UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF BAFFLED APRON DROPS
WILLARD CANAL PUMPING PLANT NO. 1
WEBER BASIN PROJECT, UTAH

HYDRAULICS BRANCH

Laboratory Report No. HYD-490

DIVISION OF ENGINEERING LABORATORIES

OFFICE OF ASSISTANT COMMISSIONER AND CHIEF ENGINEER
DENVER, COLORADO

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CONTENTS

CONTENTS--Continued

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Office of Assistant Commissioner and Chief Engineer
Division of Engineering Laboratories
Hydraulics Branch
Denver, Colorado
July 12, 1962

Laboratory Report No. Hyd-490
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Subject: Hydraulic model studies of baffled apron drops--Willard Canal Pumping Plant No. 1--Weber Basin Project, Utah

PURPOSE

The studies were conducted to develop a satisfactory design for two baffled apron drops, one on a 3:1 slope and the other on a 4-1/2:1 slope, in the bypass canal at Willard Canal Pumping Plant No. 1.

CONCLUSIONS

1. It was determined that the headworks, Section D-D, (Figure 3) of baffled apron drop No. 1 was satisfactory. However, if desired, the length of the stilling basin could be reduced by 10 feet without reducing its effectiveness.

2. The most effective spacing between rows of blocks on the 3:1 sloped apron was determined to be 9 feet (Figures 10, 11, and 12). A 6-foot spacing was too conservative (Figures 8 and 9), and a 12-foot spacing permitted excessive flow acceleration between rows.

3. A spacing of 13.5 feet between rows of blocks and a combined spacing of 9 feet between rows from Rows 1 to 7, and 13.5 feet from Row 7 on, were investigated on the 4-1/2:1 sloped apron. Either spacing would be satisfactory. The 13.5-foot spacing (Figures 18, 19, and 20) caused greater splash and spray, while the combined spacing (Figures 23, 24, and 25) resulted in deeper bed scour.

INTRODUCTION

Willard Canal, a unit of the Weber Basin Project, is located between the Great Salt Lake and Ogden, Utah (Figure 1). The canal will be used to carry water to and from Willard Reservoir, located in

Willard Bay of the Great Salt Lake. Part of the time the canal is used to carry water by gravity from the Ogden River to Willard Reservoir; for other times, water is pumped from the reservoir into the canal for irrigation distribution.

Pumping Plant No. 1 located at Willard Reservoir consists of the pumping plant used to pump water from the reservoir into the canal, and a bypass to carry the gravity flow around the pumping plant into the reservoir (Figure 2). Two baffled apron drops in the bypass canal lower the water from invert elevation 4233.48 to 4201.00.

Baffled apron drop No. 1 at Station 0+00 of the bypass canal consists of a radial gate controlled broad-crested weir, followed by the baffled drop on a 3:1 slope (Figure 3). The drop is from invert elevation 4233.48 to 4220.29.

Drop No. 2 at Station 13+85.73 of the bypass canal is on a 4-1/2:1 slope and lowers the elevation from 4220.13 to 4201.00 (Figure 7).

A baffled apron is a sloping chute, studded with baffle piers of a height and arrangement to maintain nonaccelerating flow of water from a higher to a lower elevation. Since no stilling pool is used at the downstream end of the chute, the height and placement of the baffle piers, the height of the training walls, and the entrance characteristics of the flow are critical factors in the design of a satisfactory apron. Generalized hydraulic design data are available for chutes on a 2:1 slope, but no information exists for flatter slopes. The model studies described herein were made to develop arrangements that would give proper flow conditions in the baffled apron drops having slopes less than 2:1.

THE MODELS

The models of both drops were constructed to a geometrical scale ratio of 1:10. The model of Drop No. 1 included the turnout from the main canal, the radial gate controlled broad-crested weir, the baffled drop, and a section of the bypass canal downstream from the drop (Figure 5). The model of Drop No. 2 included the transition from the bypass canal, the baffled drop, and a section of the intake channel in Willard Reservoir (Figure 6).

With the exception of the radial gates and the transitions at the entrance portals, both models were constructed of wood, treated to resist swelling. The radial gates were constructed from galvanized sheet metal and the transitions were formed in concrete screeded to sheet metal templates. The channels at the end of the drops were formed in sand with a median diameter of approximately 0.8 millimeter, with 90 percent between the No. 8 and No. 200 Tyler standard screens.

A rock baffle at one end of the head box provided uniform flow distribution in the approach channel. Discharges in the model were measured using calibrated venturi meters permanently installed in the laboratory. Tailwater elevations were controlled by an adjustable tailgate at the downstream end of the model; the tailwater elevation was measured on a staff gage located near the center of the channel about 2 feet upstream from the tailgate.

Impact heads on the baffle blocks were measured by water manometers placed in the block nearest the chute centerline in each row. The opening of the manometer was in the center of the upstream face, 1 inch above the floor.

THE INVESTIGATION

Test data used to evaluate the performance of the drops were:

(1) Water surface profiles along the sidewalls

(2) Impact heads on the centerline baffles as an indication of flow velocity

(3) Wave heights in the channel about 20 feet downstream from the end of the drop

(4) Deptn of channel bed erosion at the end of the drop

The investigations were made at discharges of 250, 500, 750, and 950 second-feet. The tailwater depths used were the normal depths for this canal section; these were 3.95, 5.81, 7.24 and 8.21 feet, respectively, for the four test discharges. The channel bed erosion was often negligible for the two smaller discharges, in which case this test was eliminated.

The above test data for both drops are summarized in tabular form in Table 1.

Drop No. 1

Drop No. 1 consists of a transitioned turnout from the main canal, a broad-crested check weir with three 10-foot-wide radial gates separated by 18-inch-wide piers, a shallow stilling basin, and a baffled chute on a 3:1 slope (Figures 3, 4, and 5). Flow in the turnout, broad-crested weir and stilling basin was excellent at all discharges and the structure required no modifications. However, it was determined that the length of the stilling basin could be shortened by 10 feet without changing the flow conditions. In the "as-built" structure the basin was shortened 5 feet, but this change was not tested in the model.

Preliminary Baffled Apron.--The preliminary baffled apron was designed on the principles established in Hydraulics Branch Report No. Hyd-445.1/ The chute on a 3:1 slope was 33 feet wide by 76 feet 2 inches long. Eleven rows of baffle blocks were equally spaced along the chute; the distance between the rows was 6 feet and the chute was extended 10 feet 2 inches beyond the last row of blocks. The blocks were 3 feet high by 4 feet 1.5 inches wide. In the odd-numbered rows of blocks there were three full blocks and a half block adjacent to each wall; the space between blocks was the same as the block width. Four blocks were in the even-numbered rows and were placed opposite the spaces of the odd-numbered rows. The upstream faces of the blocks were placed normal to the slope of the chute (Figure 4). The last two rows of blocks were below the level of the channel bed. The specifications required that the blocks be covered with riprap; however, in the model they were covered with the same sand used to form the channel.

The appearance of the flow in the preliminary design was excellent for all test flows (Figure 8). The water surface profiles (Figure 9) showed that the 10-foot-high sidewalls would not be overtopped. The highest water surface occurred with the 75-second-foot discharge, and was 2.25 feet below the tops of the wall. At the maximum discharge, the highest point in the profiles was 3 feet below the top of the wall. The impact pressure measurements indicated that the velocity increased past the first three rows of blocks and then remained practically constant down the remainder of the chute (Figure 9).

Erosion for discharges of 250, 500, and 750 second-feet was negligible. For the 950-second-foot discharge, a small amount of scour occurred adjacent to the sidewalls upstream from the end of the chute (Figure 8). The deepest point in the scour hole was only 19 inches below the original bed level.

1/Progress Report V, Research Study on Stilling Basins, Energy Dissipators and Associated Appurtenances. Section 9 - Baffled apron on 2:1 slope for canal or spillway drops (Basin IX).

The waves 20 feet downstream from the end of the chute were 0.5 foot high at the 250-second-foot discharge and increased to 1.2 feet high for the 950-second-foot discharge. The waves caused negligible damage to the side slopes of the downstream channel.

The excellent performance of the preliminary drop indicated that the design was very conservative and that it was possible to increase the spacing between the rows of baffle blocks.

First Modification (recommended).--For the first modification the spacing between the rows of baffle blocks was increased to 9 feet. The size, number, and spacing of blocks in each row were not changed.

The appearance of the flow in the modified drop was very good at all test discharges (Figure 10). The water surface profiles did not overtop the sidewalls at any point (Figure 11). The maximum water surface level occurred with the 950-second-foot discharge. The high point was 2 feet below the top of the wall between the second and third rows of blocks.

The impact pressure (Figure 11) indicated that there was a slight increase in the velocity of the flow down the chute for the two higher test discharges. The velocity remained essentially constant for the two lower test flows.

The erosion for the two lower flows was about 3 feet deep and was confined almost entirely to the portion of the chute that had been backfilled. The amount of erosion resulting from the larger discharges was slightly less than that measured for the lower flows, Figure 12.

An erosion test was also made with the 950-second-foot discharge with the tailwater less than normal in the downstream channel. Under this condition, the erosion was about 6 feet deep and almost all of the backfill was removed from the chute, Figure 12.

The waves 20 feet downstream from the end of the chute were 0.4 foot high for the 250-second-foot discharge, and increased to 0.9 foot high for the 950-second-foot discharge. The wave heights in both cases were smaller than those observed for the 6-foot row spacing. The wave action caused practically no damage to the channel side slopes.

The performance of the baffle drop with the 9-foot row spacing was very good and still seemed to be on the conservative side, so it was decided to further increase the spacing between the rows.

Second Modification.--The spacing between the rows of baffle blocks was increased to 12 feet for the second modification.

The appearance of the flow with the second modification was considerably rougher than it had been for the previous designs (Figure 13). The water surface profiles showed that the flow overtopped the training walls at the two high discharges and came to within 1 foot of the top of the walls at the two lower discharges (Figure 14). The highest water surface occurred at the fourth row of blocks for the 250-second-foot discharge, at the second and fourth rows for the 500- and 750-second-foot discharge, and at the second row for the 950-second-foot discharge.

The impact pressure measurements at all discharges indicated that there was a gradual increase in velocity through the first three rows of blocks, but that the velocity remained essentially constant down the remainder of the drop (Figure 14).

The channel bed erosion was about 1 foot deeper than that observed with the first modification (Figure 15). An erosion test at the maximum discharge with the downstream tailwater level below normal showed an almost identical amount and pattern of scour to that which had occurred with the 9-foot row spacing (Figure 15).

The waves 20 feet downstream from the end of the drop were about 0.6 foot high with the 250-second-foot discharge and increased to 0.9 foot high with the 950-second-foot discharge, or almost the same as that observed with the first modification. There was practically no damage to the channel side slopes due to the wave action.

Since the flow overtopped the training walls at the higher discharges and greater scour occurred in the downstream channel with the 12-foot row spacing, it was concluded that the 9-foot row spacing should be used for baffled apron drops on a 3:1 slope.

Increased Unit Discharge.--Drop No. 1 had been designed for a unit discharge of about 30 second-feet per foot of width. It was desired to determine the performance of the drop designed for a unit discharge of 60 second-feet per foot of width. To be able to use the existing model for this test, it was necessary to assume that the 3.6-inch-high model blocks represented the 4-foot-high blocks needed for the higher unit discharge (see Report No. Hyd-445). This changed the scale ratio of the model from 1:10 to 1:13.33. Based on this new scale ratio the existing spacing of 12 feet between rows of blocks became 16 feet. The block width and distance between blocks remained in the correct proportion to the new block height.

The appearance of the flow was extremely turbulent (Figure 16). The water surface profiles showed that the 13.33-foot-high sidewalls would be overtopped between the second and third and between the fourth and fifth rows of blocks (Figure 17). The impact tube measurements indicated an increasing velocity all the way down the chute.

The erosion after a 2-hour run was about 6 feet deep (Figure 16). This scour depth was about the same as that observed for the smaller unit discharge of 30 second-feet, with the below normal tailwater level. The waves in the channel about 27 feet downstream from the end of the chute were about 0.9 foot high, or the same as with the lower unit discharge. The damage to the side slopes although not extensive, was greater than that previously observed.

Aside from the rough appearance of the flow and inadequate height of the sidewalls, the 16-foot spacing between rows of blocks was satisfactory. If the wall heights were increased to 16 feet, all of the flow would have been contained within the chute. No tests were performed for closer row spacing, but if the spacing had been decreased to 9 or 12 feet it is reasonable to expect that even more satisfactory performance would have been attained since the result of tests with the smaller unit discharge had indicated that closer spacing gave better flow conditions.

Drop No. 2

Drop No. 2, located near the end of the bypass canal, consists of a 24-foot 6-inch-long transition between the trapezoidal canal and the rectangular drop entrance, and the baffled apron on a 4-1/2:1 slope (Figures 6 and 7). A 3-foot 3-inch-high vertical step at the drop entrance serves to check the flow to provide the proper flow depth. The baffled apron was 27 feet wide by 127 feet long with 10-foot sidewalls. The baffle blocks were 3 feet high by 4 feet 6 inches wide. The odd-numbered rows of blocks contained two full width blocks with a half block adjacent to each sidewall; the even-numbered rows contained three full width blocks. The lateral distance between the blocks was equal to the block width.

Preliminary Baffled Apron.--In the preliminary design the rows of baffle blocks were spaced 6 feet apart, as shown on Figure 7. However, the tests on Drop No. 1 showed that the 6-foot spacing was too conservative and that the vertical distance between rows of blocks should be equivalent to the block height. For a drop on a 4-1/2:1 slope, this assumption made the distance between rows equal to 13.5 feet. This spacing was used for the preliminary model installation on Drop No. 2.

The appearance of the flow in the preliminary design, with the 13.5-foot spacing, was very rough (Figure 18). For the 250- and 500-second-foot discharges the flow passed smoothly over or between the first three rows of blocks. The flow impinged against the block faces at the fourth row and was deflected upward; the amount of upward deflection increased with each succeeding row of blocks but at no time did the flow rise to the top of the sidewalls (Figure 19). The surging or upward deflection was less pronounced with the 750- and 950-second-foot discharges, but considerably more turbulence was in the flow. The water surface rose to the tops of the walls at the 750-second-foot discharge and at 950 second-feet the water surface overtopped the walls between the fourth and fifth rows of blocks.

