R-90-02

HYDRAULIC MODEL STUDY OF MC CLURE DAM EXISTING AND PROPOSED RCC STEPPED SPILLWAYS

February 1990

U.S. DEPARTMENT OF THE INTERIOR
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16. ABSTRACT

A study completed under the National Program of Inspection of Non-Federal Dams revealed additional spillway capacity was necessary to prevent damage during flood events at McClure Dam. Therefore, the existing free overflow spillway and the proposed RCC stepped spillway were investigated. The safe capacity of the existing spillway was determined under the increased reservoir head. The stepped spillway was investigated to determine capacity, step size, chute wall convergence, and energy dissipation characteristics, and stilling basin size.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. *DESCRIPTORS*-- hydraulic model/ stepped spillway/ roller-compacted concrete/ energy dissipation/ spillway capacity

b. *IDENTIFIERS*-- McClure Dam, Santa Fe, New Mexico/ Sangre de Cristo Water Company

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by

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Denver Office
Denver, Colorado

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

ACKNOWLEDGMENTS

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Mission: As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural and cultural resources. This includes fostering wise use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also promotes the goals of the Take Pride in America campaign by encouraging stewardship and citizen responsibility for the public lands and promoting citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

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BACKGROUND

An agreement between the Bureau of Reclamation, the city and county of Santa Fe, and the Public Service Company of New Mexico allows delivery of San Juan-Chama Project water to the city of Santa Fe. The Sangre de Cristo Water Company, a division of the Public Service Company of New Mexico, owns and operates three dams upstream of Santa Fe. A safety of dams study revealed inadequate spillway capacity at two of these dams, McClure and Nichols. McClure, 111 feet high, and Nichols, 80 feet high, are embankment dams. Scanlon and Associates, a consulting firm, was contracted by the Sangre de Cristo Water Company to perform the feasibility studies of several alternatives for rehabilitating the dams. Due to mutual interest by Reclamation and Sangre de Cristo Water Company, the RCC (roller-compacted concrete) stepped spillway alternative for McClure Dam was model studied in the hydraulic laboratory.

CONCLUSIONS

The existing McClure Dam spillway:

- Free flow discharges up to 709 ft^3/s with 2.19 feet of head above the crest were contained within the chute walls, without any crest or chute modifications.

- Rectangular orifices over the existing ogee crest were ineffective in eliminating chute wall overtopping without increasing the chute wall height or channelizing the flow in the chute transition below the crest.

- The left chute wall downstream of the horizontal bend was overtopped when the discharge exceeded 1,100 ft^3/s. Superelevating the bend allowed passage of 1,650 ft^3/s at 13.5 feet of head with the 30- by 3.5-foot orifice.

The proposed stepped spillway:

- The design discharge, 16,534 ft^3/s, was passed with a head of 10.26 feet (fig. 1).

- Maximum chute wall convergence, 12.68°, producing a 50-foot width at the dam toe, provided adequate flow conditions and energy dissipation.

- Any step height between 1 and 4 feet would successfully pass the required discharge. Therefore, step height in this range can be chosen based upon economy of construction.

- The steps, both 1 and 4 feet high, produced approximately 53 percent energy dissipation under the design discharge.

TESTS

Tests were completed for both the existing and proposed RCC stepped spillways. Operating criteria required the existing spillway to pass small discharges before the emergency spillway is used. However, when the emergency spillway is operating, the existing spillway discharge must be limited to prevent overtopping of the chute walls. Tests were done to determine if the existing spillway could be modified to allow passage of the more frequent low flow rates of 1,600 to 2,000 ft³/s. The following items for the existing spillway were investigated:

- Discharge rating curves for a 3.5-foot-high rectangular orifice above the entire 47.67-foot-long ogee crest and for a narrower 30-foot-long section of the crest.

- An orifice that restricts the existing spillway discharge to an amount that would not require modification of the chute width or wall height.

- The capacity and flow conditions in the chute for each orifice above the crest, including determining wall heights necessary to contain the flow.

- Superelevation of the horizontal bend to prevent overtopping of the chute wall downstream.

The following items were investigated for the proposed RCC stepped spillway:

- The discharge capacity of the RCC spillway with a broad crest 32.53 feet wide and 167 feet long.

- Flow conditions and energy dissipation characteristics in the chute for straight and converging walls for discharges of 5,000, 10,000, 16,534, and 24,800 ft³/s.

- The effect of 1- and 4-foot step heights on flow depths and energy dissipation.

- Stilling basin performance with and without an end sill.

HYDRAULIC MODEL

The 1:30 scale model included the reservoir approach area, a 450-foot-wide section of the embankment dam, the existing spillway and the proposed RCC stepped spillway, and about 360 feet of the downstream river channel (fig. 2). The model was designed to allow passage of 150 percent of the design discharge through the RCC spillway and to investigate the capacity of the existing spillway under these increased reservoir head requirements. The model structures were built according to drawings provided by Scanlon and Associates (fig. 3). The existing 47.67-foot-long ogee spillway crest (El. 7876.5) and the orifice, located 3 feet lower than the RCC spillway crest (El. 7879.5), were designed from the drawings (no center pier). The chute channel geometry was estimated from an aerial photograph. The downstream chute channel transitioned quickly to a 20-foot width which was maintained throughout the remainder of the chute. The right side of the chute channel consisted primarily of the excavated mountainside; the left side consisted of 5-foot-high walls (fig. 4). The broad crest of the RCC spillway was 32.53 feet wide in the flow direction and 167 feet long. The stepped RCC spillway chute was located on the downstream face of the 2.18:1 sloping embankment dam. The chute and stilling basin walls were built on a 0.8:1 slope because they will also be constructed of RCC. The stepped spillway was constructed to allow modification of the step height, the convergence angle of the spillway chute walls, and the stilling basin width.

EXISTING SPILLWAY TEST RESULTS

Rectangular Orifices

A rectangular orifice was formed across the entire 47.67-foot width of the existing crest with a 3.5-foot-high opening. This orifice was designed to allow free flow for low discharges, then restrict the flow to the capacity of the chute channel as the head increased. The structure passes a maximum free flow discharge of 1,330 ft^3/s at 3.5 feet of head above the ogee crest and a discharge of 3,440 ft^3/s with orifice control with a head of 13.5 feet at reservoir elevation 7890 (fig. 5).

Free flow discharges up to 709 ft^3/s at a head of 2.19 feet above the crest were adequately contained in the chute. However, as the head increased, flow overtopped the left chute wall and could erode the dam embankment in this area. Only the left wall of the spillway chute was overtopped because the flow was contained by the mountainside on the right. Flow from the right side of the crest impinged on the right transition wall downstream and reflected a wave across the chute that overtopped the left wall. Flows from the left side of the crest overtopped the left wall near the end of the transition where the chute width was 20 feet (fig. 6). Overtopping of the chute walls also occurred about 150 feet downstream from the center of the horizontal bend (fig. 7).

The width of the existing service spillway orifice was narrowed to 30 feet and centered on the crest with the height remaining at 3.5 feet. Restricting the flow from the right side of the crest should prevent the majority of the left wall overtopping. A free flow discharge of 620 ft^3/s was passed with no overtopping of the chute walls. At about 1,100 ft^3/s, during orifice control, flow overtopped the left wall and continued to overtop through the maximum discharge of 1,650 ft^3/s[1] at 13.5 feet of head (fig. 5). The unusual shape of the discharge curve could not be readily explained by approach channel flow conditions or observations of the model. The curve indicated the flow is choked off between reservoir heads of 8 and 10.5 feet as would be expected under orifice control; however, the curve flattened back out under higher heads.

The jet from the rectangular orifice aerated from the downstream side of the orifice regardless of the flow rate. This caused the jet to spring free from the ogee crest, impact on the invert of the chute, and spread laterally to the side walls in the transition section. This flow immediately overtopped the left side wall downstream of the crest. The jet hit the transition side wall on the right side and sent a wave across the chute that overtopped the left wall in the transition further downstream (fig. 8). The left wall downstream from the horizontal bend was also overtopped in the same area as before, however, by a lesser amount than with the full crest opening.

Investigations showed that rectangular orifices of any width caused the flow to aerate from the downstream side of the opening and spring free from the crest, impinge on the invert, and create waves that overtop the chute walls. Alternatives for correcting the chute wall overtopping created by flow from a rectangular orifices include:

- Prevent aeration of the jet by channeling the flow with structural walls from the orifice sides to the minimum chute width section.

