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MISSISSIPPI RIVER COMMISSION

MODEL STUDY
OF
STILLING BASIN, DELAWARE DAM
OLENTANGY RIVER
OHIO

TECHNICAL MEMORANDUM NO. 205-1

U. S. WATERWAYS EXPERIMENT STATION

VICKSBURG, MISS.

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31803

MODEL STUDY OF STILLING BASIN

FOR DELAWARE DAM, OLENTANGY RIVER, OHIO

SYNOPSIS

1. This memorandum constitutes a report on the results of tests conducted at the U. S. Waterways Experiment Station on a model of the Delaware Dam stilling basin. The general purpose of the tests was to examine the hydraulic performance of the stilling basin as designed by the Cincinnati District Office. An existing 1-to-60 undistorted scale model of the Conemaugh Dam was used for the tests. Inasmuch as the height and width of the Conemaugh Dam are greater than the Delaware Dam, the height was made to agree by assuming a model-scale ratio of 1 to 31 existed; the discharge per foot of width was made to agree with the Delaware conditions. All details of the stilling basin were constructed in accordance with the Delaware Dam drawings to the scale of 1 to 31.

2. As designed by the Cincinnati District Office, the spillway for the Delaware Dam will be of the ogee type; it will be equipped with six 32-ft gates to regulate the reservoir for flood control. The spillway is designed to pass a maximum discharge of 96,000 cfs under a head of 28 ft. As a result of excess tailwater for the formation of a hydraulic jump, two rows of baffle piers and a high end sill will aid in the dissipation of energy and deflection of high velocity current away from the channel bed downstream.

3. The model investigations were concerned solely with the performance of the originally designed stilling basin. No attempts were

made to effect refinements to the elements of the stilling basin (baffle pier or end sill height, position, etc.). It was determined from the model tests that the stilling basin as designed was satisfactory. At low discharges the baffle piers destroyed all energy contained in the flow from the spillway while at high discharges the baffle piers in combination with the high end sill created surface and ground rollers which aided in the dissipation of energy and caused erodible material in the exit channel to be washed upstream to the area immediately downstream from the end sill. Although the baffle piers are not a necessity to the safety of the structure, their use improves flow conditions a great deal and their use in the Delaware basin is recommended.

PART I: AUTHORIZATION

4. The model tests of the Delaware Dam were requested verbally by Mr. R. L. Irwin, Engineer of the Ohio River Division Office, and Mr. H. A. Seaman, Senior Engineer of the Cincinnati District Office, during a visit to the Experiment Station on 14 and 15 December 1943. Authority for the work was confirmed in a teletype dated 17 December 1943 from the Division Engineer, Ohio River Division. The tests were conducted during the period 16 - 24 December 1943.

PART II: THE PROTOTYPE[1]

The Dam

5. The Delaware Dam is proposed for construction on the Olentangy River, about 6 miles above the city of Delaware or about 164 miles above the mouth of the Scioto River at Portsmouth, Ohio (see plate 1). The dam will consist of a gravity concrete spillway section in the valley, with gravity concrete nonoverflow abutment sections flanked by rolled-fill embankments terminating in low dikes on the abutments. The dam will have an over-all length of about 18,700 ft and a maximum height of 90 ft; it will contain approximately 72,500 cu yd of concrete and 860,000 cu yd of earth. The gross capacity of the reservoir formed by the dam, including the surcharge to elevation 950 msl will be about 162,000 acre-ft.

Spillway

General description

6. The concrete overflow section will be located in the valley on the left bank of the present river channel (see plate 2). The flow over the spillway will be controlled by means of six radial gates, each 32 ft long and 25 ft high, with fixed crest at elevation 922. The spillway with a drop of 52 ft from crest to basin will have a gross width of 232 ft and a net width of 192 ft. It has been designed to pass a design discharge of 96,000 cfs under a head of 28 ft; the maximum flood of record is about 35,000 cfs. The stilling basin at the toe of the crest

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1. Information on the prototype was obtained from the "Definite Project Report on Delaware Reservoir, Scioto River Watershed, Olentangy River, Ohio."

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is the standard horizontal apron type with two rows of 6-ft baffle piers and a 10-ft end sill; the length of apron is 66.5 ft.

Outlet Works

7. Original plans outlined in the Definite Project Report called for the use of five conduits, one in each pier section, to control in part the flow in the river below the dam. The five conduits will have a capacity of 4,500 cfs with the pool at spillway crest elevation and 6,500 cfs at controlled reservoir elevation. Five vertical-lift sluice gates individually operated from the top of the piers and one vertical-lift emergency gate lifted by a crest-gate hoisting crane will control sluice flow. It is understood, however, that the number of conduits is still open to question. The latest plans and drawings call for two conduits located as shown on plate 2.

PART III: THE MODEL

Purpose

8. The general purpose of the model study was to examine the hydraulic performance of the stilling basin of the Delaware Dam as designed by the Cincinnati District Office.

Description

9. In order to study the performance of the Delaware Dam stilling basin of original design as quickly and efficiently as possible, an existing 1-to-60-scale model of the Conemaugh Dam was utilized for the tests of the Delaware basin. The 100.5-ft drop from crest to basin of the Conemaugh Dam on a 1-to-60-scale model was equivalent to the 52-ft drop from crest to basin of the Delaware Dam on a 1-to-31 scale. Accordingly the details of the Delaware stilling basin were reproduced on a 1-to-31 scale and installed at the toe of the Conemaugh overflow section; no attempt was made to alter the crest shape. Reference is made to plates 3-5 and photographs 1 and 2 which show details of the model as tested. Inasmuch as the basin width was in excess of that called for in the Delaware design, the total discharge was increased to secure the discharge per foot of width that would exist for the Delaware conditions. Throughout this report, however, all discharges described are based on the correct Delaware dimensions and not the actual overflow and model basin width.

10. All Conemaugh model appurtenances were utilized in the Delaware Dam tests. Discharges were measured with a venturi meter;

velocities with a pitot tube; and water-surface elevations with hook or point gages. The tailwater elevation was adjusted by means of a flap gate at the lower end of the model.

PART IV: TESTS OF STILLING BASIN

Description

11. The stilling-basin design for the Delaware Dam spillway was of the standard horizontal apron type with two rows of 6-ft baffle piers and a 10-ft end sill; the length of the apron was 66.5 ft. The high end sill was necessary to protect the river channel downstream since it was at a higher elevation than the elevation of the apron of the stilling basin. Since the elevation of the apron at 870 was too low for the formation of a good hydraulic jump at any discharge and a high end sill was necessary at the end of the apron, a roller action rather than a true hydraulic jump type basin resulted.

12. The complete investigation of the Delaware Dam stilling basin of original design was accomplished within a week's time and involved (a) observation of flow conditions, (b) determination of effect of tailwater variation, (c) measurement of water-surface profiles, (d) investigation of erosion of the exit channel, and (e) measurement of bottom velocities in the exit channel. In describing test results, all discharges and dimensions are presented in terms of their prototype equivalents.

Results

13. Flow conditions. The action within the stilling basin was observed at discharges of 96,000, 70,000, 50,000, 30,000, and 10,000 cfs with the high and low tailwater corresponding thereto; however, the observation of flow at a discharge of 96,000 cfs and the high tailwater was

necessarily omitted since the walls of the model were not of sufficient height (see photographs 3-16). These observations indicated that for all discharges flow conditions within the stilling basin were satisfactory. The flow from the spillway was deflected upward by the baffle piers and end sill forming a broad low surface roller, similar to a hydraulic jump in appearance, and a ground roller downstream from the end sill. Under no conditions would the flow from the spillway remain beneath the tailwater; this was true even for conditions of unbalanced gate operation (see photograph 12). Some lateral flow existed over the wing walls but was not of sufficient force to depress the flow being deflected upward by the baffle piers.

14. In several of the tests the baffle piers were removed to study the effect of the baffle piers in deflecting the swift moving jet from the spillway. These tests indicated that the baffle piers greatly improved flow conditions within the basin. Failure of the piers, however, should not result in failure of the structure as the end sill was sufficient to maintain the roller action at all discharges. The removal of the baffle piers resulted in a greater concentration of flow over the end sill and a more pronounced standing wave (see photographs 5, 10, 11, and 16).

15. Effect of tailwater variation. Inasmuch as the accuracy of the computed tailwater curves was in some doubt, it was important that the stilling basin perform satisfactorily through a wide range of tailwater depths. In addition to the tests conducted using the two computed tailwater curves (plate 6) observation tests were conducted with the tailwater raised and lowered from the computed curves until complete

submergence of the spillway flow occurred or until the tailwater was lowered to such an extent that severe impact of flow on the baffle piers occurred. The upper and lower limits developed as described are shown on plate 6, and indicate that the basin as designed should be satisfactory. At no discharge could the tailwater be lowered sufficiently as to cause spray action; this is attributed to the backwater effect of the high end sill. During these tests the tailwater elevation at which best basin action occurred was also recorded and plotted on plate 6; this curve followed closely the lower computed tailwater curve.

16. Water-surface profiles. Average water-surface profiles over the basin and exit channel were measured for discharges of 96,000, 50,000, and 10,000 cfs and with and without baffle piers on the apron (see plates 7-9). These data indicate that the baffle piers, as stated in paragraph 14, do have the effect of causing a greater dispersion of flow and improving basin action. The size of surface and ground rollers is also increased through use of baffle piers. Attention is invited to the fact, however, that safe stilling-basin performance is not contingent upon the use of baffle piers.

17. Scour. Erosion tests were conducted at discharges of 96,000, 50,000, and 10,000 cfs with tailwater depths corresponding thereto (see plates 10-15). These tests were conducted with the sand bed of the exit channel molded flat to elevation 880 (elevation of top of end sill). From the scour data it should be noted that with all gates open and uniform flow across the stilling basin the greatest amount of scour occurred at a discharge of 96,000 cfs; the scour, however, was not excessive and the area subjected to the greatest erosion was located about 100 ft

downstream from the end sill (see plate 10). At discharges of 50,000 cfs and 10,000 cfs scour was practically nonexistent (see plates 12, 13, and 15). One scour test conducted to investigate the effect of end sill shape (photograph 4) revealed that little difference existed and that the shape of the sill should depend on the economics involved from a construction rather than a hydraulic standpoint (see plates 5 and 11). One scour test conducted at a discharge of 50,000 cfs to demonstrate the effect of closing gates on one side of the spillway indicated that more scour resulted than occurred at a discharge of 96,000 cfs with all gates open (see plate 14).

18. It is desired to emphasize the fact that the scour obtained in the model does not quantitatively simulate true prototype conditions. The scour tests indicate the location of the scouring attack rather than its magnitude; the velocity measurements discussed in the following paragraphs are considered to indicate the magnitude of the scouring attack.

19. Velocities. Reference is made to plates 16-18 showing the magnitude of bottom velocities in the exit channel for discharges of 96,000 and 50,000 cfs; velocities were too low to record at a discharge of 10,000 cfs. At a discharge of 96,000 cfs and low tailwater no velocities were in excess of 7 ft per sec, and velocities in general were in the range of 5 ft per sec. The velocities also indicate that the downstream limit of the ground roller formed was about 150 to 200 ft below the end sill. At a discharge of 50,000 cfs velocities in the vicinity of the basin were negligible at the high tailwater of 916.2 and in the range of 4.5 ft per sec at the low tailwater of 909.0. Inasmuch as the

maximum flood of record is about 35,000 cfs, no damage should be expected below the Delaware Dam stilling basin.

20. The velocity of flow over the side walls of the stilling basin varied from about 10 ft per sec for a discharge of 50,000 cfs to about 15 ft per sec for a discharge of 96,000 cfs. The velocities measured over the training walls may or may not be indicative of the actual prototype velocities inasmuch as the flow in the exit channel was confined to the limits of the model, whereas in the prototype the flow covers a larger area which might increase the strength of the lateral flow.

PART V: DISCUSSION AND RECOMMENDATIONS

21. The conduct of tests on the Conemaugh model altered to reproduce Delaware Dam conditions was very successful in demonstrating the expected performance of the proposed Delaware Dam stilling basin. On the basis of the test results described previously within the report, it is believed that the stilling basin as designed should function satisfactorily at all discharges provided the existing tailwater falls within the range shown on plate 6. It is recommended that the 66.5-ft length of apron, the 10-ft end sill, and the two rows of 6-ft baffle piers be retained as tested. It is further recommended that the shape of baffle piers and end sill be determined after a review of economies which might be effected in construction. Variation from the shape tested should not have any appreciable effect on basin performance.

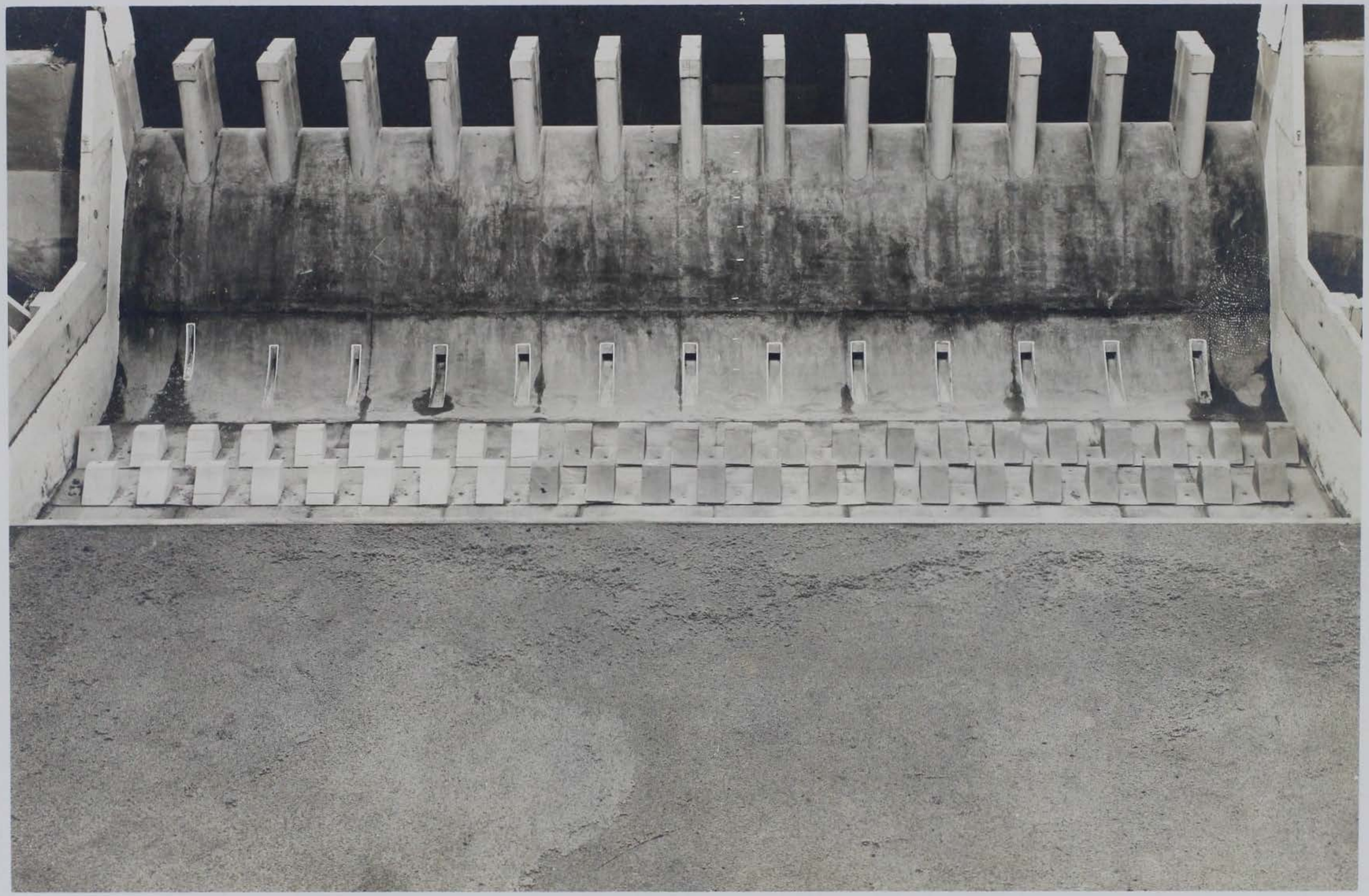
PART VI: PERSONNEL

22. The model study was accomplished in the Hydraulic Structures Section of the Hydrodynamics Division of the U. S. Waterways Experiment Station. Director of the Experiment Station is Mr. Gerard H. Matthes, Head Engineer, aided by First Lieutenant Joseph B. Tiffany, Jr., C. E., Executive Assistant. Chief of the Hydrodynamics Division and Acting Chief of the Hydraulics Structures Section is Mr. Frederick R. Brown, Associate Engineer. The project engineer in direct charge of the conduct of model tests was Mr. Americus M. Gill, Principal Engineering Aide, assisted by Mr. Robert T. Garner, Jr., Senior Engineering Aide, and Miss Martha D. Hommel, Junior Engineering Aide.

