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# HYDRAULIC MODEL STUDY OF RITSCHARD DAM SPILLWAYS

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U.S. DEPARTMENT OF THE INTERIOR
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16. ABSTRACT

The Bureau of Reclamation conducted a physical model investigation to help design the hydraulic structures associated with Ritschard Dam. Ritschard Dam will have a labyrinth weir emergency spillway and an uncontrolled ogee crest service spillway, both of which are expected to convey flows beyond the limits of contemporary design criteria. Preliminary flume studies were conducted on sections of the labyrinth and ogee crests to determine discharge coefficients and surface pressure distributions (ogee only). The Ritschard Dam model was used to determine if the ogee and labyrinth spillways could, in combination, convey the probable maximum flood peak outflow. In addition, the model was used to determine the most efficient energy dissipation structure for the service spillway and flow conditions in Muddy Creek.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. *DESCRIPTORS*-- hydraulic model study\ labyrinth weir\ ogee crest\ discharge coefficient\ stepped spillway chute\ energy dissipation

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R-91-08

# HYDRAULIC MODEL STUDY OF RITSCHARD DAM SPILLWAYS

by

**Tracy Vermeyen**

Hydraulics Branch
Research and Laboratory Services Division
Denver Office
Denver, Colorado

October 1991

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UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

# ACKNOWLEDGMENTS

The study was performed under a cooperative agreement with the CRWCD (Colorado River Water Conservation District) and Reclamation's Grand Junction Project Office with contributions from David Merritt and Michael Baker, respectively. Geoffrey Taylor led the engineering design team from Boyle Engineering Corporation. Brent Mefford, Head of Reclamation's Hydraulic Structures Section, and hydraulic engineers Perry Johnson and Kathy H. Frizell provided technical support throughout this study.

Wayne Lambert photographed the study; Peter Julius assisted with data collection; and Barbara Prokop edited this report.

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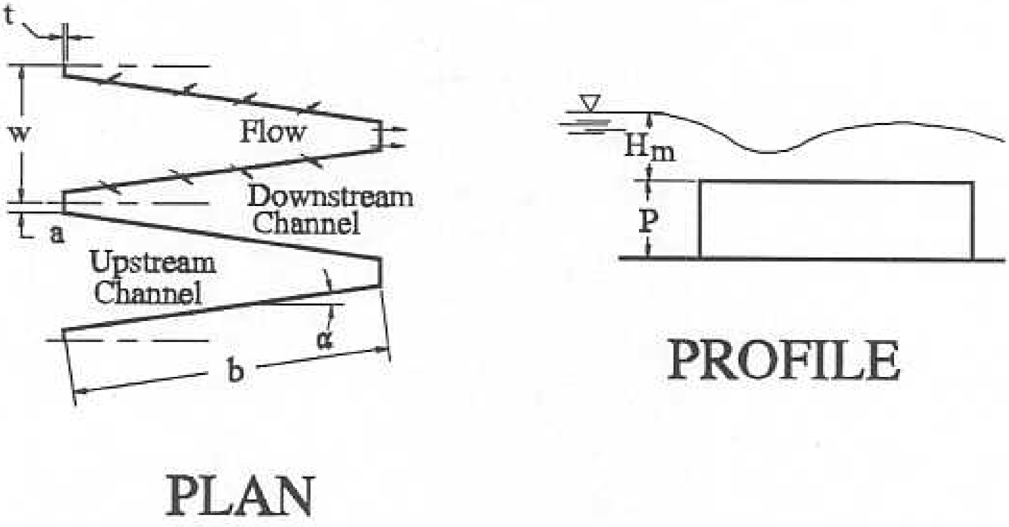
## GLOSSARY

| | |
|---|---|
| a | One-half of the weir apex length |
| b | Side length of weir |
| $H_o$ | Design head |
| $H_m$ | Head measurement taken upstream of weir crest |
| $H_v$ | Velocity head at location of $H_m$ measurement station |
| $H_t$ | Total head on weir crest ($H_m + H_v$) |
| l | Developed length of one weir cycle = $4a + 2b$ |
| w | Width of one weir cycle |
| W | Total approach channel width |
| l/w | Length magnification ratio |
| t | Weir crest thickness |
| n | Number of weir cycles |
| L | Total developed length of labyrinth weir = $l*n$ |
| P | Weir crest height |
| $H_o/P$ | Design head to weir height ratio |
| w/P | Vertical aspect ratio |
| $\alpha$ | Sidewall angle |



Schematic of labyrinth weir layout.

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## PURPOSE

Studies were conducted using scale models to provide CRWCD (Colorado River Water Conservation District) with hydraulic information pertaining to the performance of both spillways, energy dissipation structures, and flow conditions in Muddy Creek downstream of Ritschard Dam. Where necessary, modifications are recommended to improve hydraulic structure performance.

## INTRODUCTION

The proposed Ritschard Dam site is located in Grand County, Colorado, about 4 miles north of Kremmling. The dam will impound Muddy Creek, a tributary to the Colorado River. Ritschard Dam, the main feature of the Wolford Mountain Project, will be an earthen embankment structure 1,900-ft-long and will rise 120 ft above Muddy Creek. CRWCD is the project owner. Ritschard Dam will provide storage of 60,000 acre-ft of water for use by the western slope of Colorado and the Denver metropolitan area.

Ritschard Dam will be constructed with both a service and emergency spillway located in the right abutment (fig. 1). The service spillway consists of an uncontrolled ogee crest and reinforced concrete chute. The emergency spillway has a labyrinth weir control structure and an unlined rock spillway channel. Combined spillway capacity will be sufficient to pass the PMF (probable maximum flood) peak outflow of 77,000 $ft^3/s$ at the maximum allowable reservoir elevation 7499.

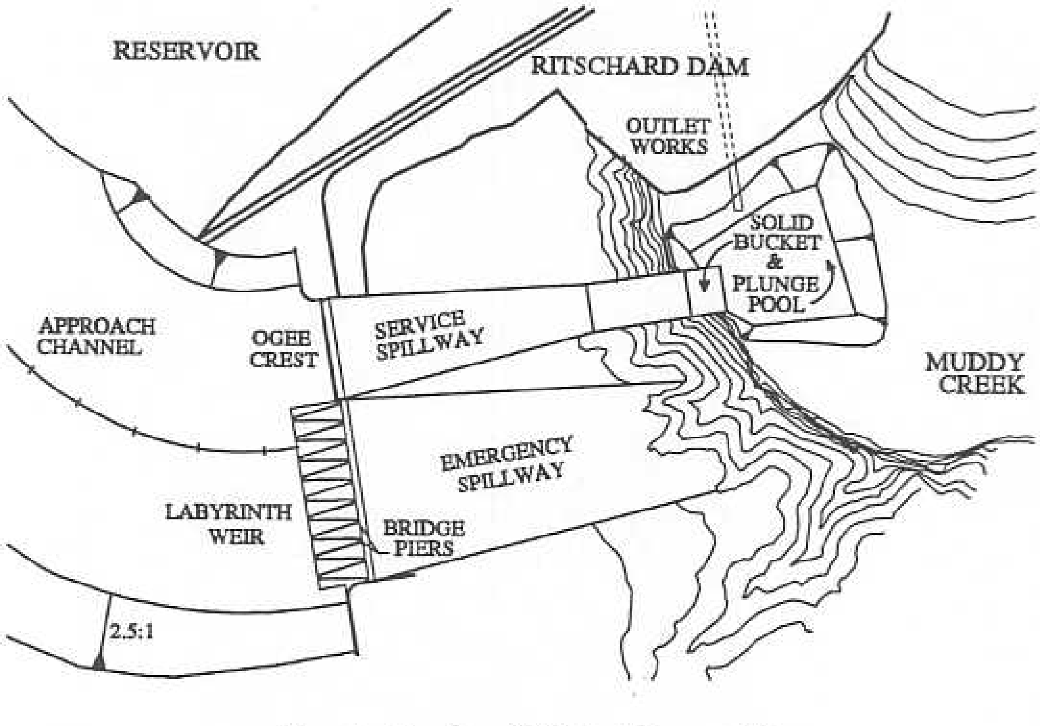

Figure 1. - Overview of Ritschard Dam model layout.