[1] Change from summary report. Discharge curve was redeveloped producing this result.

- Install flow vanes on the floor of the chute to break up or redirect the waves created by the flow conditions.

- Raise the side walls on the left side of the chute to contain the flow depth.

Raising the side walls seemed most appropriate, because slight incorrect placement of the flow vanes would not successfully redirect the flow, and channeling of the flow could be very expensive.

Chute water surface profiles along the left wall were measured for the 30- by 3.5-foot orifice. Sections of the left wall must be raised to contain the flow depth and/or to provide the required 2.5 feet of wall freeboard. For 50 feet downstream of the crest (measured along the chute centerline), the wall should be raised an additional 6.25 feet (total height, including freeboard, 11.25 feet). From between 50 and 75 feet downstream of the crest, the 5-foot wall height contained the flow adequately. The wall should be raised an additional 4.4 feet (total height 9.4 feet) between 76 and 113 feet downstream of the crest and then taper down to the existing 5-foot wall height 190 feet downstream from the crest.

Triangular Orifice

Extensive modifications to the crest or chute walls would be needed to use a reasonably large rectangular orifice. The only orifice that maintained 2.5 feet of chute wall freeboard with the existing 5-foot wall height was a 43.68-ft^2 triangular orifice (fig. 9). This opening was formed by the ogee crest as a base and a 2.25-foot-high apex located 21.5 feet from the left wall with the right corner returning to the crest 8.84 feet from the right wall. The location of the triangular orifice on the crest was critical to prevent the fin in the center of the chute from traveling to the left and overtopping the wall. The discharge capacity of this opening was only 454 ft^3/s at 13.26 feet of head over the crest.

Superelevation of the Horizontal Bend

Discharges greater than 1,100 ft^3/s passed by the existing spillway, regardless of the crest geometry, caused the sloping left wall downstream of the horizontal bend to be overtopped. Superelevation was added at the bend by forming 75-foot transition spirals into and out of a 5-foot banked section in the center of the bend. Adding the superelevation prevented overtopping of the left wall downstream of the bend for the entire discharge range of the 30- by 3.5-foot rectangular orifice (fig. 10).

Containing the flow within the chute downstream of the horizontal bend is not as critical as preventing overtopping onto the embankment near the crest. Rehabilitation of the existing spillway should be directed toward protecting the embankment near the top of the dam from erosion due to overtopping of the chute walls in this area.

RCC STEPPED SPILLWAY TEST RESULTS

As a basis for comparison, the RCC spillway was tested first with parallel chute walls or no wall convergence (fig. 11). The methods used to evaluate the performance of the stepped spillway were measuring the flow velocity and depth on the face of the chute before the jet entered the stilling basin and noting the jump position in the stilling basin.

Discharge Capacity

A total discharge of 16,534 ft^3/s was passed over the 167-foot-long RCC spillway crest at 10.26 feet of head, 0.24 foot below maximum water surface elevation 7890 (fig. 1). The discharge coefficient at design discharge was 3.01, typical of a broad crest. The head/discharge relationship is given by the equation:

$$H = (0.0155)Q^{0.6687}$$

Passing 150 percent of the design discharge required a head of 13.46 feet over the spillway. This head would overtop the embankment by almost 3 feet.

Velocity Measurement Techniques

The velocity of the jet on the stepped spillway face was determined. Data were gathered 90 feet vertically down from the crest at the chute centerline and 15 and 30 feet on both sides. This location was just above the toe of the hydraulic jump. Data for computing velocities were measured using several methods: a pitot-static tube, WPP (wave probability probe), video camera, pressure cells mounted on a plate, and a miniature current meter. The results of these measuring techniques varied significantly. Data from the pitot-static tube and the WPP gave the most consistent and recurring results and were used to compute the average velocities across the chute width.

The pitot-static tube measured the static pressure head with the velocity computed from:

$$V = (2g\Delta P)^{1/2}$$

where:

ΔP = pressure differential

The WPP was used to measure the depth of the flow at each measurement location. These depths were averaged across the width of the chute and the average velocity computed from:

$$V = Q/A = Q/dw$$

where:

d = average flow depth across the chute
w = width of the chute at the measurement station, which varied depending upon the sidewall convergence angle

These velocities were then compared to theoretical velocities, based on the total velocity head, for a nonstepped, smooth spillway to determine the energy dissipation produced by the steps.

Results for 1-Foot Step Heights

Initial tests were performed with 1-foot steps for the entire 167-foot spillway chute width or no convergence of the chute walls. Results from these tests indicated that investigation of converging spillway chute walls was applicable. The same tests were then completed for chute wall convergences that produced 116- and 50-foot widths at the toe of the dam (fig.11).

Flow conditions in the spillway chute and stilling basin with no convergence of the walls were excellent. As expected, for small unit discharges, the flow became rough very near the spillway crest and remained rough down the full length of the chute with the jet entering the basin and breaking up before impinging on the floor (fig. 12). As the discharge increased, the jet traveled further down spillway chute before becoming rough; however, flow conditions remained excellent (fig. 13).

The spillway chute walls were then modified to converge at 5.6° resulting in a 116-foot width at the dam toe. Flow conditions near the crest were identical to those with no wall convergence. Flow depths increased as the width decreased, particularly along the walls; however, no cross waves developed in the chute. Flow conditions were excellent throughout the chute and stilling basin indicating that the steps were still performing adequately (fig. 14).

The 12.68° wall convergence resulted in a 50-foot-wide basin at the dam toe. Flow conditions were excellent; however, flow depths were significantly increased. Fins rose up the side walls, but no cross waves were formed, probably due to the rough water surface created by the steps. The chute walls must contain a flow depth of 7 feet, measured from the downstream edge of the step normal to the slope. Figure 15 shows the spillway operating at 5,000 and 16,534 ft^3/s with the chute converging to 50 feet at the dam toe.

To further investigate the feasibility of converging the spillway chute walls, velocities were computed from measurements taken during each of the tests. The velocities generally increased as the walls converged due to the smaller flow area, thus greater flow depths, which reduced the ability of the steps to dissipate energy. The velocities are listed in table 1.

Table 1. - Velocities measured for 1-foot step heights

Discharge (ft^3/s)	Velocity (ft/s)		
	No convergence	116-ft basin width	50-ft basin width
5,000	34.2	32.5	-
10,000	39.6	44.6	50.3
16,534	44.1	52.4	55.8
24,800	57.8	60.8	-

The velocities do not significantly increase as the walls converge. Flow conditions in the chute were acceptable with the maximum wall convergence. Stilling basin performance was excellent with convergence of the walls to the 50-foot width at the dam toe. As a result, the spillway chute walls may converge to 50 feet at the toe of the dam.

Results for 4-Foot Step Heights

The 4-foot steps were added to the model on top of the 1-foot steps, beginning 1 foot below the broad crest, for the entire width of the chute (fig. 16). Tests were conducted only for the convergence to a 50-foot width at the dam toe based upon the results from tests with the 1-foot steps. The 4-foot steps were tested to determine if the greater step height would increase the energy dissipation characteristics of the spillway.

Observation of the flow on the stepped face indicated a rougher flow closer to the crest (fig. 17). This was shown by "white water" or a rough water surface that continued until the jet entered the basin. The rougher water surface created a greater flow depth throughout the chute than with the 1-foot steps. Figure 16 shows the water surface profiles along the right and left chute walls for 4-foot steps. At the design discharge, a maximum flow depth of 8.5 feet, measured from the edge of the steps normal to the slope, was contained by the training walls.

Velocities were computed using data-gathering techniques mentioned earlier; however, the velocities varied considerably depending on the method used. An estimate of the velocity for the 4-foot steps at the design discharge was 55 ft/s, based on the results from three measurement techniques. This velocity and the velocity for 1-foot steps with wall convergence to 50 feet were very similar.

The 4-foot steps were expected to dissipate substantially more energy than the 1-foot steps, although the velocity measurements did not so indicate. Comparing the stilling basin action with that of the 1-foot steps indicated that, with the 4-foot steps, the jump had moved slightly upstream and the flow exiting the basin appeared calmer (figs. 15 and 17).

