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HYD 94

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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MEMORANDUM TO CHIEF DESIGNING ENGINEER

- - -

HYDRAULIC STUDIES OF SPILLWAY FOR BOX BUTTE DAM - MIRAGE FLATS PROJECT

BY

ROBERT R. POMEROY, JUNIOR ENGINEER

- - -

Denver, Colorado
June 24, 1941

Denver, Colorado, June 24, 1941.

MEMORANDUM TO CHIEF DESIGNING ENGINEER
(R. R. Pomeroy Through J. E. Warnock)

Subject: Hydraulic studies of spillway for Box Butte Dam - Mirage Flats project.

1. Introduction. Box Butte Dam is to be located on the Niobrara River approximately 12 miles south of Hay Springs in northwestern Nebraska (figure 1). The dam is to be of the roller earth-fill type with a maximum height of 64 feet above the river bed. The capacity of the reservoir is estimated to be 30,000 acre-feet.

The spillway, located on the left abutment (figure 2), is a modified side-channel design having a crest length of 150 feet. The concrete-lined, rectangular channel connecting the crest and stilling pool is 521 feet long and varies in width from 16 to 40 feet.

An auxiliary spillway, located northeast of the permanent spillway, is designed to handle extremely high floods. Across the upper end of the spillway is an earthen dike built on a permanent foundation. Increase of the water-surface elevation to flood level will cause the dike to be swept out, thus providing another channel for the release of unusually high flows.

2. Problems for model study. Several features are incorporated in the design of the permanent spillway which have not been previously studied, thus it was deemed imperative to make model studies to determine its ability to cope with the conditions under which it might be forced to operate.

3. Construction of model. The model of the Box Butte Dam permanent spillway was constructed to a scale of 1 to 24 (figures 3 and 4). This model consisted of a head box, crest and invert, chute, stilling pool, and sand box. The head box was made of wood with light sheet-metal lining, the intake sections of concrete and tin, and the chute of wood. A pyralin sheet was used as the roof of the covered portion of the channel to facilitate flow observation. The dentates and piers were made of redwood. The sand box was constructed in the same manner as the head box and included a hinged wooden and canvas gate for regulating the tailwater elevation. Water columns attached to piezometer openings in the head box and tail box were utilized to measure the depth of water flowing over the crest and the height of the tailwater.

pier. This difficulty was overcome by changing the upstream face of each pier so that it was no longer parallel to the axis of the pier but inclined toward it. This presented a surface which was not so nearly perpendicular to the direction of flow and therefore less of an obstruction.

The most serious objection to these piers was their appearance. This objection was partly eliminated by cutting down the height and streamlining the shape. It was, however, decided to make an attempt to develop a "step" which would not be so incongruous and might perhaps be an even better solution from the standpoint of performance.

Considerable experimentation was carried out in this connection, but none of the steps developed proved as satisfactory as the piers. Some were fairly successful at lower flows, but soon lost their effectiveness as the flow increased (figure 10). This, together with the complicated nature of the more successful shapes and the shortness of time available for testing, caused the abandonment of this type of solution.

A change in the floor of the invert gave further improvement of the flow conditions. A uniform slope from the upstream end, elevation 3995.00, to a point just below the entrance, elevation 3990.00, was substituted for the original design.

6. Entrance to closed conduit. Two problems became apparent in this portion of the structure when the model was operated for the first time. One of these concerned the presence of two large vortices which formed near the transitions to the conduit entrance at high flows. An attempt was made to eliminate these manifestations by changing the transitions to circular curves, thus making the approach less abrupt. Such a change only served to move the vortices nearer the entrance. There seemed to be no way of eliminating the condition without radically changing the design.

Since any radical changes were not feasible because of the limited time allowed for testing, it was decided to replace the original transitions. It was believed that no damage would result from the formation of the vortices. Moreover, the occasions when the spillway would be forced to operate under the conditions of high flow necessary for their formation would probably be at infrequent intervals and then only for relatively short periods of time.

The second problem concerned the unstable flow through the entrance (figure 12). A large wave, which oscillated from side

to side of the channel, formed downstream from the entrance, parallel to the direction of flow. Part of this effect was removed by utilizing the piers to correct the unstable flow conditions upstream in the invert. Further improvement was achieved by reducing the height of the entrance from 8.25 feet to 7.5 feet and by aerating the entrance through a vent placed in the roof of the conduit immediately downstream from the rounded edge of the entrance (figure 13).

7. Channel and stilling pool. The open section of the channel, as originally designed, proved to be very satisfactory, and no changes were deemed necessary. Profiles and cross sections were taken at stations along the channel and showed satisfactory distribution of the water across and along the channel (figures 14 and 15). The stilling pool could have been used as originally designed, but it was noticed that excessive scouring was taking place in the stream bed near the ends of the training walls. This scour seemed to originate from the circular eddy formed below the wing walls next to the excavated side slopes. The eddy formation was attributed to the excessive velocity of the flow leaving the stilling pool.

The scour was reduced by the insertion of a dentated sill at the end of the stilling pool. This alone, however, did not produce the desired results, and an apron of 8 to 1 slope was installed to give proper relations of water-surface elevations for forming the hydraulic jump at all flows. Marked improvement was noted for the small discharges, but the design proved detrimental for discharges near the maximum discharge and the design was abandoned.

Apron teeth were installed at the upstream end of the stilling pool. Working in conjunction with the dentated sill, these teeth reduced the scour (figure 16), but did not eliminate the eddies. The apron was lengthened 15 feet to destroy this condition, but the results obtained, although constituting an improvement, did not seem to warrant the added cost (figure 17).

The circular motion of the water after leaving the stilling pool could not be completely eliminated, but the condition was considerably reduced by building up to the $1\frac{1}{2}$ to 1 side slopes to a height seven feet above the original elevation. This reduces the available area in which such a motion could take place.

The scouring effects, although not entirely eliminated by the dentated sill and apron teeth, were prevented from doing any damage by riprapping the floor and side slopes of the stream bed

(figures 18, 19, 20, and 21). This riprap consisted of one- and two-foot rocks. Sweep-out tests were conducted and it was found that the hydraulic jump swept off the apron at elevations $4\frac{1}{4}$ and 4 feet below the normal tailwater elevations for 2,000 cubic feet per second and 3,000 cubic feet per second, respectively (figure 22).

8. Conclusions and recommendations. In view of the model tests the following suggestions are made (figure 6):

(a) Piers, of the shape shown on the figure should be placed at angles of 60 degrees with the invert center line.

(b) The floor of the invert should have a uniform slope from elevation 3995.00 at the upstream end to elevation 3990.00 at station 1+00.

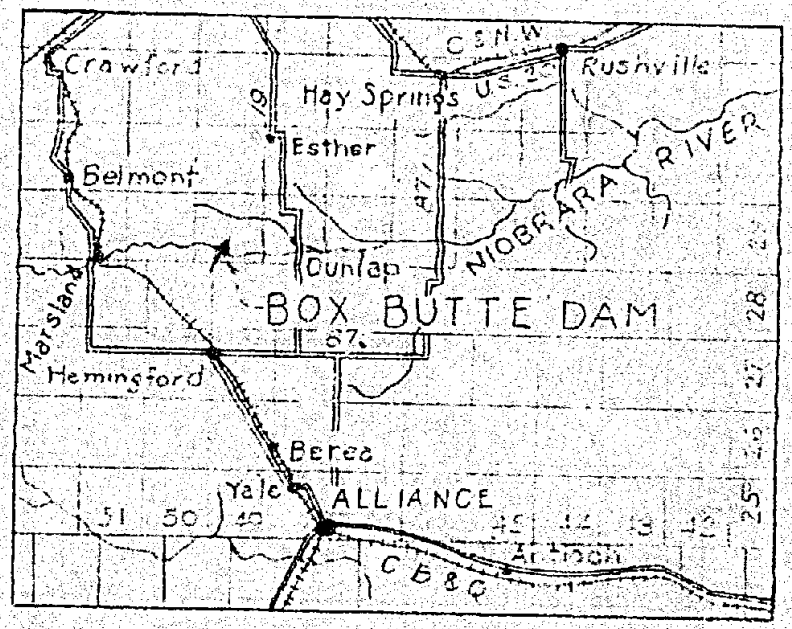
(c) The height of the entrance should be made 7.5 feet, the curve of one-foot radius shown in the original design being retained.

(d) The closed conduit should be aerated, an air vent one foot behind the upstream face of the entrance being utilized for this purpose.

(e) A dentated sill and toothed apron should be installed in the stilling pool.

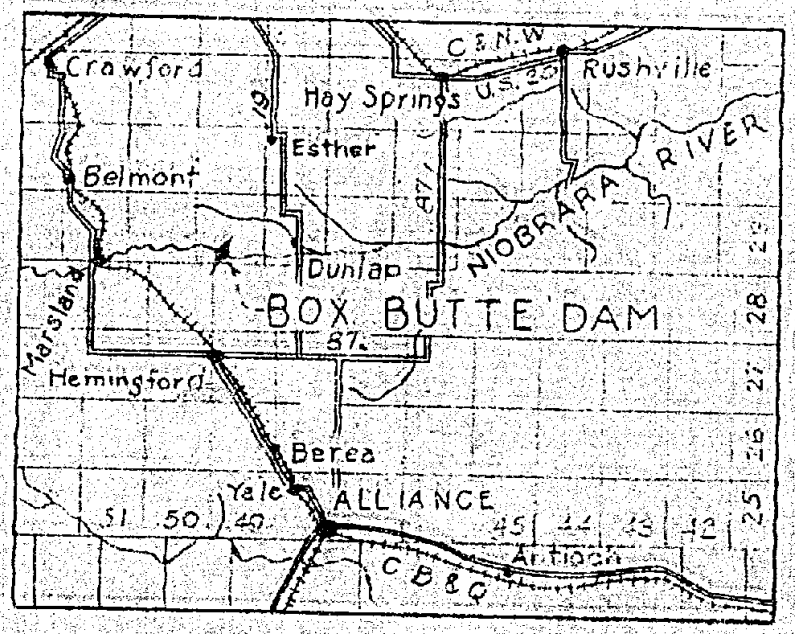
(f) The $1\frac{1}{2}$ to 1 side slopes in the stream bed should be built up to an elevation of 3967.00 for a distance of 70 feet downstream from the end of the stilling pool.

(g) Riprap, the majority of which should be one- and two-foot rocks, should be placed on the side slopes and bottom of the stream bed as shown on the figure.



