RECLAMATION

Managing Water in the West

Hydraulic Laboratory Technical Memorandum PAP-1021

Blue River Fish Barrier: Additional Physical Modeling to Optimize the Fish Barrier

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulic Investigations and Laboratory Services Group
Denver, Colorado

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Blue River Fish Barrier: Additional Physical Modeling to Optimize the Fish Barrier

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Introduction

Previously, two hydraulic models (one physical and one numerical) were used to assess and improve the design of a proposed fish barrier weir structure to be built on the Blue River in eastern Arizona approximately 0.5 miles upstream of the confluence with the San Francisco River (Lentz 2010; Russell 2010). The structure is being considered to block upstream movement of non-native fish. The models evaluated local scour expected to be caused by the structure as well as aggradation and degradation upstream and downstream from the barrier. Flow conditions during the 2-, 25- and 100-year discharges were simulated to determine the maximum amount of scour expected at the structure.

The original physical model study recommended that a training wall be installed on the left side of the fish barrier to prevent localized scour from occurring on the toe of the structure. This technical memorandum details the additional physical modeling that was completed in an effort to optimize the fish barrier to reduce scour without using obtrusive physical features (such as the previously recommended training wall).

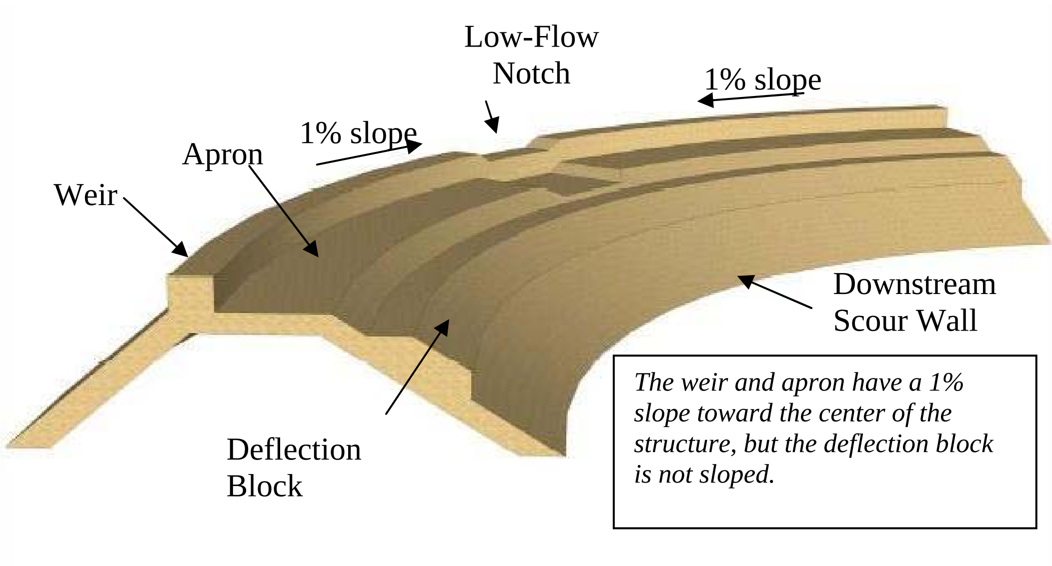

Figure 1. 3-D rendering of the fish barrier initial design.

Investigations and Results

Lower the Barrier

The original model study recommended that the entire barrier be lowered 2 ft to help reduce scour, however this recommendation was not modeled until this round of modeling was implemented. See Figure 2 showing the lowered barrier. Lowering the barrier did reduce both the depth of localized scour holes and the overall degradation of the channel immediately downstream from the barrier.

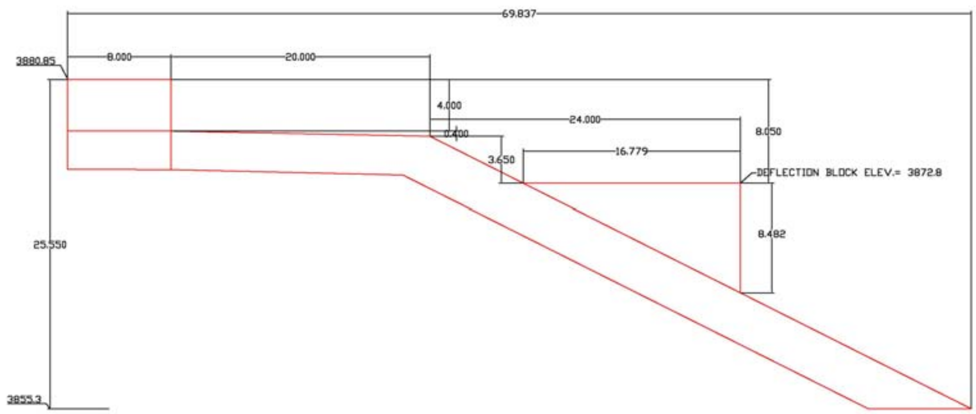

Figure 2. Cross section of the barrier at the abutments. The weir and apron of the barrier slope towards the center of the river channel. At the center of the barrier the weir and apron are 1.15 ft lower than at the abutments. The deflection block does not slope and has a constant elevation of 3872.8 ft NAVD 88.

