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Managing Water in the West

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Self-Regulating Articulated Fishway

Bureau of Reclamation, Research and Development Office, Science and Technology Project ID:
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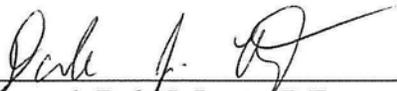
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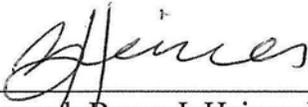
Self-Regulating Articulated Fishway

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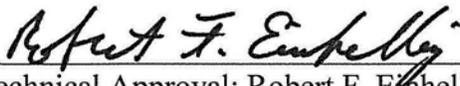
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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Acknowledgments

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Hydraulic Laboratory Reports

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GLOSSARY OF SYMBOLS

WSE	Water surface elevation
CFD	Computational Fluid Dynamics
BOR	U.S. Bureau of Reclamation
ODF&W	Oregon Department of Fish and Wildlife

Project Background

Fishways are designed with the upstream end of the fishway fixed at a set elevation. Over a range of headwater elevations, varying amounts of flow pass through the fishway if the upstream end is not gated. During high river flows, the water surface elevation upstream of the fishway increases and significant flow is passed down the fishway. At small diversion dams, this can limit the amount of flow available for diversion. The inability to design for a fixed fishway flow over the range of headwaters on an ungated fishway often prohibits fishway construction on small diversion dams or results in frequent closure of the fishway. Fishways may be shut down during high diversion periods or flow may be restricted with weir boards, this can impede fish passage.

A self-regulating articulated fishway is being developed at Reclamation's Hydraulics Laboratory in Denver, CO. A self-regulating fishway self-adjusts to changing headwater elevations in order to maintain a more consistent flow through the fishway. By adjusting to the changing headwater a nearly constant flow passes through the fishway. A self-regulating articulated fishway can be used at small diversion dams with water surface fluctuations between about 1 to 3 ft.

In a typical fishway the upstream end of the fishway (fishway exit) has a fixed elevation. When the upstream headwater increases, flow through the fishway also increases. In a self-regulating articulated fishway design, the downstream half of the fishway is at a fixed elevation and the upstream half can pivot around a hinge in the middle of the fishway (Figure 1 through Figure 3). In this manner, when the headwater increases in elevation the upstream end of the fishway also increases in elevation and the flow through the fishway remains constant.

The Klamath Basin Area Office and the Oregon Department of Fish and Wildlife (ODF&W) share a need to develop a fishway suitable for passage of endangered sucker species and other native fish indigenous to highly regulated streams in the west. These fishways need to be able to pass a constant flow over a range of headwater elevations. After research is completed in a laboratory setting, future testing will be carried forward and tested at a field site by ODF&W with assistance from Reclamation.

Model Setup

A dual vertical slot technical fishway with 9 pools was tested in the hydraulics laboratory. The width of the fishway was 2 ft and the length of each pool was 2 ft. The depth of the fishway was 1.5 ft. See Figure 1 through Figure 3 detailing the model layout. This model can be scaled up to larger sizes of fishways. In this study, the downstream half of the fishway was kept at a constant slope of 3 degrees for all tests. The upstream half of the fishway was tested at slopes ranging from 0.2 to 5.7 degrees. Initially the slope of the upstream half of the fishway was controlled manually with a chain hoist. Different methods of self-regulation were subsequently evaluated.

Flow rates tested ranged from 0.35 ft³/s to 1.05 ft³/s. Flow rates into the model were calculated with the laboratory's venturi flow measurement system. The downstream tailwater was manually controlled with stop logs to maintain a water surface drop across the most downstream baffle of about 1.6 inches. Figure 1 shows how the downstream half of the fishway penetrates through the dam. The hinged portion of the fishway is just upstream of the axis of the dam, therefore allowing the upstream half of the fishway to adjust with varying upstream water surface elevation (WSE).