The surging at the faces of the blocks was reflected in a progressively slight increase in the impact pressures as the flow passed down the chute at the two lower discharges (Figure 19). With the two higher discharges a slight increase in the impact pressures was noted at the first three rows, but the pressures remained constant down the rest of the chute.

The waves 20 feet downstream from the end of the chute were 0.53 foot high for the 250-second-foot discharge and increased to 1.05 feet high with the 950-second-foot discharge.

The erosion was very moderate for all discharges (Figure 20). Most of the erosion with the two lower flows was confined to the area where the backfill of the channel came in contact with the invert of the chute. In this area the bed material was removed to a depth of about 2 feet. For the two higher discharges the greatest erosion occurred along the right wall near the end of the chute. The depth of the eroded area was about 2 feet for both the larger flows.

The 13.5-foot spacing between rows of blocks seemed to be too great, particularly at the upstream end of the chute. The excessive distance between the rows permitted the flow to accelerate and deflect upward when it impinged on the next row of blocks. This was more noticeable at the lower flows when the flow depth was shallowest. Although the water surface overtopped the sidewalls only at the maximum discharge, there was excessive splash and spray at all discharges. The extent of the erosion was moderate for all flows and was not considered excessive. It appeared that the operation of the apron could be improved if the upward deflection of the flow at the pier faces could be reduced.

First Modification.--If a greater flow depth (less velocity) were maintained at the upper end of the chute, the flow conditions might be improved. To provide this increased depth, the height of the blocks in the first row was increased by 1 foot. The other blocks were not changed.

This modification did not change the appearance of the flow down the chute (Figure 21). The water surface profiles (Figure 22) were practically the same as with the preliminary arrangement. Because of the similarity in appearance, no impact pressure measurements or erosion tests were made.

Second Modification.--For the second modification the spacing between the first seven rows of blocks was reduced to 9 feet; the 13.5-foot spacing between the remaining rows was retained. This modification was very effective; the water flowed very smoothly past the first seven rows at all discharges. At the two lower flows there was still some upward deflection in the water surface at the faces of the blocks in Row 8 and succeeding rows. With the two higher flows there was very little upward deflection, but quite an increase in the turbulence was noted (Figure 23). The water surface profiles indicated that the sidewalls would not be overtopped by discharges up to 750 second-feet. The water surface rose to the top of the walls near the seventh row of blocks and overtopped the walls from the eighth row on when the discharge was 950 second-feet (Figure 24). The impact measurements indicated a slight increase in velocity at the first two or three rows of blocks and a near constant velocity down the remainder of the chute (Figure 24).

The waves 20 feet downstream from the end of the chute were about 0.5 foot high when the discharge was 250 second-feet and increased to about 1.0 foot high when the discharge was 950 second-feet. There was very little damage to the channel banks due to wave action. The maximum depth of bed erosion after 8 hours of operation at the 950-second-foot discharge was about 3 feet just upstream from the end of the chute (Figure 25). The tops of the lowest row of blocks were uncovered, but considering the quantity of flow and length of run the erosion was very moderate.

The tests indicated that either the 13.5-foot spacing or the combined spacing of 9.0 feet between the first seven rows and 13.5 feet between the remaining rows provided adequate flow conditions on the 4-1/2:1 sloping chute. There was greater splash and spray with the 13.5-foot spacing and slightly more bed scour with the combined spacing, but the differences were insignificant, and either would give satisfactory performance.

Table 1

Test Data for Baffled Apron Drops

Apron slope	Row spacing	Height of maximum W.S. below top of 10-foot sidewall	Location	Flow acceleration	Wave heights	Maximum depth erosion at end of apron	Remarks
3:1	6-ft	2.25 ft at 750 cfs 3.00 ft at 950 cfs	Rows 4-5 Rows 2-9	Increase--first 3 rows--then slight decrease	1.20 ft	1.5 ft	
3:1	9-ft	2.50 ft at 750 cfs 2.00 ft at 950 cfs	Rows 2-3 Rows 2-3	Very slight increase all down chute	0.90 ft	3.00 ft	
3:1	12-ft	Overtopped at 750 cfs and 950 cfs	Rows 4-5 Rows 2-3	Increase first 3 rows--then no increase	0.90 ft	4.00 ft	
4-1/2:1	13.5-ft	0.0 ft at 750 cfs overtopped at 950 cfs	Rows 4-5 Rows 4-5	Slight increase first 3 rows--then no increase	1.05 ft	2.00 ft	Surging at faces of blocks produces considerable splash and spray
4-1/2:1	Rows 1-7 9-ft Row 7 on 13.5-ft	Overtopped at 750 cfs Overtopped at 950 cfs	Rows 8-9 Rows 7-8	Slight increase first 2 or 3 rows then no increase	1.00 ft	3.00 ft	

Note: All data are for maximum discharge (950 cfs) unless otherwise noted.

FIGURE I
REPORT HYD 490

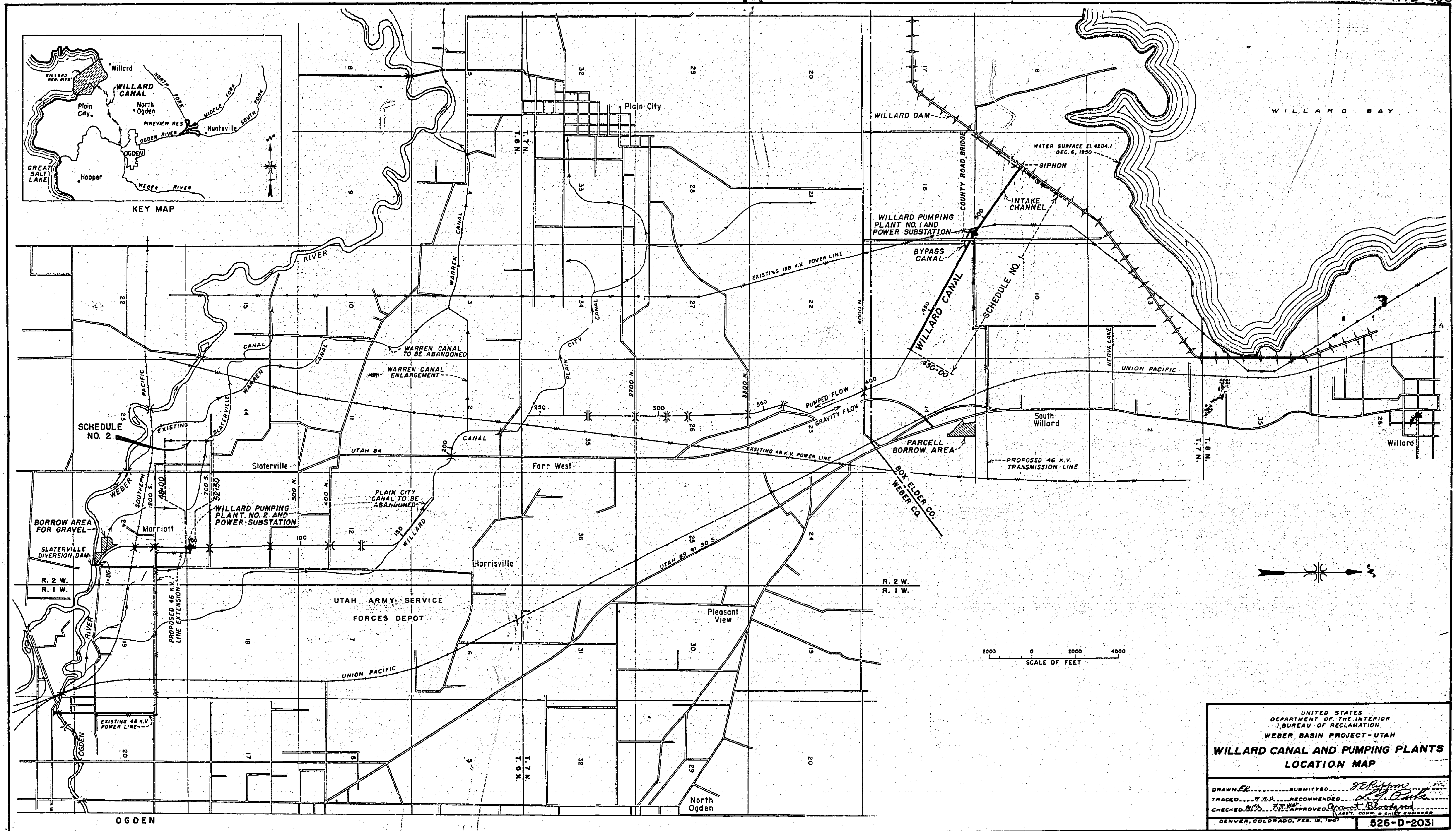


FIGURE 2
REPORT HYD 490

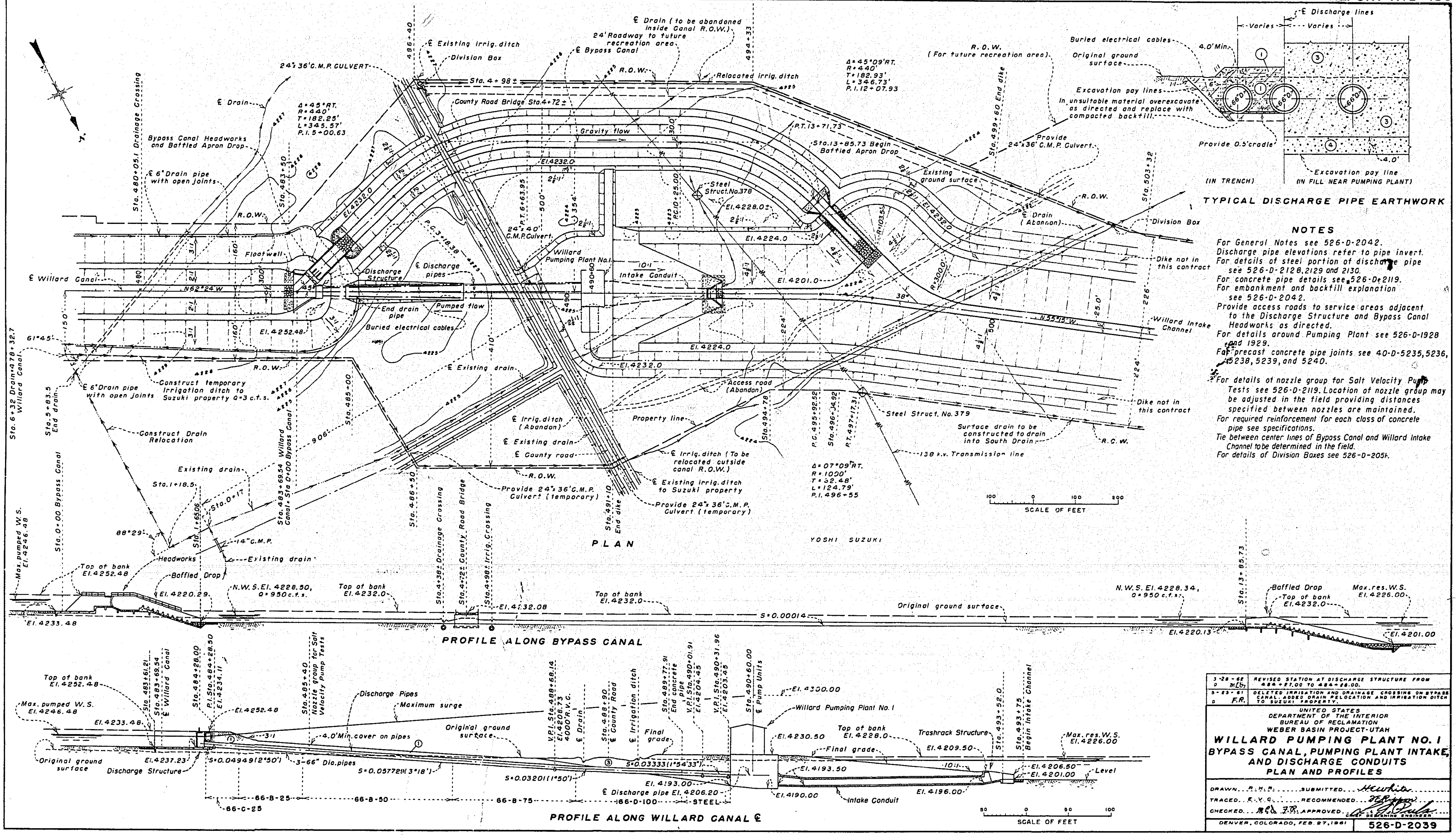
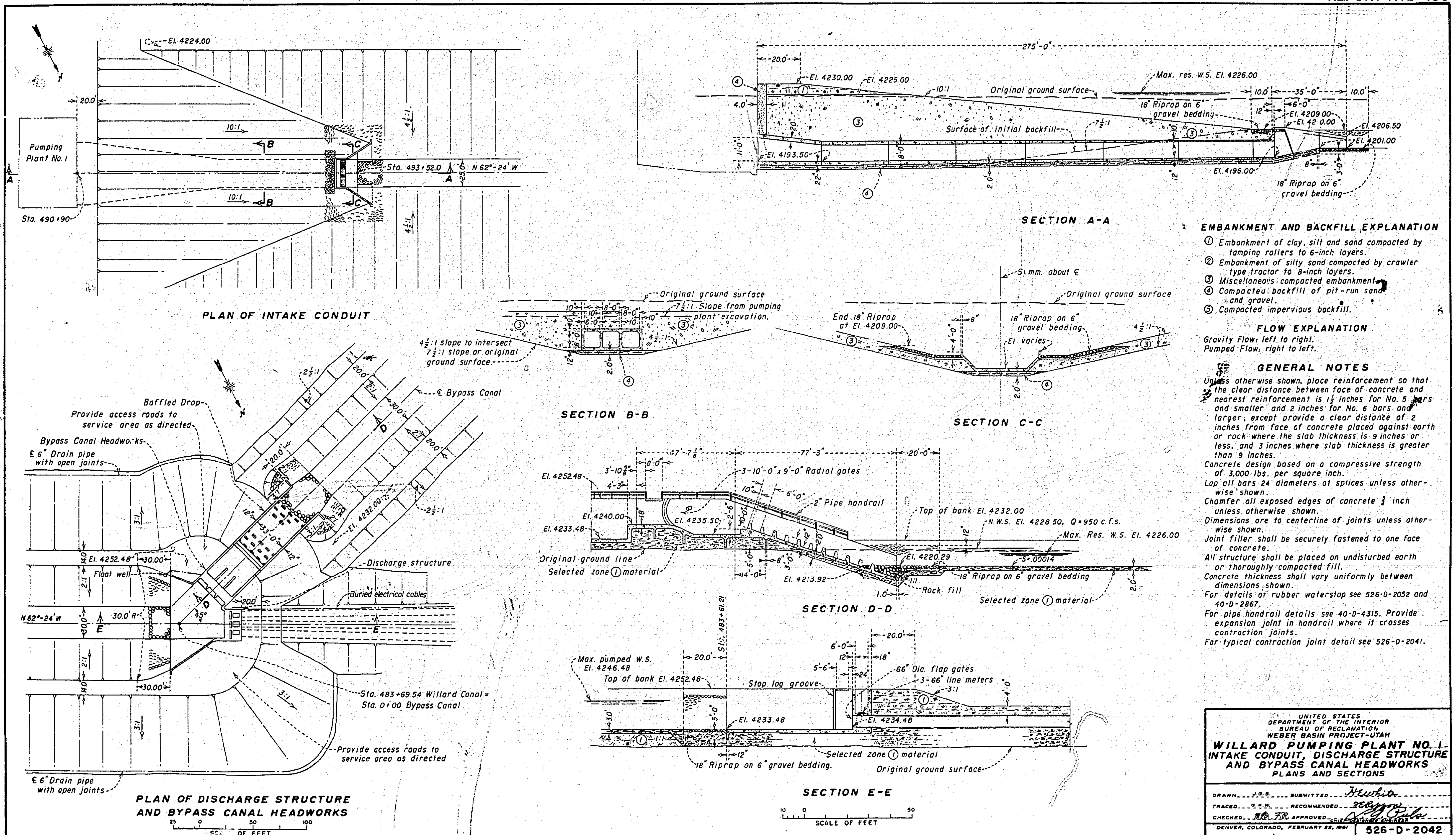


