but the water surface at A fluctuates.

PAONIA DAM SPILLWAY
RECOMMENDED LEFT APPROACH WALL--12,600 CFS
1:36 SCALE MODEL

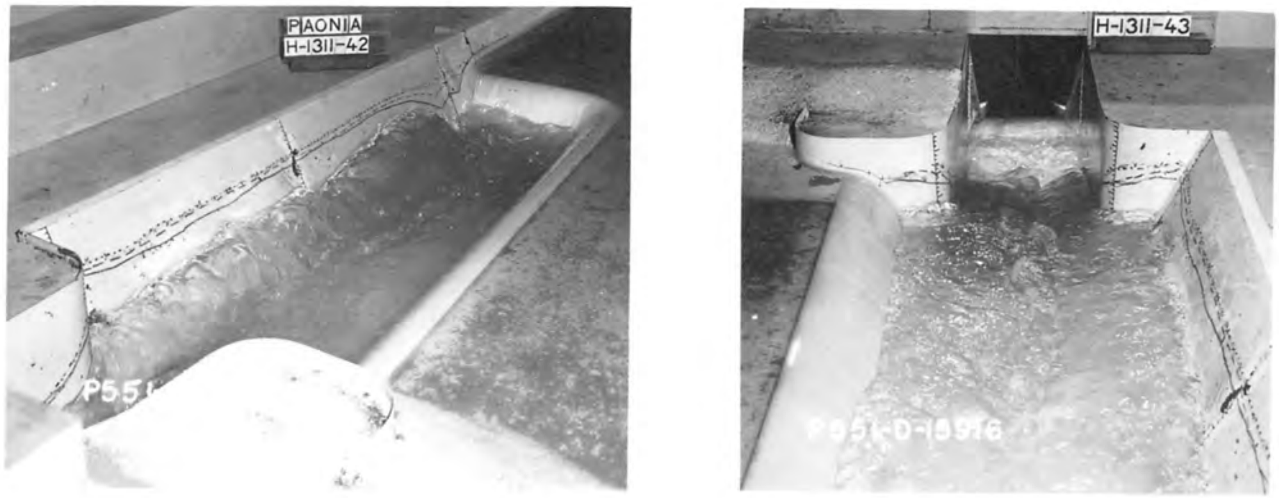
White line is the average water surface profile.

Water surface fluctuates 3 feet from the white line average at Sta. 8+90.

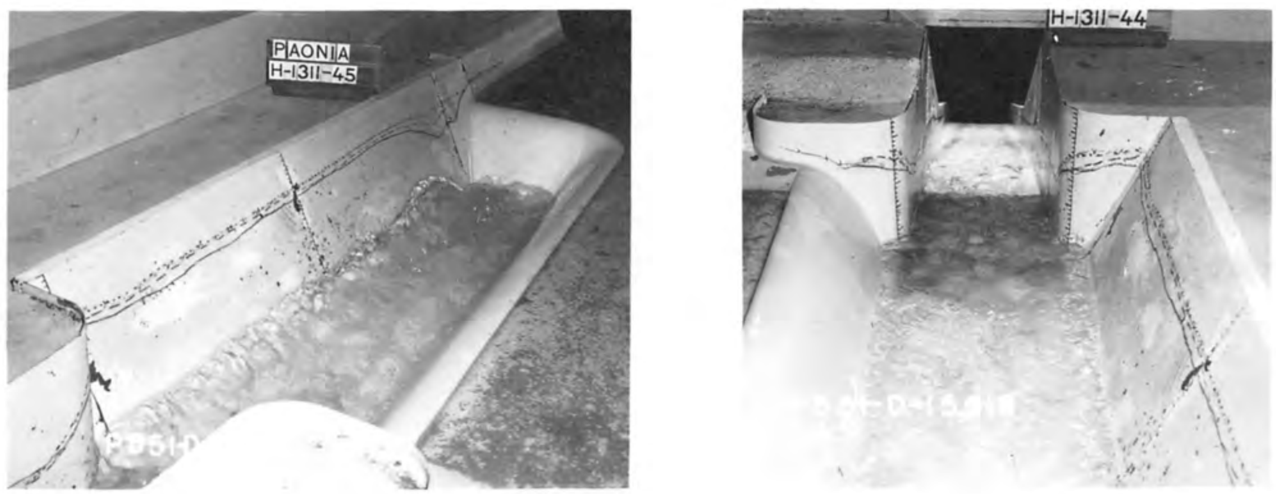
Water surface fluctuates 3 feet from the white line average at Sta. 8+90 and Sta. 8+65.