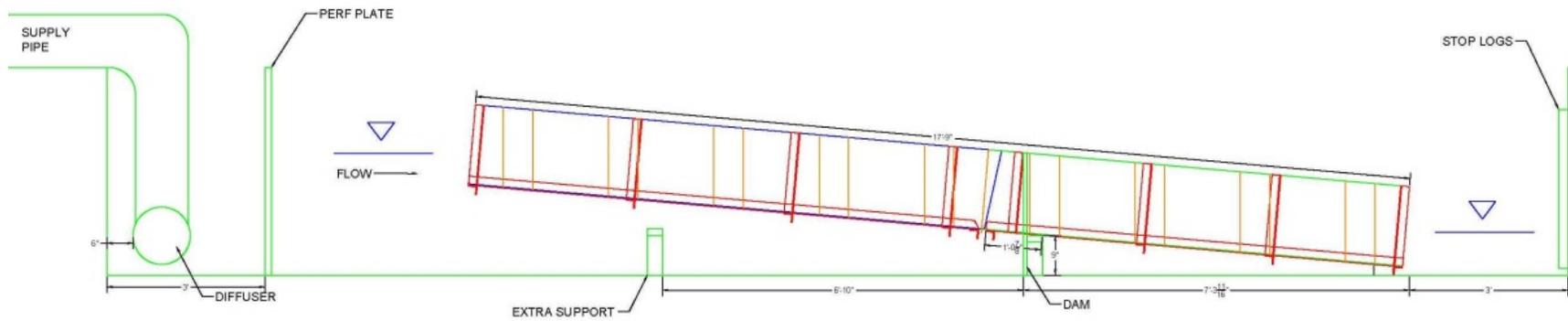


Figure 1. Model fishway setup showing the supply water, upstream WSE, attachment to the dam structure, and tailwater controls with stop logs.

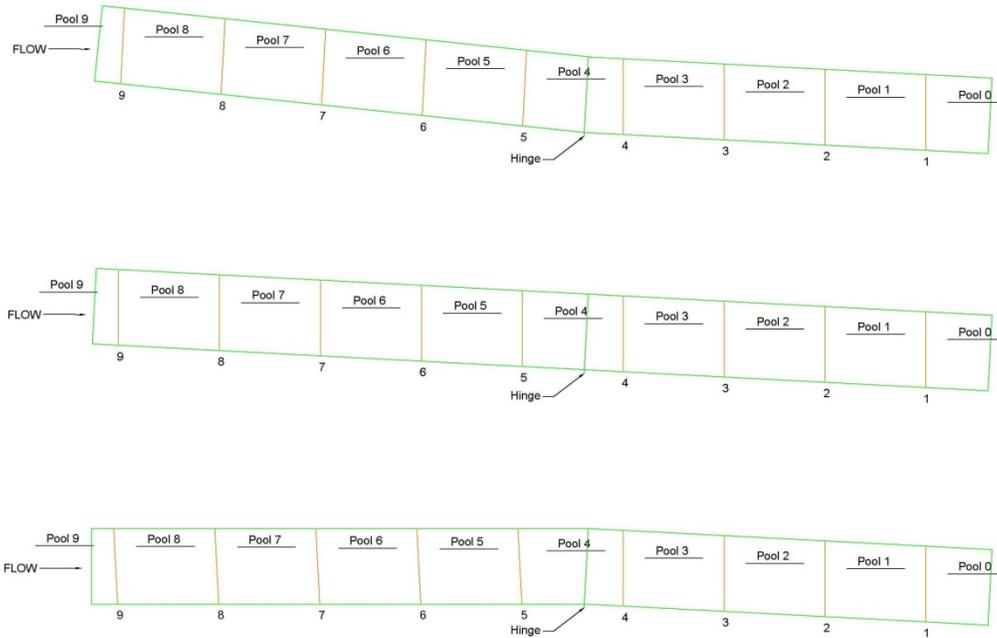


Figure 2. Elevation view of the articulated fishway. Notice the hinge in the middle allowing the upstream half of the fishway to rotate up (top view) and down (bottom view) with the changing upstream WSE. Also note the naming convention of the pool and baffle numbering.