Topography Upstream of the Barrier

On the left side of the channel, some of the existing ground surface immediately upstream of the proposed barrier location is higher in elevation than the weir of the barrier (see Figure 3).   The initial design called for the barrier to be constructed out of roller compacted concrete (RCC) and a deep scour wall to be placed upstream from the barrier. This would require a significant portion of the upstream topography to be excavated. The initial physical model was built assuming that the upstream topography would be backfilled at an elevation of 5 ft below the weir of the barrier.

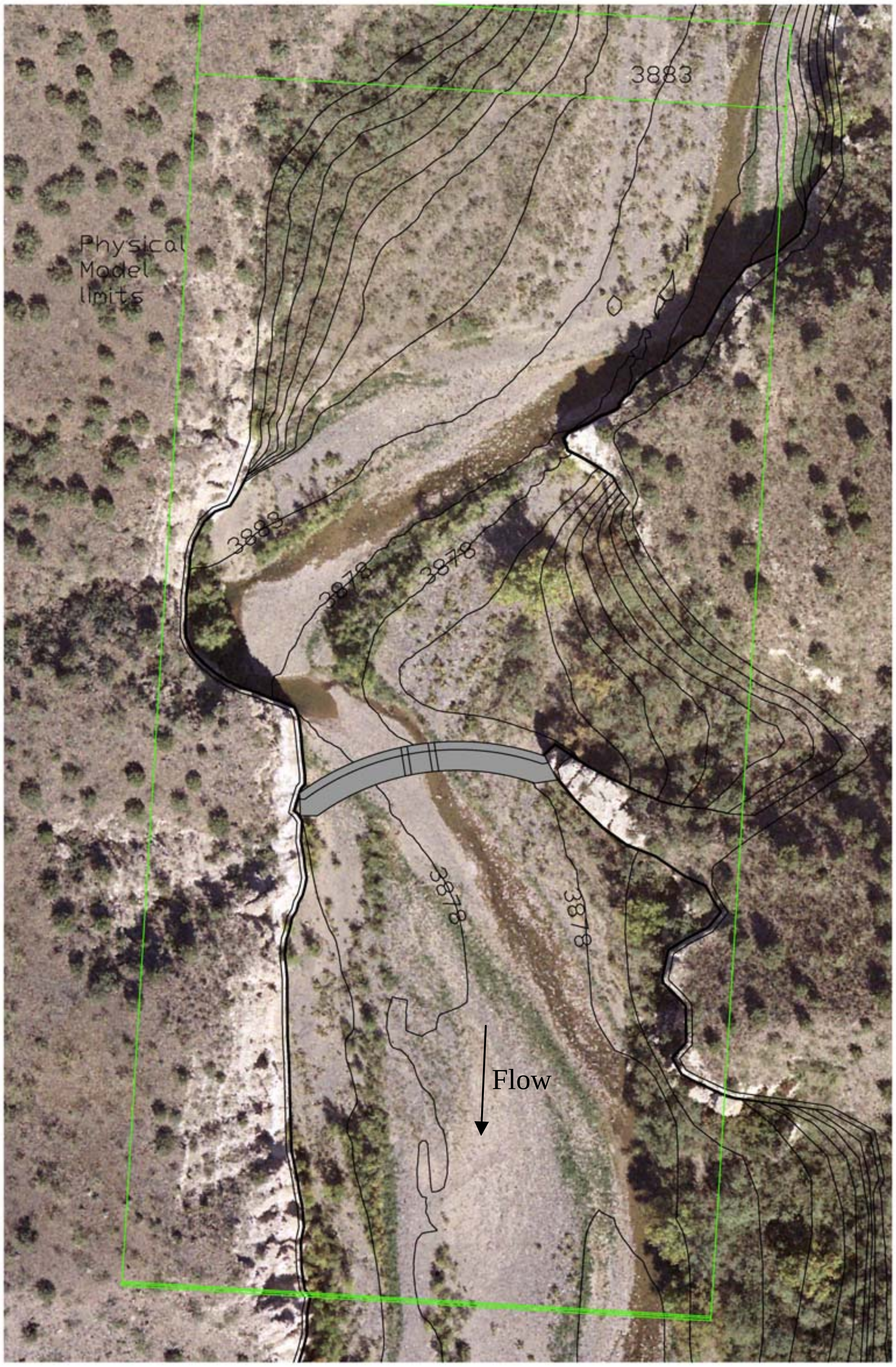

Figure 3. Existing conditions 5-ft contour map. At the sides the barrier is at elevation 3880.85 and 3879.7 in the center.

Numerical modeling of the original design showed that the upstream scour wall does not have to be as deep as originally planned, so other construction methods for the upstream scour wall are being explored. In this scenario, the excavation footprint might not be as large as originally expected, and the upstream topography would be left as-is, rather than being backfilled to a lower elevation . To model the effects of such a change, the unmodified existing topography upstream from the barrier was added into the model. This topography was modeled as non-transportable gravel, as shown in Figure 4.

Figure 4. Physical model looking upstream at the lowered barrier and the upstream topography.