## CONCLUSIONS

1. The 9-cycle labyrinth weir adequately conveyed flood discharges up to 53,800 ft$^3$/s at reservoir elevation 7499, which is less than the 54,900-ft$^3$/s theoretical design capacity. This undercapacity is due to minor deviations in the weir geometry from the Hyrum Dam labyrinth that was the basis for design.

2. A 153-ft-long ogee crest with a design head of 4.5 ft is recommended for the service spillway. This ogee will convey the 100-year flood discharge of 6,500 ft$^3$/s at reservoir elevation 7490, thus preventing flow through the emergency spillway.

3. At the maximum reservoir elevation of 7499, the emergency and service spillways provide a combined discharge capacity of 86,000 ft$^3$/s. This discharge is greater than the peak probable maximum flood discharge of 77,000 ft$^3$/s. The governing constraint on the spillway design is the 100-year flood capacity of the service spillway. As a result, the only means to reduce the combined discharge capacity is to modify the labyrinth weir. For this configuration the design discharge of 77,000 ft$^3$/s was passed at reservoir elevation 7498, leaving 2 ft of freeboard below crest elevation 7500.

4. The solid flip bucket and plunge pool included in the preliminary design performed poorly. High tailwater suppressed the jet nappe for discharges greater than 20,000 ft$^3$/s.

5. A Reclamation type-I hydraulic jump stilling basin (horizontal apron) is recommended to dissipate flow energy from the service spillway.

6. Smooth and stepped spillways were tested on the 32° sloped section of the service spillway chute. Both geometries provide acceptable flow conditions in the stilling basin and pool. Velocity measurements of flow entering the basin from the stepped slope indicated a 15-percent increase in energy dissipation for combined (service+emergency spillway) discharges over a range of 6,500 to 12,000 ft$^3$/s. A 7-percent increase was measured for a combined discharge of 81,600 ft$^3$/s. These modest levels of energy dissipation derived by adding steps did not allow the basin size to be significantly reduced. Therefore, a smooth invert is recommended for the entire service spillway chute.

7. The 26-ft-high stilling basin sidewalls contain service spillway flows up to 6,500 ft$^3$/s. At larger flows the sidewalls overtop and provide makeup water from the plunge pool, preventing the hydraulic jump from sweeping out of the basin.

8. The original plunge pool was redesigned, and the width and length dimensions were reduced. In addition, an exit channel leading from the plunge pool into Muddy Creek was angled farther downstream to use the strong velocity component acting in that direction. These modifications helped redirect flows into Muddy Creek.

9. During large spillway flows a strong return flow eddy formed between the stilling pool and embankment toe. Designers suggested that a sacrificial berm be used to protect the embankment from erosion. Furthermore, a spur dike was tested and provided additional protection to the embankment and outlet works.

## MODELS

Discharge characteristics of the labyrinth weir and two ogee crest geometries were evaluated using 36-in-wide sectional models. These tests provided information needed to size the spillway crests for the three-dimensional Ritschard Dam model. All model tests were based on Froude law similitude. This study included the following hydraulic models:

- Model 1 - A 1:20 scale sectional model of two trapezoidal cycles of the labyrinth weir, including bridge piers.
- Model 2 - A 1:20 scale sectional model of the ogee crest with a design head ($H_o$) of 2.5 ft. The crest was equipped with eight piezometer taps along the crest centerline to measure surface pressures.
- Model 3 - A 1:20 scale sectional model of the redesigned ogee crest ($H_o$ = 4.5 ft). The crest was equipped with eight piezometer taps at similar locations to model 2, along the crest centerline to measure surface pressures.
- Model 4 - A 1:45 scale, three-dimensional model of the Ritschard Dam was constructed to investigate the overall performance of the hydraulic structures and natural channel downstream of the dam.

The Ritschard Dam model was constructed based on prototype design specifications provided by Boyle Engineering Corporation, and included these features (fig. 2):

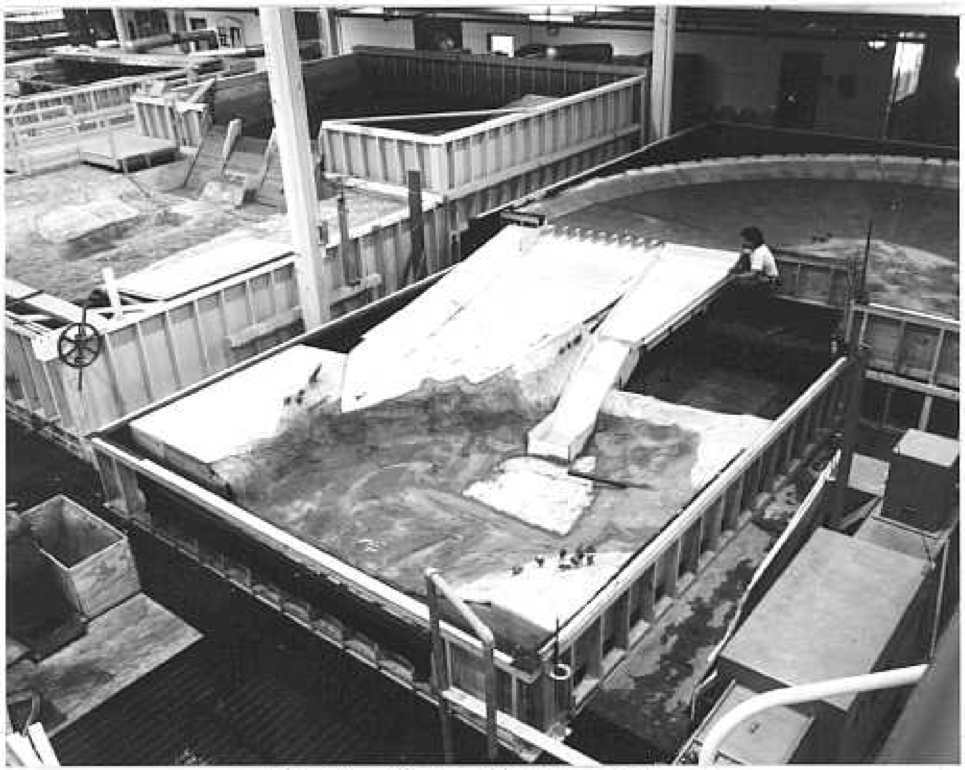

Figure 2. - Ritschard Dam hydraulic model.

(9)

**Head box with reservoir topography -** A gravel-filled baffle was installed in the model to smooth the water surface and evenly distribute inflow from a 12-in-diameter pipe. Prototype features modeled included the 485-ft-wide, curved approach channel and part of the right abutment and dam crest. In addition, sufficient topography was used to simulate the approaching flow conditions toward the spillway crests.

**Spillway control structures -** The labyrinth weir model consisted of nine trapezoidal cycles with each downstream apex containing a 30-in-diameter bridge pier (fig. 3). The labyrinth weir was 10 ft high and 20 in thick. The upstream edge was shaped to a 10-in-radius, quarter-round crest. The standard ogee crest profile was milled from high-density urethane using an automated milling machine. Five piezometer taps were installed along the ogee crest centerline to measure surface pressures.