Closer examination of the flow down the spillway chute provided a possible explanation of the very similar energy dissipation characteristics of the two step heights. As the flow left the crest and began tumbling down the 4-foot steps, it appeared that the jet impinged on the edge of a step and left the surface of the spillway, returning again after jumping over the next row of steps. This phenomenon occurred at low flow rates and continued as the discharge increased. Reducing the contact of the jet with the stepped face lessened the ability of the steps to dissipate energy. These observations indicate the 4-foot steps did increase the energy dissipation, but only to a limited extent.

These results indicate that, under the tested flow conditions (head, unit discharge, flow depth, dam slope, and wall convergence), any step height in the range of from 1 to 4 feet could be used successfully in the design, depending on which would be the most economical construction alternative. At the design discharge, approximately 53 percent of the total energy available was dissipated by the stepped spillway with 1- or 4-foot step heights.

Stilling Basin Investigation

The 50-foot-wide stilling basin was investigated to determine its energy dissipation characteristics. The 131-foot-long basin was tested with and without the design end sill (fig. 3). The basin with the 17.7-foot-high end sill produced excellent energy dissipation for all flow rates under normal tailwater elevations. Tailwater elevations were referenced to a streambed elevation of 7767.86 feet. This gives a tailwater elevation of 11.0 feet at design discharge (fig. 18).

Tests conducted after removal of the end sill indicated the tailwater is not adequate to produce an acceptable jump with any of the flow rates tested. At 5,000 ft^3/s the jet from the chute impinged on the basin floor forming a weak hydraulic jump with low energy dissipation. Higher flow rates swept out the end of the basin without forming a jump.

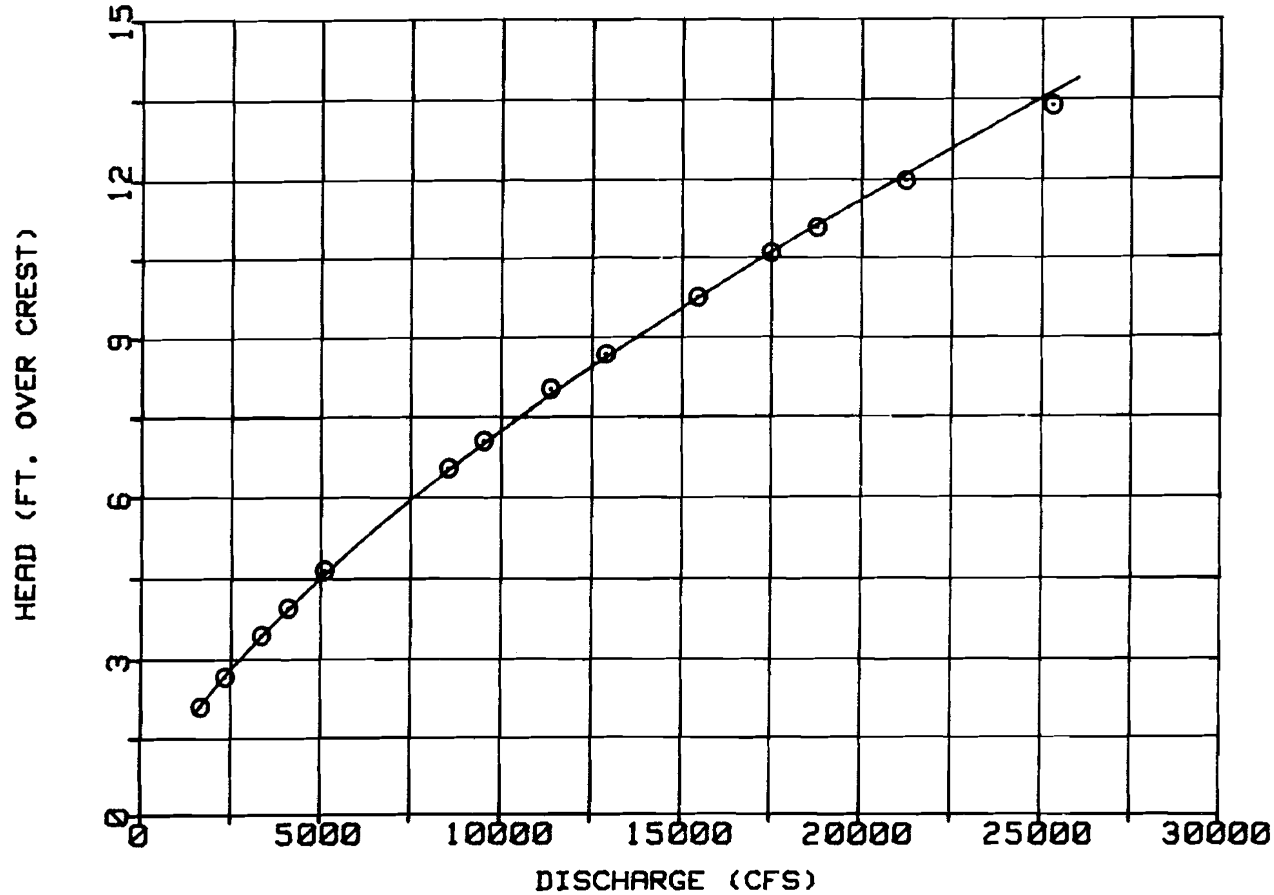


Figure 1. - Discharge rating curve for the RCC spillway.

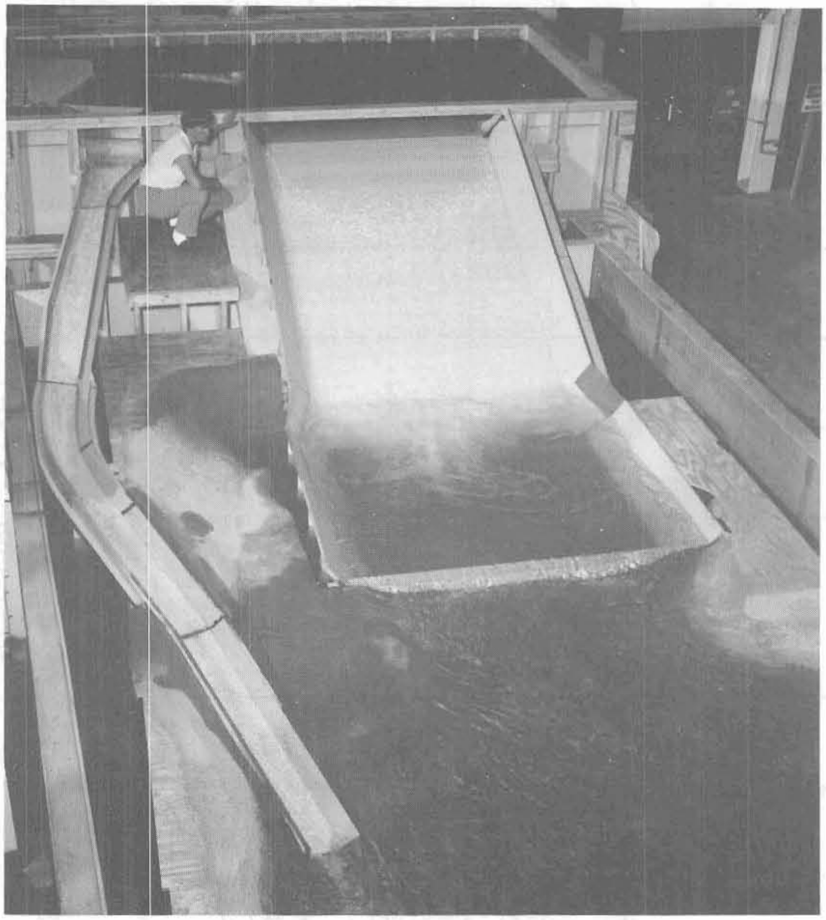


Figure 2. - 1:30 scale model of the initial design for the existing and RCC stepped spillways.

