UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

# HYDRAULIC MODEL STUDIES OF RUEDI DAM SPILLWAY AND OUTLET WORKS FRYINGPAN-ARKANSAS PROJECT, COLORADO

Report No. Hyd-534

Hydraulics Branch
DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

October 29, 1964

CONTENTS

CONTENTS--Continued

## ABSTRACT

Hydraulic model studies were performed to verify the design of the spillway crest, chute, and stilling basin; the junction of the auxiliary outlet works with the spillway chute; the outlet works stilling basin; and the Rocky Fork Creek bypass flume and stilling basin. The configuration of the structures is unusual in that the three stilling basins are located very close together and discharge into a common channel at three different angles. Flow conditions at the spillway inlet were satisfactory. Some turbulence developed at the inlet but was propagated only a short distance downstream; flow throughout the remainder of the chute was excellent. The discharge capacity of the spillway met design requirements. The spillway stilling basin was satisfactory for all discharges. Flow from the auxiliary outlet works tunnel into the spillway stilling basin was satisfactory. The performance of the service outlet works stilling basin was very good for both symmetrical and unsymmetrical operation. Dynamic pressure measurements on the sidewalls of the stilling basins fluctuated from about 30 feet of water below atmospheric to 80 feet of water above atmospheric. There was an adequate safety margin against sweepout in both basins. The Rocky Fork Creek bypass channel and stilling basin were satisfactory for discharges up to 1,720 cfs; at higher discharges the jump swept out of the basin as expected. Erosion tests indicated that additional riprap was necessary near the bypass basin but that little or no riprap was necessary in the river channel. In other areas, the specified riprap was adequate.

DESCRIPTORS--bypass channels/ *outlet works/ *spillways/ hydraulic models/ *stilling basins/ discharge coefficients/ discharge measurement/ backwater/ hydraulic jumps/ open channel flow/ wave action/ negative pressures/ safety factors/ bank protection/ riprap/ water surface profiles/ water pressures/ research and development/ model tests/ laboratory tests/ hydraulics/ scour/ hydraulic structures/ hydrostatic pressures/ turbulence/stream channels

IDENTIFIERS--Ruedi Dam/ Fryingpan-Arkansas Project/ sweepout


**RUEDI DAM**

FRYINGPAN-ARKANSAS PROJECT-COLORADO

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Office of Chief Engineer
Division of Research
Hydraulics Branch
Denver, Colorado
October 29, 1964

Report No. Hyd-534
Author: U. J. Palde
Checked by: T. J. Rhone
Reviewed by: W. E. Wagner
Submitted by: H. M. Martin

# HYDRAULIC MODEL STUDIES OF RUEDI DAM SPILLWAY AND OUTLET WORKS FRYINGPAN-ARKANSAS PROJECT, COLORADO

## PURPOSE

The purpose of this study was to verify the hydraulic design of the spillway crest, chute, and stilling basin; the junction of the auxiliary outlet works with spillway chute; the outlet works stilling basin; and the Rocky Fork Creek bypass flume and stilling basin, and to investigate the required geometry and extent of downstream river channel improvement and protection.

## CONCLUSIONS

1. Flow conditions in the spillway approach, inlet areas, and at the crest were satisfactory. Some turbulence was developed at the inlet, but was propagated only a short distance downstream; flow conditions throughout most of the chute were excellent. Figures 7 and 8.

2. Discharge capacity of the spillway at maximum reservoir elevation 7781.80 was found to be 5,540 cubic feet per second (cfs), yielding a coefficient of discharge of 3.53. Figure 9.

3. The spillway stilling basin performance was satisfactory for discharges up to the maximum discharge of 5,540 cfs. At the maximum discharge, the water surface fluctuated up to 15 feet and considerable splashing occurred. Average manometer pressures on the basin sidewalls were well above atmospheric and nearly hydrostatic, but instantaneous pressures fluctuated over 110 feet of water at some locations. Minimum pressures in the cavitation range were measured in the vicinity of the toe of the jump, Figure 11. Since their frequency was less than 25 percent of the time, no modifications to the structure were recommended.

4. Flow through the auxiliary outlet works junction with the spillway and into the stilling basin was satisfactory at the maximum outlet discharge of 600 cfs. Figure 12.

5. The outlet works stilling basin performance was very good for both symmetrical and one-gate operation for discharges of 1,950 and 975 cfs, respectively, Figure 13. Average sidewall manometer pressures were all nearly hydrostatic; there was considerable fluctuation in instantaneous dynamic pressures, up to 67 feet at some points, Figure 14. Tailwater sweepout tests indicated that the basin has a safety margin of about 6 feet of tailwater.

6. Rocky Fork Creek bypass flume and stilling basin performed very well for discharges up to 1,720 cfs with minimum tailwater elevation (no other structures operating) when the hydraulic jump begins to leave the basin. At the maximum probable discharge of 4,000 cfs the flume walls were slightly overtopped and the tailwater was completely swept out of the basin. Operation for 2.5 hours (prototype), with 4,000 cfs discharging, produced considerable damage to the downstream discharge channel, riprapped sideslopes, and adjacent unprotected areas. Figures 15, 16, 17, and 24.

7. Scour testing indicated that some of the proposed riprap protection in the main channel could be eliminated. Figures 18 and 21.

8. Some scour of the unprotected channel bed can be expected during extreme discharges, Figure 21. Particles up to 10 inches in diameter may be moved in the constricted channel to the left of the outlet works when the spillway is discharging 5,540 cfs and the bypass flume 1,200 cfs.

9. Increasing the height of two areas submerged by maximum tailwater during high discharges was effective in eliminating undesirable wave action on the bypass stilling basin walls and on the large unprotected area between the bypass flume and outlet works stilling basin. Figures 20 and 23.

10. Scour testing with smaller size riprap indicated that the 12- to 36-inch nominal size riprap specified would be more than adequate in all areas except possibly on the left side of the river channel downstream of the spillway stilling basin. Riprap smaller than about 15 inches, placed on slopes steeper than 2:1 adjacent to the exposed rock, would be moved at near maximum discharges. Figure 25.

## ACKNOWLEDGMENT

The studies described in this report were accomplished through cooperation between the Hydraulics Branch, Division of Research, and the Spillways and Outlet Works Section of the Dams Branch, Division of Design. Model photography was by W. M. Batts, Office Services Branch.

## INTRODUCTION

Ruedi Dam is one of the principal features of the Fryingpan-Arkansas Project, Colorado. The earthfill dam will be located on the Fryingpan River about 13 miles east of Basalt, Colorado, and just upstream from the confluence of Rocky Fork Creek with the Fryingpan River, Figure 1. The primary purpose of the reservoir will be replacement storage for downstream water users. Releases will be made from storage as required to replace upstream water diverted to the eastern slope.

The dam, Figure 2, is 285 feet high* above the riverbed, 1,060 feet long at the crest, and contains approximately 3,800,000 cubic yards of fill material.

The principal hydraulic features, Figure 3, are the spillway, the service outlet works, and an auxiliary outlet works. In addition, a bypass is provided to carry runoff from Rocky Fork Creek across the spillway stilling basin, and direct it into the main channel.

Design of the hydraulic structures was strongly influenced by the location of the dam, which is just upstream of an abrupt bend in the river. The confluence of Rocky Fork Creek with the Fryingpan River is just downstream of this bend. The most feasible location for a chute spillway (determined to be the most economical type) was on the right abutment, in a sandstone formation. The centerline of the chute and stilling basin was placed almost perpendicular to the river channel in order to take advantage of a rock formation in the left bank. It was felt that the rock formation could withstand the forces of the flow leaving the stilling basin and would facilitate turning of the flow in a downstream direction. The other hydraulic structures were then located so as not to interfere with the operation of, or cause damage to, the spillway chute and stilling basin, and vice vérsa.

The spillway, Figure 4, designed for a maximum discharge of 5,540 cfs, has a 25-foot-wide uncontrolled ogee crest at elevation

*A table of metric equivalents of important dimensions of these structures is located at the end of the text.

7766.00. The flow passes through a 1,000-foot-long chute--340 feet at .02 slope, a 100-foot vertical curve, and 560 feet on a 1.75:1 slope--into a hydraulic jump stilling basin with a floor at elevation 7450.00. The chute diverges from 25 feet wide at the start of the vertical curve to 31 feet wide at the stilling basin. The stilling basin, Figure 10, is 31 feet wide, 128.5 feet long, with vertical walls to elevation 7496.00, or 46 feet above the floor. The Type II basin has nine chute blocks 24 inches high and 20 inches wide, and a dentated end sill 7 feet high with three 4.5-foot-wide slots. Beyond the sill, a horizontal apron, also at elevation 7496.00 and excavated in rock, extends 60 feet to the intersection with a 1:1 excavated rock slope, Figure 3.

The auxiliary outlet works intake structure is located near the toe of the right embankment. Flow passes through a 6-foot-diameter tunnel to a gate chamber, then through a 5- by 6-foot flat-bottom tunnel to its junction with the spillway chute through a slot 72 feet upstream of the spillway stilling basin, Figure 3.

The intake structure for the outlet works, located about 200 feet upstream of the right toe of the dam embankment, leads into a 10-foot-diameter tunnel which terminates at a gate chamber. The flow then passes through a 76-inch steel pipe, a symmetrical Y-branch, and two 3.5- by 4-foot rectangular conduits, which lead to a control house containing two sets of two 3.5- by 4-foot high-pressure slide gates in tandem. The downstream gates are to be used to control the flow leading into a Type II stilling basin. The stilling basin, Figures 3 and 14, is 25.5 feet wide and 100 feet long, with its floor at elevation 7460.00. Vertical sidewalls extend 33 feet above the floor to elevation 7493.00. A 26-foot-high center wall terminates 33 feet upstream from the end of the basin.

A dike with its crest at elevation 7512.0 extends across the Fryingpan River just upstream of the spillway stilling basin. The dike diverts Rocky Fork Creek runoff through a bypass and flume. The bypass and flume, Figure 15, are 25 feet wide, about 275 feet long, and terminate in a 61.5-foot-long hydraulic jump stilling basin. The basin floor is at elevation 7473.00 and has 17-foot-high vertical sidewalls.

The downstream channel lies in alluvium material composed of boulders, cobbles, and gravel in a silt, sand, and clay matrix, with banks composed of talus and fine deposits. The channel will be excavated to a uniform width and slope for several hundred feet downstream of the hydraulic structures and will be protected with a 3-foot layer of 12- to 36-inch nominal size riprap, along both sides and on the bottom where required.

## THE MODEL

The 1:42 scale model, Figure 5, included a portion of the reservoir topography and upstream dam embankment adjacent to the spillway inlet; the spillway inlet, crest, chute, and stilling basin; the outlet works rectangular conduits just upstream of the control house, two 3-foot 6-inch by 4-foot 0-inch slide gates, and the outlet works stilling basin; the auxiliary outlet works junction with the spillway chute; the dike, flume, and stilling basin for the Rocky Fork Creek bypass; and a section of the excavated river channel extending about 250 feet downstream from the end of the outlet works stilling basin.

The spillway inlet walls and crest were fabricated from sheet metal, while the spillway chute, the Rocky Fork Creek bypass, and the three stilling basins were made of plywood. Cement mortar was used to form all reservoir topography and river channel topography above elevation 7490, as well as to represent the exposed rock downstream from the spillway stilling basin. River channel topography and improvements below elevation 7490 were formed in sand and gravel to facilitate scour testing.

Rock baffles were placed at the upstream ends of the reservoir headbox and the river channel tailbox to smooth out flows entering the reservoir and the Fryingpan River (from Rocky Fork Creek), respectively.

Flow to the reservoir headbox was supplied through the laboratory's central supply system and measured with permanently installed volumetrically calibrated Venturi meters. Reservoir water surface elevation was measured by means of a hook gage in a stilling well connected to a bottom opening near the center of the headbox. Rocky Fork Creek runoff flowing into the downstream river channel was supplied by a portable vertical turbine-type pump and measured with a Venturi-orifice meter. Tailwater elevations were controlled by an adjustable tailgate at the downstream end of the model and measured on a staff gage located 300 feet downstream from the end of the outlet works stilling basin. The tailwater elevations were determined from the curve shown on Figure 6.

Average pressures on the three stilling basin sidewalls were measured through piezometers connected to open-tube manometers. Instantaneous pressures were measured with electronic pressure cells which actuated a direct writing oscillograph. Water surface elevations in the spillway chute were obtained by point gage traverses.

## THE INVESTIGATION

In this report the investigation was divided, with some overlapping, into two phases: first, hydraulic performance of the three hydraulic structures including the effectiveness of the stilling basins under various operating combinations and second, the required geometry and extent of river channel improvement and protection.

Although the degree of riprap protection required downstream from the stilling basins depends on their efficiency as energy dissipators, the investigation of the required protection will be discussed as part of the second phase.

### Performance of Hydraulic Structures

Spillway crest and chute. --For the maximum discharge of 5,540 cfs, the flow approaching the inlet was very smooth. However, there was some turbulence on the left side, caused by water entering the inlet across the approach walls normal to the direction of flow, Figure 7A. The effect of this turbulence on the water surface level at the spillway crest can also be seen in the water surface profiles in Figure 8.

About 35 feet downstream from the crest, at Station 10+10, the water surface had smoothed considerably, and by the time the flow had reached the start of the vertical bend, Station 13+39.42, the water surface was practically level, Figures 7B and 8. The spillway flows also passed over the auxiliary outlet works junction with a minimum of disturbance, Figure 7C.

