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HYDRAULIC MODEL STUDIES OF DEER CREEK DAM SPILLWAY AND OUTLET WORKS AND A REPORT ON THE OPERATION OF THE PROTOTYPE TUBE VALVES AND STILLING BASIN

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FOREWORD

The model tests for Deer Creek Spillway were performed in 1937. This report was prepared in 1946 from the original notes and data. Naturally, methods of testing and design conceptions have changed in the intervening years, thus, the logic followed in the test program described in this report may differ somewhat from that which would be followed today.

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Subject: Hydraulic model studies of Deer Creek Dam spillway and outlet works, and a report on the operation of the prototype tube valves and stilling-basin--Provo Project.

PART I MODEL STUDIES

Introduction

Deer Creek Dam is located about 16 miles northeast of Provo, Utah (Figure 1). The dam is a combination earth and rockfill structure approximately 1,300 feet long at the crest, rising a maximum height of 150 feet above the bed of the river. It intercepts the flow of the Provo River to form a reservoir with an estimated capacity of 147,000 acre-feet at the maximum water-surface elevation of 5417.0.

The spillway at the right abutment of the dam (Figure 2) is a concrete-lined open channel approximately 953 feet long, designed to pass a maximum discharge of 12,000 second-feet. Flow is controlled by two radial gates 21 feet long by 20 feet high installed at the crest of the spillway.

The outlet works pass through the left abutment of the dam. A 12-foot circular concrete-lined tunnel approximately 437 feet long extends from the trashrack structure to the gate chamber. The gate chamber is constructed over a concrete tunnel-plug in which are installed two 5-foot by 6-foot high hydraulically-operated emergency gates. Two 72-inch welded plate-steel outlet pipes, contained in a horseshoe-shaped tunnel, lead from this chamber to the valve house substructure where each branches to a 48-inch needle valve and a 72-inch penstock. At the downstream end of each penstock is a steel bulkhead to provide for a future power unit. The two 48-inch needle valves are designed to pass a total of 1,500 second-feet at the maximum reservoir elevation of 5417.0.

With reference to the spillway, the following factors were investigated by model tests:

1. Flow conditions in all parts of the structure and the determination of suitable alternates for any portion of the design which proved unsatisfactory.

2. Verification of the discharge capacity of the structure.

3. The extent of prototype scour to be expected in the channel below the stilling-pool, and the determination of the best combination of steps, sills, and intermediate sills to achieve the minimum scour.

4. Water-surface profiles for the entire structure.

Concerning the outlet works, satisfactory answers were found for the following problems:

1. The practicality of permitting the needle valves to discharge directly into a pool in the riverbed without concrete chutes and stilling-basins.

2. The physical outlines of a stilling-pool that would prevent (a) future erosion of the banks, particularly on the left side, (b) deposition of gravel and other material in the draft-tubes of the power units and in the river channel, and (c) scouring and undermining of the concrete foundations.

3. The determination of the dimensions and location of individual chutes and stilling-basins for the needle valves if such a pool proved unsatisfactory.

Summary

Approach Structure

The original spillway approach structure (Figure 3) was satisfactory and no changes in it were made. Very little turbulence was evident upstream from the crest even for the maximum discharge of 12,000 second-feet and the discharge capacity was shown to be adequate (Figure 7). Flow conditions for a wide range of discharges were observed, and data for discharge curves for single and double gate openings were taken.

Spillway Chute

The original chute and two alternate designs were tested for flow distribution and maximum wave heights (Figure 9). Operation with the original chute indicated uneven distribution of flow which nearly overtopped the training-walls in the upper portion of the 0.09 slope at high discharges (Figure 8). An alternate design, designated as the final design on Figure 9, was developed which eliminated this characteristic and afforded more uniform flow distribution both with single and double gate operation.

Stilling-pool

A series of 56 tests were conducted to determine the best combination of step, sill, and intermediate baffle piers to prevent excessive

scour below the paved apron. All tests were run without riprap in the area below the stilling-pool. Scour and water-surface profiles were taken for the two final designs, and for several comparable designs involving 90-degree and 45-degree wing-walls (Figures 13 and 14).

Outlet Works Model

Testing of the outlet works demonstrated the practicality of permitting the needle valves to discharge directly into a riprap-lined pool without concrete chutes and stilling-basins.

The original pool design (Figure 5) was tested with the needle valves set in the following combinations perpendicular to the valve house wall, with a valve convergence of 20 degrees, with each valve depressed 5 degrees and with a valve convergence of 20 degrees together with a depression of 5 degrees. Performance for each valve setting was tested under conditions of single and double valve operation.

Pool Design No. 2 was tested with a 20-degree valve convergence and a 5-degree depression, and finally with valve convergences of 20 and 25 degrees with no depression. Each valve setting was again tested under single and double valve operation.

Velocity direction studies were made on each design, and velocity measurements were taken at prototype distances of 10 feet, 25 feet, and 190 feet from the valve house for the last two tests made on Pool Design No. 2.

Experimentation indicated that decreasing the cross-sectional area of the pool and turning each valve inward at an angle of 12-1/2 degrees to its original (Figure 21) improved the operation considerably. This arrangement provided satisfactory flow patterns for both single and double valve operation (Figure 18), and decreased the amount of scour and deposition to a satisfactory minimum.

Tests with several types of flow arresters in the stilling-pool and without riprap demonstrated the necessity of installing such devices to reduce scour (Figure 11) and to permit a reasonable variation in tailwater without destroying the effectiveness of the jump (Figure 15). The design shown in Figure 14, which made use of 11 Type A-2 dentated steps (Figure 10) 12 B-5 baffle piers at Station 12+95 (Figure 10) and a Type C-5 sill (Figure 14), was recommended for construction in the field. Tests on this scheme indicated a maximum scour of approximately 6 feet, located about 15 feet below the end of the apron (Figure 14), and also showed that a reduction in tailwater elevation of 3 feet below normal at 12,000 second-feet was necessary to cause the jump to sweep out of the pool.

Prototype

The operation of the prototype outlet works was observed and photographed on May 15, 1946. The performance of the tube valves

and stilling-basin was found satisfactory for a range of operating conditions. Figures 23-26 show the operation of the prototype structure. Fifty-two-inch tube valves were installed in the prototype instead of the 48-inch needle valves shown on the prototype drawing in this report.

Recommendations

In view of the model results obtained, the following recommendations are made:

1. The original spillway approach and gate structure should be retained, but it is recommended that the chute design be altered to that shown as the final design in Figure 9, to maintain overall satisfactory flow distribution.

2. It is also recommended that the combination of flow arresters shown in Figure 14 be installed in the stilling-pool to minimize scour downstream, and that riprap be used from the end of the stilling-pool to a point 100 feet downstream to aid in the prevention of scour.

3. The recommended form of outlet works pool should conform to the design shown in Figure 21 with a total valve convergence angle of 25 degrees and 0 degrees depression angle.

The Models

Spillway

A 1:48 model of the spillway was constructed including all pertinent features (Figure 4). The model consisted of a headbox containing the approach topography and the gate structure, a long wooden chute, representing the spillway channel, and a tailbox containing the stilling-pool and downstream topography details.

The headbox, 9 feet 6 inches long, by 10 feet 3 inches wide, by 1 foot 3-1/4 inches high, was constructed of wood and lined with sheet iron. Necessary topographic details were reproduced in concrete and the gate and crest structure were made of redwood. The chute was fabricated from plywood and waterproofed to prevent warping.

The tailbox construction was similar to the headbox. The floor of the excavated channel downstream from the stilling-pool was simulated in sand, while the side slopes and other topography were reproduced in cement mortar. This method of construction was used because it was planned to limit the scour studies to the floor of the channel. To discover more easily the areas where erosion might occur, sand was used in place of the riprap shown in the original design.

A hinged wood and canvas gate was installed at the downstream end of the tailbox to regulate the tailwater elevation. Water manometers, connected to piezometer openings in the headbox and tailbox, were used to measure the elevations of the reservoir and tailwater.

Outlet Works

A 1:20 model, entirely removed from the spillway model, was constructed of the outlet works. It consisted of a tailbox containing the two 2.8-inch needle valves, the excavated and riprapped areas downstream from the valves, and the necessary water supply piping and measuring devices (Figure 5).

The tailbox, 20 feet 0 inches long by 10 feet 8 inches wide by 2 feet 6 inches high, was constructed of the same material as that of the spillway model. A system of false flooring was used in order that the quantity of sand and rock used would not be excessive, and the box depth would be sufficient to care for any topography changes considered necessary. All pertinent features of the excavated and riprapped areas downstream from the valves were reproduced to scale in this tailbox. The undisturbed alluvial deposit was represented by sand, and rock of approximately 1-inch average diameter was used for riprap.

A hinged wood and canvas gate, installed at the downstream end of the tailbox, was used to regulate the elevation of the tailwater. A water manometer was used to measure this elevation.

The model needle valves, installed in the upstream wall of the tailbox, were mounted in such a way that both vertical and horizontal alinement could be changed if required. Water was supplied through a 6-inch pipe which terminated in a manifold behind the valves. The valves were connected to this manifold by short lengths of rubber hose.

Piezometers, located at the upstream ends of the valves, were used to determine pressure heads. The discharge was measured by 4- and 6-inch Venturi meters located between the supply pump and manifold. The valve openings required for each discharge and head combination were determined from curves based on data which had been obtained from a previous calibration.

Spillway Investigation

Approach and Crest Studies

The original approach for Deer Creek Dam (Figure 3) consisted of a channel, curved in plan with centerline radius of 150 feet, extending from Station 3+65.34, the beginning of the paved section, to the crest structure. The sidewalls of this channel consisted of warped sections which gradually changed the direction of flow through an angle of 60 degrees until it became parallel to the centerline of the spillway. The floor of the channel was 4 feet below the maximum crest elevation.

This design was tested for a large number of flows with both single and double gate operation. No serious difficulty was experienced, the change of direction in the approach being so gradual as to cause very little disturbance even at high discharges. Flow over the crest also was satisfactory and no changes were considered necessary.

The discharge curves for single and double gate openings obtained from these tests are shown in Figure 7.

Chute Studies

The original chute design, as incorporated in the model (Figure 9), was 716.94 feet in horizontal length with a vertical drop of 137 feet from crest to stilling-pool. This drop was achieved by a series of simple curves and slopes. The width of the structure decreased from 45 feet at the gate structure to 30 feet at Station 6+75.00, then increased from Station 9+85.00 to a width of 75 feet at the entrance to the stilling-pool.

Model tests at maximum discharge indicated that these changes in width were not correct either in location or in rate of change. There was a marked increase in water depth along the sidewalls in the upper portion of the 0.25 slope. This characteristic tended to make the flow distribution entering the stilling-pool uneven.

It was decided that a more balanced performance might result from the design shown in Figure 9, First Revision. It seemed to offer the advantage of allowing a greater increase in velocity before the decrease in width began. This assumption proved erroneous, however, when the design was tested. At maximum discharge, the wave height was much greater than in the original, and the performance of the jump indicated that the amount of water entering the stilling-pool from the sides was much greater than that from the center of the channel.

The final design (Figure 9) greatly decreased the abruptness of the upper transition and performed satisfactorily at all discharges. Tests at 5,300 second-feet, with the left gate open, also showed an even distribution of the flow entering the stilling-pool.

Stilling-pool Studies

The original design of the stilling-pool (Figure 5) included a dentated step at Station 12+45.00 and a combination Rehbock sill at the downstream end of the stilling-pool. However, it was thought that they might not be necessary for the formation of a satisfactory jump, so the first model test of the pool, DC-18 Figure 11, was made without them.

It was found that tailwater elevation 3.5 feet above normal was necessary to produce a satisfactory jump for 12,000 second-feet. The tailwater elevation, at maximum discharge, at which the jump swept out of the pool was only 1 foot below normal. In Figure 15 are shown the

curves giving minimum tailwater elevations for a satisfactory jump and for jump sweep out at various discharges. These curves indicate, when compared to the normal tailwater curve, that any discharge of more than 9,000 second-feet would not produce a satisfactory jump at normal tailwater elevation. This was also evidenced by the excessive amount of scour caused by the maximum discharge at normal tailwater elevation when no riprap was used below the stilling-pool (Figure 11). The maximum scour occurred at the base of the left wing-wall, possibly caused by a strong eddy which was observed at the point.

Successive additions of a 3-foot dentated step (Figures 10 and 11). and a 4-foot dentated step lessened the total amount of scour, but did not eliminate the side eddy at the base of the left wing-wall. An extensive series of tests was then initiated to determine the best combination of flow arresters to eliminate these objectionable features. The sizes and types of the structures used are shown in Figure 10. These tests, together with the qualitative results obtained, are shown in Table I.

TABLE I

Test	Number and type of steps used	Number, type, positon of baffle piers used	Type of sill used	Observations
DC--18	None	None	None	Required tailwater elevation 3.5 feet above normal for good jump. Swept out at 1 foot below normal tailwater elevation at 12,000 cfs.
DC--19	12, A-2	None	None	Good jump formed 2 feet above normal tailwater elevation, but crest of jump was approximately 25 feet beyond end of pool. Strong side eddies.
DC--20	12, A-6	None	None	Good jump formed 1.5 feet above normal tailwater elevation. Side eddies still strong.
DC--21	12, A-6	11, B-1, Station 12+95	C-1	A-6 step threw jet too high, pushing jump downstream, and rendering sill less effective. Tailwater elevation of 5286 necessary for good jump.
DC--22	11, A-3	11, B-1, Station 12+95	C-1	Required tailwater elevation 1 foot above normal for efficient jump.
DC--23	12, A-2	11, B-1, Station 12+95	C-1	Good jump for normal tailwater except crest was high causing considerable spray.
DC--24	12, A-1	11, B-1, Station 12+95	C-1	Jump formed further downstream than in Test DC-23, causing greater scour.
DC--25	None	11, B-1, Station 12+95	C-1	Inferior to DC-23, requiring tailwater elevation 3 feet greater than normal for good jump.

TABLE I (Continued)

Test	Number and type of steps used	Number, type, position of baffle piers used	Type of sill used	Observations
DC--26	12, A-2	11, B-2, Station 12+95	C-2	A good jump was formed; however, crest was 5 feet beyond end of pool. Strong side eddy, causing deep scour.
DC--27	12, A-2	11, B-3, Station 12+95	C-3	Good jump with crest at end of pool. Deep scour due to eddies.
DC--28	12, A-2	11, B-1, Station 12+95	C-1	Jump approximately the same as DC-27. Scour was much less except for left-corner hole.
DC--29	12, A-2	None	C-1	Long flat jump formed with more general scour.
DC--30	12, A-2	11, B-3, Station 12+95	None	Much better jump than obtained previously, but general scour was excessive.
DC--31	12, A-2	11, B-3, Station 12+95	C-14	Scour much better, but not as good as DC-30 otherwise.
DC--32	12, A-2	12, B-2, Station 12+80; 11, B-3, Station 13+08	C-14	Scour very good, and jump crest moved into pool.
DC--33	12, A-2	12, B-2, Station 12+84; 11, B-1, Station 13+02	C-14	Results approximately the same as DC-32.
DC--34	12, A-2	11, B-2, Station 12+84; 12, B-2, Station 13+02	C-15	Results approximately the same as DC-32.
DC--35	8, A-2	7, B-2, Station 12+84; 8, B-1, Station 13+02	C-14	Jump not as good as when all teeth are in, but was sufficiently good. Left scour hole deep.

TABLE I (Continued)

Test	Number and type of steps used	Number, type, position of baffle piers used	Type of sill used	Observations
DC--36	8, A-2	7, B-2, Station 12+84; 8, B-1, Station 13+02	C-15	Using 8-foot high auxiliary training-wall to eliminate eddy on left side, scour much improved.
DC--37	8, A-2	7, B-2, Station 12+84; 8, B-1, Station 13+02	C-15	Using 6-foot high auxiliary training-wall to eliminate eddy on left side, scour was slightly more than test DC-36.
DC--38	8, A-2	7, B-2, Station 12+84; 8, B-1, Station 13+02	C-15	Using 4-foot auxiliary training-wall, scour was slightly more than Test DC-37, but still less than DC-35.
DC--39	8, A-2	7, B-1, Station 12+84; 8, B-1, Station 13+02	C-15	Using 4-foot auxiliary training-wall, scour was approximately same as Test DC-38.
DC--40	8, A-2	7, B-4, Station 12+84; 8, B-4, Station 13+02	C-15	Using 4-foot auxiliary training-wall, better than DC-38.
DC--41	8, A-2	7, B-5, Station 12+84; 8, B-5, Station 13+02	C-15	Using 4-foot auxiliary training-wall, scour appears a little deeper than DC-40. Side jet is more active.
DC--42	8, A-2	7, B-4, Station 12+84; 8, B-4, Station 13+02	C-15	2 feet of sand placed on basin floor before test, 4-foot training-wall used. All of sand washed out of basin during test showing that effectiveness of sill is not decreased by sand in front of sill.
DC--43	8, A-2	None	C-11	Jump crest out of pool. Much more turbulence downstream. 4-foot training-wall used. Corner scour about same as DC-40.

TABLE I (Continued)

Test	Number and type of steps used	Number, type, position of baffle piers used	Type of sill used	Observations
DC--44	8, A-2	None	C-12 (9 teeth)	4-foot auxiliary training-wall used. Result approximately same as DC-43. General scour deeper showing that sill is probably too high.
DC--45	8, A-2	None	C-10 (11 teeth)	4-foot training-wall used. Amount of scour decreased, but crest of jump was further downstream.
DC--46	11, A-2	None	Bucket design	General scour much greater. Not an efficient design.
DC--47	10, A-2	None	C-12 (11 teeth)	Using 90° wing-wall; more general scour than DC-44.
DC--48	10, A-2	10, B-4, Station 13+02	C-4	Using 90° wing-wall; much better scour conditions than DC-47.
DC--49	10, A-2	9, B-4, Station 12+84; 10, B-4 Station 13+02	C-4	Using 90° wing-wall; less scour than DC-48.
DC--50	10, A-2	9, B-4, Station 12+84; 10, B-4 Station 13+02	C-4	Using 45° wing-wall; much less scour than with 90° wing-wall.
DC--51	10, A-2	10, B-4, Station 13+02	C-4	Using 45° wing-wall; less scour than DC-48 or DC-50.