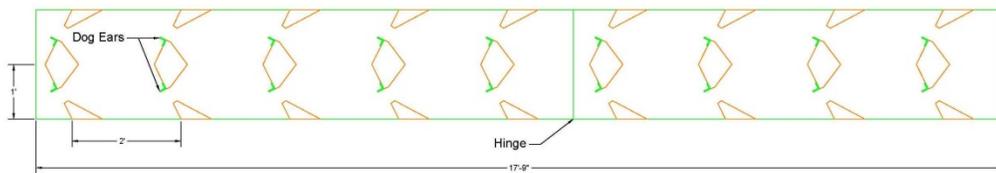


Figure 3 Plan view of the duel slot fishway.

Objectives:

- Evaluate the hydraulic conditions in the fishway over a range of upstream fishway slopes with a constant downstream slope).
- Evaluate the hydraulic conditions in the fishway over a range of flow rates.
- Design ways to self-regulate the fishway.

- Compare physical model study results with computational fluid dynamics (CFD) results.

Investigation and Analysis

Baffle Dog Ears

A duel vertical slot fishway was used for the self-regulating articulated fishway design. During the initial testing flow instabilities within the fishway developed that caused inconsistent water surface drops from pool to pool. Before testing of the articulated design could begin, a modification to the duel vertical slot fishway was needed. To produce a more uniform flow condition “dog ears” were added to the baffle center pier as shown in Figure 4. Without the dog ears the water surface drop per baffle oscillated between a large drop and small drop as shown in Figure 5.

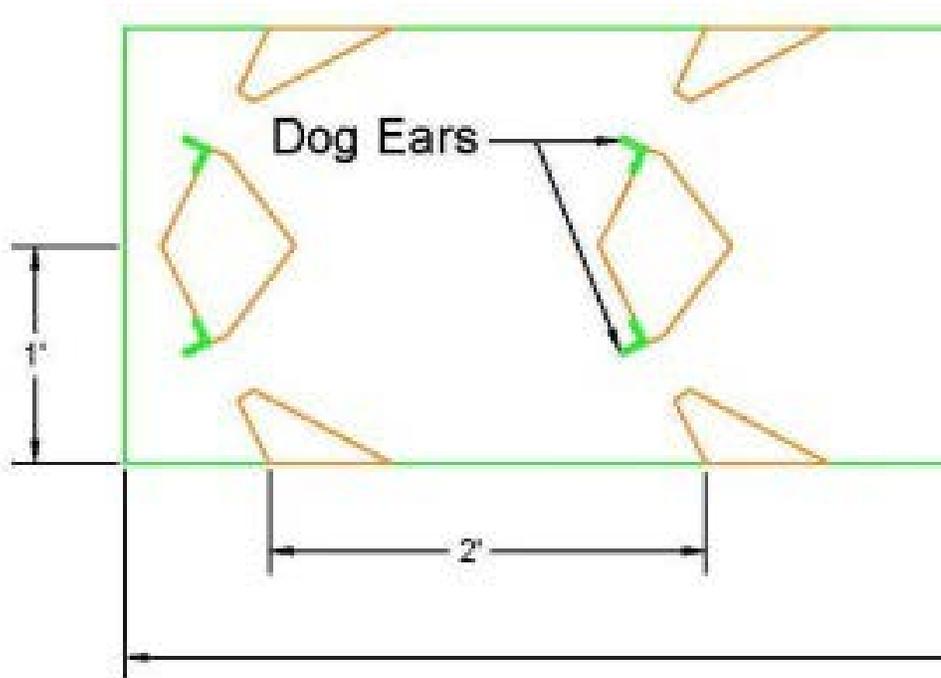


Figure 4. Plan view detail showing the "dog ear" extensions that were added to the center baffles after initial testing showed flow instabilities in the fishway.