The excellent flow conditions in the chute just upstream of the vertical curve further supported by very close agreement of the model spillway discharge capacities with those assumed in design, indicated that modification of the entrance to decrease the turbulence at the crest was unjustified.

Spillway discharge capacity. --The discharge capacity of the spillway at assumed maximum reservoir elevation 7781.80 was found to be 5,540 cfs. These values yield a coefficient of discharge, $C_d$, of 3.53, duplicating the value assumed in the design of the spillway. A curve of reservoir elevation versus discharge is plotted, along with the corresponding coefficients of discharge, in Figure 9. The coefficients were computed from the equation $Q = C_d L(H)^{3/2}$, where Q is the discharge in cubic feet per second, L is the length at the spillway crest, and H is the head on the crest (reservoir elevation minus crest elevation).

Spillway stilling basin. --The spillway stilling basin performed satisfactorily for all discharges up to and including the maximum of 5,540 cfs. At the maximum discharge, Figure 10, there was considerable fluctuation in water surface, at some points as high as 15 feet between maximum and minimum, Figure 11. The fluctuation was irregular; that is, no periodic oscillation or surging was evident. Random surges overtopped the walls near the end of the basin, and occasional splashing brought water to the top of the walls as far as 80 feet upstream; also, occasional splashes hit the underside of the Rocky Fork Creek bypass flume. None of the splashing was considered detrimental to the structures, but would probably produce heavy spray in the prototype.

All average pressures observed on the stilling basin sidewalls, Figure 11, were well above atmospheric, and--except in the vicinity of the chute blocks--were nearly hydrostatic as indicated by close agreement with the average of the maximum and minimum of the water surface at the same points. There was considerable fluctuation in instantaneous dynamic pressures at some points. In the vicinity of the toe of the jump the range was about 110 feet of water, and minimum pressures equivalent to vapor pressure were recorded, Figure 11. Since the low pressures occurred less than 25 percent of the time, no modifications were recommended.

Although the mushroom boil of the jump extended beyond the end of the stilling basin, turbulence along the floor was quite low, and the flow was smooth after it had turned and entered the main channel. Waves hitting the exposed rock directly opposite the basin splashed no higher than elevation 7498, well below the upper limits of the rock as indicated by preliminary explorations.

Auxiliary outlet works. --The performance of the auxiliary outlet works was judged on the flow conditions at its junction with the spillway chute and on the appearance of the flow as it entered the spillway stilling basin. A thin leaf gate located in the rectangular section just upstream of the junction was used to provide the proper flow depth at the maximum discharge of 600 cfs. The auxiliary outlet works will not be operated when the spillway is discharging; therefore, this condition was not investigated.

Flow through the junction and in the stilling basin was satisfactory for the maximum discharge of 600 cfs, Figure 12.

Outlet works stilling basin. --Flow into the outlet works stilling basin was controlled by a thin leaf slide gate in each of the two conduits representing the downstream prototype control gates. The gates were calibrated to yield discharges of 1,810 and 2,000 cfs at maximum reservoir elevation 7781.80, corresponding to maximum and minimum head loss through the outlet works, respectively. The minimum loss discharge for reservoir elevation 7766.00 (spillway crest) is 1,950 cfs, which was used to evaluate the stilling basin performance with outlet works only operating, Figure 13A.

At the 1,950 cfs discharge with tailwater at elevation 7481.5, the jump in the stilling basin was steady; energy dissipation was excellent, and all pressures on the sidewalls were nearly hydrostatic except in the vicinity of chute blocks, Figure 14, where they were slightly subatmospheric. The maximum fluctuation between maximum and minimum water surface was about 8 feet, and occurred about 50 feet from the end of the basin. No overtopping by either surging or splashing was evident. The center dividing wall, however, was frequently overtopped. The basin also performed well when operated in combination with maximum discharges from the other structures and the corresponding higher tailwater. Flow conditions were also excellent with only one gate discharging, Figure 13B.

Tailwater sweepout tests indicated that the tailwater would have to be lowered about 6 feet before the toe of the jump uncovered the stilling basin chute blocks. This would require extreme degradation of the downstream channel and complete scour of the outlet channel riprap.

Instantaneous pressure measurements on the basin walls indicated dynamic pressure fluctuations up to 67 feet of water in the vicinity of the toe of the jump, with a minimum of 21 feet below atmospheric, Figure 14.

Due to the excellent performance, no changes were recommended in the outlet works stilling basin.

<u>Rocky Fork Creek bypass.</u>--The maximum probable flood was computed to have a peak flow of 4,380 cfs. The maximum flow tested in the model was 4,000 cfs. Because of the physical relationship of the drainage areas, the maximum flow that can be expected in combination with the maximum spillway discharge is 1,200 cfs. A 100-year flood discharge is 880 cfs.

The stilling basin performed very well at 1,200 cfs with tailwater elevations resulting from various operating combinations of the other structures, Figure 15. The hydraulic jump was somewhat choppy, but flow leaving the basin was sufficiently smooth to insure good downstream flow conditions. Basin sidewall pressures and maximum and minimum water surface profiles, Figure 16, were obtained for 1,200 cfs discharging in combination with an outlet works discharge of 1,950 cfs and tailwater elevation 7482.3. Instantaneous dynamic pressures, obtained for the 1,200-cfs discharge with the tailwater at elevation 7480.7, did not fluctuate over 8 feet, Figure 16.

The stilling basin also performed well at the 1,200-cfs discharge in combination with the maximum outlet works discharge plus maximum spillway discharge with a corresponding tailwater elevation of 7485.0, Figure 15B.

A flow of 4,000 cfs produced extremely unfavorable flow conditions, Figure 17. The water surface in the flume was just at the top of the sidewalls and occasionally overtopped them. The jump was completely swept out of the basin with tailwater at 7483.9, which is the maximum possible with outlet works discharging 1,950 cfs. The high velocity flow leaving the stilling basin produced considerable damage to the downstream channel.

Tailwater sweepout tests with the bypass only operating indicated that the jump began to sweep out at a discharge of 1,720 cfs with a corresponding tailwater elevation of 7481.3. The jump was completely swept out at a discharge of 2,060 cfs. The jump was considered swept out when the toe of jump left the junction of sloping chute and the stilling basin floor.

In the design of the Rocky Fork Creek bypass it had been determined that the jump would sweep out of the basin at a discharge of approximately 2,000 cfs. The model studies confirmed this premise; therefore, no changes were made to attempt to improve the flow conditions. A flood with a peak of 2,000 cfs is estimated to have a frequency of from 500 to 1,000 years.

## River Channel Protection

The model was initially operated under maximum discharge conditions for a short time without any riprap protection; that is, the channel was shaped in loosely packed sand in all areas below maximum tailwater elevation. After a qualitative examination of the resulting scour, it was decided that the channel would first be lined with a 36-inch-thick layer of riprap as specified in the preliminary design, Figure 18. Any improvements in geometry and possible elimination of riprap would be determined by model investigation.

Preliminary investigation.--A layer of 3/8- to 3/4-inch gravel, representing prototype riprap sizes of about 15 to 32 inches, was first used in the model. Erosion could be expected to occur in a number of areas, including the river channel downstream of the spillway stilling basin adjacent to the probable limits of the rock outcrop, where the riprap would be placed on approximately a 1.5:1 slope; downstream of the outlet works stilling basin at the end of the 4:1 slope leading to the main channel and the riprap jetty which separates this area from the main channel; and just downstream, and especially to the right of, the Rocky Fork Creek bypass stilling basin. Also, the unprotected areas to the left of the bypass stilling basin at elevation 7486.5 and to the left of the outlet works stilling basin at about elevation 7485.0 could be expected to erode due to wave action at high tailwater.

The model was operated with the outlet works only discharging 1,950 cfs, with the spillway only discharging 5,540 cfs, with the bypass flume only discharging 1,200 cfs, and with various combinations of the three structures operating at the above discharges, Figure 19. None of the operating conditions caused any movement of the riprap during a 20-hour (prototype) test period.

When all three structures were operating, with the corresponding tailwater at elevation 7485.0, the two unprotected areas to the left of the bypass and outlet works stilling basins were submerged, Figure 20. Waves produced slight washing of sand in the large unprotected area between the bypass stilling basin and the outlet works, Figure 20A. More extensive washing was evident in the area to the left of the bypass stilling basin, Figure 20B, and some sand was deposited on the 2:1 slope adjacent to the end of the basin. Occasional waves also overtopped the stilling basin wall.

It was recommended that the two low areas be raised so that they would be above maximum tailwater, which would prevent the waves from overtopping the unprotected area and eliminate the sand movement.

As was mentioned previously, with a flow of 4,000 cfs through the Rocky Fork Creek bypass, the hydraulic jump was swept out of the stilling basin and the high velocity flow produced considerable scour on the downstream right bank. It was decided that further improvement in this area would be attempted only after investigation of other changes had been completed.

First modification--Recommended.--The flat area to the left of the outlet works stilling basin was raised to elevation 7489.5. The area between the bypass stilling basin and the spillway stilling basin was raised to elevation 7490.0. The 2:1 riprapped slopes on either side of this area were also extended to elevation 7490.0. This provided a 10-foot-wide protective riprap bank 3.5 feet higher than the previous bank, Figure 21.

In addition, the riprap was removed from the main channel bed to within 10 feet of the toe of the bank slopes, except for a distance of 40 and 70 feet, respectively, from the end of the 4:1 slopes downstream of the spillway and outlet works stilling basins. The riprap was not removed from the bypass channel between the flume and the main river channel. The removed riprap was replaced with sand containing random gravel particles up to three-eighths inch in size, which was leveled and loosely packed in place. The revisions are shown in Figure 21.

Operation of the outlet works at 1, 950 cfs caused erosion of finer sand particles downstream of the riprap. Operation equivalent to 26 prototype hours resulted in a maximum depth of erosion of about 4 feet, Figure 22A. The maximum-size particles removed were about 3/16 inch, or about 8 inches prototype.

Operation of the outlet works at 2, 000 cfs, the spillway at 5, 540 cfs, and the bypass flume at about 3, 000 cfs for about 20 prototype hours produced scour in other areas where the riprap had been removed. The main channel was eroded up to 7 feet deep in the constricted area to the left of the outlet works stilling basin and the finer sand particles were deposited in a bar downstream and in line with the jetty separating the outlet works and main river channels, Figure 22B. Maximum size particles removed were about one-fourth inch, or about 10 inches prototype.

A small amount of scour, not more than 3 feet deep, occurred downstream from the riprapped areas of both the bypass and spillway basins. The maximum size particles removed were less than 3/16 inch, or 8 inches prototype.

Since the sand used in the channel was not scaled representation of bed material to be found in the prototype, the same degree of erosion cannot be expected to occur in the prototype. The maximum-size particles removed from the various areas should, however, give an indication of the approximate size of loose bed material that would be moved during severe discharges.

The elevated areas proved to be effective in eliminating the previously observed undesirable effects of wave action resulting from a bypass flume discharge of 1, 200 cfs in combination with maximum discharges from the other two structures, Figure 23.

The remaining riprapped areas along the main channel bank and downstream from the bypass stilling basin, held up well under all combinations of discharges, except for slight riprap movement downstream of the bypass for discharges when the jump begins to sweep out of the stilling basin. It was evident, however, that wave action at high discharges would not permit removal of this protection.

Scour from maximum bypass discharge. --With 4,000 cfs discharging from the Rocky Fork Creek bypass, and minimum possible tailwater, Figure 24A, the jump was swept out of the stilling basin, and the high velocity flow produced considerable scour of the maximum-size riprap in the discharge channel leading to the main river channel. After initial removal of material from the bed, sloughing of the right bank riprap occurred. This movement of riprap gradually advanced downstream and exposed the unprotected sand at elevation 7489.5 which was immediately washed away. The material was deposited in the vicinity of the junction with the main channel. The left bank was not eroded. Areas of scour and deposition after 2.5 hours' prototype operation can be seen in Figure 24B. Similar scour, to a lesser degree, would occur for discharges down to about 2,000 cfs. For discharges less than 2,000 cfs, the jump remained in the basin and there was no erosion problem.

Reduced riprap size. --Investigations were made with smaller riprap in areas of high turbulence to determine whether the larger riprap was necessary. The 1/4- to 3/8-inch gravel, representing about 10- to 15-inch prototype rock, was placed on both sides downstream of the spillway basin and on the 4:1 slope downstream of the outlet works basin, Figure 25A.

Operation of the spillway at 5,540 cfs for 20 prototype hours resulted in considerable removal of riprap on the left side of the channel downstream from the spillway stilling basin, on the approximately 1.5:1 slope adjacent to the assumed limits of exposed rock, Figure 25B. This removal of riprap indicated that placement of the smaller riprap on slopes steeper than 2:1 should be avoided in this area. The riprap placed to the right of the exposed rock on approximately a 1.5:1 slope stayed in place, as did the riprap on the 4:1 slope and in the main channel.

Several hours of outlet works operation at 1,950 cfs showed no signs of movement of the smaller riprap in the outlet works discharge channel.