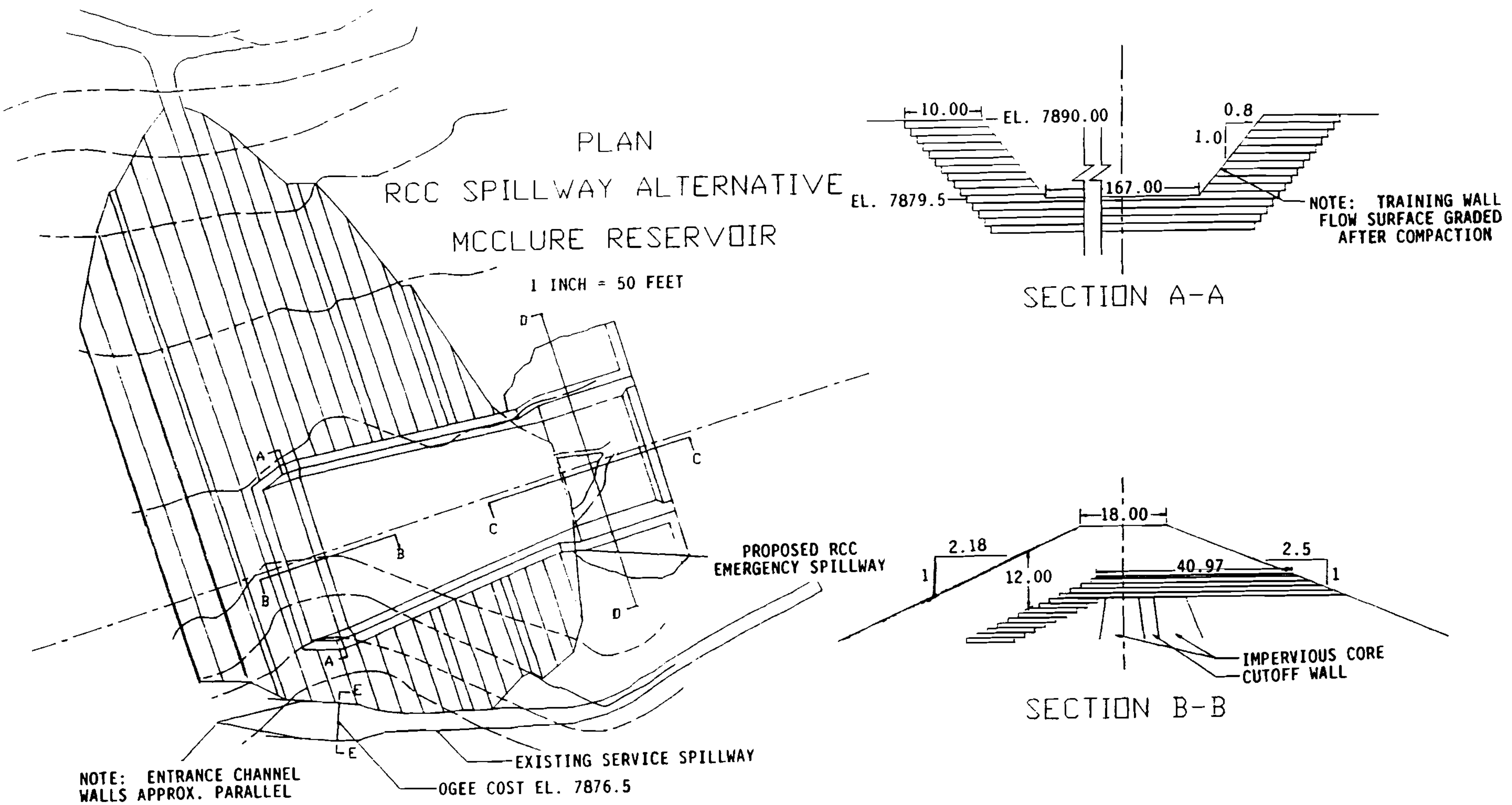
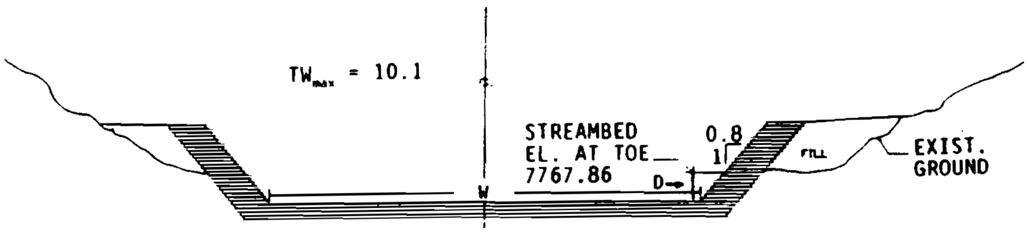
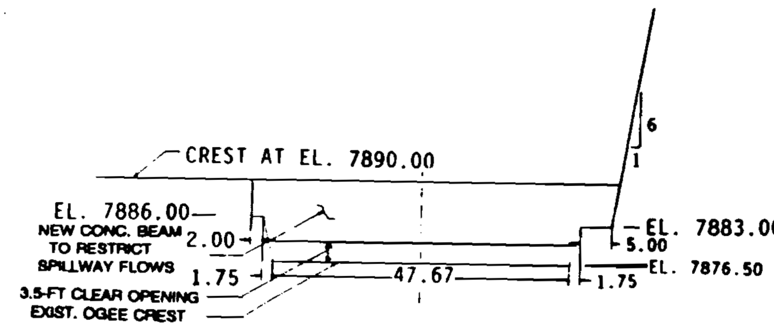


Figure 3. - Feasibility drawings of the RCC stepped spillway.



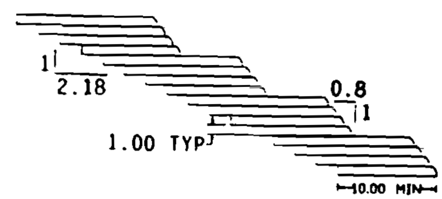
SECTION D-D



SECTION E-E

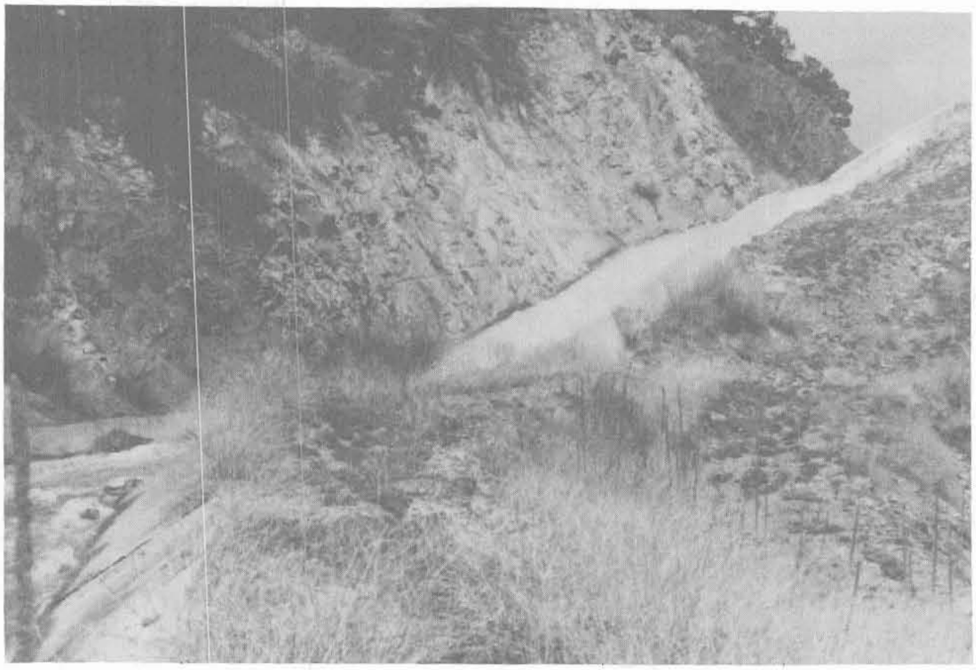
STILLING BASIN WIDTH "W"	DEPTH "D"	LENTH "L"
116	7.4	86
50	17.7	131