Initial runs with the higher upstream topography showed that it caused the left side of the barrier to be hydraulically less effective. Much more of the flow was pushed to the right side. This significantly increased scour downstream from the barrier.

Following initial runs, the upstream topography (gravel) was excavated in the model down to the elevation of the weir, 3880.85 at the left side and 3879.7 in the center. Figure 5 shows that water surface elevations upstream from the weir were very uneven and the resulting unit discharge was much more concentrated on the right side when the existing topography was in place (Config 7), versus an excavated condition (Config 7.1).

Based on these additional tests it is recommended that the existing upstream topography within 200 ft of the barrier be excavated down to the elevation of the weir.

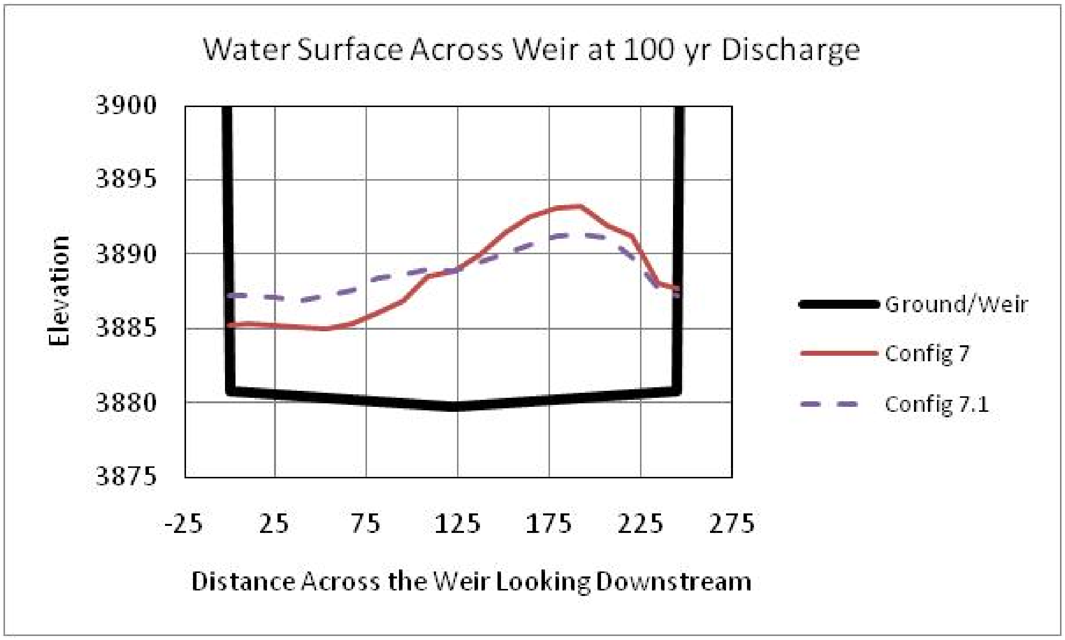

Figure 5. Water surface elevations across the barrier at the 100 yr event. Configuration 7 is the unmodified upstream topography, and configuration 7.1 represents the upstream topography excavated to the elevation of the weir. Configuration 7.1 is flatter and more uniform.

Unsymmetrical weir

A super-elevated weir was modeled to try to flatten the water surface profile across the barrier. The weir was 3.5 ft higher on the right side than on the left.

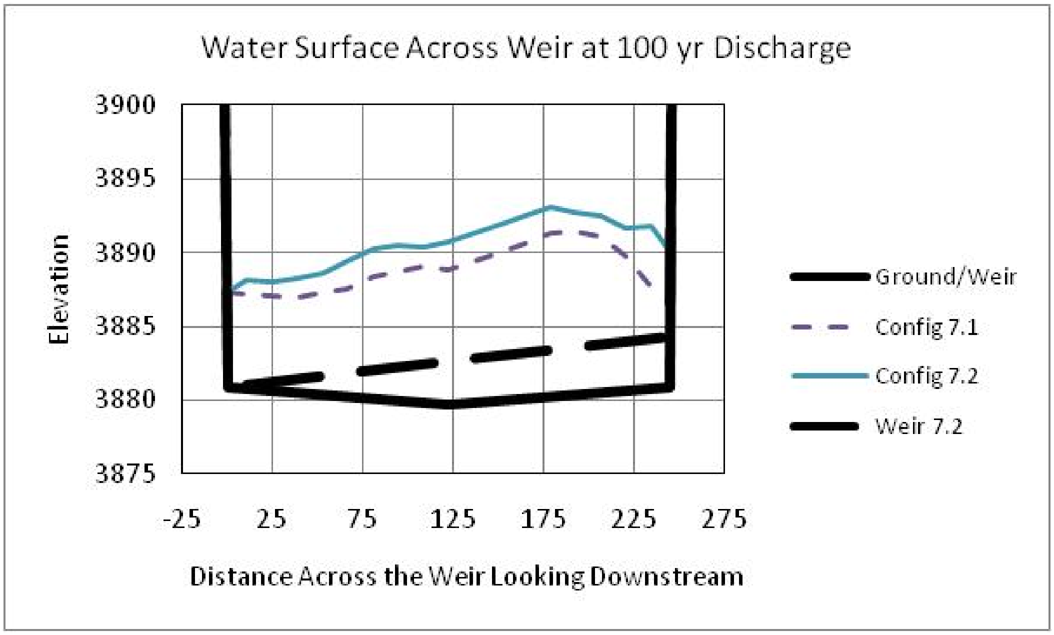

Figure 6. Water surface elevations across the barrier at the 100 yr event comparing the original "V" shaped weir versus an unsymmetrical weir.