TABLE I (Continued)

Test	Number and type of steps used	Number, type, position of baffle piers used	Type of sill used	Observations
DC--52	10, A-2	None	C-12 (11 teeth)	Using 45° wing-wall; more scour at base of left wing-wall than DC-51.
DC--53	10, A-2	None	C-12 (11 teeth)	Using 95-foot stilling-pool, 45° wing-walls; general scour greater than DC-51.
DC--54	10, A-2	11, B-4, Station 13+00	C-4	Using 95-foot stilling-pool, 45° wing-walls; scour much less than DC-53.
DC--55	11, A-2	12, B-4, Station 12+95	C-4	Using original pool length and wing-walls; scour very good.
DC--56	11, A-2	None	C-12 (12 teeth)	Using original pool length and wing-walls; scour good; not as good as DC-55.

The auxiliary training-walls referred to in Tests DC-36 to DC-45, inclusive, extended outward at a 60-degree angle from the left wing-wall, Test DC-38 (Figure 12). They were intended to eliminate the strong eddy existing in that region. Although fairly successful, they were not adopted because it was hoped that some less costly remedy could be discovered.

Tests DC-47 to DC-52, inclusive, are comparative tests using 90-degree and 45-degree wing-walls (Figure 12). A comparison of scour on the centerline to the maximum is shown in Figure 13. In general, no marked superiority in the case of the 45-degree wing-wall was apparent.

In Tests DC-53 and DC-54, the length of the stilling-pool was increased to 95 feet, using 45-degree wing-walls. Any advantage gained was not sufficient to offset the additional cost.

It was, therefore, decided to return to designs similar to DC-47 and DC-48, as they seemed to offer some promise even though excessive scour occurred in the area at the base of the left wing-wall. Both designs combined the minimum number of accessory structures necessary for good performance, together with simplicity of design of those structures.

One dentil was added to the step in both tests, two baffle piers were added in DC-55, and one tooth was added to the Rehbock sill in DC-56. Comparative scour and water-surface profile tests were then run, with the trapezoidal block and sill design used in Test DC-55 proving markedly superior in all respects (Figure 14).

It was recommended, therefore, that this combination be adopted for prototype construction. Model tests indicated a maximum scour of approximately 6 feet occurring at Station 13+95 with a maximum depth of erosion at the base of the sill of less than 4 feet. This was much less than that indicated by a comparable test using the Rehbock sill.

This design afforded an acceptable jump for 12,000 second-feet at tailwater elevation 5282, 3 feet below normal (Figure 15). The jump did not sweep out until the water surface was lowered to 5278.

Outlet Works

Determination of Testing Procedure

The riprap-lined pool, provided for in the original design, is not commonly used in conjunction with needle valve outlets. It was desirable in this case because of a considerable saving in cost over that necessary for a concrete-lined structure. There was no necessity for complete freedom from scour. However, it was imperative that the amount of erosion not be so large as to cause the formation of sand

bars below the pool and the deposition of excessive amounts of eroded material near the draft-tube outlets. Scour of sufficient magnitude would also contribute to riprap instability which eventually might be instrumental in weakening the foundations of the valve house.

In the model tests, it was therefore necessary to take particular note of all phenomena which would cause such reactions. The major factors were considered to be:

1. Direction and velocity of currents in the vicinity of the draft-tube openings.

2. The presence and magnitude of upstream and downstream currents in all sections of the pool.

3. Wave action.

4. Scour and riprap movement.

To observe and measure these factors under extreme conditions, each modification of design was tested with both valves operating under maximum head and maximum discharge, with one valve operating under maximum head and maximum discharge, and with both valves operating under maximum head and the design discharge.

By calculation it was estimated that each prototype valve was capable of passing a discharge of 796 second-feet at the maximum reservoir elevation of 5417. This was established as the maximum discharge to be used in model tests. The design discharge had previously been set at 600 second-feet.

Considering the model scale, the model valves should be 2.4 inches in diameter to be homologous to the 48-inch prototype valves. However, since 2.8-inch model valves were available immediately, they were used in the model tests. Figure 22 gives the calibration curves for the 2.8-inch valves. The valve openings required to obtain model discharges corresponding to the maximum discharge and the design discharge at 7.4 and 5.2 turns, respectively.

Considerable difficulty was experienced in determining the proper tailwater elevation for each discharge. During the first series of tests, 1-DCO-1 to 4-DCO-3A, inclusive, Curve A in Figure 16 was used. This was a computed curve for a station approximately 220 feet downstream from the end of the outlet pool, based on the premise that considerable excavating and cleaning of the river channel below the dam was to be done. At the beginning of the 5-DCO series of tests, it was decided that this work would not be done, and Curve C was recommended for use in the remaining tests. The curve was based on a section about 560 feet nearer the dam. This uncertainty was responsible for the variations in tailwater elevations for equal discharges, which may be noted in the description of the tests.

The Tests

Effect of valve divergence and depression. The 1-DCO series of tests was run with the original design shown in Figure 5. The valves were placed at an elevation corresponding to elevation 5280 prototype, their axes being perpendicular to the face of the valve house and separated by a distance of 62 feet.

In test 1-DCO-1, 2 valves, 7.4 turns open, were operated. A maximum discharge of 15,590 second-feet (0.890 second-feet model) at a head corresponding to a reservoir elevation of 5417 was passed through the valves. The tailwater elevation was maintained at elevation 5275.6 (Figure 16). The appearance of the pool was fairly satisfactory. The major portion of the jet struck the water surface about 80 feet downstream from the valve house, the disturbance ending about 35 feet beyond. When streams of purple dye were injected in the water, no appreciable bottom velocities and upstream currents could be noted. The flow at the pool outlet, however, was very rough (Figure 17).

In Test 1-DCO-2, only the right valve was operated with a discharge of 796 second-feet at the same reservoir elevation. A tailwater elevation of 5273.6 was maintained. The pool conditions proved to be unsatisfactory. There were no waves in front of the draft-tubes, but the velocity of flow toward the right side of the pool was very high. Strong upstream currents along the left pool wall and downstream currents along the right wall existed. High bottom velocities were also observed.

Each of these tests was run for about 3 hours. After completion of 1-DCO-2, the scour was examined. A large area in front of the right valve, about 30 feet by 10 feet prototype, at Station 18/15 had been scoured to a depth of about 3 feet. The remainder of the riprap had not been moved, but the sand channel beyond the riprap had been badly eroded for a distance of 60 feet (Figure 17).

The eroded material was then replaced and Test 1-DCO-3 was run. In this test the valves were opened 5.2 turns, resulting in a flow of 1,200 second-feet at the maximum head. The performance was approximately the same as for 1-DCO-1. This design was particularly unsatisfactory for single-valve operation. Before making any attempt to change the pool, it was decided to vary the alinement of the valves to observe the effect on performance.

In Tests 2-DCO-1, 2-DCO-2, and 2-DCO-3, each valve was turned in at an angle of 10 degrees. The same testing procedure as that described in the 1-DCO series was used. This design showed a marked improvement in performance, particularly in the case of single-valve operation. There was no scour in the riprap, and the shooting flow along both sides was less evident. Erosion of the sand downstream from the riprap was decreased.

In the next series, 3-DCO, the valves were returned to the parallel position and each valve was depressed 5 degrees. Using the same testing

procedure, it was discovered that with two valves operating, flow was concentrated in a small region near each side slope allowing an upstream current along the bottom as far downstream as Station 18+00. Single-valve operation also gave a strong back surface current along the left wall of the pool. The riprap erosion for this test was the same as for Test 1-DCO, and scour in the sand channel also occurred, although to a smaller degree than in the original design.

Test Series 4-DCO was a combination of 2-DCO and 3-DCO, each valve being turned in 10 degrees and depressed 5 degrees. This design gave considerable upstream flow on each side during two-valve operation, but was otherwise satisfactory in that the flow was well centered in the pool, and there were no bottom currents near the draft-tubes. Single-valve operation, however, still caused strong upstream surface currents along the left wall. There was no movement of riprap, but there was considerable sloughing of the sand slopes downstream.

Effect of pool shape. Tests on the various valve arrangements indicated a need for redesign of the pool itself. It had been evident in all the tests that the width of the pool was too great, particularly for single-valve operation, as shown by the strong upstream currents along the sidewalls. The pool was, therefore, changed as shown in Figure 21. The bottom width was reduced from 70 feet to 25 feet; the side slopes were changed to 1-1/2:1; and the riprap extended approximately 60 feet. It was also definitely established that the proposed river channel excavation would not be carried out, and Curve "C" (Figure 16) was recommended as the proper tailwater elevation for the remaining tests.

In Test Series 5-DCO, the valve positions used in 4-DCO were retained. Use of the new tailwater curve increased the tailwater elevation to 5278.1 for Run 1, 5276.2 for Run 2, and 5277.4 for Run 3. For both double- and single-valve operation, the pool appearance was improved over the previous tests, but strong upstream currents existed along the bottom with both valves operating, and to a lesser degree along the left wall with one valve operating. For the latter condition the main current flow was directed about 10 degrees to the left of the pool centerline.

Recommended design. It was suspected that many of these detrimental conditions were caused by depressing the valves 5 degrees, thus causing the jet to strike the tailwater too directly. Series 6-DCO and 7-DCO were run, therefore, with each valve turned in at 10 degrees and 12-1/2 degrees, respectively, and with no vertical tilt.

Pitot-tube velocity measurements were made during both of the last tests. Figure 19 is a comparison of prototype velocity intensities toward the powerhouse at distances of 10 and 25 feet downstream, with a discharge of 1,590 second-feet at a reservoir elevation of 5417. Both show the superiority of 25-degree total convergence and demonstrate that the upstream currents at 25 feet decreased sufficiently to become negligible at the valve house wall.

Figure 20 shows the velocity distribution at Station 18+85 (end of 3:1 slope) for 1,590 and 1,200 second-feet.

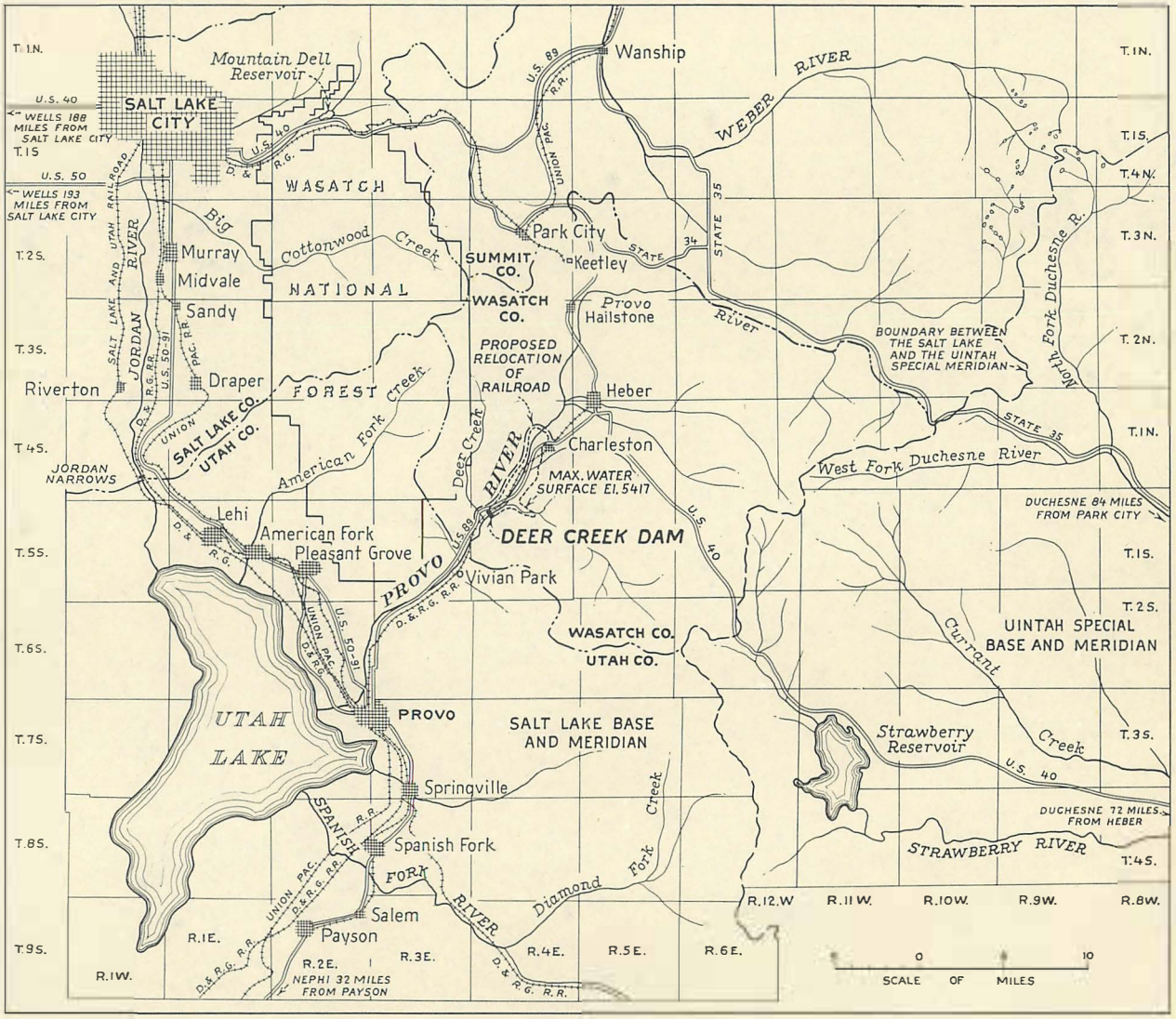
PART II PROTOTYPE TESTS

Prototype Operations

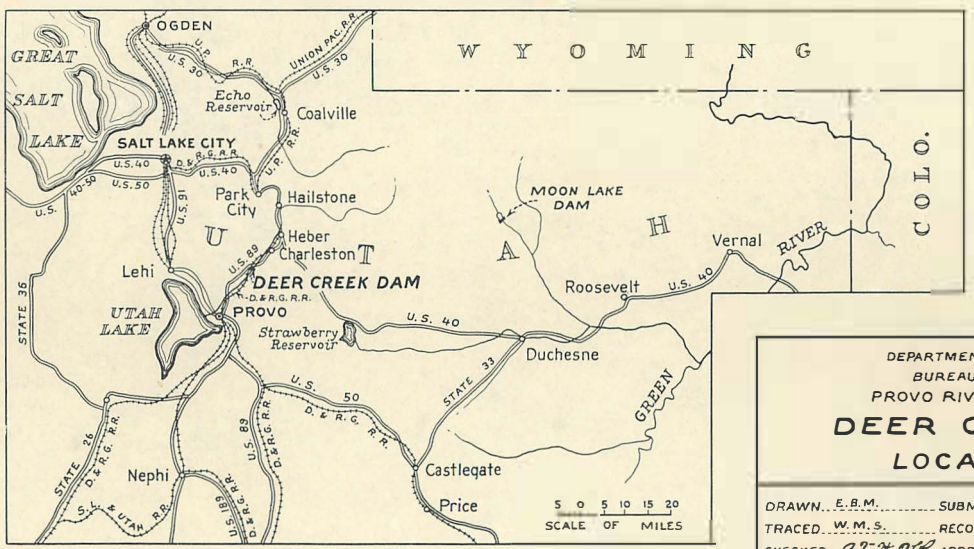
On May 15, 1946, an opportunity was found to observe and photograph the operation of the tube valves and stilling-basin. Fifty-two-inch tube valves had been installed in the prototype instead of the 48-inch needle valves shown on the prototype drawings in this report. Reference is made to a letter from the Construction Engineer at Provo, Utah, to the Chief Engineer, Branch of Design and Construction, Denver, dated June 17, 1946, which states:

> "The operation of the outlet works stilling-basin has proved to be very satisfactory. Under all conditions of operation the major part of turbulence of the water was found to occur in the stilling-basin, and the turbulence occurring in the channel which leads from the stilling-basin to the river was not considered to be excessive. It has been found from past operations that the operation of one tube valve at high rate of discharge causes a circular swirling motion of the downstream portion of the stilling-basin. Whenever possible all discharge into the stilling-basin is divided equally through the two tube valves.
>
> "The present condition of the riprap in the stilling-basin and stilling-basin channel is considered to be good with the exception of one small area on the south bank of the basin. This area of riprap sloughed into the stilling-basin after a concentration of surface drainage water had eroded the bank upon which the riprap had been placed. The concentration of the drainage water resulted from a spring storm of short but intense duration which clogged a culvert underneath the highway on the side hill immediately above the stilling-basin. The necessity of discharging water into the stilling-basin through only one tube valve during the time that the storm occurred further aggravated this condition. Repair work to the area of riprap is being made at the present time."

Figures 23 to 26 illustrate the operation of the tube valves and the stilling-basin.