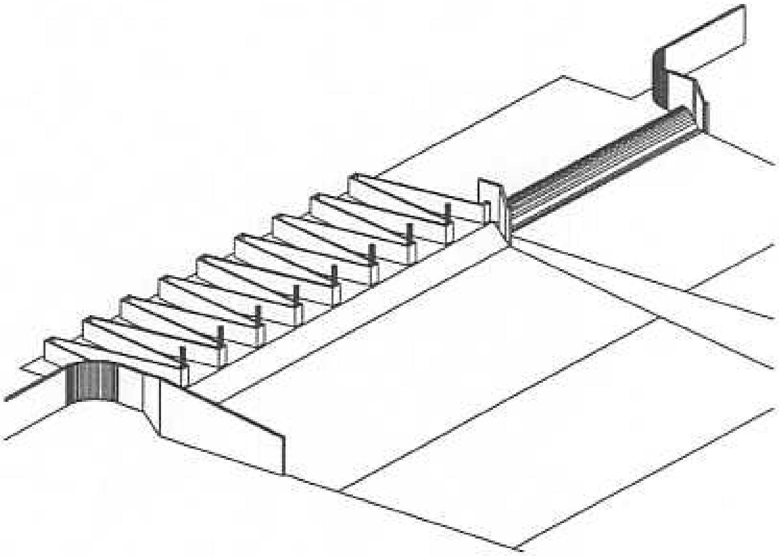

Figure 3. - Perspective view of labyrinth weir and ogee crest layout.

**Spillway chutes -** The service spillway and emergency spillway chutes conveyed the reservoir outflows into the tailwater box.

**Outlet works -** The only feature of the outlet works modeled for this investigation was the 8-ft-diameter river outlet conduit. The river outlet conduit was positioned at invert elevation 7375.

**Tailwater box and stilling basin -** The tailwater box contained the solid bucket, plunge pool, and topography for 500 ft of Muddy Creek and its floodway. The plunge pool and river topography were constructed from concrete, without plans for a movable bed study. The 50-ft-long, 45° solid bucket contained five piezometer taps along the spillway centerline to measure surface pressures. The tailwater elevations were regulated with an adjustable gate.

**Data collection -** Model inflow rates were determined using the laboratory's permanent bank of venturi meters. Reservoir and tailwater elevations were measured using point gauges mounted in

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stilling wells. Average surface pressures were measured using piezometer taps connected to water column manometers. Flow velocities were measured using a electromagnetic current meter.

## SIMILITUDE AND TEST DISCHARGES

The Ritschard Dam model was designed to a 1:45 geometric scale using Froude law relationships to ensure dynamic similarity. The Froude number was chosen because the hydraulic performance of the model/prototype structures are primarily dependent on gravitational and inertial forces.

The 1:45 scale model of Ritschard Dam has the following scaling relations:

| | |
|---|---|
| Length ratio | $L_r = 1:45$ |
| Velocity ratio | $V_r = L_r^{1/2} = (1:45)^{1/2} = 1:6.71$ |
| Discharge ratio | $Q_r = L_r^{5/2} = (1:45)^{5/2} = 1:13584.1$ |

The 1:20 scale sectional models have the following scaling relations:

| | |
|---|---|
| Length ratio | $L_r = 1:20$ |
| Velocity ratio | $V_r = L_r^{1/2} = (1:20)^{1/2} = 1:4.47$ |
| Unit discharge ratio | $q_r = L_r^{3/2} = (1:20)^{3/2} = 1:89.44$ |

For example, a prototype discharge of 6,000 $ft^3/s$ is equivalent to a 1:45 scale model discharge of:

$$\frac{6000\ ft^3/s}{(45)^{5/2}} = 0.442\ ft^3/s$$

A representative range of discharges were tested to ensure proper hydraulic performance.

## THE INVESTIGATION

### Goals

The model study was conducted in two phases to optimize the hydraulic structure performance, including approach channel shape, spillway geometry, and energy dissipation efficiency of the solid bucket and plunge pool.

Phase one included sectional model tests on the labyrinth weir and ogee crest. These studies provided discharge relationships for ideal approach conditions, i.e., flowlines parallel to the spillway centerline. Phase two incorporated information from phase one and design engineers to construct the three-dimensional Ritschard Dam model. The following items were investigated in the model study:

- Adequacy of approach channel excavation, and the effect of spillway alignment on entrance conditions and discharge capacity.

- Combined spillway discharge capacity for entire range of reservoir elevations.

- Flow conditions over control structures and through spillway chutes, including water surface profiles, sidewall heights, cross waves, bridge pier effects, and chute convergence angles.
- Emergency spillway performance and flow conditions over the downstream shale bluff and into Muddy Creek.
- Energy dissipation of flow through the service spillway, solid bucket, and plunge pool.
- Erosion potential at toe of embankment caused by spillway and outlet works releases.
- Potential for nitrogen/oxygen supersaturation in Muddy Creek due to reservoir releases.

## LABYRINTH WEIR

The Ritschard Dam labyrinth weir design is based on previous hydraulic model study results for the two-cycle labyrinth spillway recently developed for Hyrum Dam, Utah (Houston, 1983; Hinchliff, 1984). The geometric parameters for the labyrinth are essentially the same as the Hyrum design (table 1), except that nine cycles are necessary to pass the PMF peak discharge. Also, the downstream apexes are designed to include bridge support piers (fig. 4). The piers obstruct most of the apex width; therefore, for design purposes, the downstream apex length (2 x a) was not included in the developed weir length (l). By removing downstream apexes from the developed weir length, the length magnification ratio (l/w) ratio is reduced from 5.0 to a value of 4.6. The design head to weir height ratio ($H_o/P$), for Ritschard's labyrinth weir is equal to 0.9. This ratio is greater than the maximum value of 0.5 for which Hyrum model data are available. As a result, a sectional model was tested to verify the discharge relationship that was extrapolated from Hyrum model data.

**Table 1. - Comparison of Ritschard and Hyrum labyrinth weir dimensions.**

| Design parameter | Hyrum | Ritschard |
|---|---|---|
| Total width (W), ft | 60 | 275 |
| Crest length (L), ft | 300 | 1350 |
| Wall height (P), ft | 12.0 | 10.0 |
| Design head ($H_o$), ft | 5.5 | 9.0 |
| $H_o/P$ ratio | 0.46 | 0.90 |
| Number of cycles (n) | 2 | 9 |
| Sidewall angle, $\alpha$ | 8.93° | 8.13° |
| Width/cycle (w), ft | 30 | 30 |
| Developed weir length per cycle (l) | 150 | 138.8 |
| Length magnification ratio (l/w) | 5 | 4.6 |
| Total design flow (Q), $ft^3/s$ | 9,050 | 54,900 |
| Design flow per cycle (Q/n), $ft^3/s$ | 4,525 | 6,100 |

**Table 2. - Discharge relationship for 1:20 scale sectional model of labyrinth weir.**

| Prototype reservoir elevation* (ft) | Prototype discharge ($ft^3/s$) | Discharge coefficient $C = Q \div (LH_e^{1.5})$, $L = 1249.2$ ft | Head $H_e$ (ft) |
|---|---|---|---|
| 7490.63 | 2,601 | 4.17 | 0.63 |
| 7491.20 | 6,648 | 4.07 | 1.20 |
| 7491.50 | 8,261 | 3.59 | 1.50 |
| 7492.12 | 12,593 | 3.27 | 2.12 |
| 7492.43 | 14,522 | 3.07 | 2.43 |
| 7492.99 | 18,118 | 2.80 | 2.99 |
| 7493.84 | 23,577 | 2.51 | 3.84 |
| 7494.57 | 27,897 | 2.28 | 4.57 |
| 7495.60 | 33,883 | 2.05 | 5.60 |
| 7496.63 | 39,526 | 1.85 | 6.63 |
| 7497.15 | 42,272 | 1.77 | 7.15 |
| 7497.93 | 46,557 | 1.67 | 7.93 |
| 7498.82 | 53,171 | 1.63 | 8.82 |
| 7499.29 | 55,994 | 1.58 | 9.29 |
| 7499.87 | 58,896 | 1.52 | 9.87 |

* Reservoir elevation contains a correction for velocity head.