SECTION C-C

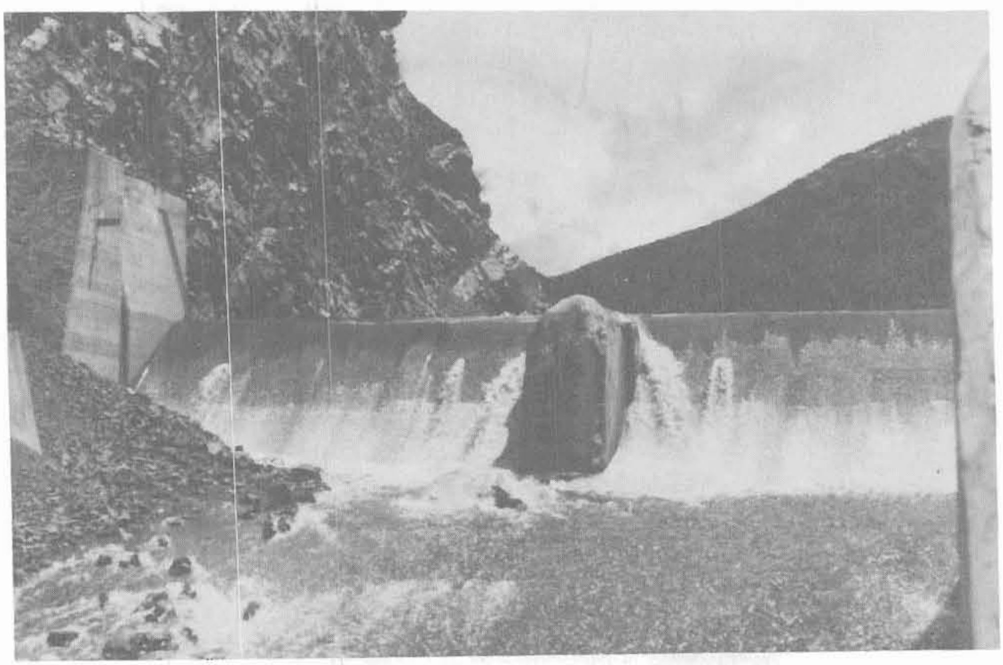


SPILLWAY FLOW SURFACE
ALTERNATE STEP CONFIGURATION

Figure 3. - Feasibility drawings of the RCC stepped spillway. - Continued



(a) Existing service spillway chute.



(b) Crest for existing service spillway.

Figure 4. - Existing service spillway. (Note: Center pier not included in model.)

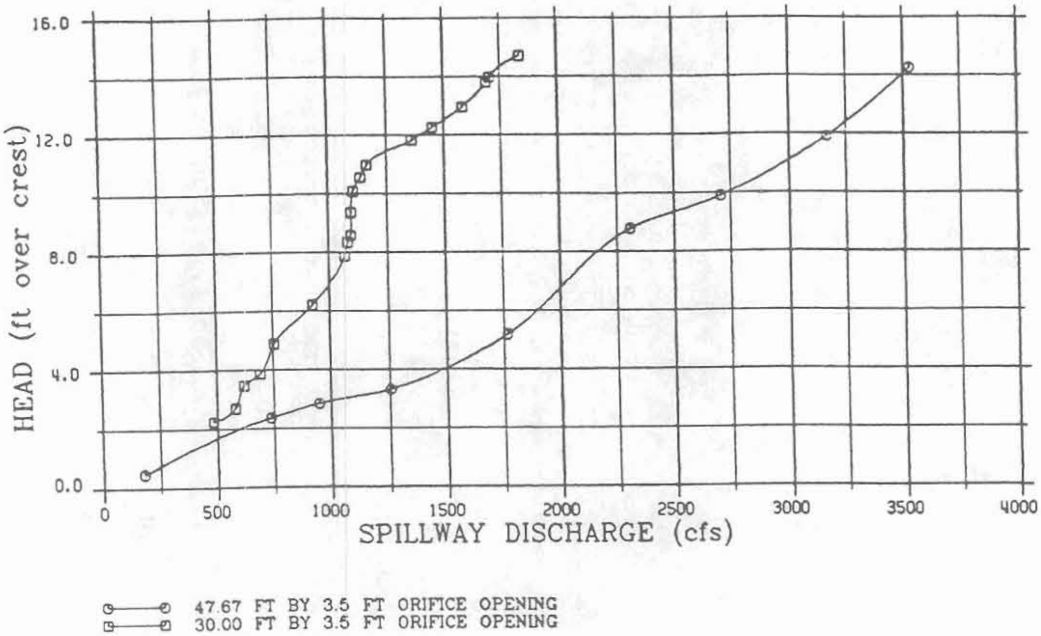


Figure 5. - Discharge rating curve for the existing spillway with an orifice constructed above the crest.

Figure 6. - Overtopping the left chute wall downstream of the crest for a discharge of 3,440 ft^3/s through the 47.67- by 3.5-foot opening.

Figure 7. - Overtopping the left wall downstream of the horizontal bend for a discharge of 3,440 ft^3/s through the 46.67- by 3.5-foot orifice.

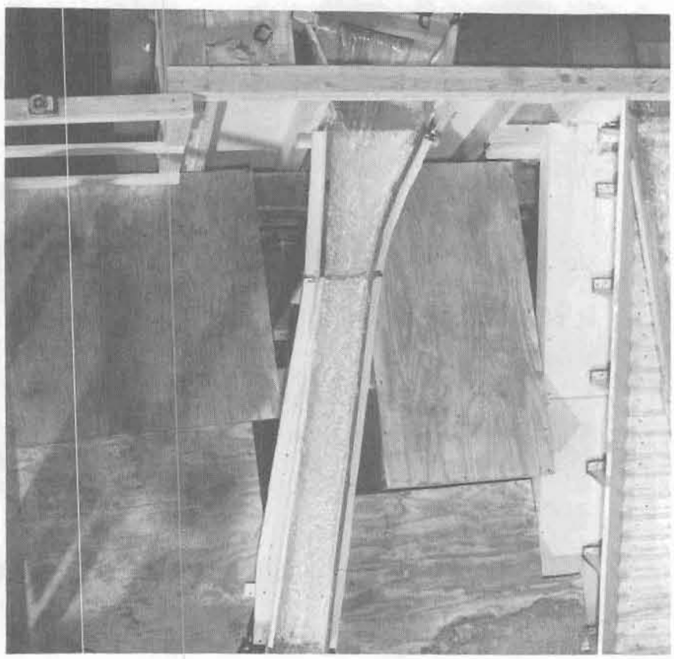


Figure 8. - Overtopping the left wall downstream of the crest (30- by 3.5-foot orifice).

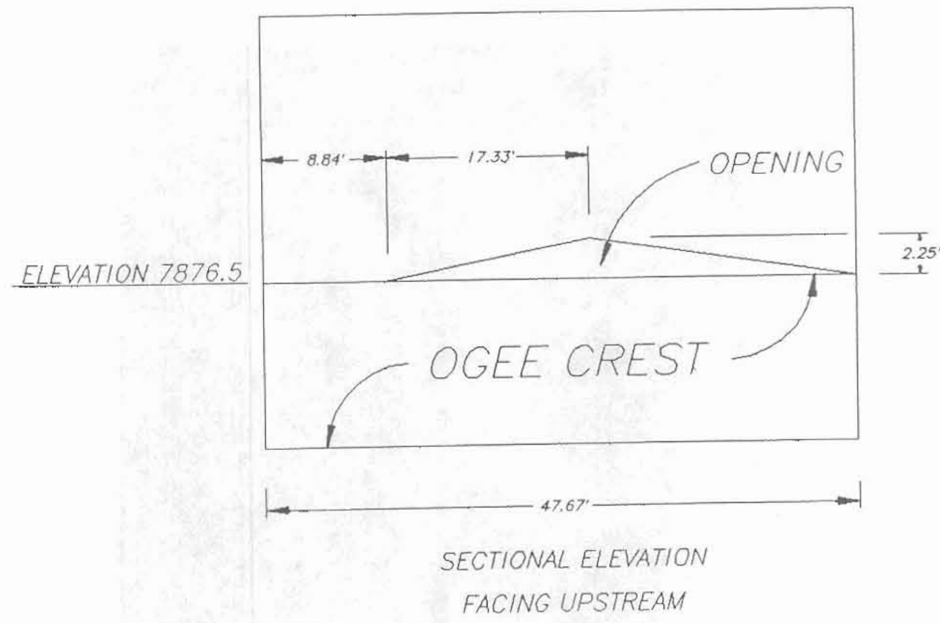


Figure 9. - Triangular orifice that successfully restricts chute discharge at maximum water surface.