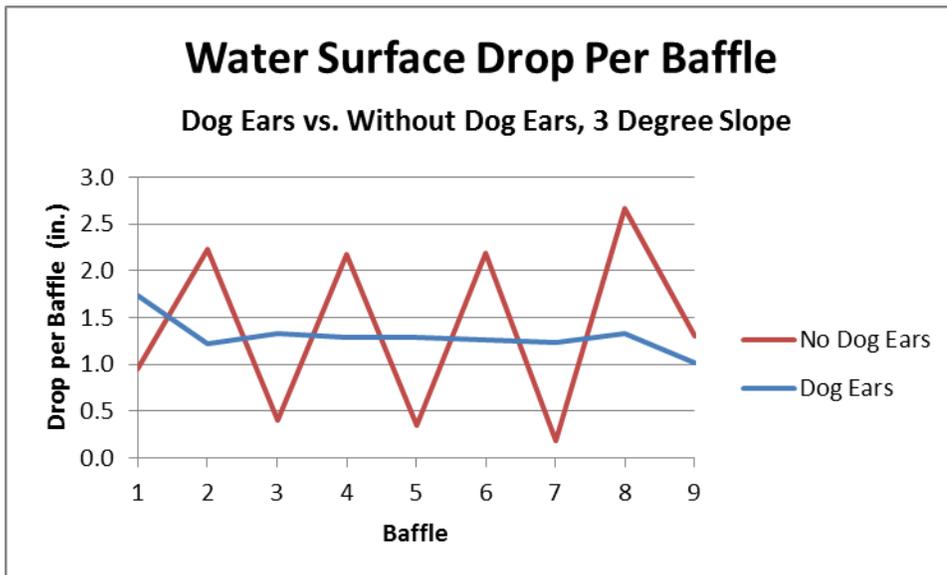


Figure 5. Water surface drop per baffle, with and without dog ears for a 3 degree slope. Notice that without the dog ears the water surface drop across the odd numbered baffles is much lower than the even numbered baffles.

This oscillation between a large drop and small drop is caused by the flow patterns that develop in the pools. In the even numbered pools the water entered the upstream end of the pool with the velocity vector directed towards the outside of the pool. At the downstream end of the pool the water recirculated toward the center of the fishway. In the odd numbered pools the water recirculated in the opposite direction. The water entered the upstream end of the pool with the velocity vector directed towards the center of the fishway. At the downstream end of the pool the water recirculated toward the outside of the fishway (see Figure 6). For example, the resulting water surface drop across baffle 6 (from pool 6 to pool 5) is a large drop (Figure 5).