23. Mr. H. A. Seaman, Senior Engineer, of the Cincinnati District Office, and Mr. R. L. Irwin, Engineer, of the Ohio River Division Office, were present during the conduct of the observation tests to study basin action.

31803

PHOTOGRAPHS



Photograph 1. View of the Conemaugh Dam model with the Delaware Dam stilling basin installed.

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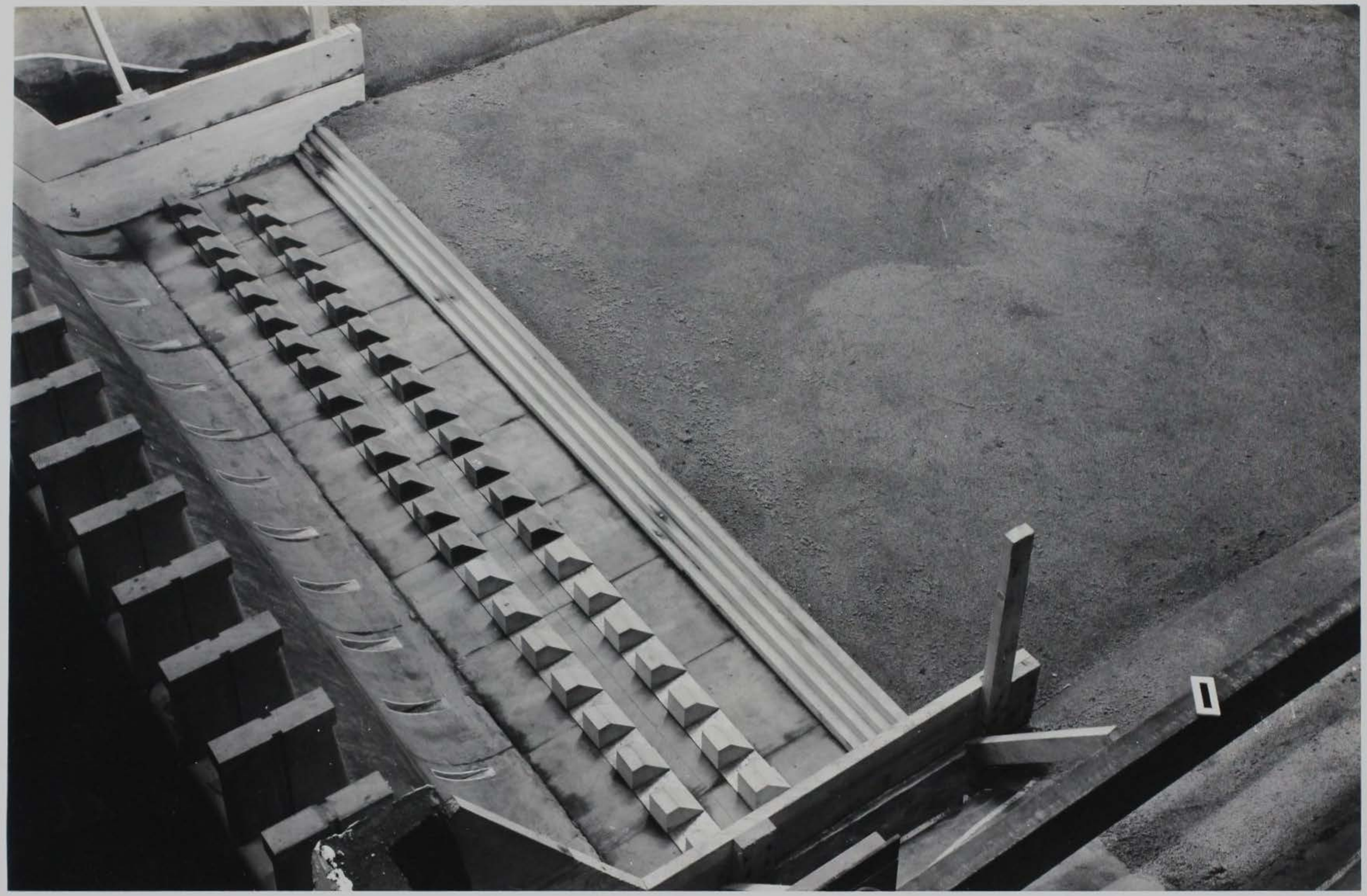
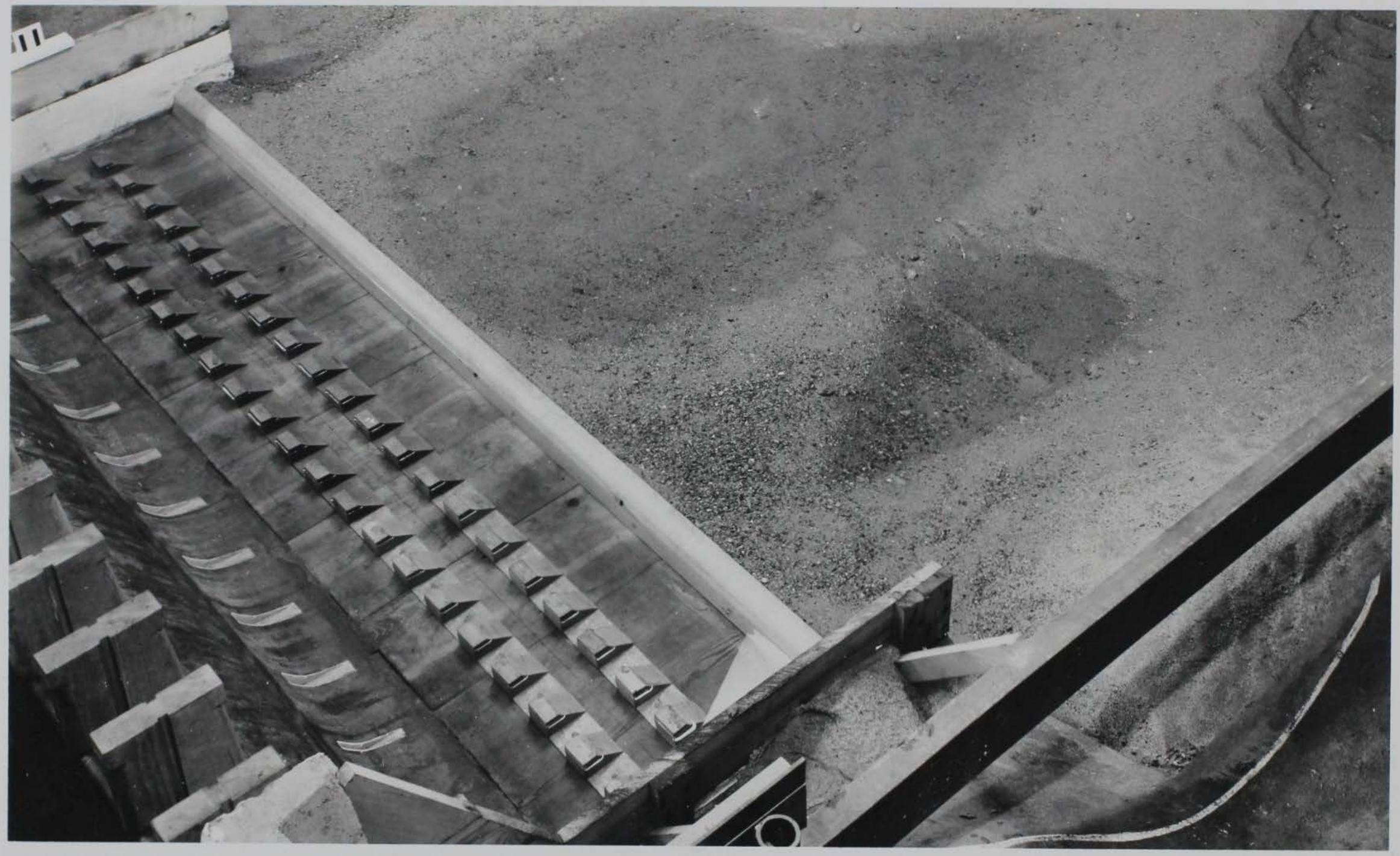


Photograph 2. View of Delaware Dam stilling basin.

Photograph 3. A broad low standing wave existed over the end sill at high discharges.

Discharge = 96,000 cfs Tailwater Elev. = 919.4



Photograph 4. View of scoured bed after 1 hour's operation. Rounded type end sill.

Discharge = 96,000 cfs Tailwater Elev. = 919.4

Photograph 5. Removal of the baffle piers resulted in a higher concentration of flow at the end sill.

Discharge = 96,000 cfs . Tailwater Elev. = 919.4

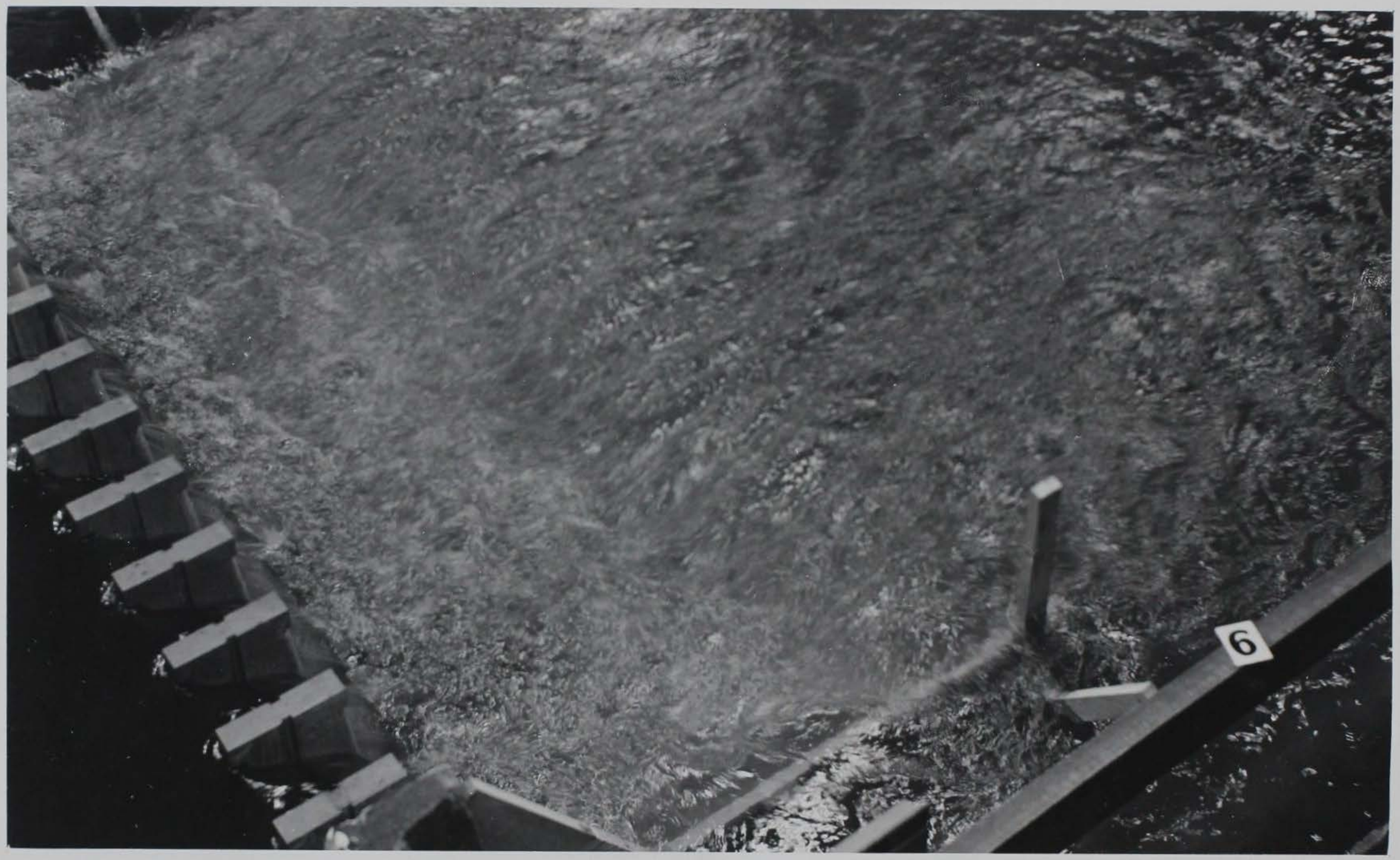
Photograph 6. At high tailwater elevations lateral flow existed over the stilling-basin walls.

Discharge = 70,000 cfs Tailwater Elev. = 926.2

Photograph 7. The lateral flow over the stilling-basin walls was practically eliminated at the minimum tailwater elevation.

Discharge = 70,000 cfs Tailwater Elev. = 914.1

A7 W

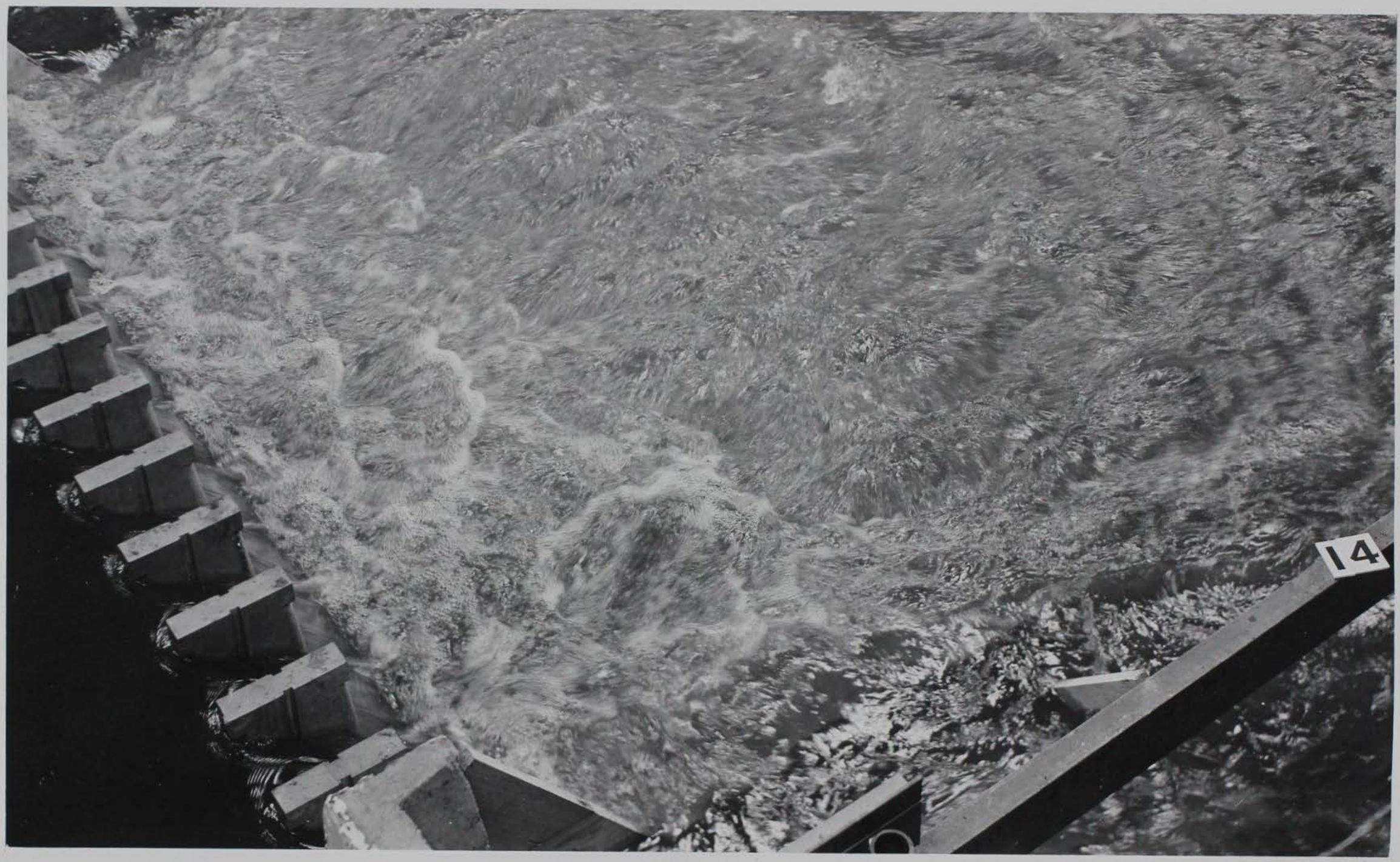


Photograph 8. Flow conditions were satisfactory for intermediate discharges and high tailwater elevations.