LOCATION MAP

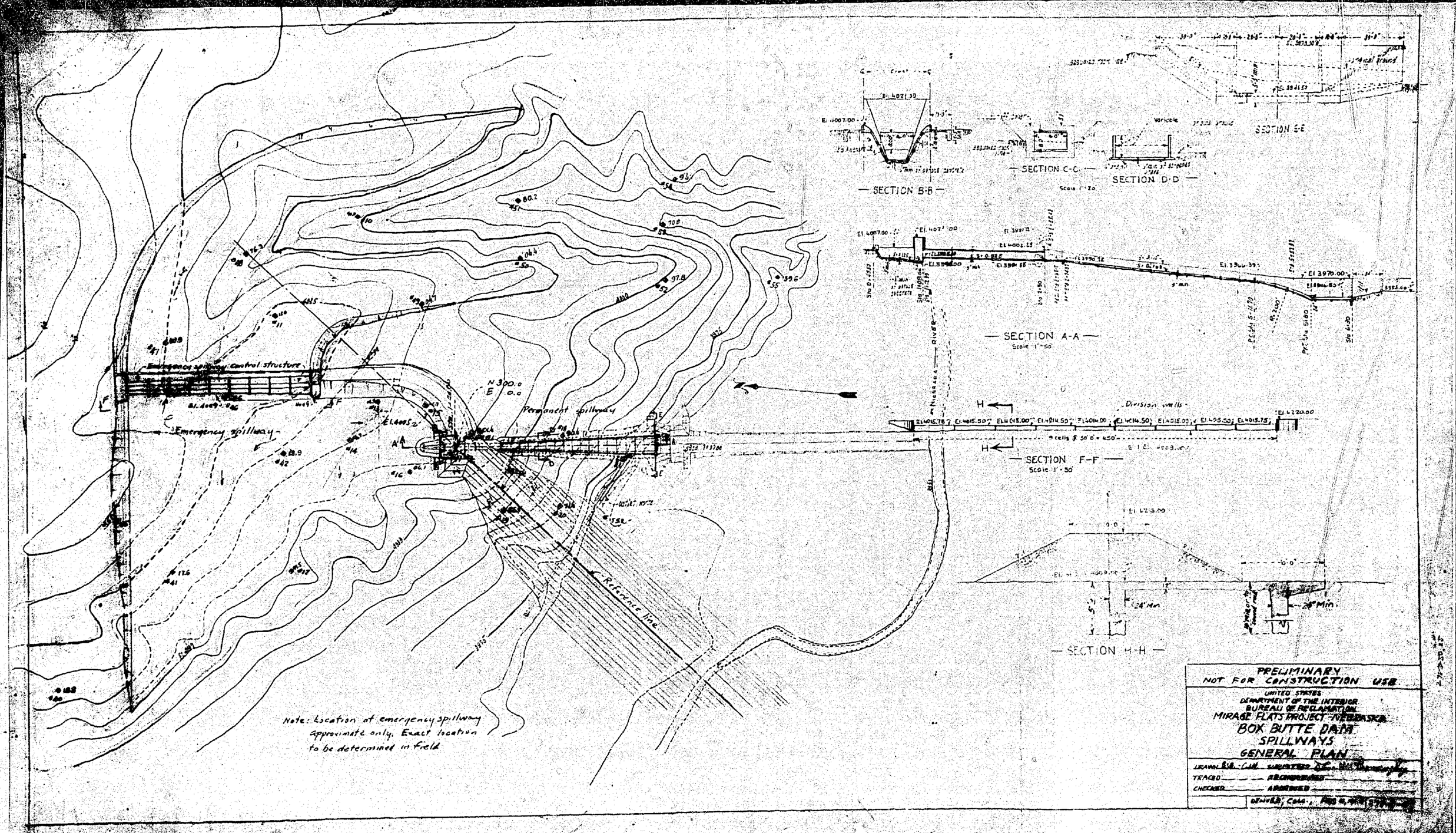
13

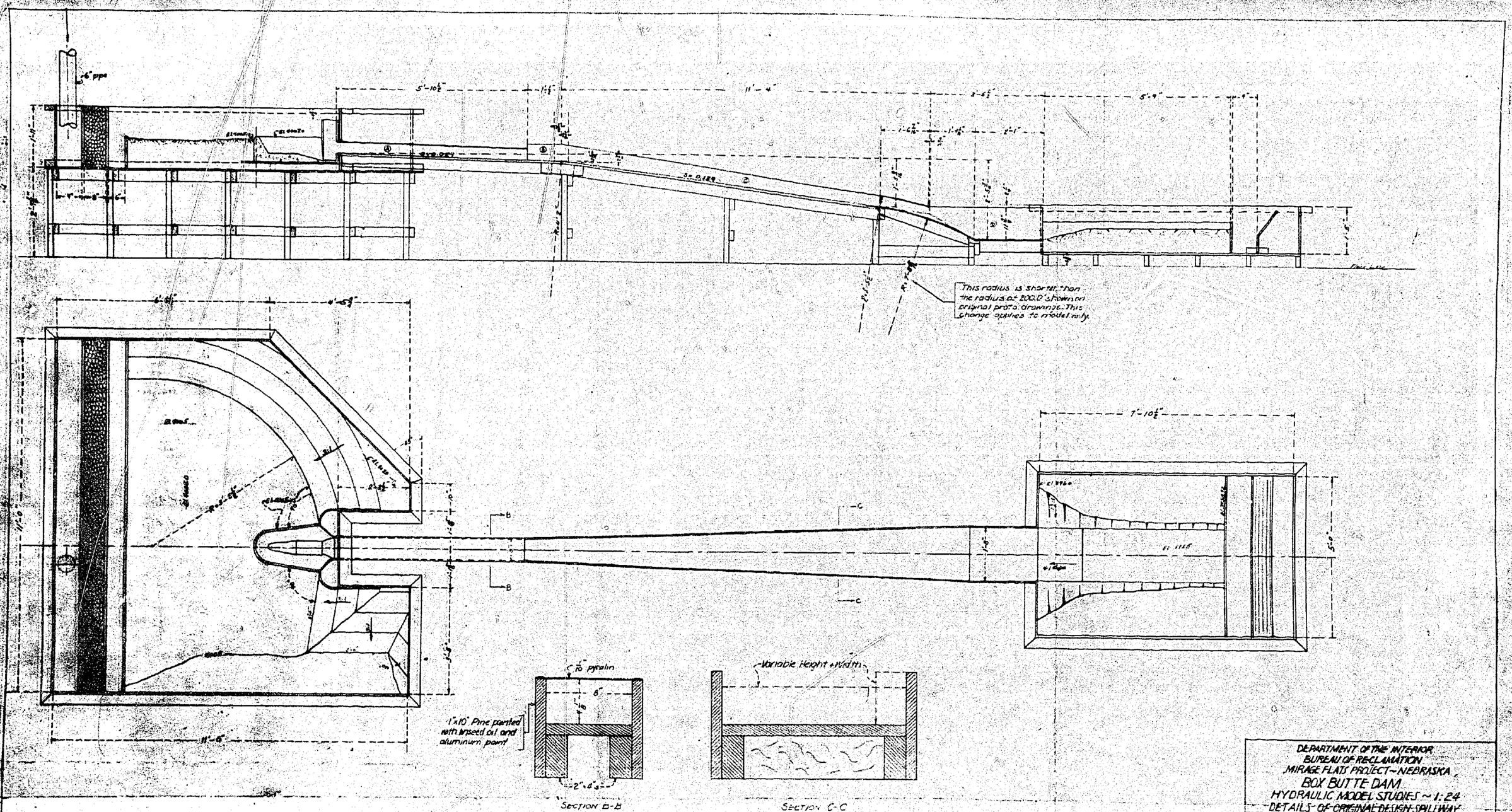


LOCATION MAP

13

FIGURE 1


Emergency spillway control structure
Emergency spillway
Permanent spillway
Reference line
N 300.0
E 0.0
Note: Location of emergency spillway approximate only. Exact location to be determined in field
SECTION B-B
SECTION C-C
SECTION D-D
SECTION E-E
SECTION A-A
SECTION F-F
SECTION H-H
Division walls
PRELIMINARY
NOT FOR CONSTRUCTION USE
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MIRAGE FLATS PROJECT - NEBRASKA
BOX BUTTE DAM
SPILLWAYS
GENERAL PLAN
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLO.



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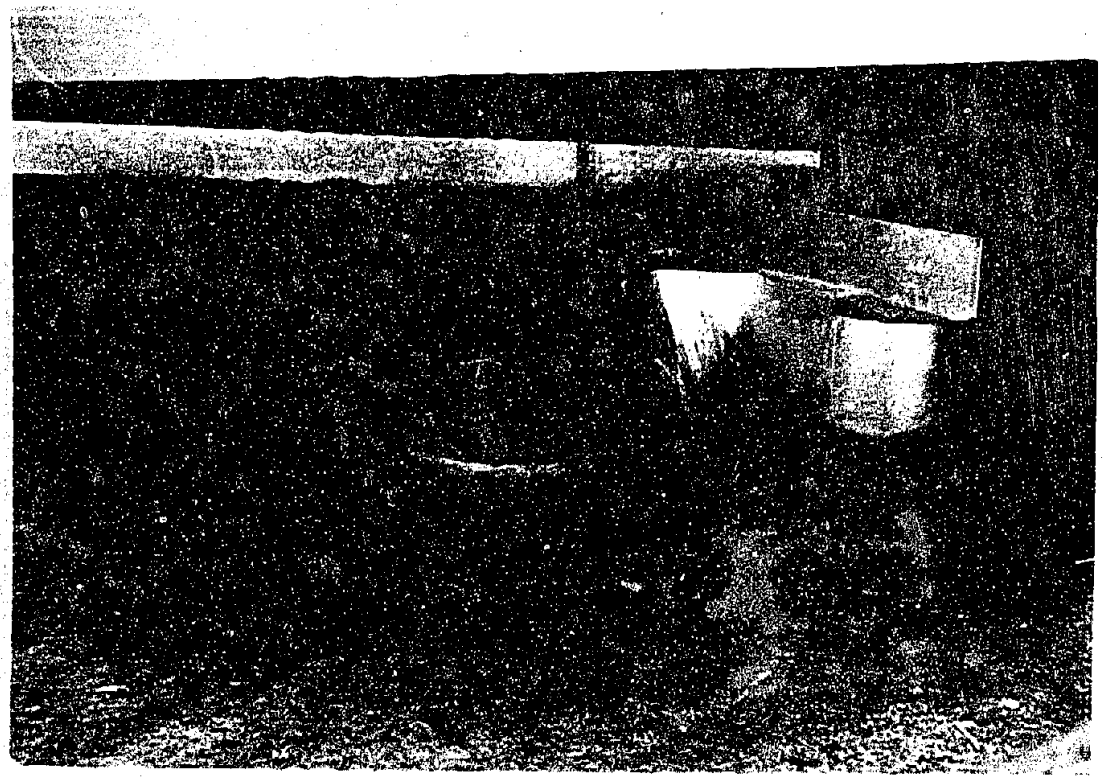
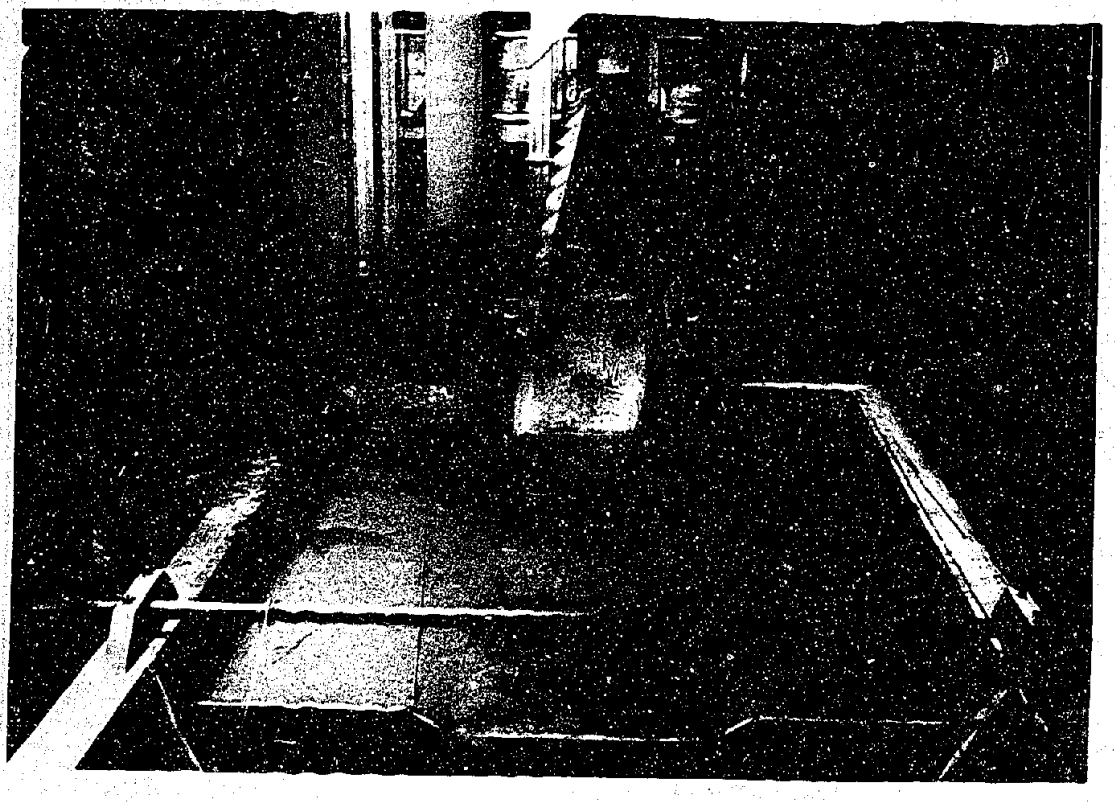
BUREAU OF RECLAMATION
MIRAGE FLATS PROJECT ~ NEBRASKA
BOX BUTTE DAM
HYDRAULIC MODEL STUDIES ~ 1:24
DETAILS OF ORIGINAL DESIGN SPILLWAY
DRAWN: R.R.P.