**Sectional model study -** Two complete cycles of the labyrinth, including bridge piers, were installed in a 3- by 2- by 60-ft horizontal flume. A stage-discharge relationship was established for reservoir elevations ranging from 7490 to 7500 (fig. 5). Water surface levels or heads (depth of flow above the weir crest) were measured using a point gauge located 10 ft upstream of the labyrinth. Head measurements ($H_m$) were corrected to account for velocity head ($V_h = V^2/2g$). Sectional model results showed the labyrinth crest could pass 54,250 $ft^3/s$ (interpolated) for the maximum head of 9 ft (table 2). This flow rate is 1.2 percent below the design value of 54,900 $ft^3/s$. This disparity is most likely attributed to the reduced sidewall angle and the bridge piers. Both modifications increase nappe interference which reduces discharge efficienty. Rather than modify the labyrinth weir geometry to achieve additional capacity, design engineers decided to enlarge the service spillway to convey this discharge deficit.

## OGEE CREST

The ogee crest design was based on methods described in Reclamation's *Design of Small Dams* (Bureau of Reclamation, 1987). The 153-ft-long ogee crest was designed to pass the 100-year flood, 6,500 $ft^3/s$, with a maximum water surface elevation of 7490 (i.e., to prevent flow over labyrinth weir). The ogee crest was originally designed for $H_o$ equal to 2.5 ft. This design head is much less than the 14 ft of head on the crest during the PMF. The resulting maximum head on crest ($H_e$) to design head ratio ($H_e/H_o$) is 5.6. This ratio is greater than the value of 1.6 which is the maximum value for which discharge coefficients have been reported in *Design of Small Dams* (Bureau of Reclamation, 1987). A sectional model study was conducted to find the discharge coefficients for high discharges.

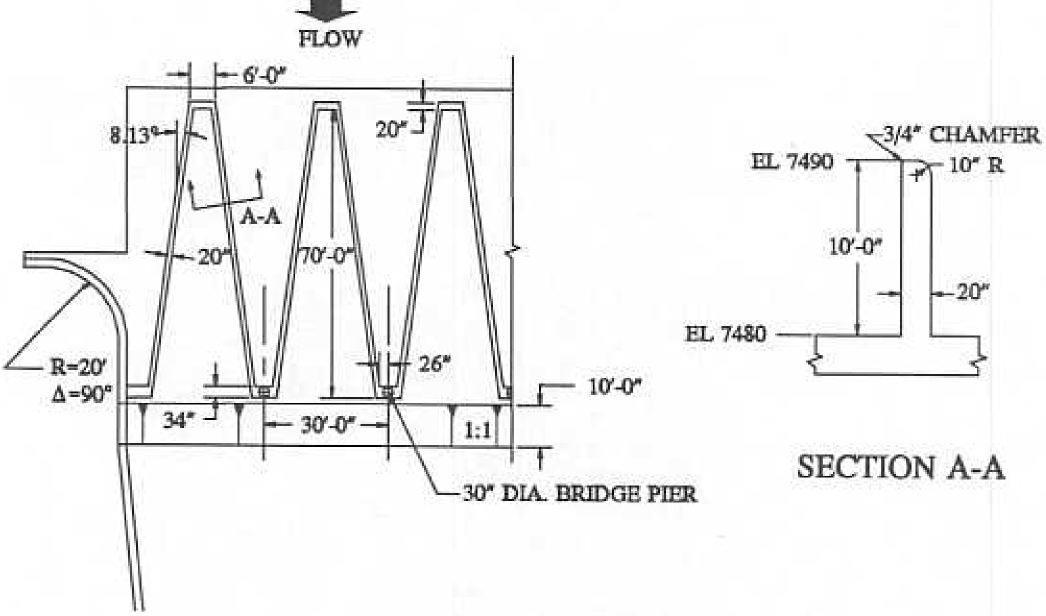


Figure 4. - Plan view of three cycles of the Ritschard Dam labyrinth weir.

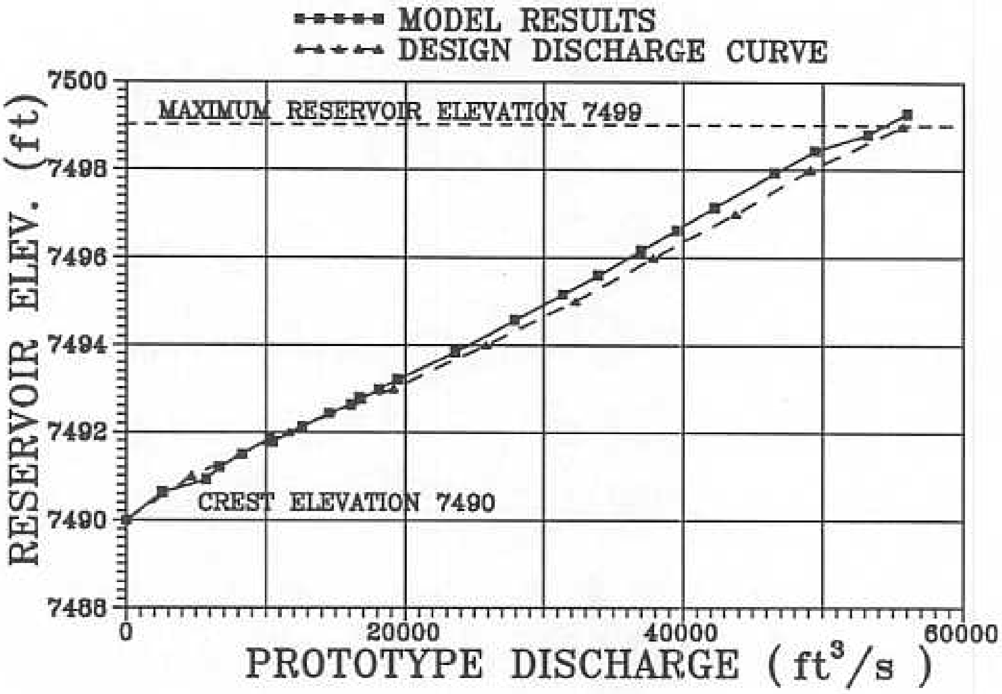


Figure 5. - Stage-discharge relationship for 1:20 scale model of Ritschard Dam labyrinth weir.

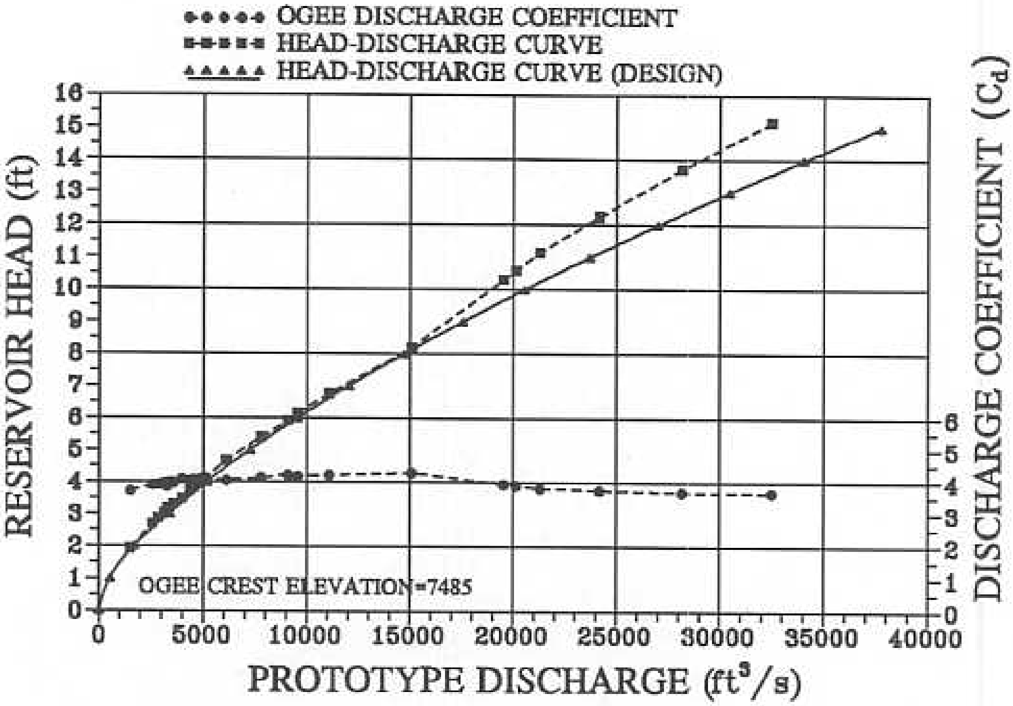


Figure 6. - Head-discharge relationship for 1:20 scale model of ogee crest ($H_o$ = 2.5 ft).