FIGURE 3
REPORT HYD 490



EMBANKMENT AND BACKFILL EXPLANATION

① Embankment of clay, silt and sand compacted by tamping rollers to 6-inch layers.
② Embankment of silty sand compacted by crawler type tractor to 8-inch layers.
③ Miscellaneous compacted embankment.
④ Compacted backfill of pit-run sand and gravel.
⑤ Compacted impervious backfill.

FLOW EXPLANATION

Gravity Flow: left to right.
Pumped Flow: right to left.

GENERAL NOTES

Unless otherwise shown, place reinforcement so that the clear distance between face of concrete and nearest reinforcement is 1½ inches for No. 5 bars and smaller and 2 inches for No. 6 bars and larger; except provide a clear distance of 2 inches from face of concrete placed against earth or rock where the slab thickness is 9 inches or less, and 3 inches where slab thickness is greater than 9 inches.
Concrete design based on a compressive strength of 3,000 lbs. per square inch.
Lap all bars 24 diameters at splices unless otherwise shown.
Chamfer all exposed edges of concrete ¾ inch unless otherwise shown.
Dimensions are to centerline of joints unless otherwise shown.
Joint filler shall be securely fastened to one face of concrete.
All structure shall be placed on undisturbed earth or thoroughly compacted fill.
Concrete thickness shall vary uniformly between dimensions shown.
For details of rubber waterstop see 526-D-2052 and 40-D-2867.
For pipe handrail details see 40-D-4315. Provide expansion joint in handrail where it crosses contraction joints.
For typical contraction joint detail see 526-D-2041.

UNITED STATES
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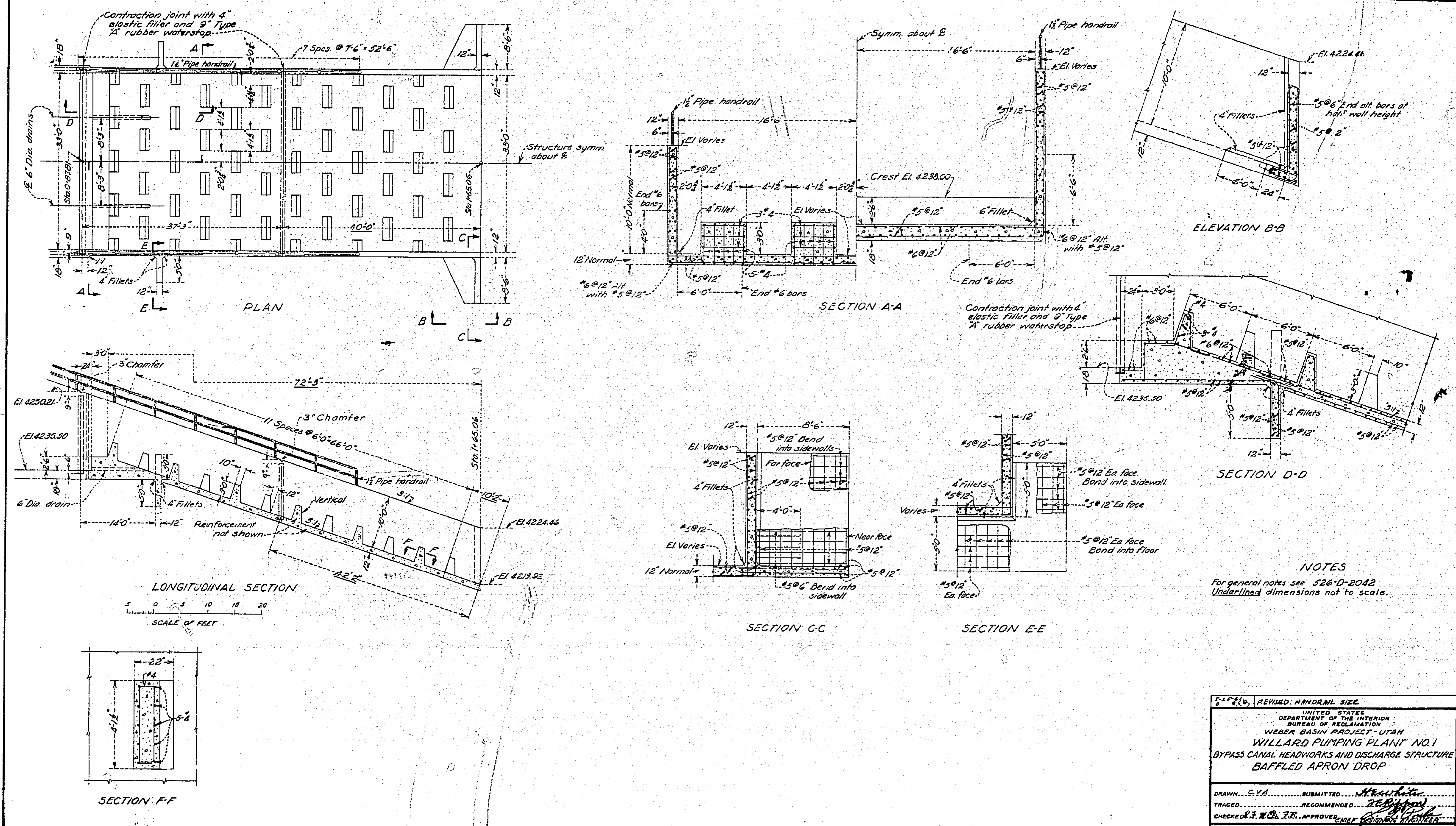
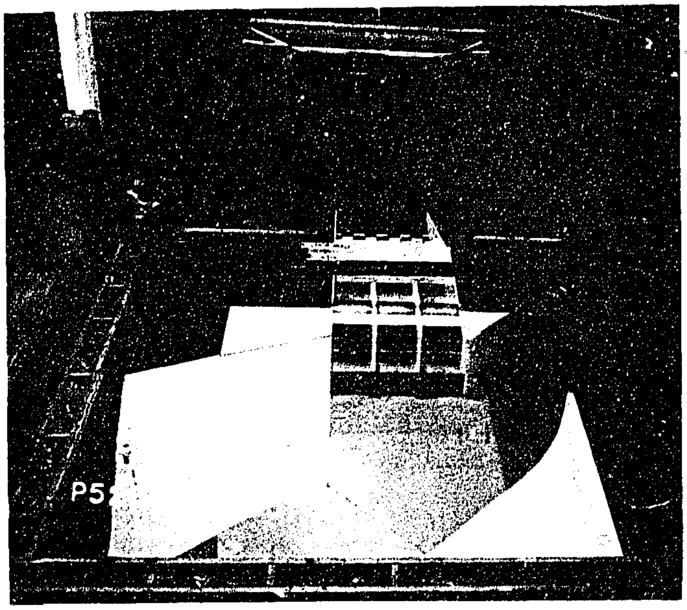
WEBER BASIN PROJECT-UTAH

WILLARD PUMPING PLANT NO. 1
INTAKE CONDUIT, DISCHARGE STRUCTURE AND BYPASS CANAL HEADWORKS
PLANS AND SECTIONS

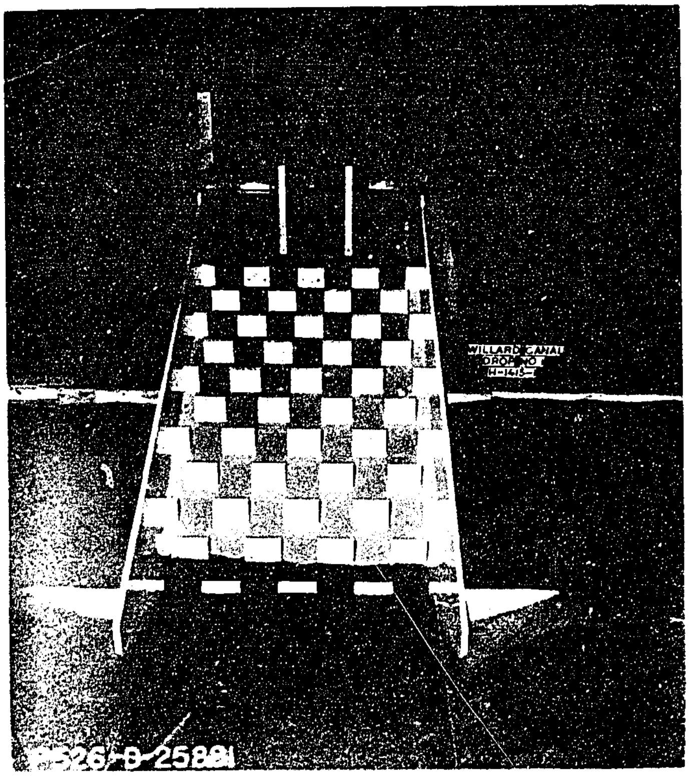
DRAWN J.O.S. SUBMITTED H. E. White
TRACED G.K.W. RECOMMENDED
CHECKED M.O. F.R. APPROVED CHIEF DESIGNING ENGINEER
DENVER, COLORADO, FEBRUARY 22, 1961
526-D-2042