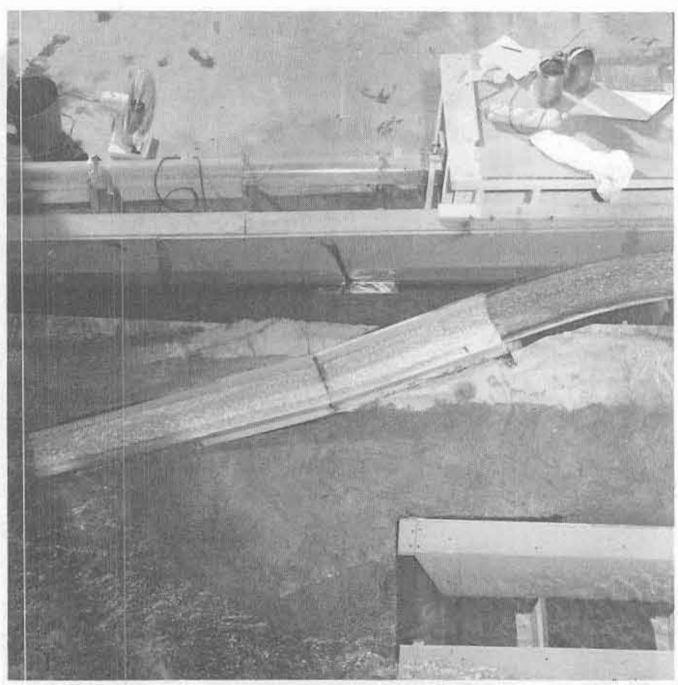


Figure 10. - Superelevation of the bend prevented overtopping of the left chute wall downstream.

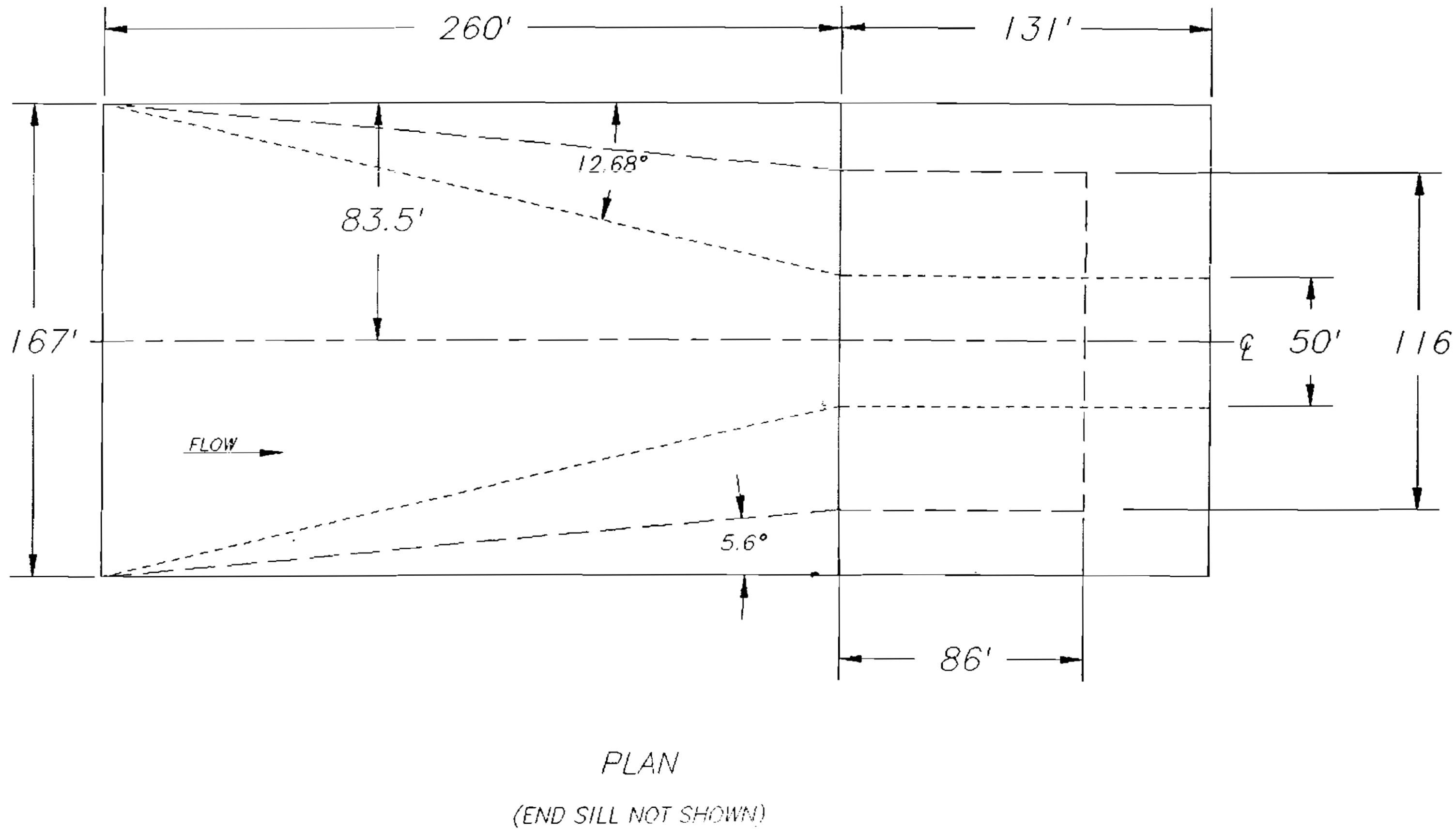


Figure 11. - Plan of the RCC spillway and stilling basin showing the wall convergences tested.

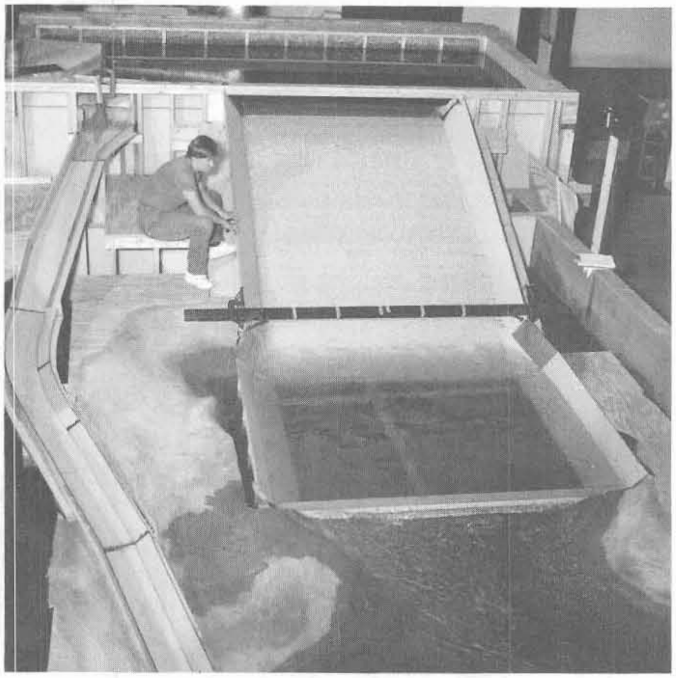


Figure 12. - Discharge of 5,000 ft^3/s over the 1-foot-high stepped RCC spillway with no chute wall convergence.