Discharge = 50,000 cfs Tailwater Elev. = 916.2

Photograph 9. Flow in the stilling basin resembled that secured in a good hydraulic jump basin.

Discharge = 50,000 cfs Tailwater Elev. = 909.0



Photograph 10. The removal of the baffle piers at intermediate discharges had no appreciable effect on flow conditions.

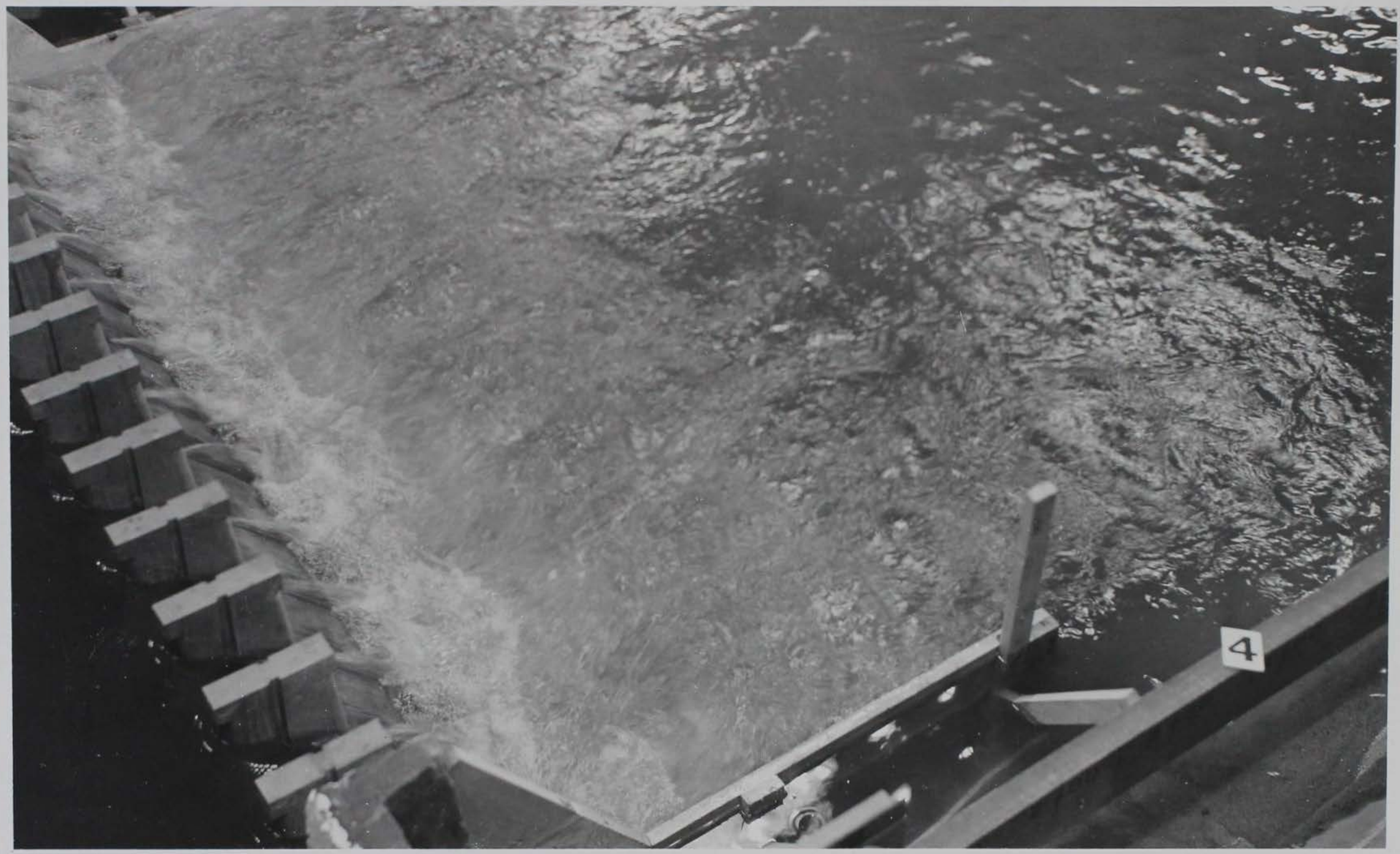
Discharge = 50,000 cfs Tailwater Elev. = 916.2

Photograph 11. The removal of the baffle piers at low tailwater elevations caused more of a concentration of flow at the end sill.

Discharge = 50,000 cfs . Tailwater Elev. = 909.0

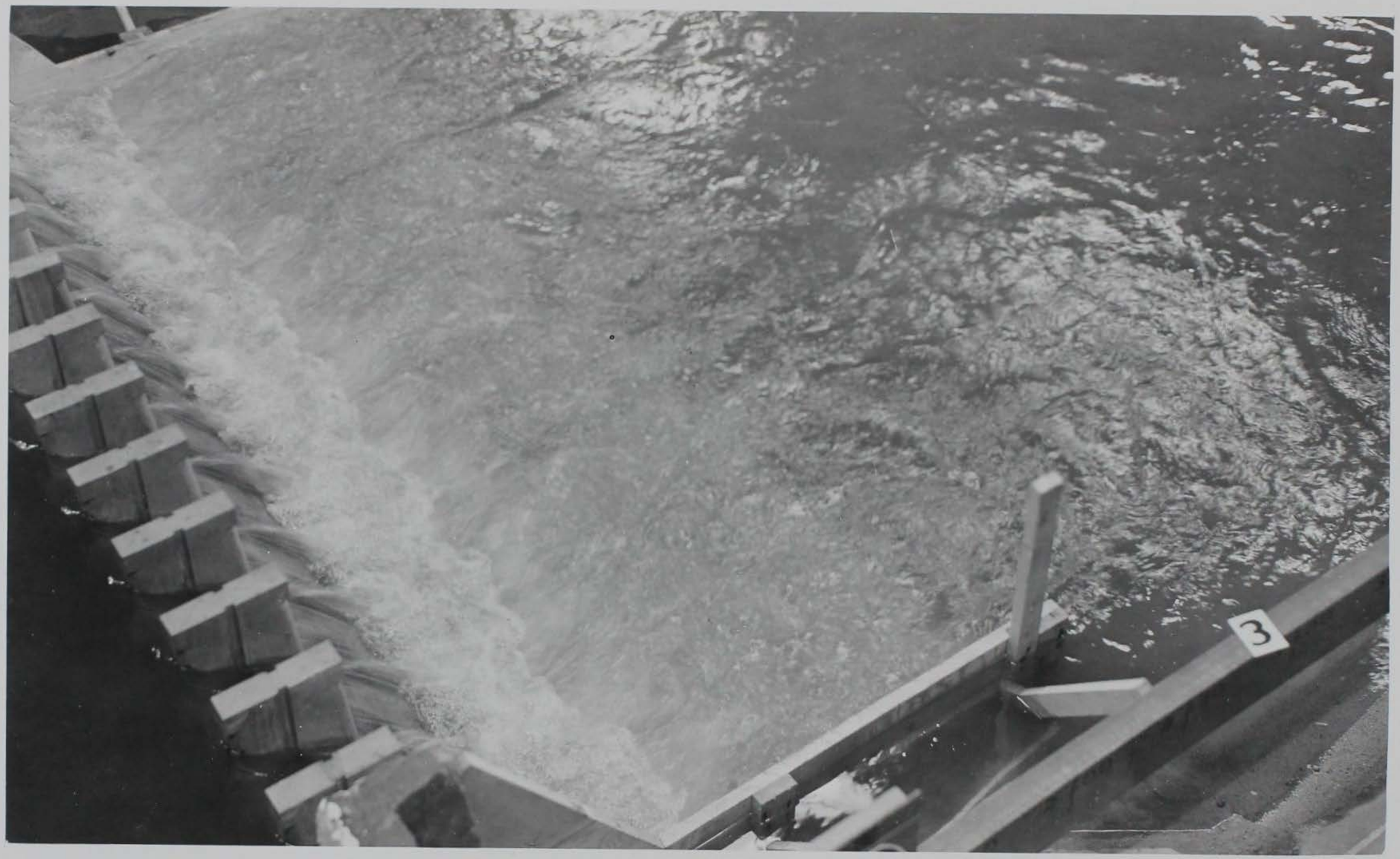
Photograph 12. Closure of the gates on the right portion of the spillway caused eddy conditions within the basin.

Discharge = 50,000 cfs Tailwater Elev. = 909.0



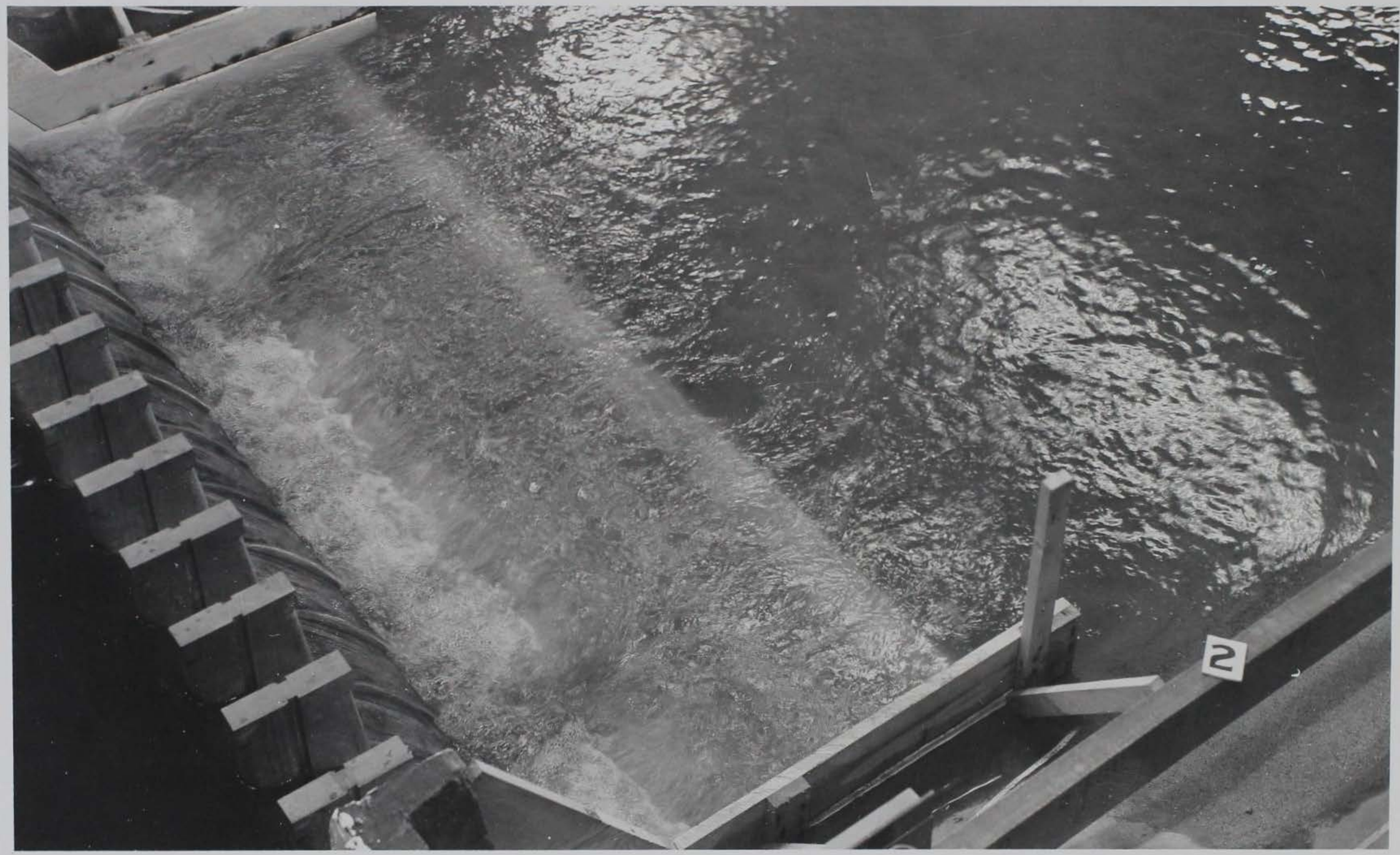
Photograph 13. Flow in the stilling basin was excellent at low discharges.

Discharge = 30,000 cfs Tailwater Elev. = 905.3



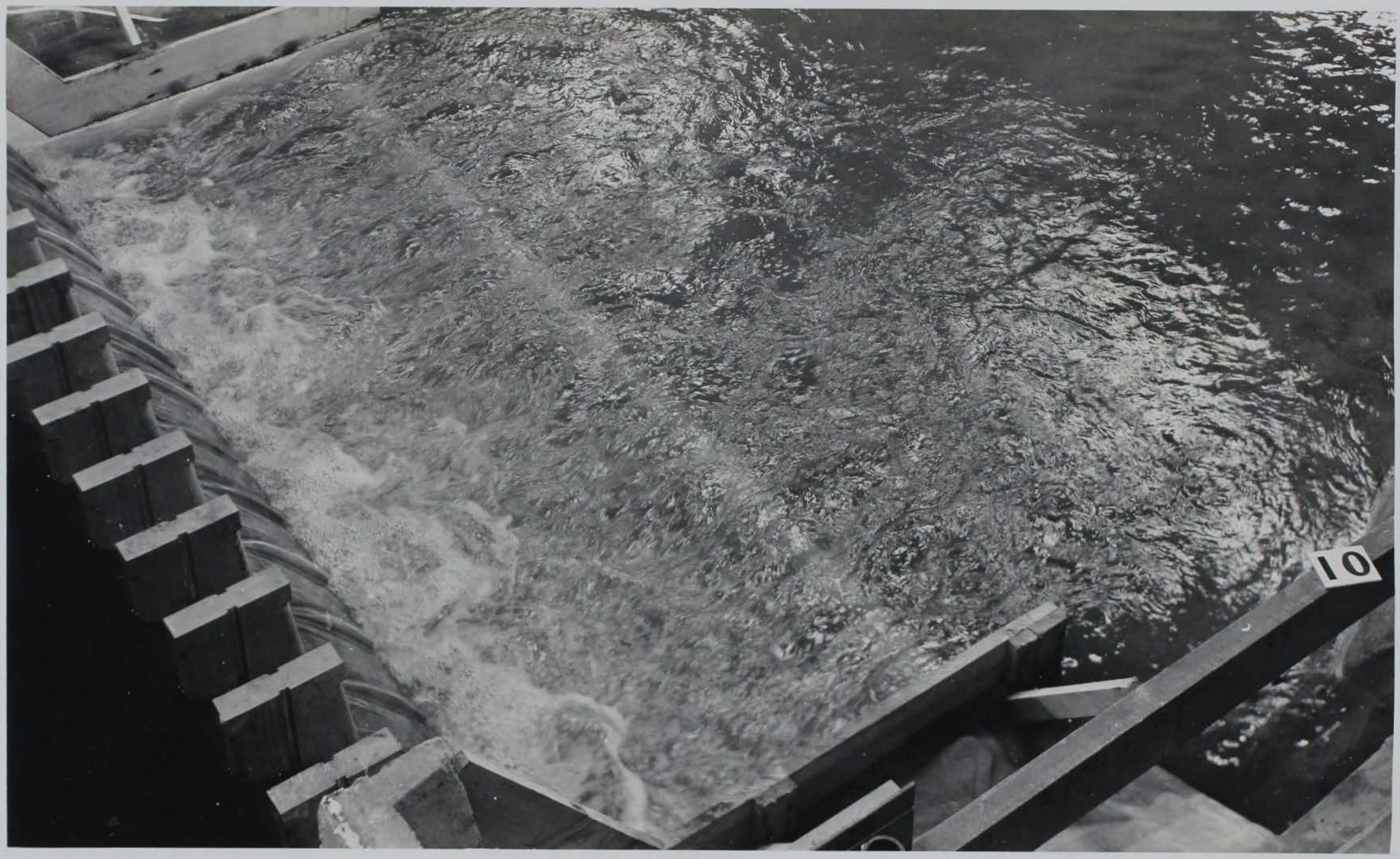
Photograph 14. Flow in the stilling basin was excellent at low discharges.