**Sectional model study -** A 60-ft length of the ogee crest and the first 25 ft of the service spillway chute were modeled in a horizontal flume. There were eight piezometer taps installed along the crest centerline to measure surface pressures. However, pressure tap No. 5 produced inconsistent data and was abandoned. Similar head measurements were taken for the labyrinth sectional model. The ogee model was tested for heads up to 15 ft above crest elevation 7485. The head-discharge relationship followed the design curve for heads up to 8 ft (~3 x $H_o$). For heads greater than 8 ft a significant reduction in the discharge coefficient occurred (fig. 6). This can be attributed to the short transition section between the ogee profile and spillway chute. Consequently, as flow depths increase, the subatmospheric pressure region is suppressed. This is apparent in the 6 x $H_o$ pressure head profile on figure 7(a), which shows a diminished subatmospheric pressure region. Subatmospheric pressures that are distributed along the overfall face are conducive to high discharge coefficients. Therefore, if this region of subatmospheric pressure is truncated during large discharges a reduced spillway efficiency can be expected.

As a result of this sectional model test, the following ogee changes were incorporated prior to constructing the Ritschard Dam 3-D model:

- Redesign the ogee crest based on the "effective" ratio of head ($H_e$) to design head ($H_o$). Where the maximum "effective" head is 8 ft and the design head is 2.5 ft, and $H_e/H_o$ is equal to 3.2. This method was used to determine the revised design head of 4.5 ft, i.e. divide maximum head of 14 ft by 3.2.

- The ogee crest was lengthened from 153 to 163 ft to provide more discharge capacity. The final crest length will depend on discharge capacity reductions resulting from approach channel losses and bridge pier influences.

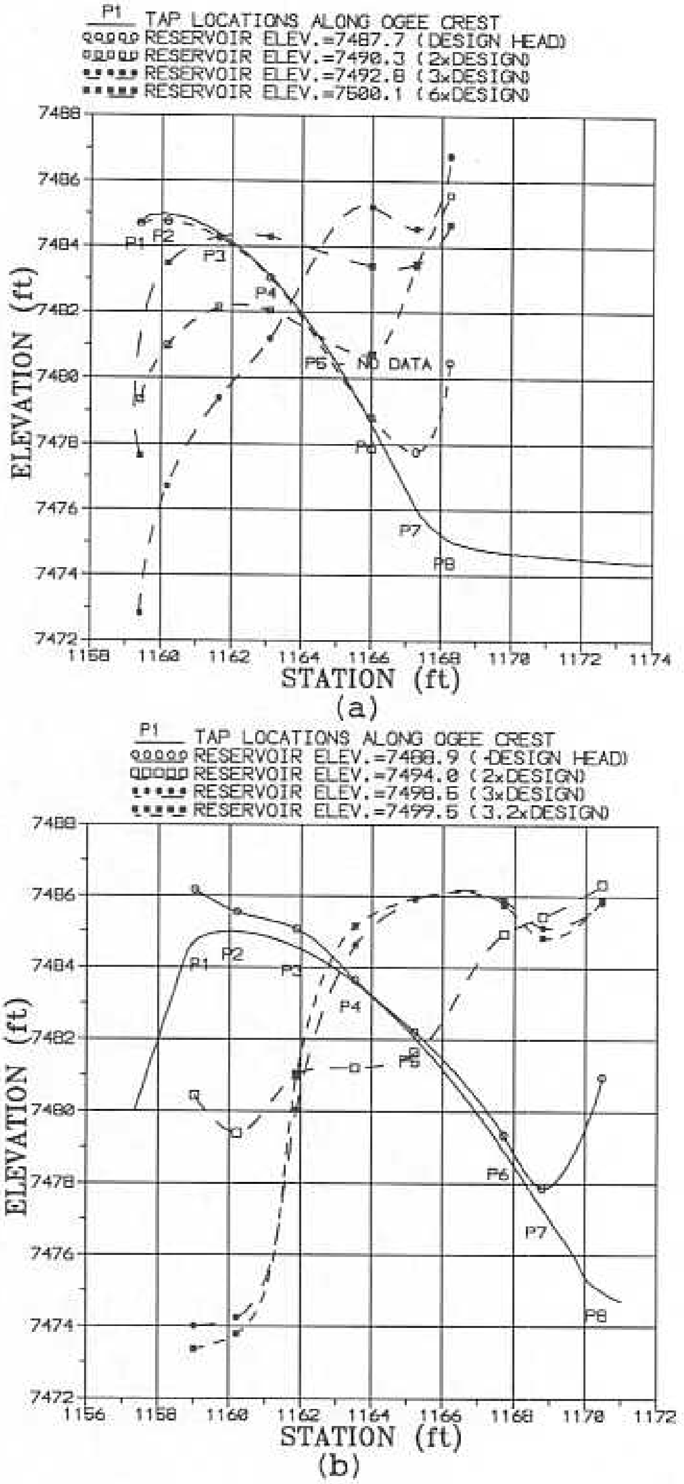


Figure 7. - Ogee crest piezometric pressure profiles (in ft of water, plotted vertically); (a) original ogee crest ($H_o$ = 2.5 ft) and (b) recommended ogee crest ($H_o$ = 4.5 ft).

- A 1H:3V sloping transition was added to the upstream face of the ogee to further improve the discharge coefficient.

**Recommended ogee crest -** A sectional model for the revised ogee crest (fig. 8) was constructed and tested to establish a discharge relationship and collect surface pressure data. Construction and data collection techniques were identical to the first ogee model. The discharge relationship (table 3) for this design provides adequate capacity to convey the 100-year flood of 6,500 $ft^3/s$ while maintaining a reservoir elevation below 7490. The discharge was 33,400 $ft^3/s$ (interpolated using data in table 3). Discharge data indicated only a small reduction in discharge coefficient for heads greater than the design head of 4.5 ft (table 3). Figure 7(b) illustrates the mechanism forcing the improvement in discharge coefficient. The maximum coefficient occurs at approximately twice the design head. This corresponds to where the surface pressures are subatmospheric over the largest area of the ogee crest (from taps P1 to P5). As the head increases the surface pressures are further reduced; however, the surface area over which it acts is reduced (from taps P1 to P3). The net result is a small decrease in discharge coefficient. These results support the assertion that an ogee crest with a short transition slope (Sta. 11+67.96 to Sta. 11+69.78) and a head to design head ratio of 3.2, or lower, will maintain a high discharge coefficient. It should be noted that discharge coefficients for the sectional model are optimum values and do not take approach, pier, or entrance losses into account. Therefore, the sum of the sectional model discharges is only an estimate of the combined discharge through the service and emergency spillways.