13



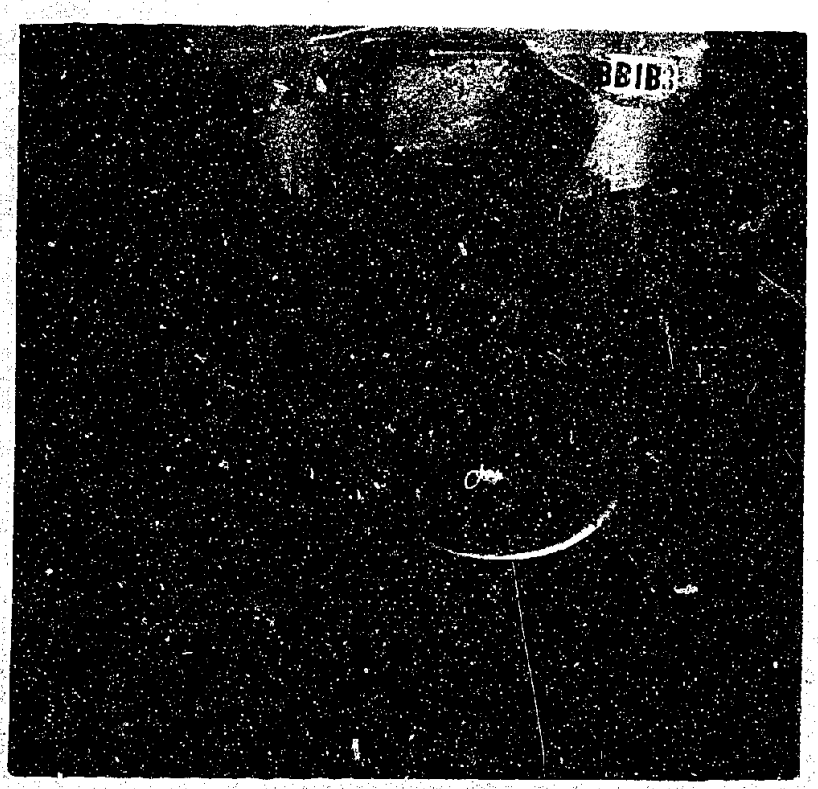
Spillway Crest



Tail Box and Channel

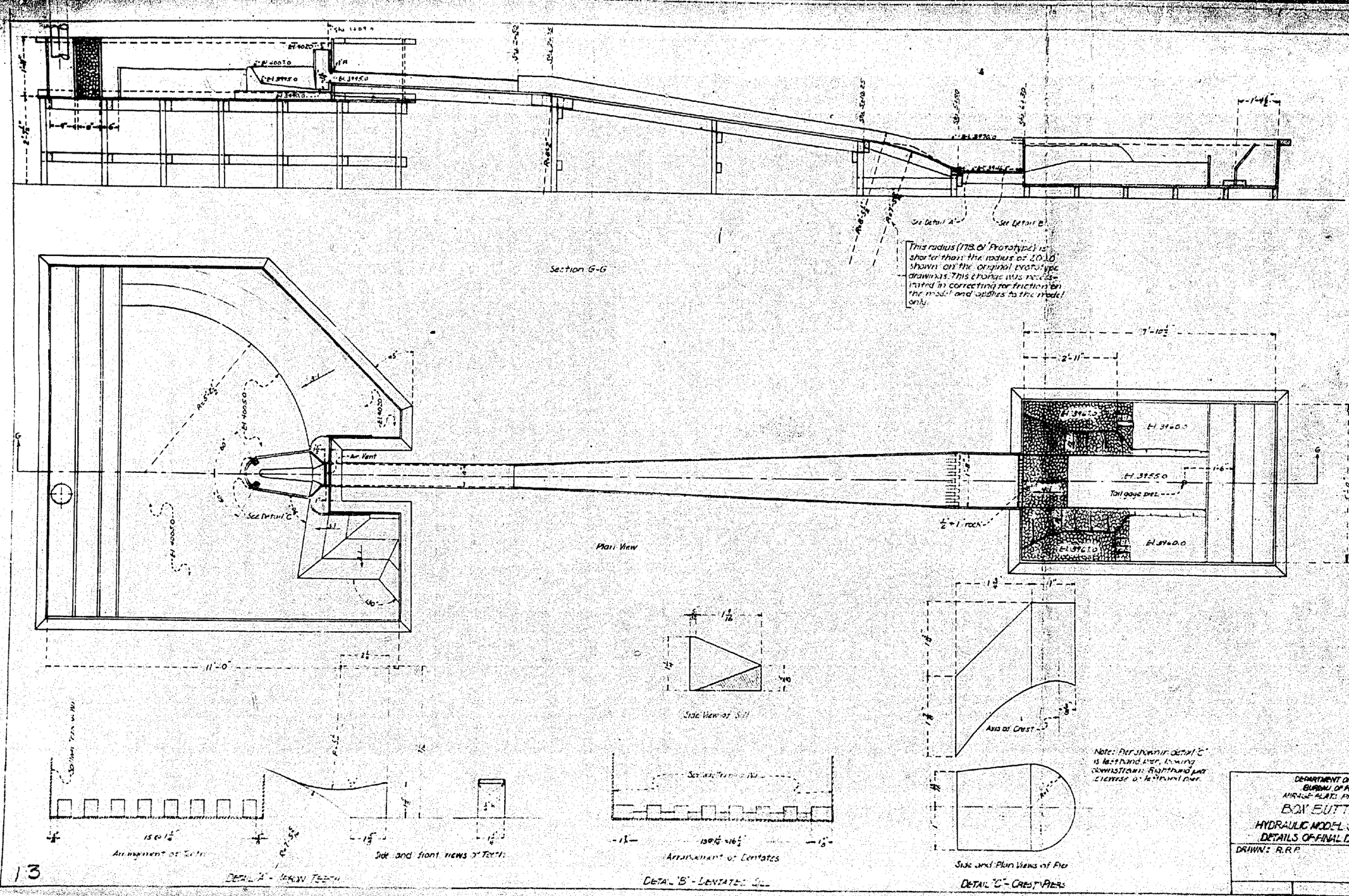
DETAILS OF MODEL

Discharge 1000 Second-feet



Discharge 2000 Second-feet

ACTION OF WATER IN INVERT - ORIGINAL DESIGN



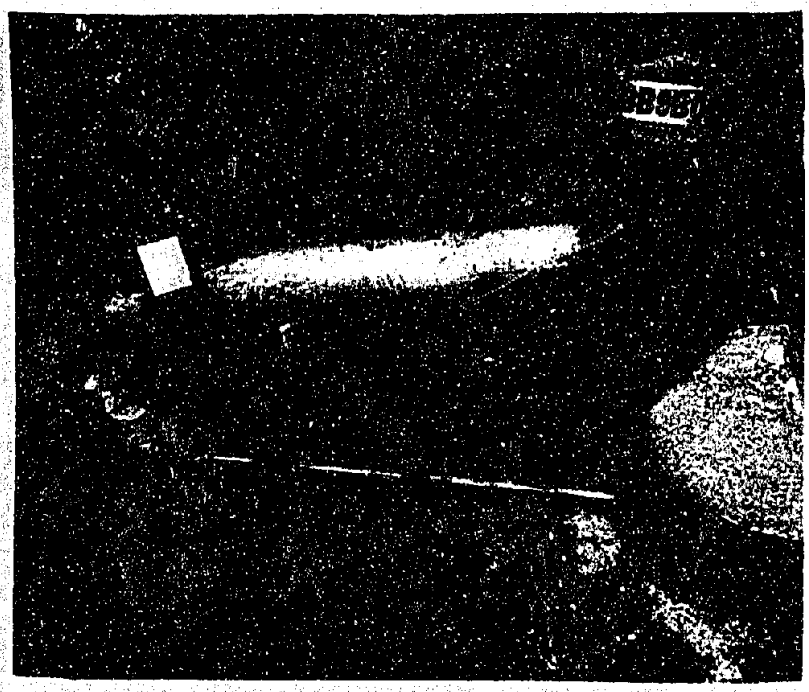
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MIRAGE FLATS PROJECT - NEBR.

BOX BUTTE DAM

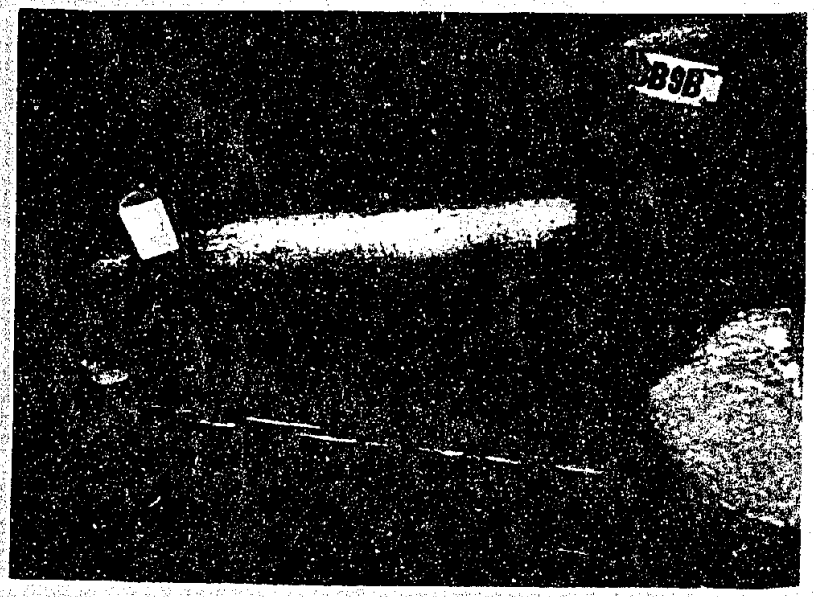
HYDRAULIC MODEL STUDIES ~ 1:24

DETAILS OF FINAL DESIGN SPILLWAY

DRAWN: R.R.P.