PAONIA DAM SPILLWAY
RECOMMENDED SIDE CHANNEL BASIN--12,600 CFS
1:36 SCALE MODEL

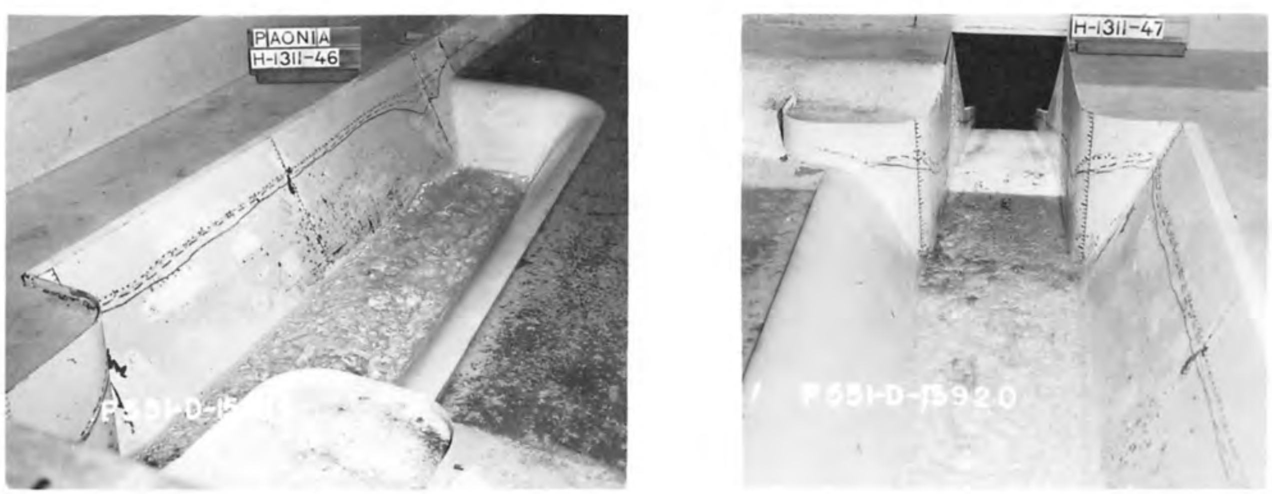
FIGURE 18
REPORT HYD 44



A. 7500 cfs



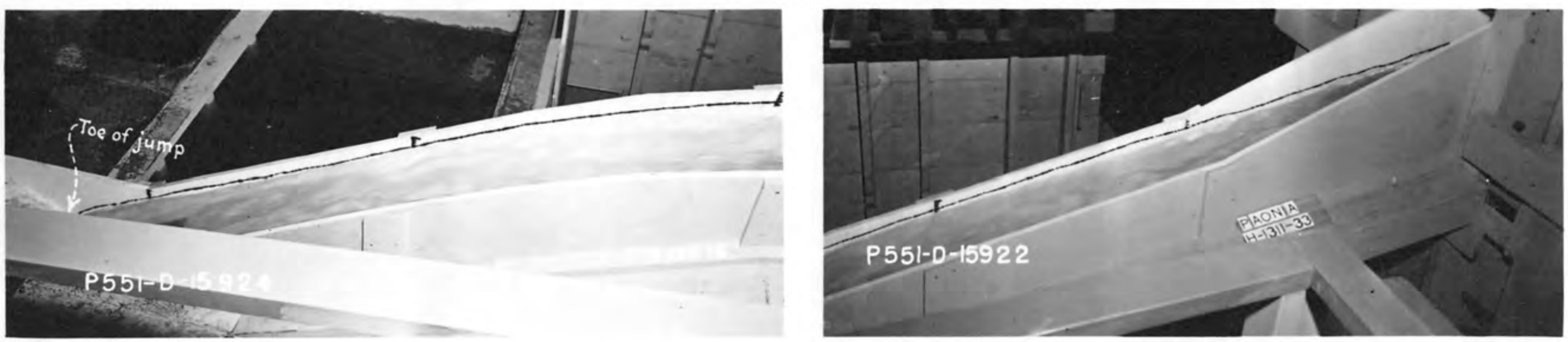
B. 2500 cfs



C. 1000 cfs

PAONIA DAM SPILLWAY
RECOMMENDED SIDE CHANNEL BASIN--INTERMEDIATE DISCHARGES
1:36 SCALE MODEL

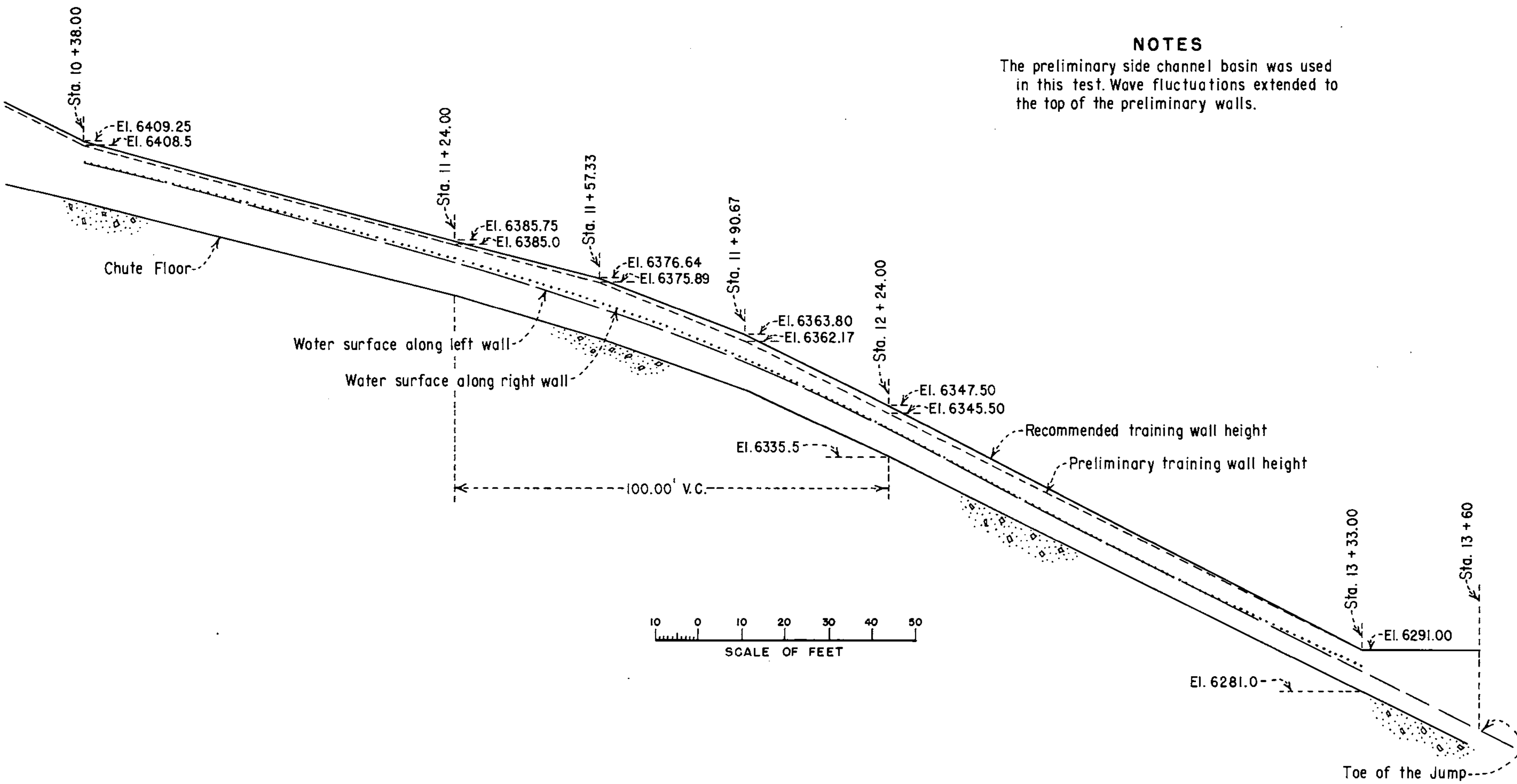
A. Left wall



B. Right wall

Note: The line on the training walls is the water surface elevation before the recommended side channel basin was installed. The average depth of flow at toe of the hydraulic jump is 3.6 feet.

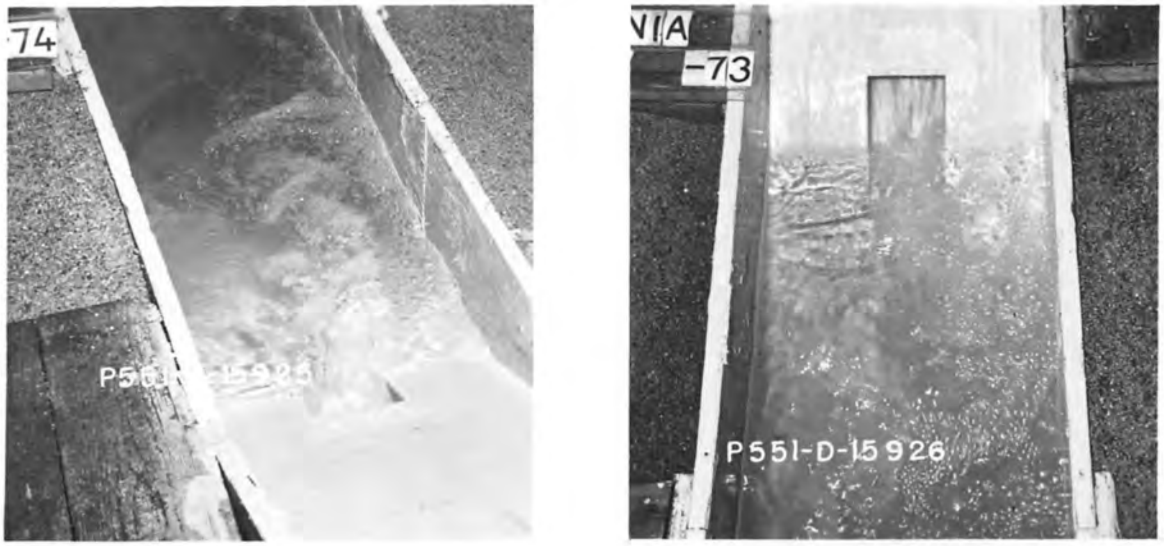
PAONIA DAM SPILLWAY
SPILLWAY CHUTE--12,600 CFS
1:36 SCALE MODEL