Figure 6 shows that super-elevating the weir on the right side did not flatten the water surface profile nor redistribute the unit discharge across the weir (Config 7.2). This comparison shows that the super-elevated water surface is caused by the upstream flow conditions, not by the barrier.

Submerged Vertical Training Wall

During the initial model study the large localized scour hole that formed downstream from the barrier on the left side was attributed to the upstream flow conditions and a large recirculating eddy downstream from the barrier. The model showed that a vertical training wall extending up to elevation 3889 was effective in moving the eddy and associated scour hole downstream away from the structure. The objective of this phase of the modeling was to reduce scour without such an obtrusive training wall.

The top of the submerged training wall was placed at the elevation of the deflection block, 3872. The numerical modeling indicates that the long term scour downstream from the barrier will be similar to the scour associated with the 2 yr event (Russell, 2010), which is approximately at the level of the deflection block. Thus, a wall at this elevation would be buried the majority of the time.

The submerged vertical training wall produced less scour than no training wall, but much more scour than the full height vertical training wall developed in the initial model study. The left side scour hole exposed the downstream scour wall and the toe of the structure at the 100-yr event. Flow from the eddy was 11 ft deep over the top of the submerged training wall. The flow over the top of the training wall must be stopped in order to effectively move the scour downstream away from the structure.

Several model runs were completed with various configurations of baffle blocks placed on top of the deflection block. The blocks were 2.5 ft tall and 3.75 ft wide. The blocks were spaced 3.75 ft apart on the left 1/3 of the structure. At the 100 yr event the discharge over the barrier is so large that the baffle blocks had very little effect on the resulting scour.

Aesthetically Pleasing Full-Height Training Wall

During the initial model studies the only way to prevent scour from revealing the toe of the structure was to stop the downstream eddy with a full-height training wall. An aesthetically pleasing proposal for the construction of a full-height wall was thus studied. This wall would be constructed from RCC with a side slope of 0.8:1 (h:v) up to the height of the deflection block, with the remaining portion of the wall composed of a soil berm with stabilized slopes, such as gabion baskets. The side slope of the proposed berm was 1:1. The RCC portion of the training wall was constructed in the physical model using plywood and high density foam. A black, flexible plastic screen material was used to stabilize the soil berm (see Figure 7).

Figure 7. Recommended training wall configuration. Scour after the 100 yr event.

This training wall performed well and was adopted as the recommended configuration. The flow conditions along the training wall varied enough from those associated with the vertical training wall that a modified wall alignment was chosen (see Figure 8). In this configuration, velocities along the soil berm during the 100-yr event were approximately 17 ft/s.

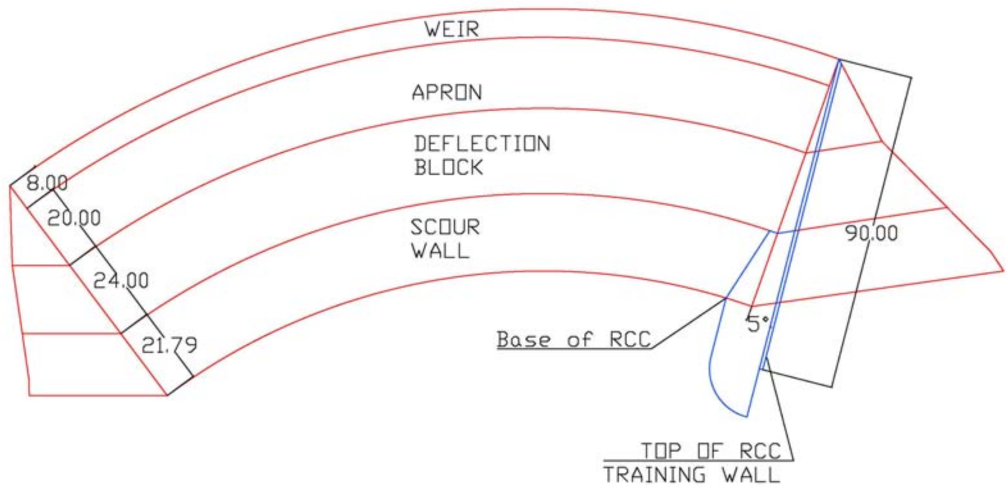

Figure 8. Plan view of the barrier showing the position of the top of the RCC wall, which is the start of the soil berm.

Effectiveness of the Fish Barrier.