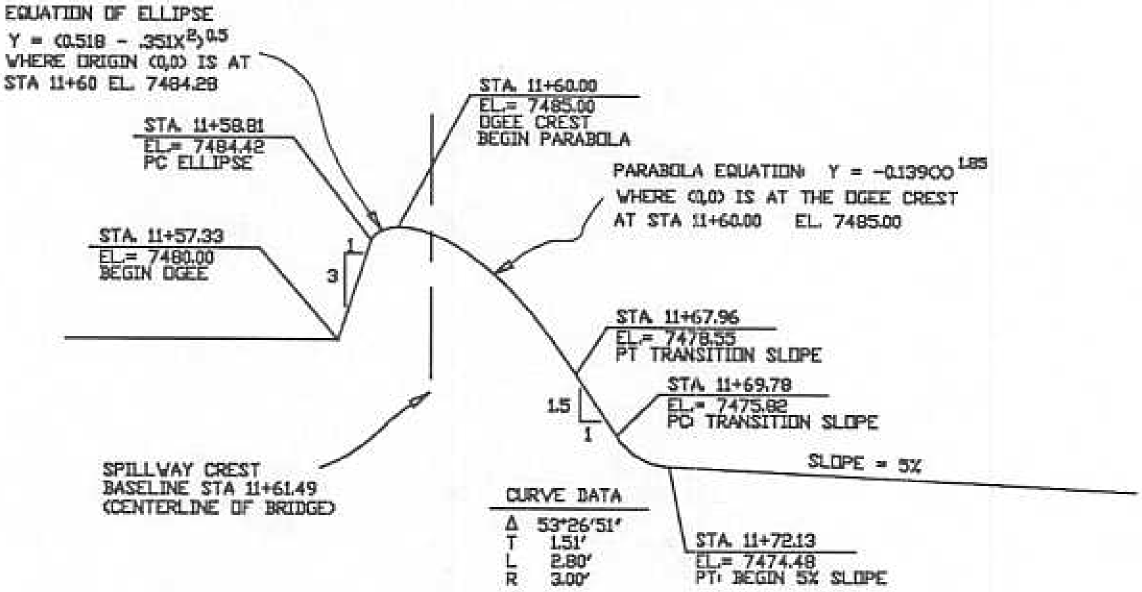


Figure 8. - Redesigned ogee crest with a design head ($H_o$) equal to 4.5 ft.

## RITSCHARD DAM MODEL

Ritschard Dam hydraulic model was constructed at a 1:45 scale to use the available space in the hydraulics laboratory. The curved approach channel, spillways, solid bucket, plunge pool, and a portion of Muddy Creek were modeled (fig. 2).

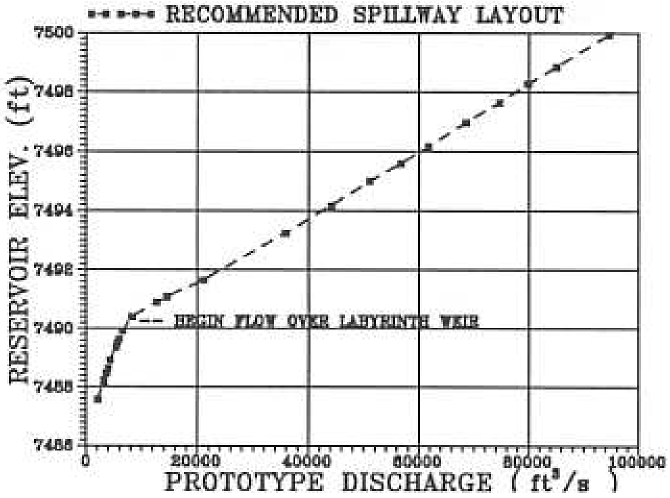
Table 3. - Discharge relationship for 1:20 scale sectional model of ogee crest ($H_o = 4.5$ ft).

| Prototype reservoir elevation* (ft) | Prototype discharge ($ft^3/s$) | Discharge coefficient $C = Q \div (LH_e^{1.5})$, $L = 150$ ft | $H_e/H_o$ |
|---|---|---|---|
| 7486.67 | 1,340 | 4.16 | 0.37 |
| 7487.53 | 2,282 | 3.77 | 0.56 |
| 7488.54 | 3,927 | 3.94 | 0.79 |
| 7488.96 | 4,897 | 4.14 | 0.88 |
| 7490.04 | 6,999 | 4.12 | 1.12 |
| 7491.06 | 9,294 | 4.16 | 1.35 |
| 7492.32 | 12,685 | 4.27 | 1.63 |
| 7492.99 | 14,656 | 4.33 | 1.78 |
| 7494.08 | 17,681 | 4.31 | 2.02 |
| 7494.90 | 20,261 | 4.33 | 2.20 |
| 7495.79 | 23,028 | 4.33 | 2.40 |
| 7496.65 | 25,822 | 4.33 | 2.59 |
| 7498.04 | 30,195 | 4.27 | 2.90 |
| 7498.65 | 32,221 | 4.26 | 3.03 |
| 7499.46 | 35,000 | 4.24 | 3.21 |

* Reservoir elevation contains a correction for velocity head.

**Spillway approach channel** - The flow distribution within the headbox was examined to verify that the flow entering the approach channel was indicative of the reservoir condition. A gravel-filled baffle was necessary to distribute evenly the point source inflow and dampen wave action. Flow visualization techniques, including dye tracing and floating pathlines, showed that the baffle was very effective at both distributing and stilling the inflow. Flow entering the excavated approach channel was distributed evenly, thus adequately simulated the proposed reservoir condition. The adverse approach channel slope ($s = 0.019$) provided a smooth transition to the spillway apron (elevation 7480). As a result, there was no apparent effect on the spillway performance due to the curved approach channel. Training walls for both the labyrinth weir and ogee crest provided adequate entrance conditions and reduced waves entering the spillway chutes.

**Discharge capacity** - Based on results from the sectional model study, the ogee crest shape was redesigned for a design head of 4.5 ft. The crest length was also increased by 10 ft, for a total length of 163 ft. The ogee crest discharge capacity was calibrated for reservoir elevations between 7485 and 7490, above which the labyrinth weir begins to spill. The maximum combined spillway capacity at reservoir elevation 7499 was 86,400 $ft^3/s$, which exceeded the design value of 77,000 $ft^3/s$ by 12.2 percent. Consequently, the ogee crest length was adjusted based on flood routing using the discharge coefficients from the ogee crest sectional model results. The revised ogee crest length is 153 ft, including 3 ft for the bridge piers; therefore, the effective crest length is 150 ft. For this ogee length, the maximum discharge through both spillways is about 86,000 $ft^3/s$. A 153-ft ogee crest length is recommended because it meets the criterion that the service spillway will pass the 100-year flood (6,500 $ft^3/s$) while maintaining a reservoir elevation below 7490. For the 153-ft crest length, the measured service spillway discharge at reservoir elevation 7490 was 6,600 $ft^3/s$ (interpolated). The combined stage-discharge relationship for the recommended spillway configuration is shown in figure 9.



| Prototype reservoir elevation (ft) | Prototype discharge (ft³/s) |
|---|---|
| 7487.6 | 2,040.20 |
| 7488.2 | 3,166.63 |
| 7488.9 | 4,294.98 |
| 7489.9 | 6,539.03 |
| 7490.9 | 12,647.80 |
| 7491.7 | 21,067.30 |
| 7493.2 | 35,919.50 |
| 7494.2 | 44,167.80 |
| 7495.0 | 51,101.67 |
| 7495.6 | 56,748.20 |
| 7496.2 | 61,798.18 |
| 7497.0 | 68,605.23 |
| 7497.7 | 74,726.30 |
| 7498.3 | 79,867.31 |
| 7498.9 | 85,061.66 |
| 7499.9 | 94,651.07 |

Figure 9. - Combined discharge relationship for recommended Ritschard Dam spillways.

**Service spillway chute** - The service spillway chute is a reinforced concrete structure. The preliminary design consisted of three sections: (1) a converging rectangular channel at a 2.9° slope, (2) a 70-ft-wide vertical curve transition, and (3) a 70-ft-wide rectangular channel at a 32° slope. The chute width converges at a 6.8° training wall angle from 163 ft (Sta. 11+72.13) to a constant width of 70 ft (Sta. 15+21.81) (fig. 10). After initial testing indicated excess capacity the converging rectangular channel was modified to accommodate the 153-ft-long ogee crest. Training wall convergence angle was reduced to 6.1°.

Chute convergence results in the formation of cross waves. These standing waves impinged on the sidewalls just upstream of the vertical curve transition, (fig. 10). For the PMF discharge cross waves intermittently overtopped the 12-ft-high training wall at the entrance to the vertical transition, at Sta. 15+25. Training wall overtopping occurred only for the maximum flow through the spillway and results in a small volume of spillage out of the chute. Overall, the flow distribution within the converging chute is uniform. The 70-ft-wide rectangular chute adequately conveyed flows

Figure 10. - View of cross waves impinging on service spillway training walls (Q – 30,000 ft³/s).

through the vertical curve transition, and down the 32° slope. However, flow concentrates in the center of the spillway chute at high flow rates.