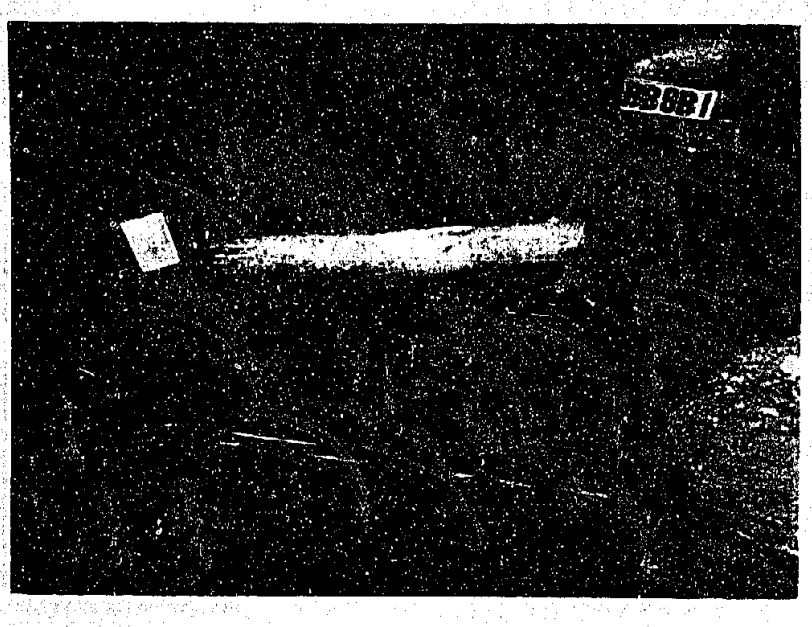


Piers and Uniformly Sloping Bottom Added

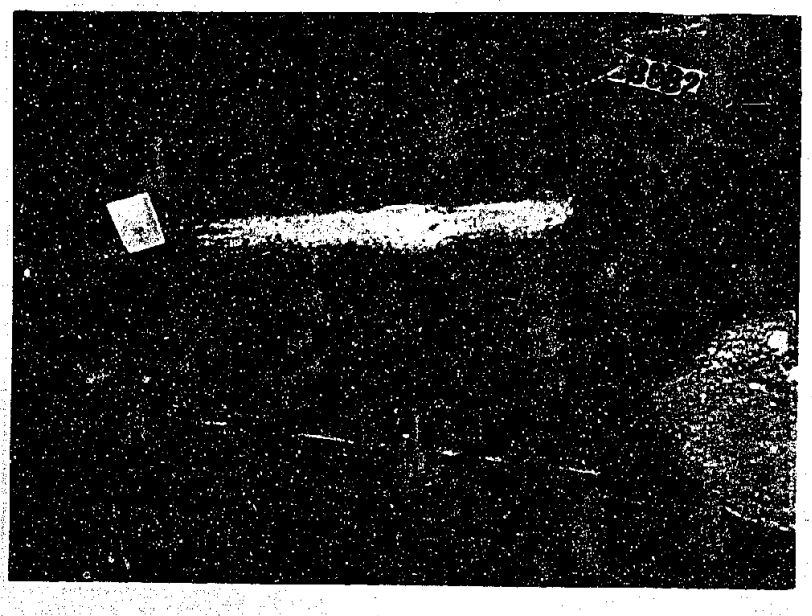


Discharge 500 Second-feet

ACTION OF WATER IN INVERT - RECOMMENDED DESIGN

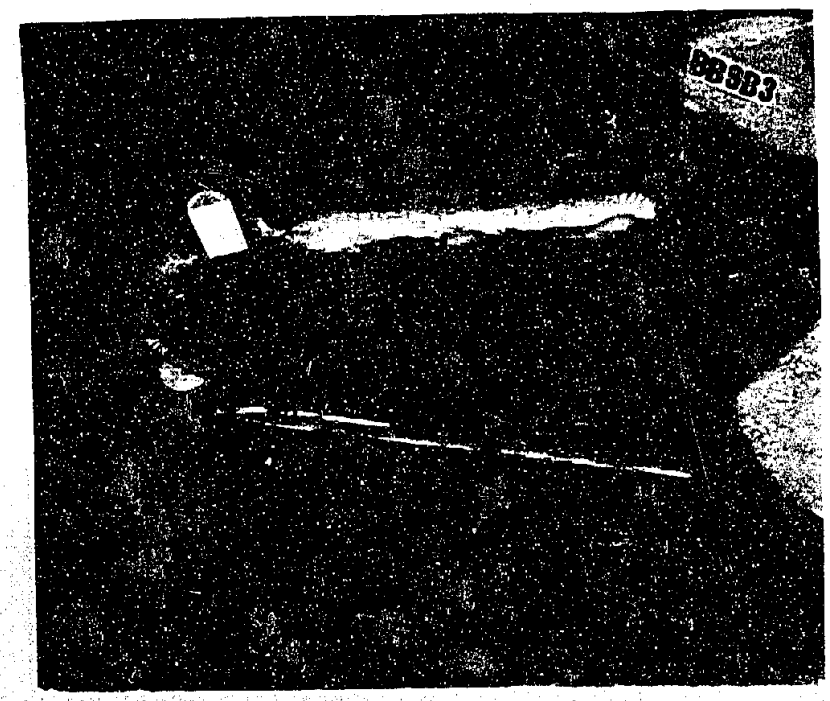


Discharge 1000 Second-feet

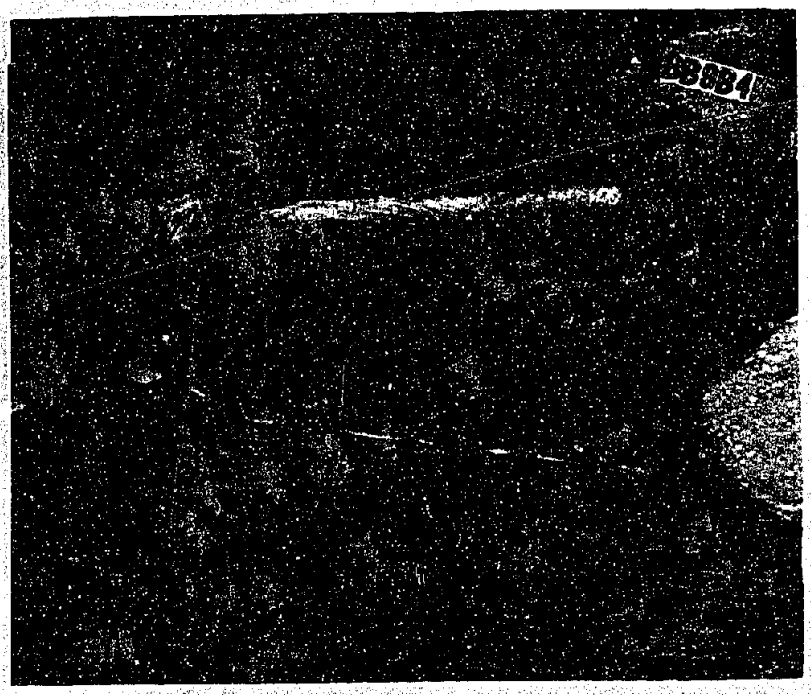


Discharge 1500 Second-feet

ACTION OF WATER IN INVERT - RECOMMENDED DESIGN



Discharge 2000 Second-feet



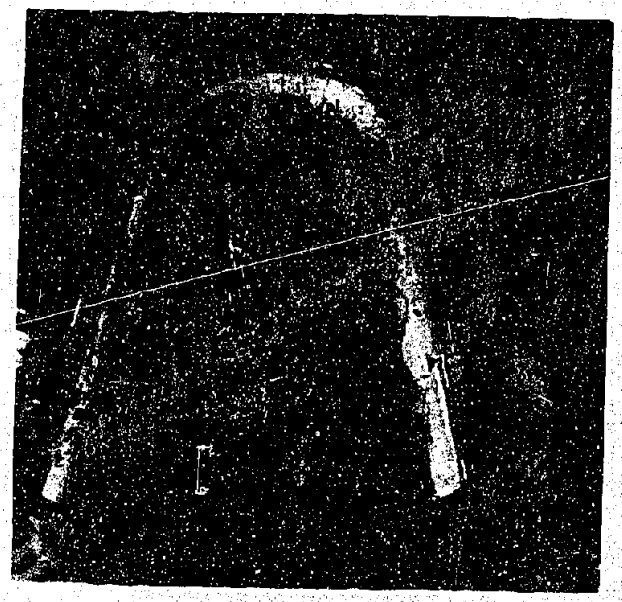
Discharge 2500 Second-feet

ACTION OF WATER IN INVERT - RECOMMENDED DESIGN

Step Installed in Invert

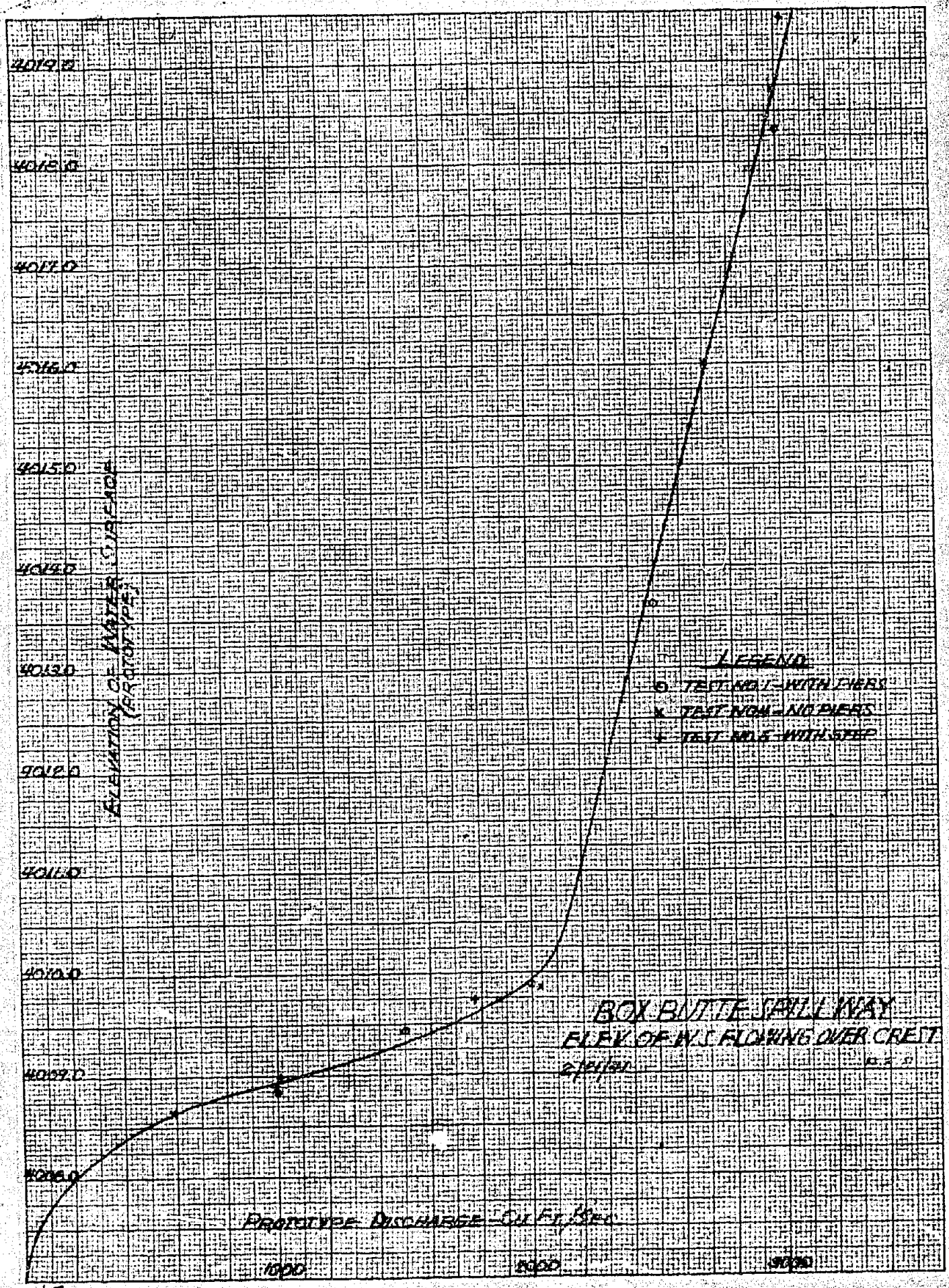
Discharge 500 Second-feet

Discharge 1000 Second-feet



Discharge 2000 Second-feet

ACTION OF WATER IN INVERT WITH "STEP" INSTALLED


4019.0
4018.0
4017.0
4016.0
4015.0
4014.0
4013.0
4012.0
4011.0
4010.0
4009.0
4008.0
ELEVATION OF WATER SURFACE
(PROTOTYPE)
LEGEND
TEST NO. 1 - WITH PIERS
TEST NO. 4 - NO PIERS
TEST NO. 5 - WITH SPEP
BOX BUTTE SPILLWAY
ELEV. OF W.S. FLOWING OVER CREST
PROTOTYPE DISCHARGE - CU. FT. PER SEC.
1000
2000
3000