PAONIA DAM SPILLWAY
WATER SURFACE PROFILES IN CHUTE--12,600 CFS
1:36 SCALE MODEL

FIGURE 21
REPORT HYD. 444

800

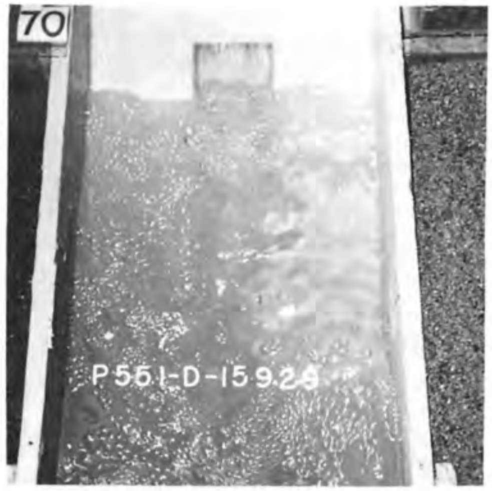


A. Outlet works discharge 700 cfs. Note: The flow veers to either the right or the left. No spillway discharge.

B. Spillway discharge 10,200 cfs
Outlet works discharge
1,400 cfs

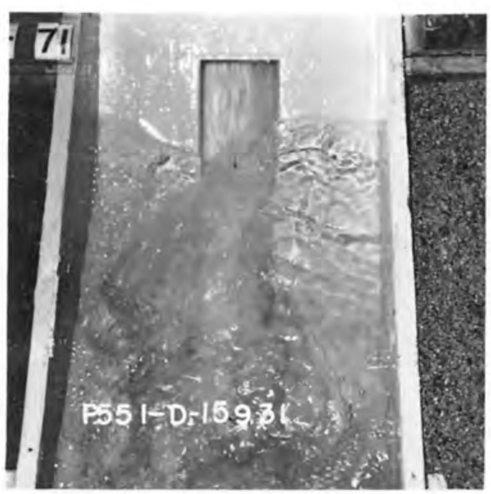
C. Spillway discharge 12,600 cfs

PAONIA DAM SPILLWAY & OUTLET WORKS JUNCTION
OUTLET WORKS AND SPILLWAY DISCHARGING
1:36 SCALE MODEL



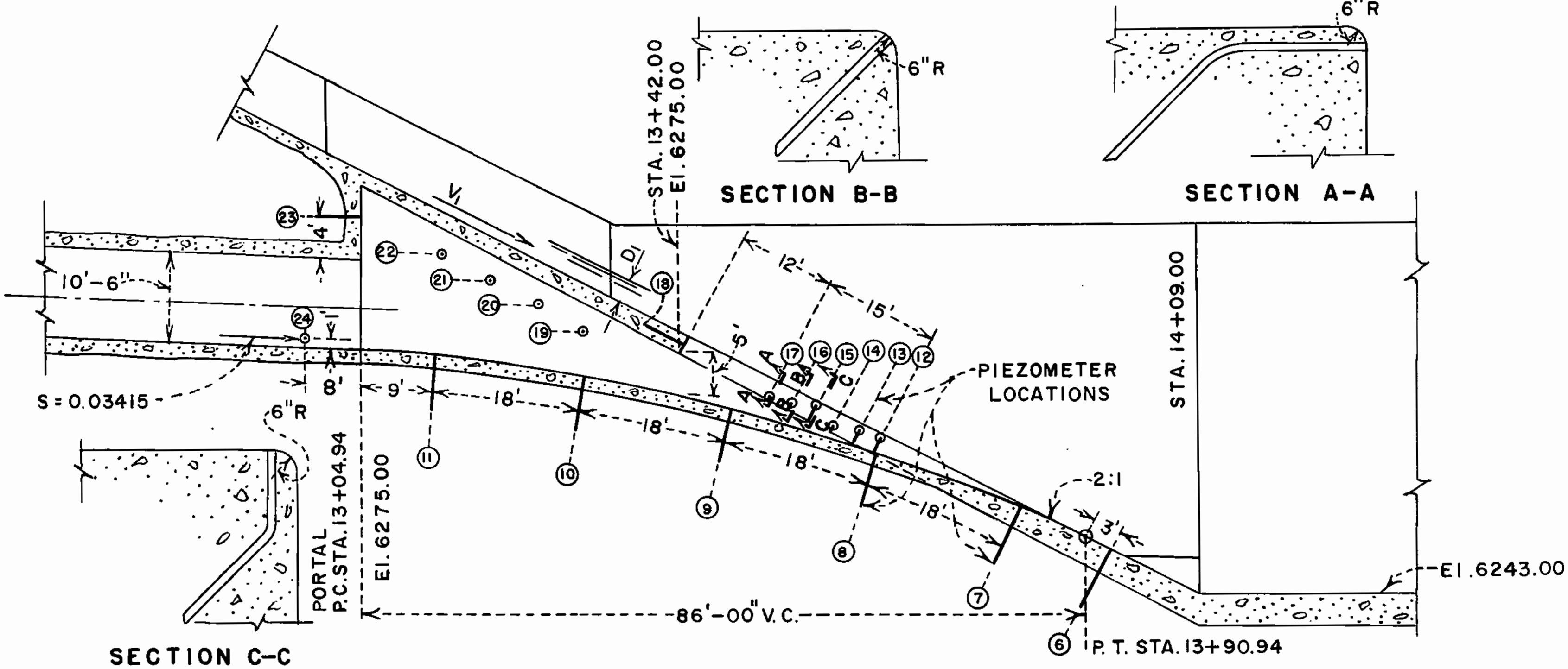
A. Spillway discharge 200 cfs
Outlet works discharge 1,300 cfs
Note: Outlet works flow veers to the right.

B. Outlet works discharge 1,200 cfs
No spillway discharge
Note: Flow veers to the left.



C. Same as B.
Note: Flow veers to the right.

PAONIA DAM SPILLWAY & OUTLET WORKS JUNCTION
OUTLET WORKS AND SPILLWAY DISCHARGING
1:36 SCALE MODEL



SPILLWAY Q C.F.S.	O. W. Q. C.F.S.	T.W. ELEV. (FEET)	PRESSURES IN FEET OF WATER AT PIEZOMETERS 6 THROUGH 24																		
			6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
12,600 *	———	6285.20	+20.0	+6.9	+14.9	-1.2	-1.5	-0.4	+3.4	+11.7	+13.5	+3.4	+1.0	-0.1	-1.9	-1.6	-0.2	-0.9	-0.4	-1.5	-0.5
0	1470	6276.00	+21.8	+17.1	+9.4	+2.0	+0.6	+0.2	+8.2	+5.6	+4.4	+4.3	+2.3	+1.2	-1.1	-2.0		-0.9	+0.2	-1.0	
0	700	6273.50	+20.2		+7.4		+0.2	+0.8	+6.2	+4.4	+2.7	+2.0	+1.0	-0.3	-1.2	-2.2	+0.2	-0.8	+0.6	-0.4	-1.9
1000	1470	6278.00	+22.8	+16.5	+9.9	+1.8	-1.5	0	+7.5	+6.0	+6.0	+6.0	+5.4	+1.8	-1.2	-1.8	+0.3	-0.6	0	-0.6	0

* STA. 13+34 D_1 = 3.6 FT., V_1 = 90 FPS, F = 8.4

PAONIA DAM SPILLWAY AND OUTLET WORKS

PRESSURES AT SPILLWAY AND OUTLET WORKS JUNCTION

1:36 SCALE MODEL

FIGURE 24
REPORT HYD. 444

River channel is molded in sand for erosion testing.

The apron is at elevation 6243. Top of training walls at El. 6291. Upstream end of apron is at station 14+09. Downstream end is at station 15+29. Chute blocks are 4 feet high and dentils on end sill are 9 feet high. Chute blocks have elliptical corners on top face and dentils have elliptical corners on front face. Basin is 42 feet wide.