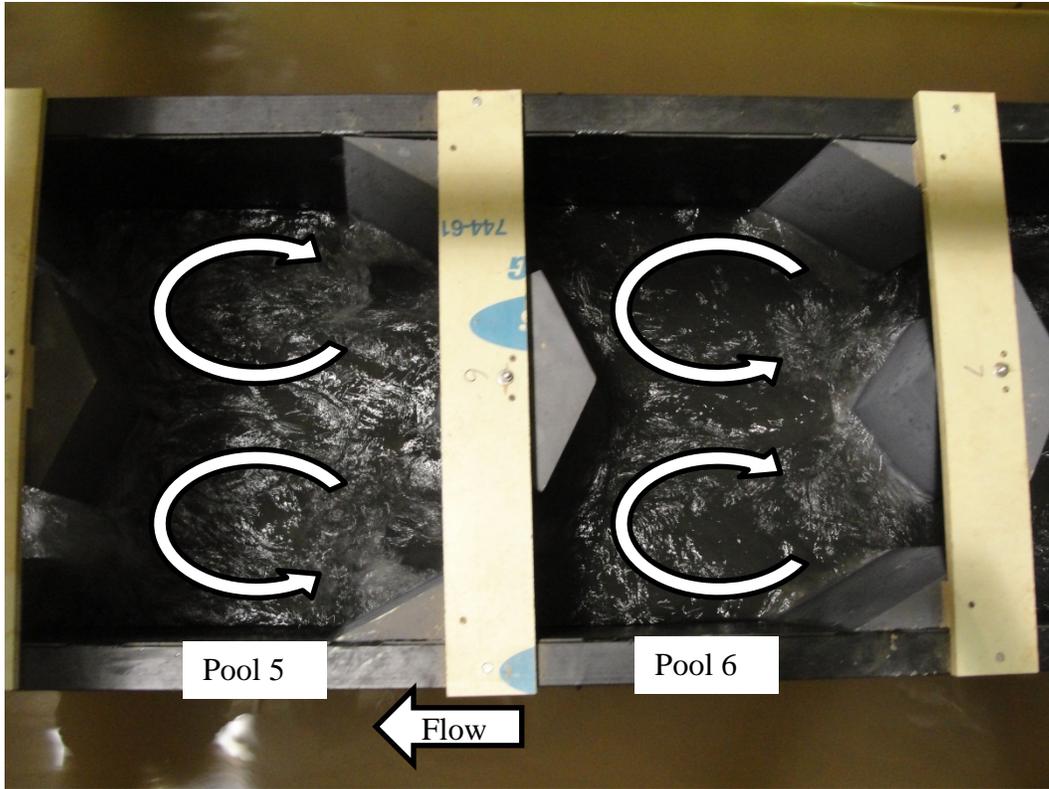


Figure 6. View of pools 6 and 5 showing the different flow patterns that develop in each pool without the dog ears. $Q=0.6 \text{ ft}^3/\text{s}$, upstream slope= 3 degrees, downstream slope= 3 degrees.

After the dog ears were added to the baffles the flow recirculation in every pool was the same as in pool 5. The water entered upstream end of the pool with the velocity vector directed towards the center of the fishway. At the downstream end of the pool the water recirculated toward the outside of the fishway (see Figure 7). This caused the water surface drop from pool to pool to be uniform (see Figure 5). In the duel slot vertical fishway design, the baffle dog ears are required in order to achieve uniform water surface drop across each baffle. The remainder of the study included dog ears for all tests.