Evaluating the effectiveness of the fish barrier was not part of the scope of this study, but a few observations are detailed below. The fish barrier relies on a 4 ft vertical drop and a 20 ft extent of shallow, high velocity water on the apron to prevent fish passage. At the mean daily discharge the apron was not backwatered. At the 2-yr discharge about 90% of the apron was not backwatered, with only a small amount of backwater on the apron at the sides of the structure (see Figure 9). This condition persists at larger flows without a full-height training wall, especially on the left side. Model observations suggest that during the 25 and 100-yr events without a full-height training wall the large eddy on the left side might facilitate fish passage at the left end of the structure. The aesthetically pleasing full-height training wall appeared to cut off all possibility for fish passage utilizing these backwater zones.

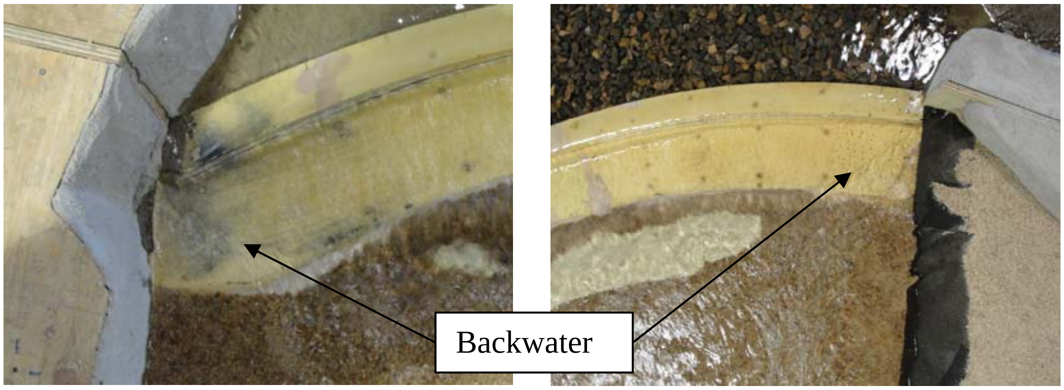

Figure 9. Backwater effect on the apron during the 2-yr event.

FINAL RESULTS

Recommended Design Photos and Scour Mapping

Figures 10-22 show the recommended design at the mean daily, 2-, 25-, and 100-yr flow conditions, and the resulting scour. Contour maps detailing scour and deposition relative to the pre-test river bed were obtained with photogrammetry techniques.

Figure 10. Recommended design with the existing downstream topography.

Figure 11. Recommended design at the mean daily discharge.

Figure 12. Recommended design showing scour after the mean daily discharge.

Figure 13. Recommended design at the 2-yr discharge.

Figure 14. Recommended design showing scour at the 2-yr discharge.

Figure 15. Recommended design at the 25-yr discharge.

Figure 16. Recommended design showing scour at the 25-yr discharge.