**Tailwater elevations -** To model accurately the tailwater conditions below Ritschard Dam, a relationship between reservoir outflow and tailwater elevation must be known. This relationship was developed by Boyle Engineering Corporation using the U.S. Army Corps of Engineers' water surface profile computer model, HEC-2. Throughout testing the proper tailwater elevation was established for the corresponding reservoir discharge, using this relationship.

**Solid bucket dissipator -** The solid bucket dissipator was investigated over the entire range of flows. Observations of the solid bucket performance showed the bucket would not maintain a free jet for each corresponding tailwater elevation. For discharges less than 20,000 $ft^3/s$ there was insufficient fluid momentum to sweep ponded water from the bucket. For discharges exceeding approximately 20,000 $ft^3/s$, the lower jet nappe was submerged by the tailwater. Consequently, the flip bucket and plunge pool design was ineffective in dissipating the flow energy and generated large waves downstream (fig. 10). To improve performance the bucket outlet elevation would have to be increased from 7375.4 to 7383.4 to eliminate submergence. The foundation elevation is controlled by the location of a suitable base material that is at elevation 7355. Consequently, the solid bucket design would require a massive concrete foundation that was regarded as cost prohibitive. As alternatives, a stepped spillway and smooth chute were tested, both of which discharged into a Reclamation type-I hydraulic jump basin. These alternatives take advantage of the high tailwater elevations for energy dissipation and reduce costs by eliminating construction of the solid bucket and foundation.

**Spillway chute modification -** A stepped spillway chute was investigated to determine if additional energy dissipation derived from the stepped geometry would significantly reduce the stilling basin size. The 70-ft-wide, rectangular part of the service spillway chute was designed to incorporate 2-ft-high steps down the face of the 32° slope. The vertical curve transition contained 1- and 1.5-ft steps that comprised the transition section of the stepped slope (fig. 11). The steps extended into the plunge pool to elevation 7355 where acceptable foundation material is found.

The average depth through the 70-ft-wide section of the stepped spillway chute was 8.7 ft while passing a combined discharge of 86,000 $ft^3/s$. Prototype flow depths will be greater because of bulking associated with air entrainment. No air entrainment was observed in the model chute for discharges greater than the 100-year flood of 6,500 $ft^3/s$. However, a hydraulic model study of Monksville Dam, NJ (Sorenson, 1985) has many similar features to Ritschard Dam, including a stepped spillway with 2-ft-high steps placed on a 0.8H:1V slope (twice as steep as Ritschard) and a comparable elevation drop of 100 to 120 ft. The Monksville Dam model study provides a conservative benchmark for estimating the effects of air entrainment for Ritschard Dam service spillway. Results from this 1:25 scale model study show a 5- to 8-percent increase in flow depths due to air entrainment for unit discharges between 60 and 150 $ft^3/s$-ft. The maximum unit discharge (based on a 150-ft crest length) through the Ritschard Dam service spillway is 222 $ft^3/s$-ft. Normally, air entrainment data collected from scaled model studies is underestimated due to inadequate reproduction of boundary layer development. Assuming a 10-percent air-to-water ratio the flow depth over the steps would be approximately 9.6 ft. Based on these results, the 12-ft-high training walls are adequate to convey the design discharge with 2.4 ft of freeboard. For a smooth invert surface air entrainment is not likely to cause a significant increase in flow depth. Therefore, the training wall heights would not have to be increased by 10 percent to account for bulking.

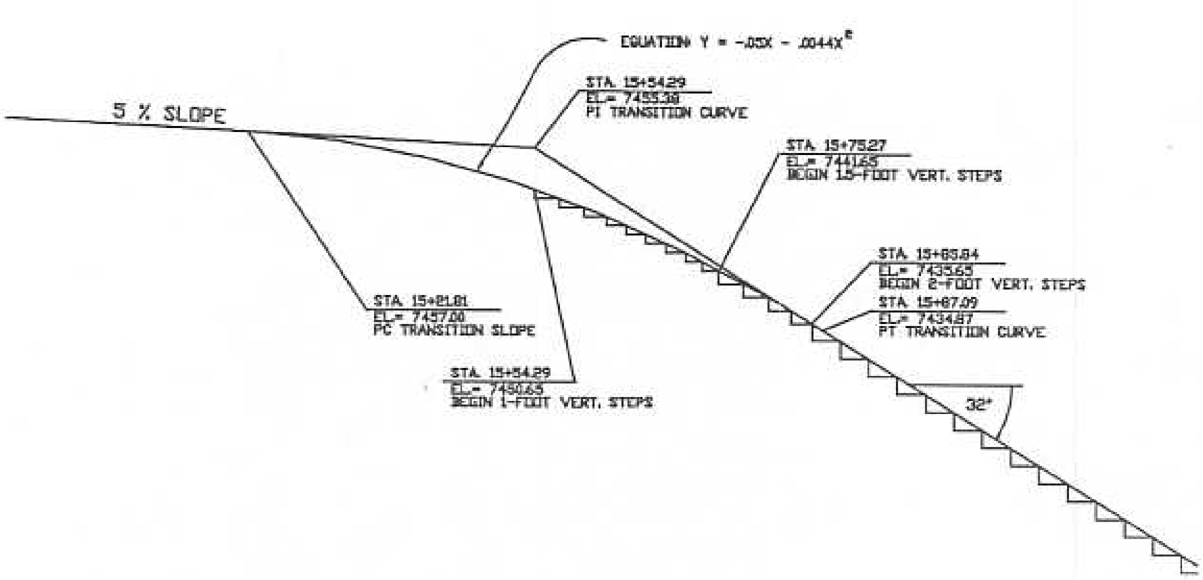


Figure 11. - Service spillway chute profile of vertical curve transition and step configuration.

Velocity data were collected on the stilling basin floor, just downstream of the slope toe, to compare the energy dissipation characteristics of the stepped and smooth invert spillway. Data showed that for flows of 6,500 and 12,000 ft$^3$/s, velocities for the stepped chute, when compared to the smooth invert, were reduced from 18.3 to 15.5 ft/s (15.3 percent) and from 21.7 to 18.5 ft/s (14.7 percent), respectively. Similarly, for a combined discharge of 86,400 ft$^3$/s the velocity was reduced from 55.1 to 51.2 ft/s (7 percent). The reduced influence of the steps for increased flows reflects a smaller relative roughness produced by the steps as flow depths increase. For large discharges, flow skims over the steps; whereas, at small discharges the flow impinges on the tread of each consecutive step. As a result, the percentage of energy dissipation decreases with increasing flow depths.

Cavitation potential was analyzed for a smooth chute invert using a computer model; however, this model cannot accurately simulate the hydraulic characteristics of a stepped chute. The smooth chute results suggested a very limited potential for cavitation damage. Nonetheless, care should be taken to limit the size and number of vertical offsets at construction joints for a smooth chute.

**Stilling basin/pool -** The stilling basin sidewalls were set to elevation 7387, or 32 ft high. Flows up to 22,000 ft$^3$/s can be spilled before the 32-ft-high sidewalls become submerged. For extreme flood events, submerging the sidewalls was desired to reduce the differential hydrostatic loading across the walls and help maintain the hydraulic jump within the stilling basin. By submerging the walls the jump can be contained within the basin without the need for floor blocks or an end sill (type I). It is recommended that the sidewalls extend to elevation 7381 (26 ft high), which is high enough to contain the 100-year flood discharge without overtopping the sidewalls.