Discharge 1000 Second-feet

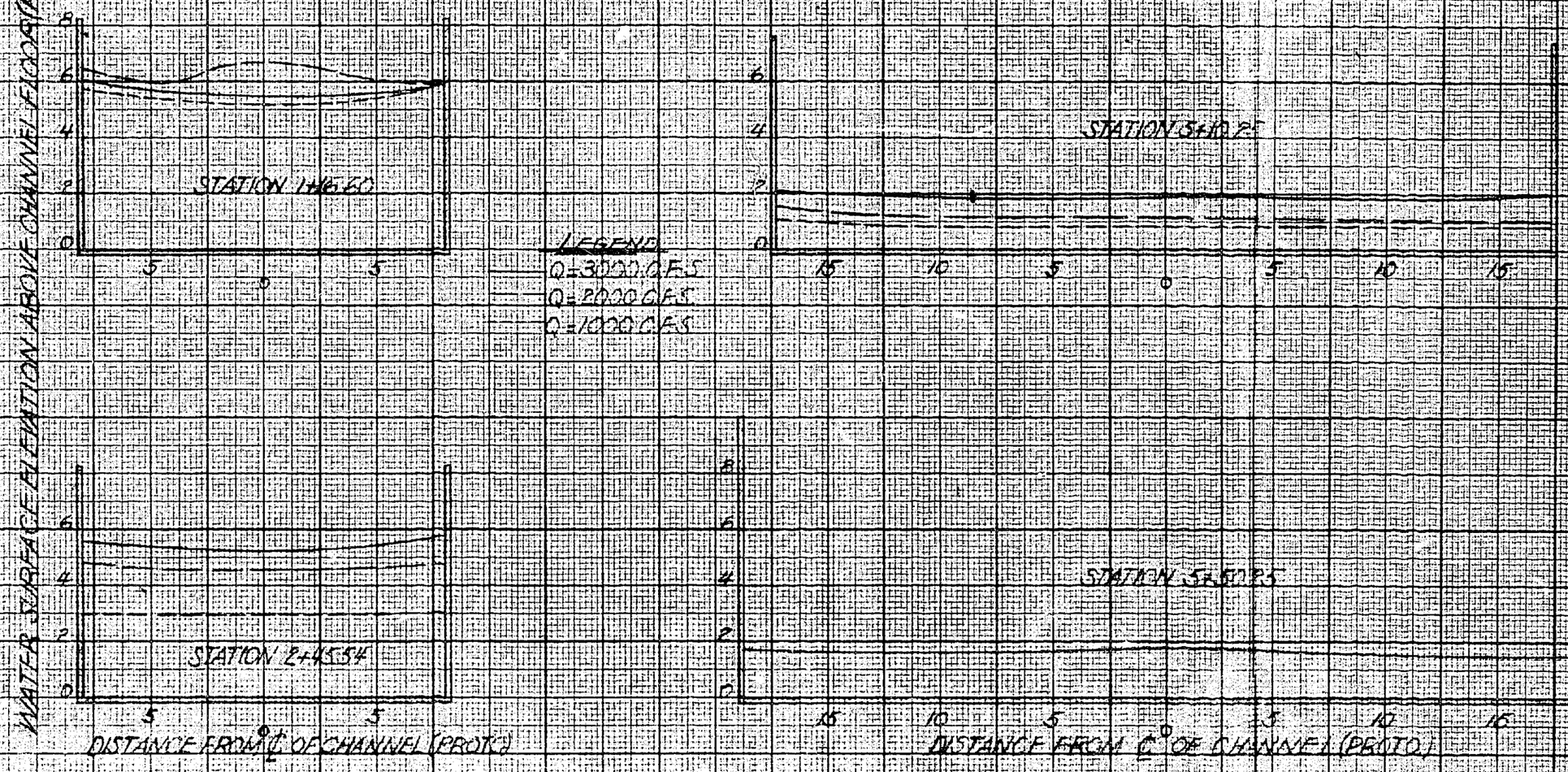
Discharge 2000 Second-feet

FLOW DOWNSTREAM FROM ENTRANCE TO CLOSED CONDUIT - ORIGINAL DESIGN

Discharge 1000 Second-feet

Discharge 2000 Second-feet

FLOW DOWNSTREAM FROM ENTRANCE TO CLOSED CONDUIT - RECOMMENDED DESIGN

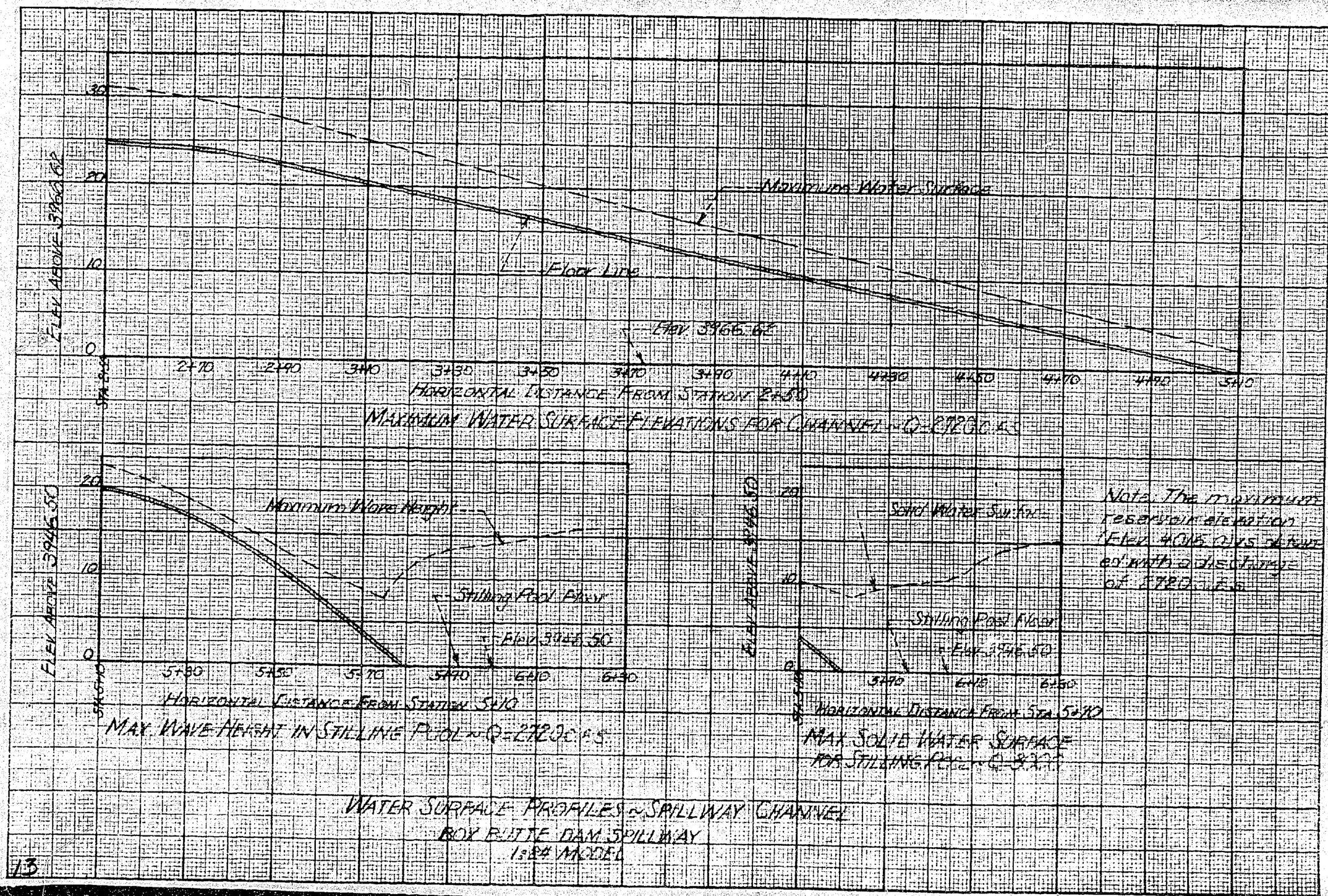


WATER SURFACE CROSS SECTIONS ~ SPILLWAY CHANNEL