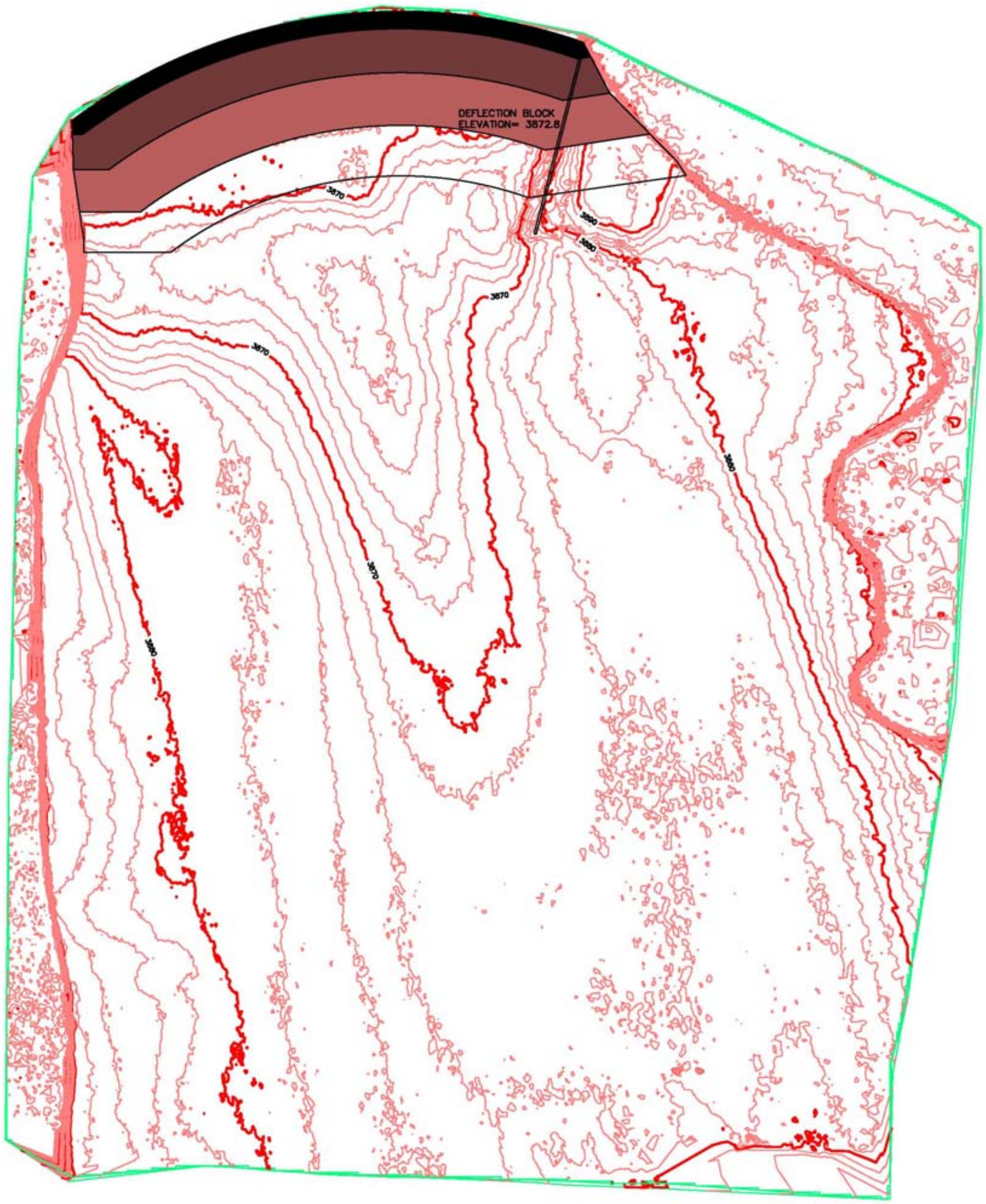

Figure 17. Recommended design showing scour at the 25-yr discharge, 2-ft contour map.

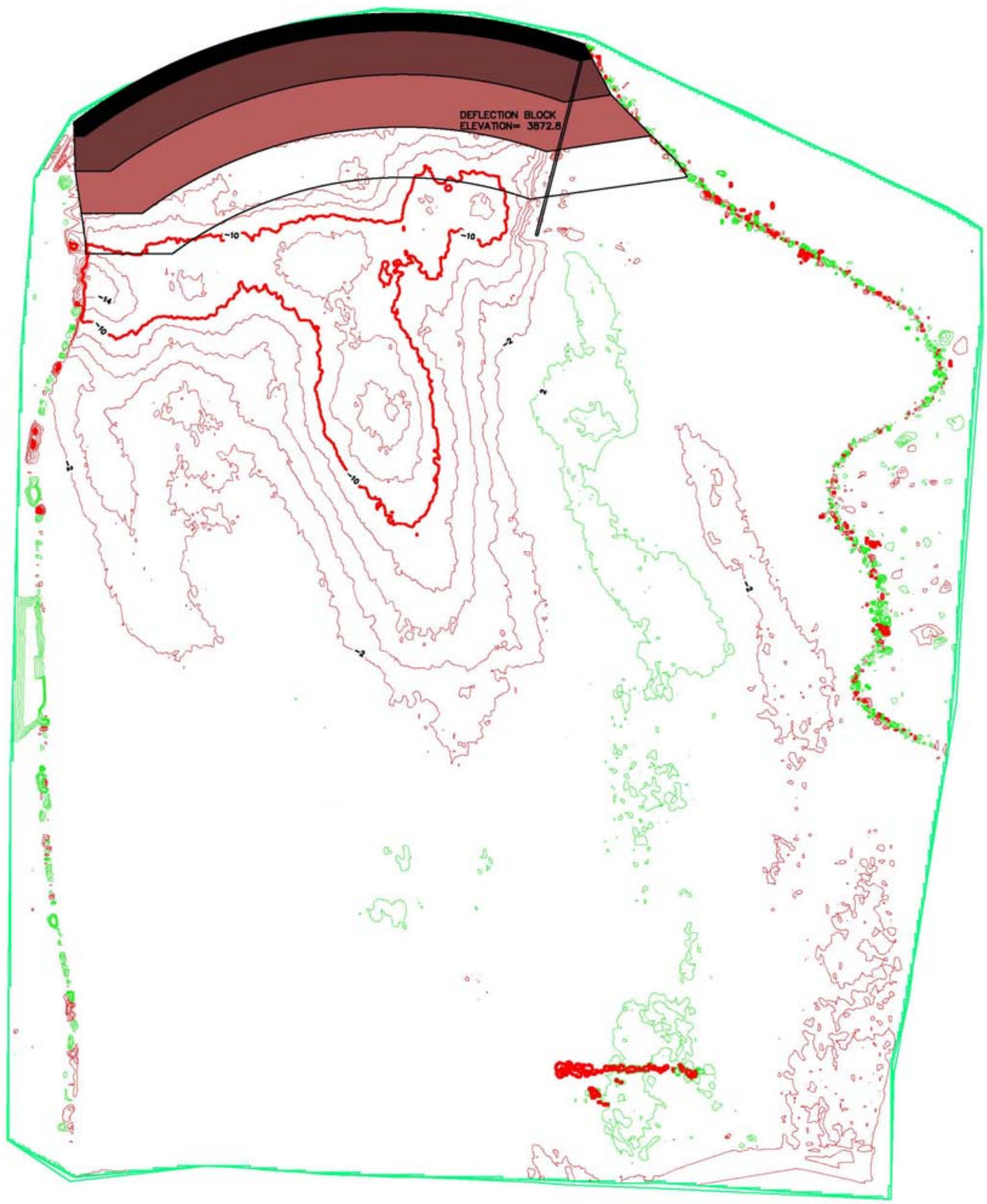

Figure 18. Recommended design showing scour at the 2-yr discharge, 2-ft contour map. Red contours represent scour and green contours represent deposition.