During initial review of both the solid bucket and smooth spillway chute, it was apparent that the stilling pool's hydraulic performance could be enhanced by reducing its size and modifying its geometry to direct flow away from the embankment toe. The original pool geometry resulted in an intense eddy, or recirculating flow, which could cause severe erosion at the embankment toe. The pool was redesigned and both the width and length dimensions were reduced. In addition, an exit channel leading from the pool into Muddy Creek was angled downstream to use the strong velocity component in that direction (fig. 12). This modification helped in redirecting flows into Muddy Creek.

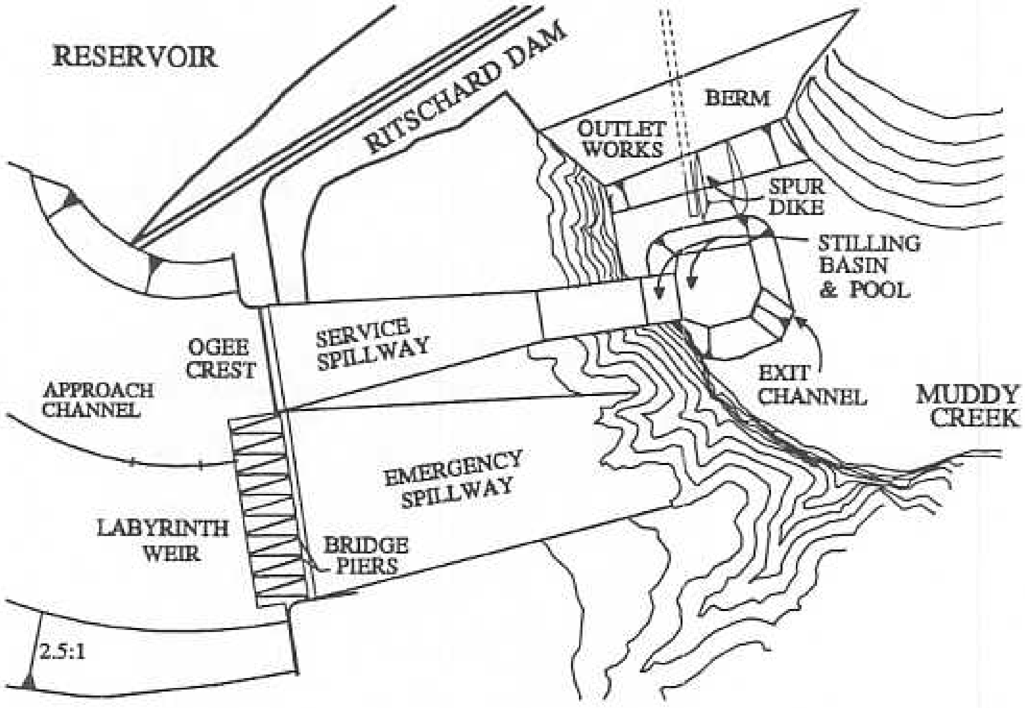


Figure 12. - Ritschard Dam - final model configuration.

To protect the embankment toe from erosion a sacrificial berm was incorporated into the model (fig. 12). However, this change did not eliminate the source of the problem, which is the eddy that forms between the stilling pool and dam. Flow conditions in the pool were improved further by adding a spur dike downstream of the outlet works structure. The spur dike was placed perpendicular to the embankment and extended to the edge of the stilling pool. Without the spur dike, spillway flows of 81,600 $ft^3$/s caused an intense eddy to develop as flow recirculated over the stilling basin sidewalls and back into the stilling basin. At this discharge, a velocity of 22 ft/s was measured along the berm near the outlet works. However, the spur dike deflects the recirculating flows into the stilling basin. The velocity along the sacrificial berm was reduced to about 2 ft/s in the area upstream of the outlet works. The reduced velocity will help reduce erosion around the outlet works and berm. Extreme floods may cause erosion and scour in the pool and surrounding areas, but will not endanger the embankment or outlet works structure if a berm or spur dike is constructed.

**Nitrogen/oxygen supersaturation** - Muddy Creek is a meandering stream, below the proposed Ritschard Dam, down to its confluence with the Colorado River. Streams in this category raise concerns about supersaturated gas concentrations downstream of stilling basins. Supersaturated gas concentrations in excess of approximately 110 percent can lead to gas bubble disease in the local fish population. The possibility of supersaturating tailwater with dissolved nitrogen and oxygen gas exists whenever a jet containing entrained air is discharged into a deep pool, as is the case with the service spillway hydraulic jump basin. The quantity of dissolved gas that water will absorb is directly proportional to the absolute pressure on the water. Therefore, with large tailwater depths the potential for supersaturation is high if the jet penetrates deep into the basin. A stepped spillway chute has the advantage of reducing jet penetration through increased energy dissipation. However, it will increase the quantity of air entrainment, which is undesirable. Dissolved gases are readily removed from solution through large-scale turbulence or white waterflow. If these flow conditions do not exist downstream of the stilling basin the dissolved gas can remain in solution for several miles and threaten the fish population throughout that reach.

Observations of the Ritschard Dam model indicate that conditions exist for supersaturation of dissolved gases for flood discharges greater than the 100-year event (6,500 $ft^3/s$). However, flow conditions in Muddy Creek at this discharge were very rapid and had the capacity to remove dissolved gases from solution. For the 5-, 10-, and 50-year flood discharges (400, 1,300, and 4,600 $ft^3/s$, respectively), the spillway jet was dissipated near the tailwater surface and did not create an excessive supersaturated condition. A detailed account of this subject is available in a Reclamation report entitled *Prediction of Dissolved Gas at Hydraulic Structures* (Johnson, 1975). Using methods outlined in this report, an analysis was performed, for a smooth chute, to determine the quantity of nitrogen gas uptake for the 5-, 10-, and 50-year floods through the service spillway, table 3. The 50-year flood has an estimated dissolved nitrogen concentration of 115 percent which may affect immature fish. However, for such an infrequent flood event this nitrogen concentration is of little concern. Based on these results, it is not necessary to include the 2-ft steps in the service spillway for limiting supersaturation in Muddy Creek downstream of Ritschard Dam.

**Table 4. - Results of supersaturation analysis for Ritschard Dam service spillway.**

| Discharge ($ft^3/s$) | Recurrence interval flood (years) | Dissolved nitrogen gas (mg/l) | Percent supersaturation* |
|---|---|---|---|
| 400 | 5 | 18.15 | 101 |
| 1,300 | 10 | 18.92 | 105 |
| 4,600 | 50 | 20.72 | 115 |

* $\frac{C_{supersat}}{C_{Initial}} * 100\%$, *where* $C_{Initial}$ = 18.0 *mg/l*

**Emergency spillway chute** - The emergency spillway chute will be an unlined rock channel founded on firm shale bedrock, trapezoidal in cross section, with 2.5:1 side slopes. The chute has the following characteristics: a 5-percent slope, 5.7° convergence angle, and the maximum excavated depth is 25 ft at Sta. 15+20. The emergency spillway chute discharges over a shale bluff and into Muddy Creek. The total freefall from the emergency spillway to Muddy Creek is approximately 80 ft.

The spillway performed very well for the entire range of discharges. The flow was evenly distributed throughout the channel cross section. At the PMF discharge, the maximum measured flow depth was 8.0 ft, at Sta. 12+60 and a velocity of 37 ft/s was measured at Sta. 17+00. Flow depths were relatively constant throughout the converging chute. Flow over the shale bluff and into Muddy Creek was very turbulent and will likely cause a scour hole to develop at the base of the bluff. This scour does not represent a threat to Ritschard Dam. However, high tailwater elevations associated with extreme floods, will help reduce scour caused by plunging flow. Observations indicated that the emergency spillway discharges have very little effect on the service spillway's operation.

**Downstream channel.** - Flow conditions in Muddy Creek were calm for discharges less than 6,600 $ft^3/s$ because most the flow energy was dissipated within the stilling basin. For floods that cause both spillways to operate, the flow in Muddy Creek was rapid and turbulent due to the plunging flows over the emergency spillway. Muddy Creek's flood plain is also inundated. Even though a movable bed study was not conducted it was obvious that significant erosion and scour will accompany these infrequent floods.

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