FIGURE 4
REPORT HYD 490



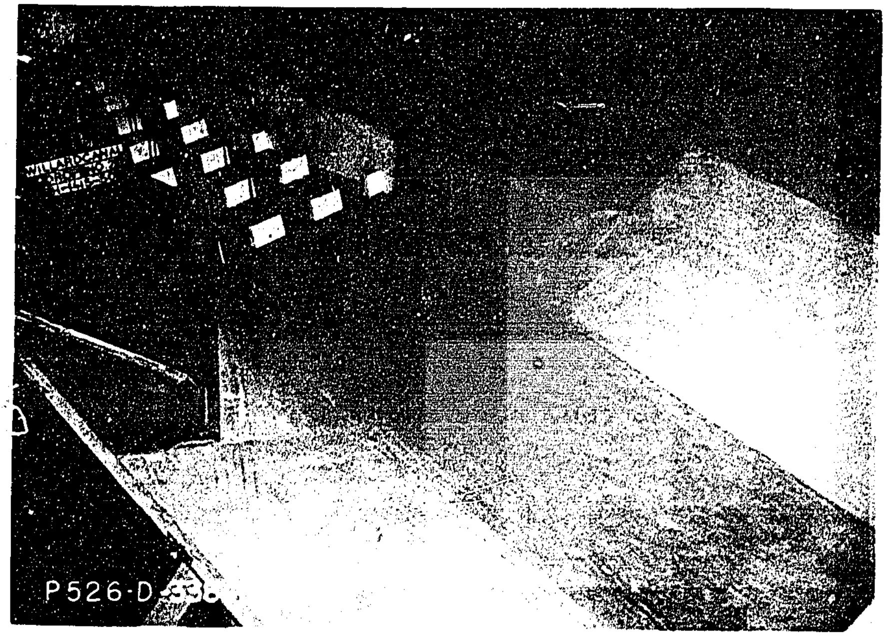


General view of model

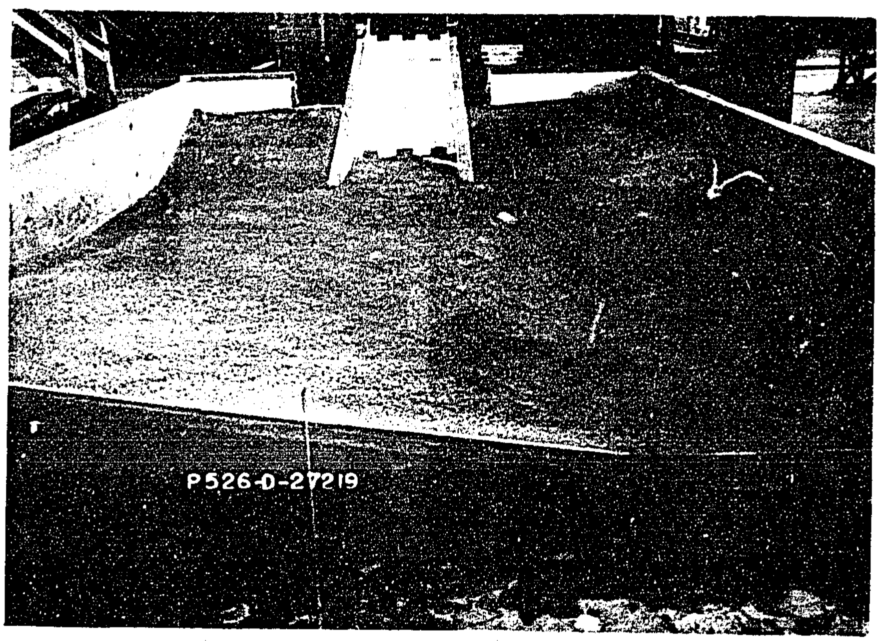


6-foot row spacing on 3:1 slope

WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 1
1:10 scale model



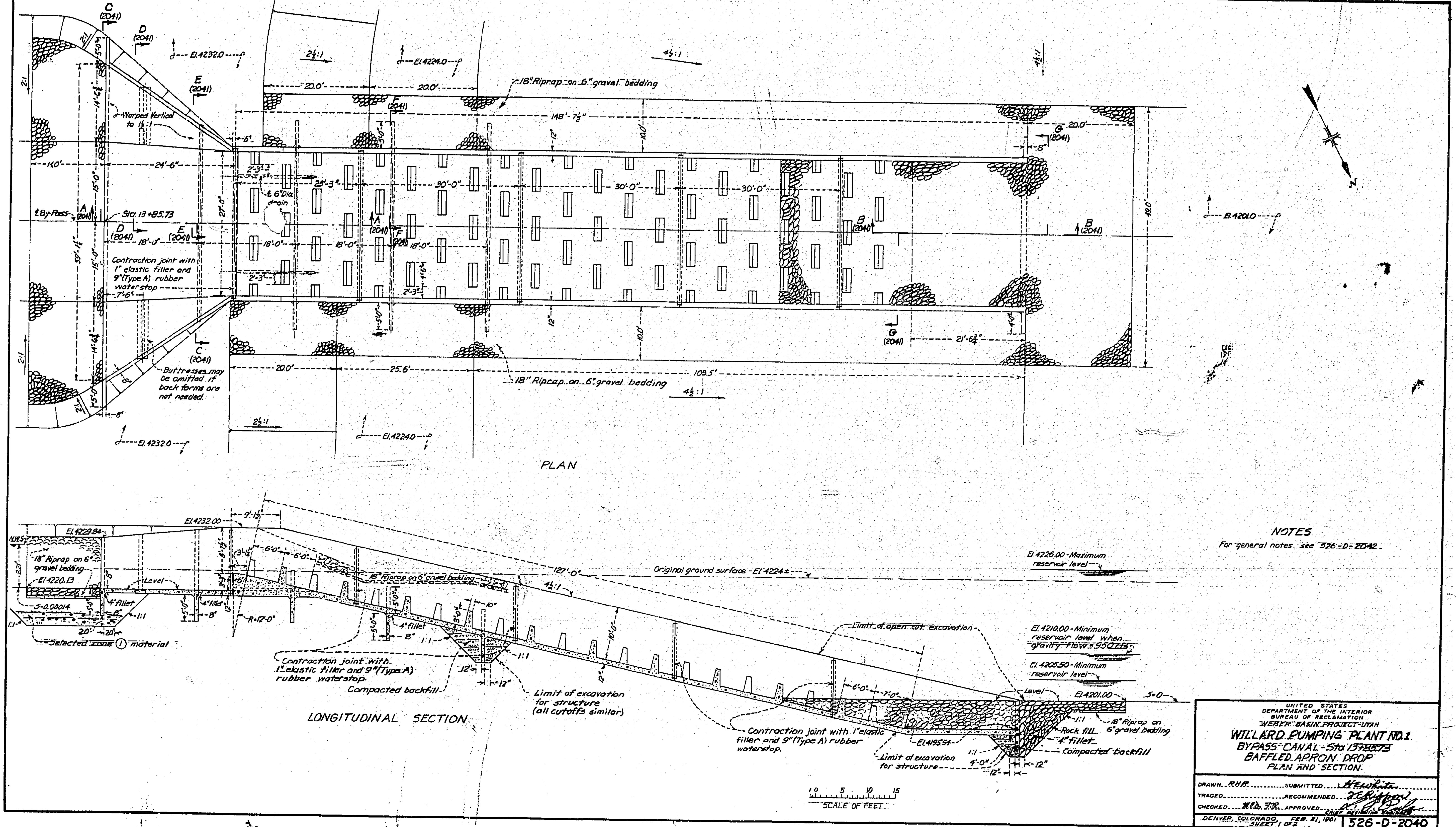
Entrance to Drop No. 2

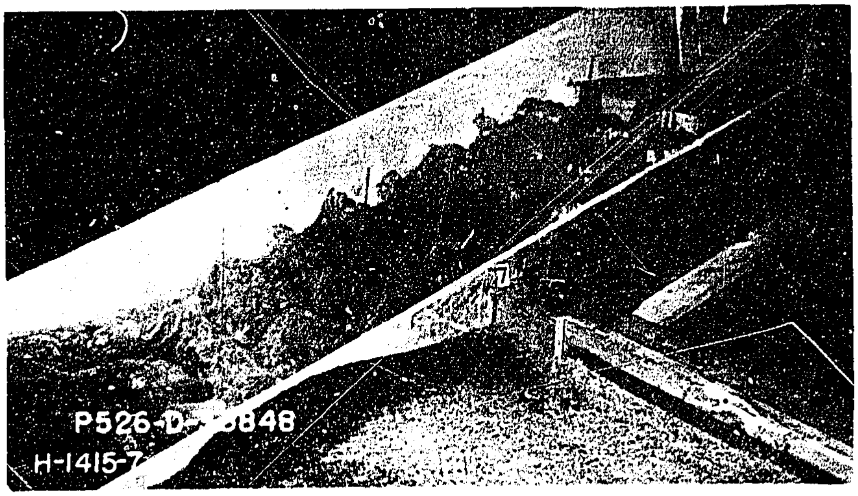


13.5-foot row spacing on 4-1/2:1 slope

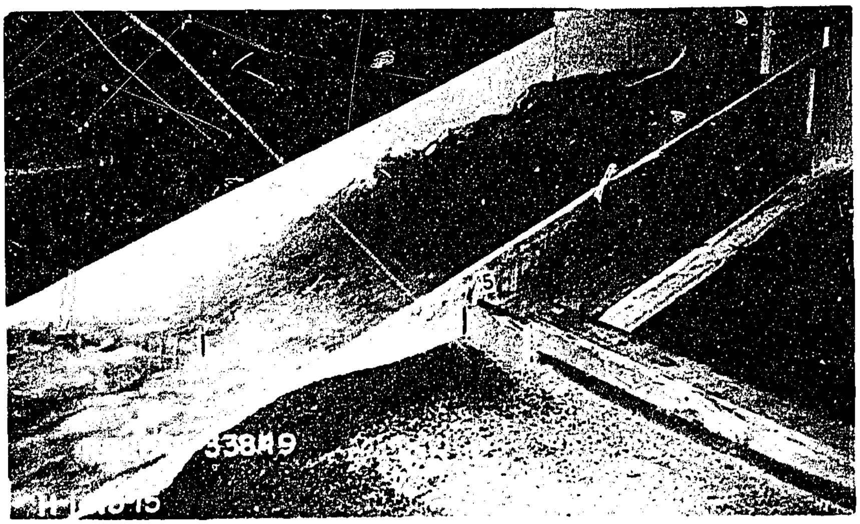
WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 2
1:10 scale model

FIGURE 7
REPORT HYD 490

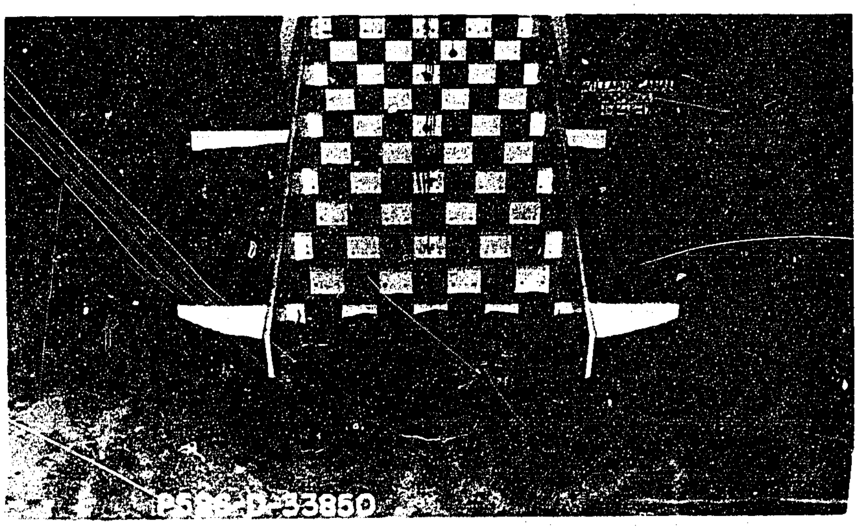




Discharge = 250 cfs

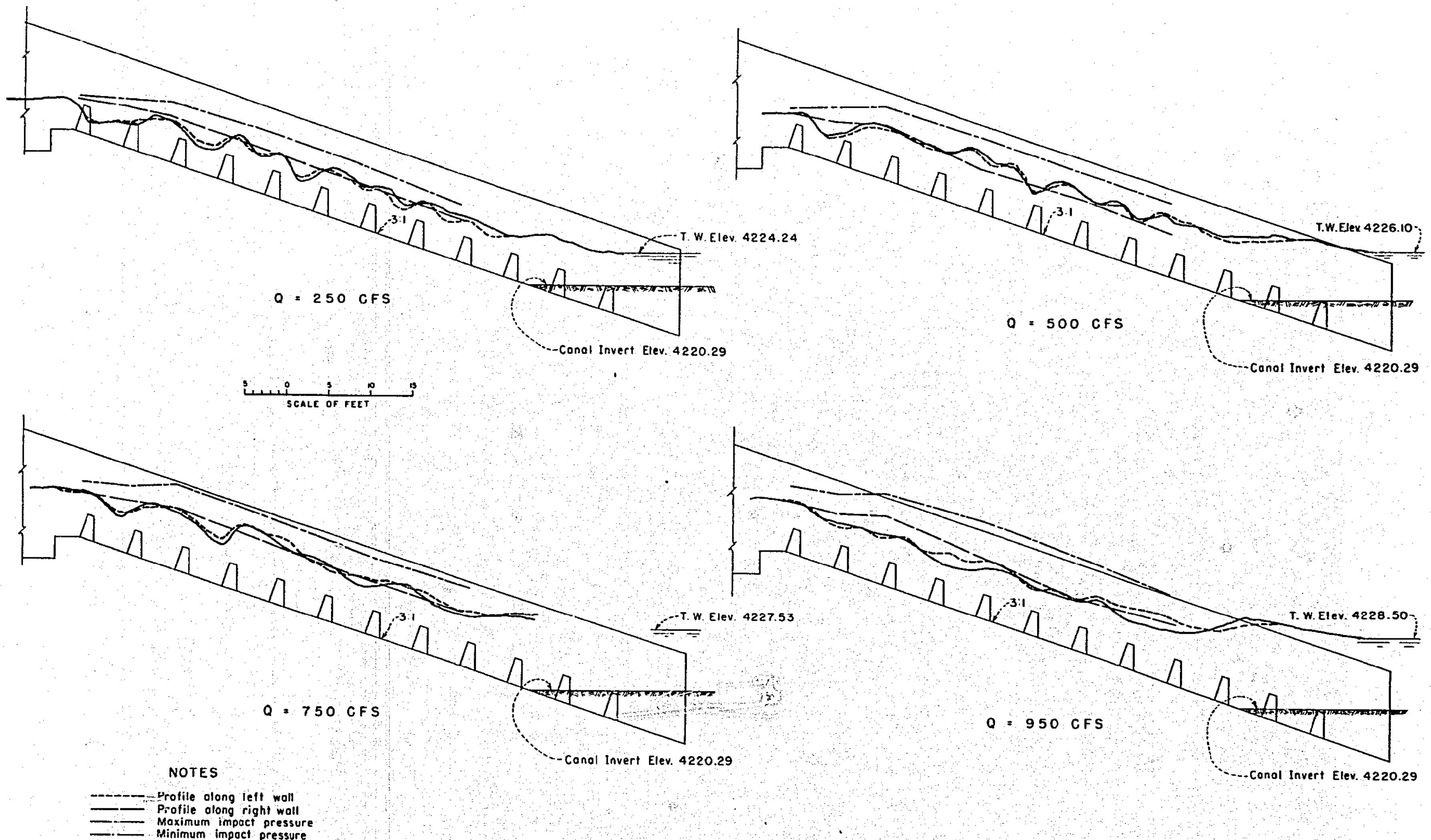


Discharge = 500 cfs



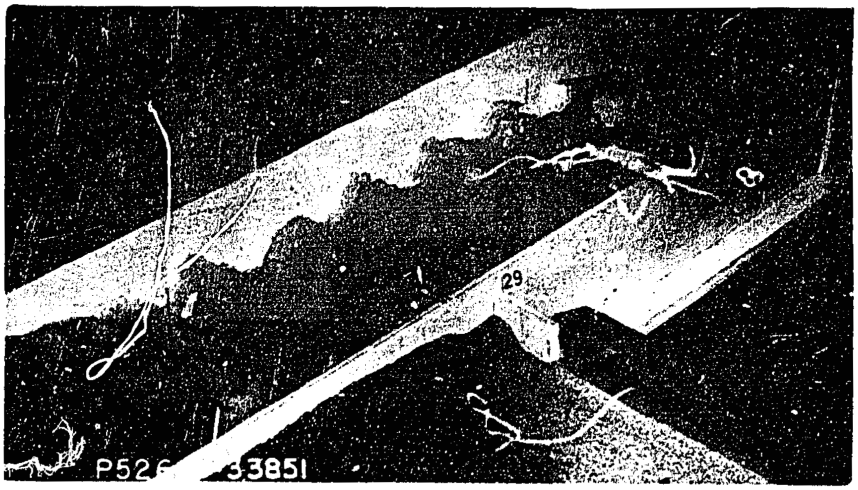
Erosion after 4-hours operation at 950 cfs

WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 1
Flow Conditions and Erosion
6-Foot Row Spacing (Preliminary)
1:10 scale model