Figure 19. Recommended design at the 100-yr discharge.

Figure 20. Recommended design showing scour at the 100-yr discharge.

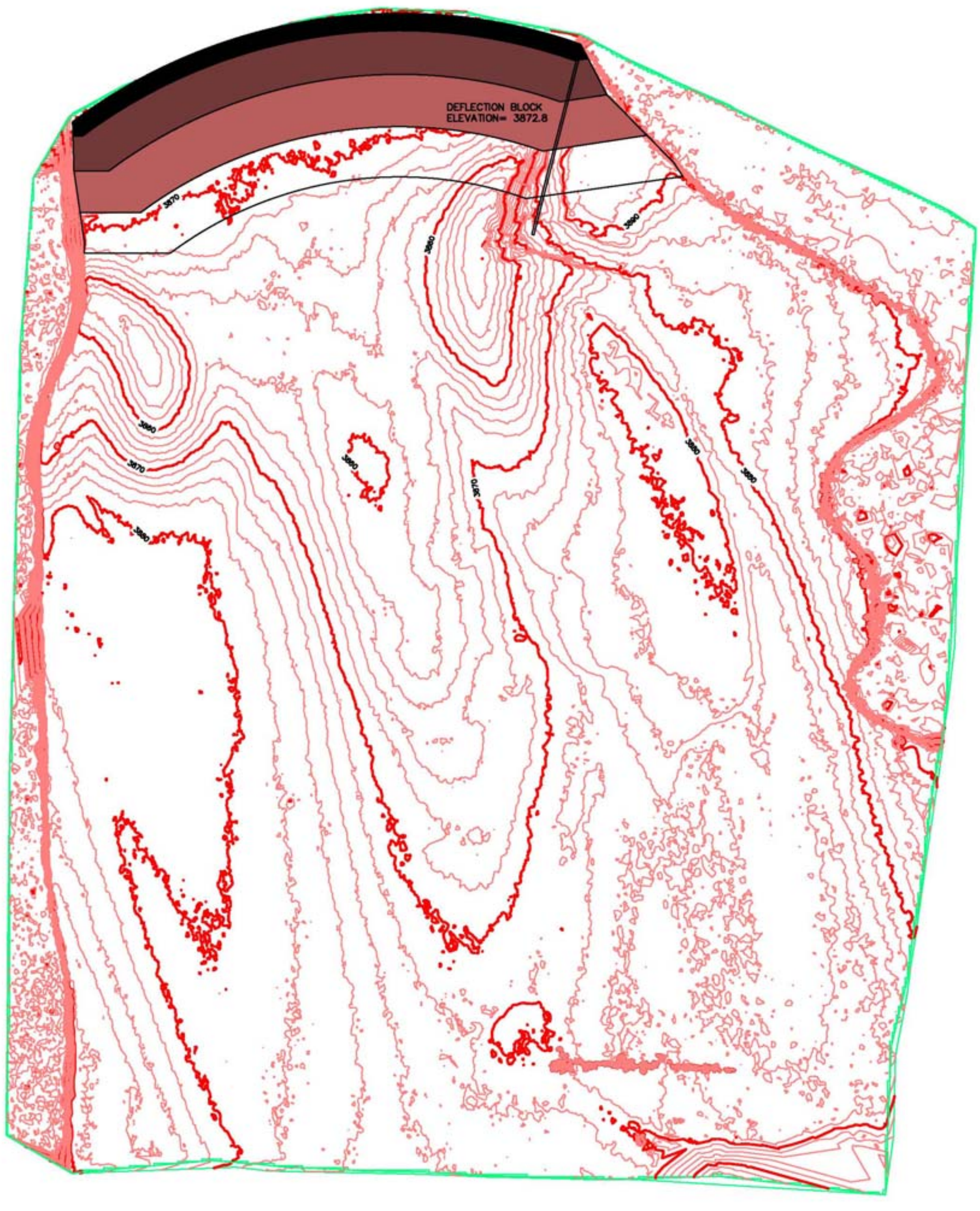

Figure 21. Recommended design showing scour at the 100-yr discharge, 2-ft contour map.