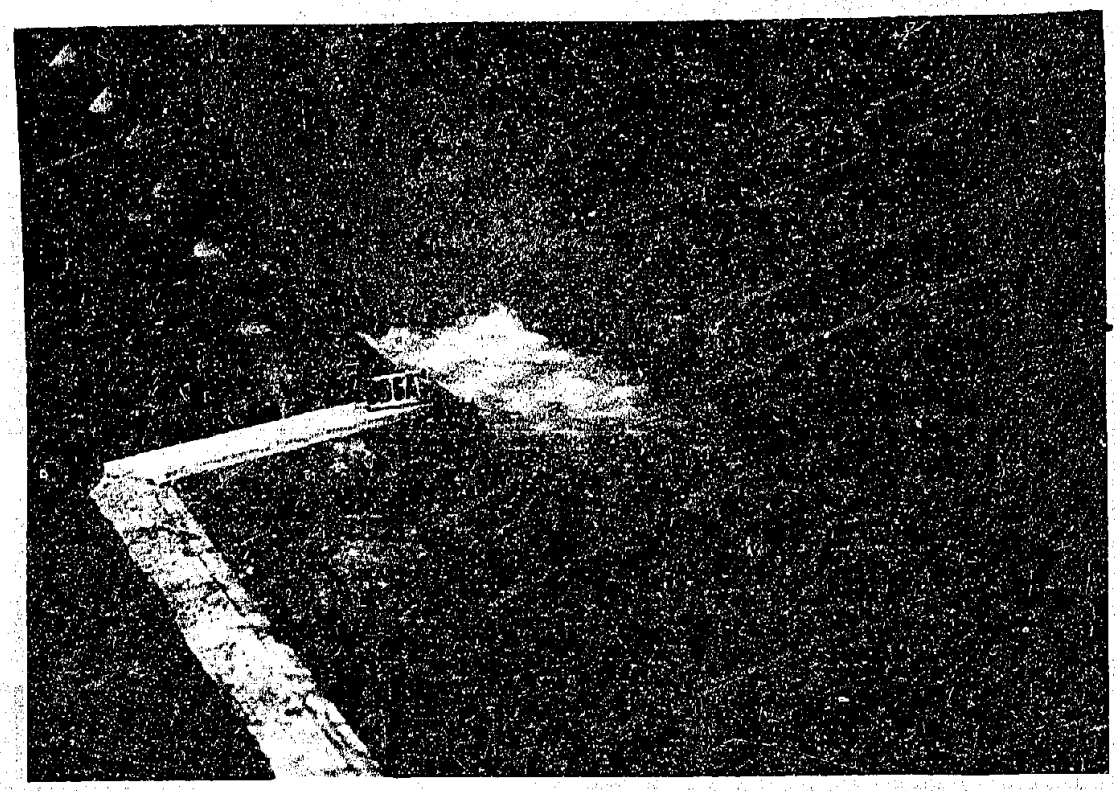
BOX BUTTE DAM SPILLWAY

1:24 MODEL

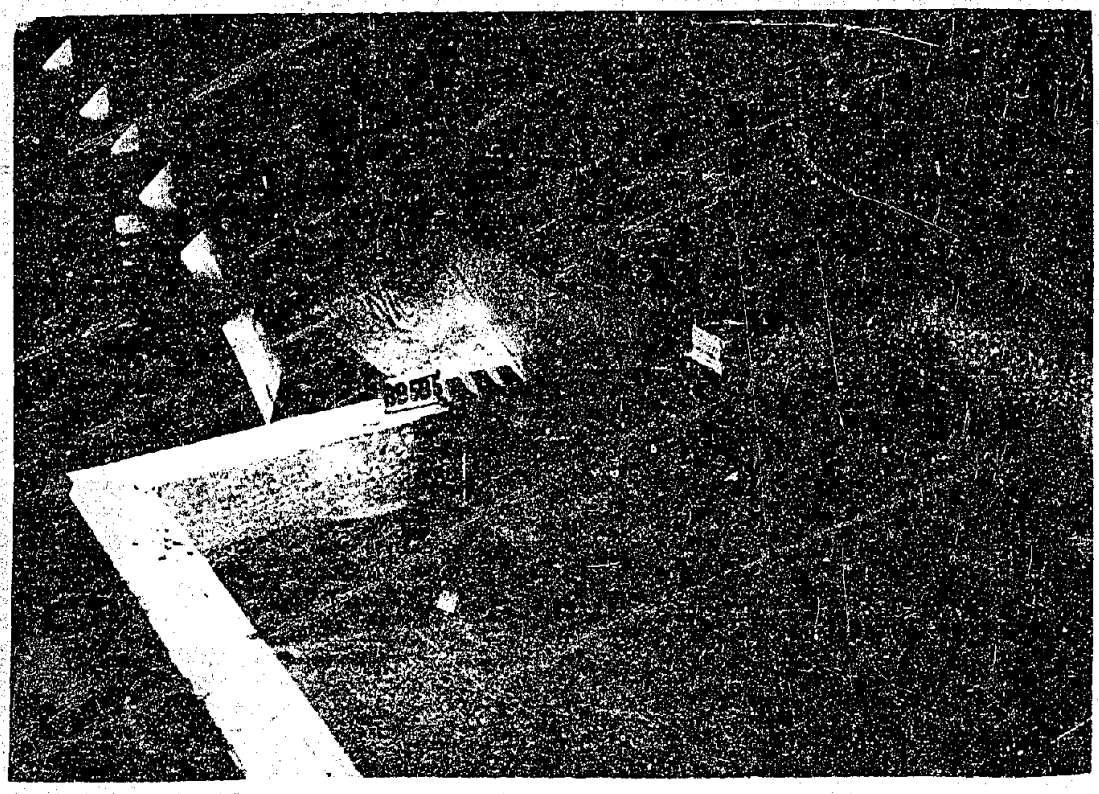
4/23/74 RRP



Water Surface Profiles - Spillway Channel
Roy Butte Dam Spillway
1:24 Model

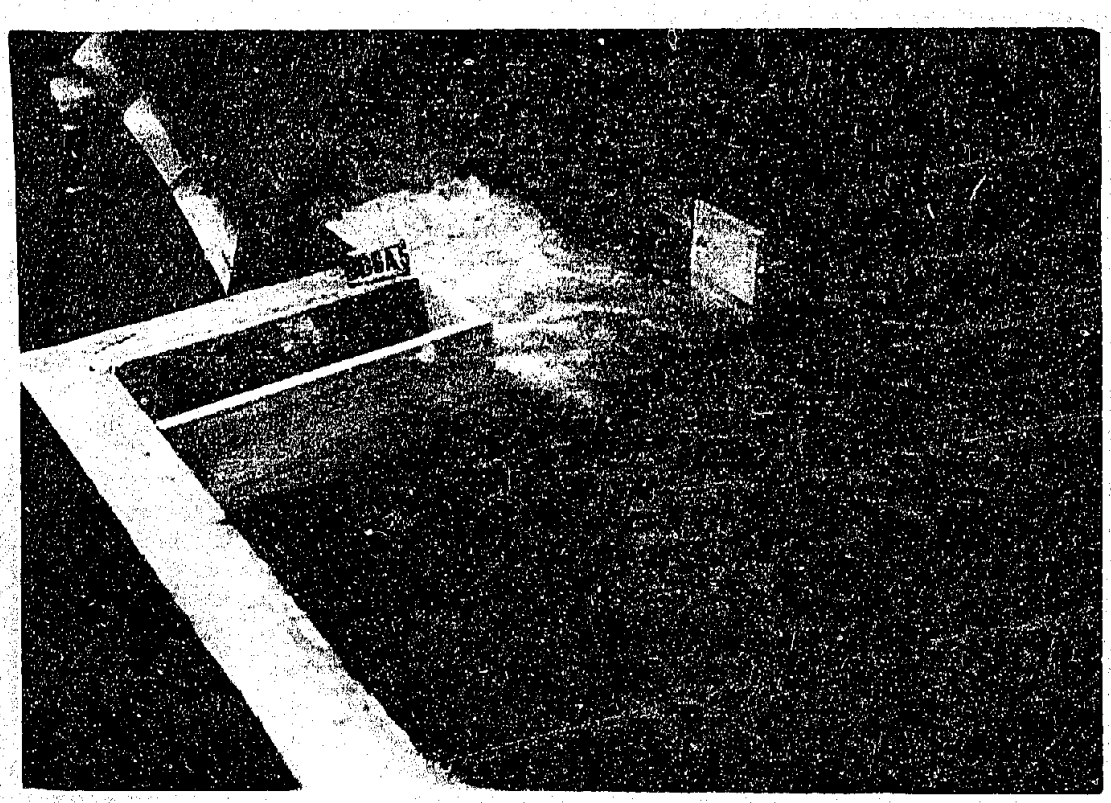


Discharge 3000 Second-feet

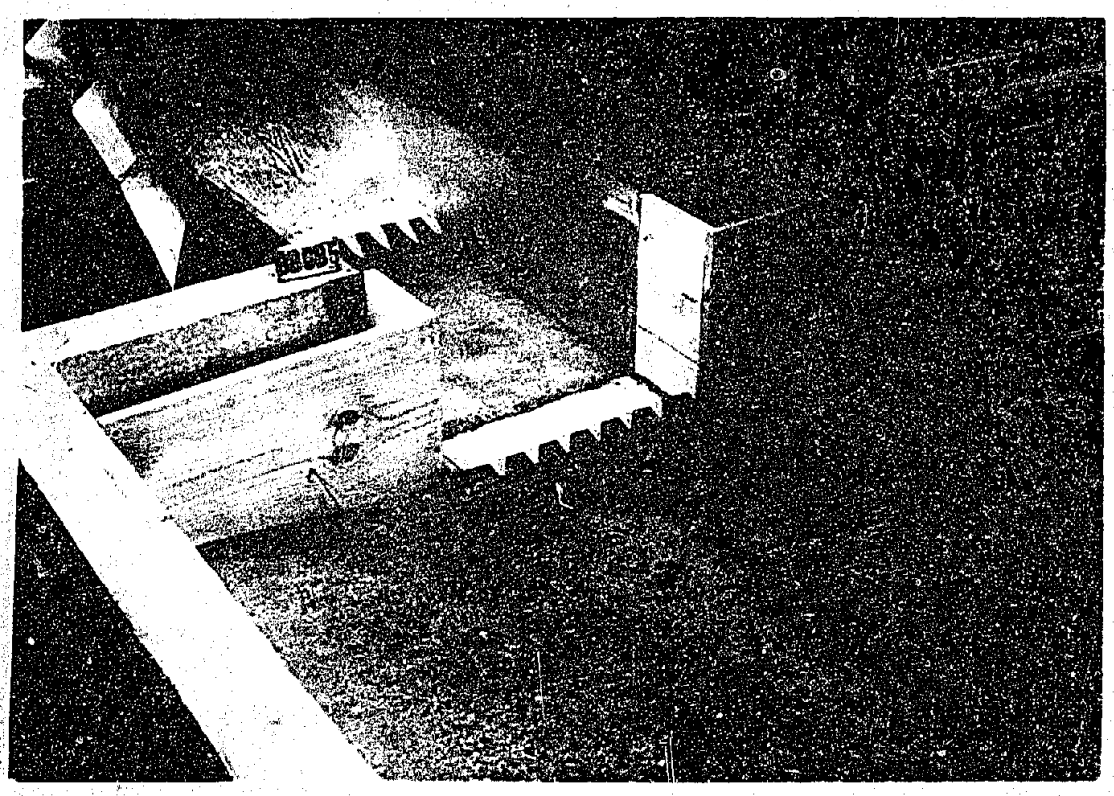


Streambed after Discharge of 3000 Second-feet for One-half Hour