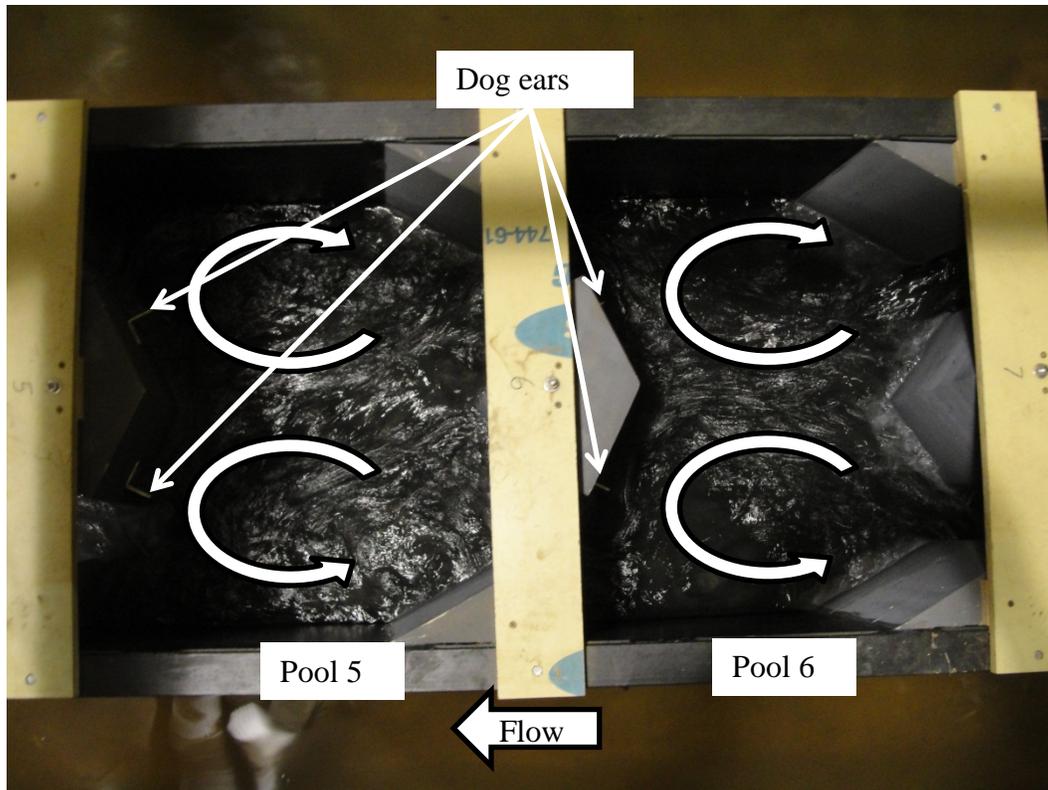


Figure 7. View of pools 6 and 5 showing the same flow patterns that develop in each pool with the dog ears. Notice the flow recirculation pattern is the same in both pools. $Q=0.6 \text{ ft}^3/\text{s}$, upstream slope= 3 degrees, downstream slope= 3 degrees.

Hydraulic Conditions for Varying Slopes

A major objective of this study was to investigate hydraulic conditions when the fishway has two different slopes along its length. For all tests the downstream half of the fishway was at a constant 3 degree slope. The fishway was tested with the upstream half at slopes ranging from 0.2 through 5.7 degrees. Pool WSEs and visual observations were made for each test configuration. WSE was measured with an ultrasonic water level sensor (Massa products Corporation, Hingham, MA). Velocity through the slot was measured with a Swoffer 3000 (Swoffer Instruments, Seattle, WA). Energy Dissipation Factors (EDF) were calculated for each configuration using the following equation:

$$EDF = \frac{\gamma}{(V_{pool})(Q)(h)}$$

Where:

EDF= Energy Dissipation Factor

γ = Unit weight of water ($62.4 \text{ lb}/\text{ft}^3$)

V_{pool} = Volume of the pool at minimum tailwater (ft^3)

Q = Flow rate entering the pool (ft^3/s)

h = Total energy head of the flow entering the pool (ft) (velocity head plus drop)

Figure 8 shows the WSE in each pool for varying upstream slopes with a constant discharge of $0.6 \text{ ft}^3/\text{s}$. Pool 9 is the forebay and pool 0 is downstream of the fishway (see Figure 2). Since the downstream slope remained constant, the downstream individual pool WSE does not change when the upstream slope was changed. However, when the upstream slope increases or decreases the upstream WSE consequently increases or decreases, respectively.

Figure 9 shows the water surface drop per baffle over the range of upstream slopes. This figure also shows illustrates how the water surface drop per individual baffle does not change for the downstream baffles. When the upstream slope is greater than 3 degrees (equivalent to the downstream slope), the water surface drop is greater than those drops in the downstream half of the fishway. When the downstream slope is less than 3 degrees, the water surface drop is less than those drops in the downstream half of the fishway.