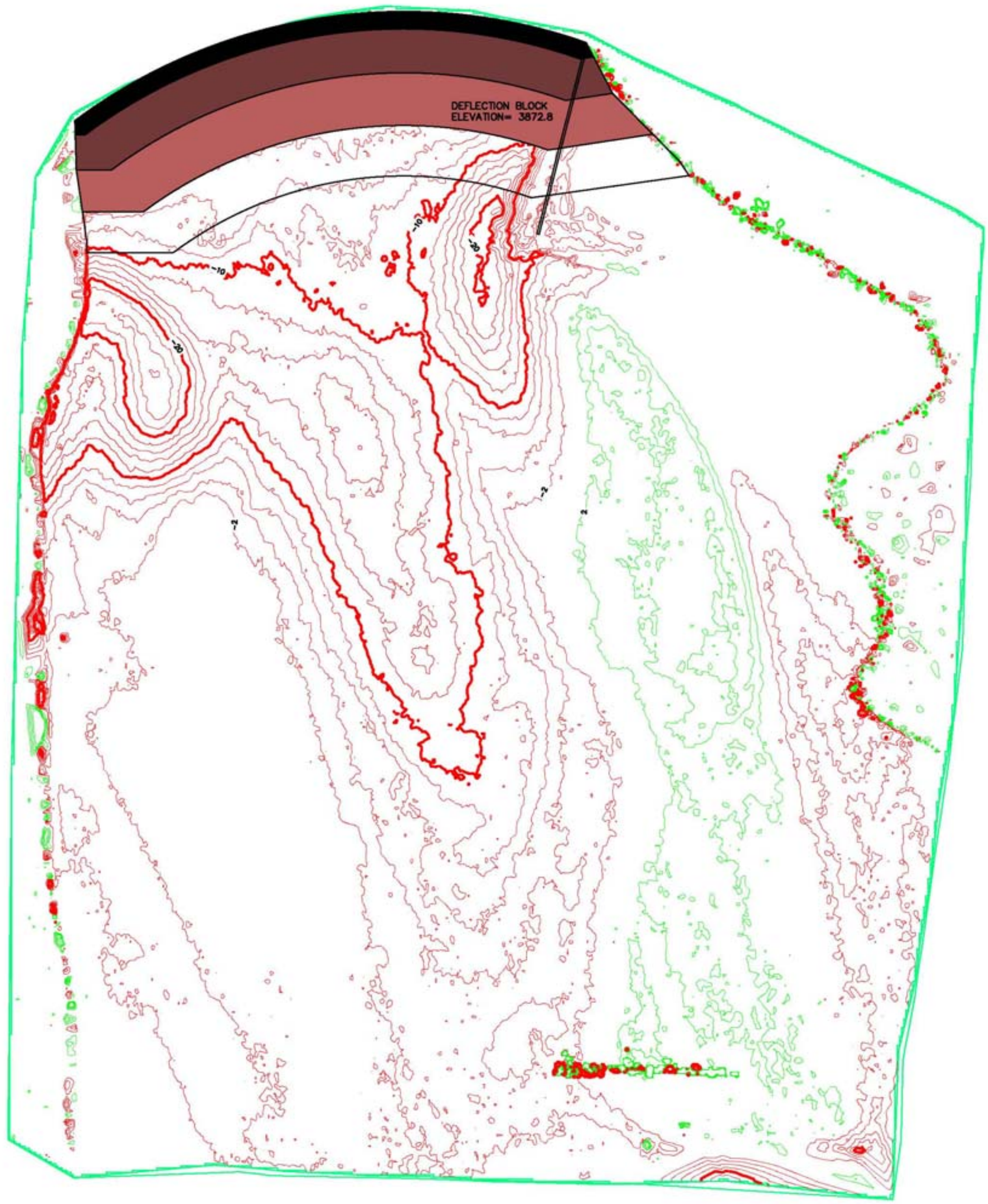

Figure 22. Recommended design showing scour at the 100-yr discharge, 2-ft contour map. Red contours represent scour and green contours represent deposition.

Conclusions

- Lowering the fish barrier by 2 ft helped reduce overall scour downstream from the structure. Adding in the topography upstream from the barrier and sloping the training wall increased overall scour.
- The topography that is immediately upstream from the barrier and is higher than the weir increases flow nonuniformity over the weir and resulting scour. It is recommended that the existing topography within 200 ft upstream from the barrier be excavated down to the elevation of the weir.
- Three-dimensional flow conditions (skewed approach flow, concentration of flow on downstream left side of structure, recirculating eddy in downstream left tailwater zone) lead to concentrated scour around the downstream toe of the left end of the fish barrier. A training wall is required on the left side to reduce this scour and move it away from the structure.
- Average depth of scour for clear water tests at the mean daily discharge is less than 1 ft.
- The apron is not backwatered during the mean daily discharge.
- Average depth of scour for clear water tests at the 2-yr discharge is about 2 ft, located on the deflection block.
- At the 2-yr discharge 90 % of the apron is not affected by backwater; there are small backwater influences near the abutments.
- Average localized depth of scour for clear water tests at the 25-yr discharge is about 12 ft with holes reaching 16 ft.
- Average localized depth of scour for clear water tests at the 100-yr discharge is about 16 ft with holes reaching 26 ft.
- Velocities along the soil berm during the 100-yr event were approximately 17 ft/s.
- The model tests provided a good relative indication of the scour associated with different design alternatives, but scour erosion in the prototype is expected to be less severe than in the model due to several conservative simplifications in the model design and operation (clear water testing, model sediment gradations that did not include all of the coarsest material fraction, etc.). See Lentz (2010) for more discussion of these factors.

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Russell, K., 2010. Blue River Fish Barrier: 1-D Numerical Sediment Transport Modeling SRH-2010-11. U.S. Department of the Interior, Bureau of Reclamation, Sedimentation and River Hydraulics Group, Denver, CO.

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