1.0 Introduction
Previously, two hydraulic models (one physical and one numerical) were used to assess and improve the 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 (Russell 2010 and Lentz, 2010). The structure is being considered to block upstream movement of non-native fish. The objective of the numerical modeling was to evaluate aggradation and degradation of the channel bed upstream and downstream from the proposed fish barrier. Flow conditions during the 25-year and 100-year discharges were simulated to determine the maximum amount of scour expected at the structure.

Further numerical modeling was requested to estimate the anticipated typical or normal scour near the barrier, as opposed to maximum scour previously reported. The additional numerical model runs looked at higher frequency (2-, 5-, and 10-year) floods followed by “average” flow discharges in Blue River. The barrier structure was revised from the original model to represent the most recent design recommendations. In addition to the scour analysis, an incipient motion analysis was completed to determine at what flow the sediment in the system becomes mobilized.

2.0 Model Input Updates
This section discusses the changes made to the data and information used for the setup of the 1D hydraulic and sediment transport numerical model: Sedimentation and River Hydraulics – One Dimensional model (SRH-1D) (Huang and Greimann 2008). A discussion of SRH-1D is provided in Attachment 1 of this memo. The previous report documented model methodology and results and should be referenced for additional information, as the additional model runs discussed here were adapted from the previous model (Russell 2010). The parameters discussed below were the only values that changed from the previous report; parameters such as roughness values, bed material, and incoming sediment load, were not changed.
2.1 Topography Data

2.1.1 Existing Conditions
Several changes occurred in the cross sections used for the existing condition: 13 cross sections were added. The cross section geometry from station 899 was copied downstream for two cross sections over 0.2 miles and adjusted for a reach average slope of 0.0077. Eleven cross sections were added upstream of station 5,261.1 by copying station 5,261.1 upstream for 0.9 miles using the same slope.

2.1.2 Modified Final Proposed Conditions
In the previous report, the final proposed condition is outlined. A final recommendation had been made to drop the overall crest height by 2 feet (ft), but was not included in the previous numerical model simulations. The lowered crest height is included in the modified final proposed geometry. In addition, the crest was modified to have a v-shape with a 1% slope towards the center. The apron was also dropped 2 feet and modified to have a v-shape with a 1% slope towards the center. The training wall in the final proposed condition was included in the modified final proposed conditions. Figure 1 shows the modified profile and Figure 2 shows the cross-sectional view.

Figure 1. Profile elevation of fish barrier structure and fill for modified final proposed geometry.
Figure 2. Cross section at station 2,851.5 showing previous model crest and the lowered v-shaped crest.

2.2 Model Boundary Conditions
The previous stage-discharge rating curve used for the downstream boundary of the SRH-1D model included discharges from 2,000 ft³/sec to 35,700 ft³/sec. In order to extend the simulations to include non-flood discharges, the rating curve was extended to 50 ft³/sec. Water surface elevations were estimated using the 2002 HEC-RAS model (used to create the previous rating curve) (Reclamation 2002). The extended rating curve was adjusted to station 50 by subtracting 6.54 feet from all the elevations for the specified discharges. The 6.54 feet was based on an average slope of 0.0077 between station 5,261.1 and station 899. Figure 3 shows the extended rating curve.
2.3 Model Discharges

In addition to the 25- and 100-year floods previously simulated, the 2-, 5-, and 10-year floods were simulated in the additional runs. In the previous report, it was determined that the Arizona Department of Transportation Method used in the 2002 report titled “Hydraulics and Hydrology: Blue River Fish Barriers” gave the best flood peak discharges (Reclamation 2002). The 2-year flood flow on Blue River was estimated at 2,600 ft³/sec, the 5-year flood flow was estimated at 7,100 ft³/sec, and the 10-year flood flow was estimated at 12,500 ft³/sec.

The USGS National Streamflow Statistics (NSS) Program was used to generate inflow hydrographs for the 2-, 5-, and 10-year floods. The NSS hydrographs were scaled to match the peaks from the 2002 analysis. A 105.6 hour duration was used for the higher frequencies floods. Figure 4 shows the scaled 2-, 5-, and 10-year flood hydrographs with a 105.6 hour duration which is a result of a 48 hour lag time.
Figure 4. Scaled flood hydrographs from USGS NSS Program.

All hydrographs were extended 21 days past the end of the flood hydrograph. To extend the hydrographs, gage data from United States Geological Survey (USGS) gage 09444200, Blue River Basin was used. Any average daily flow recorded within 10% of the flood peak discharge values was used as well as the highest 4 discharges recorded. A total of 13 events were used occurring from 1972 to 2008. Flows for 24 days from the peak were averaged to determine the hydrograph extension. The first 3 days were eliminated because they overlapped the NSS generated hydrograph. Figure 5 shows the daily discharge values from the USGS gage data as well as the average values used. Figure 6 shows the 2-, 5-, 10-, 25-, and 100-year extended flood hydrographs.
Figure 5. USGS gage09444200 daily average discharge data used to develop the extended hydrographs.