Discharge = 30,000 cfs Tailwater Elev. = 902.5



Photograph 15. Flow in the stilling basin was excellent at low discharges.

Discharge = 10,000 cfs Tailwater Elev. = 892.0



Photograph 16. Removal of the baffle piers at low discharges had no appreciable effect on flow conditions.

Discharge = 10,000 cfs Tailwater Elev. = 892.0

PLATES

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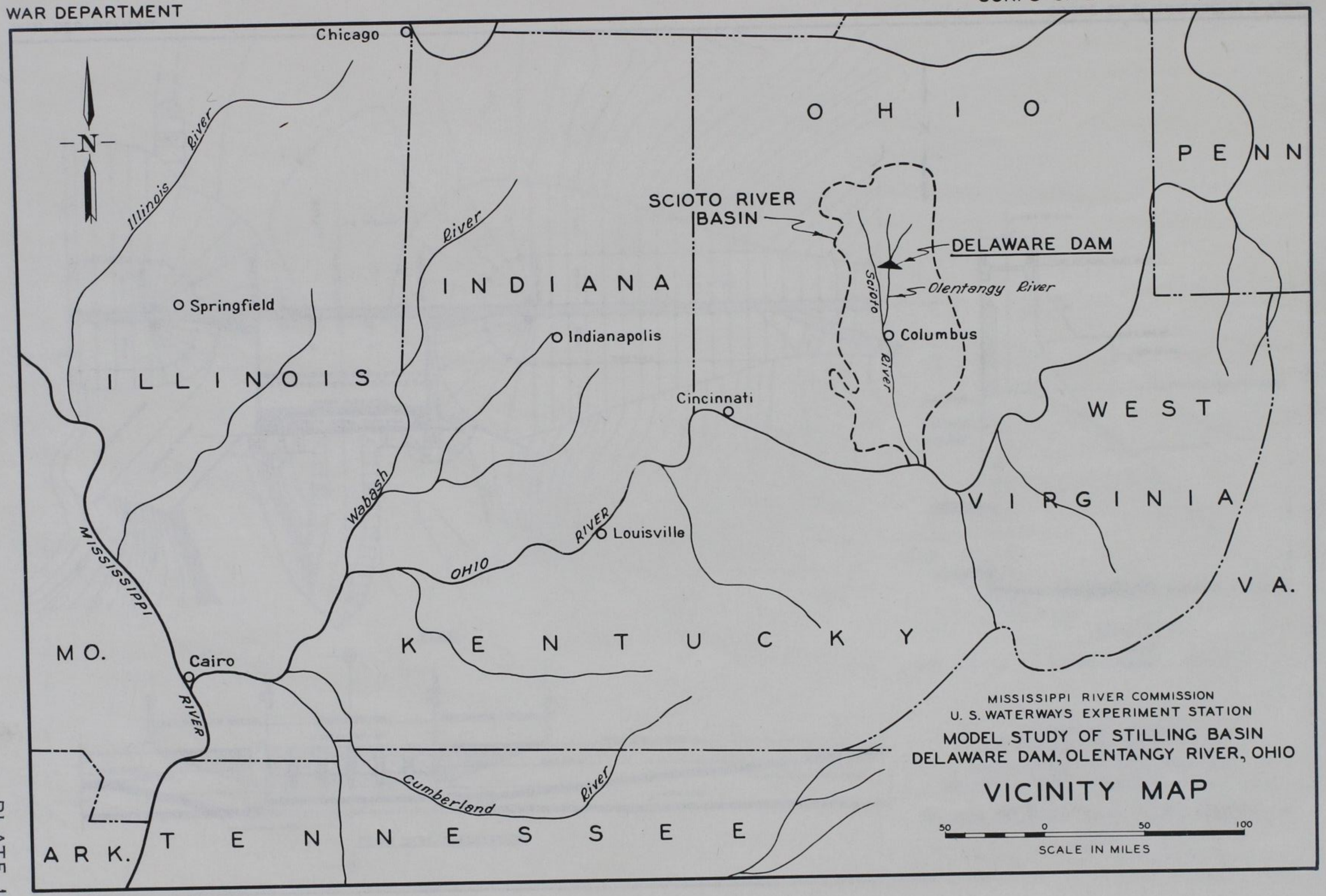

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U. S. WATERWAYS EXPERIMENT STATION

MODEL STUDY OF STILLING BASIN
DELAWARE DAM, OLENTANGY RIVER, OHIO

VICINITY MAP

50 0 50 100
SCALE IN MILES

PLATE 1

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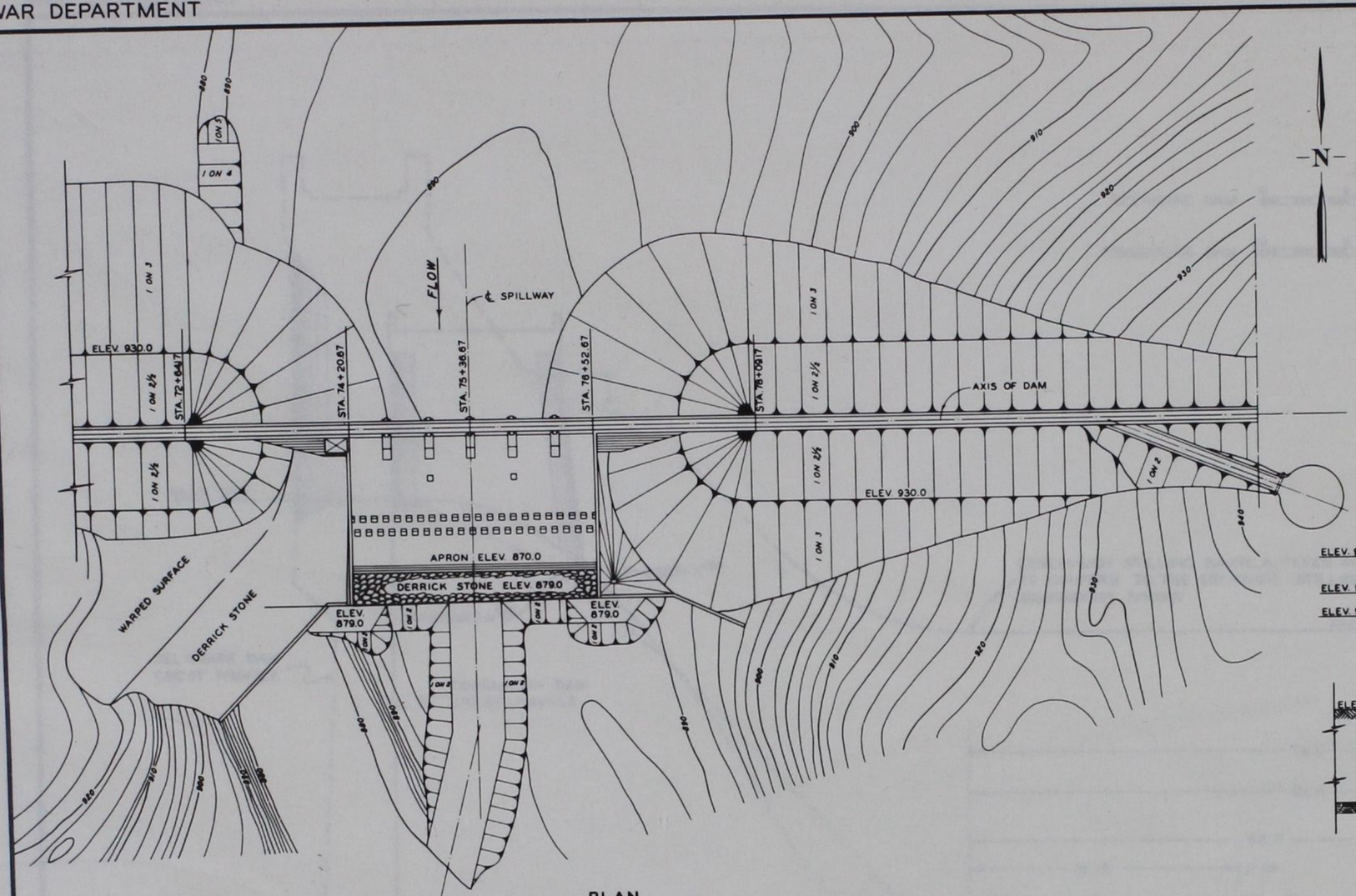
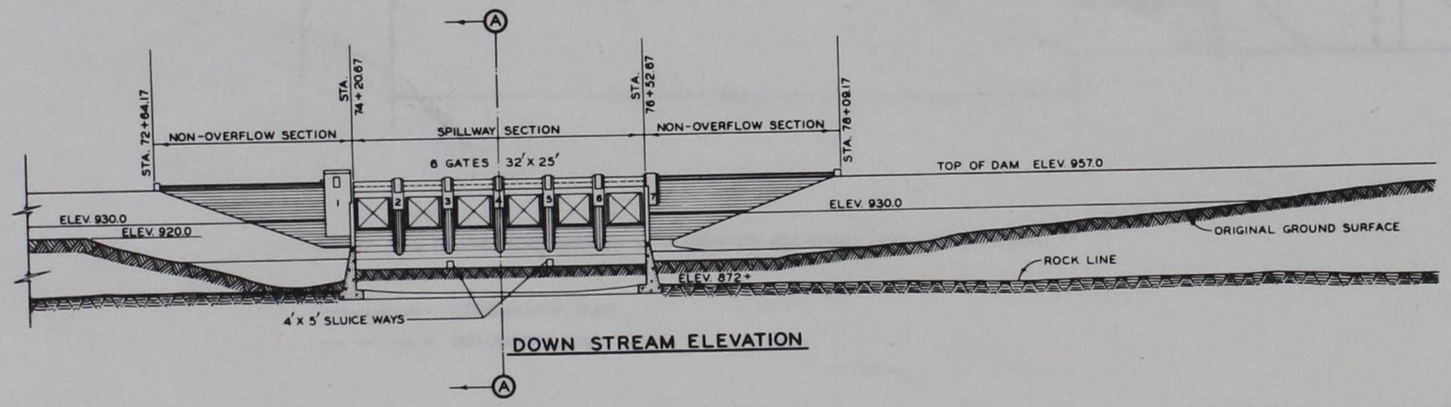
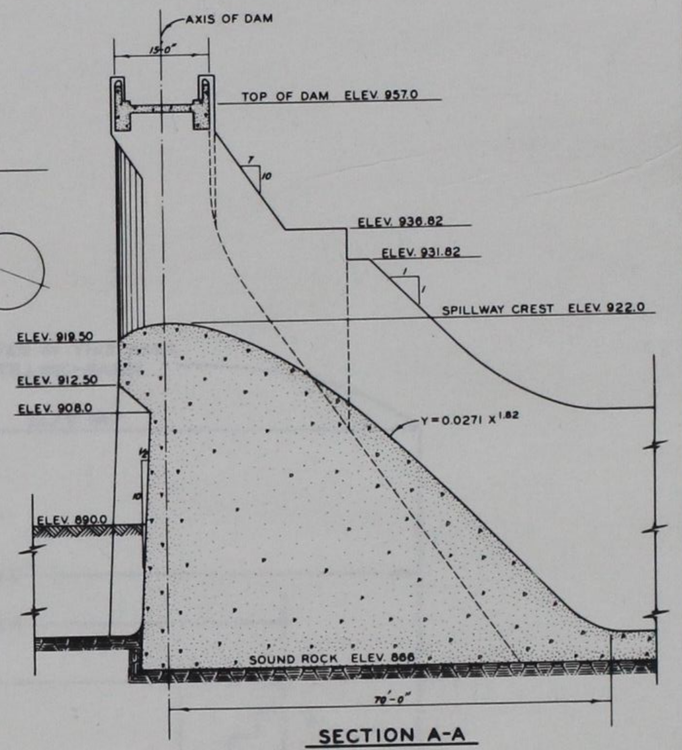


PLAN



DOWN STREAM ELEVATION



SECTION A-A

SCALE

10 0 10 20 30 40 FEET

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U. S. WATERWAYS EXPERIMENT STATION

MODEL STUDY OF STILLING BASIN

DELAWARE DAM, OLENTANGY RIVER, OHIO

PLAN, ELEVATION AND SECTION

SCALE

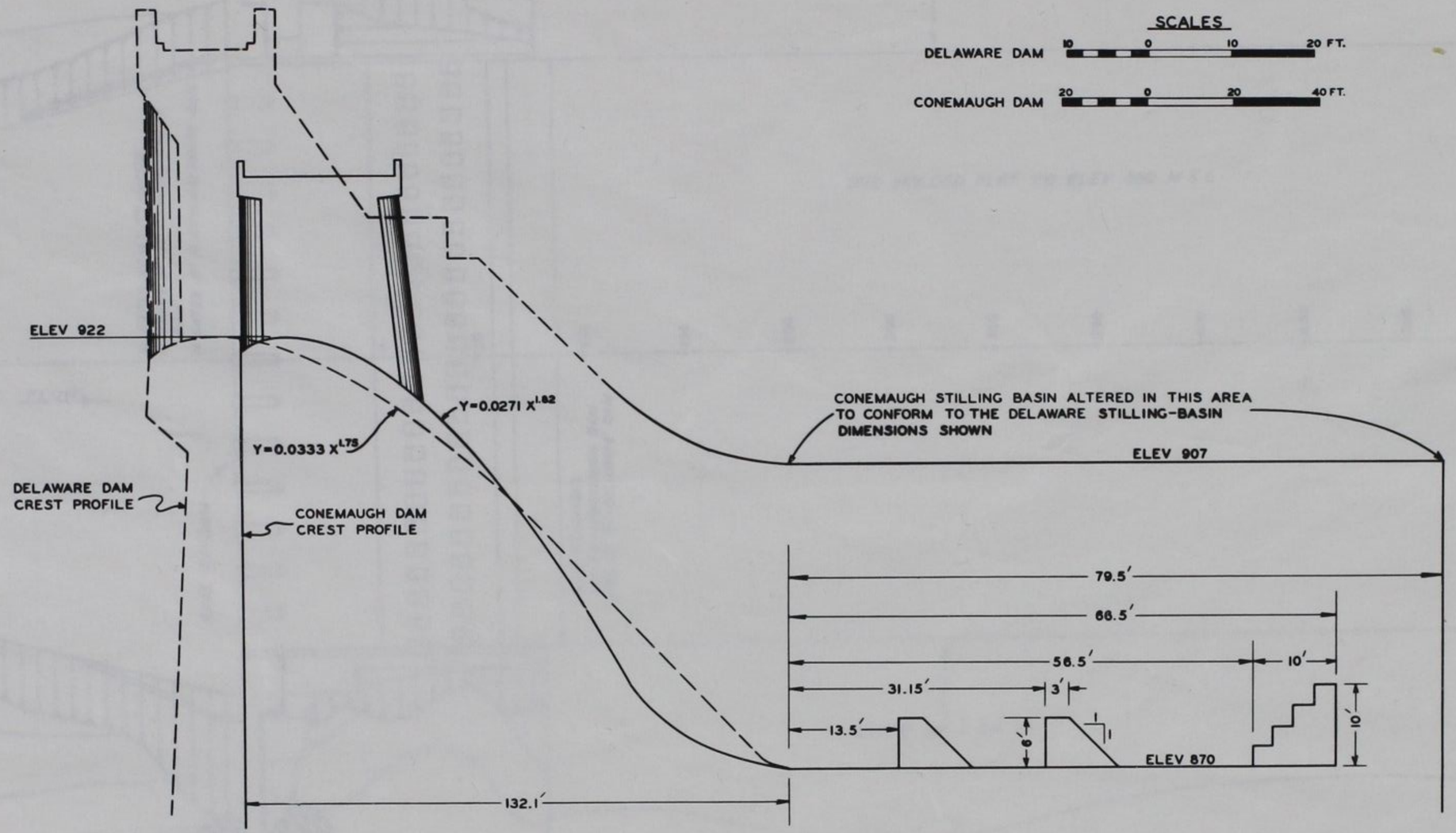
50 0 50 100 150 200 250 300 FEET

PLATE 2

SCALES

DELAWARE DAM 10 0 10 20 FT.

CONEMAUGH DAM 20 0 20 40 FT.