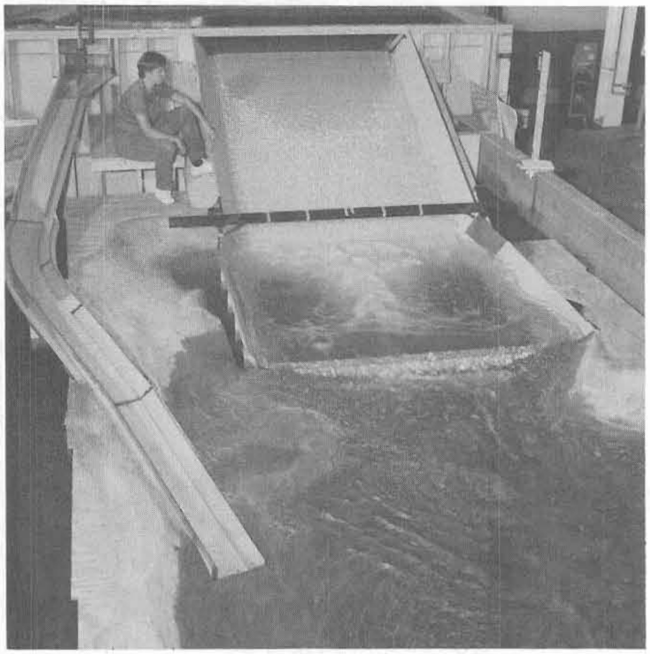
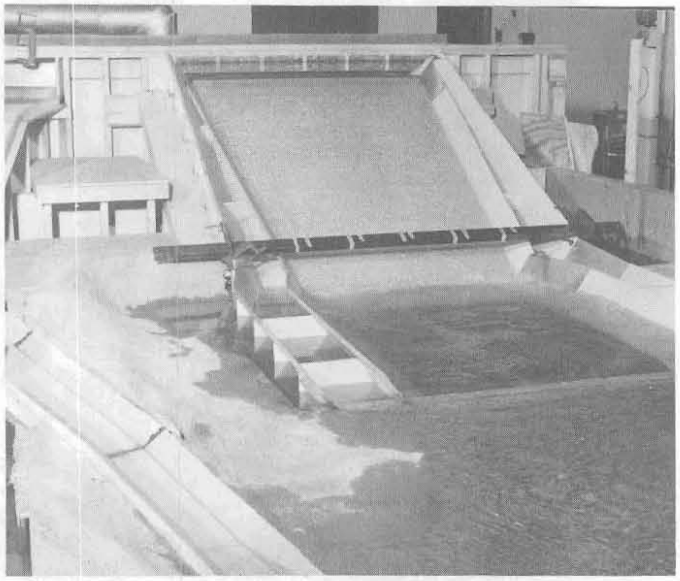
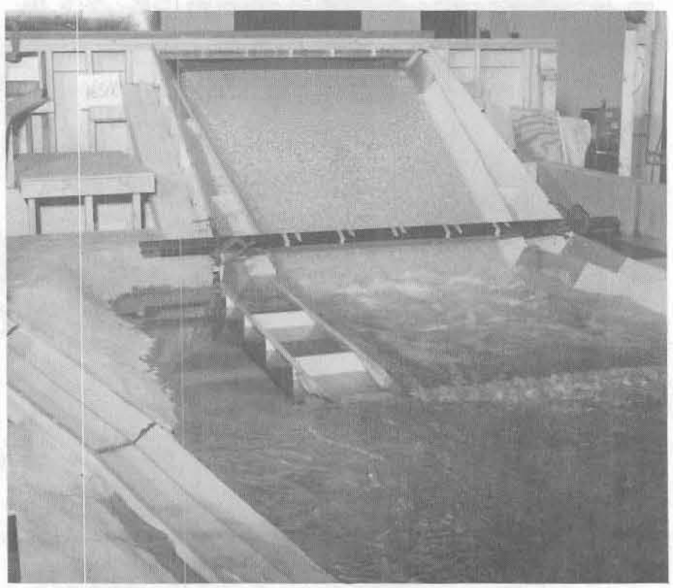


Figure 13. - Passage of design discharge over the 1-foot-high stepped RCC spillway.

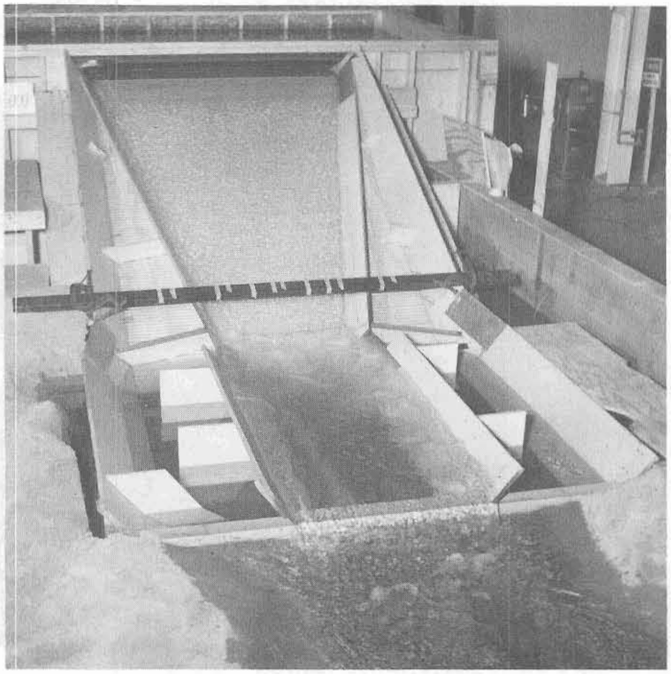


(a) Q = 5,000 ft^3/s

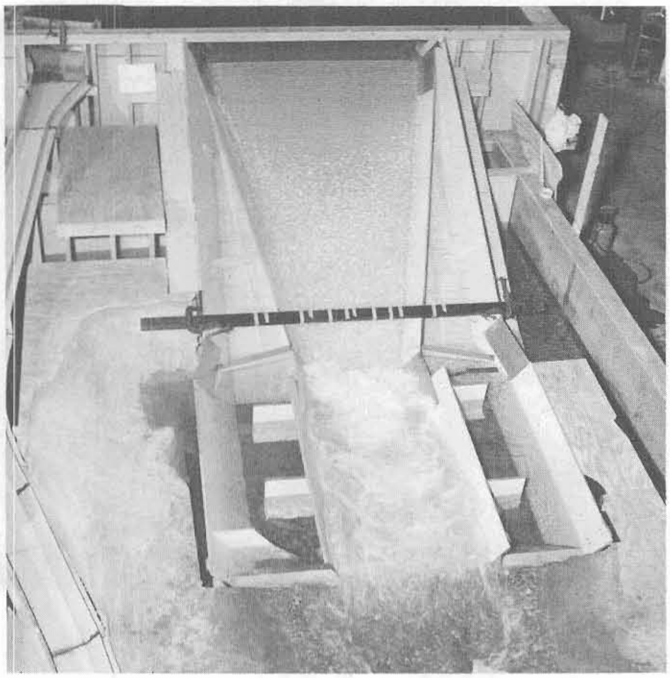


(b) Q = 16,534 ft^3/s

Figure 14. - RCC spillway with 1-foot steps and a 116-foot chute width at the dam toe.



(a) Q = 5,000 ft^3/s.



(b) Q = 16,534 ft^3/s.

Figure 15. - RCC spillway with 1-foot steps and a 50-foot chute width at the dam toe.