Figure 6. Extended flood hydrographs using the NSS and USGS gage data.
2.4 Additional Model Parameters
In the previous report, a sensitivity analysis of the model parameters was completed. Based on that analysis, one set of parameters was chosen to run the additional simulations. The Wilcock scenario had a median amount of maximum scour. The parameters used in the scenario were: sediment supply scaling was set to 1, the sediment equation used was Wilcock and Crowe’s (2003) method using Einstein’s method to calculate grain shear stress (referred to as Wilcock in SRH-1D), the roughness value was 0.028, and the bed material gradation was an average of the test pits and pebble count data. Refer to the previous report for more information on the parameters used.

2.5 Incipient Motion Analysis
Incipient motion is defined as the threshold conditions between movement and deposition of a single particle (Julien, 1998). The incipient motion analysis identifies the largest particle diameter the river is likely to move at a given flow rate. Comparing incipient motion calculations to the size of material present in the active channel identifies discharges that are likely to mobilize the channel bed material resulting in the reworking of the active channel.

The program SRH-Capacity was used to determine the flow at which bed material particles would move (Huang and Bountry, 2009). Required program input includes channel hydraulic properties, flow discharges, bed material gradations, and which sediment transport methods to use. To perform the incipient motion calculations, the existing conditions geometry was used to look at system wide effects. Only the non-interpolated cross sections (between station 5,261 and 899) were considered. A range of steady flows between 10 ft\(^3\)/sec and 3,000 ft\(^3\)/sec were simulated to determine the hydraulic parameters. The parameters (velocity, top width, friction slope, hydraulic depth, etc.) were averaged for all cross sections at each flow. D\(_{50}\) values of the pebble counts, test pits, and an average of both data sets were used to determine when sediment would be mobilized. Three methods were used for the sediment transport equation: Wilcock’s method, Parker’s (1990) method using Einstein’s method to calculate grain shear stress (referred to as Parker), and Wu, Wang, and Jia’s (2000) method (referred to as Wu).

3.0 Model Results and Discussion

3.1 Existing Conditions
For each existing conditions scenario, the maximum scour (difference between the initial thalweg elevation and the thalweg elevation at time t) was found at any cross section at any time. Table 1 shows the results. The scour values ranged from 1.2 to 4.2 feet. The station and time to maximum scour varies for the different flood frequency hydrographs. The maximum scour depth increased with the increasing flood frequency discharges as expected. For the 100-year flood the
maximum scour occurred upstream of the proposed barrier location. For all other floods, the maximum scour occurred downstream of the proposed barrier location.

### Table 1. Maximum scour results for existing conditions geometry.

<table>
<thead>
<tr>
<th>Flood Frequency</th>
<th>Station</th>
<th>Time t (hrs)</th>
<th>Thalweg Elevation at Time t (ft)</th>
<th>Max Scour (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-year</td>
<td>2736.6</td>
<td>66.3</td>
<td>3872.5</td>
<td>1.2</td>
</tr>
<tr>
<td>5-year</td>
<td>2194.1</td>
<td>37.74</td>
<td>3868.8</td>
<td>2.1</td>
</tr>
<tr>
<td>10-year</td>
<td>2093.4</td>
<td>35.7</td>
<td>3867.1</td>
<td>3.1</td>
</tr>
<tr>
<td>25-year</td>
<td>2093.4</td>
<td>47.94</td>
<td>3866.6</td>
<td>3.7</td>
</tr>
<tr>
<td>100-year</td>
<td>3597.6</td>
<td>37.74</td>
<td>3873.8</td>
<td>4.2</td>
</tr>
</tbody>
</table>

The amount of scour seen in the existing conditions simulations changes over time. Figure 7 shows the thalweg bed profile at $t=37.74$, on the rising limb of the hydrograph, and at the time where the maximum scour for the 5-year and 100-year floods occurs. Figure 8 shows the thalweg bed profile at $t=609.6$ which is the final timestep in the hydrograph. The bed returns to approximately the same elevation as the initial conditions by the end of the simulation. The scour that occurs on the rising limb at some locations such as between station 3,000 and 4,000 is replaced by deposition. Overall, the existing conditions appear to be relatively close to “equilibrium” based on the small amounts of change even at the 100-year flood.