NOTE: ALL ELEVATIONS SHOWN CONFORM TO DELAWARE DAM DIMENSIONS

——— CONEMAUGH DAM

— — — — DELAWARE DAM

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U.S. WATERWAYS EXPERIMENT STATION

MODEL STUDY OF STILLING BASIN, DELAWARE DAM, OLENTANGY RIVER, OHIO

MODIFICATION OF CONEMAUGH MODEL TO FIT DELAWARE DAM DIMENSIONS

PLATE 3

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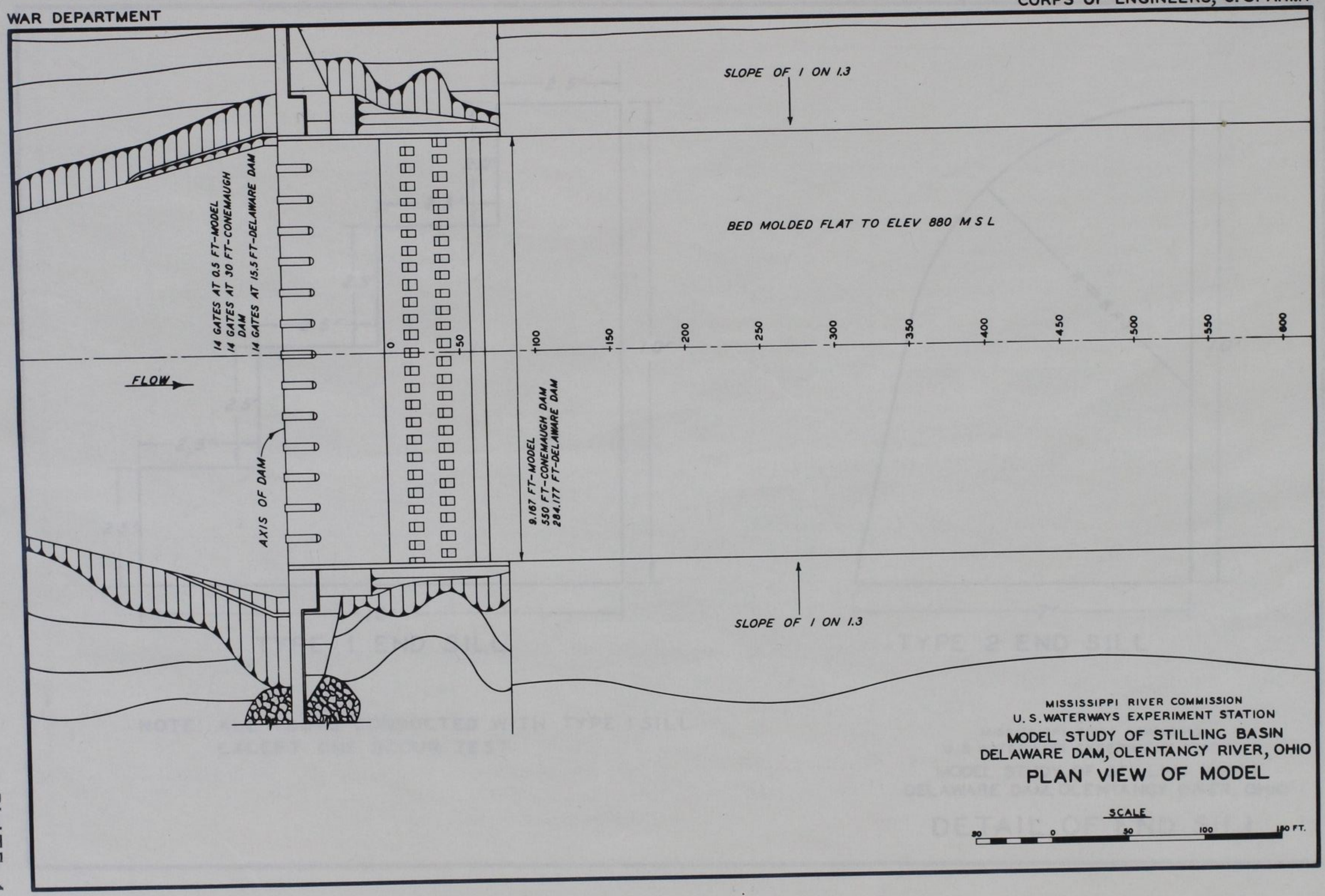

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U. S. WATERWAYS EXPERIMENT STATION

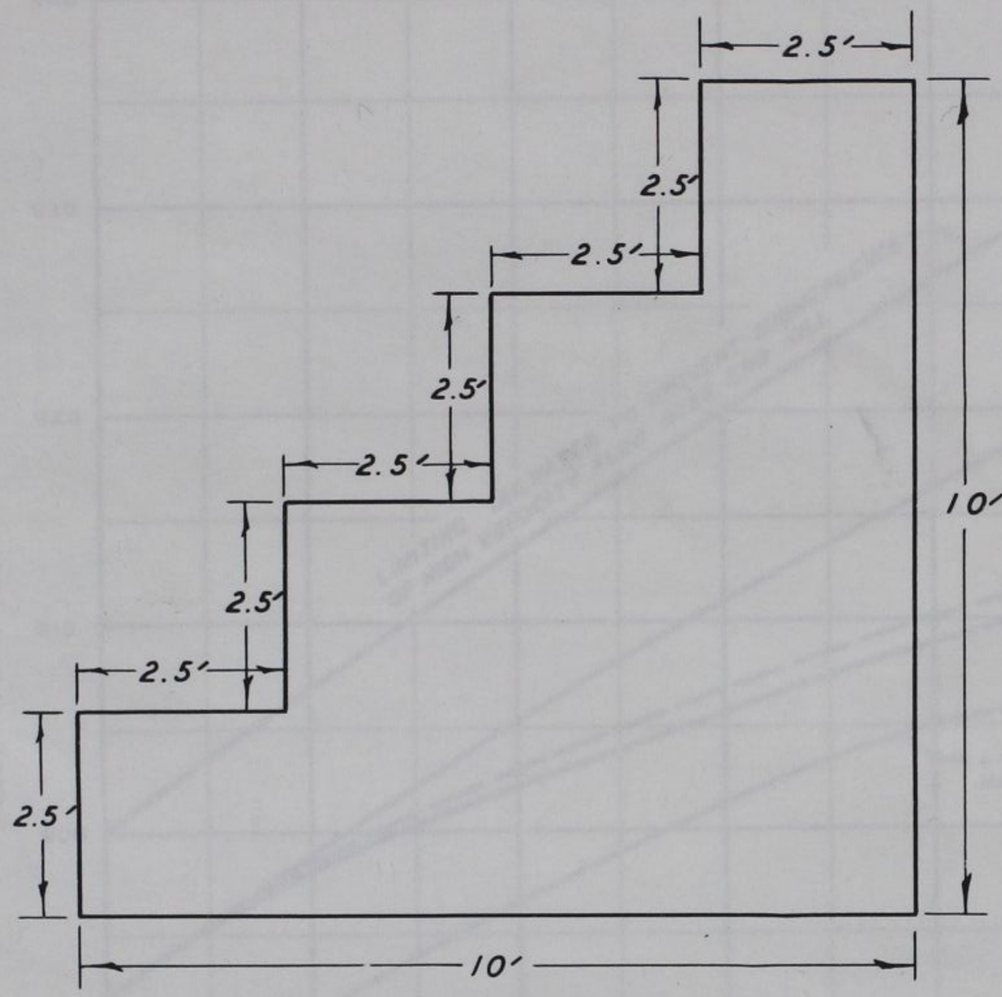
MODEL STUDY OF STILLING BASIN
DELAWARE DAM, OLENTANGY RIVER, OHIO

PLAN VIEW OF MODEL

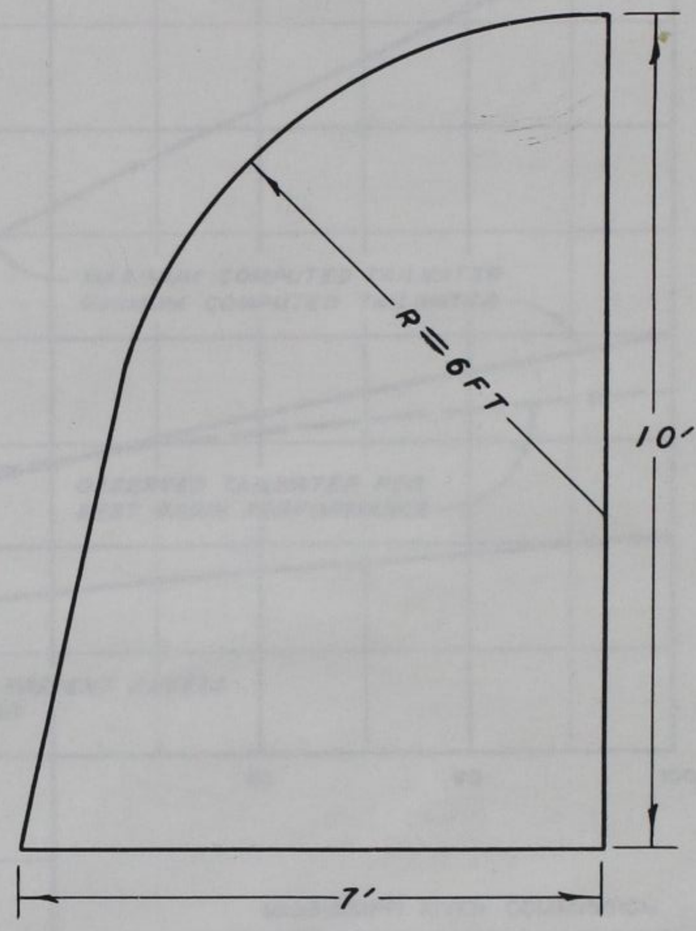
SCALE

-50 0 50 100 150 FT.

PLATE 4



TYPE 1 END SILL



TYPE 2 END SILL

NOTE: ALL TESTS CONDUCTED WITH TYPE I SILL
EXCEPT ONE SCOUR TEST

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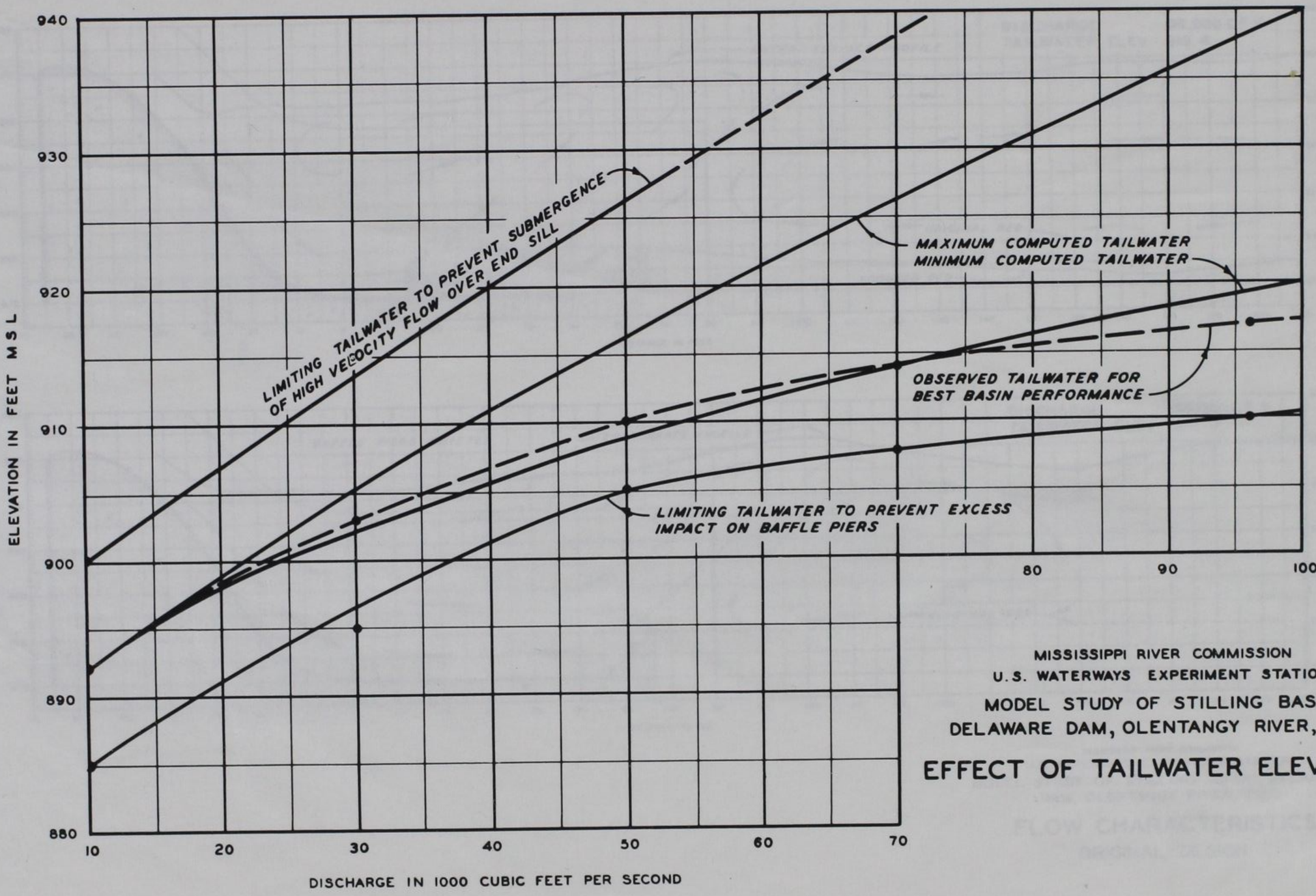
MODEL STUDY OF STILLING BASIN
DELAWARE DAM, OLENTANGY RIVER, OHIO

DETAIL OF END SILL

PLATE 5



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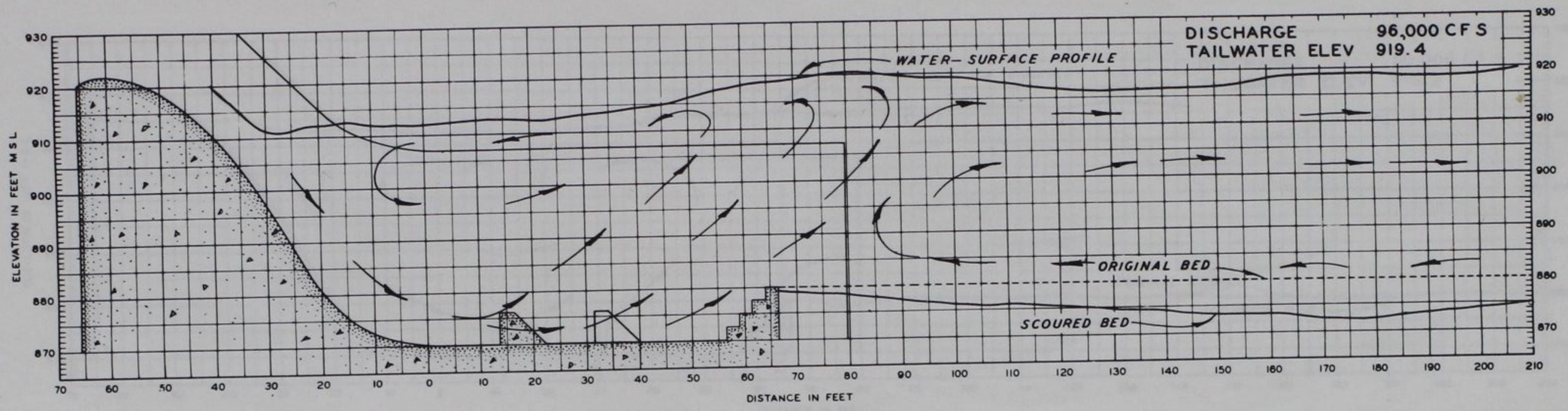
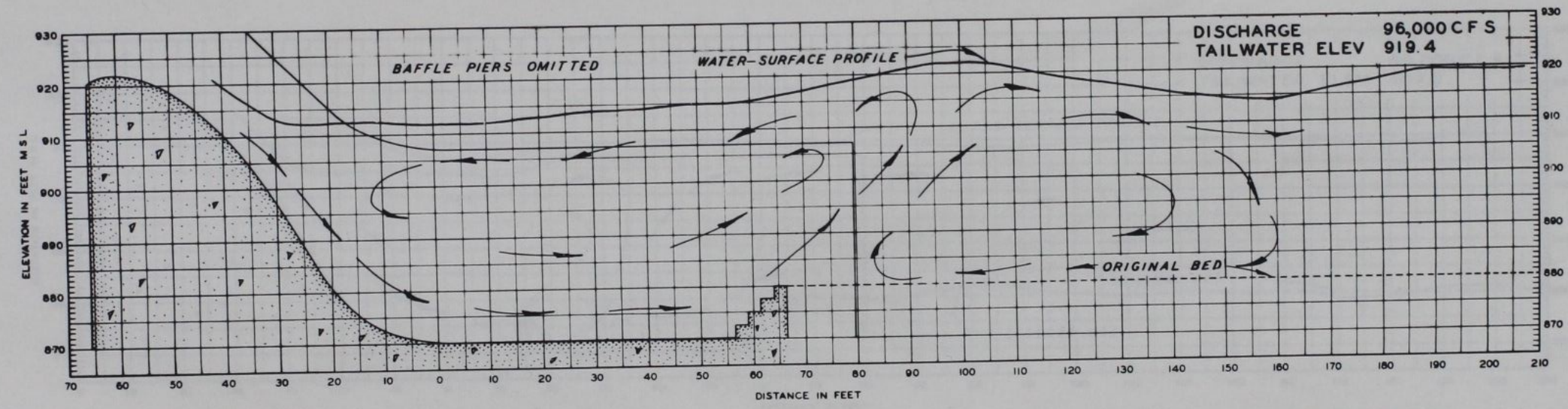
U.S. WATERWAYS EXPERIMENT STATION