Table 1

METRIC EQUIVALENTS TO IMPORTANT QUANTITIES
REFERRED TO IN THIS REPORT

| Feature | English units | Metric units |
|---|---|---|
| Height of dam | 285 feet | 86.868 meters |
| Length of dam | 1,060 feet | 323.880 meters |
| Volume of fill | 3,800,000 cubic yard | 2,900,000 cubic meters |
| Width of spillway | 25 feet | 7.620 meters |
| Length of spillway chute | 1,000 feet | 304.800 meters |
| Drop from spillway to basin | 316 feet | 96.317 meters |
| Width of spillway basin | 31 feet | 9.449 meters |
| Length of spillway basin | 128.5 feet | 39.167 meters |
| Height of spillway basin walls | 46 feet | 14.021 meters |
| Dentates on end sill | 4.5 x 7.0 feet | 1.372 x 2.134 meters |
| Size of auxiliary O.W. | 5.0 x 6.0 feet | 1.524 x 1.829 meters |
| Service O.W. gates | 3.5 x 4.0 feet | 1.067 x 1.219 meters |
| O.W. basin width | 25.5 feet | 7.772 meters |
| O.W. basin length | 100 feet | 30.48 meters |
| O.W. basin, sidewall height | 33 feet | 10.058 meters |
| Bypass flume width | 25 feet | 7.620 meters |
| Bypass flume length | 275 feet | 83.820 meters |
| Bypass flume stilling basin length | 61.5 feet | 18.745 meters |
| Bypass flume basin depth | 17 feet | 5.182 meters |
| Riprap size | 12 to 36 inch | 30.480 to 91.440 cms. |
| Spillway max Q | 5,540 cubic feet per second | 156.876 cubic meters per second |
| Auxiliary O.W. max Q | 600 cubic feet per second | 16.990 cubic meters per second |
| Service O.W. max Q | 2,000 cubic feet per second | 56.634 cubic meters per second |
| Bypass channel design Q | 1,200 cubic feet per second | 33.980 cubic meters per second |
| Bypass channel max Q | 4,000 cubic feet per second | 133.268 cubic meters per second |

FIGURE 1
REPORT HYD. 534

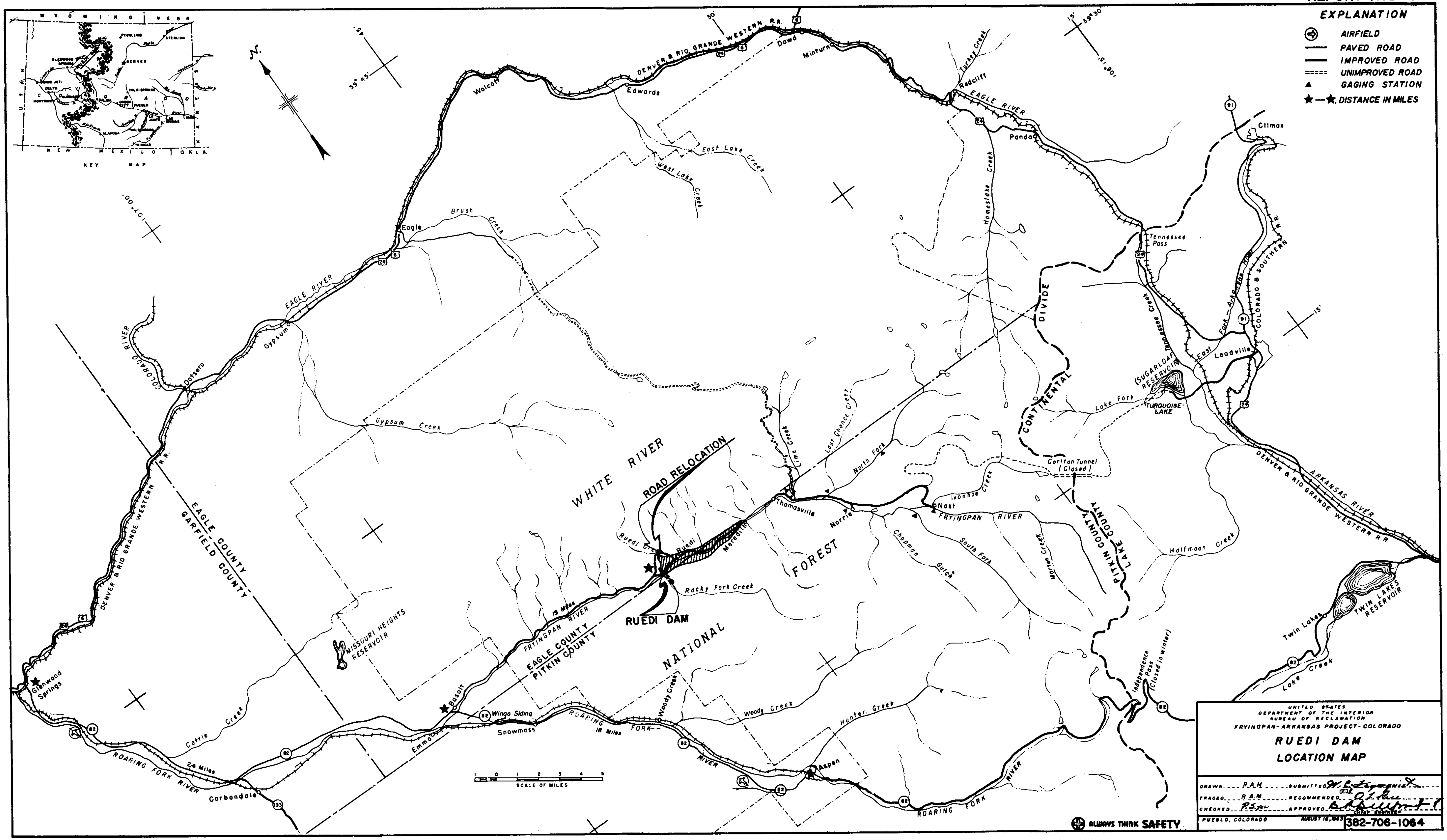
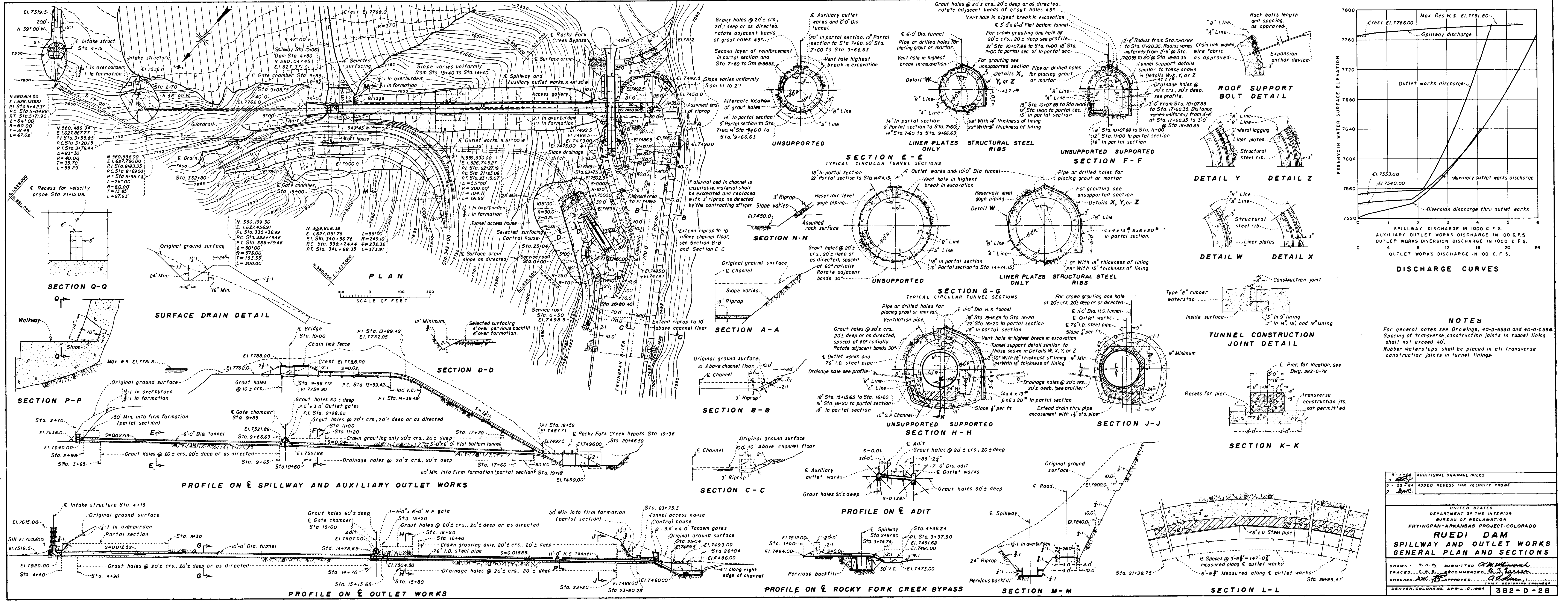
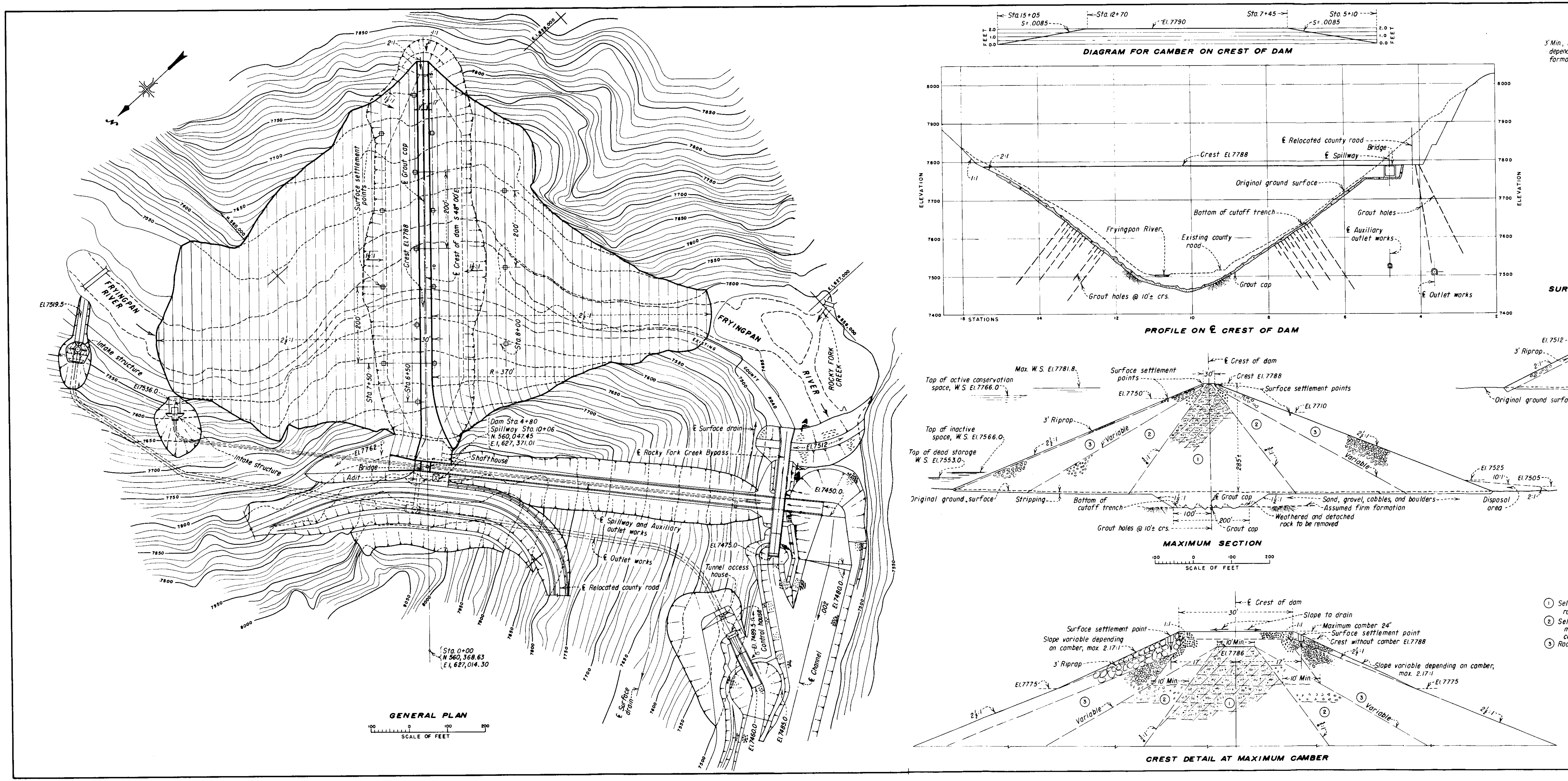
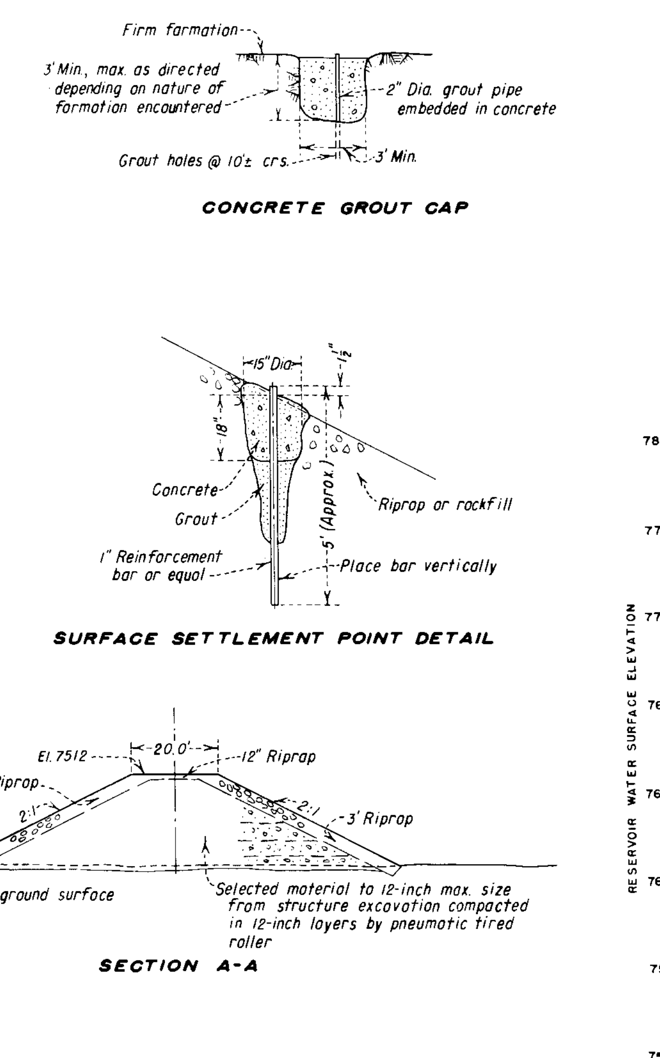