VICINITY MAP



INDEX MAP

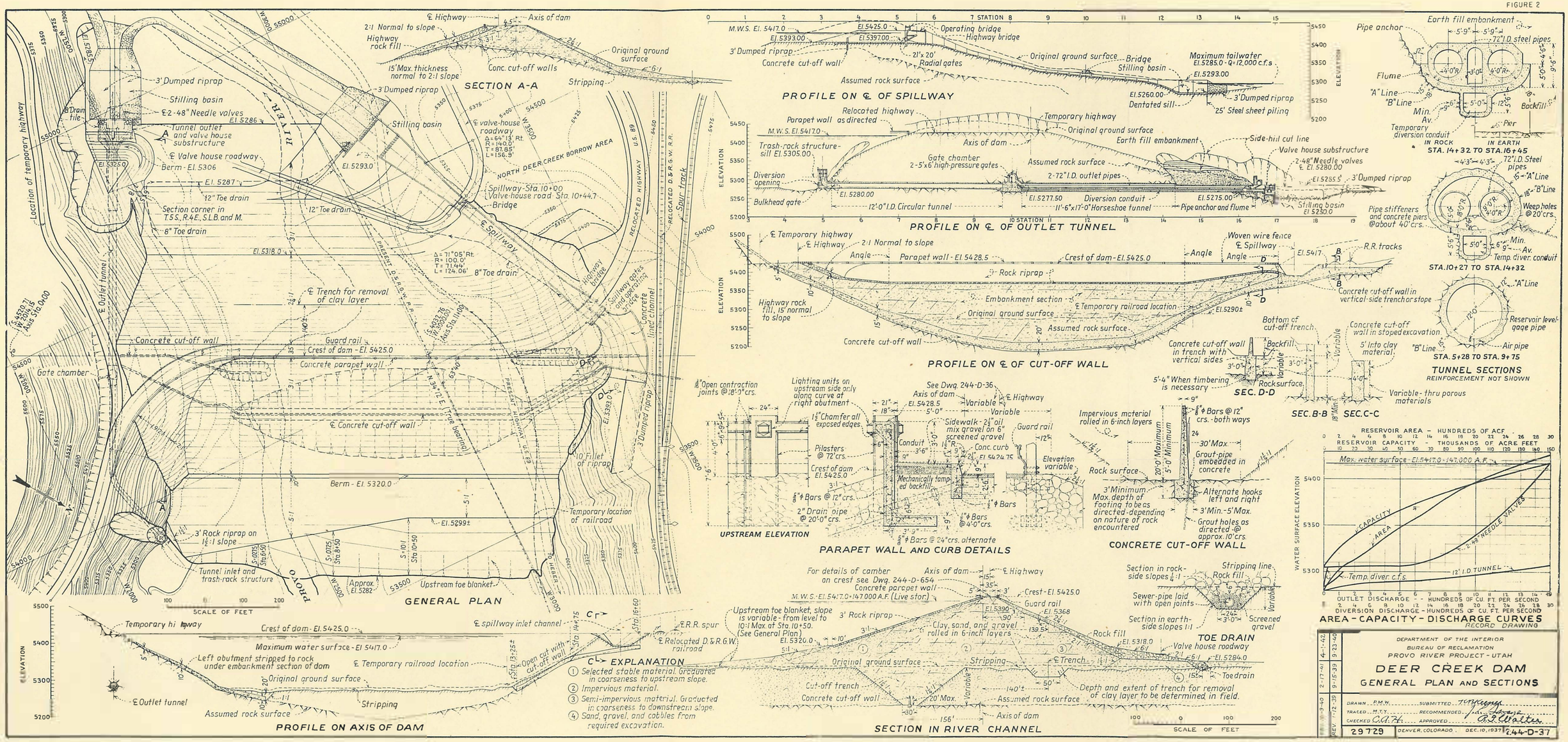
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PROVO RIVER PROJECT - UTAH

DEER CREEK DAM
LOCATION MAP

DRAWN E.B.M. SUBMITTED
TRACED W.M.S. RECOMMENDED
CHECKED APPROVED

29723 DENVER COLO. AUG. 14, 1936 244-D-31

FIGURE 2


GENERAL PLAN
SECTION A-A
PROFILE ON ℄ OF SPILLWAY
PROFILE ON ℄ OF OUTLET TUNNEL
PROFILE ON ℄ OF CUT-OFF WALL
TUNNEL SECTIONS
REINFORCEMENT NOT SHOWN
SEC. D-D
SEC. B-B
SEC. C-C
PARAPET WALL AND CURB DETAILS
CONCRETE CUT-OFF WALL
TOE DRAIN
AREA - CAPACITY - DISCHARGE CURVES
RECORD DRAWING
PROFILE ON AXIS OF DAM
SECTION IN RIVER CHANNEL
EXPLANATION
1 Selected stable material. Graduated in coarseness to upstream slope.
2 Impervious material.
3 Semi-impervious material. Graduated in coarseness to downstream slope.
4 Sand, gravel, and cobbles from required excavation.
UPSTREAM ELEVATION
Location of temporary highway
Outlet tunnel
Gate chamber
Concrete cut-off wall
Concrete parapet wall
Crest of dam - El. 5425.0
Guard rail
Trench for removal of clay layer
Spillway
Stilling basin
Needle valves
Tunnel outlet and valve house substructure
Valve house roadway
Berm - El. 5306
Berm - El. 5320.0
Tunnel inlet and trash-rock structure
3' Rock riprap on 1½:1 slope
Toe drain
Section corner in T.5S., R.4E., S.L.B. and M.
Spillway-Sta. 10+00
Valve-house road Sta. 10+44.7
Bridge
NORTH DEER CREEK BORROW AREA
PRESENT U.S.89
RELOCATED HIGHWAY U.S. 89
RELOCATED D.&R.G.W. R.R.
Spur track
Concrete lined channel
Highway bridge
Spillway gates and operating house
Temporary location of railroad
10' Fillet of riprap
3' Dumped riprap
Original ground surface
Stripping
Highway rock fill
15' Max. thickness normal to 2:1 slope
Conc. cut-off walls
Axis of dam
℄ Highway
2:1 Normal to slope
Approx. El. 5282
Upstream toe blanket
SCALE OF FEET
M.W.S. El. 5417.0
El. 5425.0
El. 5393.00
El. 5397.00
Operating bridge
Highway bridge
21'x 20' Radial gates
Concrete cut-off wall
Assumed rock surface
Bridge
Stilling basin
Maximum tailwater El. 5285.0 - Q=12,000 c.f.s
El. 5293.00
El. 5260.00
Dentated sill
3' Dumped riprap
25' Steel sheet piling
ELEVATION
STATION
Relocated highway
Parapet wall as directed
Temporary highway
Original ground surface
Earth fill embankment
Side-hill cut line
Valve house substructure
2-48" Needle valves ℄ El. 5280.00
Trash-rock structure-sill El. 5305.00
Gate chamber 2-5'x6' high-pressure gates
Assumed rock surface
2-72" I.D. outlet pipes
Diversion opening
Bulkhead gate
El. 5280.00
12'0" I.D. Circular tunnel
El. 5277.50
Diversion conduit
11'-6"x17'-0" Horseshoe tunnel
El. 5275.00
Pipe anchor and flume
Stilling basin El. 5250.0
℄ Temporary highway
Woven wire fence
℄ Spillway
R.R. tracks
Angle
Parapet wall - El. 5428.5
Crest of dam - El. 5425.0
Rock riprap
Embankment section
℄ Temporary railroad location
Concrete cut-off wall in vertical-side trench or stope
Concrete cut-off wall in trench with vertical sides
Concrete cut-off wall in stoped excavation
Backfill
Bottom of cut-off trench
Rock surface
5' into clay material
Variable - thru porous materials
Pipe anchor
Earth fill embankment
72" I.D. steel pipes
Flume
"A" Line
"B" Line
Min. Av.
Backfill
Pier
Temporary diversion conduit
IN ROCK
IN EARTH
STA. 14+32 TO STA. 16+45
Pipe stiffeners and concrete piers @ about 40' crs.
Weep holes @ 20' crs.
STA. 10+27 TO STA. 14+32
Reservoir level-gage pipe
Air pipe
STA. 5+28 TO STA. 9+75
Open contraction joints @ 18'-0" crs.
Lighting units on upstream side only along curve at right abutment
See Dwg. 244-D-36
Axis of dam
Variable
℄ Highway
1½" Chamfer all exposed edges
Sidewalk - 2½" oil mix gravel on 6" screened gravel
Guard rail
Conduit
Conc. curb
Pilasters @ 72' crs.
Crest of dam El. 5425.0
Mechanically tamped backfill
Elevation variable
⅝" ϕ Bars @ 12" crs.
2" Drain pipe @ 20'-0" crs.
⅝" ϕ Bars @ 4'-0" crs.
⅝" ϕ Bars @ 24" crs. alternate
Impervious material rolled in 6-inch layers
⅝" ϕ Bars @ 12" crs. - both ways
30' Max
Grout-pipe embedded in concrete
Rock surface
3' Minimum Max. depth of footing to be as directed - depending on nature of rock encountered
Alternate hooks left and right
3' Min. - 5' Max.
Grout holes as directed @ approx. 10' crs.
RESERVOIR AREA - HUNDREDS OF ACRES
RESERVOIR CAPACITY - THOUSANDS OF ACRE FEET
Max. water surface - El. 5417.0 - 147,000 A.F.
CAPACITY
AREA
2-48" NEEDLE VALVES
12' I.D. TUNNEL
Temp. diver. c.f.s.
WATER SURFACE ELEVATION
OUTLET DISCHARGE - HUNDREDS OF CU. FT. PER SECOND
DIVERSION DISCHARGE - HUNDREDS OF CU. FT. PER SECOND
Temporary highway
Crest of dam - El. 5425.0
Maximum water surface - El. 5417.0
Left abutment stripped to rock under embankment section of dam
Original ground surface
Stripping
Assumed rock surface
℄ Outlet tunnel
℄ Spillway inlet channel
℄ R.R. spur
℄ Relocated D.&R.G.W. railroad
Open cut with cut-off wall
For details of camber on crest see Dwg. 244-D-654
Concrete parapet wall
M.W.S. - El. 5417.0 - 147,000 A.F. (Live stor.)
Upstream toe blanket, slope is variable - from level to 10:1 Max. at Sta. 10+50. (See General Plan)
3' Rock riprap
Clay, sand, and gravel rolled in 6-inch layers
Cut-off trench
Concrete cut-off wall
Assumed rock surface
Axis of dam
Crest - El. 5425.0
Guard rail - El. 5368
Rock fill
Depth and extent of trench for removal of clay layer to be determined in field.
Section in rock-side slopes ¼:1
Section in earth-side slopes 1:1
Stripping line
Rock fill
Sewer-pipe laid with open joints
Screened gravel
Valve house roadway
Toe drain
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PROVO RIVER PROJECT - UTAH
DEER CREEK DAM
GENERAL PLAN AND SECTIONS
DRAWN P.M.W. SUBMITTED
TRACED M.T.Y. RECOMMENDED
CHECKED C.C.A. APPROVED
29729 DENVER, COLORADO. DEC. 10, 1937
244-D-37
REV. 9-30-40 9-15-39 2-17-41 4-1-42 9-23-40

PLAN

SCALE OF FEET

NOTE
Reinforcement not shown

SECTION A-A

SECTION B-B

SECTION C-C

SECTION D-D

SECTION E-E

SECTION F-F

SECTION G-G

SECTION H-H

METAL SEAL

SPILLWAY DISCHARGE AND TAILWATER CURVES

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PROVO RIVER PROJECT - UTAH

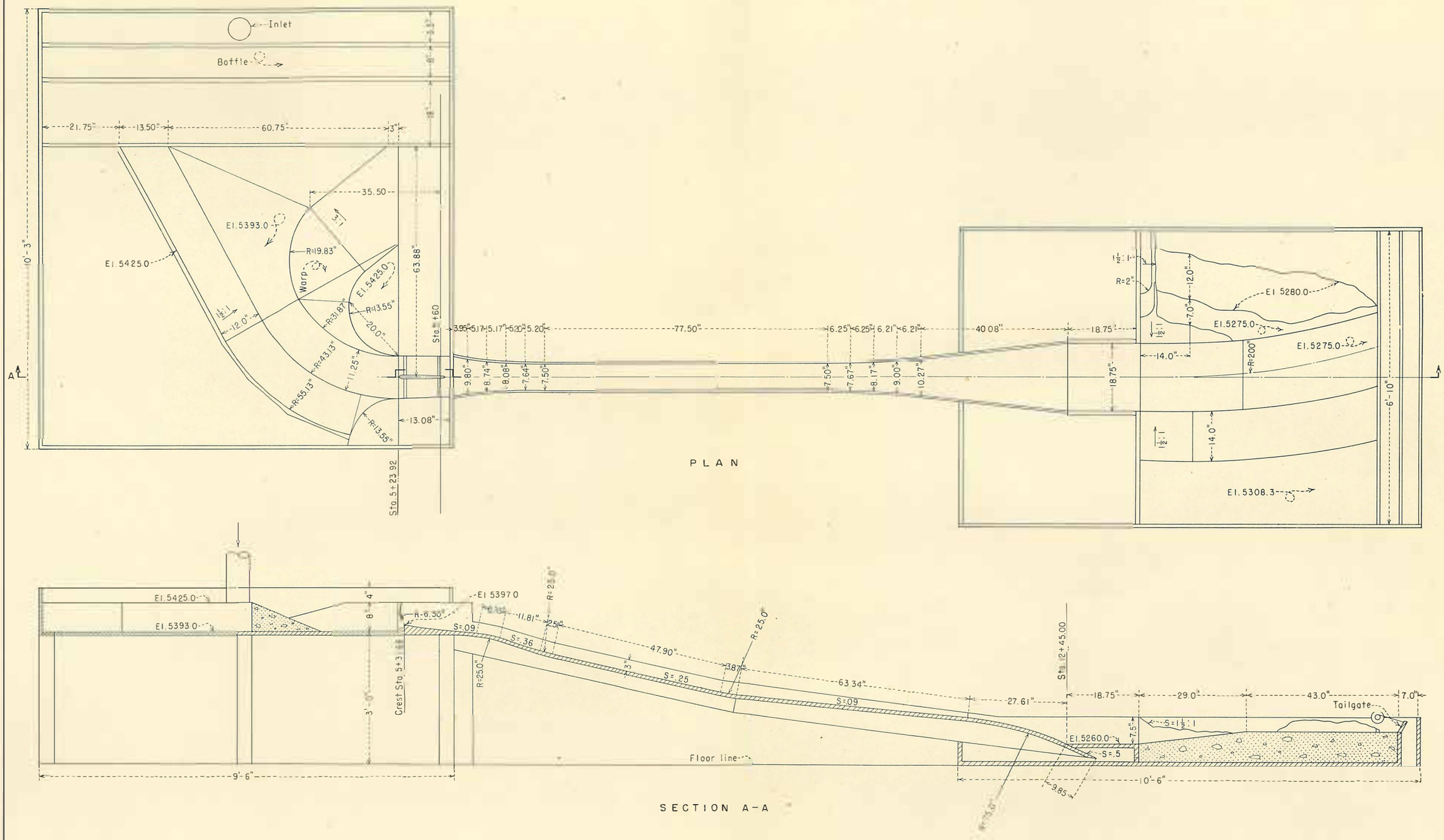
DEER CREEK DAM
SPILLWAY
PLAN AND SECTIONS

DRAWN U.V.E.	SUBMITTED		
TRACED J.E.M.	RECOMMENDED		
CHECKED D.J.S.	APPROVED		

REV. 7-28-39 | 9-21-39 | 1-22-40

29 730 | DENVER, COLORADO, DEC. 10, 1937 | 244-D-38

26

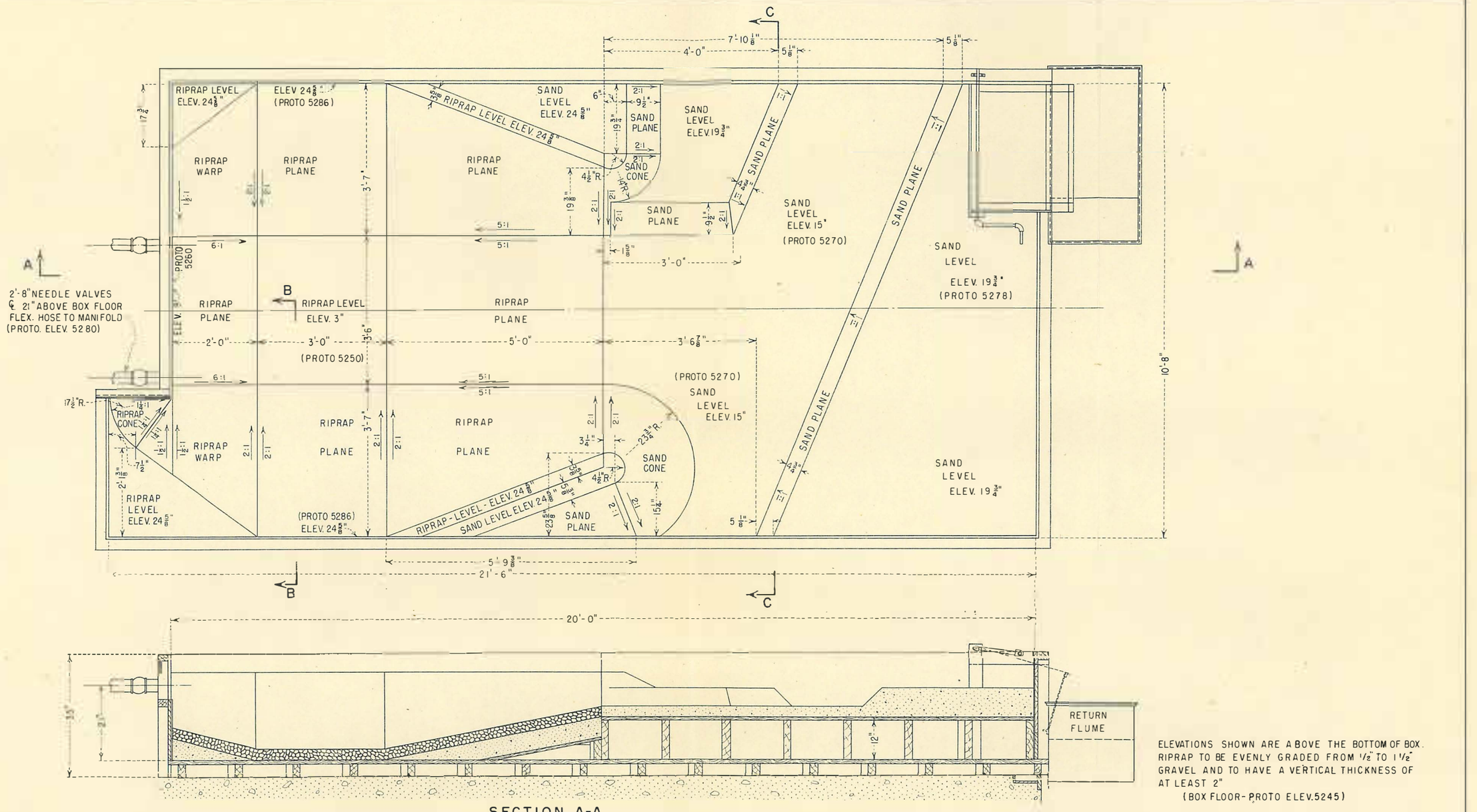


UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PROVO RIVER PROJECT

DEER CREEK DAM
1:48 HYDRAULIC MODEL
SPILLWAY

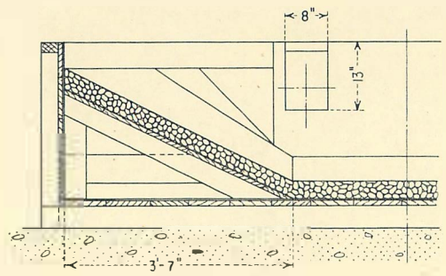
DRAWN	A.S.R.	SUBMITTED	
TRACED	S.C.S. F.L.D.	RECOMMENDED	
CHECKED		APPROVED	

DENVER, COLORADO - MAY 15, 1946.