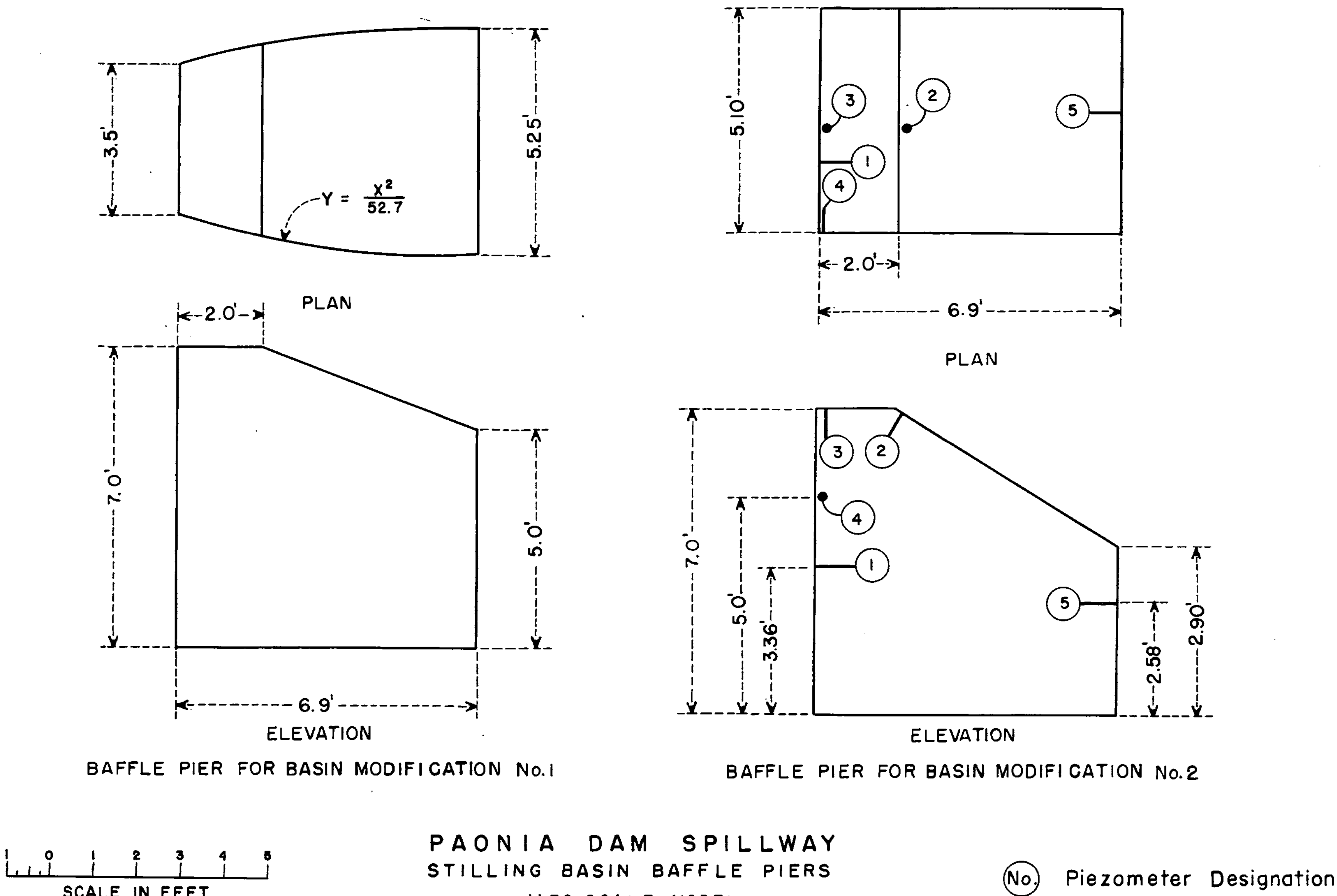
PAONIA DAM SPILLWAY
PRELIMINARY STILLING BASIN
1:36 SCALE MODEL

Operating conditions:
Res. El. 6496.8
Gate controlled flow
12,600 cfs
T.W. El. 6285.2
Chute width (w) at toe of jump = 38.7 feet
D_1 = 3.2 feet
V_1 = 102 feet/sec
F = 10.0
D_2 = 42.0 feet
L = 120 feet

Hydraulic jump extends beyond the end of stilling basin.

Erosion after one hour model test.

PAONIA DAM SPILLWAY
PERFORMANCE OF PRELIMINARY STILLING BASIN
1:36 SCALE MODEL



BAFFLE PIER FOR BASIN MODIFICATION No. 1

BAFFLE PIER FOR BASIN MODIFICATION No. 2

PAONIA DAM SPILLWAY
STILLING BASIN BAFFLE PIERS
1:36 SCALE MODEL

(No.) Piezometer Designation

FIGURE 27
REPORT HYD. 444

600

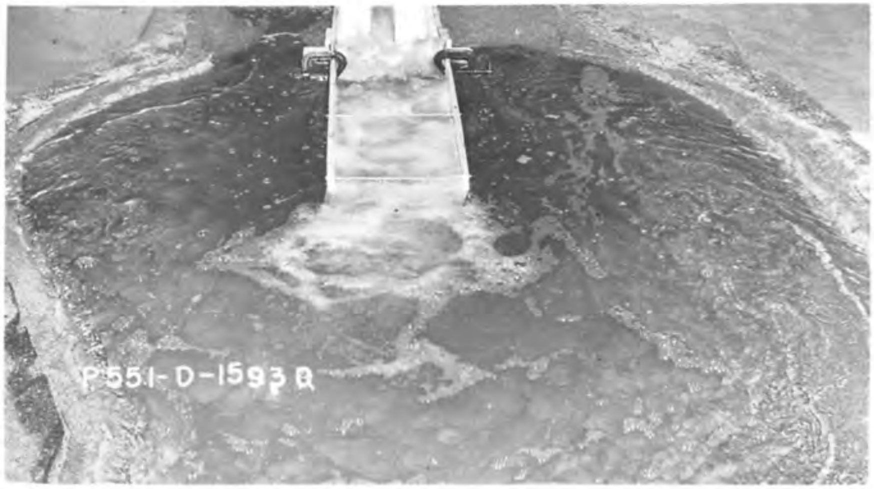
Same operating conditions as in Figure 26.

Note boil has moved upstream. Compare with Figure 26.

Erosion after one hour model test run.

PAONIA DAM SPILLWAY
PERFORMANCE OF STILLING BASIN MODIFICATION NO. 1
1:36 SCALE MODEL

FIGURE 29
REPORT HYD 444

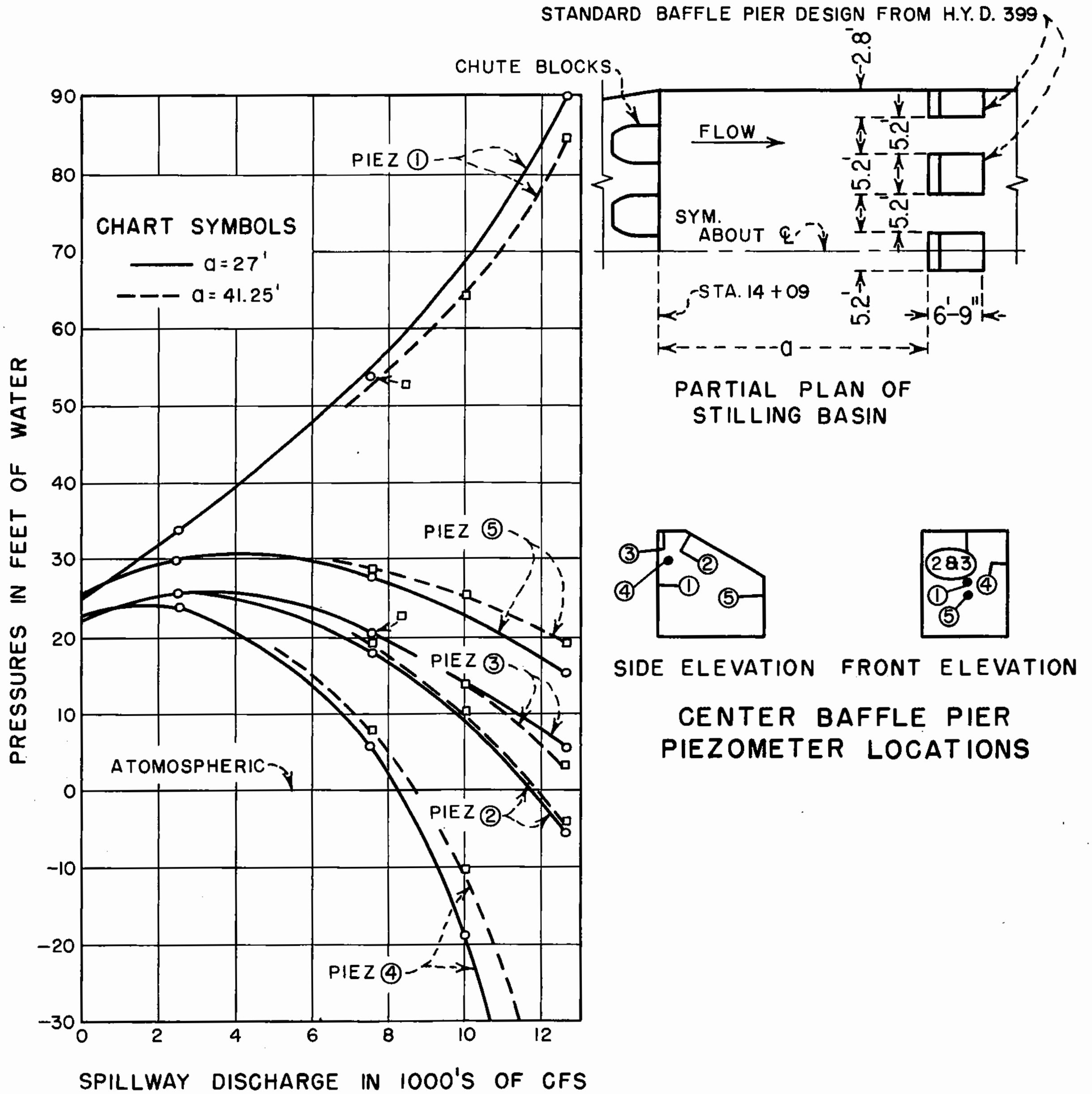


Same operating conditions as in Figure 26.

Note boil has moved to upstream end of basin and has been reduced.

Erosion after one hour model test.

PAONIA DAM SPILLWAY
PERFORMANCE OF STILLING BASIN MODIFICATION NO. 2
1:36 SCALE MODEL



NOTES

When outlet works alone is discharging 1470 second feet the pressure at all five piezometers is hydrostatic.