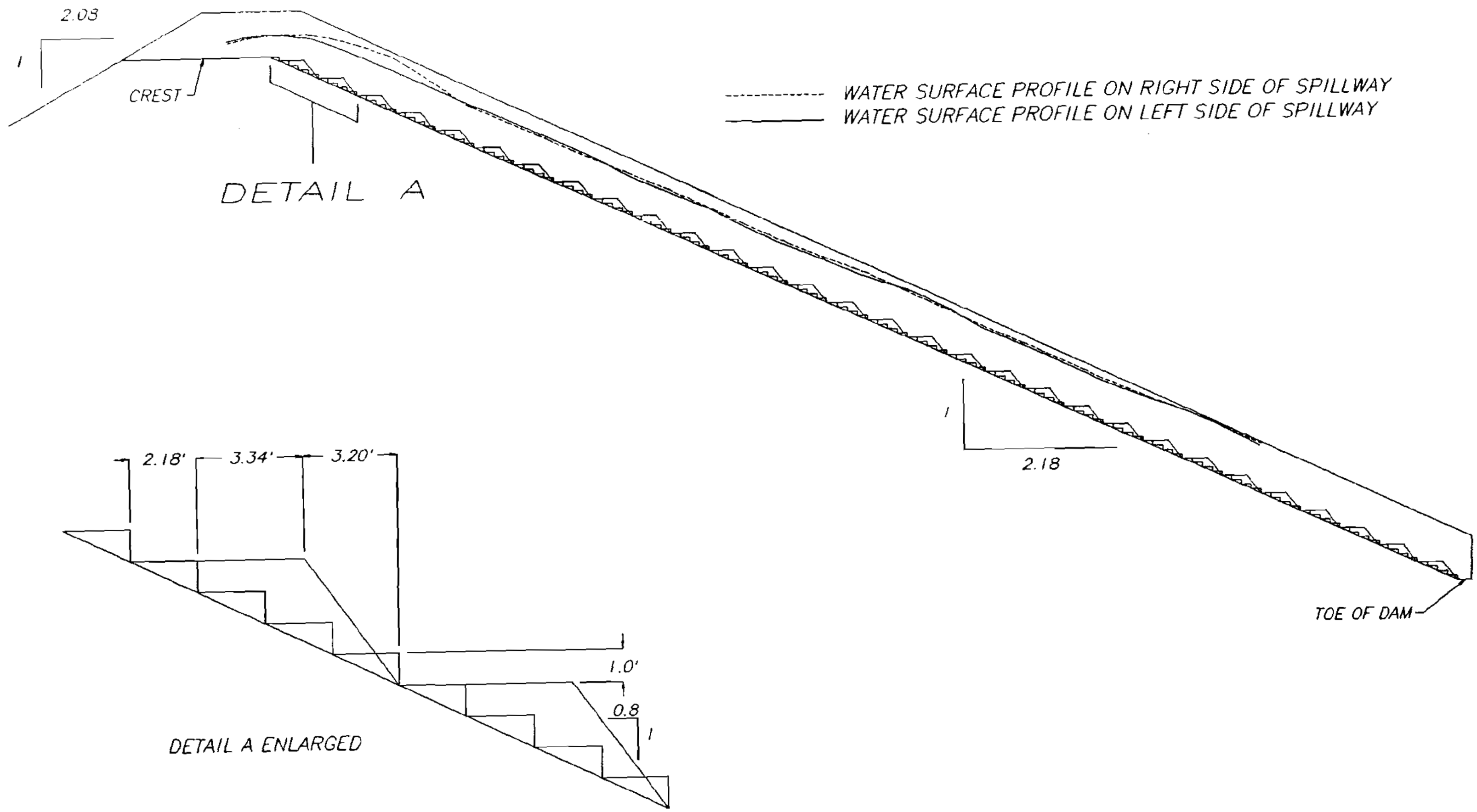
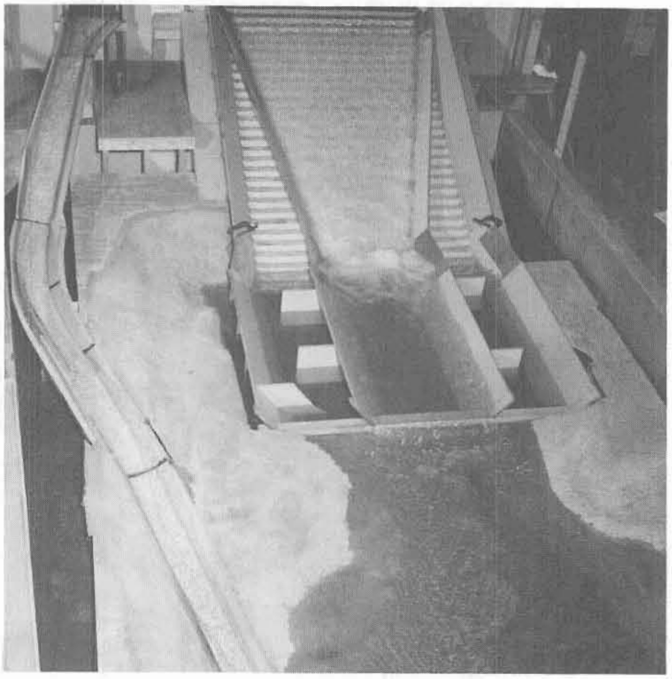
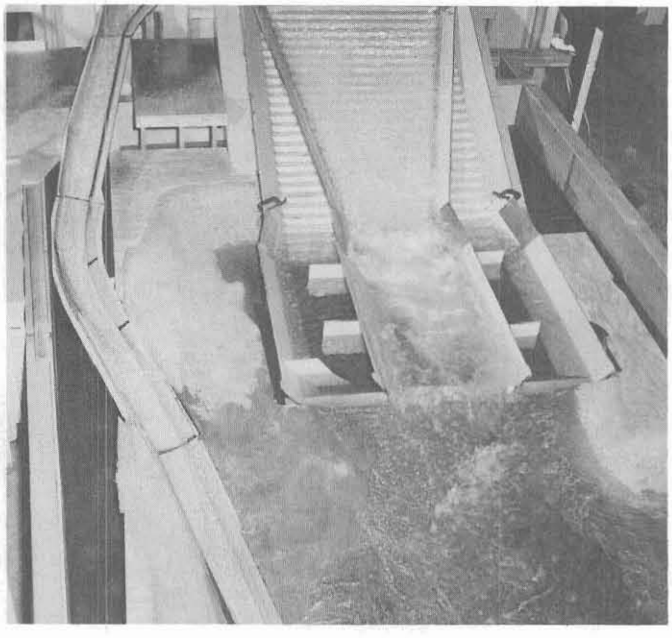


Figure 16. - Step geometry and chute water surface profiles for 4-foot steps.



(a) Q = 5,000 ft^3/s.



(b) Q = 16,534 ft^3/s.

Figure 17. - RCC spillway with 4-foot steps and a 50-foot chute width at the dam toe.

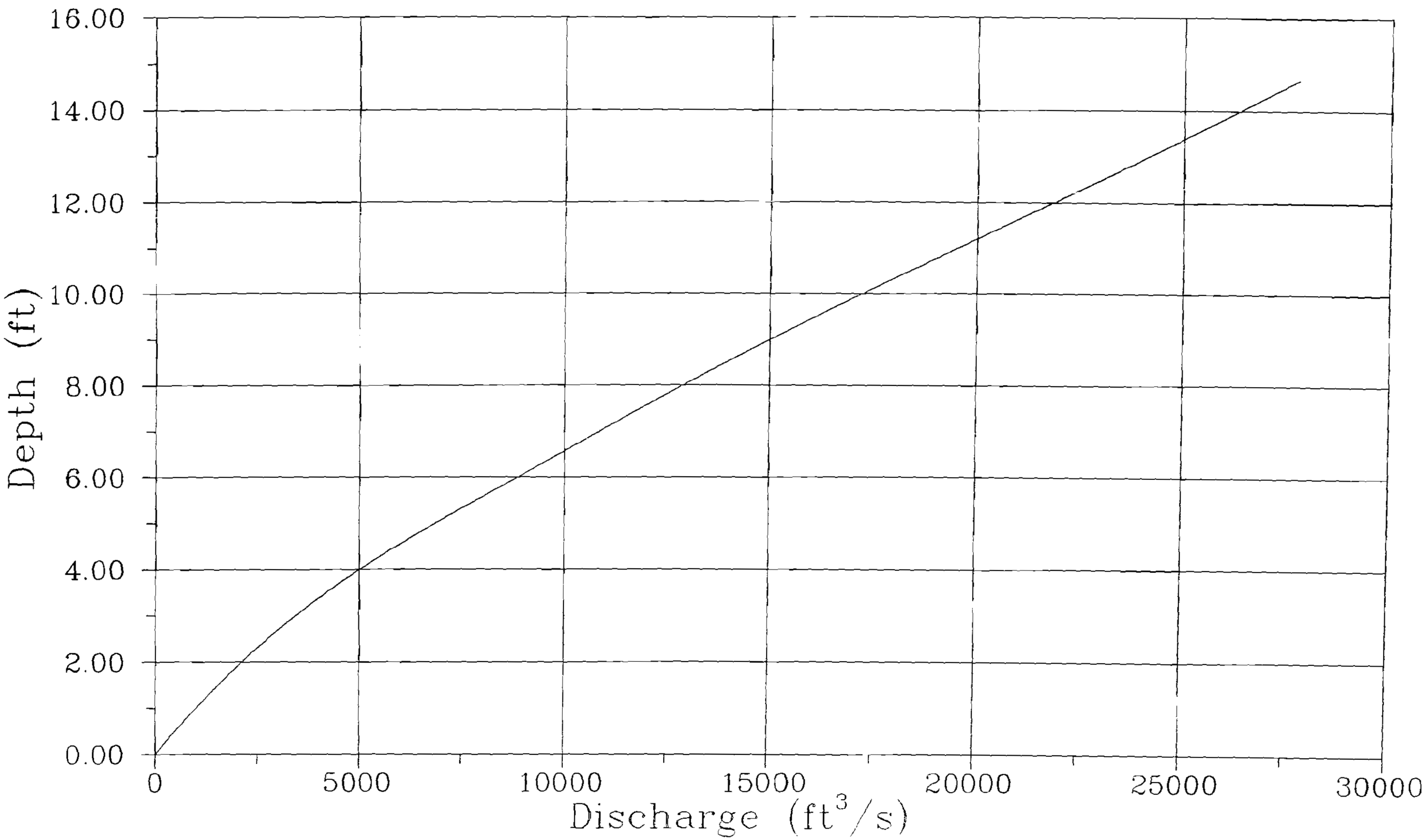


Figure 18. - Tailwater rating curve.

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-7923A, PO Box 25007, Denver Federal Center, Denver CO 80225-0007.