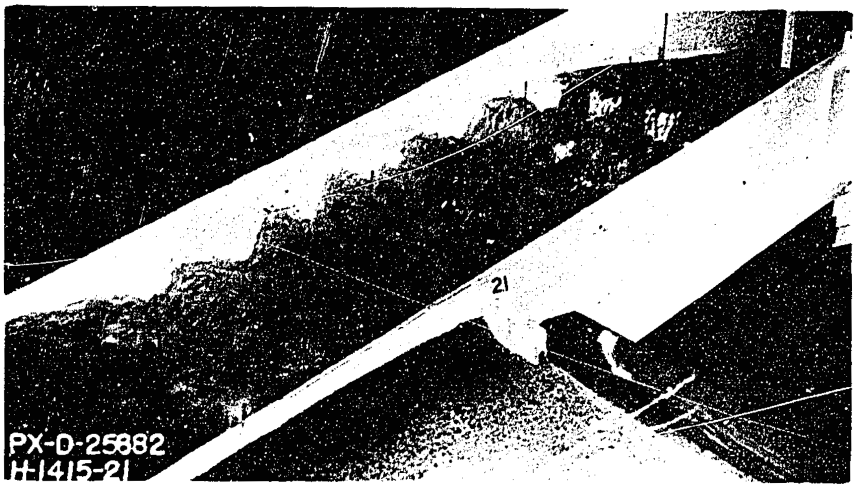


WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 1
WATER SURFACE PROFILES AND IMPACT PRESSURES
PRELIMINARY — 6-FOOT ROW SPACING
1:10 SCALE MODEL

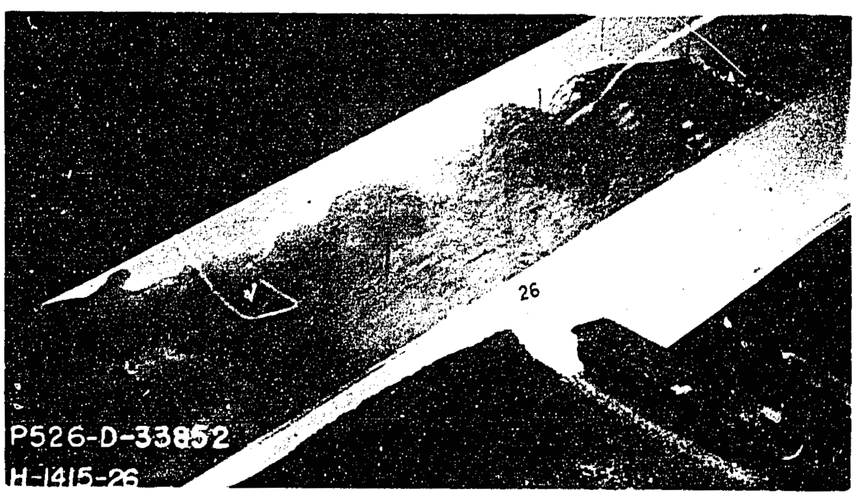
Figure 10
Report Hyd 490



Discharge = 250 cfs

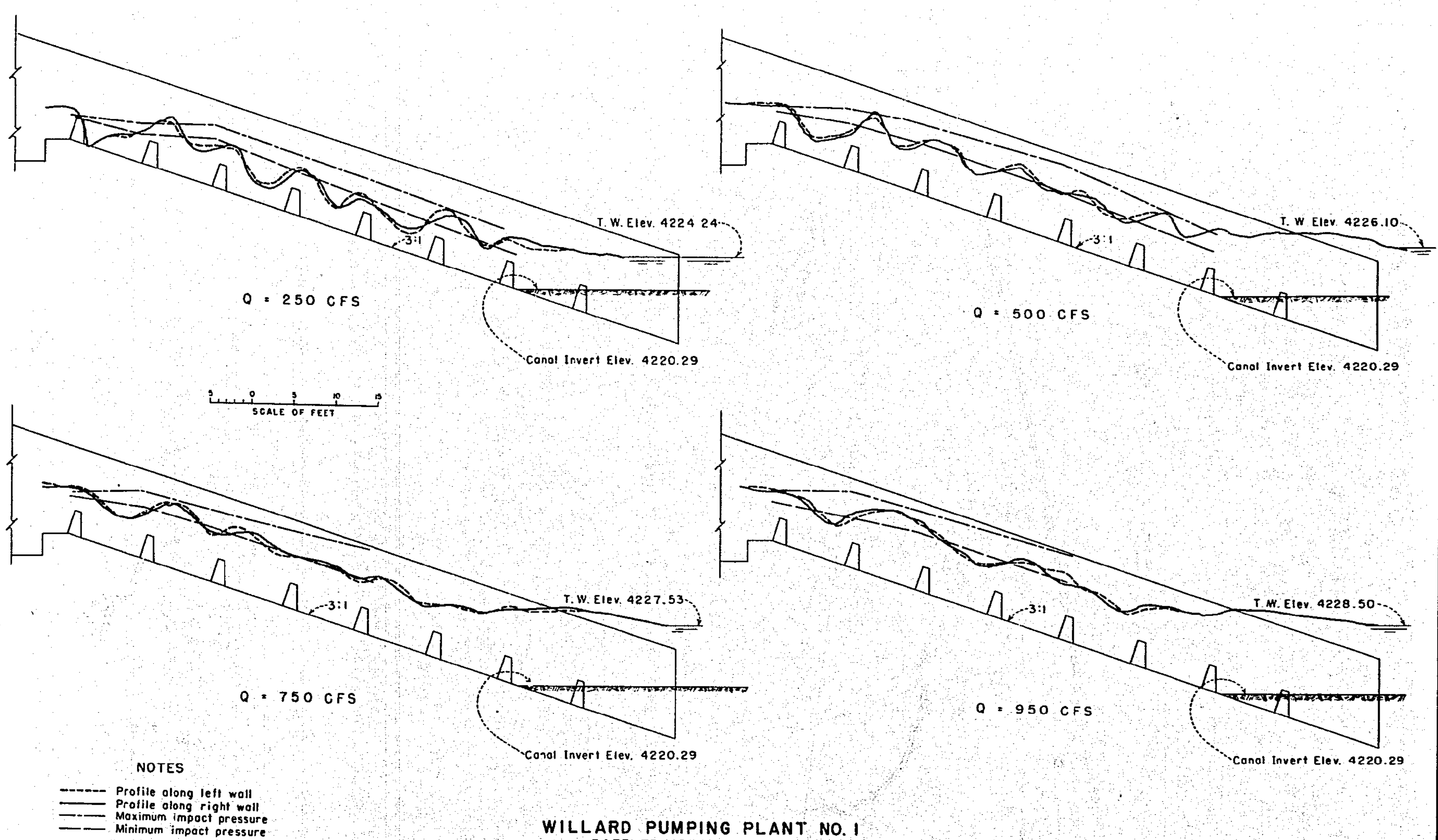


Discharge = 500 cfs



Discharge = 950 cfs

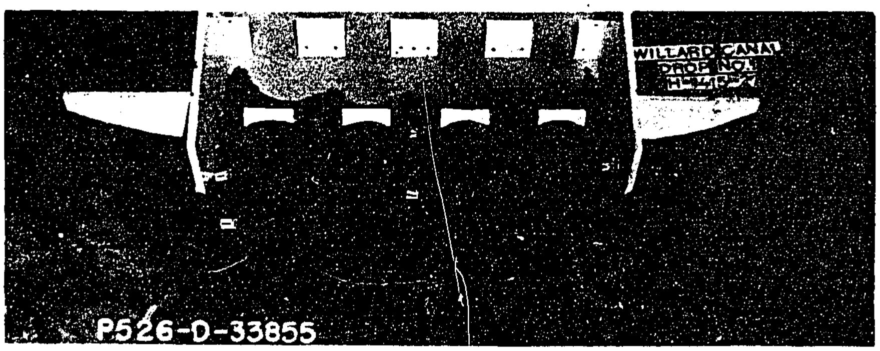
WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 1
Flow with 9-Foot Row Spacing (Recommended)
1:10 scale model



WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 1
WATER SURFACE PROFILES AND IMPACT PRESSURES
FIRST MODIFICATION — 9-FOOT ROW SPACING (RECOMMENDED)
1:10 SCALE MODEL

4 hours operation
at 250 cfs
T. W. Depth = 3.95 ft.

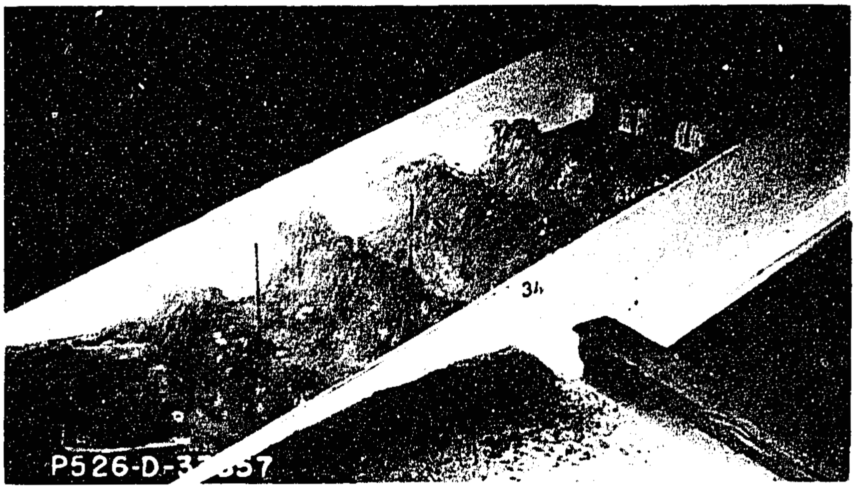
4 hours operation
at 500 cfs
T. W. Depth = 5.81 ft.



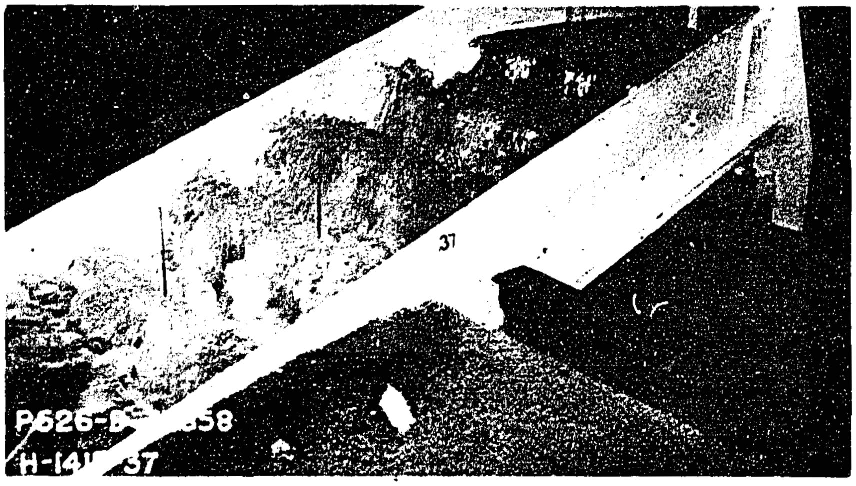
4 hours operation
at 950 cfs
T. W. Depth = 8.21 ft.

4 hours operation
at 950 cfs
T. W. Depth = 3.00 ft.

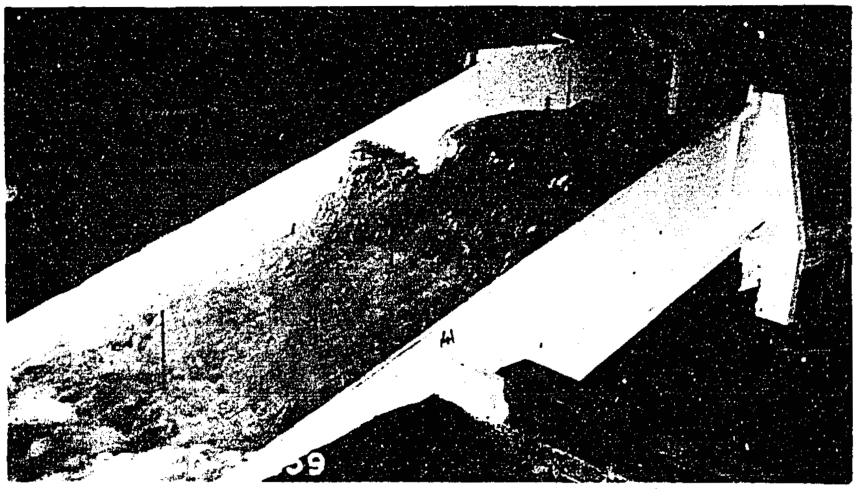
WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 1
Erosion with 9-Foot Row Spacing (Recommended)
1:10 scale model