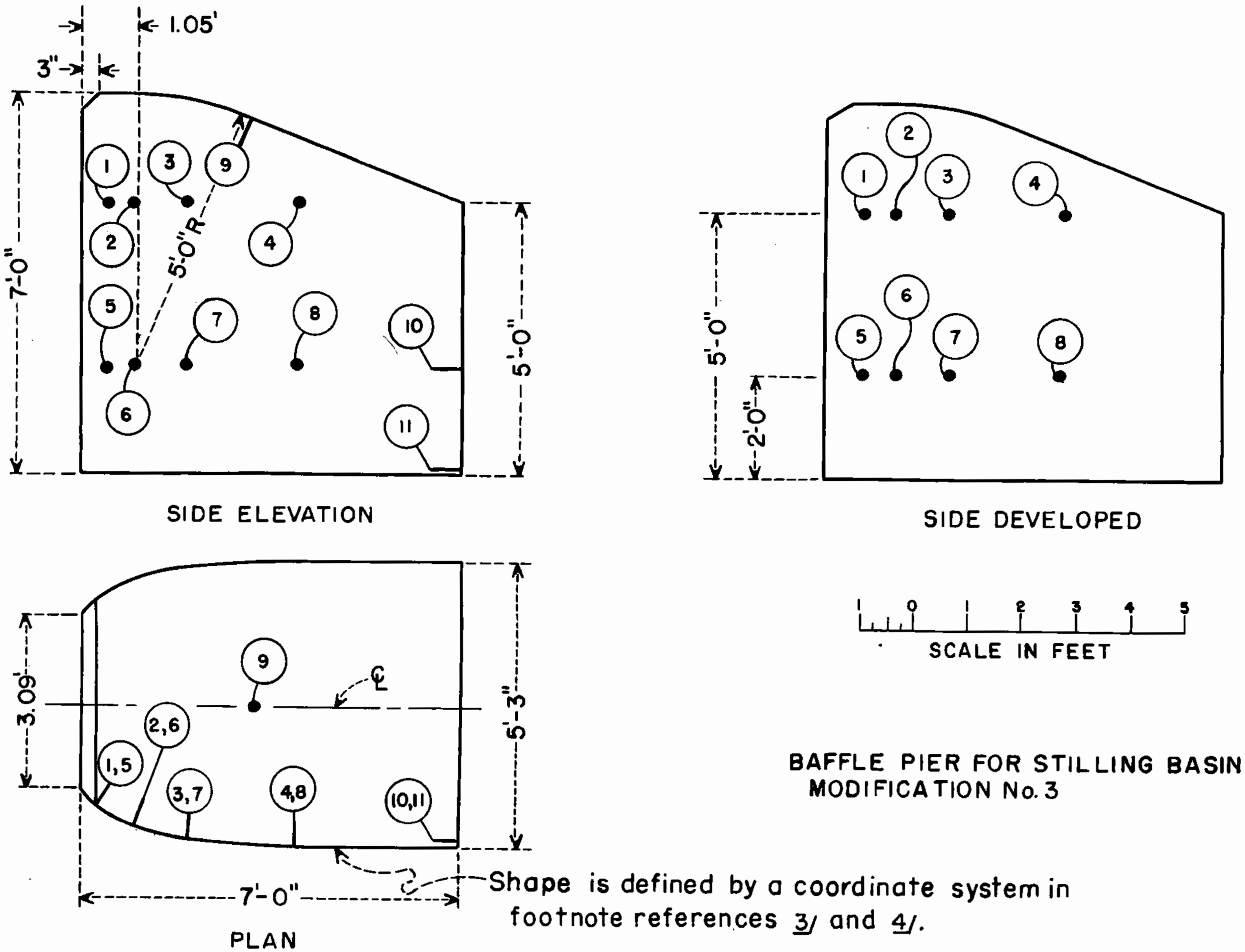
When five full piers are used, spaced 3' apart and located 27 feet downstream from Sta. 14+09, the pressures are about the same as for the 5.2 foot spacing located 41 feet 3 inches downstream from Sta. 14+09.

Operating conditions are the same as in figure 26 for design flow of 12,600 c.f.s.