![Figure 7. Existing conditions at $t=37.74$ hours (rising portion of each flood hydrograph) in the 2-, 10-, 25-, and 100-year hydrographs.](image-url)
3.2 Modified Final Proposed Conditions
For each modified final proposed conditions scenario, the maximum scour (difference between the initial thalweg elevation and the thalweg elevation at time t) was computed at any cross section at any time. Table 2 shows the results. The scour values ranged from 3.5 to 9.1 feet. The time to maximum scour varies for the different flood frequency hydrographs.

<table>
<thead>
<tr>
<th>Flood Frequency</th>
<th>Station</th>
<th>Time t (hrs)</th>
<th>Thalweg Elevation at Time t (ft)</th>
<th>Max Scour (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-year</td>
<td>2802.3</td>
<td>441.66</td>
<td>3872.7</td>
<td>3.5</td>
</tr>
<tr>
<td>5-year</td>
<td>2802.3</td>
<td>369.24</td>
<td>3870.6</td>
<td>5.6</td>
</tr>
<tr>
<td>10-year</td>
<td>2802.3</td>
<td>585.48</td>
<td>3868.7</td>
<td>7.5</td>
</tr>
<tr>
<td>25-year</td>
<td>2802.3</td>
<td>368.22</td>
<td>3867.2</td>
<td>9.0</td>
</tr>
<tr>
<td>100-year</td>
<td>2802.3</td>
<td>178.5</td>
<td>3867.0</td>
<td>9.1</td>
</tr>
</tbody>
</table>

The only scenario with the proposed condition geometry that was simulated in the previous report is the 25-year flood. The maximum scour for the 25-year flood using the Wilcock scenario for the proposed conditions was 7.7 feet. This amount of scour is less than the modified final
proposed conditions, which is not intuitive since the structure was lowered by 2 feet. However, the maximum scour in the modified final proposed condition occurred during the average flow after the flood hydrograph was completed \((t=368.22\text{ hours})\). The proposed conditions maximum scour occurred at \(t=54.06\text{ hours}\). At \(t=54.06\text{ hours}\), the modified final proposed condition maximum scour is 6.6 feet, less than the proposed conditions.

Prior to running the simulations, it was thought that the maximum scour would occur during the flood hydrograph, redeposit on the receding limb of the hydrograph, and continue to aggrade slightly to a lesser total scour depth. This was not the case; instead the scour depth at most cross sections continued to increase with time before reaching an elevation where almost no change occurred in approximately the last 200 hours of flow. The channel elevation continued to be lowered because the river downstream of the barrier was readjusting the slope in the entire reach to the new hydraulic regime. Figure 9 and Figure 10 show the thalweg elevation over time for station 2,802.3 for the 5-year and 100-year flood respectively. They both have similar trends of bed elevation change. The 100-year simulation shows some deposition on the receding limb of the flood hydrograph followed by more degradation during the extended portion of the hydrograph whereas the 5-year model run has constant scour throughout the hydrograph but at a smaller magnitude.

![Figure 9. Thalweg elevation for station 2,802.3 during the 5-year flood hydrograph simulation.](image)
Figure 10. Thalweg elevation for station 2,802.3 during the 100-year flood hydrograph simulation.

Figure 11 shows the thalweg profile for the final timestep (t=609.6 hours) for the modified final proposed condition. The bed slope and bed elevations decrease from the structure all the way to the San Francisco River. The model is not predicting a permanent scour pool but rather a decrease in the elevations for the entire river bed. However, the local scour pool cannot be captured with the 1-D model because plunging flows are not well represented in 1-D sediment models. To estimate the typical scour pool size, we suggest using the 2-yr flood estimates from the physical model. The numerical model should be used to estimate the “reach averaged” erosion. The reach averaged erosion is that erosion that occurs over a large spatial scale and is relatively uniform in the streamwise direction.
Figure 11. Modified final proposed conditions at final timestep (t=609.6 hours) in the 2-, 10-, 25-, and 100-year hydrographs.

Qualitatively, the modified final proposed condition has characteristics similar to those described in the original report. Deposition occurred upstream of the structure while the crest, apron, and deflection block were mostly clear of sediment through the hydrographs. Scour did occur downstream of the structure but it did not expose the toe of the downstream scour wall. The deposition upstream of the crest never reached the crest height. It is assumed that the area upstream of the crest will continue to deposit up to the crest height elevation and then sediment will spill over the crest. Once the area behind the crest is completely filled, the bed slope downstream of the structure may adjust again to account for the different sediment load. The magnitude of the adjustment is unknown.