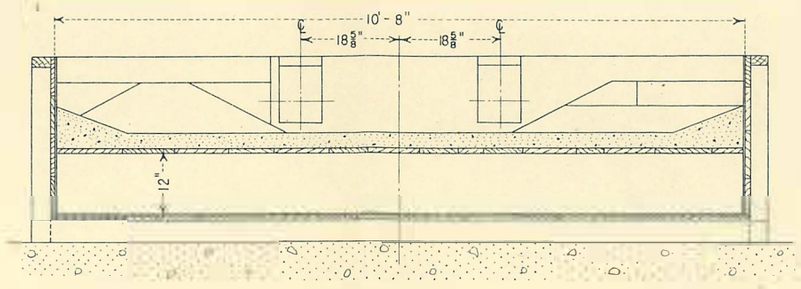


SECTION A-A

ELEVATIONS SHOWN ARE ABOVE THE BOTTOM OF BOX. RIPRAP TO BE EVENLY GRADED FROM 1/2" TO 1 1/2" GRAVEL AND TO HAVE A VERTICAL THICKNESS OF AT LEAST 2"
(BOX FLOOR- PROTO ELEV. 5245)



SECTION B-B



SECTION C-C

12" 9" 6" 3" 0 1' 2' 3'
MODEL SCALE

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PROVO RIVER PROJECT – UTAH

DEER CREEK DAM

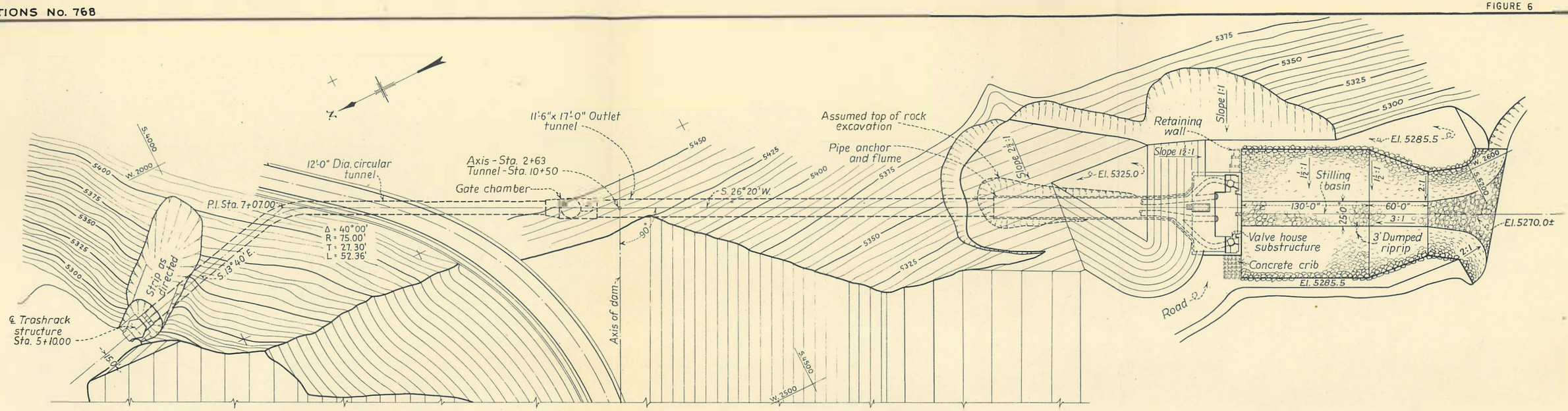
HYDRAULIC MODEL STUDIES

MODEL SCALE - 1:20

ORIGINAL PLAN OF OUTLET WORKS

DRAWN R.C.B.	SUBMITTED
TRACED J.F.S.	RECOMMENDED
CHECKED	APPROVED
	DENVER, COLORADO

FIGURE 6



NOTE

Reinforcement steel, control piping, electrical conduits, and ventilating duct not shown.

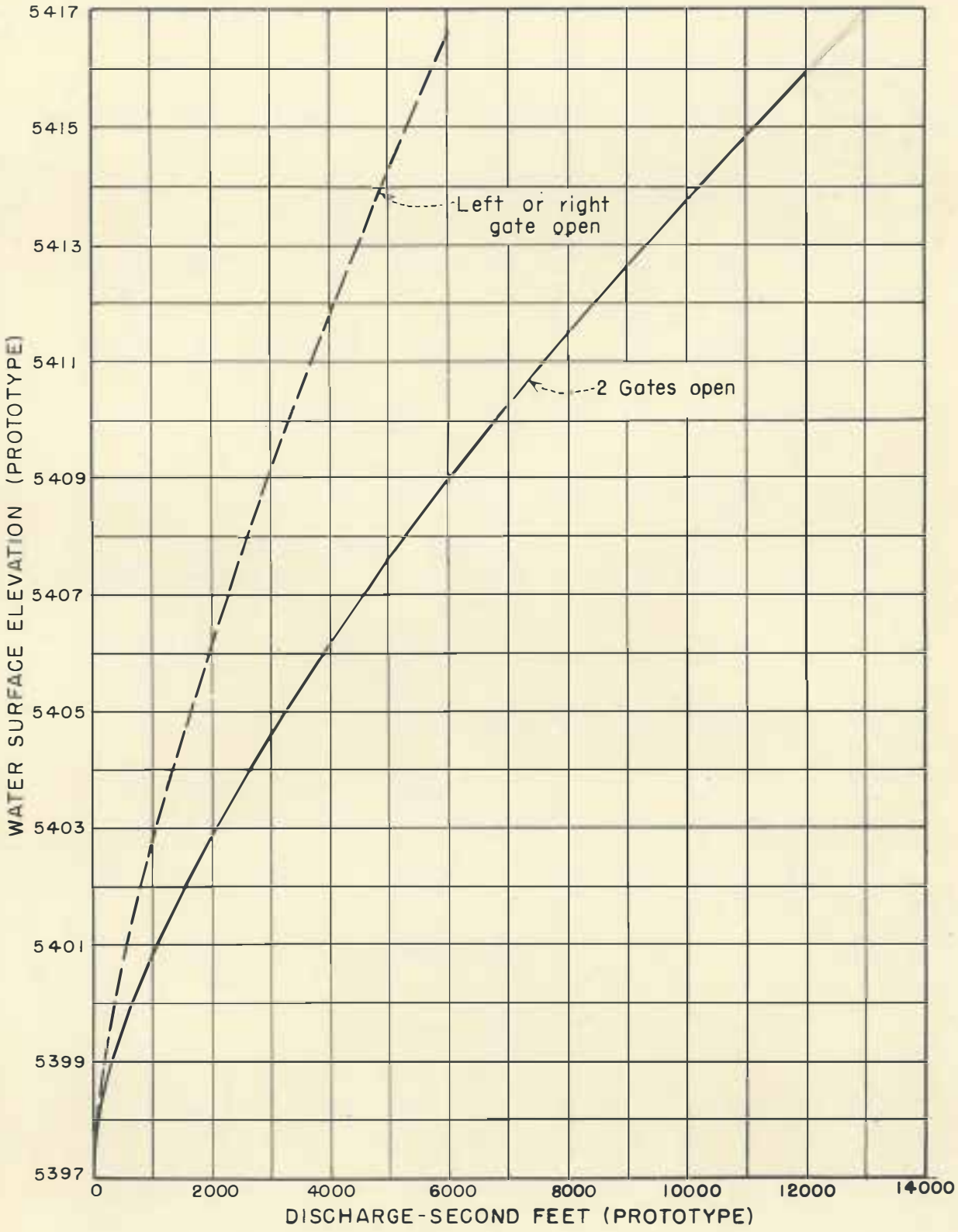
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PROVO RIVER PROJECT - UTAH

DEER CREEK DAM
OUTLET WORKS
ALINEMENT - PROFILE AND SECTIONS

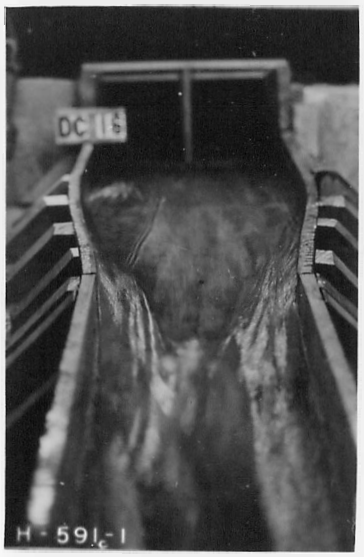
DRAWN G.F.S. - R.C.A. SUBMITTED J. L. Savage
TRACED W.M.S. RECOMMENDED J. L. Savage
CHECKED CEE APPROVED R. J. Walker

29 733 | DENVER, COLORADO, DEC. 10, 1937 | 244-D-41

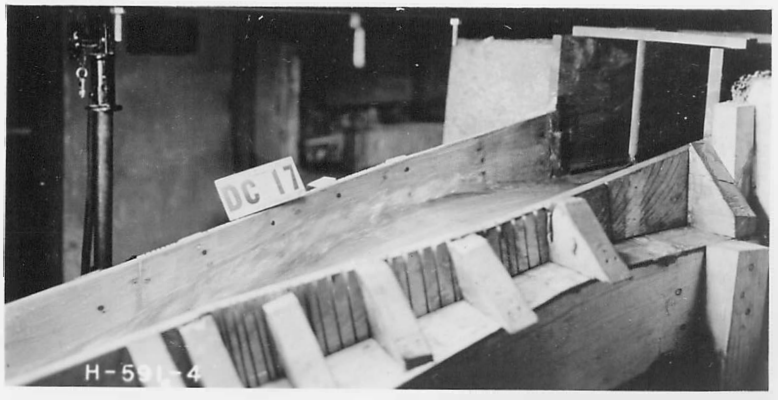
FIGURE 7



DISCHARGE CURVE SPILLWAY CREST
FREE FLOW
1:48 HYDRAULIC MODEL
DEER CREEK DAM

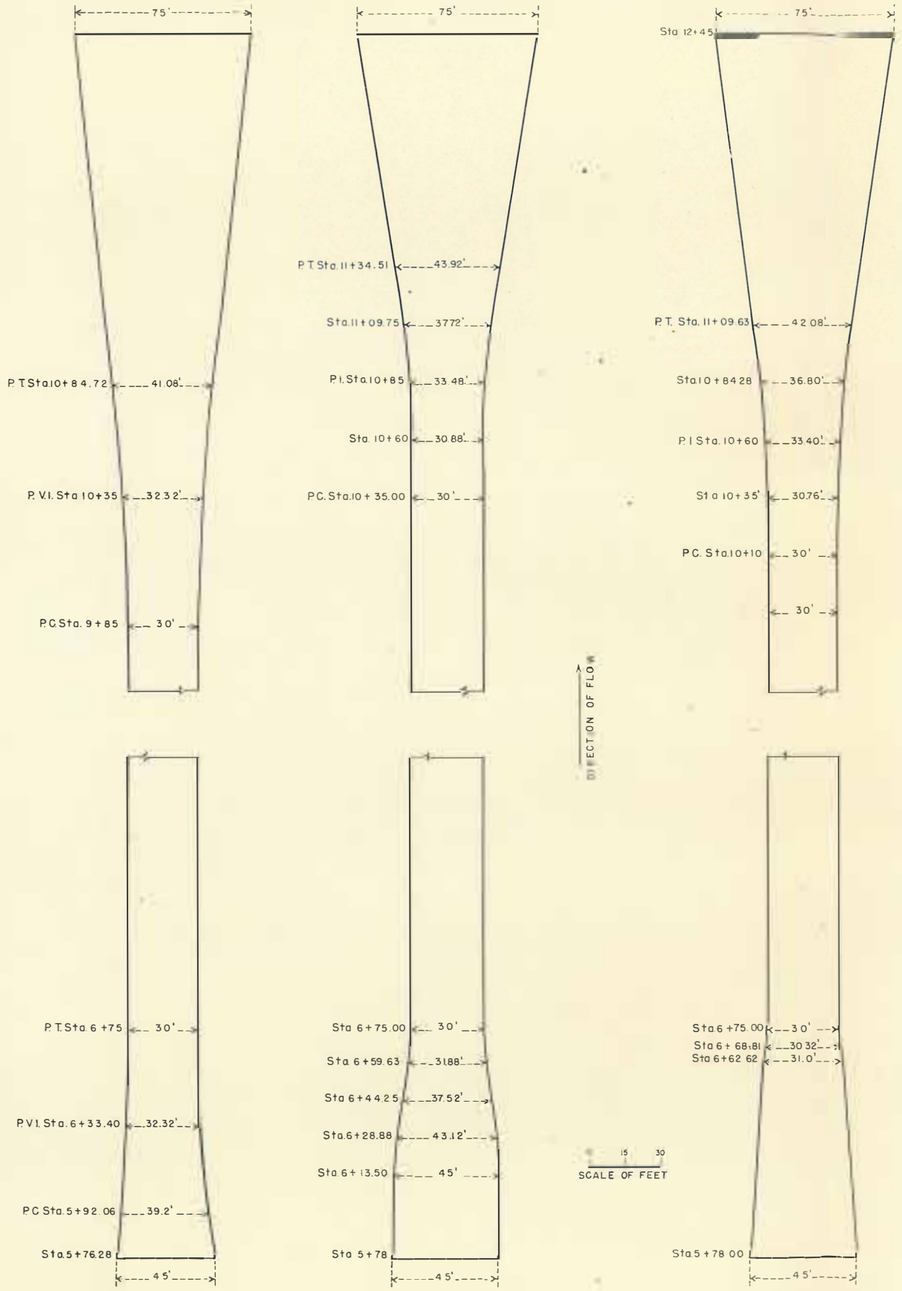


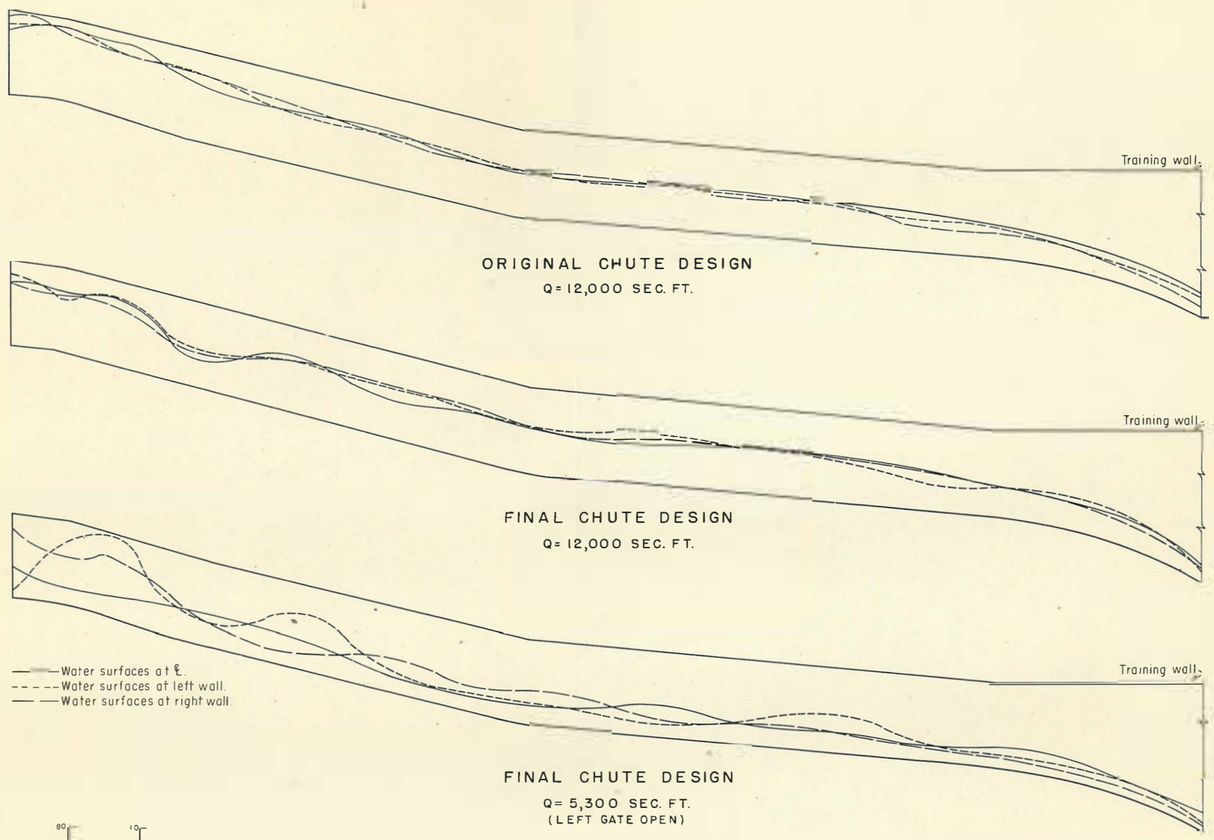
Discharge of 12,000 second-feet, both gates open

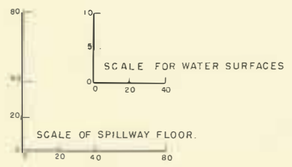


Discharge of 5,300 second-feet, left gate open

DEER CREEK DAM
CHUTE STUDIES
Original Design







NOTES

In order to assist in interpretation, the vertical scale for water surfaces has been exagerated. Water surface levels are measured above the spillway floor with a scale of 1 inch equals ten feet. The horizontal and vertical scale for the profile of the spillway floor is 1 inch equals 40 feet.