MODEL STUDY OF STILLING BASIN
DELAWARE DAM, OLENTANGY RIVER, OHIO

EFFECT OF TAILWATER ELEVATION

PLATE 6





MISSISSIPPI RIVER COMMISSION
U.S. WATERWAYS EXPERIMENT STATION
MODEL STUDY OF STILLING BASIN, DELAWARE DAM, OLENTANGY RIVER, OHIO

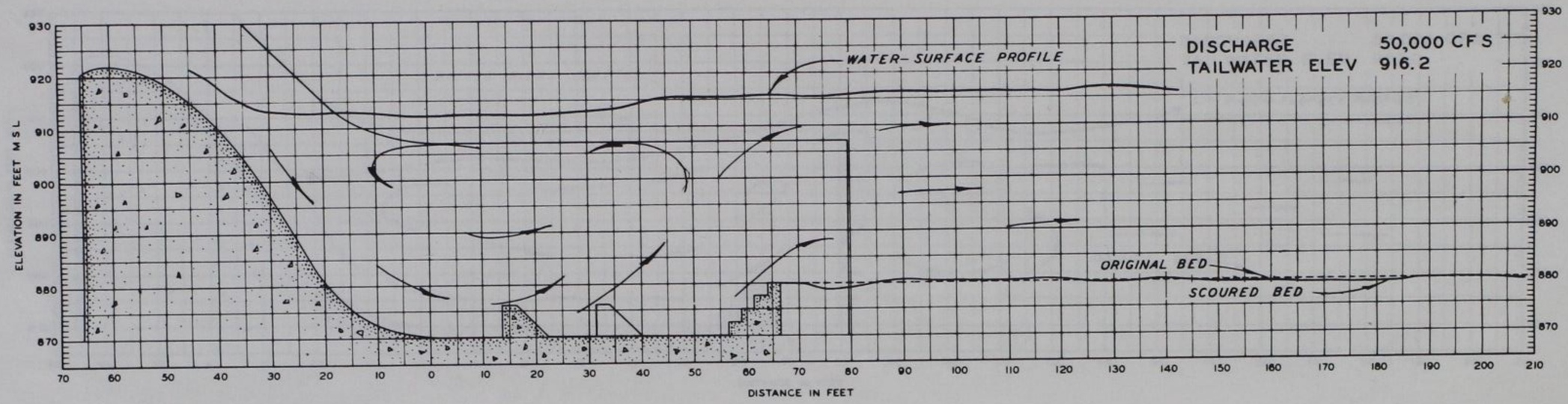
FLOW CHARACTERISTICS

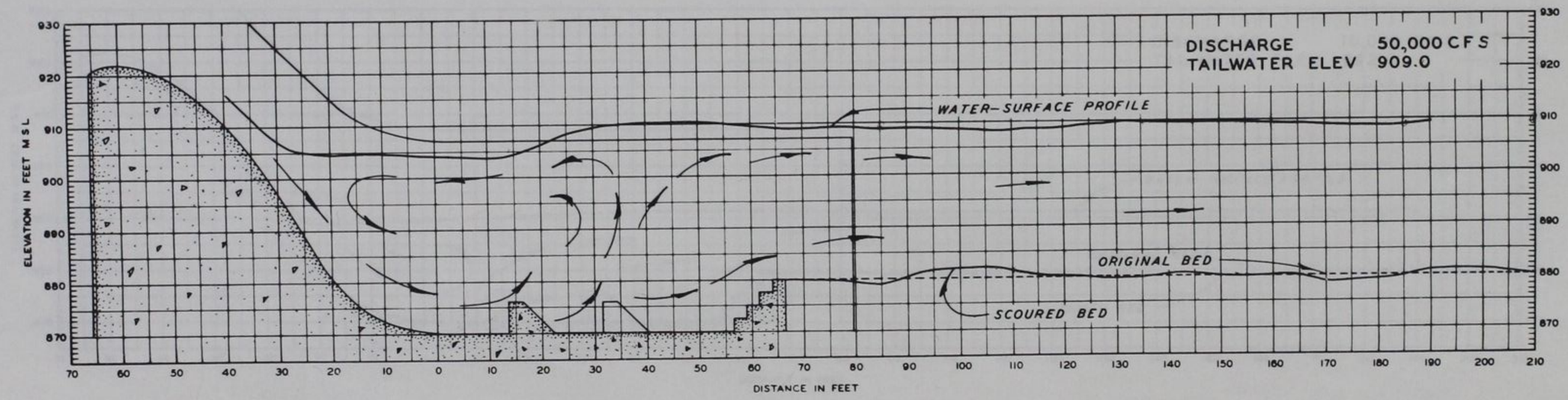
ORIGINAL DESIGN

PLATE 7

WAR DEPARTMENT

CORPS OF ENGINEERS, U.S. ARMY

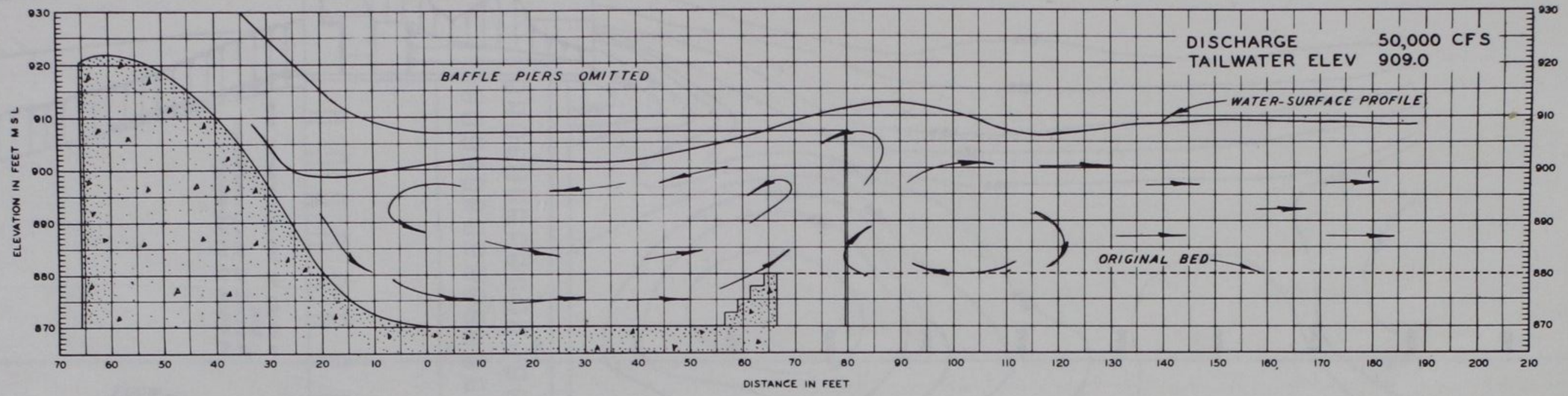


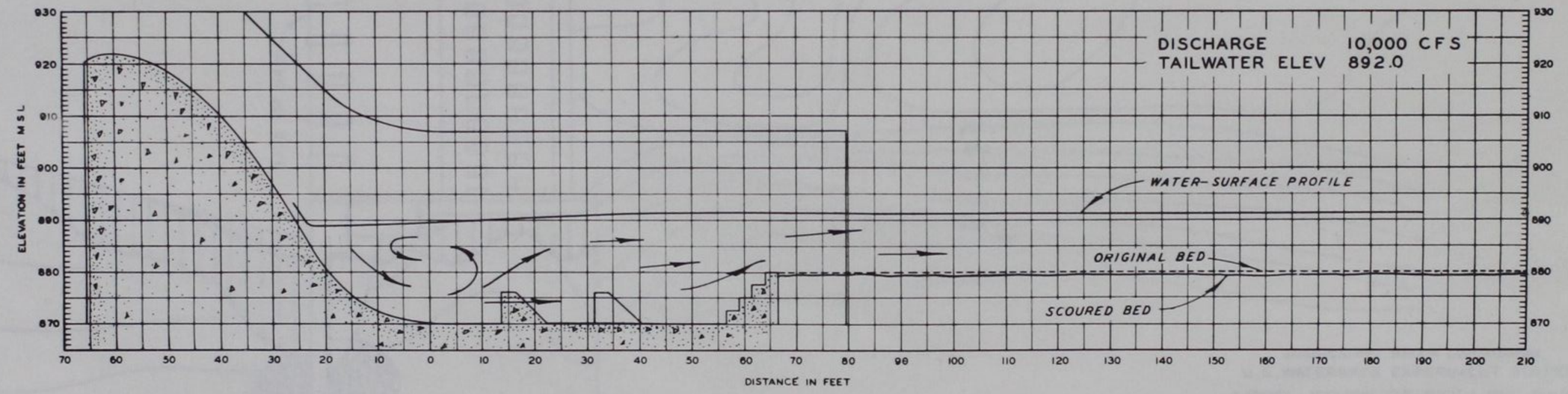


MISSISSIPPI RIVER COMMISSION
U.S. WATERWAYS EXPERIMENT STATION
MODEL STUDY OF STILLING BASIN, DELAWARE DAM, OLENTANGY RIVER, OHIO

FLOW CHARACTERISTICS
ORIGINAL DESIGN

PLATE 8

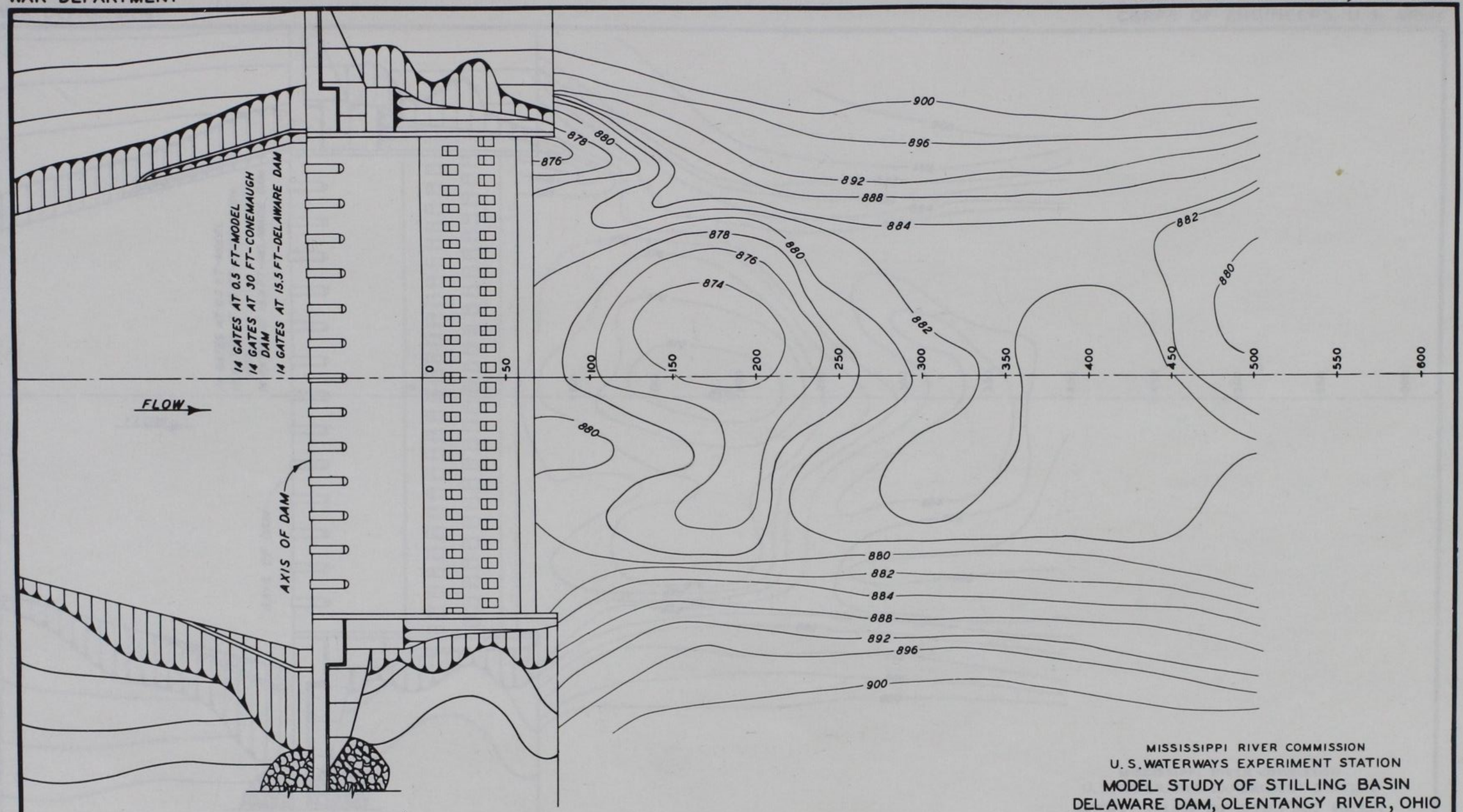




MISSISSIPPI RIVER COMMISSION
U.S. WATERWAYS EXPERIMENT STATION
MODEL STUDY OF STILLING BASIN, DELAWARE DAM, OLENTANGY RIVER, OHIO

FLOW CHARACTERISTICS
ORIGINAL DESIGN

PLATE 9



DISCHARGE 96,000 CFS
TAILWATER ELEV 919.4

MISSISSIPPI RIVER COMMISSION
U. S. WATERWAYS EXPERIMENT STATION

MODEL STUDY OF STILLING BASIN
DELAWARE DAM, OLENTANGY RIVER, OHIO

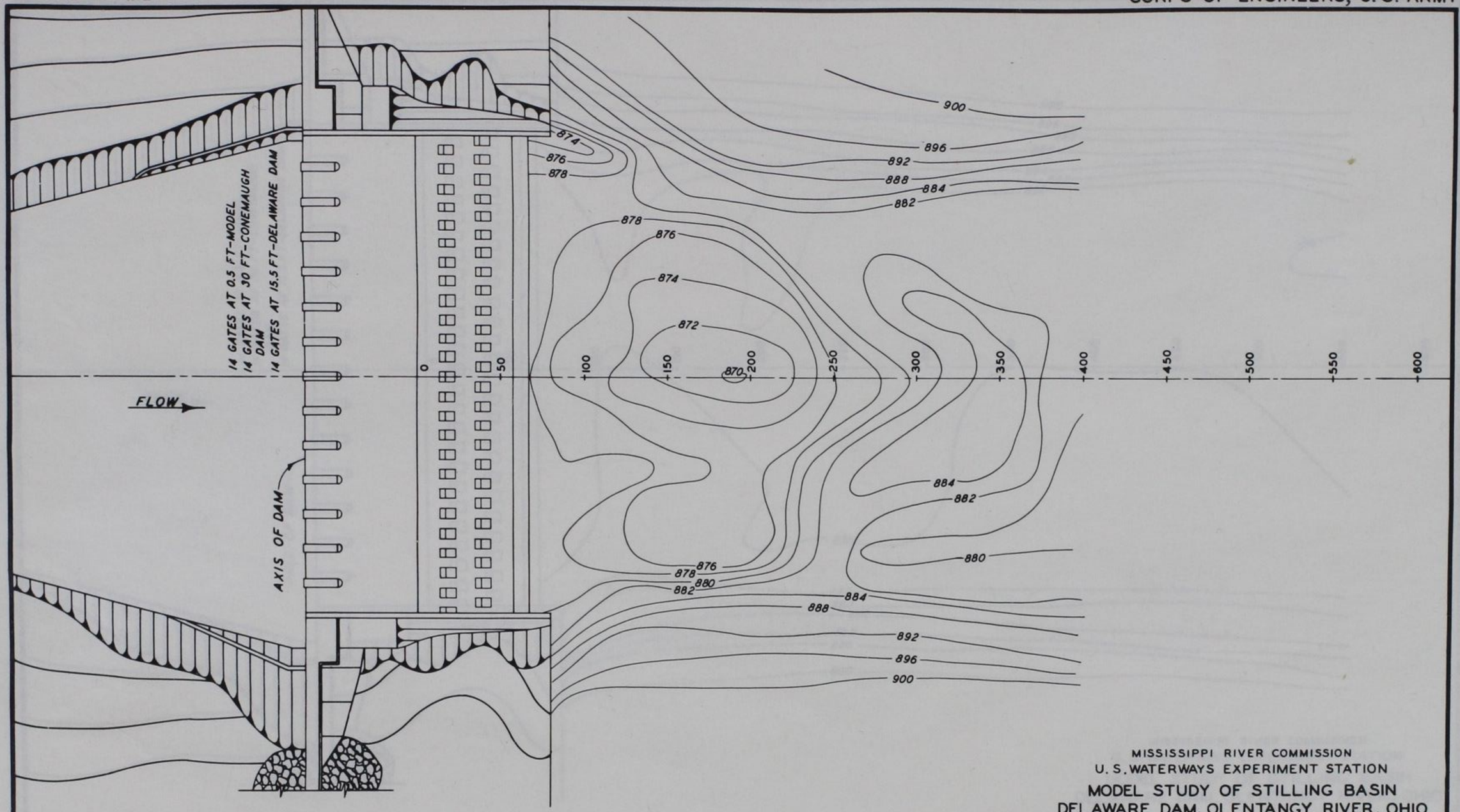
SCOUR PATTERN

ORIGINAL DESIGN

SCALE

50 0 50 100 150 FT.