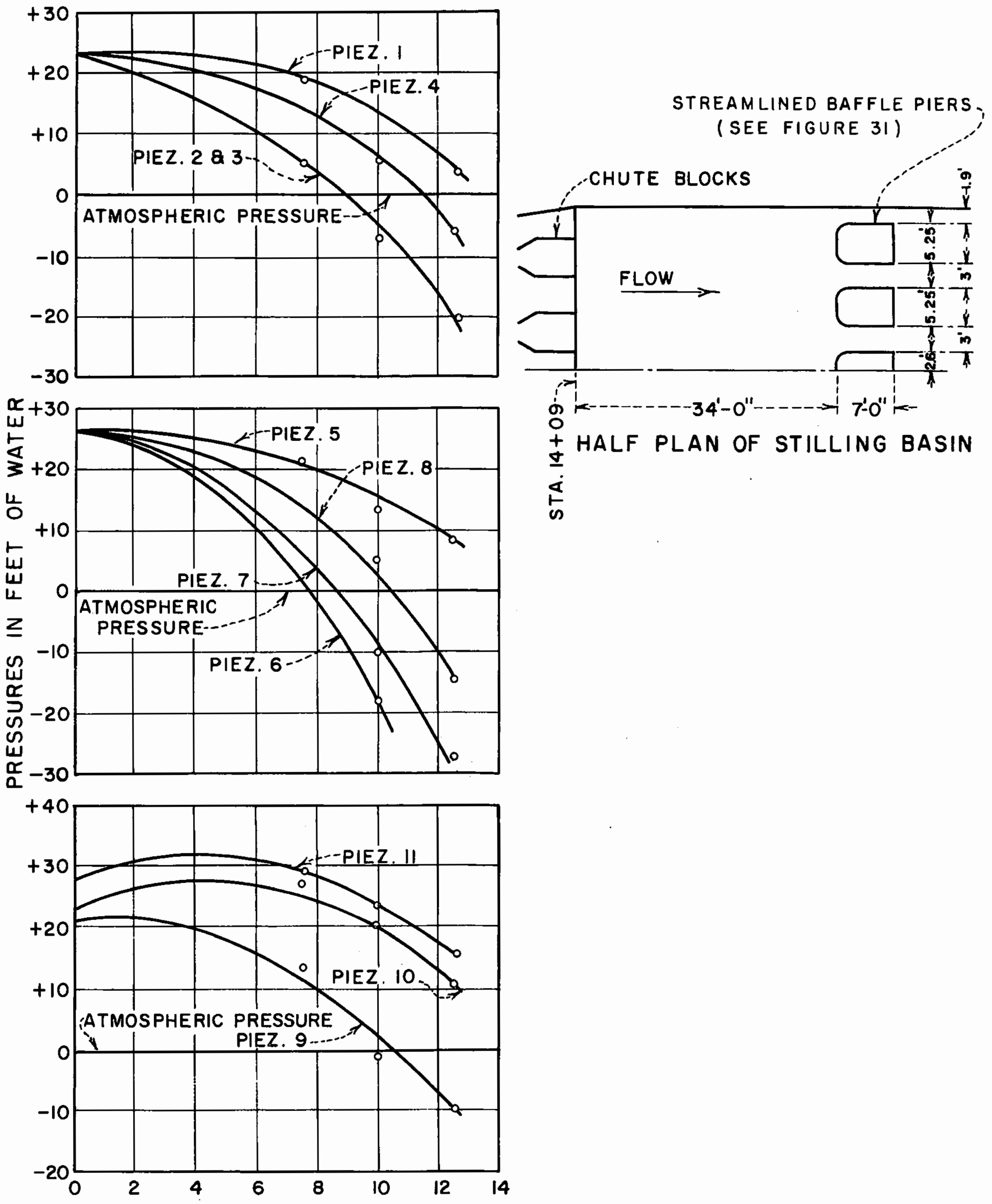
PAONIA DAM SPILLWAY

PRESSURES ON SQUARE EDGED BAFFLE PIERS

1:36 SCALE MODEL



PAONIA DAM SPILLWAY
STREAMLINED BAFFLE PIER
1:36 SCALE MODEL



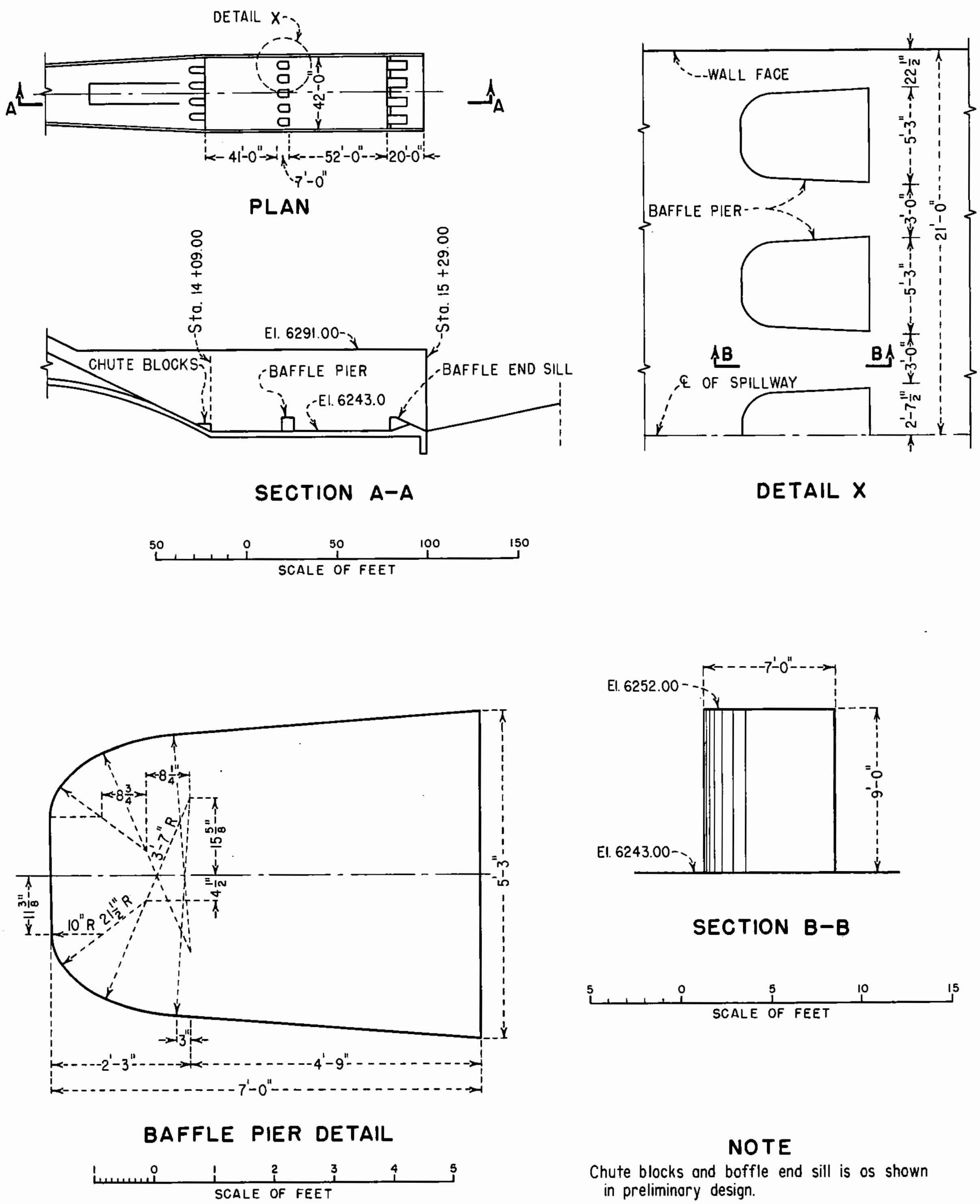
See Figure 31 For Piezometer Locations

PAONIA DAM SPILLWAY

PRESSURES ON STREAMLINED BAFFLE PIER

1:36 SCALE MODEL

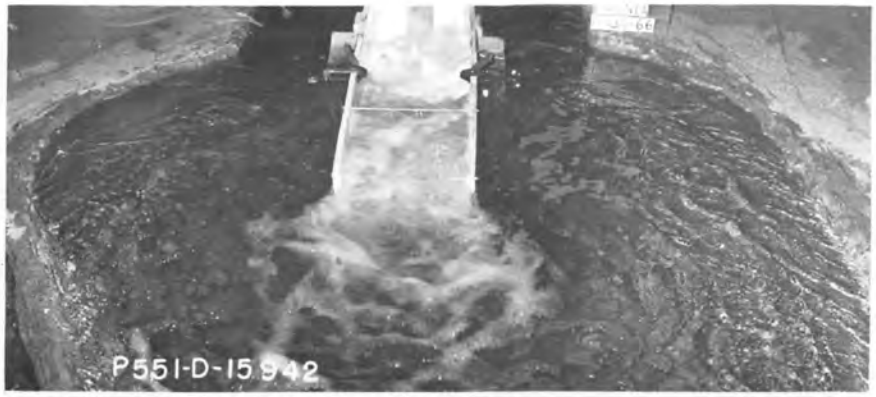
FIGURE 33
REPORT HYD. 444



NOTE

Chute blocks and baffle end sill is as shown in preliminary design.

PAONIA DAM SPILLWAY
RECOMMENDED STILLING BASIN
1:36 SCALE MODEL

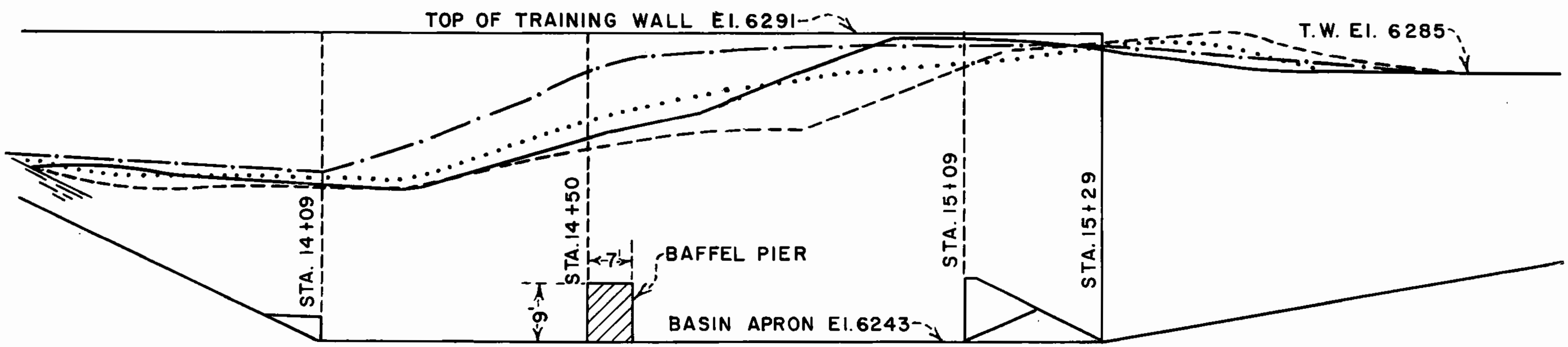


Same operating conditions as in Figure 26.

Note boil upstream from end of basin. Compare with Figure 26.

Erosion after one hour model test.

PAONIA DAM SPILLWAY
PERFORMANCE OF RECOMMENDED STILLING BASIN
DISCHARGING 12,600 CFS
1:36 SCALE MODEL



LONGITUDINAL SECTION THROUGH RECOMMENDED BASIN

- - - - - - - - Profile in preliminary basin – no baffle piers (See Figure 3)

———— Profile in recommended basin. (See Figure 33)

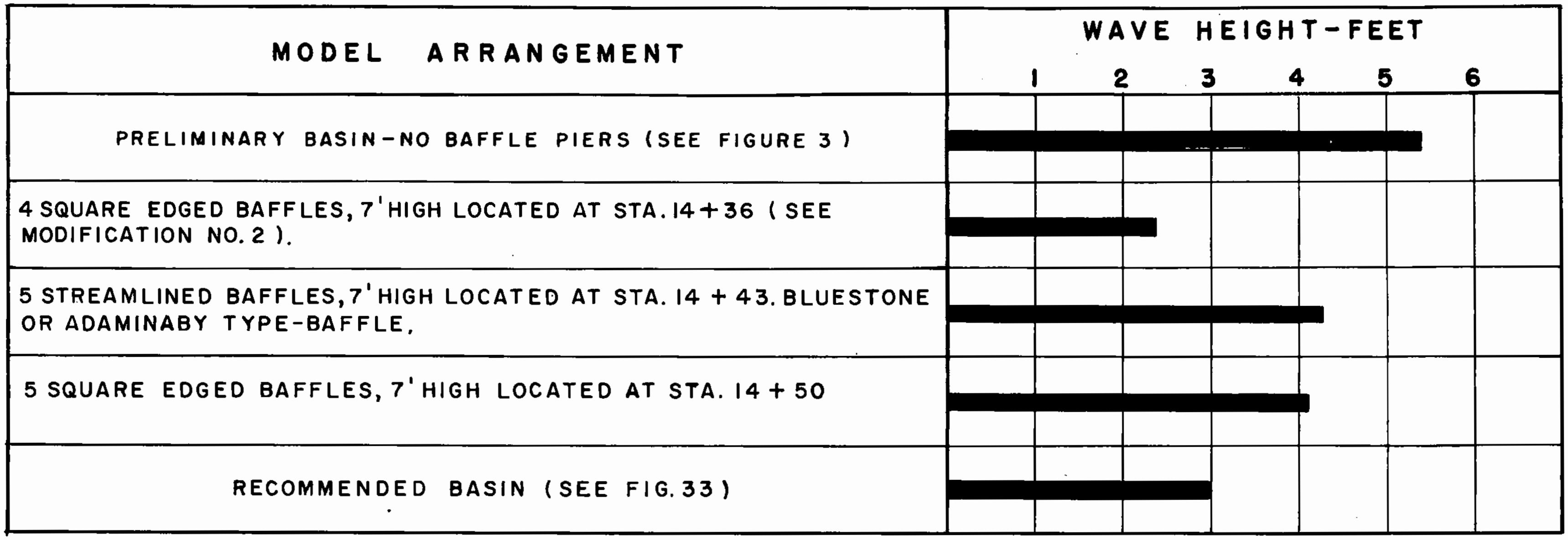
. . . . Profile for 5 streamlined baffles (Adaminaby Type) 7' high located at sta. 14+43.