FIGURE 3
REPORT HYD. 534



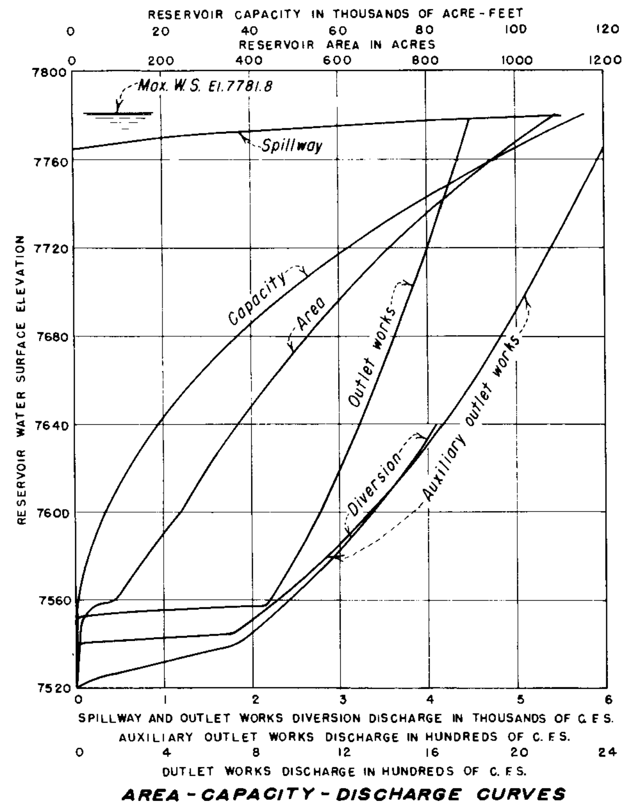



## RESERVOIR STORAGE ALLOCATIONS

| PURPOSE | ELEVATIONS | STORAGE ACRE-FEET |
|---|---|---|
| Active conservation | 7566.0 to 7766.0 | 100,048 |
| Inactive | 7553.0 to 7566.0 | 881 |
| Dead | Streambed to 7553.0 | 130 |
| Total reservoir capacity | | 101,059 |

A surcharge of 16,504 a.f. (Max. W.S. El. 7781.8) plus a spillway discharge of 5540 c.f.s. and a river outlet discharge of 1810 c.f.s. is provided to protect against the inflow design flood which has a peak of 17,500 c.f.s. and 15-day volume of 110,000 a.f.




AREA - CAPACITY - DISCHARGE CURVES

### EMBANKMENT EXPLANATION

(1) Selected clay, silt, sand, gravel and cobbles compacted by tamping rollers to 6-inch layers

(2) Selected material of sand, gravel and rock fragments to 12 inch max. size from required excavation, and from rock source compacted in 12" layers by pneumatic tired roller

(3) Rockfill placed in 3-foot layers

| | |
|---|---|
| 5-21-64 D. A.Z. | DELETED NOTE PERTAINING TO RESERVOIR STORAGE ALLOCATIONS REGARDING ALLOWANCE FOR SEDIMENT DEPOSITION AND LABELED CUTOFF TRENCH SIDE SLOPES |

ALWAYS THINK SAFETY

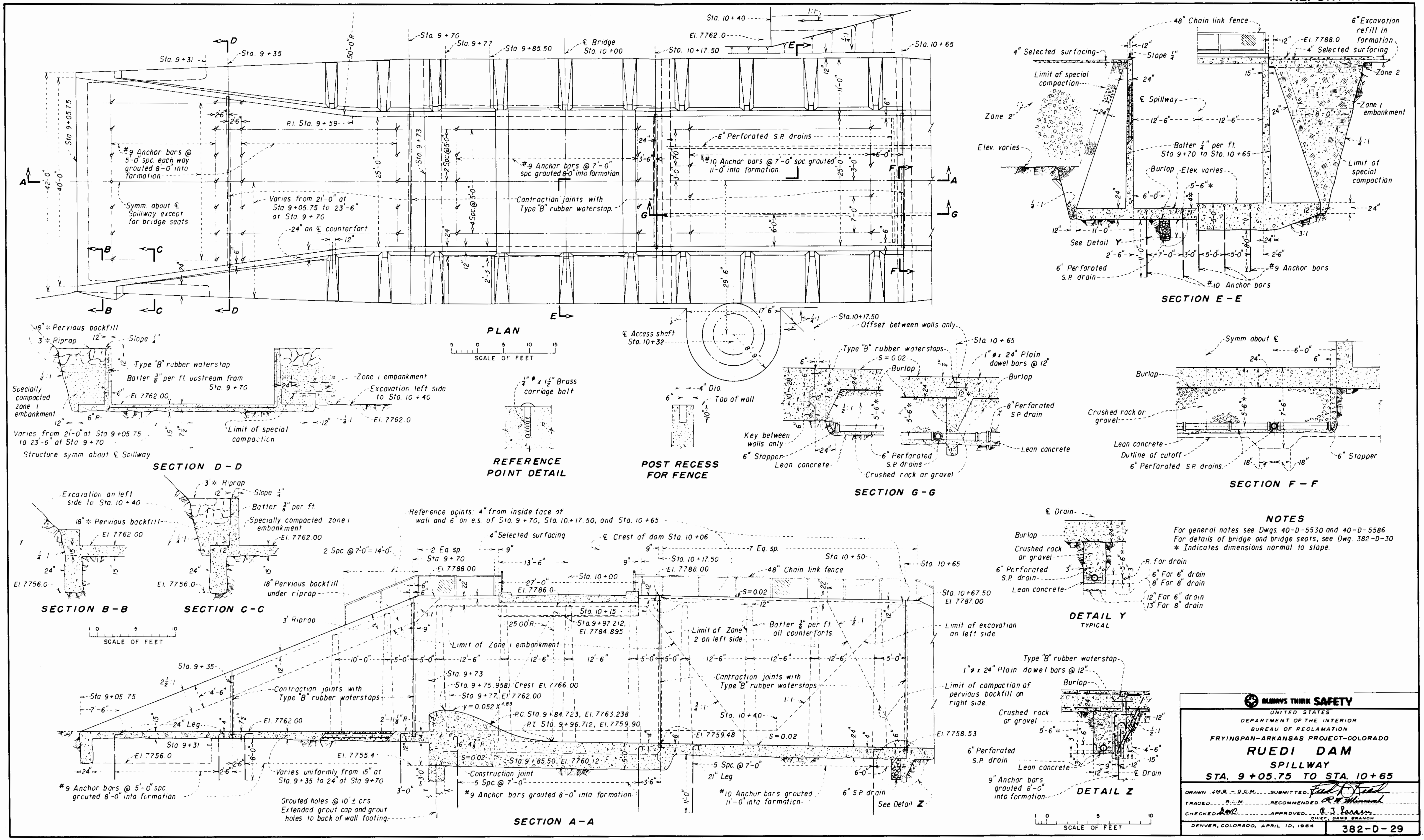
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
FRYINGPAN-ARKANSAS PROJECT - COLORADO

## RUEDI DAM
## GENERAL PLAN AND SECTIONS

DRAWN A.Z. SUBMITTED [signature]
TRACED W.A.P. RECOMMENDED R. J. Larsen
CHECKED [signature] APPROVED [signature] CHIEF DESIGNING ENGINEER

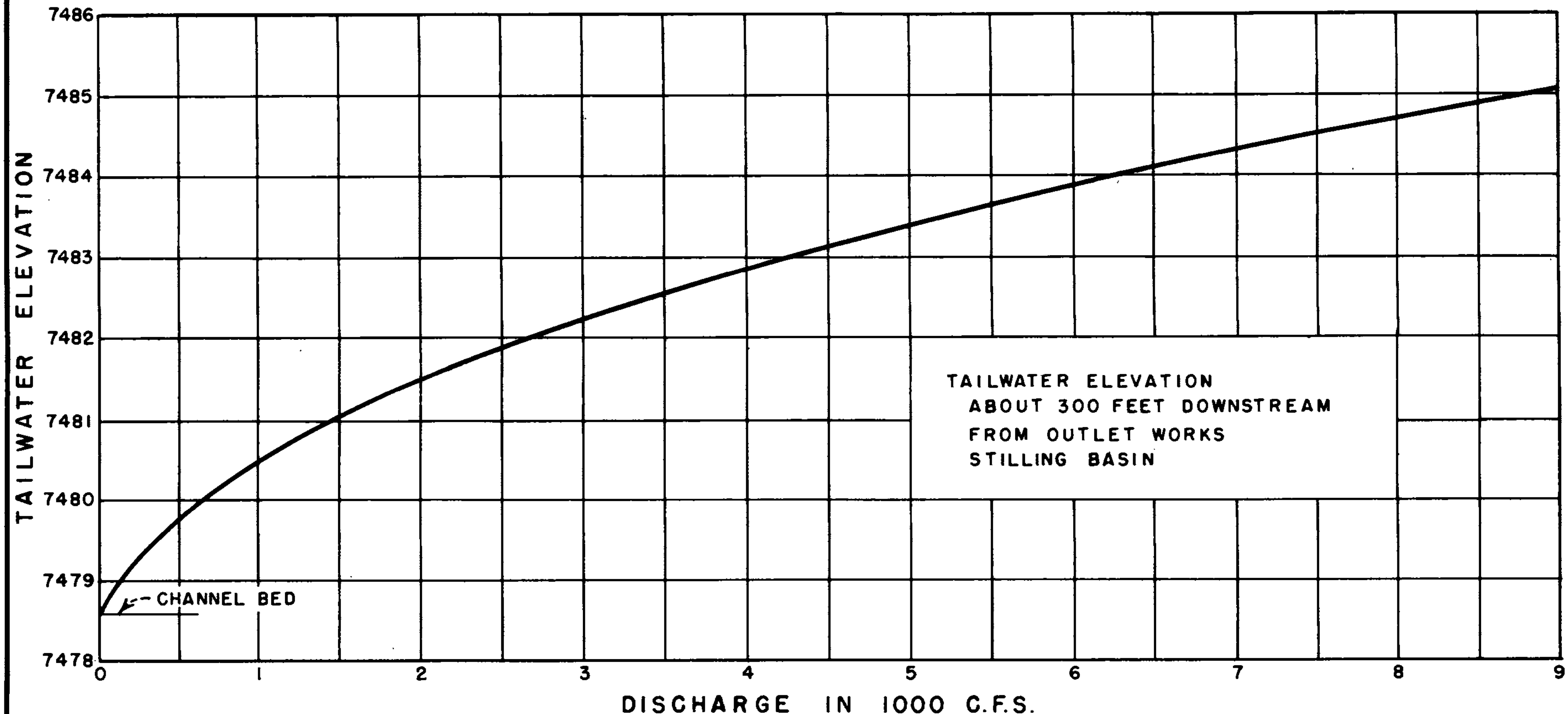
DENVER, COLORADO, MARCH 26, 1964 — 382-D-55