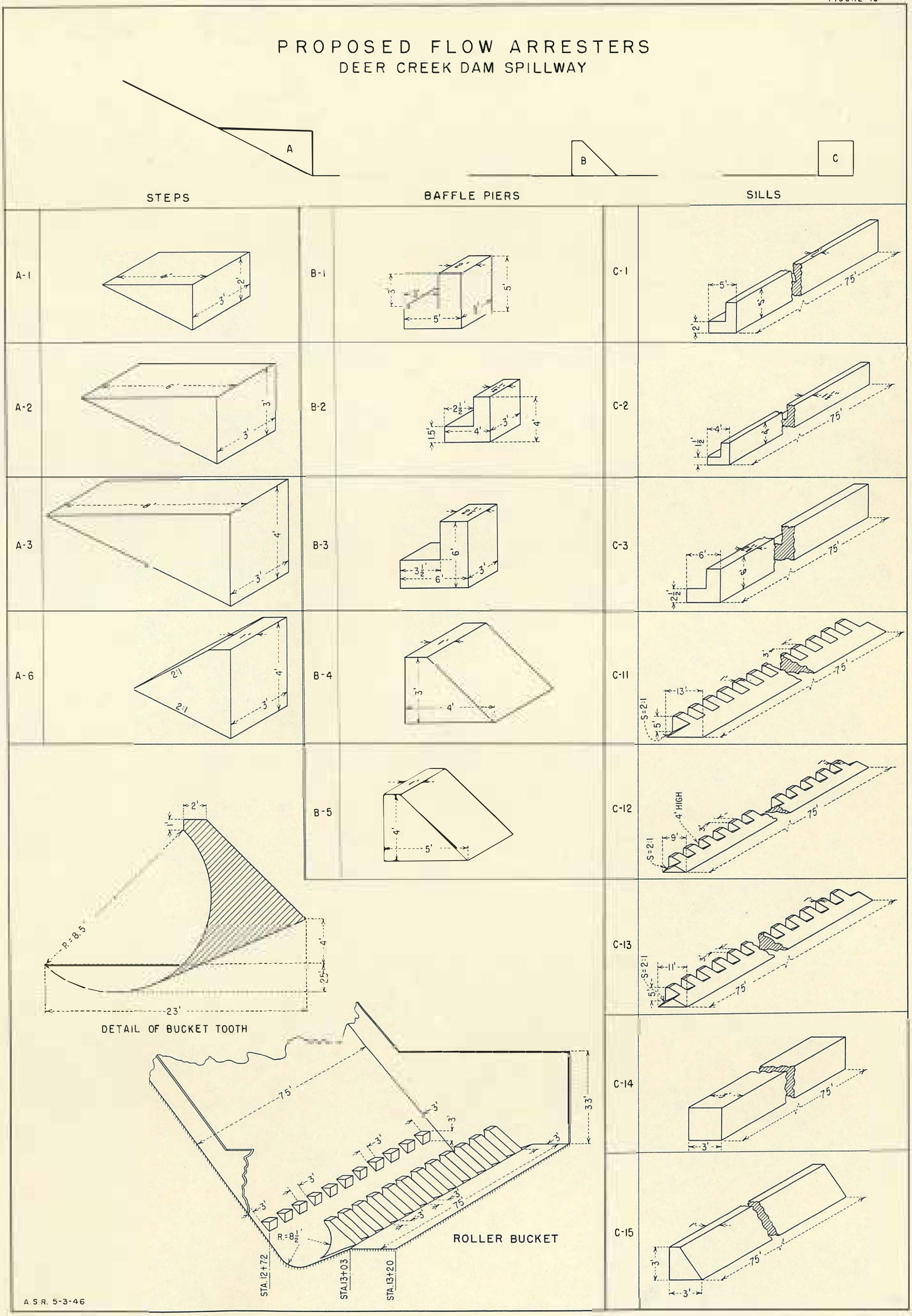
COMPARISON OF WATER SURFACES AND CHUTE DESIGNS

48 HYDRAULIC MODEL STUDIES

DEER CREEK SPILLWAY

A.S.R. – 5-21-46

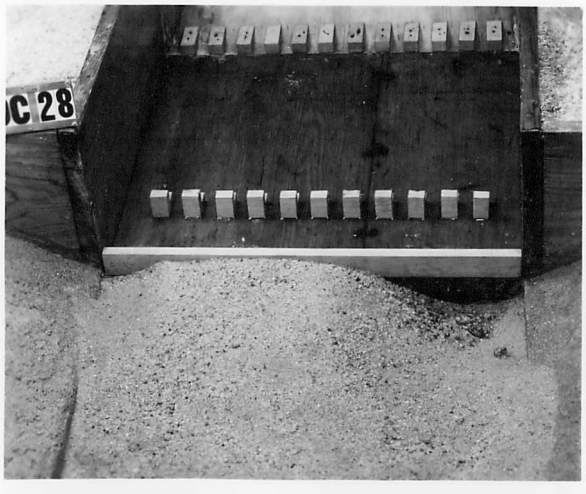
FIGURE 10


PROPOSED FLOW ARRESTERS
DEER CREEK DAM SPILLWAY
A
B
C
STEPS
BAFFLE PIERS
SILLS
A-1
A-2
A-3
A-6
B-1
B-2
B-3
B-4
B-5
C-1
C-2
C-3
C-11
C-12
C-13
C-14
C-15
4'
3'
2'
6'
8'
2:1
5'
75'
S=2:1
13'
4' HIGH
9'
11'
DETAIL OF BUCKET TOOTH
R.=8.5'
23'
ROLLER BUCKET
33'
STA. 12+72
STA. 13+03
STA. 13+20
A.S.R. 5-3-46

Test DC-18--No Flow Arresters

Test DC-19--Step Only

Test DC-29--Step and Sill

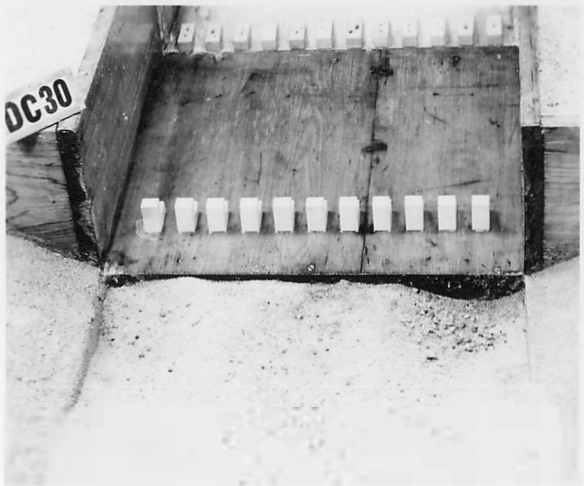


Test DC-28--Step, Baffle Piers, Sill

Test DC-46--Bucket Design

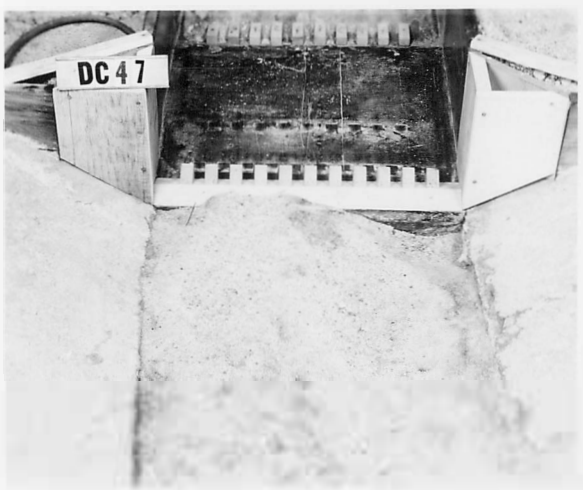
DRY CREEK DAM
SCOUR STUDIES--REPRESENTATIVE TESTS
Erosion After Flow of 12,000 Second-feet for 30 Minutes

Test DC-32--Step, 2 Rows of Baffle Piers. Sill



Test DC-30--Step, Baffle Piers, No Sill

Test DC-38--Auxiliary Training Wall



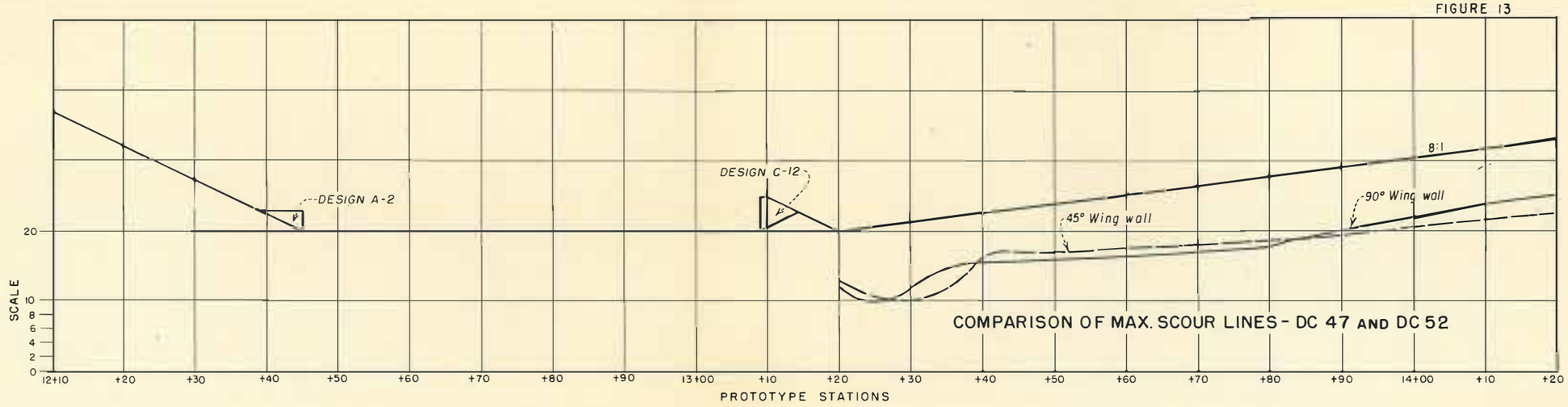
Test DC-47--90° Wing Walls

Test DC-52--45° Wing Wall

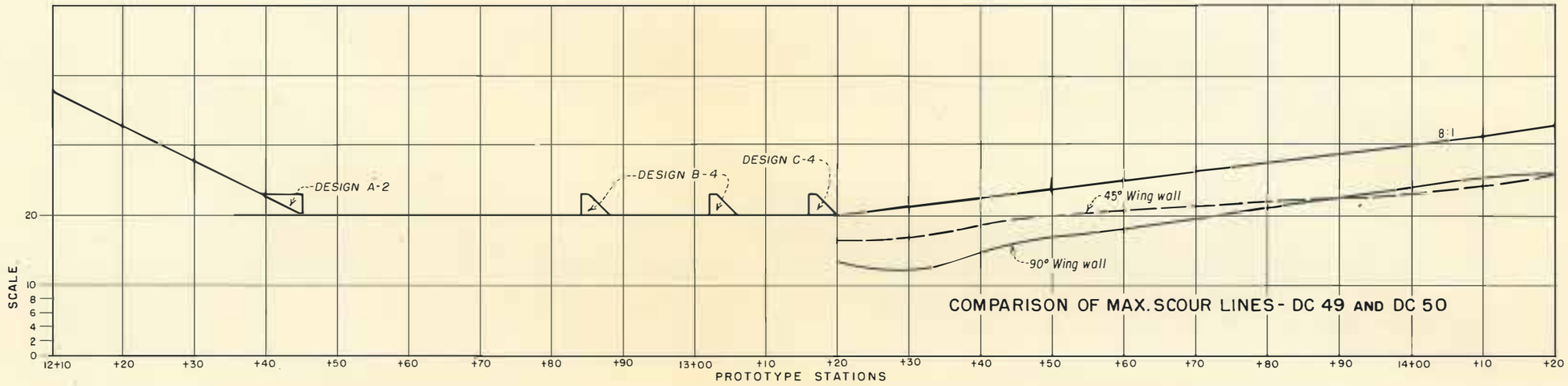
DC-53--Extended Pool, 45° Wing Walls

DEER CREEK DAM
SCOUR STUDIES--REPRESENTATIVE TESTS
Erosion After Flow of 12,000 Second-feet for 30 Minutes

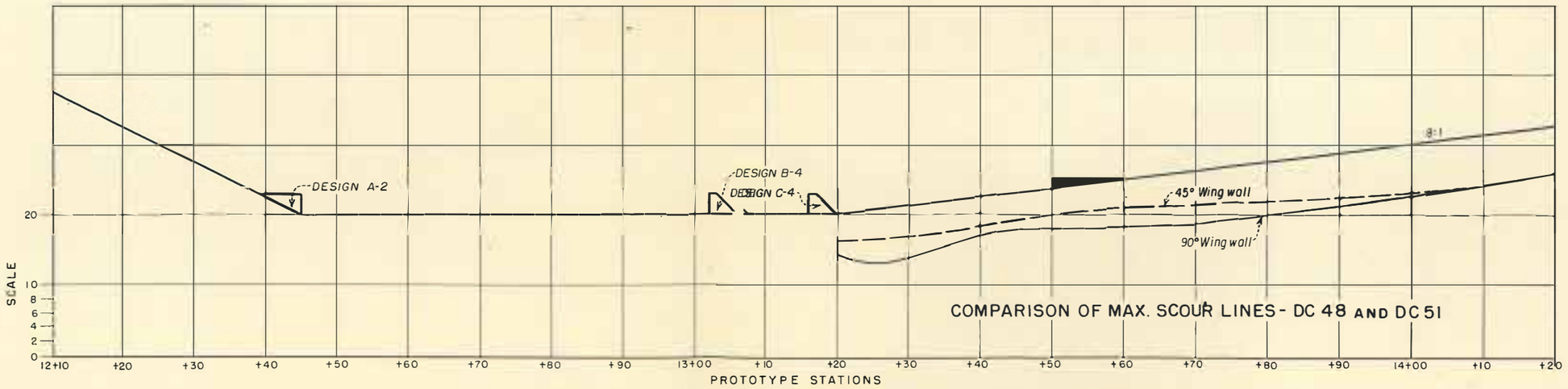
FIGURE 13



COMPARISON OF MAX. SCOUR LINES - DC 47 AND DC 52



COMPARISON OF MAX. SCOUR LINES - DC 49 AND DC 50



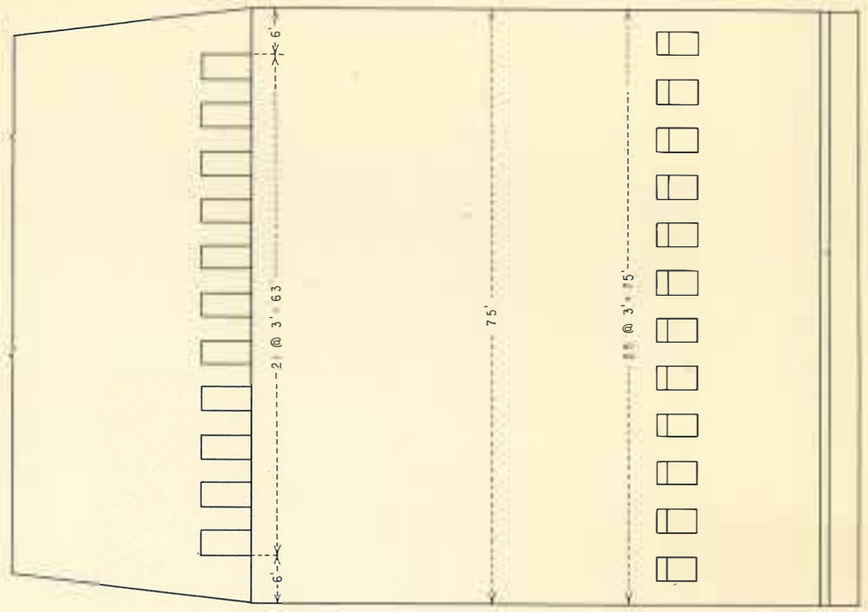
COMPARISON OF MAX. SCOUR LINES - DC 48 AND DC 51

