RECLAMATION
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U.S. Department of the Interior
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Technical Service Center, Denver, Colorado **Sedimentation and River Hydraulics Group**

Modeling Three-Dimensional Hydraulics of Rock Weirs

Design Guidelines for River Spanning Rock Structures

What Is The Problem?

The complex flow patterns and performance of rock weirs is not understood. Without accurate hydraulics, designers cannot address the failure mechanisms of structures. There are no 1D hydraulic guidelines for rock weirs, field work cannot quantify and capture detailed processes, and physical modeling is expensive and time intensive. Collecting enough detailed field and laboratory data to include a wide range of design parameters (structure geometry, grain sizes, channel characteristics, etc) and performing an analysis of structure performance would be costly and take years to accomplish.

What Is The Solution?

Numerical modeling provides an opportunity to test design parameters over large ranges for less money and in a shorter amount of time than field measurements or physical models. The numerical model must capture significant flow patterns and replicate the important processes.

One-dimensional, 1D, numerical simulations model downstream changes in hydraulics while neglecting vertical and lateral variation. Two-dimensional, 2D, models incorporate lateral differences in velocity and water surface elevation, but neglect flow not perpendicular to the stream bed. Three-dimensional, 3D, modeling simulates the motion of water in all directions and most accurately captures flow patterns. Estimating structure performance with lower dimensional methods requires understanding the impact of representing a feature with methods farther divorced from real world processes. The limited understanding of the complex flow patterns around rock weirs require 3-dimensional simulations

What Are The Benefits Of This Solution?

Flow characteristics such as jets, near bed velocities, recirculation, and plunging flow govern scour pool development. 3D numerical models capture these patterns without requiring the prior, and possibly incorrect assumptions of lower order models.

Plate 1 shows a U-Weir in the field and the corresponding water surface and velocity from a 3D numerical model. In the photograph, entrained air reveals areas of high velocity. The 3D model captured flow features including the draw down curve, hydraulic jump, and variations in velocity. Dry areas in the photograph, such as the protruding rocks in the upper left corner match the 3D model water surface. Plate 1 demonstrates the capability of three-dimensional numerical modeling to match field conditions.

3D modeling directly captures the physics of the flow hydraulics and can provide adjustments defensible to funding sources and regulatory agencies.