### 3.3 Incipient Motion

Several sediment transport equations (Parker, Wilcock, and Wu) were used to determine the discharge at which sediment begins to move in the Blue River system. A wide range of discharges resulted from the various equations and bed material values used, from 55 ft³/sec to 2,075 ft³/sec. Using the bed material data that from the pebble counts appears the most applicable because this larger material on the surface will need to be mobilized before the finer subsurface material is exposed. Based on the results from SRH-Capacity it is estimated that sediment in the system will begin being mobilized at approximately 2,000 ft³/sec using a critical shear stress of 0.04.
4.0 References


Attachment A

SRH-1D Information
A. Introduction

A.1 Background

SRH-1D (Sedimentation and River Hydraulics – One Dimension) is a one-dimensional hydraulic and sediment transport model for use in natural rivers and manmade canals. It is a mobile boundary model with the ability to simulate steady or unsteady flows, internal boundary conditions, looped river networks, cohesive and non-cohesive sediment transport, and lateral inflows. The Environmental Protection Agency (EPA) and Bureau of Reclamation (Reclamation) were funding partners in the original development of the SRH-1D model.

Reclamation’s Sedimentation and River Hydraulics Group has a long history of developing numerical models for sediment transport in rivers. GSTARS, Generalized Stream Tube model for Alluvial River Simulation (Molinas and Yang, 1986; Yang and Simões, 2000; Yang and Simões, 2002), was previously published and currently supported by Prof. Ted Yang at the Department of Civil Engineering, Colorado State University.

Many other sediment and water routing models, such as the HEC-6 model (U.S. Army Corps of Engineers or USCOE, 1977, 1993), FLUVIAL-12 (Chang, 1998), CONCEPTS (Langendoen, 2000), EFDC1D (Tetra Tech, 2001), and CCHE1D (Wu and Vieira, 2002) have also been developed to solve one-dimensional alluvial river problems. These models generally have many of the same capabilities as SRH-1D.

A.2 SRH-1D Capabilities

SRH-1D is a hydraulic and sediment transport numerical model developed to simulate flows in rivers and channels with or without movable boundaries. Some of the model’s capabilities are:

- Computation of water surface profiles in a single channel or multi-channel looped networks.
- Steady and unsteady flows.
- Subcritical flows in a steady hydraulic simulation.
- Subcritical, supercritical, and transcritical flows in an unsteady hydraulic simulation.
- Steady and unsteady sediment transport.
- Transport of cohesive and non-cohesive sediments.
- Cohesive sediment aggregation, deposition, erosion, and consolidation.
- Multiple non-cohesive sediment transport equations that are applicable to a wide range of hydraulic and sediment conditions.
- Cross stream variation in hydraulic roughness.
- Fractional sediment transport, bed sorting, and armoring.
- Point and non-point sources of flow and sediments.
- Internal boundary conditions, such as time-stage tables, rating curves, weirs, bridges, and radial gates.
A.3 Limits of Application

SRH-1D is a general numerical model developed to simulate and predict cohesive and non-cohesive sediment transport and related river morphological changes due to natural or human influences. SRH-1D is an engineering tool for solving fluvial hydraulic problems with the following limitations:

(1) SRH-1D is a one-dimensional model for flow simulation. It should not be applied to situations where a two-dimensional or three-dimensional model is needed for detailed simulation of local hydraulic conditions. Phenomena such as secondary currents, lateral diffusion, superelevation, and transverse sediment movement are ignored.

(2) Many of the sediment transport modules and concepts used in SRH-1D are simplified approximations of real phenomena. Those approximations and their limits of validity are embedded in the model.

(3) SRH-1D is currently compiled to run only within the Windows 2000/XP operating system.

(4) There are no specific system requirements, but the size of the problem may be limited by the computer memory. Systems with 512 MB or more are usually sufficient.

A.4 Acquiring SRH-1D

The latest information about SRH-1D is placed on the Web and can be found by accessing http://www.usbr.gov/pmts/sediment and following the links on the web page. Requests may be sent directly to the Bureau of Reclamation’s Sedimentation and River Hydraulics Group (Attention: SRH Support, U.S. Bureau of Reclamation, Sedimentation and River Hydraulics Group, P.O. Box 25007 (86-68540), Denver, CO 80225).

SRH-1D is under continuous development and improvement. A user is encouraged to check the SRH-1D web page regularly for updates.

A.5 Disclaimer

The program SRH-1D and information in this manual are developed for use at Reclamation. Reclamation does not guarantee the performance of the program, nor help external users solve their problems. Reclamation assumes no responsibility for the correct use of SRH-1D and makes no warranties concerning the accuracy, completeness, reliability, usability, or suitability for any particular purpose of the software or the information contained in this manual. SRH-1D is a program that requires engineering expertise to be used correctly. Like other computer programs, SRH-1D is potentially fallible. All results obtained from the use of the program should be carefully examined by an experienced engineer to determine if they are reasonable and accurate. Reclamation will not be liable for any special, collateral, incidental, or consequential damages in connection with the use of the software.