COMPARISON OF SCOUR WITH 45° AND 90° WING WALLS

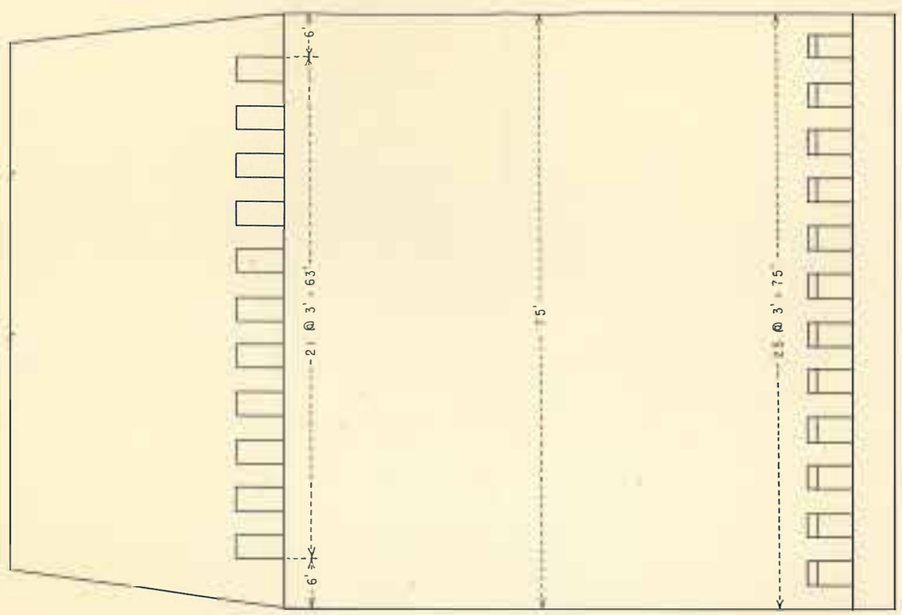
1:48 HYDRAULIC MODEL STUDIES

DEER CREEK SPILLWAY

A.S.R. 5-15-46

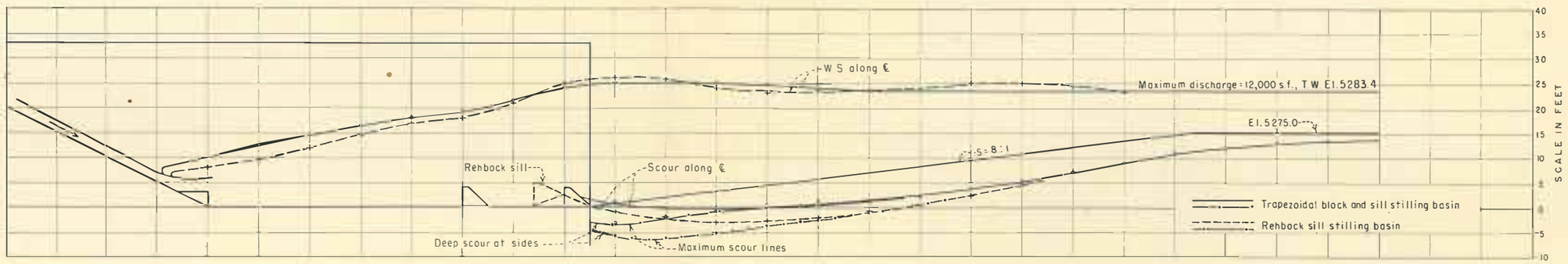


A – RECOMMENDED TRAPEZOIDAL BLOCK AND SILL STILLING BASIN



B – RECOMMENDED REHBOCK SILL STILLING BASIN

0 2 4 6 8 10
SCALE



COMPARISON OF W.S. PROFILES AND SCOUR FOR BASINS A AND B

WATER SURFACE PROFILES AND SCOUR LINES
1:48 HYDRAULIC MODEL STUDIES
DEER CREEK SPILLWAY
A.S.R. 5-7-46

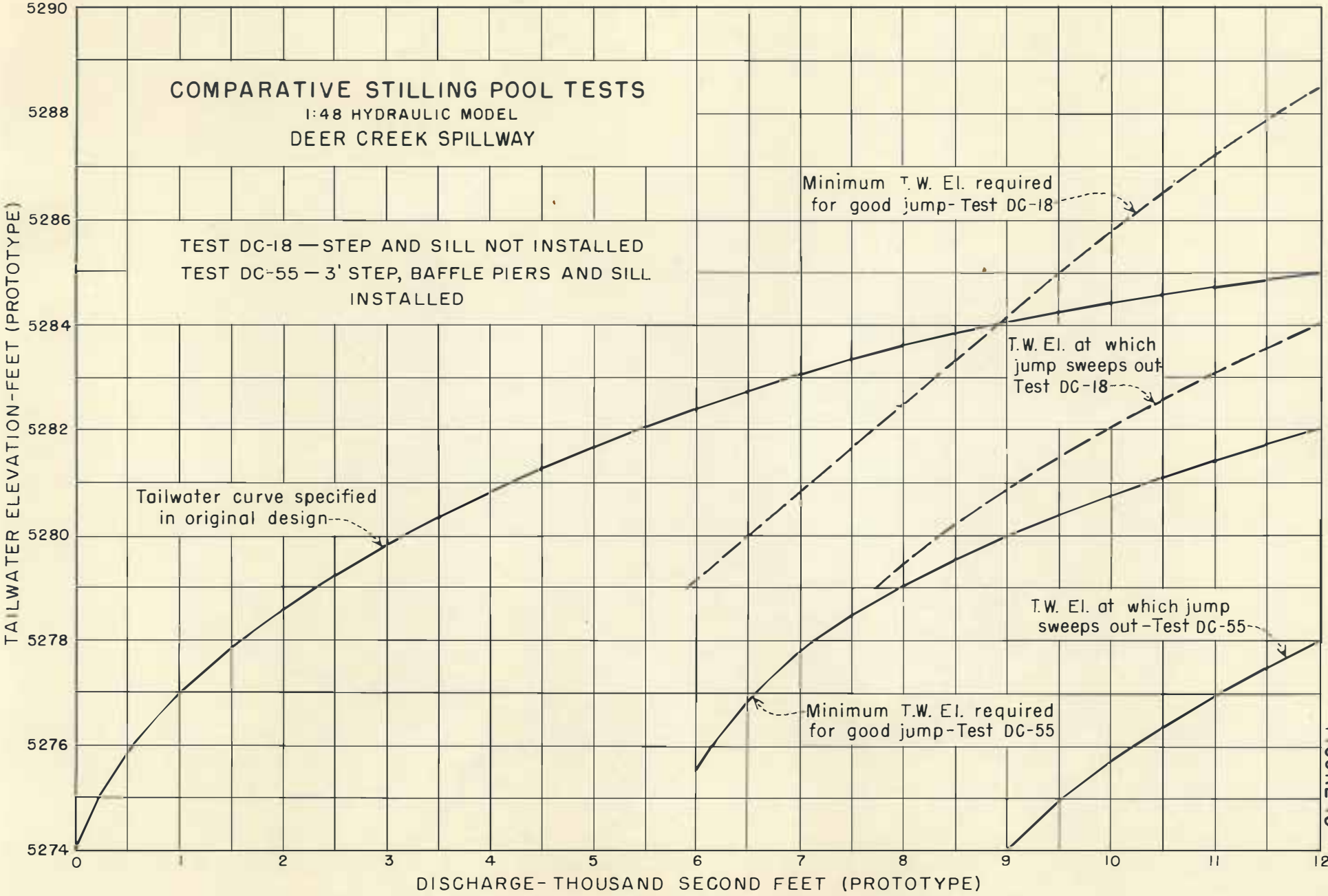
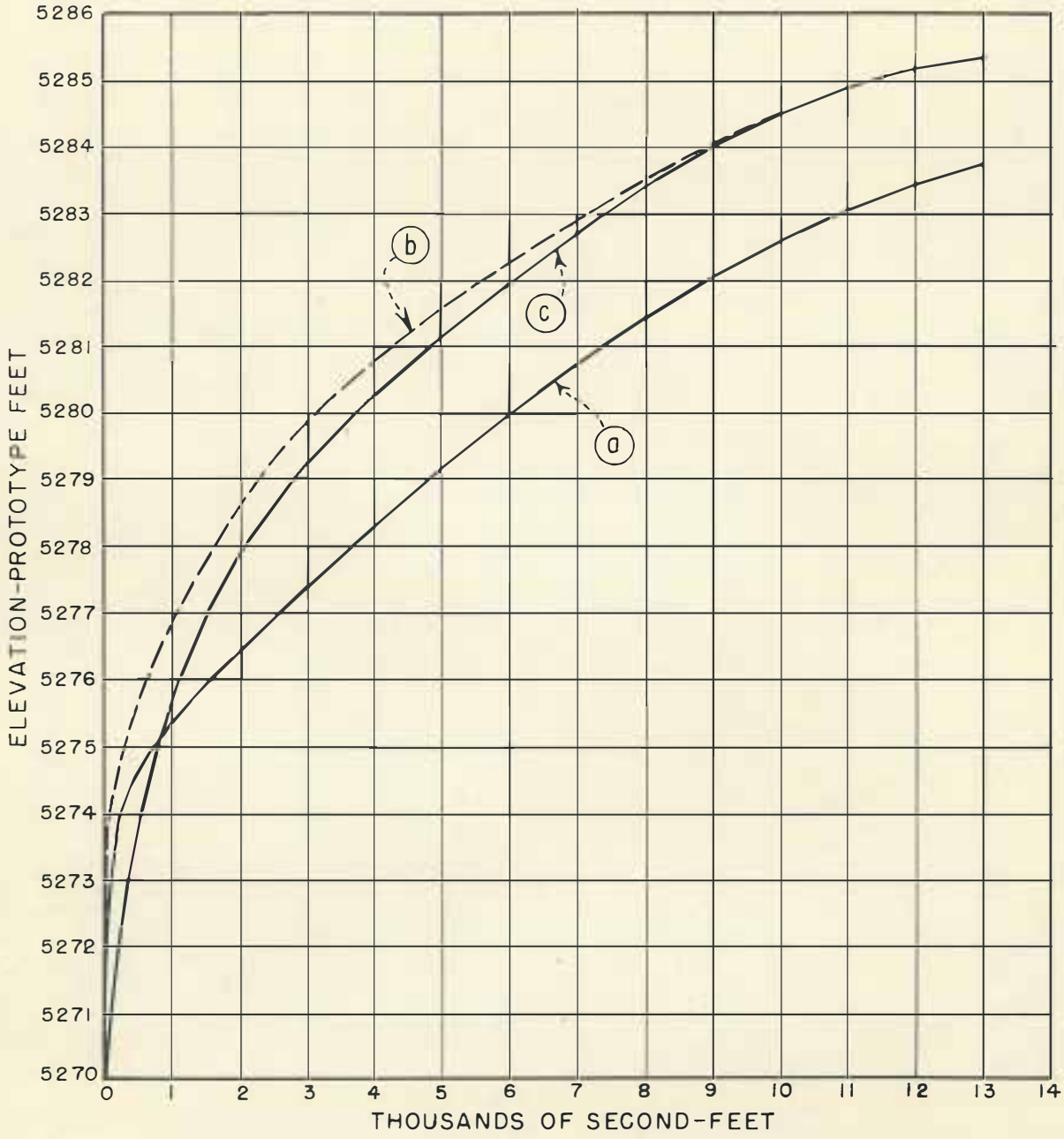

COMPARATIVE STILLING POOL TESTS
1:48 HYDRAULIC MODEL
DEER CREEK SPILLWAY
TEST DC-18 — STEP AND SILL NOT INSTALLED
TEST DC-55 — 3' STEP, BAFFLE PIERS AND SILL INSTALLED
Minimum T.W. El. required for good jump-Test DC-18
T.W. El. at which jump sweeps out Test DC-18
Tailwater curve specified in original design
T.W. El. at which jump sweeps out-Test DC-55
Minimum T.W. El. required for good jump-Test DC-55
TAILWATER ELEVATION-FEET (PROTOTYPE)
5290
5288
5286
5284
5282
5280
5278
5276
5274
0
1
2
3
4
5
6
7
8
9
10
11
12
DISCHARGE-THOUSAND SECOND FEET (PROTOTYPE)

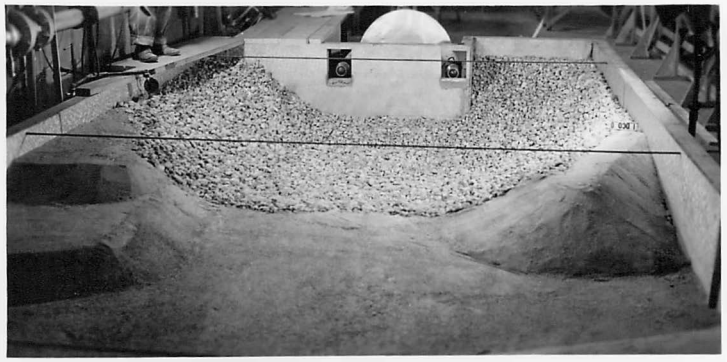
FIGURE 15



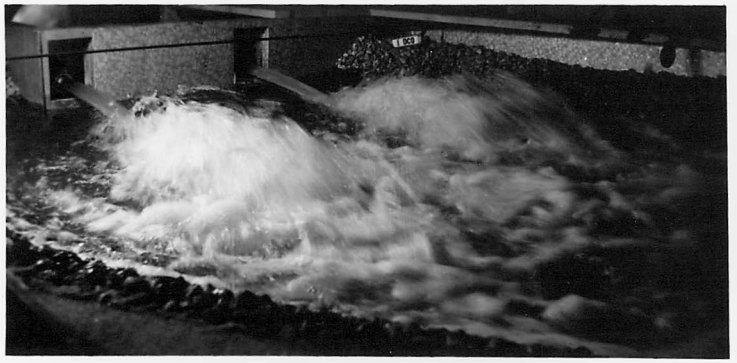
a Stage discharge curve at sta. 15+60 with channel excavation
b Stage discharge curve at sta. 7+80 without channel excavation
c Stage discharge curve at sta. 7+80 with channel excavation

COMPARATIVE TAILWATER CURVES

1:48 HYDRAULIC MODEL
DEER CREEK DAM

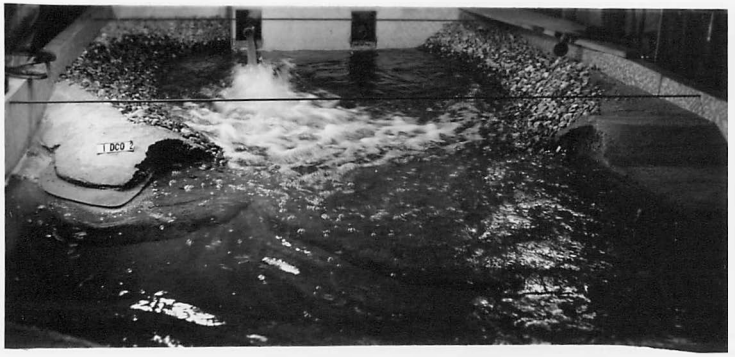


Stilling Pool



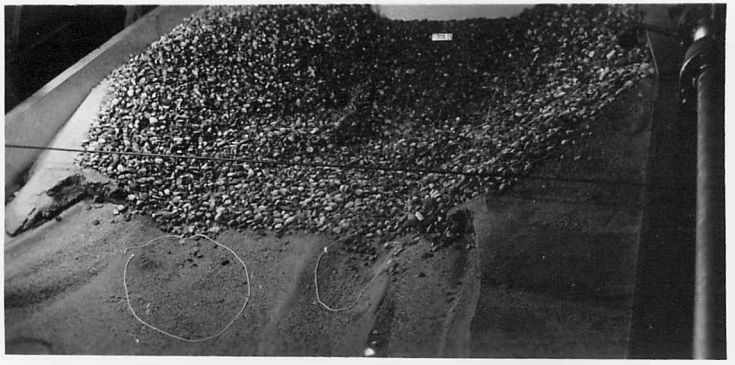
Discharge 1,590 Second-feet--2 Valves Operating

Discharge 1,590 Second-feet--2 Valves Operating



Discharge 796 Second-feet--1 Valve Operating

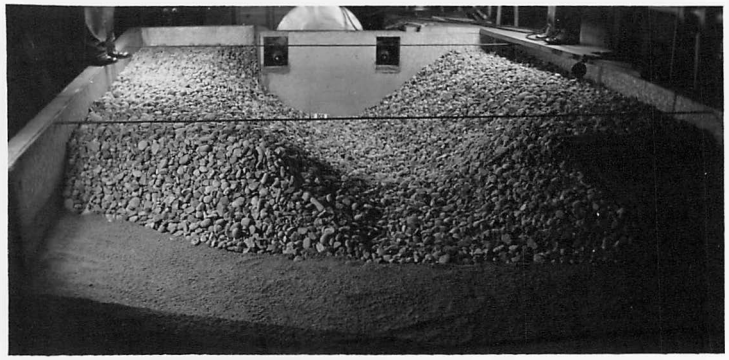
Discharge 796 Second-feet--1 Valve Operating



Scour After 3 Hours Double-valve Operation, 3 Hours Single-valve Operation

DEER CREEK DAM
OUTLET STUDIES--ORIGINAL DESIGN

Figure 17



Stilling Pool

Discharge 1,590 Second-feet--2 Valves Operating

Discharge 1,590 Second-feet--2 Valves Operating

Discharge 796 Second-feet--1 Valve Operating

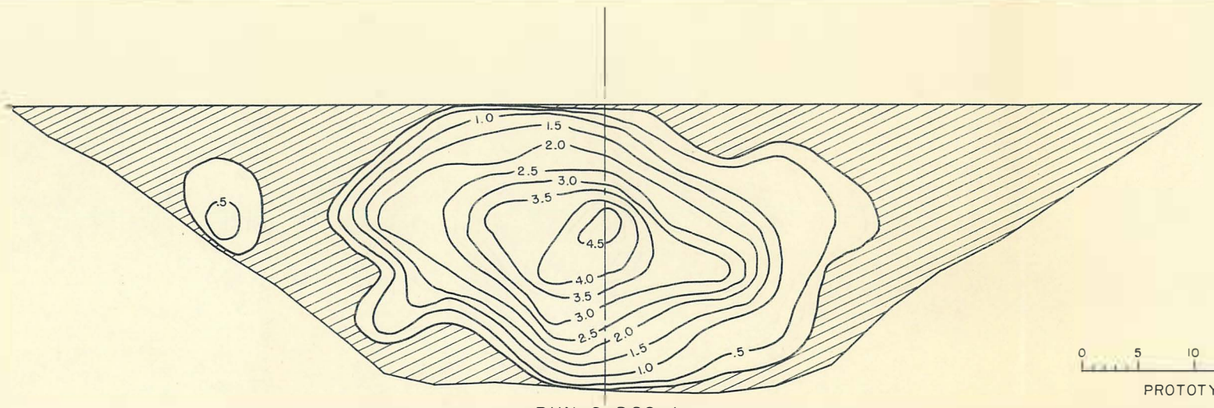
Discharge 796 Second-feet--1 Valve Operating