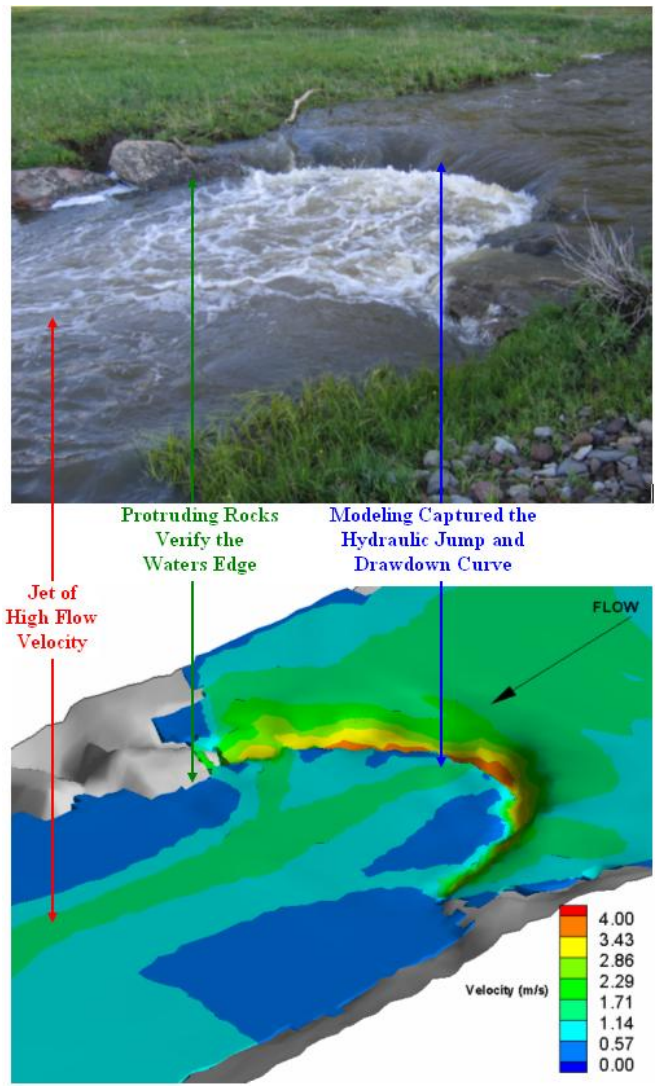

Plate 1 Field Photo and Corresponding Numerical Modeling Results

Plate 2 shows a plan view with water surface elevation contours. The areas upstream and downstream of the structure show little lateral variation. The water surface drops rapidly over the structure and follows the weir crest topology. 1D modeling assumes gradually varied flow and constant water surface elevation across a transect. Methods to meet 1D water surface requirements include constructing cross sections tracing water surface elevation contours or coding multiple cross section perpendicular to the thalweg.

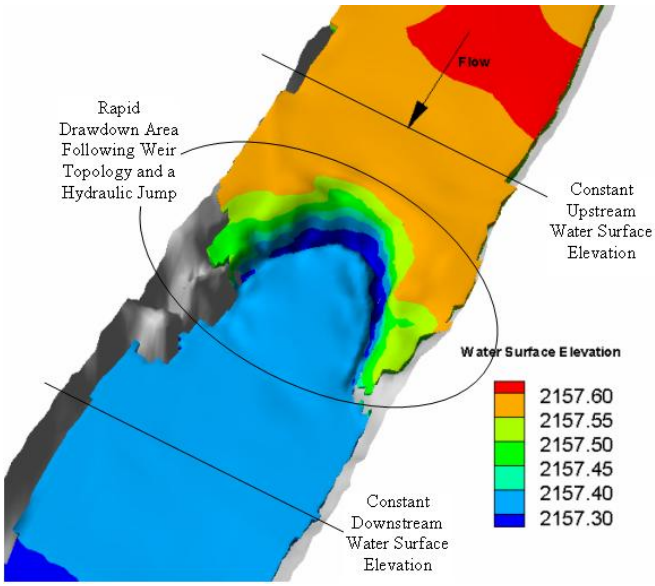

Plate 2 Modeled Water Surface Elevation (Z-Axis Scaled Factor of 5)

Plate 3 shows surface velocity vectors. In the channel upstream and downstream of the structure water flows parallel to the banks. Over the weir, the flow paths rapidly converge and then slowly expand. A jet through the center of the channel creates abrupt lateral changes in velocity. 1D modeling requires cross section lines perpendicular to the velocity vectors. Modelers accommodate lateral variability through bending the cross section.

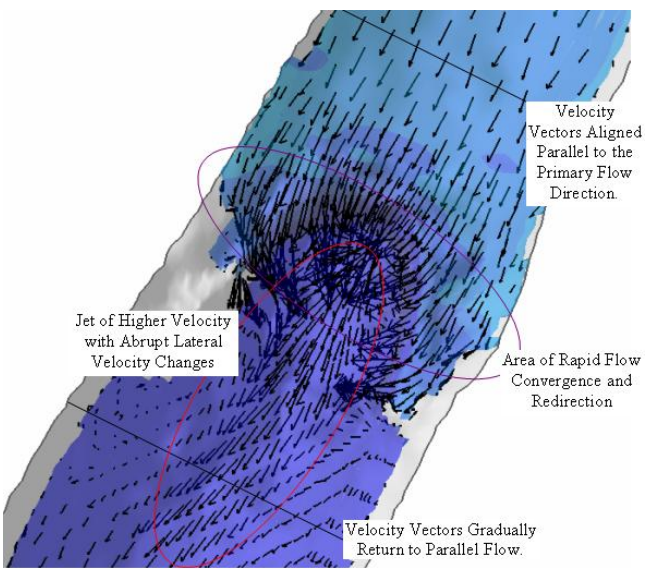

Plate 3 Plan View Velocity Vectors and Wetted Area

Plate 4 shows a profile view for velocities in a slice cut along the thalweg. Water flows parallel to the bed upstream and downstream of the structure. The stream lines rapidly converge and diverge vertically through the structure. The velocity profile contains a jet midway through the water column rather than the logarithmic profile of a typical river section. Vertical velocity components in the scour pool show plunging flow. 2D modeling requires velocity vectors perpendicular to vertical. 1D modeling requires perpendicular velocity vectors in all directions.