ORIGINAL DESIGN WITH DENTATED SILL AND TEETH ADDED

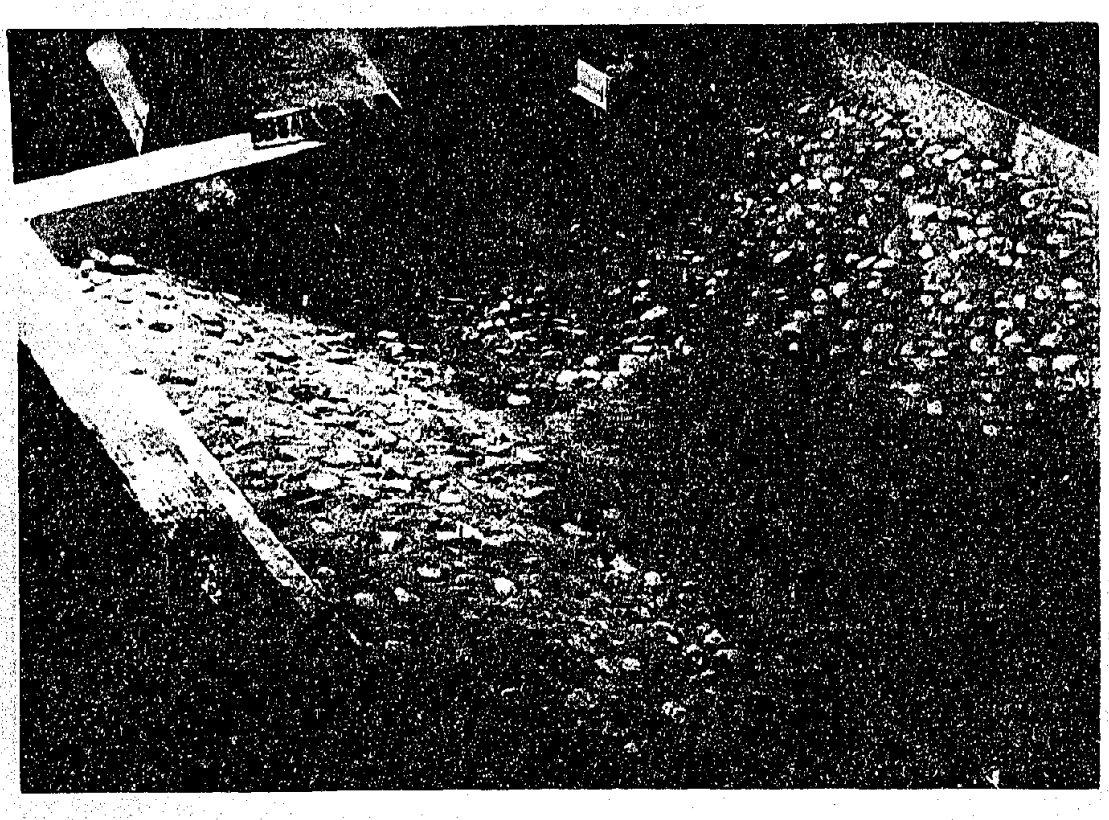


Discharge 3000 Second-feet



Streambed after Discharge of 3000 Second-feet for One-half Hour

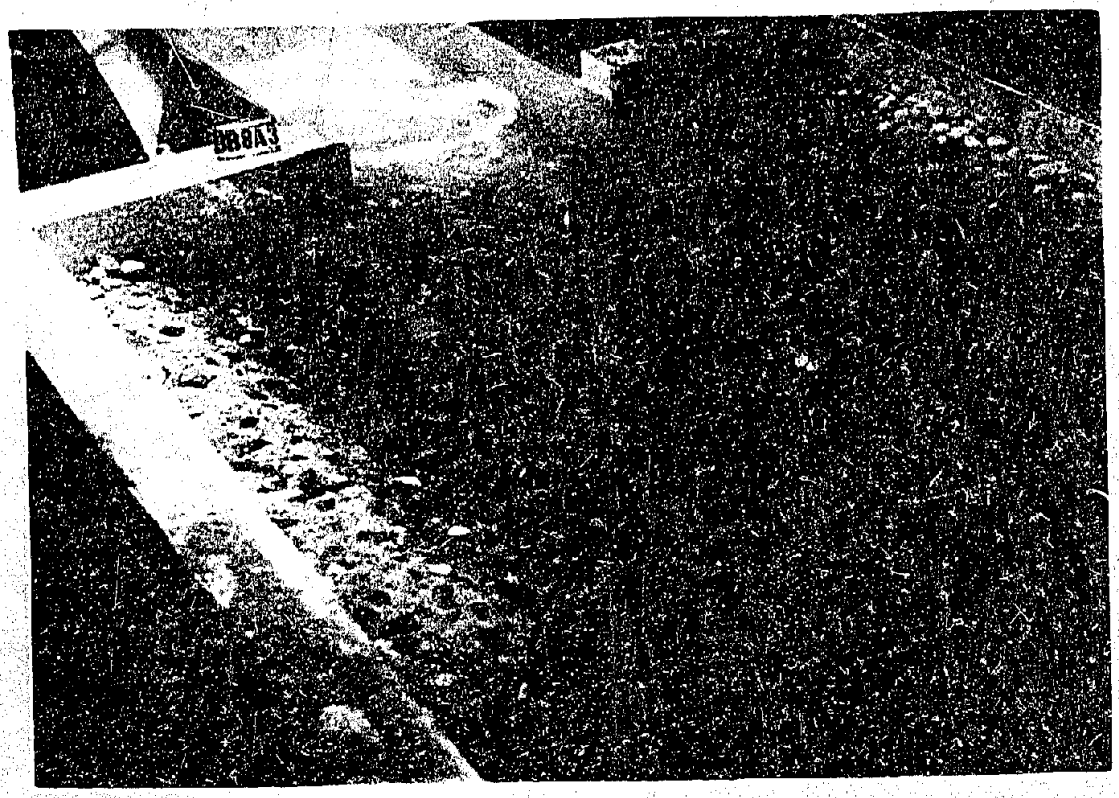
APRON LENGTHENED 15 FEET



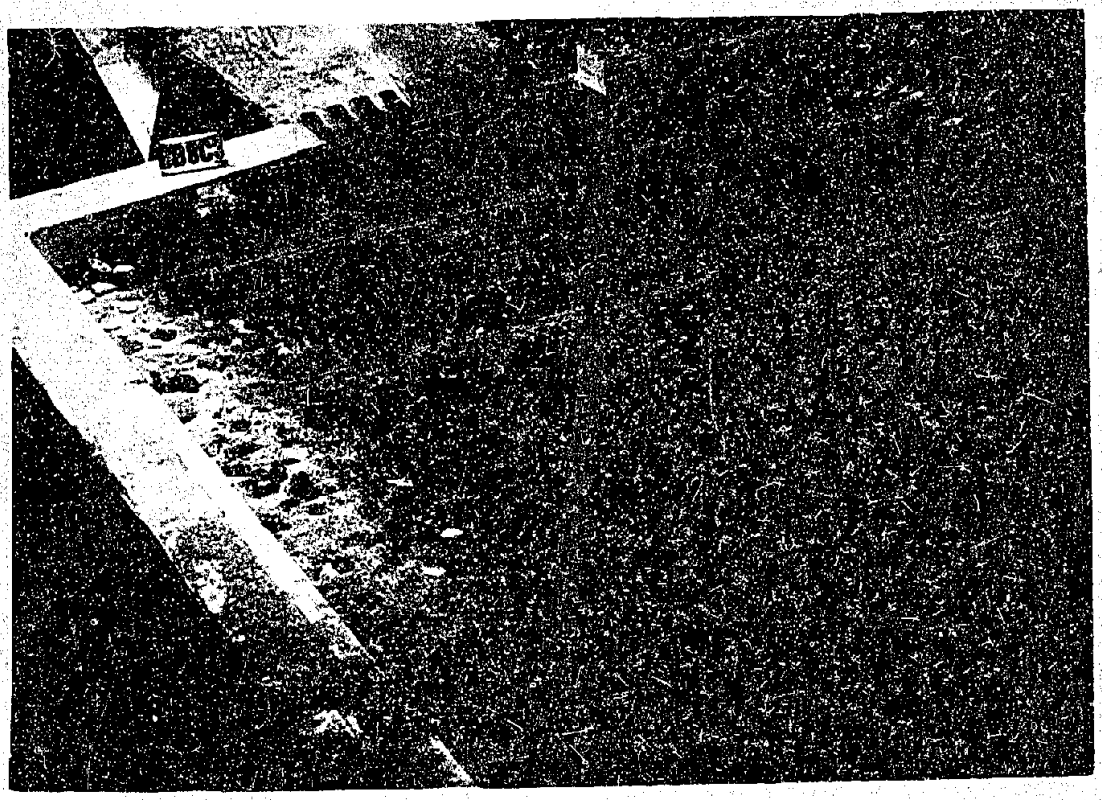
Rip Rap, Built-up Side Slopes, Sill, and Teeth Added