Scour after 3 Hours Double-valve Operation, 3 Hours Single-valve Operation

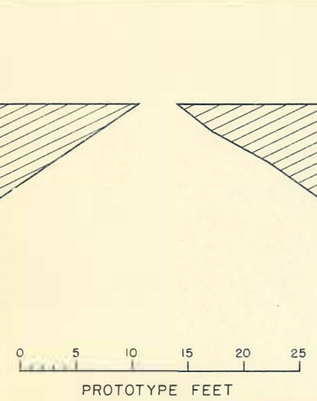
DEER CREEK DAM
OUTLET STUDIES--FINAL RECOMMENDED DESIGN

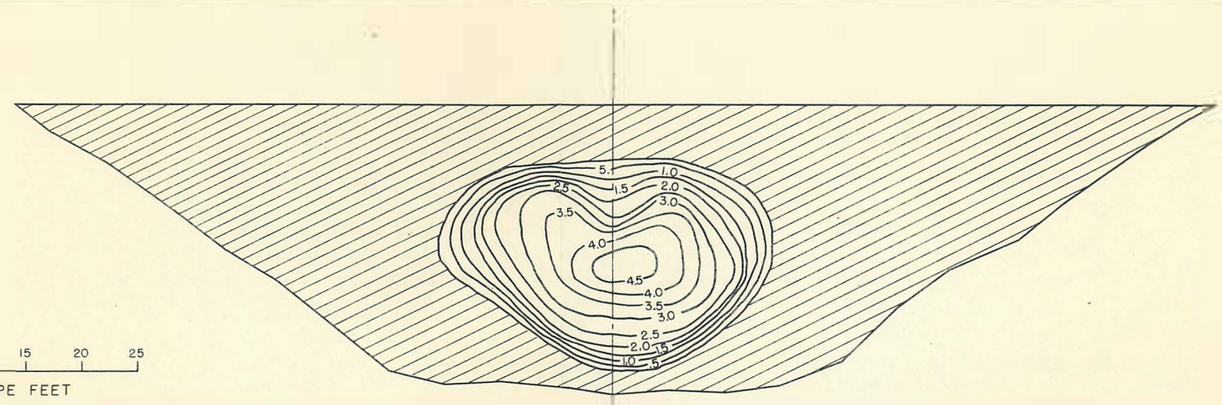
Figure 18

FIGURE 19



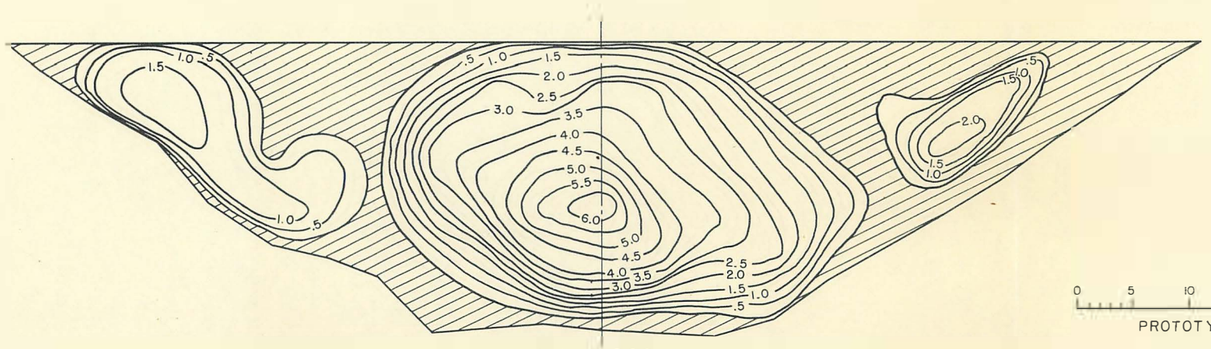
RUN 6-DCO-1
VALVES CONVERGING 20°



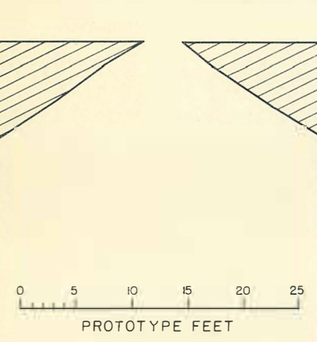


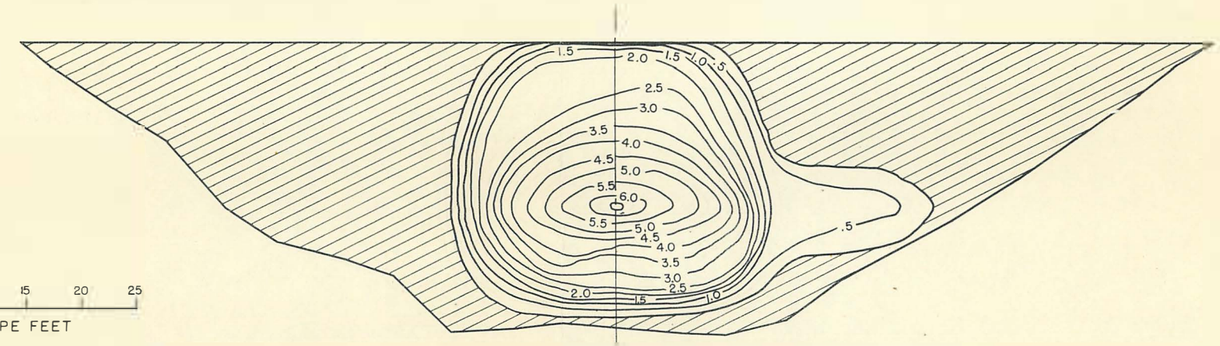
RUN 7-DCO-1
VALVES CONVERGING 25°

VELOCITY DISTRIBUTION 10 FEET FROM POWER HOUSE WALL
DISCHARGE = 1590 SEC. FT. – TAILWATER ELEVATION = 5278.1



RUN 6-DCO-1
VALVES CONVERGING 20°



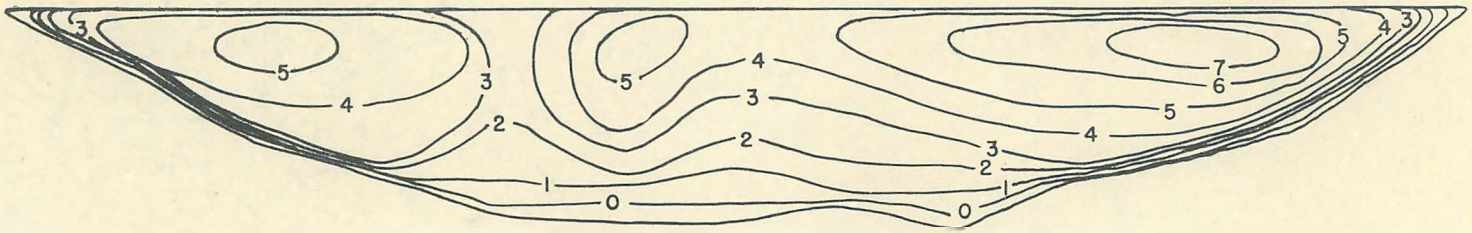


RUN 7-DCO-1
VALVES CONVERGING 25°

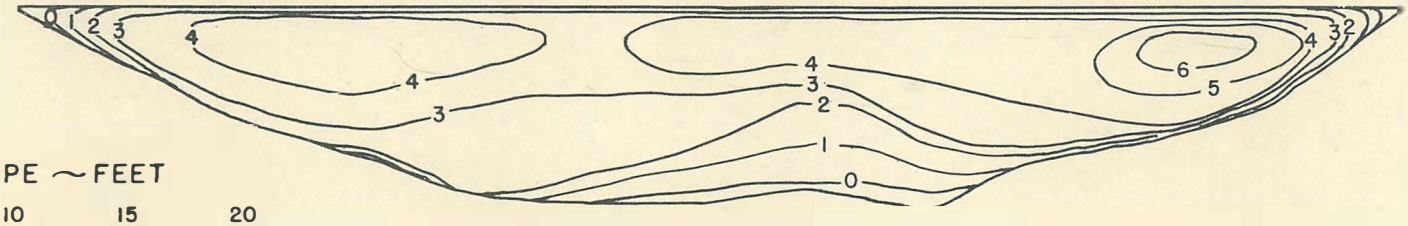
VELOCITY DISTRIBUTION 25 FEET FROM POWER HOUSE WALL
DISCHARGE = 1590 SEC. FT. – TAILWATER ELEVATION = 5278.1

NOTES: – Velocities shown are in feet per second in the prototype.
Cross-hatched area denotes forward current or region of no velocity.
Model scale = 1:20.
Prototype velocity = 4.471 x model velocity.

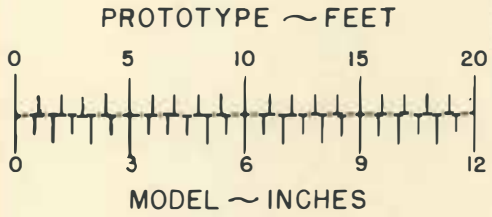
DEER CREEK DAM
1:20 MODEL STUDIES
NEEDLE VALVE OUTLET WORKS
COMPARISON OF VELOCITY DISTRIBUTION
FOR 20° AND 25° VALVE CONVERGENCE



RUN 7-DCO-1
DISCHARGE 1590 SEC. FT.
TAILWATER ELEVATION = 5278.1



RUN 7-DCO-4
DISCHARGE 1200 SEC. FT.
TAILWATER ELEVATION = 5277.3



NOTES:- Velocities shown are in feet per second in the prototype.
Model scale = 1:20.
Prototype velocity = 4.471 x model velocity.
All velocities are forward velocities.

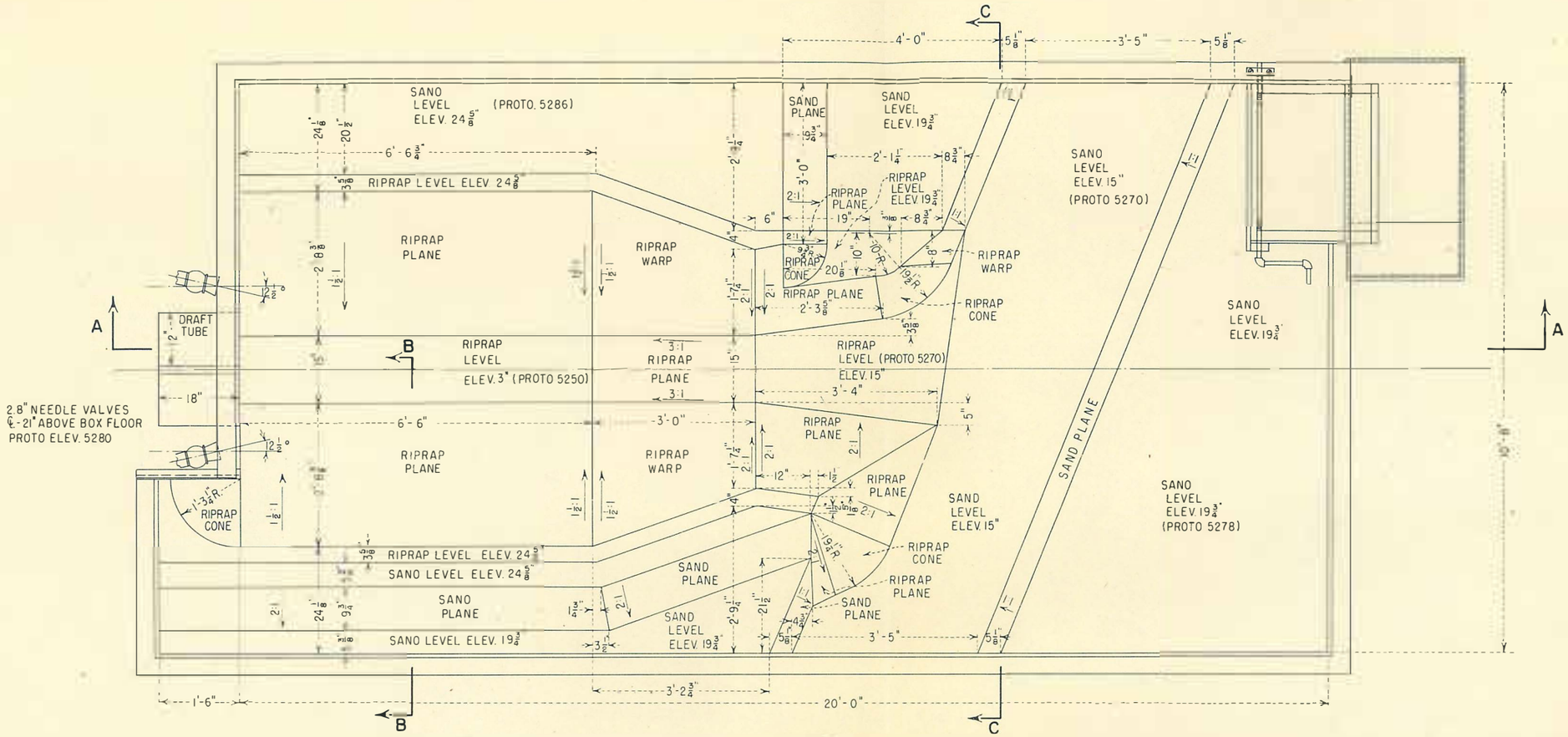
DEER CREEK DAM MODEL STUDIES

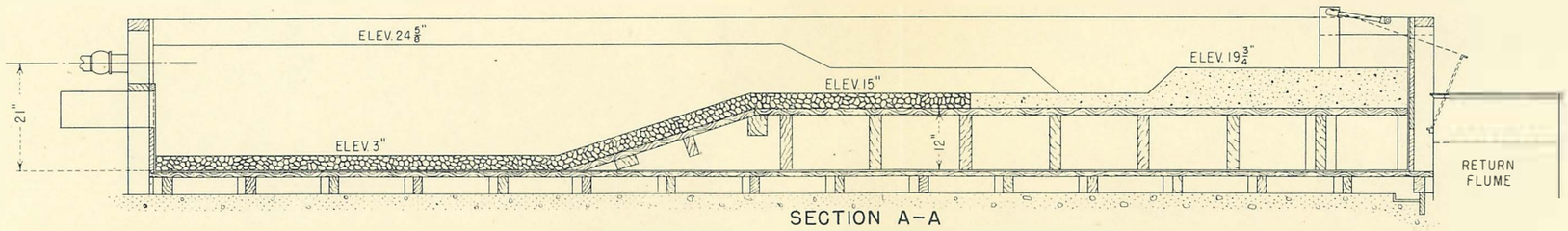
NEEDLE VALVE OUTLET WORKS

COMPARISON OF VELOCITY DISTRIBUTION FOR MAXIMUM AND DESIGNED DISCHARGES, MEASURED AT STA. 18 + 85.0

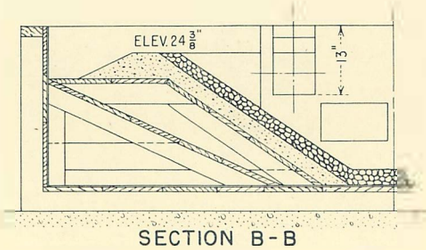
FIGURE 20

FRC 11-18-37

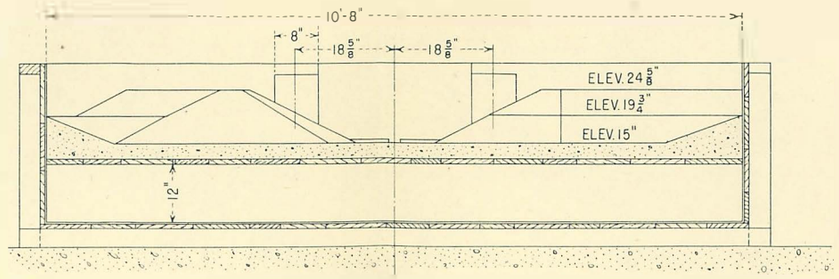




SECTION A-A



SECTION B-B



SECTION C-C

ELEVATIONS SHOWN ARE ABOVE BOX FLOOR (PROTO 5245)
RIPRAP TO BE EVENLY GRADED FROM 1/2" TO 1 1/2" GRAVEL AND TO HAVE A VERTICAL DEPTH OF AT LEAST 2"