FIGURE 4
REPORT HYD. 534




RUEDI DAM SPILLWAY AND OUTLET WORKS

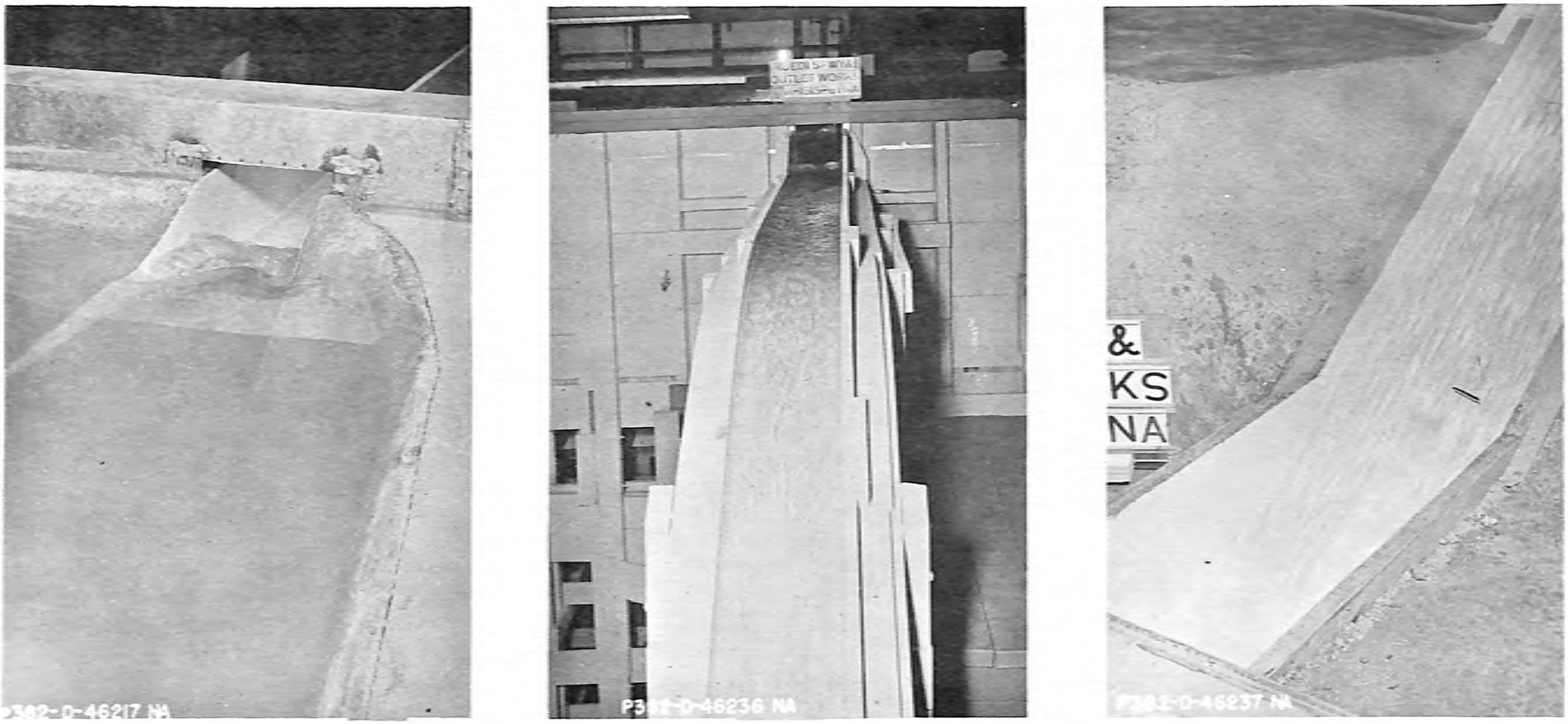
1:42 Scale Model
Overall view of the model




RUEDI DAM SPILLWAY AND OUTLET WORKS
1:42 SCALE MODEL
TAILWATER ELEVATION CURVE

FIGURE 6
REPORT HYD-534

676




A. Flow at inlet and crest.

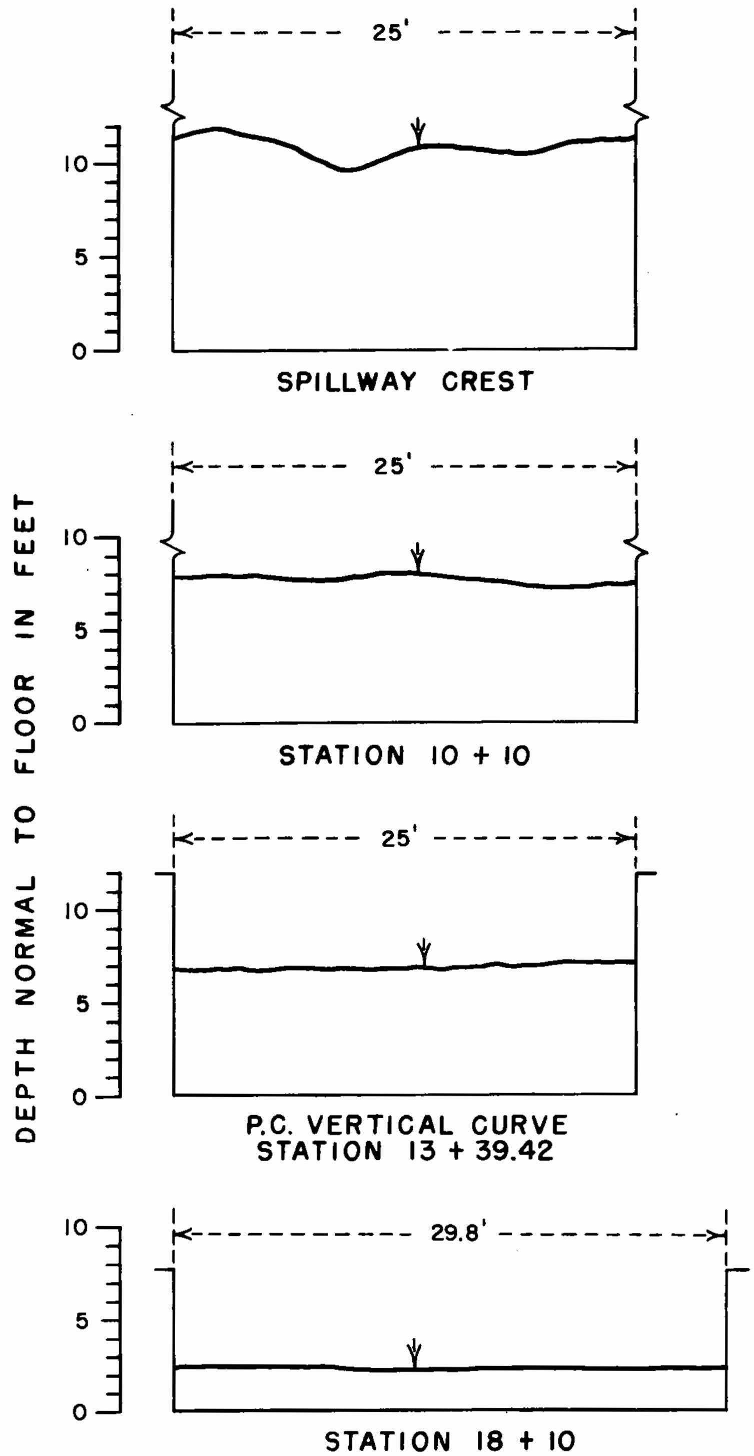
B. Flow in chute downstream of crest and at vertical bend.

C. Flow across auxiliary outlet works junction.

Figure 7
Report Hyd-534

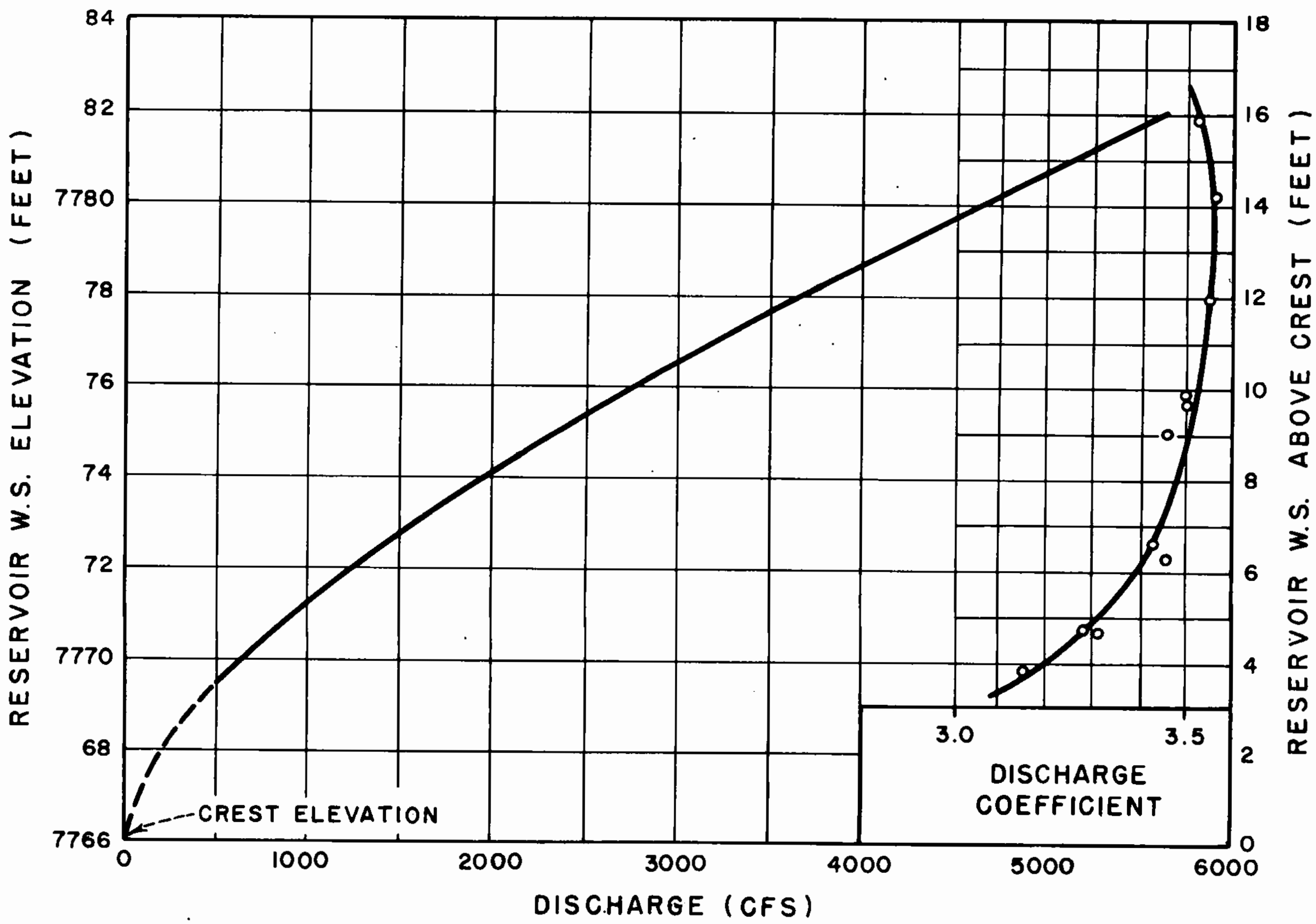
RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 Scale Model
Spillway flow conditions, Q = 5540 cfs




**RUEDI DAM SPILLWAY**
1:42 SCALE MODEL
WATER SURFACE CROSS-SECTIONS IN CHUTE
Q = 5540 CFS

676

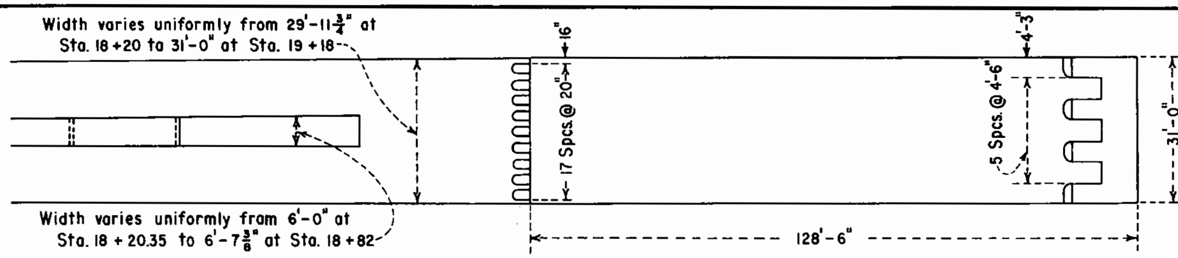



**RUEDI DAM SPILLWAY**
**1:42 SCALE MODEL**
**DISCHARGE CAPACITY**

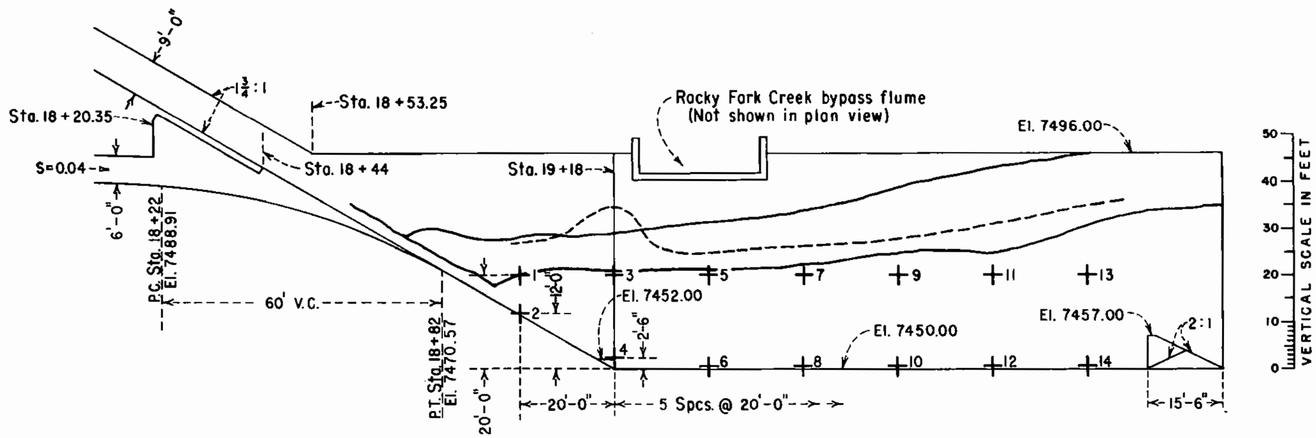


RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 Scale Model
Spillway stilling basin performance
Q = 5540 cfs; T. W. El. = 7484. 6