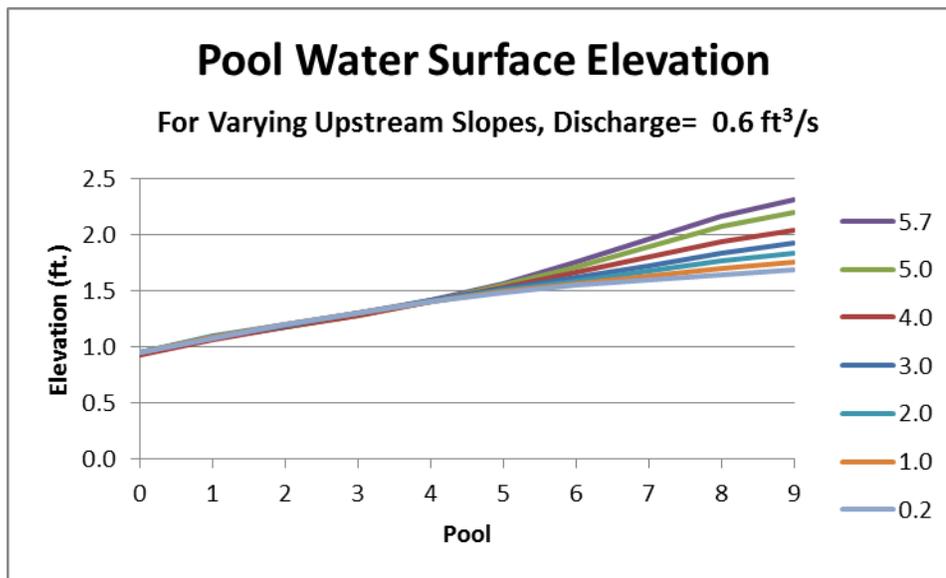


Figure 8. Pool WSE through the fishway for varying upstream slopes, discharge = $0.6 \text{ ft}^3/\text{s}$

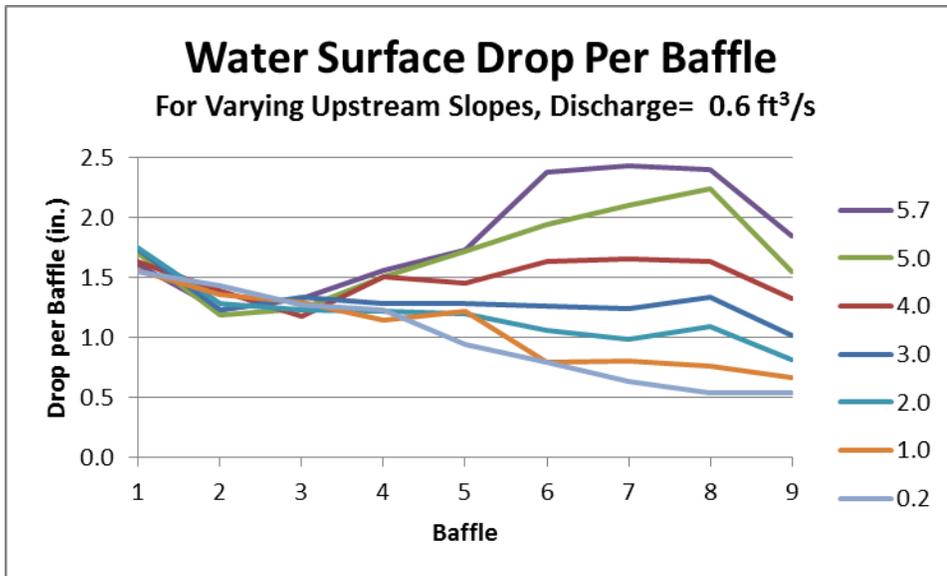


Figure 9. Water surface drop, in inches, per baffle for varying upstream slopes, discharge= 0.6 ft³/s.

Slot velocity measurements reflected the same pattern as the water surface drop per pool. Slot velocities in the upstream half of the fishway increased as the slope increased, and decreased as the slope decreases (see Figure 10). As expected, since the EDF is a function of total energy head and discharge, the calculated EDF follows a similar trend as the water surface drop per baffle and baffle slot velocity (see Figure 11).