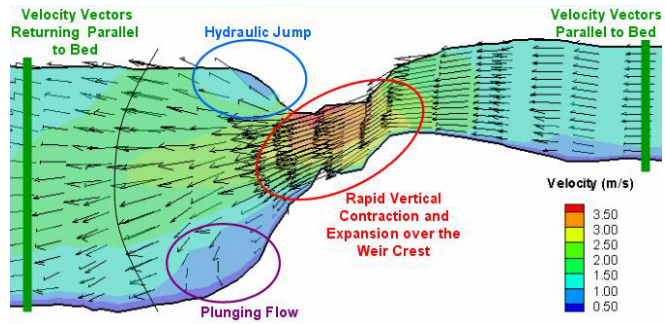

Plate 4 Thalweg Profile View and Velocity Magnitude

Plate 5 shows attempts to reconcile 1D requirement with field conditions. A cross section model can meet either water surface requirements or velocity requirements, but not both. Plate 5 demonstrates the need for a 1D model to incorporate adjustments for multi-dimensional effects. HEC-RAS contains placeholders, but the magnitude of the adjustment is unknown for rock weirs. The adjustment will depend on the throat width, profile and plan arm angle, drop height, and more.

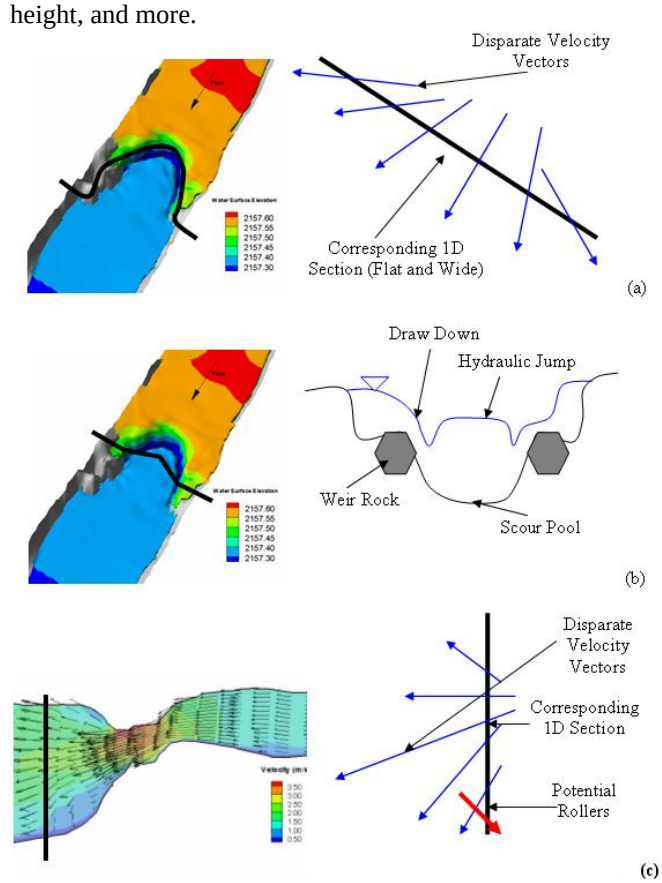

Plate 5 Meeting 1D Water Surface Criteria Fails to Meet Velocity Criteria (a) and vice versa (b). No Method captures jumps or plunging flow (c).

After understanding the 3D processes, 1D adjustment parameters can be developed where required. Additional information on the River Restoration Structures Research is available on the Sedimentation and River Hydraulics Group web site: http://www.usbr.gov/pmts/sediment/kb/spanstructs/index.html

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