12" 9" 6" 3" 0 2' 3'
MODEL SCALE

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PROVO RIVER PROJECT - UTAH

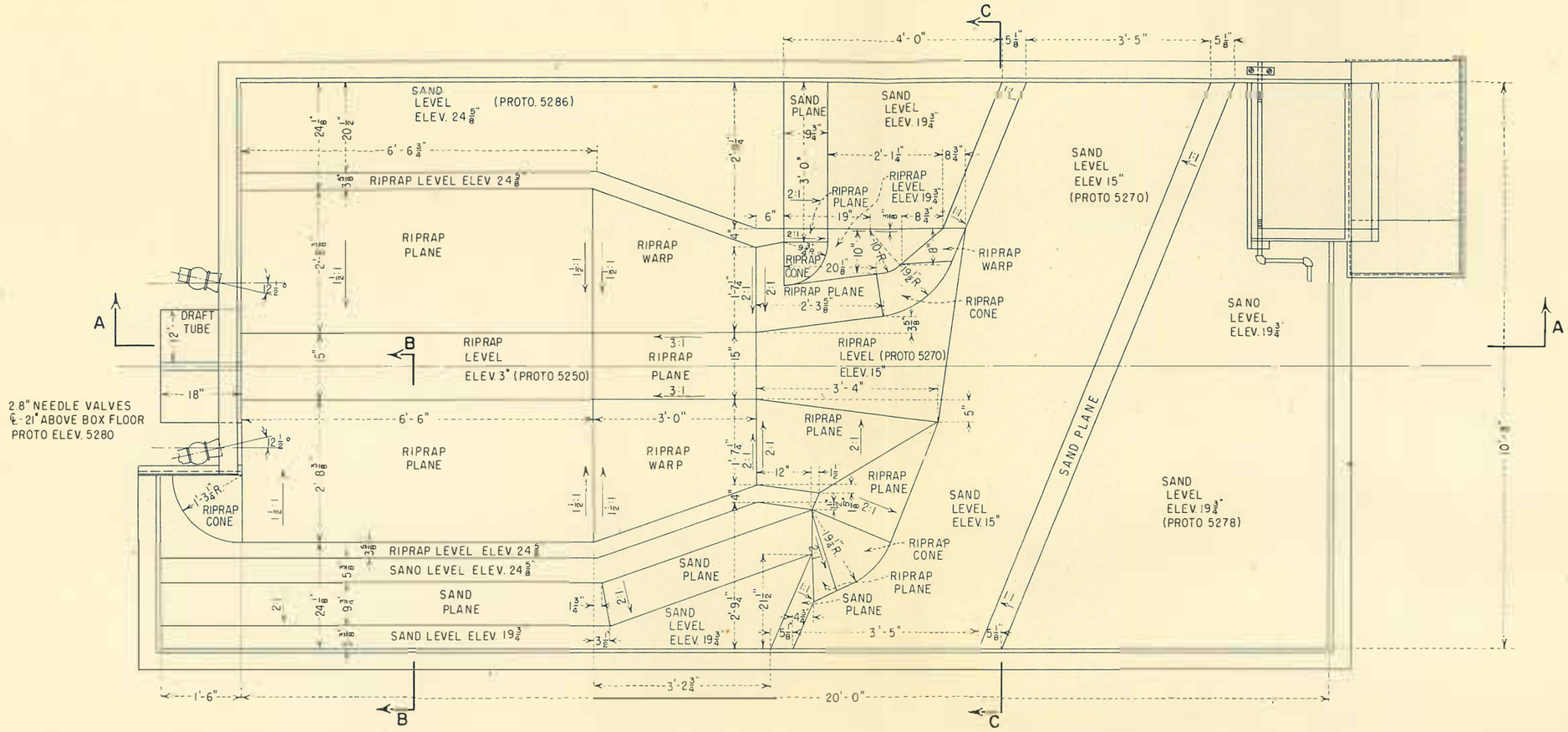
DEER CREEK DAM

HYDRAULIC MODEL STUDIES

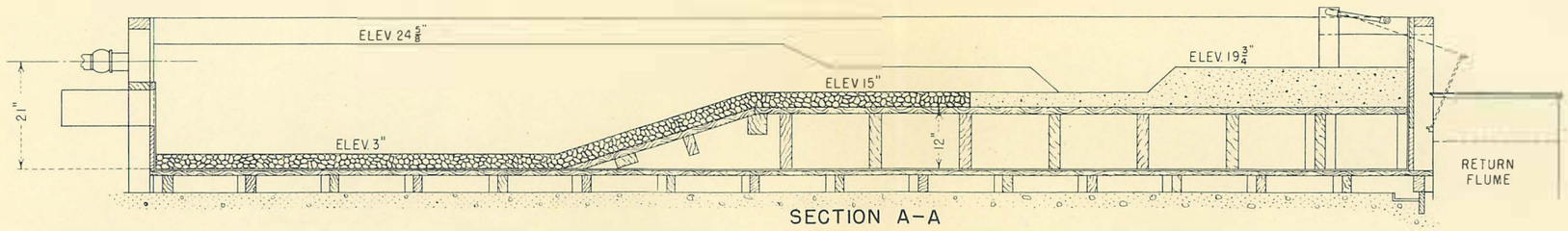
SCALE RATIO 1:20
FINAL DESIGN OUTLET WORKS

DRAWN	R.C.B.	SUBMITTED	
TRACED	J.F.S.	RECOMMENDED	
CHECKED		APPROVED	

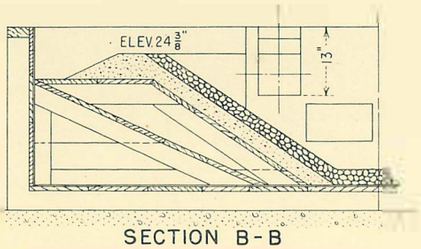
DENVER, COLORADO — JUNE 11, 1946



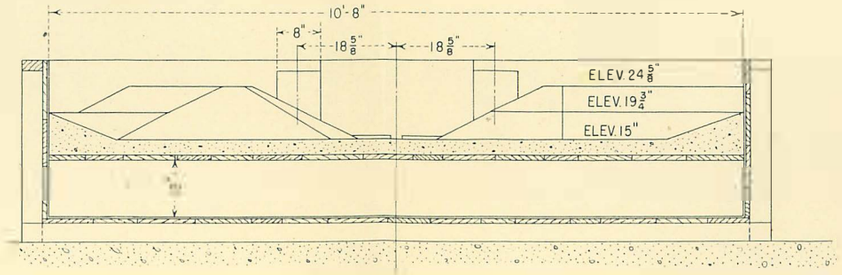
ELEVATIONS SHOWN ARE ABOVE BOX FLOOR (PROTO 5245)
RIPRAP TO BE EVENLY GRADED FROM 1/2" TO 1 1/2" GRAVEL AND TO HAVE A VERTICAL DEPTH OF AT LEAST 2"



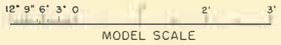
SECTION A-A



SECTION B-B



SECTION C-C



MODEL SCALE

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
PROVO RIVER PROJECT - UTAH

DEER CREEK DAM

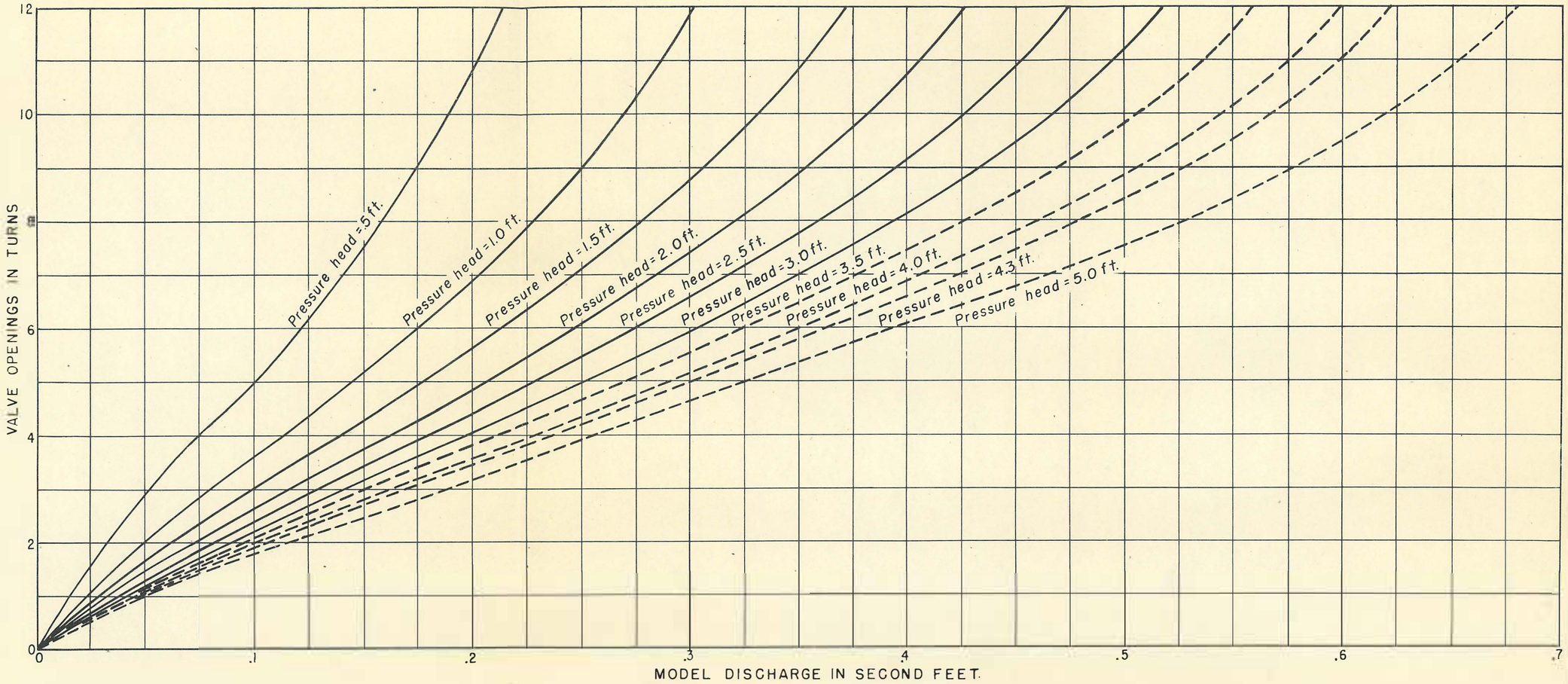
HYDRAULIC MODEL STUDIES

SCALE RATIO 1:20
FINAL DESIGN OUTLET WORKS

DRAWN	R.C.B.	SUBMITTED	
TRACED	J.F.S.	RECOMMENDED	
CHECKED		APPROVED	

DENVER, COLORADO — JUNE 11, 1946

FIGURE 22



TAKEN FROM TESTS FOR KERN COUNTY CANAL OUTLET WORKS – FRIANT DAM. TESTS SERIES 4–FD TO 9–FD INCLUSIVE.

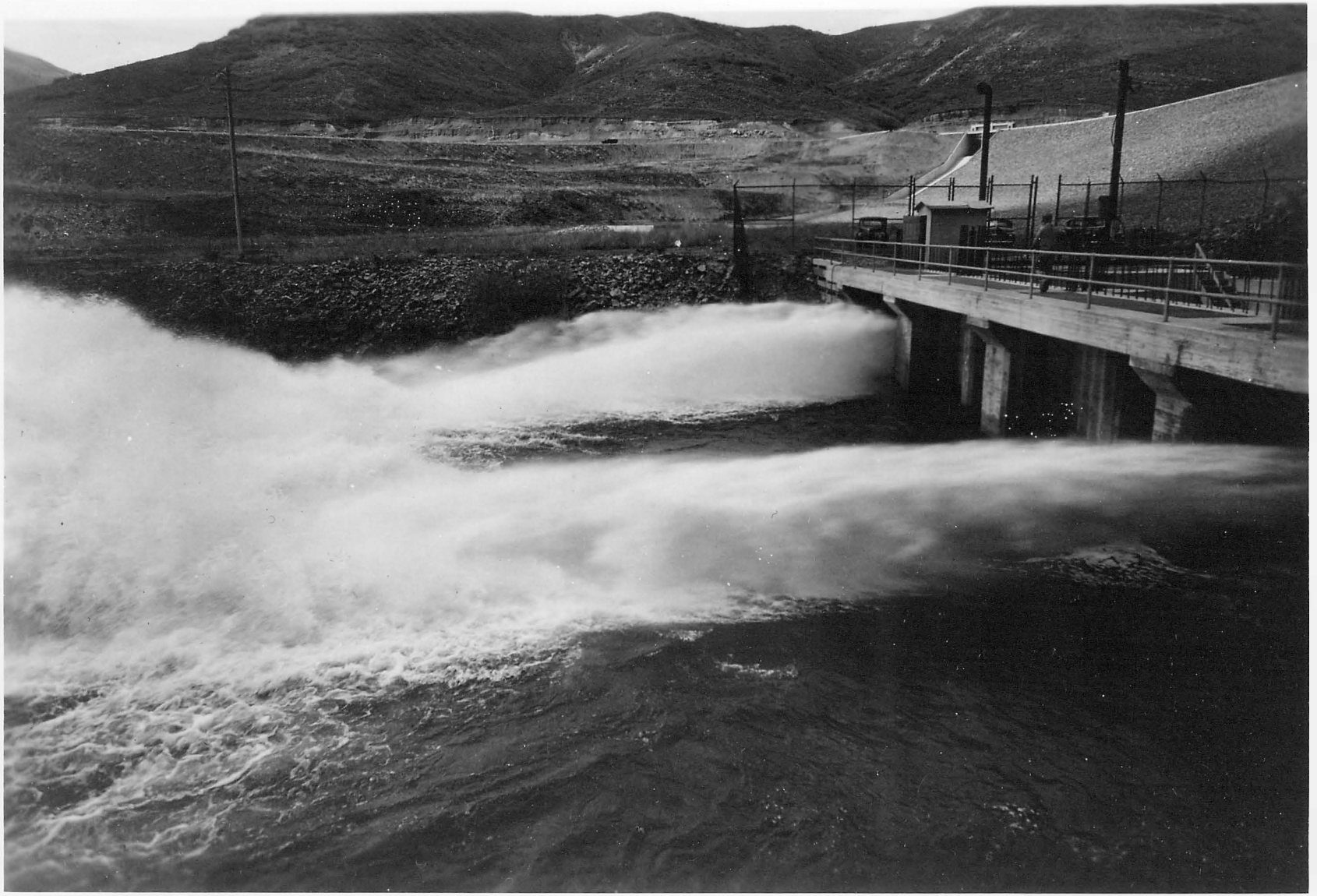
DEER CREEK DAM

DISCHARGE OF 2.8" NEEDLE VALVES WITH VARIOUS OPENINGS AND UNDER VARIOUS HEADS

F.R.C. 9-14-37

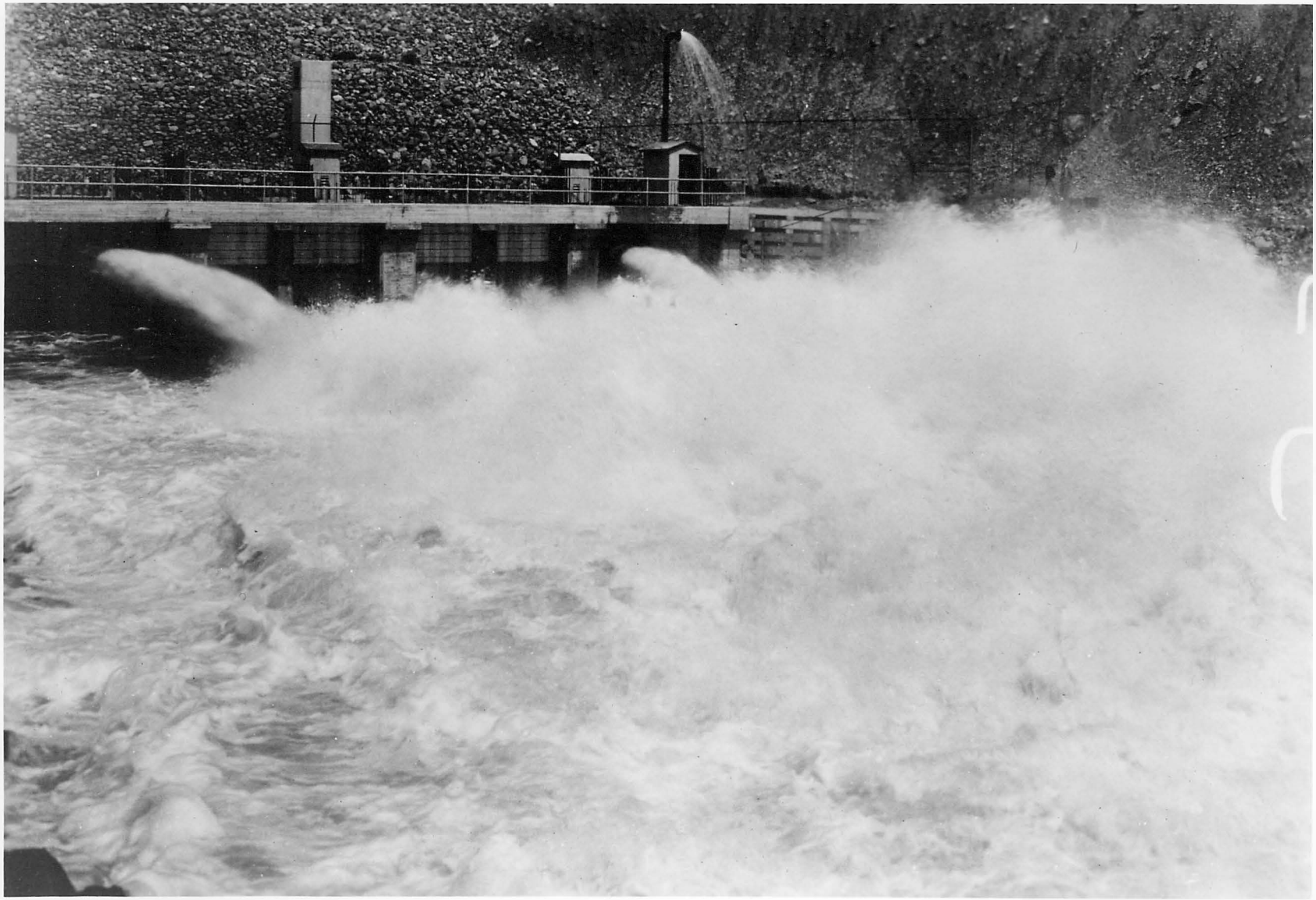
Closeup of No. 1 tube valve discharging approximately 500 second-feet.

Figure 23



Looking north across stilling-basin; tube valve in foreground discharging 700 second-feet; valve in background discharging 50 second-feet.

Figure 24



Performance of stilling-basin. Looking upstream each valve discharging 500 second-feet.

Figure 25

Performance of stilling-basin. Looking downstream from near end of basin.
Each valve discharging 500 second-feet.

Figure 26