PLAN




SECTION ALONG ℄
Piezometers in right wall of stilling basin

EXPLANATION

—— Profiles of maximum and minimum water surface points, both sidewalls; Q = 5540 cfs, T.W. = 7484.6 *

------ Average pressure profile of bottom row piezometers; Q = 5540 cfs, T.W. = 7484.6 *

PROTOTYPE PRESSURES IN FEET OF WATER

| FLOW CONDITIONS | | | PIEZOMETER NUMBER | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Q=5540 cfs T.W.=7484.6 * | AVE. MANOM. PRESS. | | 4.8 | 15.1 | 3.4 | 32.0 | 4.6 | 24.8 | 5.9 | 26.0 | 8.8 | 27.7 | 11.3 | — | 13.9 | 34.9 |
| | DYNAMIC PRESS. | MAX. | 34.4 | 82.0 | 12.4 | 91.5 | 13.4 | 54.1 | 17.6 | 49.9 | 22.9 | — | — | — | 22.2 | 44.7 |
| | | MIN. | -28.6 | ** | -5.5 | -22.0 | -5.5 | -0.5 | -5.5 | 7.9 | -3.4 | — | — | — | 3.3 | 24.7 |

* Tailwater elevation at gage 800 ft. downstream from ℄ of stilling basin.
** Vapor pressure

RUEDI DAM SPILLWAY
1:42 SCALE MODEL
AUXILIARY OUTLET WORKS JUNCTION AND SPILLWAY STILLING BASIN GEOMETRY, PIEZOMETER LOCATIONS, SIDEWALL PRESSURES, AND WATER SURFACE PROFILES

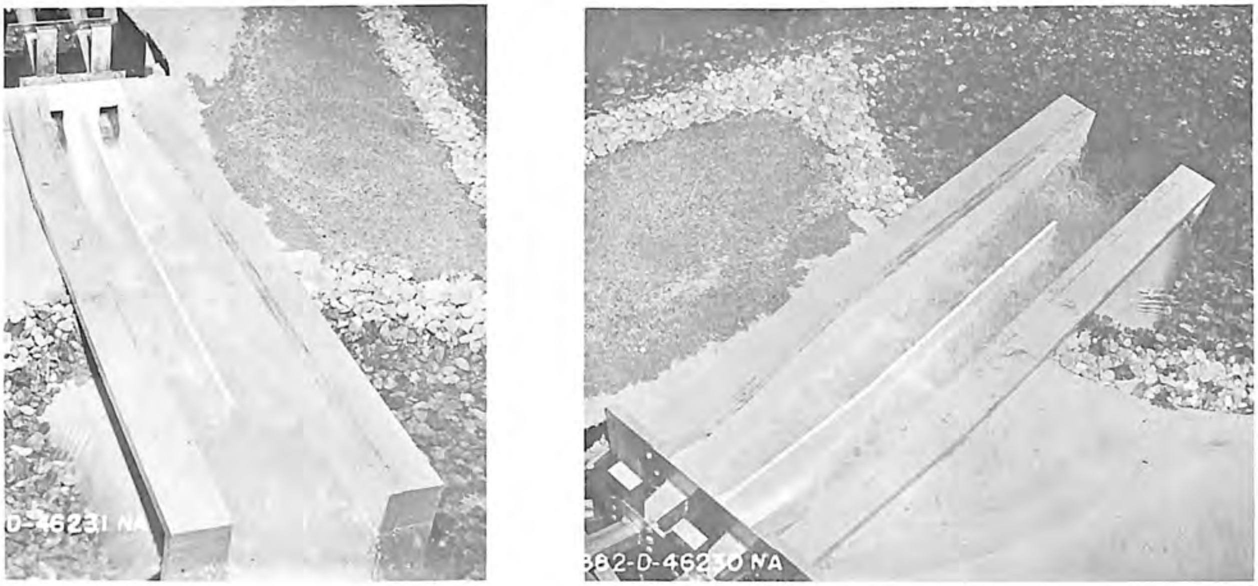
FIGURE 11
REPORT HYD-534



RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 Scale Model
Flow through auxiliary outlet works junction
Q = 600 cfs; T. W. El. = 7480.0

Figure 13
Report Hyd-534

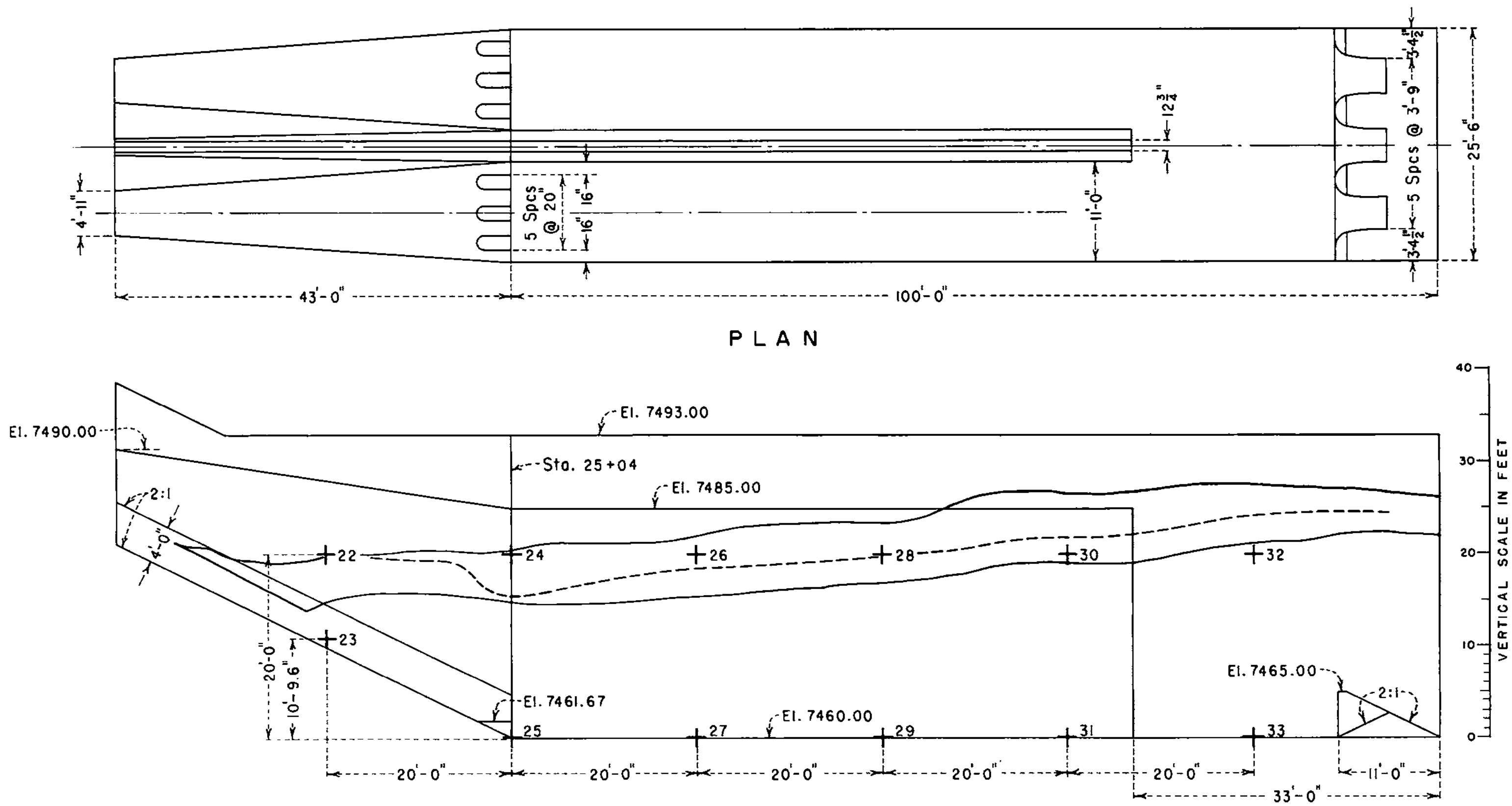


**A.** Two gates operating
Q = 1950 cfs: T. W. El. = 7481.5


**B.** Left gate only operating
Q = 975 cfs; T. W. El. = 7480.5

RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 Scale Model
Outlet works stilling basin performance




## SECTION ALONG ℄

Piezometers in right wall of stilling basin

### EXPLANATION

——— Profiles of maximum and minimum water surface points, both sidewalls; Q = 1950 cfs, T.W. = 7481.5*

- - - - - - Average pressure profile of bottom row piezometers; Q = 1950 cfs, T.W. = 7481.5*

### PROTOTYPE PRESSURES IN FEET OF WATER

| FLOW CONDITIONS | | | PIEZOMETER NUMBER | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
| TWO GATES OPEN Q=1950 cfs T.W.=7481.5* | AVE. MANOM. PRESS. | | — | 9.7 | — | 15.1 | 0.4 | 18.1 | 0.8 | 19.7 | 1.7 | 21.4 | 3.8 | 24.0 |
| | DYNAMIC PRESS. | MAX. | 0.8 | 46.7 | 0.8 | 37.8 | 0.8 | 29.2 | 3.3 | 26.8 | 4.5 | — | — | 26.0 |
| | | MIN. | -0.3 | -21.0 | -1.3 | -3.4 | -1.1 | 6.0 | -0.6 | 12.6 | 0.3 | — | — | 21.8 |
| RIGHT GATE OPEN Q=975 cfs, T.W.=7480.5* | DYNAMIC PRESS. | MAX. | — | -15.0 | — | -7.6 | — | 4.8 | — | 10.2 | — | — | — | 20.7 |
| | | MIN. | — | 41.2 | — | 34.4 | — | 27.1 | — | 25.2 | — | — | — | 23.9 |

* Tailwater elevation at gage 300ft. downstream from end of stilling basin.

# RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 SCALE MODEL

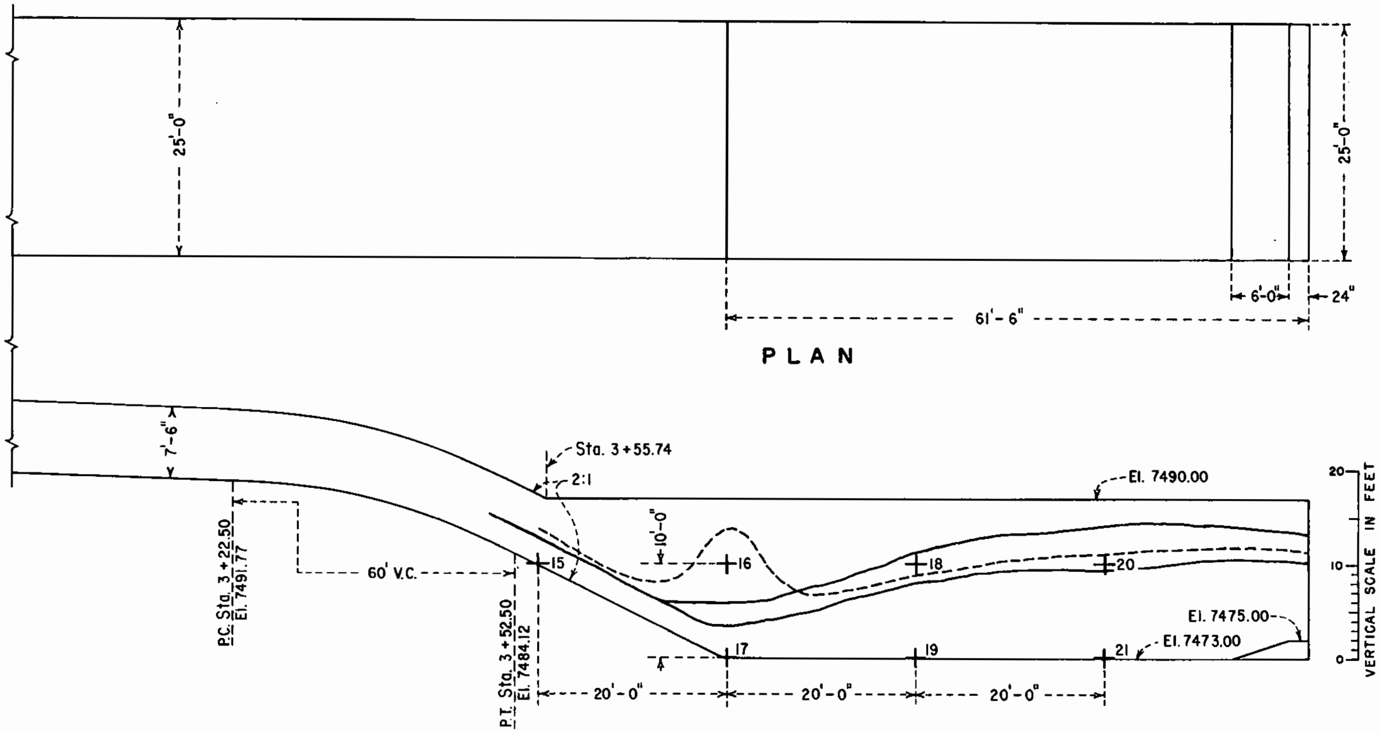
## OUTLET WORKS STILLING BASIN GEOMETRY, PIEZOMETER LOCATIONS, SIDEWALL PRESSURES, AND WATER SURFACE PROFILES


A. Q = 1200 cfs; T. W. El. = 7480.7


B. Q = 1200 cfs; T. W. El. = 7485.0

RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 Scale Model
Rocky Fork Creek bypass stilling basin performance




SECTION ALONG ℄

Piezometers in right wall of stilling basin

**EXPLANATION**

——— Profiles of maximum and minimum water surface points, both sidewalls; Q=1200 cfs., T.W.=7482.3*

------ Average pressure profile of bottom row piezometers; Q=1200 cfs., T.W. = 7482.3*

**PROTOTYPE PRESSURES IN FEET OF WATER**

| FLOW CONDITIONS | | | PIEZOMETER NUMBER | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
| Q=1200 cfs., T.W.=7482.3* | AVE. MANOM. PRESS. | | 3.8 | — | 13.9 | — | 8.9 | 1.4 | 11.0 |
| Q = 1200 cfs. T.W. = 7480.7* | DYNAMIC PRESS. | MAX. | — | — | 12.4 | — | 10.2 | — | 10.7 |
| | | MIN. | — | — | 7.0 | — | 2.6 | — | 8.2 |

* Tailwater elevation at gage 650 ft. downstream from end of stilling basin.