PLATE 10



NOTE: TYPE 2 END SILL SHOWN ON PLATE 5 USED ON APRON FOR THIS SCOUR TEST. ALL OTHER TESTS CONDUCTED WITH THE STEPPED END SILL (TYPE 1).

DISCHARGE	96,000 CFS
TAILWATER ELEV	919.4

MISSISSIPPI RIVER COMMISSION
U. S. WATERWAYS EXPERIMENT STATION

MODEL STUDY OF STILLING BASIN
DELAWARE DAM, OLENTANGY RIVER, OHIO

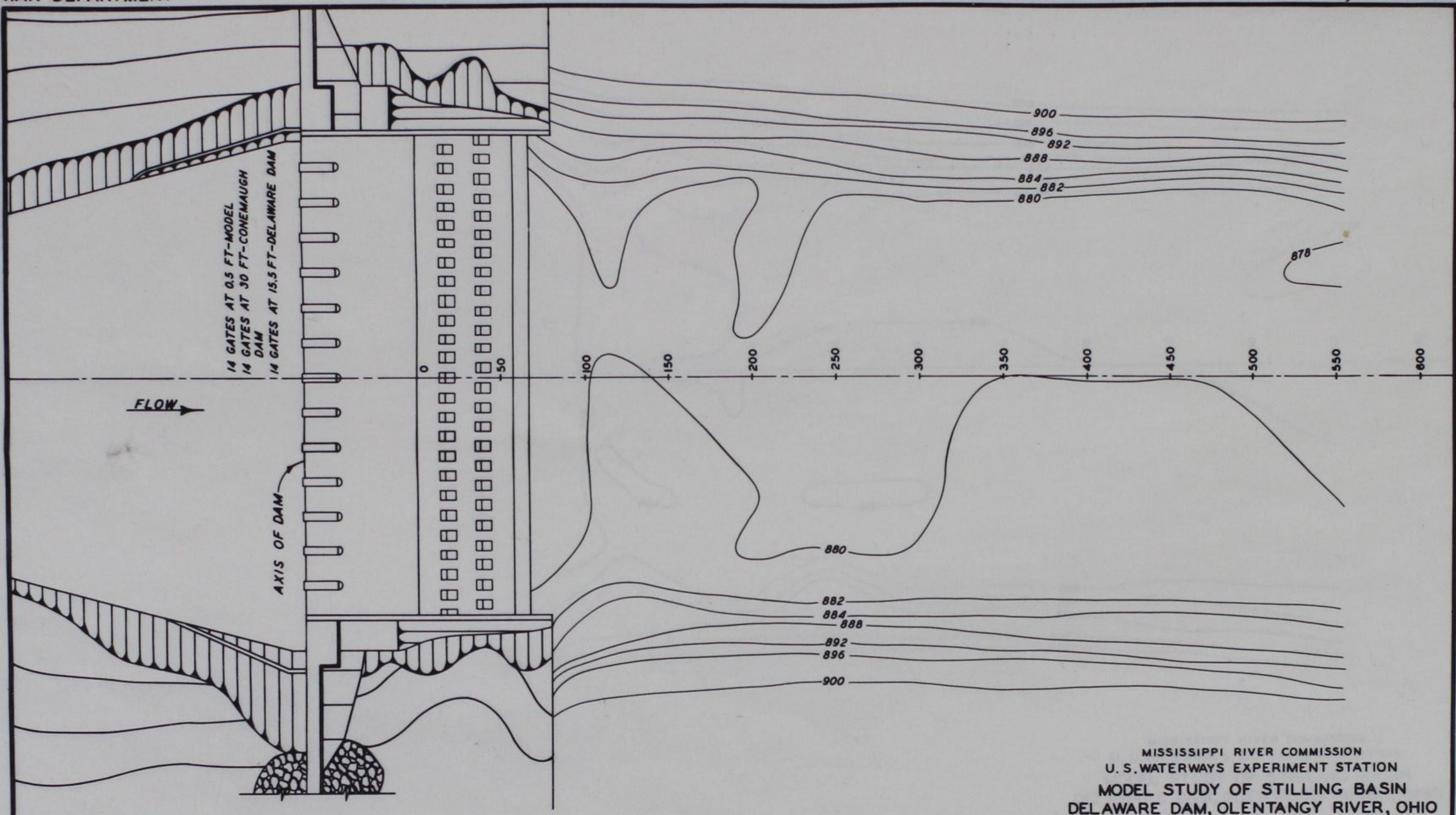
SCOUR PATTERN

ORIGINAL DESIGN

SCALE

50 0 50 100 150 FT.

PLATE 11



MISSISSIPPI RIVER COMMISSION
U. S. WATERWAYS EXPERIMENT STATION
MODEL STUDY OF STILLING BASIN
DELAWARE DAM, OLENTANGY RIVER, OHIO

SCOUR PATTERN

ORIGINAL DESIGN

DISCHARGE	50,000 CFS
TAILWATER ELEV	916.2

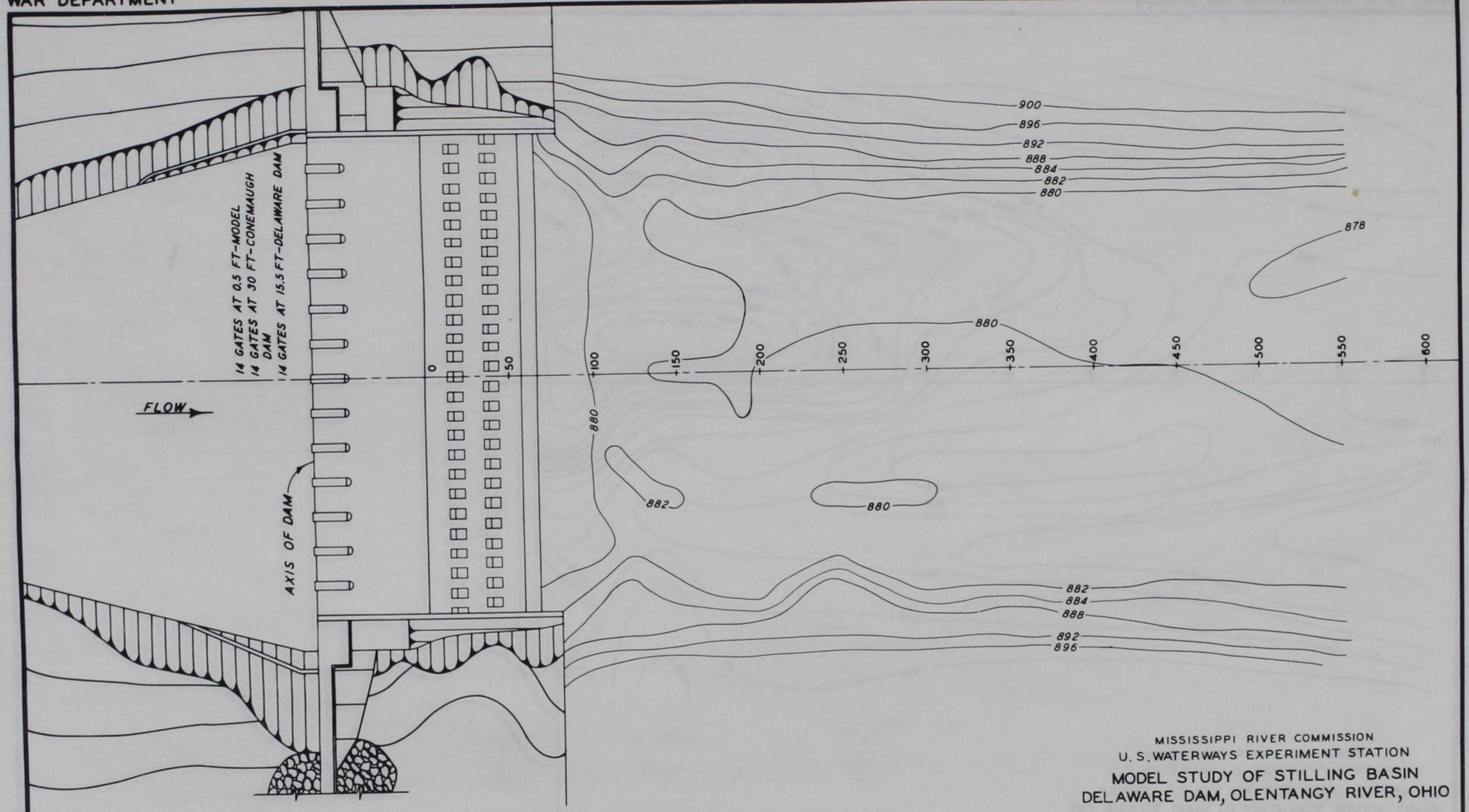
SCALE

50 0 50 100 150 FT.

PLATE 12

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



MISSISSIPPI RIVER COMMISSION
U. S. WATERWAYS EXPERIMENT STATION

MODEL STUDY OF STILLING BASIN
DELAWARE DAM, OLENTANGY RIVER, OHIO

SCOUR PATTERN

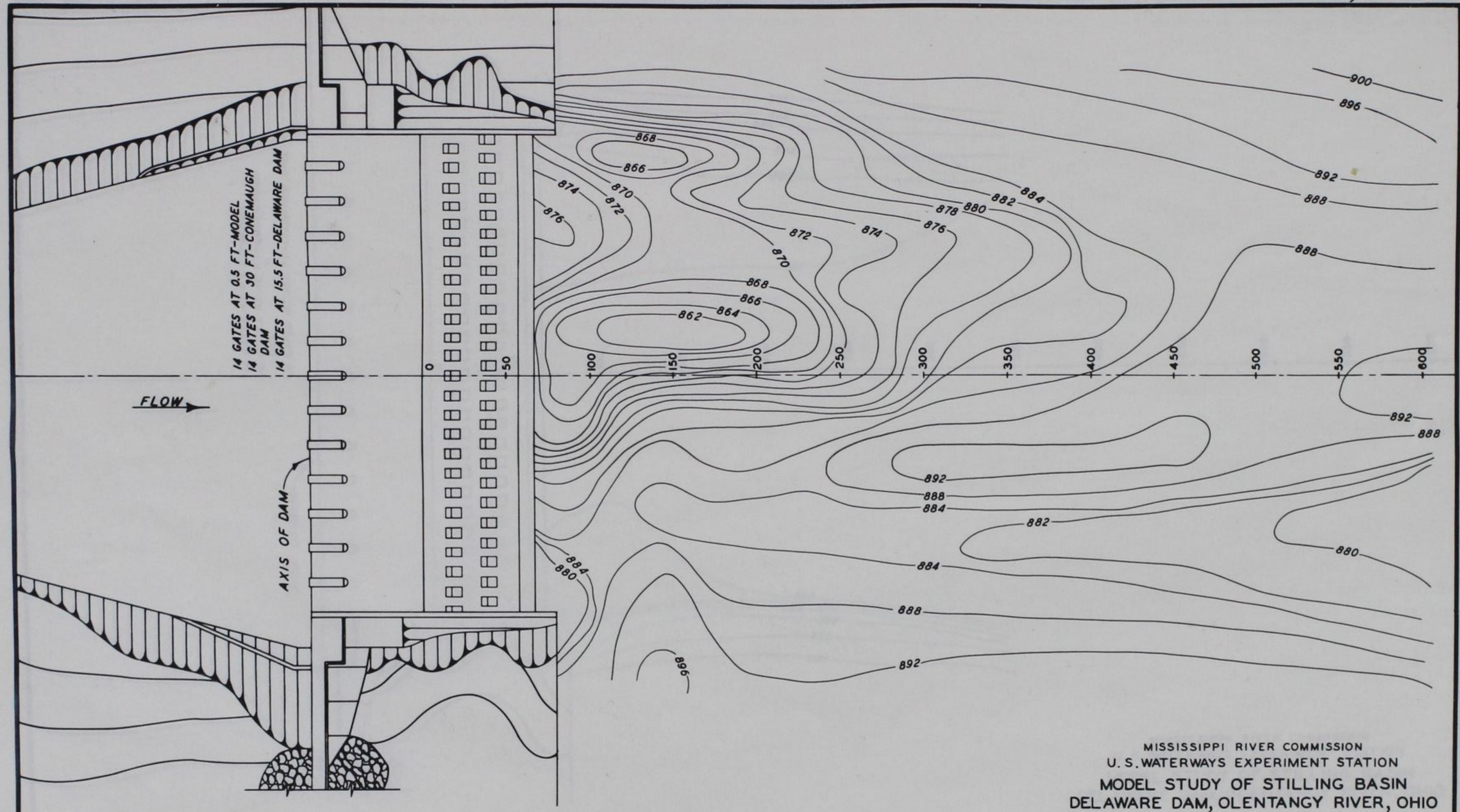
ORIGINAL DESIGN

DISCHARGE 50,000 C F S
TAILWATER ELEV 909.0

SCALE

50 0 50 100 150 FT.