Discharge = 250 cfs

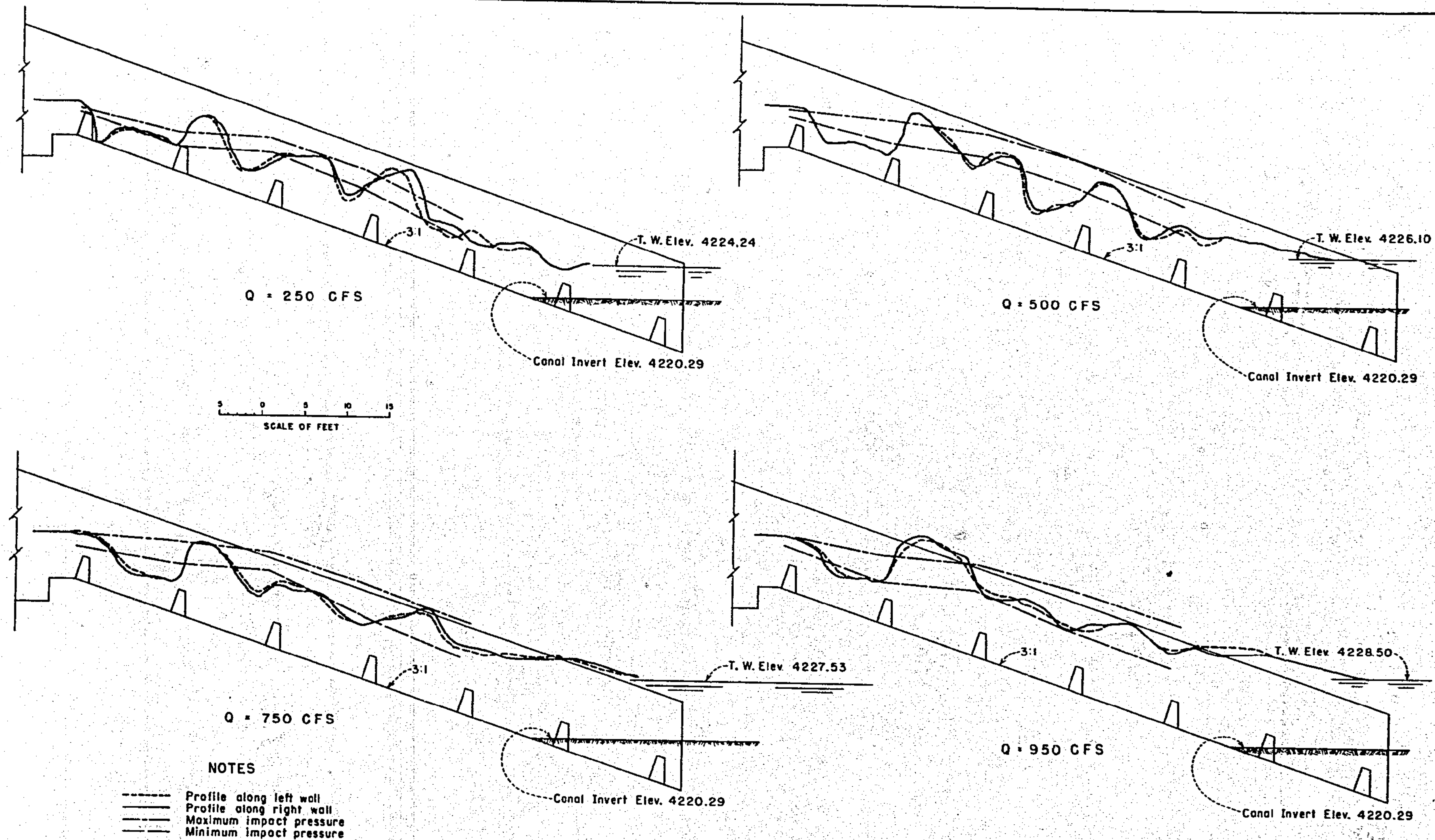


Discharge = 500 cfs



Discharge = 950 cfs

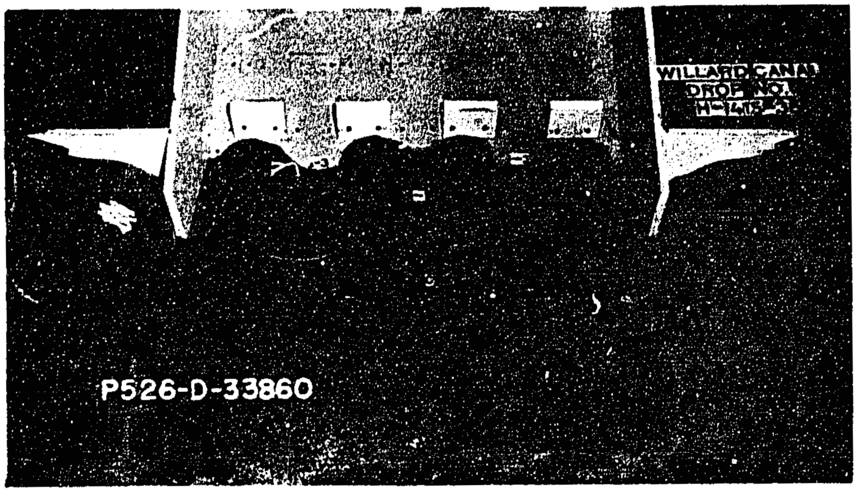
WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 1
Flow Appearance with 12-Foot Row Spacing
1:10 scale model



WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 1

WATER SURFACE PROFILES AND IMPACT PRESSURES
SECOND MODIFICATION — 12-FOOT ROW SPACING

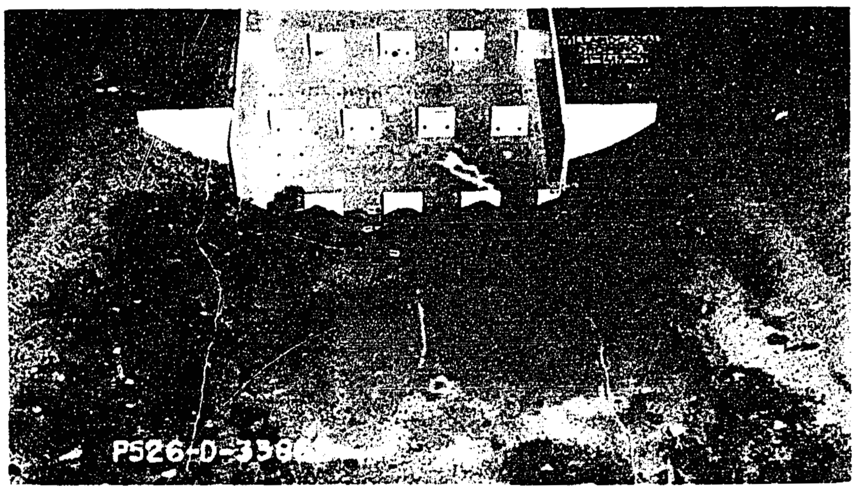
1:10 SCALE MODEL



4 hours operation at 250 cfs.

T. W. Depth = 3.95 ft.

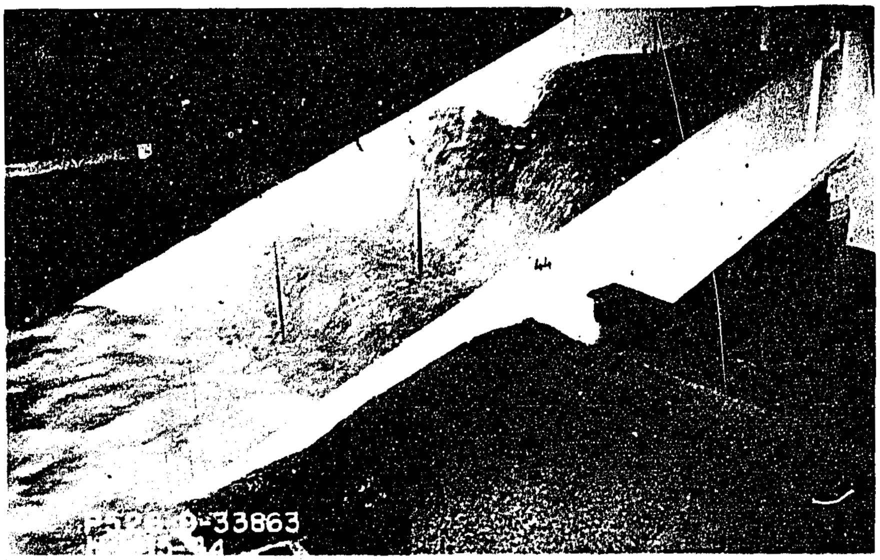
4 hours operation discharge varied from 500 cfs to 950 cfs. T. W. depths varied from 5.81 ft. to 8.21 ft.



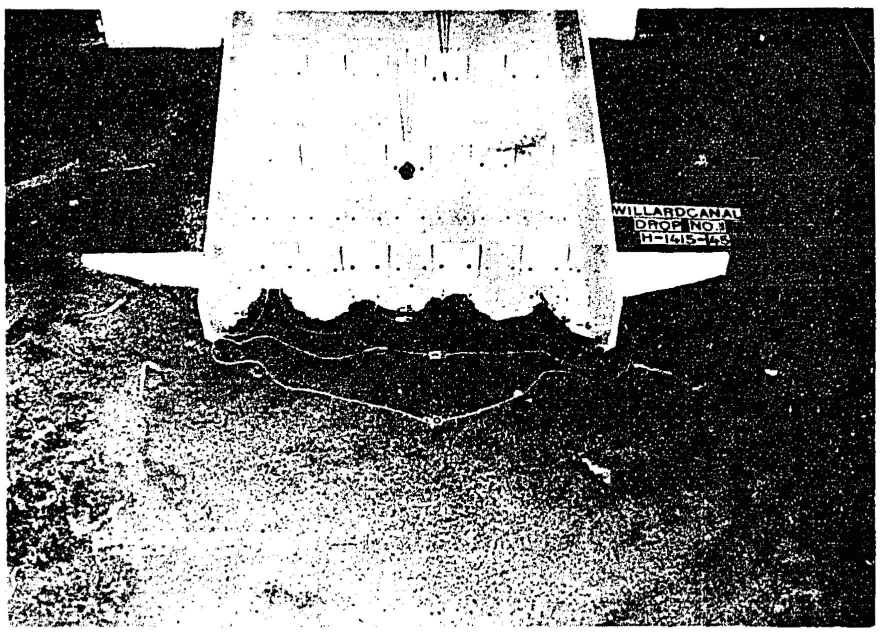
4 hours operation at 950 cfs.

T. W. Depth = 3.00 ft.

WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 1
Erosion with 12-Foot Row Spacing
1:10 scale model

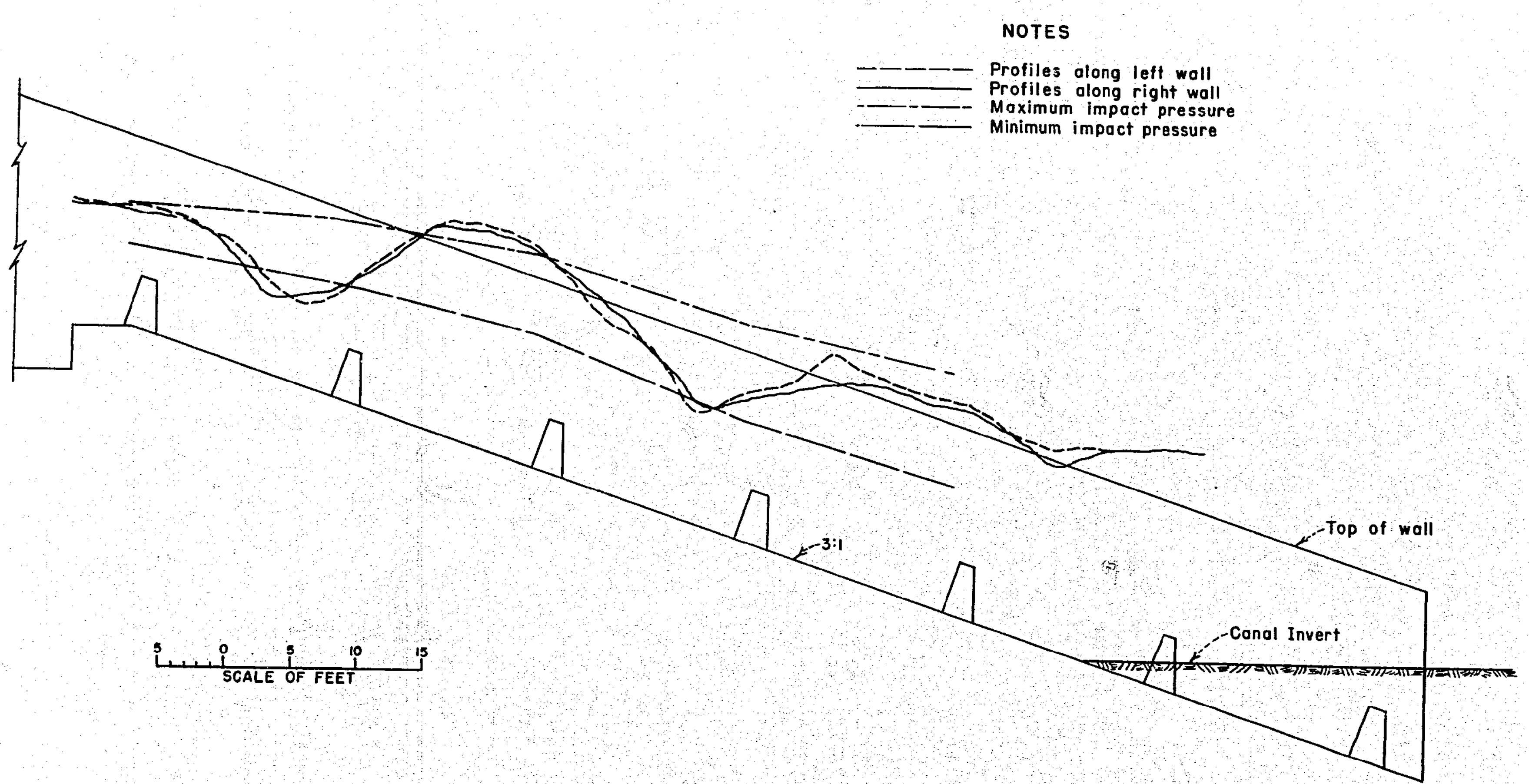


Discharge = 60 cfs per foot of width



Erosion after 2 hours operation

WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 1
Flow Appearance and Erosion with
16-Foot Row Spacing
1:13.33 scale model