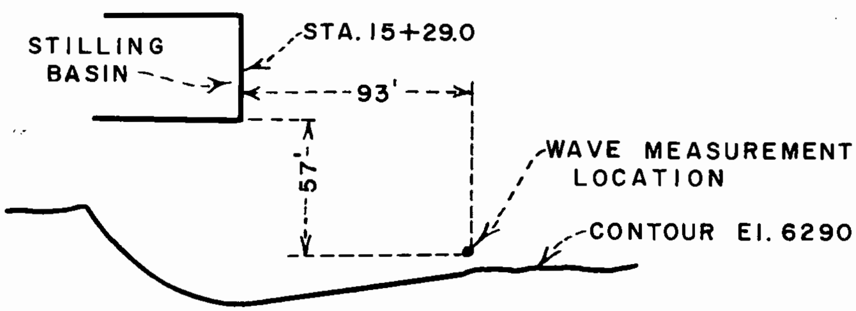
——— · ——— Profile for 4 square edged baffles 7' high located at sta. 14+36 (MODIFICATION NO. 2)

PAONIA DAM SPILLWAY
WATER SURFACE PROFILES IN STILLING BASIN
1:36 SCALE MODEL

FIGURE 35
REPORT HYD. 444

600



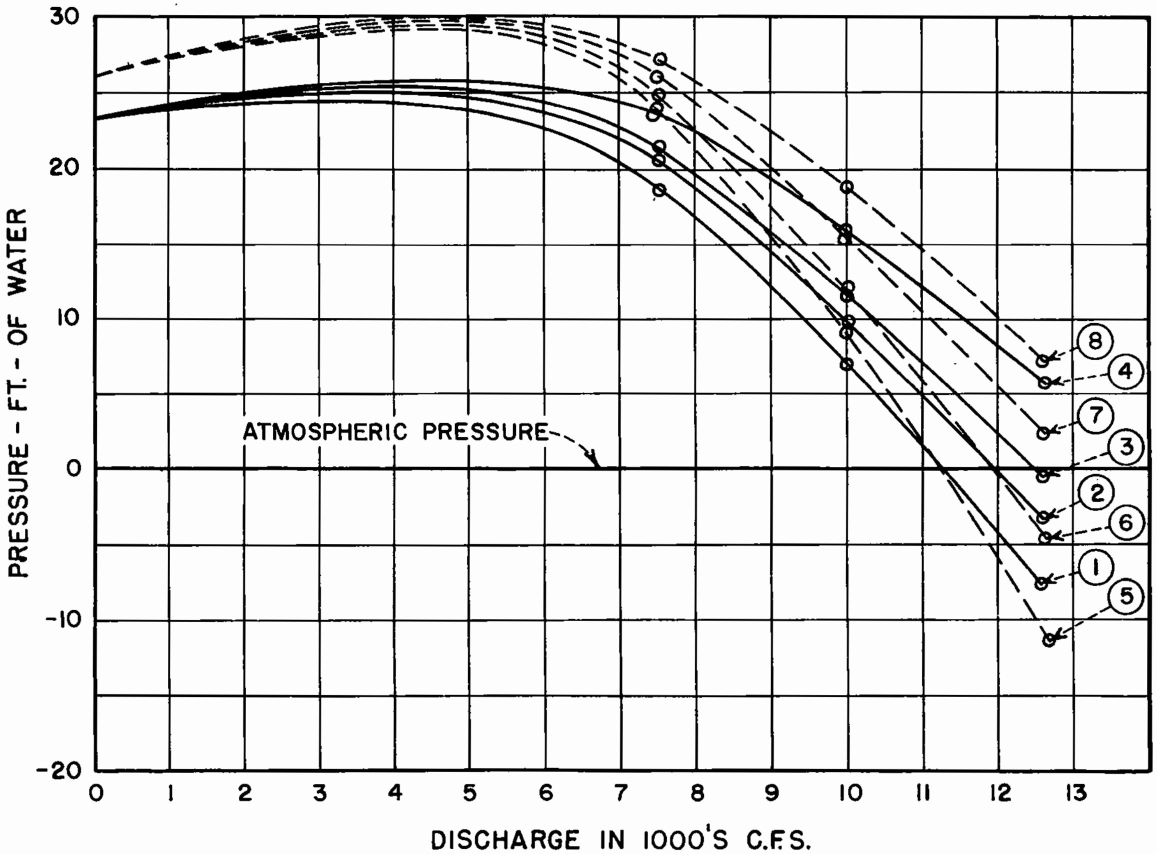


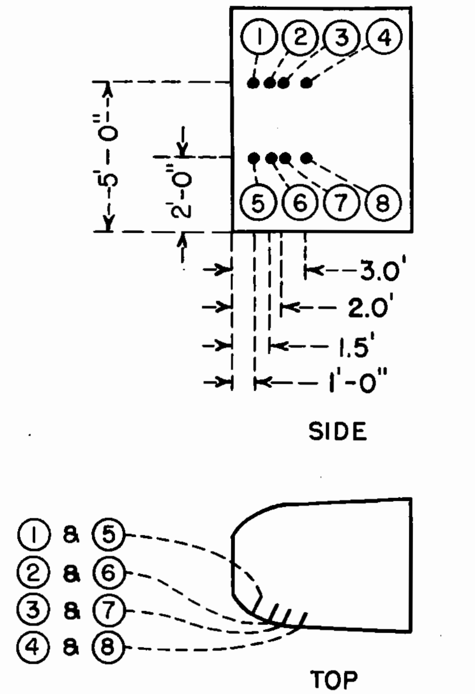
LOCATION DIAGRAM - PLAN

Discharge 12,600 c.f.s
T. W. El. 6285.2

PAONIA DAM SPILLWAY
RIVER CHANNEL WAVE HEIGHTS
1:36 SCALE MODEL

009

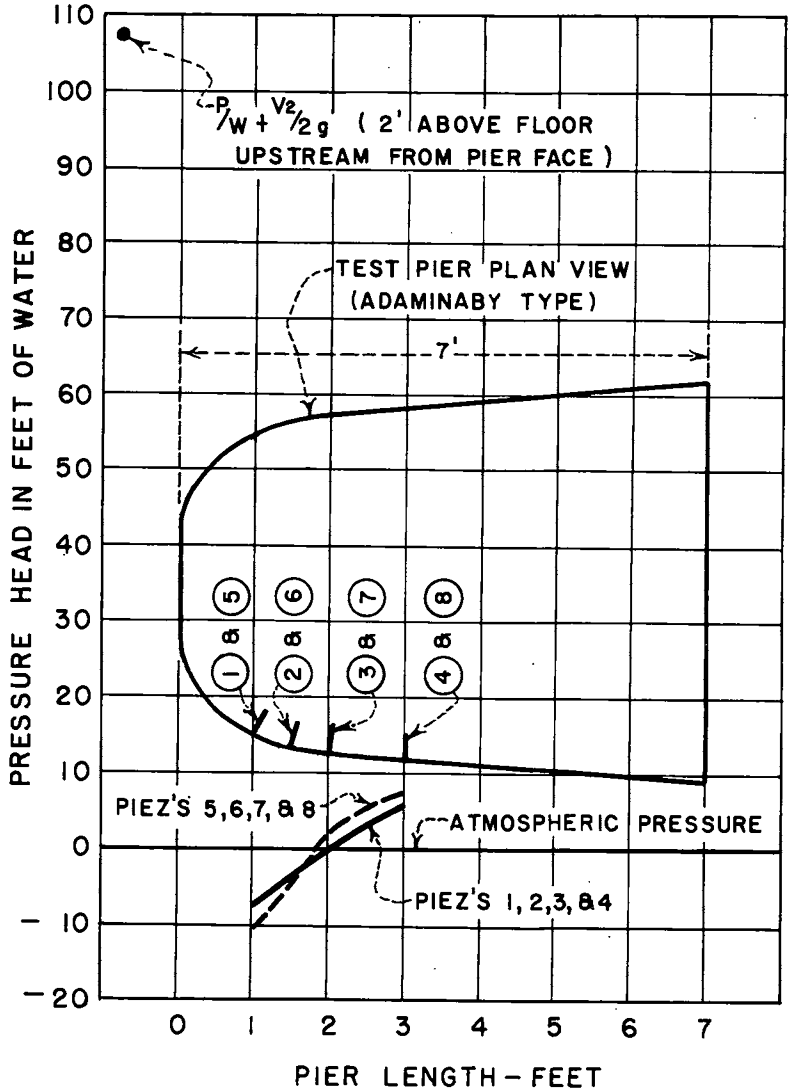




PIEZOMETER LOCATION
IN BAFFLE PIER

PAONIA DAM SPILLWAY
BAFFLE PIER PRESSURES IN RECOMMENDED
STILLING BASIN
1:36 SCALE MODEL

FIGURE 37
REPORT HYD 444



Discharge 12,600 c.f.s.
Tailwater El. 6285.2.