PLATE 13



DISCHARGE 50,000 CFS
TAILWATER ELEV 909.0
6 GATES ON RIGHT CLOSED

MISSISSIPPI RIVER COMMISSION
U. S. WATERWAYS EXPERIMENT STATION

MODEL STUDY OF STILLING BASIN
DELAWARE DAM, OLENTANGY RIVER, OHIO

SCOUR PATTERN

ORIGINAL DESIGN

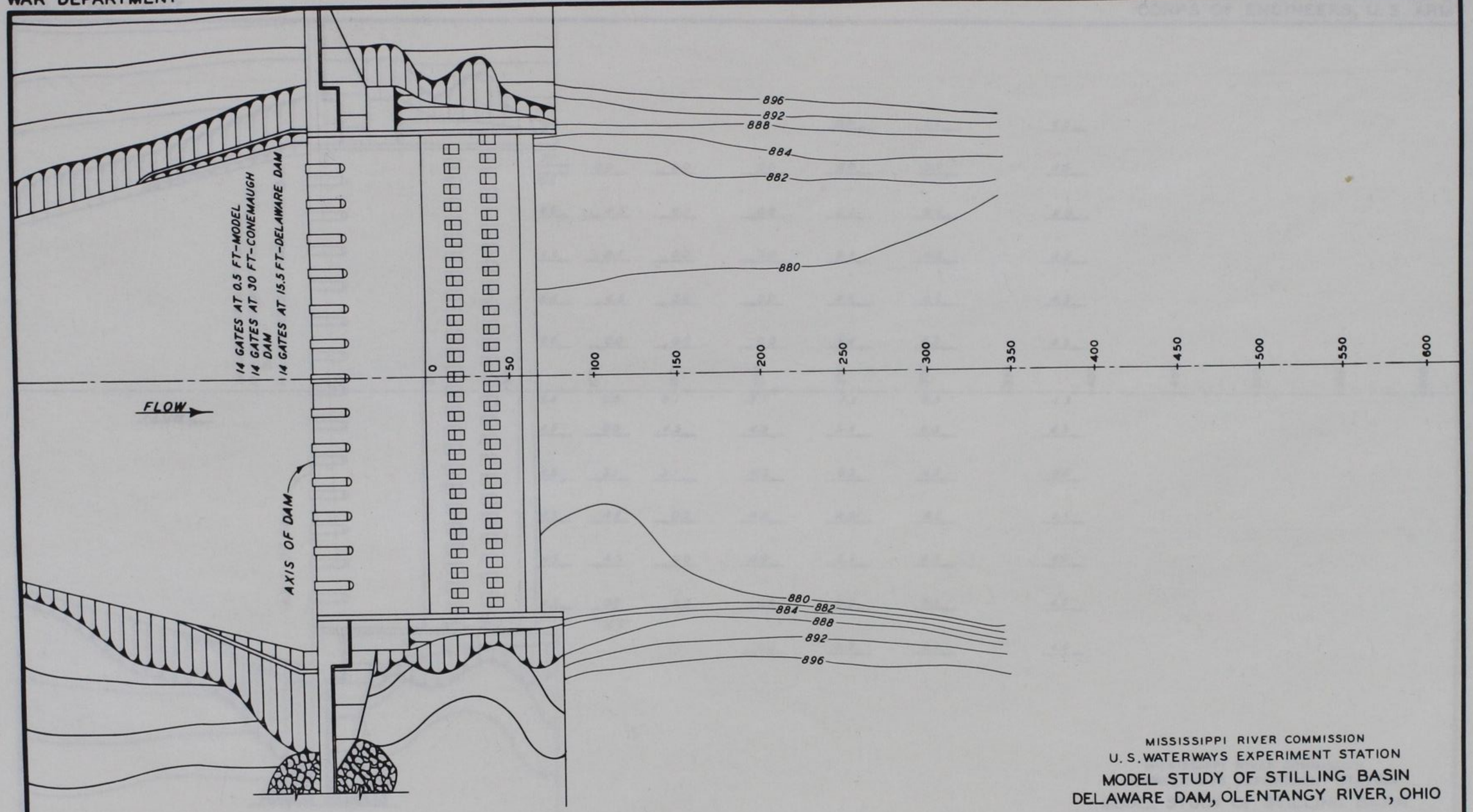
SCALE

50 0 50 100 150 FT.

PLATE 14

WAR DEPARTMENT

CORPS OF ENGINEERS, U. S. ARMY



DISCHARGE 10,000 CFS
TAILWATER ELEV 892.0

MISSISSIPPI RIVER COMMISSION
U. S. WATERWAYS EXPERIMENT STATION

MODEL STUDY OF STILLING BASIN
DELAWARE DAM, OLENTANGY RIVER, OHIO

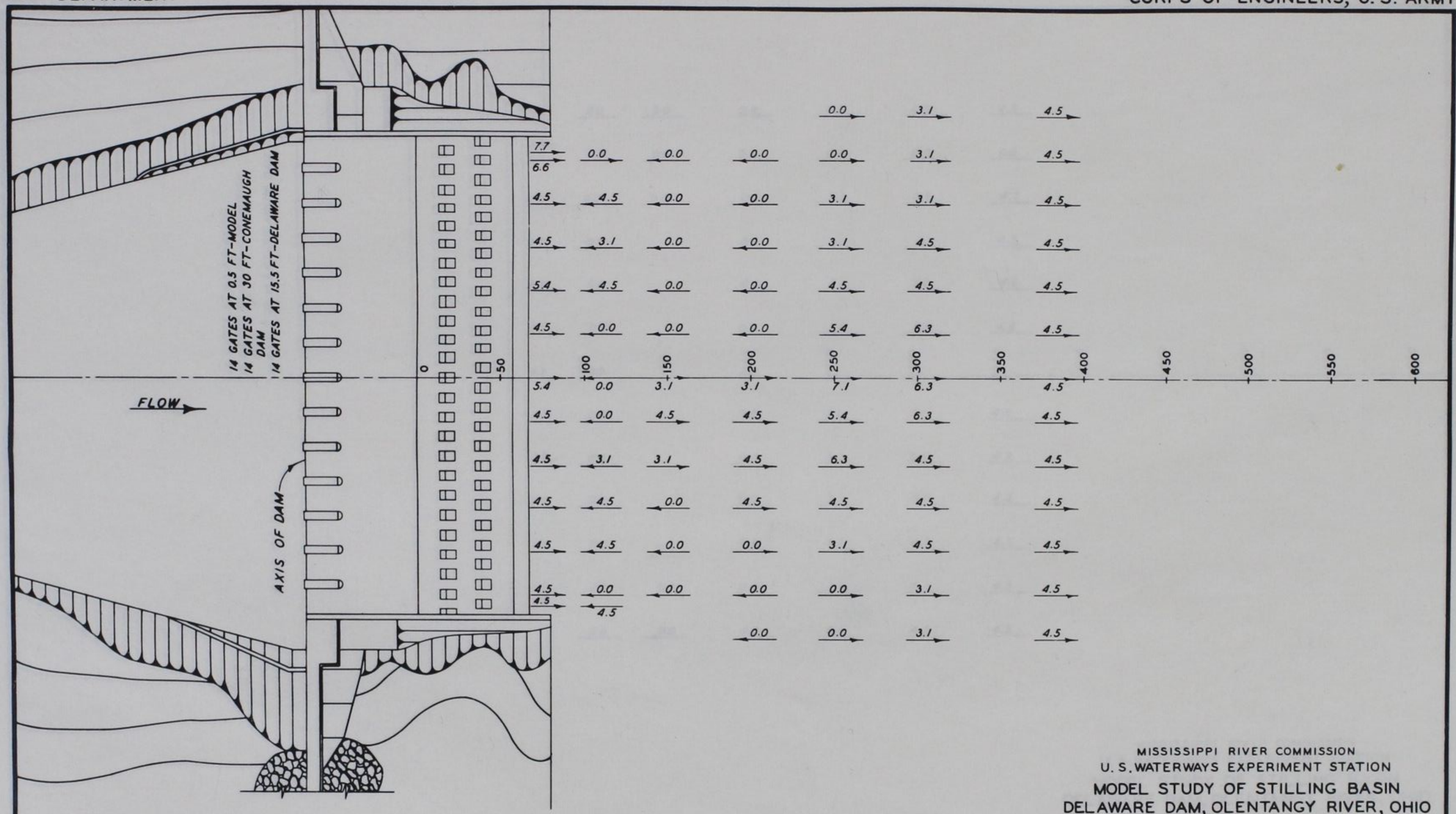
SCOUR PATTERN

ORIGINAL DESIGN

SCALE

50 0 50 100 150 FT.

PLATE 15



NOTE: VELOCITIES ARE IN FEET PER SECOND IN PROTOTYPE.

DISCHARGE 96,000 CFS
TAILWATER ELEV 919.4

MISSISSIPPI RIVER COMMISSION
U. S. WATERWAYS EXPERIMENT STATION

MODEL STUDY OF STILLING BASIN
DELAWARE DAM, OLENTANGY RIVER, OHIO

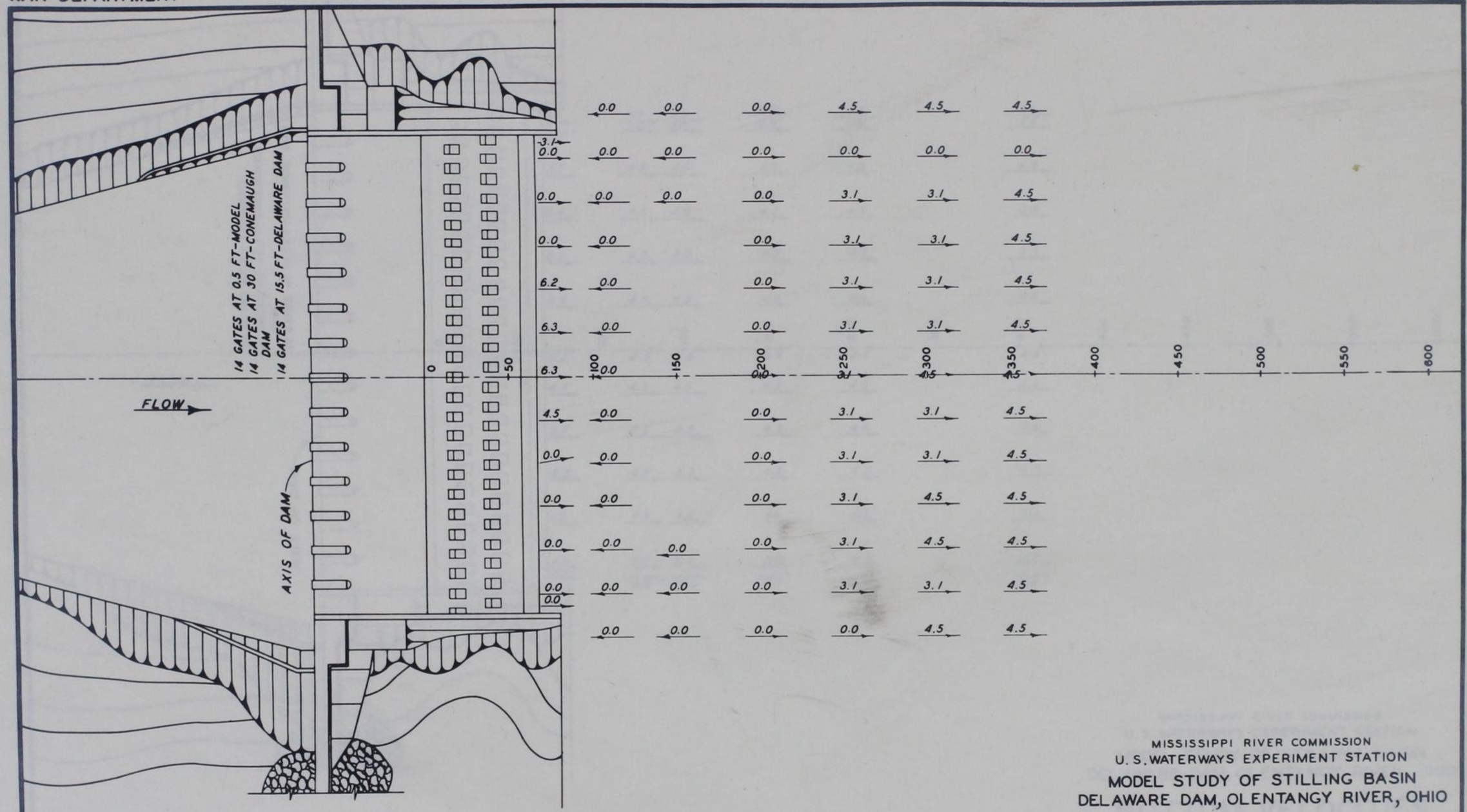
BOTTOM VELOCITIES

ORIGINAL DESIGN

SCALE

50 0 50 100 150 FT.

PLATE 16



NOTE: VELOCITIES ARE IN FEET PER SECOND IN PROTOTYPE.

DISCHARGE 50,000 CFS
TAILWATER ELEV 916.2

MISSISSIPPI RIVER COMMISSION
U. S. WATERWAYS EXPERIMENT STATION

MODEL STUDY OF STILLING BASIN
DELAWARE DAM, OLENTANGY RIVER, OHIO

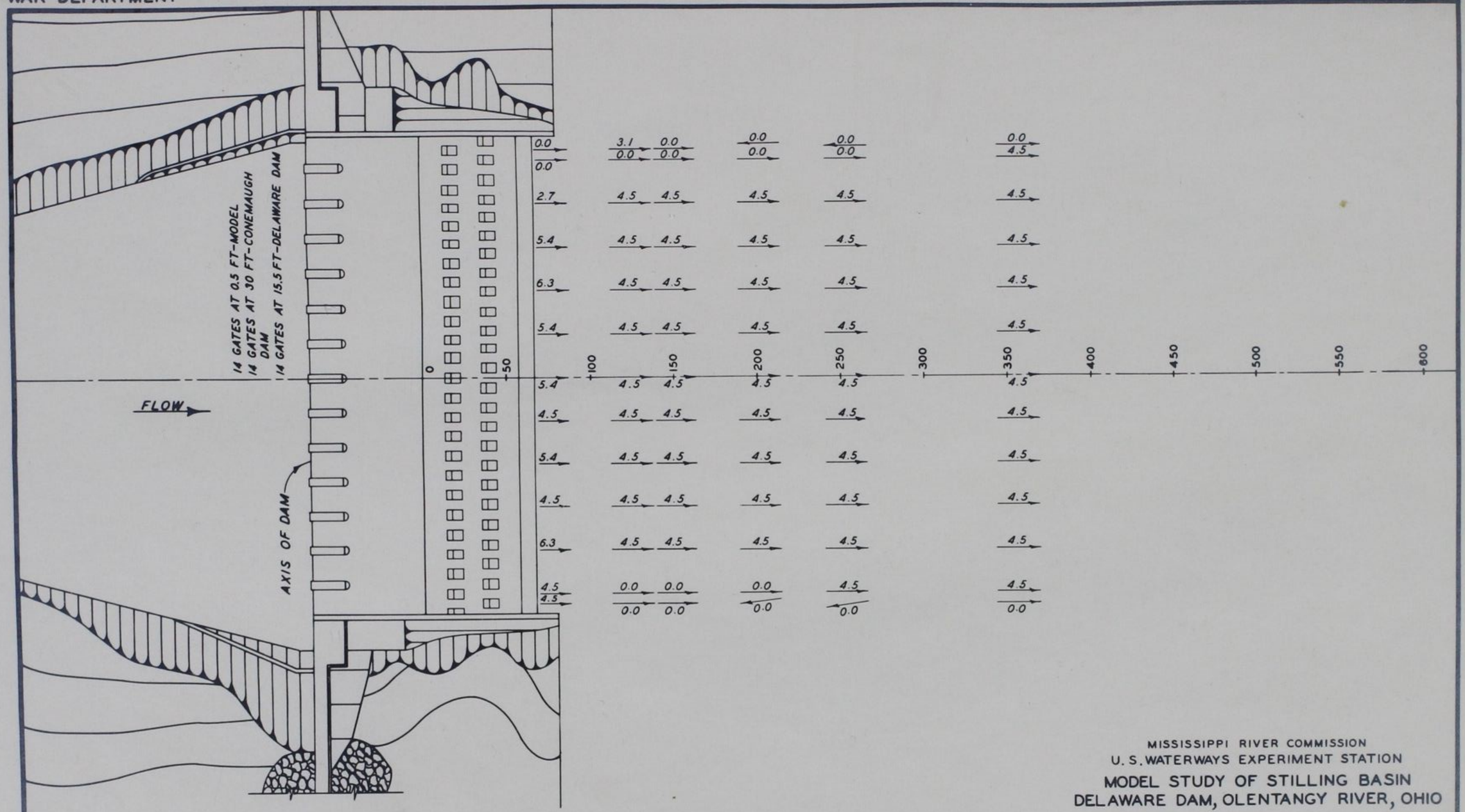
BOTTOM VELOCITIES

ORIGINAL DESIGN

SCALE

50 0 50 100 150 FT.

PLATE 17



NOTE: VELOCITIES ARE IN FEET PER SECOND IN PROTOTYPE.

DISCHARGE 50,000 CFS
TAILWATER ELEV 909.0

MISSISSIPPI RIVER COMMISSION
U. S. WATERWAYS EXPERIMENT STATION
MODEL STUDY OF STILLING BASIN
DELAWARE DAM, OLENTANGY RIVER, OHIO

BOTTOM VELOCITIES

ORIGINAL DESIGN

SCALE

50 0 50 100 150 FT.

PLATE 18