WILLARD PUMPING PLANT NO. 1

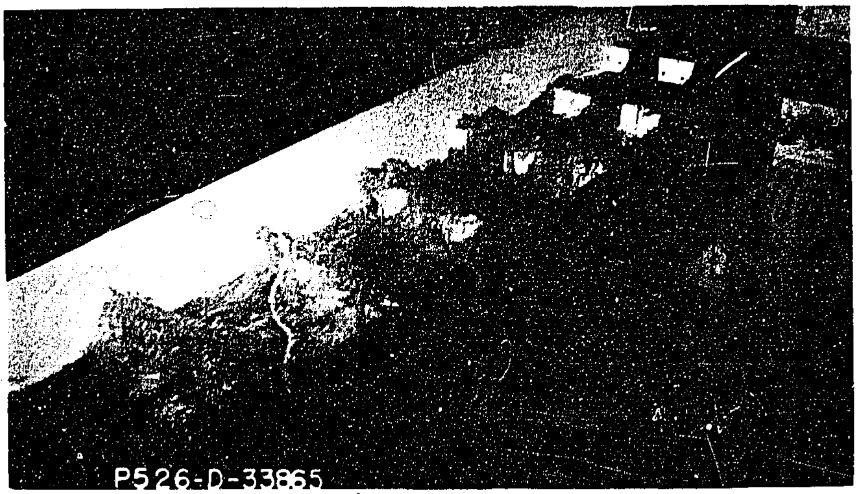
BAFFLED APRON DROP NO. 1
WATER SURFACE PROFILES AND IMPACT PRESSURES

UNIT DISCHARGE = 60 CFS PER FOOT OF WIDTH

1:13.33 SCALE MODEL

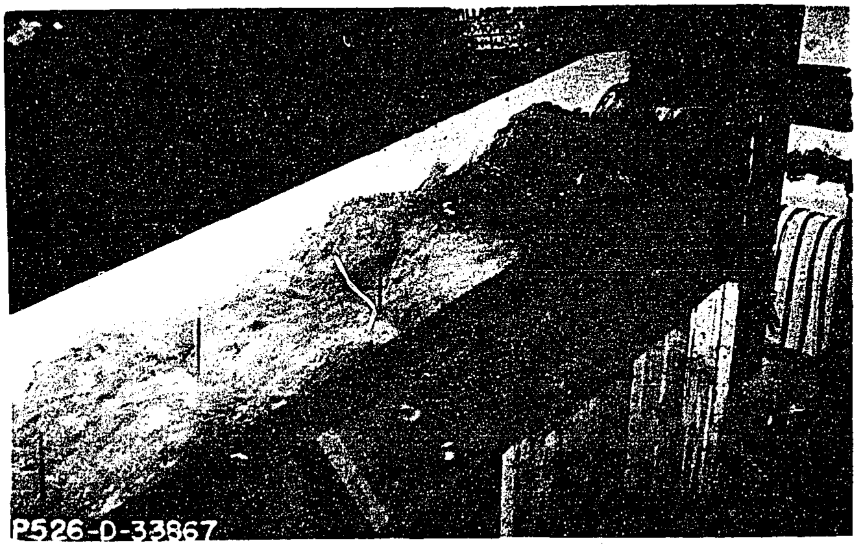
FIGURE 17
REPORT HYD. 490

634



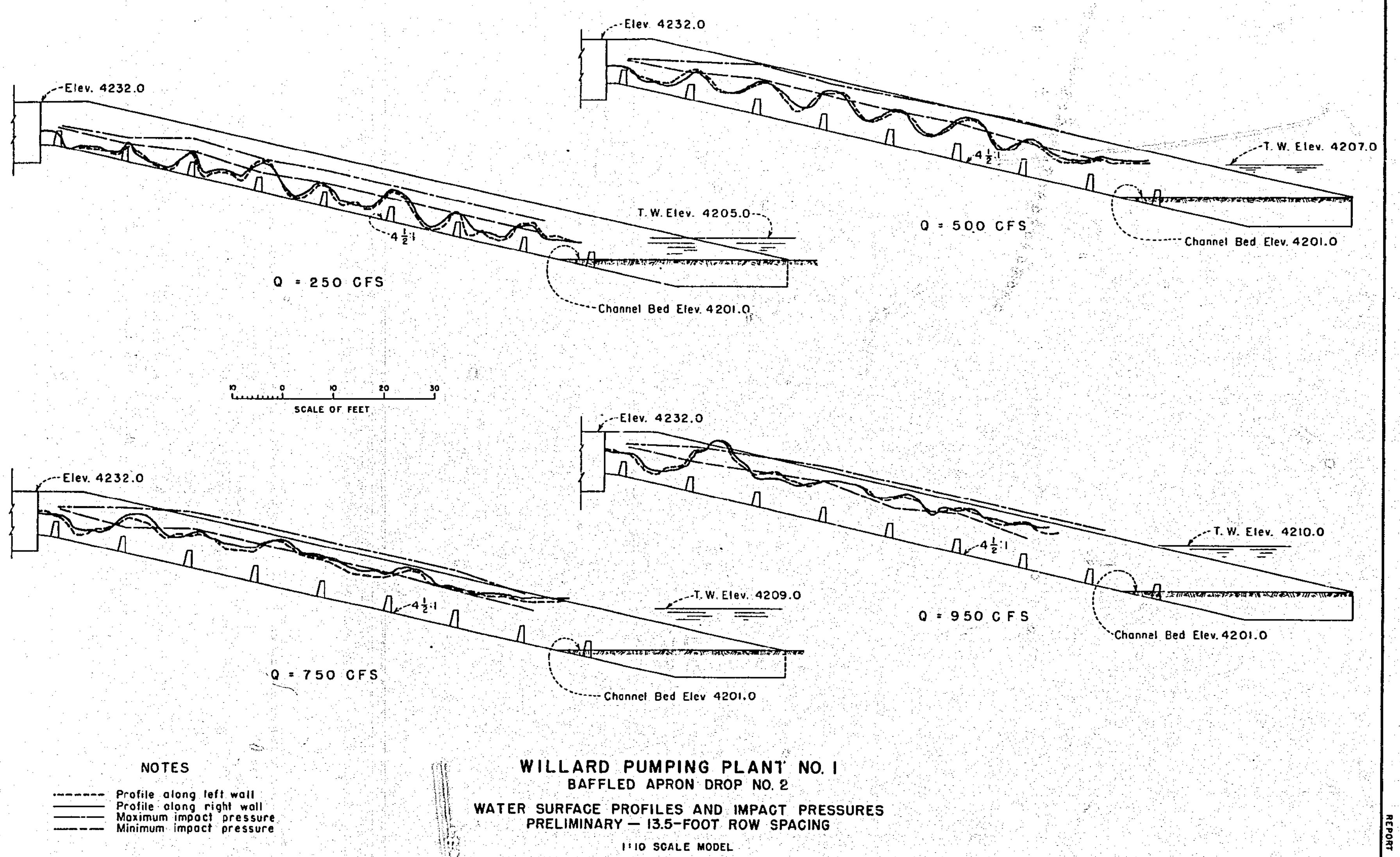
Discharge = 250 cfs

Discharge = 500 cfs

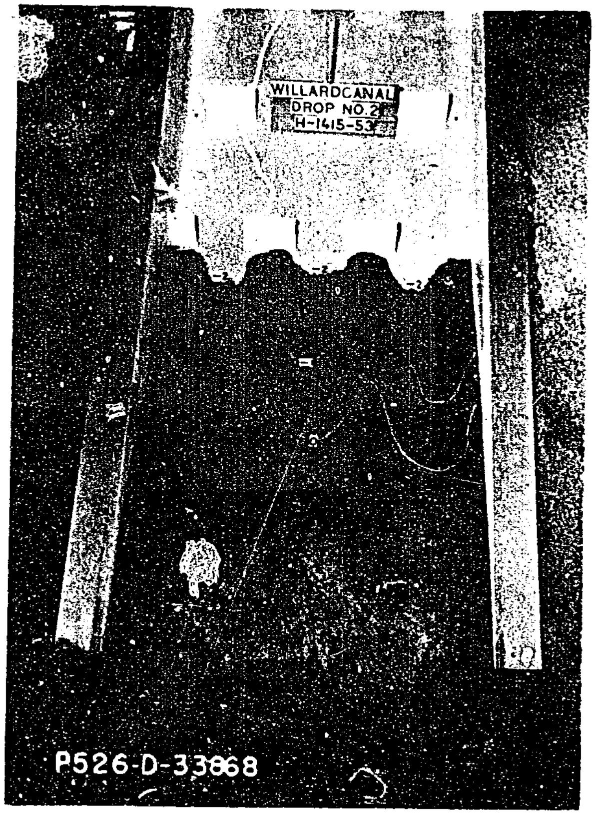


Discharge = 950 cfs

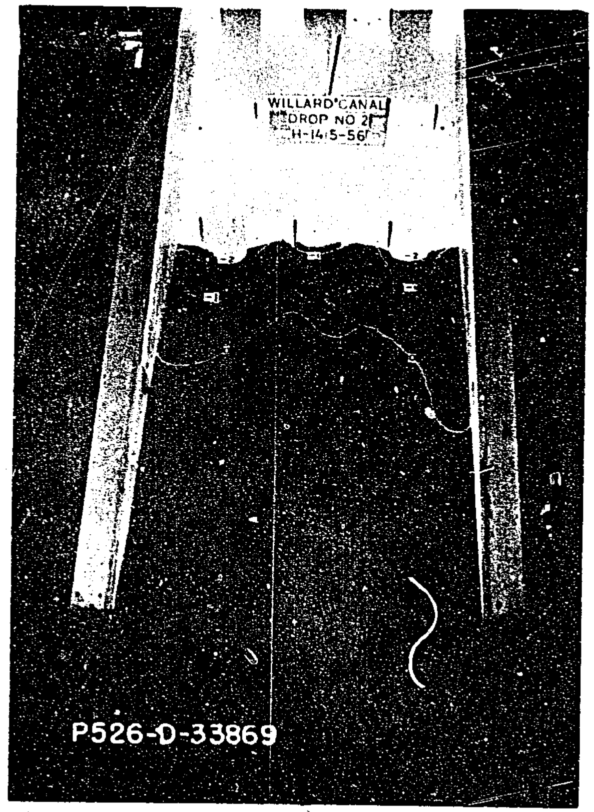
WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 2
Flow Appearance with 13.5-Foot Row Spacing
1:10 scale model



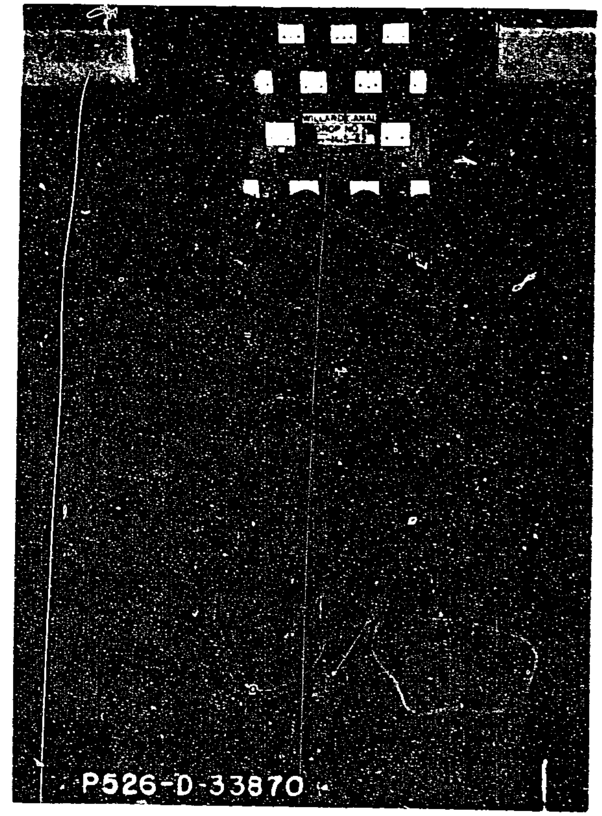
WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 2
WATER SURFACE PROFILES AND IMPACT PRESSURES
PRELIMINARY — 13.5-FOOT ROW SPACING
1:10 SCALE MODEL



3 hours operation at 250 cfs



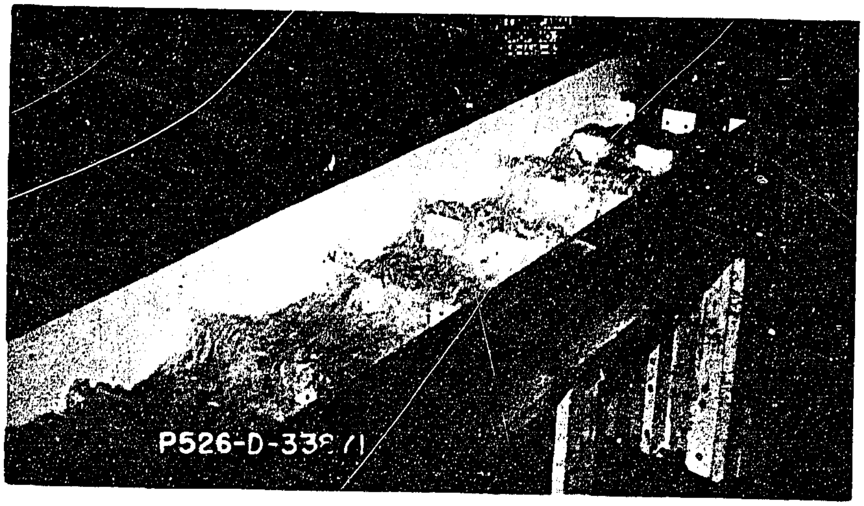
2 hours operation at 500 cfs



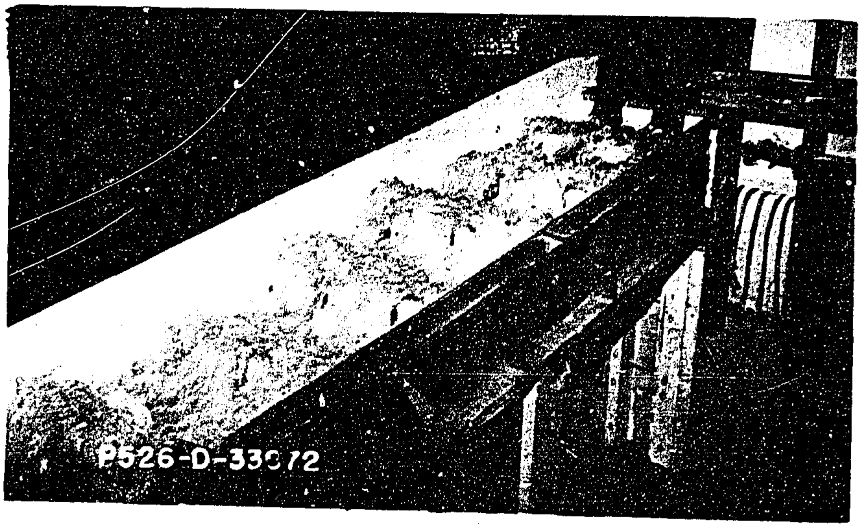
4 hours operation at 950 cfs

WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 2
Erosion with 13.5-Foot Row Spacing
1:10 scale model