**RUEDI DAM SPILLWAY AND OUTLET WORKS**

1:42 SCALE MODEL

ROCKY FORK CREEK BY-PASS

**STILLING BASIN GEOMETRY, PIEZOMETER LOCATIONS, SIDEWALL PRESSURES, AND WATER SURFACE PROFILES**



**RUEDI DAM SPILLWAY AND OUTLET WORKS**

1:42 Scale Model
Bypass flume flow with Q = 4000 cfs, T. W. El. = 7483.8
Note overtopping of flume sidewalls and sweepout of jump from stilling basin.

Figure 17
Report Hyd-534

Figure 18
Report Hyd-534



RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 Scale Model
Preliminary channel geometry and riprap protection

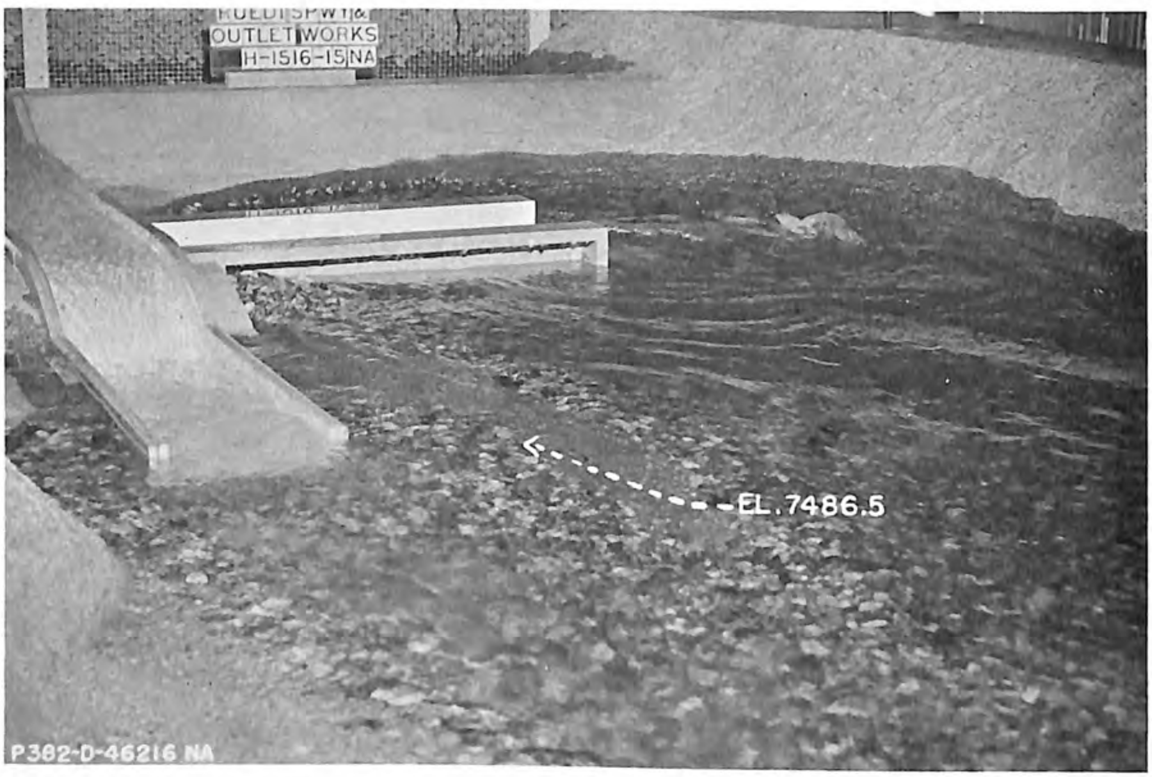

RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 Scale Model
Flow conditions with preliminary channel geometry and riprap protection
Spillway Q = 5540 cfs, outlet works Q = 1950 cfs, bypass Q = 1200 cfs
T. W. El. = 7485.0

Figure 19
Report Hyd-534

Figure 20
Report Hyd-534


A. Submergence and washing of unprotected area downstream of bypass stilling basin.




B. Wave action across submerged area on left of bypass stilling basin.

RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 Scale Model
Flow conditions with preliminary channel geometry and riprap protection
Spillway Q = 5540 cfs, outlet works Q = 1950 cfs, bypass Q = 1200 cfs
T. W. El. = 7485.0


RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 Scale Model
Revised channel geometry and recommended riprap protection

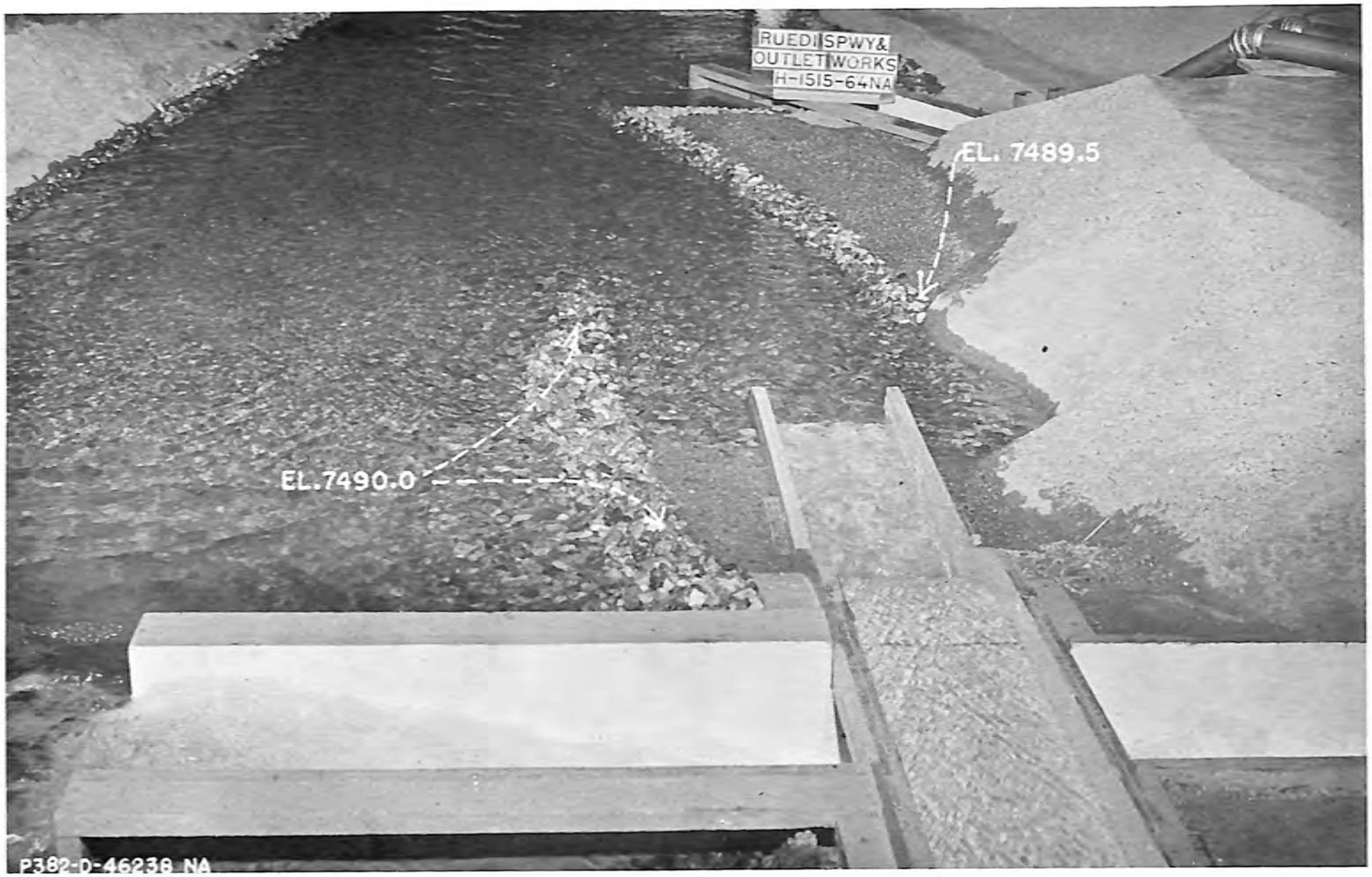
Figure 22
Report Hyd-534


A. Erosion in unprotected channel downstream of outlet works after 26 prototype hours' operation at 1950 cfs.


B. Scour in channel constriction after 20 prototype hours' operation at maximum discharges from all structures, including up to 3000 cfs through the bypass flume.

RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 Scale Model
Scour in unprotected channel




RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 Scale Model
Flow conditions downstream of bypass flume after raising of two previously inundated areas
Outlet works Q = 2000 cfs, spillway Q = 5540 cfs, bypass Q = 1200 cfs
T. W. El. = 7485.0

Figure 24
Report Hyd-534


A. Note absence of jump and high velocity stream striking downstream right bank of discharge channel.


B. Scour and deposition after 2.5 prototype hours' operation.

RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 Scale Model
Rocky Fork Creek bypass flow conditions and resulting scour with maximum possible discharge of 4000 cfs


A. Smaller riprap (10- to 15-inch prototype) before test. Arrows point to assumed limits of exposed rock, at 1.5:1 slope.



B. Scour after 20 prototype hours' operation at 5540 cfs.

RUEDI DAM SPILLWAY AND OUTLET WORKS

1:42 Scale Model
Scour test with reduced size riprap downstream of spillway stilling basin

GPO 845-666

# CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, January 1964) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given on pages 10-11 of the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg; that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Table 1

QUANTITIES AND UNITS OF SPACE

| Multiply | By | To obtain |
|---|---|---|
| | **LENGTH** | |
| Mil | 25.4 (exactly) | Micron |
| Inches | 25.4 (exactly) | Millimeters |
| | 2.54 (exactly)* | Centimeters |
| Feet | 30.48 (exactly) | Centimeters |
| | 0.3048 (exactly)* | Meters |
| | 0.0003048 (exactly)* | Kilometers |
| Yards | 0.9144 (exactly) | Meters |
| Miles (statute) | 1,609.344 (exactly)* | Meters |
| | 1.609344 (exactly) | Kilometers |
| | **AREA** | |
| Square inches | 6.4516 (exactly) | Square centimeters |
| Square feet | 929.03 (exactly)* | Square centimeters |
| | 0.092903 (exactly) | Square meters |
| Square yards | 0.836127 | Square meters |
| Acres | 0.40469* | Hectares |
| | 4,046.9* | Square meters |
| | 0.0040469* | Square kilometers |
| Square miles | 2.58999 | Square kilometers |
| | **VOLUME** | |
| Cubic inches | 16.3871 | Cubic centimeters |
| Cubic feet | 0.0283168 | Cubic meters |
| Cubic yards | 0.764555 | Cubic meters |
| | **CAPACITY** | |
| Fluid ounces (U.S.) | 29.5737 | Cubic centimeters |
| | 29.5729 | Milliliters |
| Liquid pints (U.S.) | 0.473179 | Cubic decimeters |
| | 0.473166 | Liters |
| Quarts (U.S.) | 9,463.58 | Cubic centimeters |
| | 0.946358 | Liters |
| Gallons (U.S.) | 3,785.43* | Cubic centimeters |
| | 3.78543 | Cubic decimeters |
| | 3.78533 | Liters |
| | 0.00378543* | Cubic meters |
| Gallons (U.K.) | 4.54609 | Cubic decimeters |
| | 4.54596 | Liters |
| Cubic feet | 28.3160 | Liters |
| Cubic yards | 764.55* | Liters |
| Acre-feet | 1,233.5* | Cubic meters |
| | 1,233,500* | Liters |