Discharge 1000 Second-feet

ACTION IN STILLING POOL - RECOMMENDED DESIGN

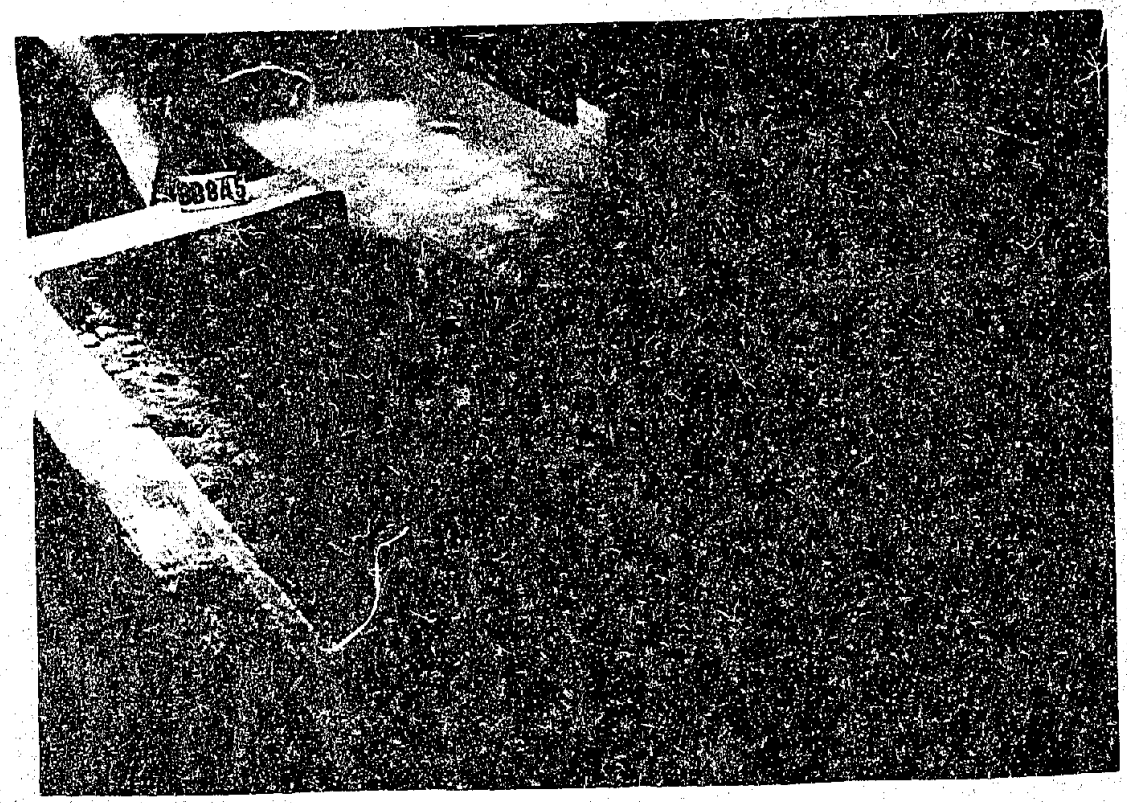


Discharge 2000 Second-feet

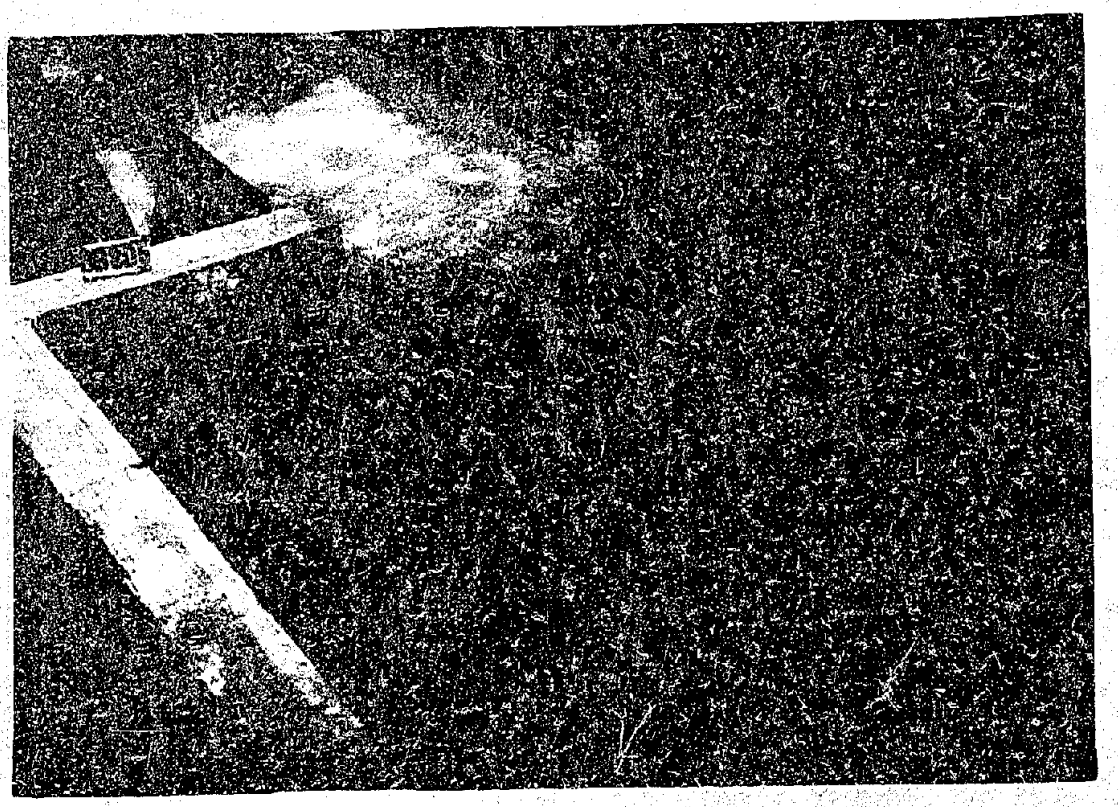


Streambed after Discharge of 2000 Second-feet for One-half Hour

ACTION IN STILLING POOL - RECOMMENDED DESIGN

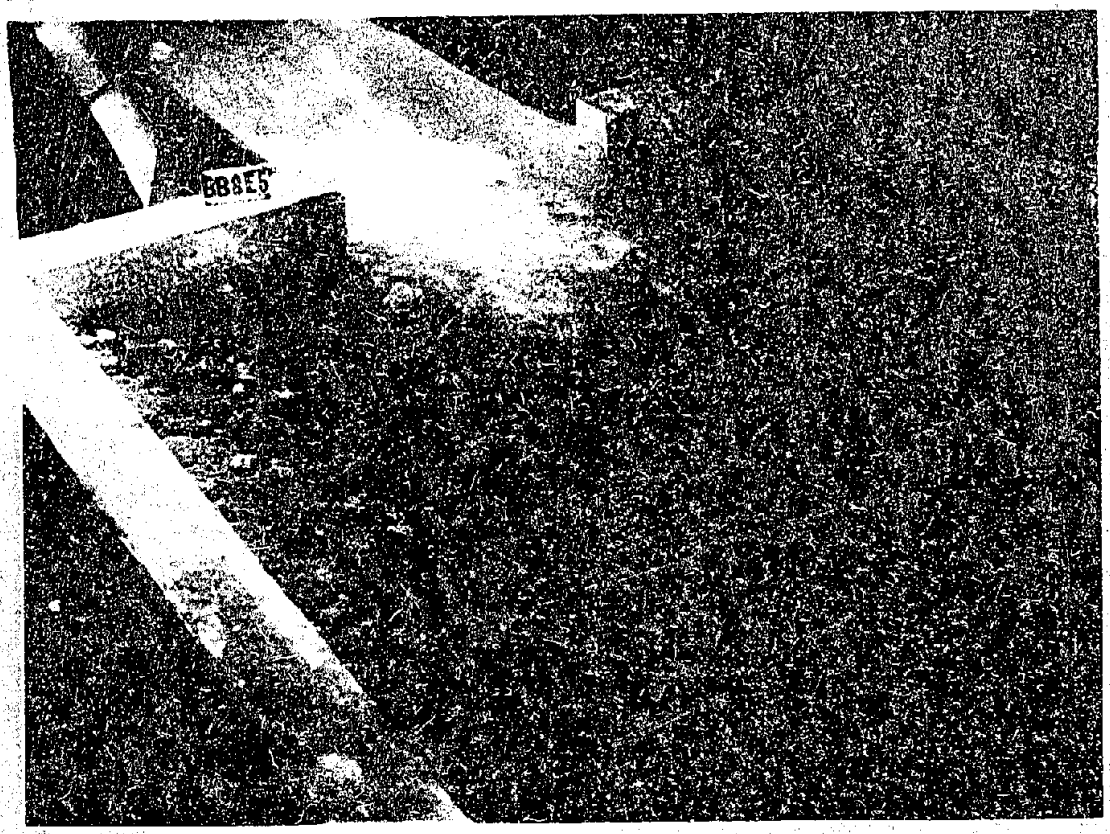


Discharge 3000 Second-feet - Normal Tailwater Elevation

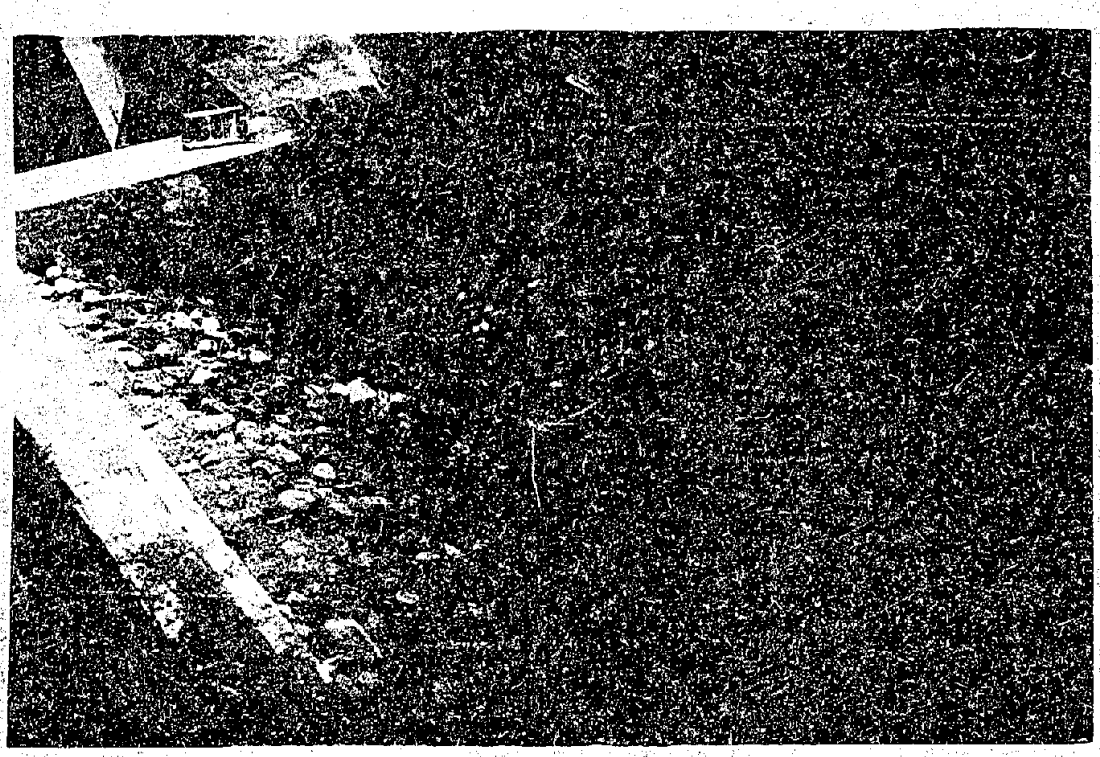


Discharge 3000 Second-feet - Tailwater Elevation for 25000 Second-feet

ACTION IN STILLING POOL - RECOMMENDED DESIGN

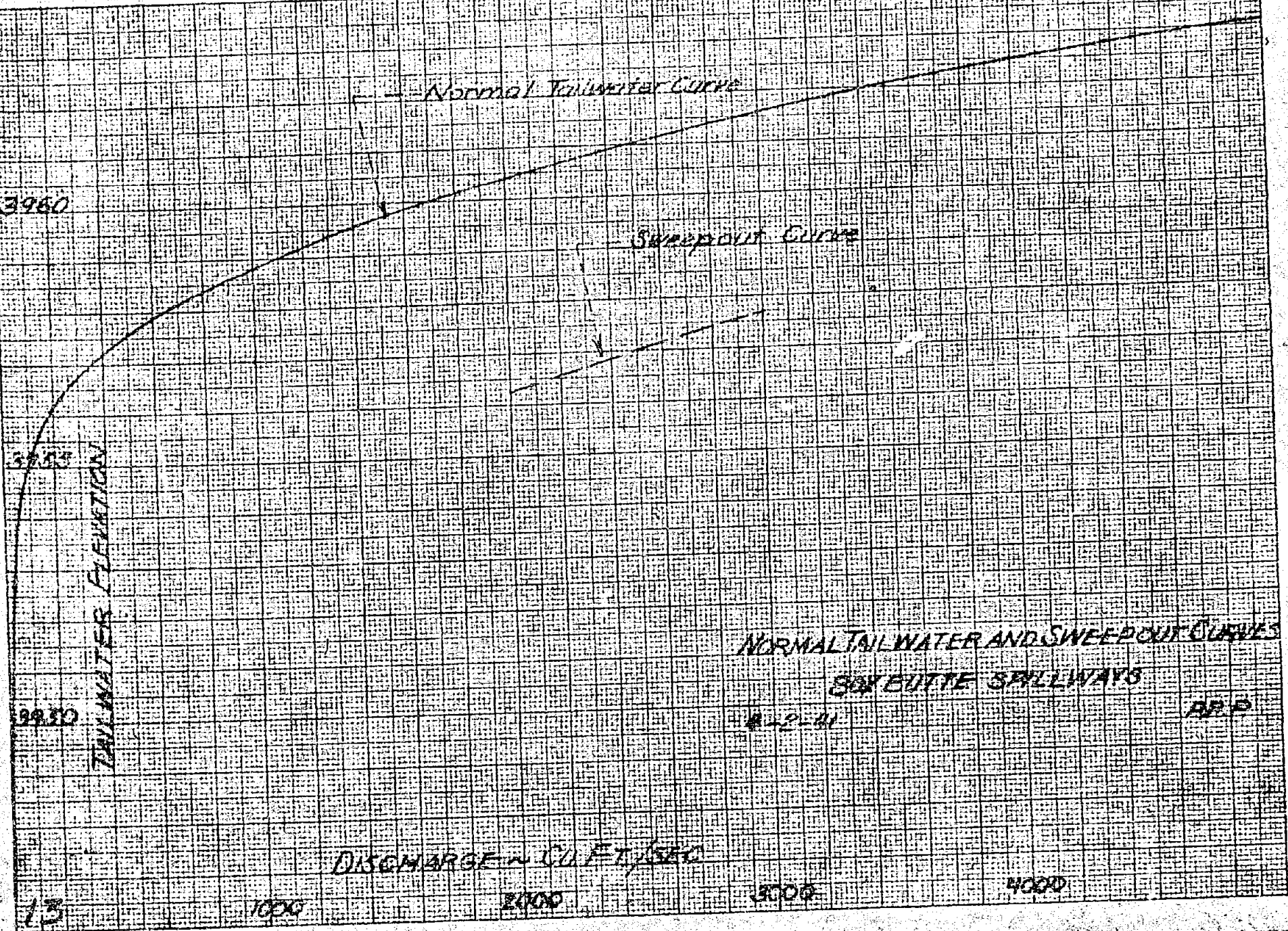


Discharge 3000 Second-feet - Tailwater Lowered to Elevation 3960



Streambed after Completion of Tests

ACTION IN STILLING POOL - RECOMMENDED DESIGN


MADE IN U.S.A.
Normal Tailwater Curve
Sweepout Curve
3960
3955
3950
TAILWATER ELEVATION
NORMAL TAILWATER AND SWEEPOUT CURVES
BOX BUTTE SPILLWAYS
8-2-41
DISCHARGE ~ CU FT/SEC
1000
2000
3000
4000
13