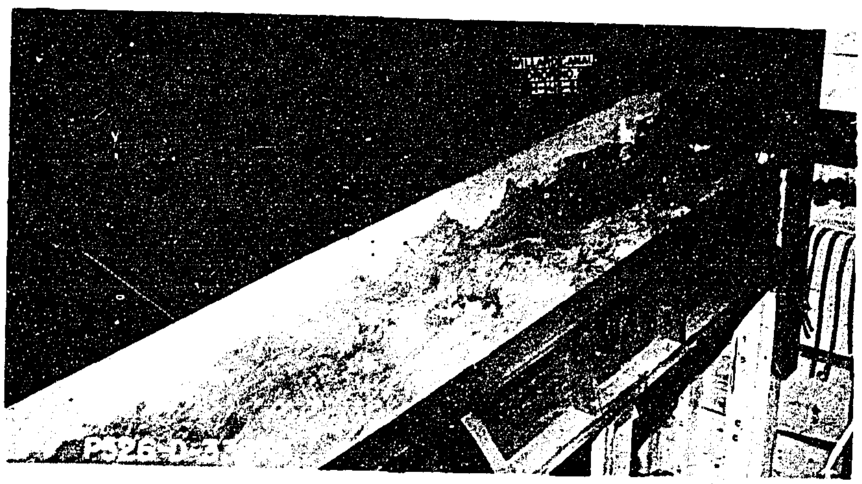
Figure 21
Report Hyd 490



Discharge = 250 cfs

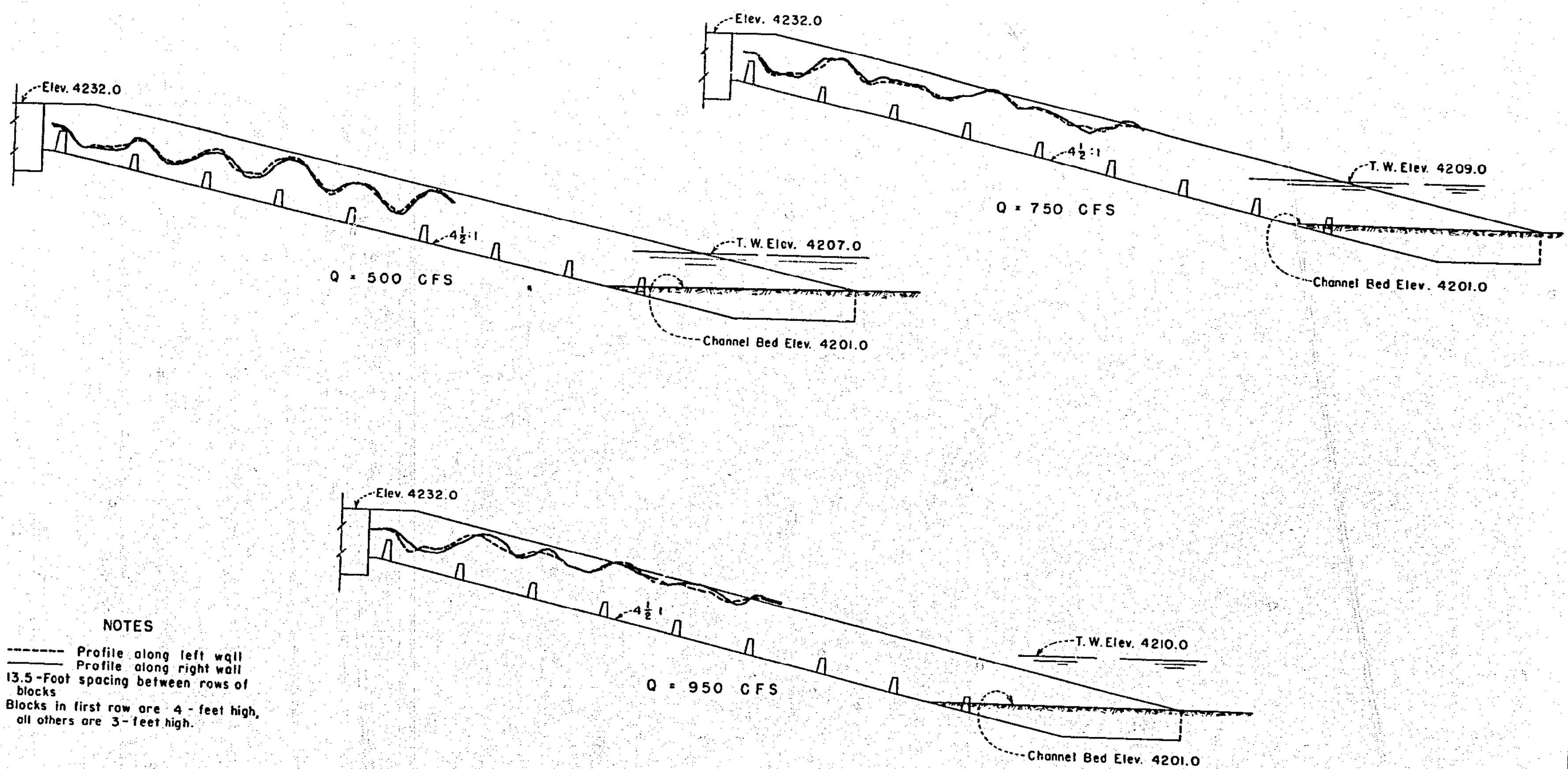


Discharge = 500 cfs



Discharge = 950 cfs

WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 2
Flow Appearance with First Modification
(Height of first row of blocks raised 1 foot)
1:10 scale model



NOTES

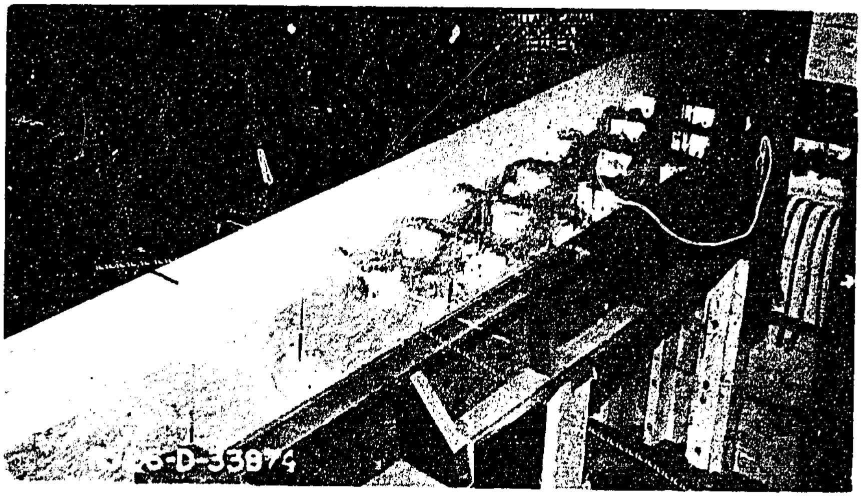
- - - - - - Profile along left wall
———— Profile along right wall
13.5-Foot spacing between rows of blocks
Blocks in first row are 4 - feet high, all others are 3 - feet high.

WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 2

WATER SURFACE PROFILES
FIRST MODIFICATION

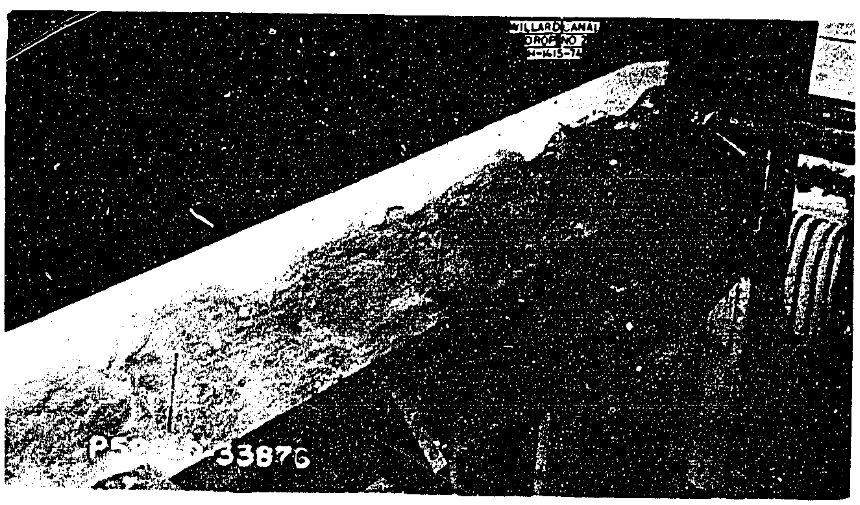
1:10 SCALE MODEL

Figure 23
Report Hyd 490



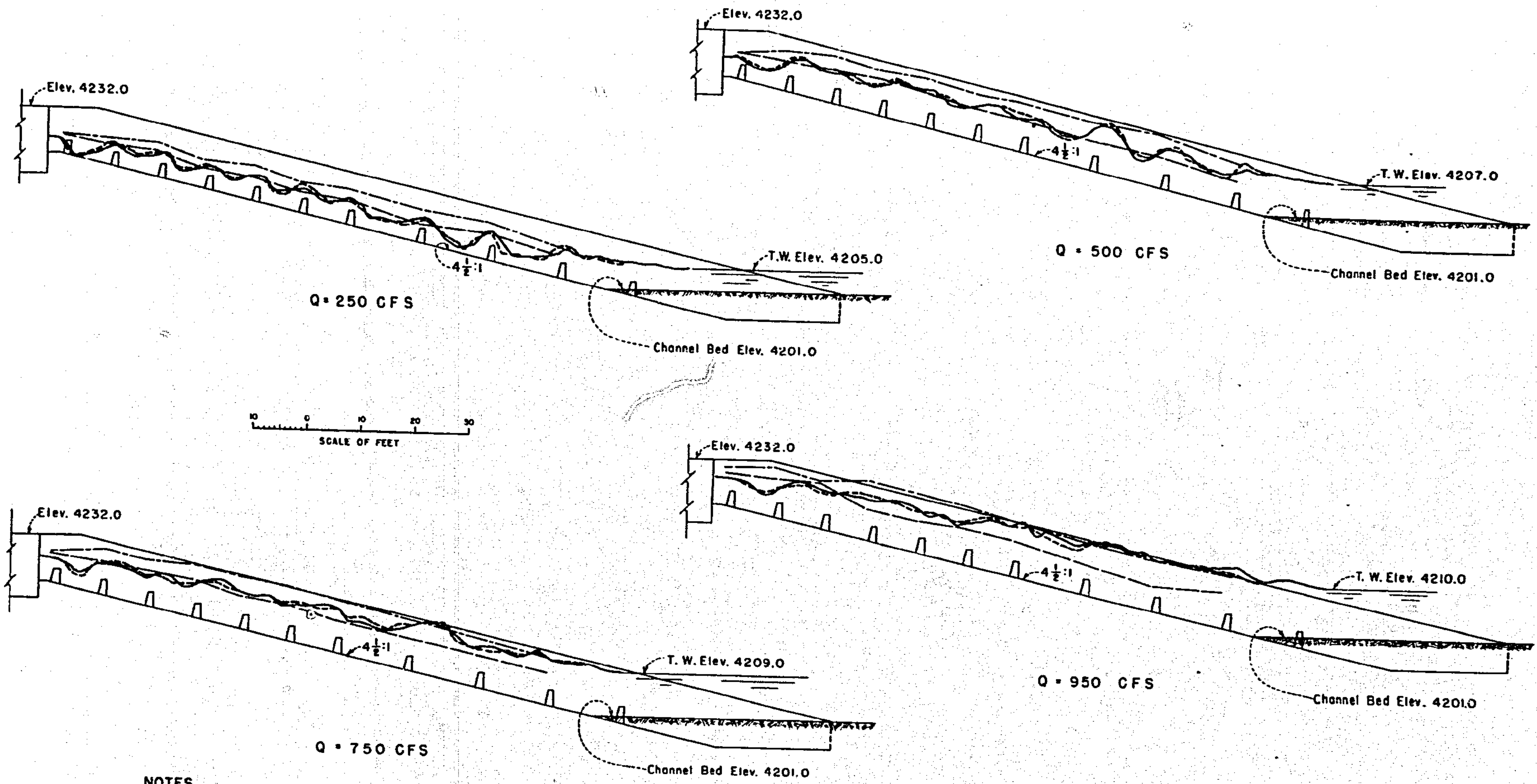
Discharge = 250 cfs

Discharge = 500 cfs



Discharge = 950 cfs

WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 2
Flow Appearance with Second Modification
(Rows 1-7 spaced 9 feet apart, 7-12 spaced 13.5 feet apart)
1:10 scale model

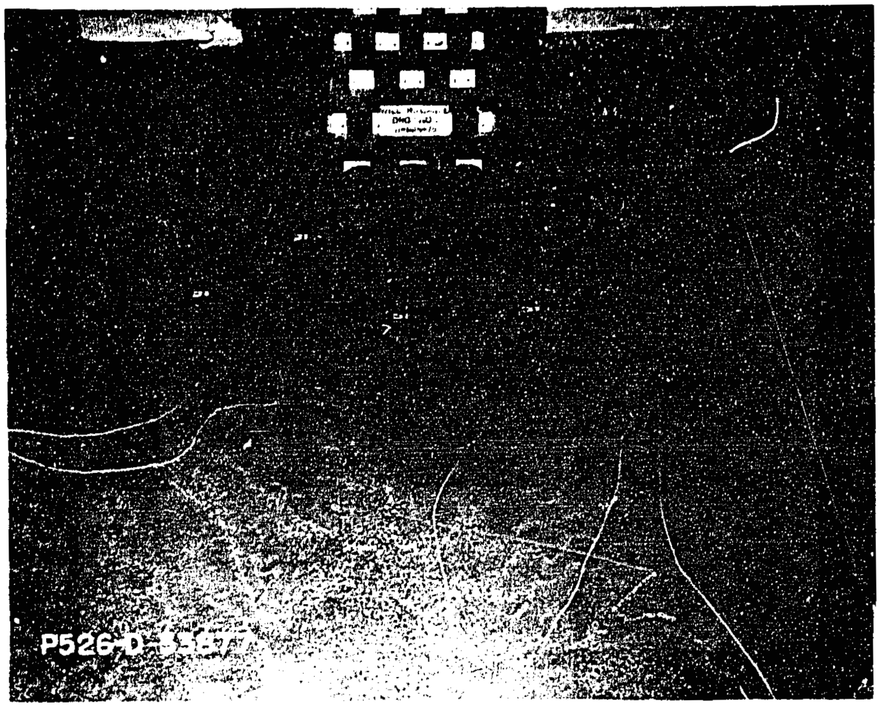


NOTES

- Profile along left wall
- Profile along right wall
- Maximum impact Pressure
- Minimum impact Pressure

Spacing between rows of baffle blocks
9-feet between rows 1 to 7
13.5-feet between row 7 - 11

WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 2
WATER SURFACE PROFILES AND IMPACT PRESSURES
SECOND MODIFICATION
1:10 SCALE MODEL



EROSION AFTER 8 HOURS OPERATION
AT 950 CFS DISCHARGE

WILLARD PUMPING PLANT NO. 1
BAFFLED APRON DROP NO. 2
Erosion with Second Modification
(Rows 1-7 spaced 9 feet apart, 7-12 spaced 13.5 feet apart)
1:10 scale model