Table II

QUANTITIES AND UNITS OF MECHANICS

| Multiply | By | To obtain |
|---|---|---|
| **MASS** | | |
| Grains (1/7,000 lb) | 64.79891 (exactly) | Milligrams |
| Troy ounces (480 grains) | 31.1035 | Grams |
| Ounces (avdp) | 28.3495 | Grams |
| Pounds (avdp) | 0.45359237 (exactly) | Kilograms |
| Short tons (2,000 lb) | 907.185 | Kilograms |
| | 0.907185 | Metric tons |
| Long tons (2,240 lb) | 1,016.05 | Kilograms |
| **FORCE/AREA** | | |
| Pounds per square inch | 0.070307 | Kilograms per square centimeter |
| | 0.689476 | Newtons per square centimeter |
| Pounds per square foot | 4.88243 | Kilograms per square meter |
| | 47.8803 | Newtons per square meter |
| **MASS/VOLUME (DENSITY)** | | |
| Ounces per cubic inch | 1.72999 | Grams per cubic centimeter |
| Pounds per cubic foot | 16.0185 | Kilograms per cubic meter |
| | 0.0160185 | Grams per cubic centimeter |
| Tons (long) per cubic yard | 1.32894 | Grams per cubic centimeter |
| **MASS/CAPACITY** | | |
| Ounces per gallon (U.S.) | 7.4893 | Grams per liter |
| Ounces per gallon (U.K.) | 6.2362 | Grams per liter |
| Pounds per gallon (U.S.) | 119.829 | Grams per liter |
| Pounds per gallon (U.K.) | 99.779 | Grams per liter |
| **BENDING MOMENT OR TORQUE** | | |
| Inch-pounds | 0.011521 | Meter-kilograms |
| | $1.12985 \times 10^6$ | Centimeter-dynes |
| Foot-pounds | 0.138255 | Meter-kilograms |
| | $1.35582 \times 10^7$ | Centimeter-dynes |
| Foot-pounds per inch | 5.4431 | Centimeter-kilograms per centimeter |
| Ounce-inches | 72.008 | Gram-centimeters |
| **VELOCITY** | | |
| Feet per second | 30.48 (exactly) | Centimeters per second |
| | 0.3048 (exactly)* | Meters per second |
| Feet per year | $0.965873 \times 10^{-6}$* | Centimeters per second |
| Miles per hour | 1.609344 (exactly) | Kilometers per hour |
| | 0.44704 (exactly) | Meters per second |
| **ACCELERATION*** | | |
| Feet per second$^2$ | 0.3048* | Meters per second$^2$ |
| **FLOW** | | |
| Cubic feet per second (second-feet) | 0.028317* | Cubic meters per second |
| Cubic feet per minute | 0.4719 | Liters per second |
| Gallons (U.S.) per minute | 0.06309 | Liters per second |
| **FORCE*** | | |
| Pounds | 0.453592* | Kilograms |
| | 4.4482* | Newtons |
| | $4.4482 \times 10^{-5}$* | Dynes |
| **WORK AND ENERGY*** | | |
| British thermal units (Btu) | 0.252* | Kilogram calories |
| | 1,055.06 | Joules |
| Btu per pound | 2.326 (exactly) | Joules per gram |
| Foot-pounds | 1.35582* | Joules |
| **POWER** | | |
| Horsepower | 745.700 | Watts |
| Btu per hour | 0.293071 | Watts |
| Foot-pounds per second | 1.35582 | Watts |
| **HEAT TRANSFER** | | |
| Btu in./hr ft$^2$ deg F (k, thermal conductivity) | 1.442 | Milliwatts/cm deg C |
| | 0.1240 | Kg cal/hr m deg C |
| Btu ft/hr ft$^2$ deg F | 1.4880* | Kg cal m/hr m$^2$ deg C |
| Btu/hr ft$^2$ deg F (C, thermal conductance) | 0.568 | Milliwatts/cm$^2$ deg C |
| | 4.882 | Kg cal/hr m$^2$ deg C |
| Deg F hr ft$^2$/Btu (R, thermal resistance) | 1.761 | Deg C cm$^2$/milliwatt |
| Btu/lb deg F (c, heat capacity) | 4.1868 | J/g deg C |
| Btu/lb deg F | 1.000* | Cal/gram deg C |
| Ft$^2$/hr (thermal diffusivity) | 0.2581 | Cm$^2$/sec |
| | 0.09290* | M$^2$/hr |
| **WATER VAPOR TRANSMISSION** | | |
| Grains/hr ft$^2$ (water vapor transmission) | 16.7 | Grams/24 hr m$^2$ |
| Perms (permeance) | 0.659 | Metric perms |
| Perm-inches (permeability) | 1.67 | Metric perm-centimeters |

Table III

OTHER QUANTITIES AND UNITS

| Multiply | By | To obtain |
|---|---|---|
| Cubic feet per square foot per day (seepage) | 304.8* | Liters per square meter per day |
| Pound-seconds per square foot (viscosity) | 4.8824* | Kilogram second per square meter |
| Square feet per second (viscosity) | 0.02903* (exactly) | Square meters per second |
| Fahrenheit degrees (change)* | 5/9 exactly | Celsius or Kelvin degrees (change)* |
| Volts per mil | 0.03937 | Kilovolts per millimeter |
| Lumens per square foot (foot-candles) | 10.764 | Lumens per square meter |
| Ohm-circular mils per foot | 0.001662 | Ohm-square millimeters per meter |
| Millicuries per cubic foot | 35.3147* | Millicuries per cubic meter |
| Milliamps per square foot | 10.7639* | Milliamps per square meter |
| Gallons per square yard | 4.527219* | Liters per square meter |
| Pounds per inch | 0.17858* | Kilograms per centimeter |

GPO 845-237

## ABSTRACT

Hydraulic model studies were performed to verify the design of the spillway crest, chute, and stilling basin; the junction of the auxiliary outlet works with the spillway chute; the outlet works stilling basin; and the Rocky Fork Creek bypass flume and stilling basin. The configuration of the structures is unusual in that the three stilling basins are located very close together and discharge into a common channel at three different angles. Flow conditions at the spillway inlet were satisfactory. Some turbulence developed at the inlet but was propagated only a short distance downstream; flow throughout the remainder of the chute was excellent. The discharge capacity of the spillway met design requirements. The spillway stilling basin was satisfactory for all discharges. Flow from the auxiliary outlet works tunnel into the spillway stilling basin was satisfactory. The performance of the service outlet works stilling basin was very good for both symmetrical and unsymmetrical operation. Dynamic pressure measurements on the sidewalls of the stilling basins fluctuated from about 30 feet of water below atmospheric to 80 feet of water above atmospheric. There was an adequate safety margin against sweepout in both basins. The Rocky Fork Creek bypass channel and stilling basin were satisfactory for discharges up to 1,720 cfs: at higher discharges the jump swept out of the basin as expected. Erosion tests indicated that additional riprap was necessary near the bypass basin but that little or no riprap was necessary in the river channel. In other areas, the specified riprap was adequate.

ABSTRACT

Hydraulic model studies were performed to verify the design of the spillway crest, chute, and stilling basin; the junction of the auxiliary outlet works with the spillway chute; the outlet works stilling basin; and the Rocky Fork Creek bypass flume and stilling basin. The configuration of the structures is unusual in that the three stilling basins are located very close together and discharge into a common channel at three different angles. Flow conditions at the spillway inlet were satisfactory. Some turbulence developed at the inlet but was propagated only a short distance downstream; flow throughout the remainder of the chute was excellent. The discharge capacity of the spillway met design requirements. The spillway stilling basin was satisfactory for all discharges. Flow from the auxiliary outlet works tunnel into the spillway stilling basin was satisfactory. The performance of the service outlet works stilling basin was very good for both symmetrical and unsymmetrical operation. Dynamic pressure measurements on the sidewalls of the stilling basins fluctuated from about 30 feet of water below atmospheric to 80 feet of water above atmospheric. There was an adequate safety margin against sweepout in both basins. The Rocky Fork Creek bypass channel and stilling basin were satisfactory for discharges up to 1,720 cfs: at higher discharges the jump swept out of the basin as expected. Erosion tests indicated that additional riprap was necessary near the bypass basin but that little or no riprap was necessary in the river channel. In other areas, the specified riprap was adequate.

ABSTRACT

Hydraulic model studies were performed to verify the design of the spillway crest, chute, and stilling basin; the junction of the auxiliary outlet works with the spillway chute; the outlet works stilling basin; and the Rocky Fork Creek bypass flume and stilling basin. The configuration of the structures is unusual in that the three stilling basins are located very close together and discharge into a common channel at three different angles. Flow conditions at the spillway inlet were satisfactory. Some turbulence developed at the inlet but was propagated only a short distance downstream; flow throughout the remainder of the chute was excellent. The discharge capacity of the spillway met design requirements. The spillway stilling basin was satisfactory for all discharges. Flow from the auxiliary outlet works tunnel into the spillway stilling basin was satisfactory. The performance of the service outlet works stilling basin was very good for both symmetrical and unsymmetrical operation. Dynamic pressure measurements on the sidewalls of the stilling basins fluctuated from about 30 feet of water below atmospheric to 80 feet of water above atmospheric. There was an adequate safety margin against sweepout in both basins. The Rocky Fork Creek bypass channel and stilling basin were satisfactory for discharges up to 1,720 cfs; at higher discharges the jump swept out of the basin as expected. Erosion tests indicated that additional riprap was necessary near the bypass basin but that little or no riprap was necessary in the river channel. In other areas, the specified riprap was adequate.

ABSTRACT

Hydraulic model studies were performed to verify the design of the spillway crest, chute, and stilling basin; the junction of the auxiliary outlet works with the spillway chute; the outlet works stilling basin; and the Rocky Fork Creek bypass flume and stilling basin. The configuration of the structures is unusual in that the three stilling basins are located very close together and discharge into a common channel at three different angles. Flow conditions at the spillway inlet were satisfactory. Some turbulence developed at the inlet but was propagated only a short distance downstream; flow throughout the remainder of the chute was excellent. The discharge capacity of the spillway met design requirements. The spillway stilling basin was satisfactory for all discharges. Flow from the auxiliary outlet works tunnel into the spillway stilling basin was satisfactory. The performance of the service outlet works stilling basin was very good for both symmetrical and unsymmetrical operation. Dynamic pressure measurements on the sidewalls of the stilling basins fluctuated from about 30 feet of water below atmospheric to 80 feet of water above atmospheric. There was an adequate safety margin against sweepout in both basins. The Rocky Fork Creek bypass channel and stilling basin were satisfactory for discharges up to 1,720 cfs; at higher discharges the jump swept out of the basin as expected. Erosion tests indicated that additional riprap was necessary near the bypass basin but that little or no riprap was necessary in the river channel. In other areas, the specified riprap was adequate.

Hyd-534
Palde, U. J.
HYDRAULIC MODEL STUDIES OF RUEDI DAM SPILLWAY AND OUTLET WORKS--FRYINGPAN-ARKANSAS PROJECT, COLORADO
Laboratory Report, Bureau of Reclamation, Denver, 15 pp., 25 figures, 1 table, 1964

DESCRIPTORS--bypass channels/ *outlet works/ *spillways/ hydraulic models/ *stilling basins/ discharge coefficients/ discharge measurement/ backwater/ hydraulic jumps/ open channel flow/ wave action/ negative pressures/ safety factors/ bank protection/ riprap/ water surface profiles/ water pressures/ research and development/ model tests/ laboratory tests/ hydraulics/ scour/ hydraulic structures/ hydrostatic pressures/ turbulence/stream channels

IDENTIFIERS--Ruedi Dam/ Fryingpan-Arkansas Project/ sweepout

Hyd-534
Palde, U. J.
HYDRAULIC MODEL STUDIES OF RUEDI DAM SPILLWAY AND OUTLET WORKS--FRYINGPAN-ARKANSAS PROJECT, COLORADO
Laboratory Report, Bureau of Reclamation, Denver, 15 pp., 25 figures, 1 table, 1964

DESCRIPTORS--bypass channels/ *outlet works/ *spillways/ hydraulic models/ *stilling basins/ discharge coefficients/ discharge measurement/ backwater/ hydraulic jumps/ open channel flow/ wave action/ negative pressures/ safety factors/ bank protection/ riprap/ water surface profiles/ water pressures/ research and development/ model tests/ laboratory tests/ hydraulics/ scour/ hydraulic structures/ hydrostatic pressures/ turbulence/stream channels

IDENTIFIERS--Ruedi Dam/ Fryingpan-Arkansas Project/ sweepout

Hyd-534
Palde, U. J.
HYDRAULIC MODEL STUDIES OF RUEDI DAM SPILLWAY AND OUTLET WORKS--FRYINGPAN-ARKANSAS PROJECT, COLORADO
Laboratory Report, Bureau of Reclamation, Denver, 15 pp., 25 figures, 1 table, 1964

DESCRIPTORS--bypass channels/ *outlet works/ *spillways/ hydraulic models/ *stilling basins/ discharge coefficients/ discharge measurement/ backwater/ hydraulic jumps/ open channel flow/ wave action/ negative pressures/ safety factors/ bank protection/ riprap/ water surface profiles/ water pressures/ research and development/ model tests/ laboratory tests/ hydraulics/ scour/ hydraulic structures/ hydrostatic pressures/ turbulence/stream channels

IDENTIFIERS--Ruedi Dam/ Fryingpan-Arkansas Project/ sweepout

Hyd-534
Palde, U. J.
HYDRAULIC MODEL STUDIES OF RUEDI DAM SPILLWAY AND OUTLET WORKS--FRYINGPAN-ARKANSAS PROJECT, COLORADO
Laboratory Report, Bureau of Reclamation, Denver, 15 pp., 25 figures, 1 table, 1964

DESCRIPTORS--bypass channels/ *outlet works/ *spillways/ hydraulic models/ *stilling basins/ discharge coefficients/ discharge measurement/ backwater/ hydraulic jumps/ open channel flow/ wave action/ negative pressures/ safety factors/ bank protection/ riprap/ water surface profiles/ water pressures/ research and development/ model tests/ laboratory tests/ hydraulics/ scour/ hydraulic structures/ hydrostatic pressures/ turbulence/stream channels

IDENTIFIERS--Ruedi Dam/ Fryingpan-Arkansas Project/ sweepout