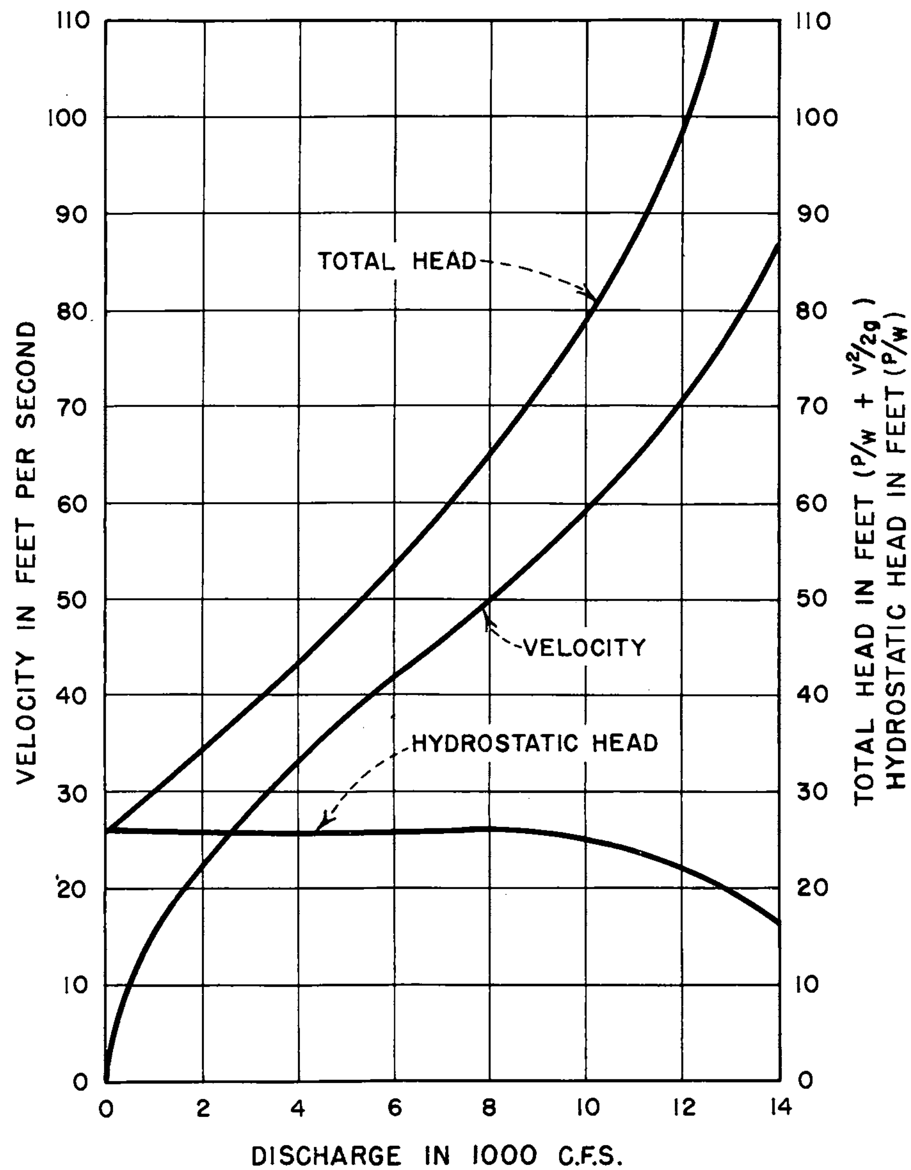
NOTE

Piez's 1,2,3&4 are 5 feet above apron elevation 6243.

Piez's 5,6,7&8 are 2 feet above apron elevation 6243

PAONIA DAM SPILLWAY
BAFFLE PIER PRESSURE GRADIENTS
IN RECOMMENDED STILLING BASIN

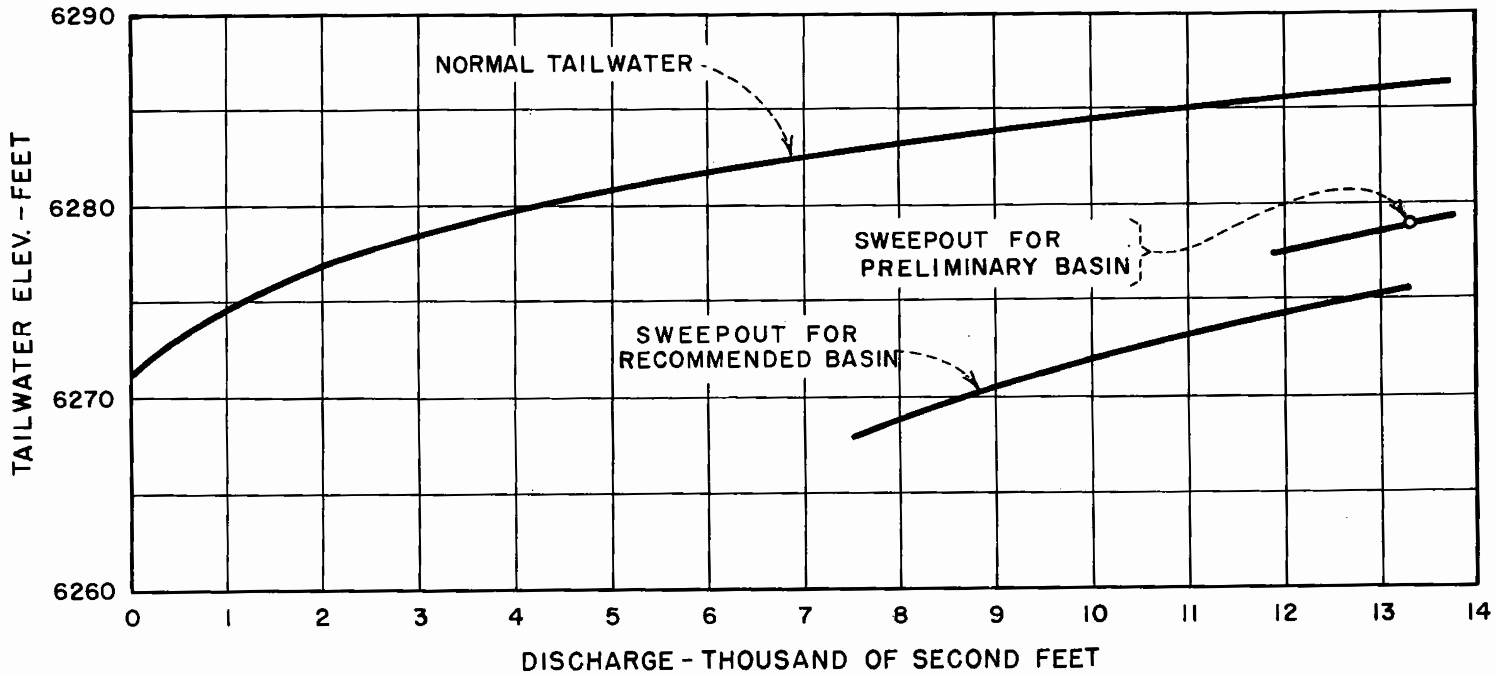
1:36 SCALE MODEL



NOTE

Total head, velocity, and hydrostatic head are measured 2 feet above basin floor approximately 30 feet downstream from chute blocks on centerline of basin.

PAONIA DAM SPILLWAY
HEAD AND VELOCITY IN RECOMMENDED BASIN
1:36 SCALE MODEL



PAONIA DAM SPILLWAY

HYDRAULIC JUMP SWEEPOUT

1:36 SCALE MODEL