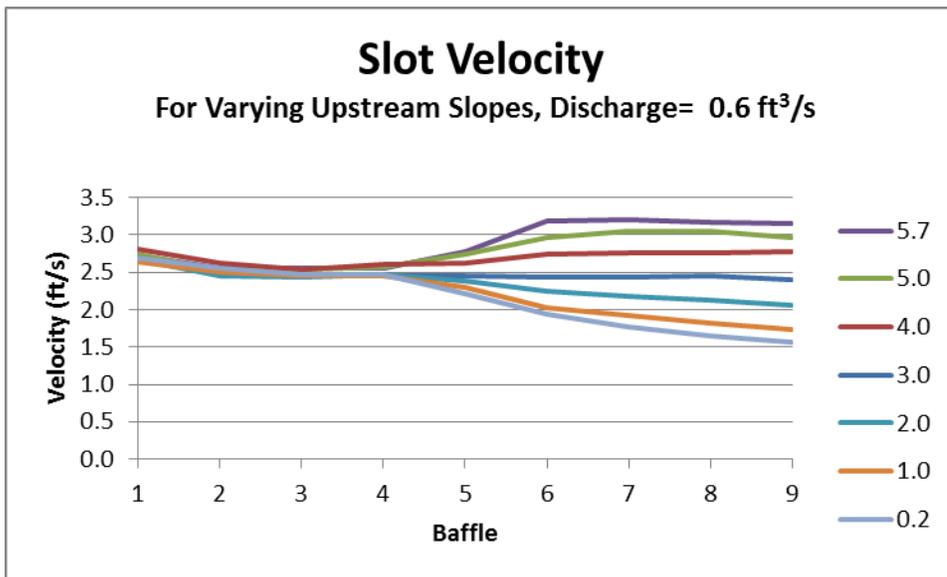


Figure 10. Baffle Slot velocity for varying upstream slopes, discharge= 0.6 ft³/s.

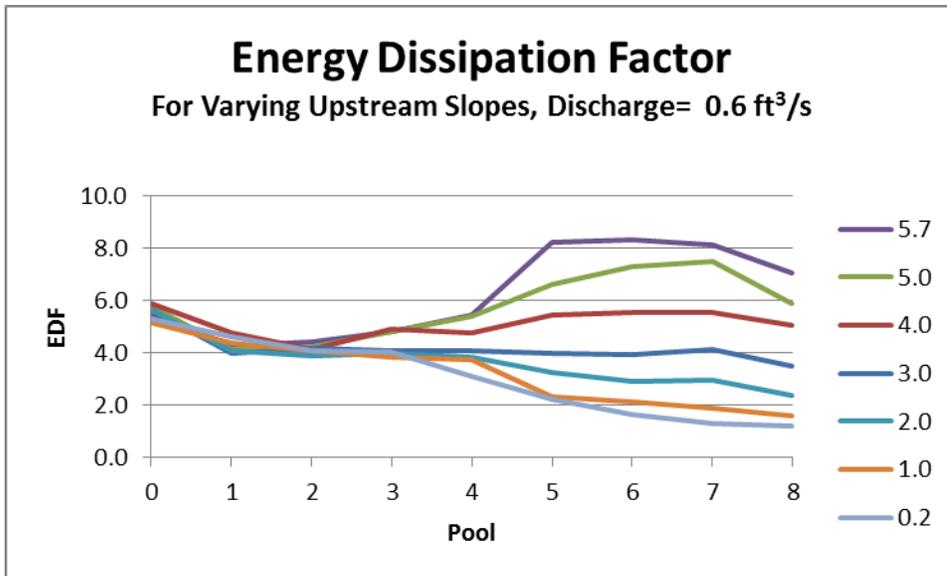


Figure 11. Energy Dissipation Factor for varying upstream slopes, discharge= 0.6 ft³/s.

Visual comparisons and video observations for differing upstream slopes showed identical flow patterns (see Figure 12 and Figure 13). Over the ranges of slopes tested, the only visual difference in hydraulics was a greater water surface drop and greater slot velocity in the upstream half of the fishway for steeper slopes. For shallower slopes the upstream half of the fishway had smaller water surface drops and smaller slot velocities. Throughout the range of slopes tested, there were no adverse hydraulic conditions that would hinder fish passage. No hydraulic jumps developed in the fishway. However, the fishway should be designed so that the maximum pool-to-pool drop and slot velocity does not exceed the target species design criteria. Tested flow rates did not adversely affect hydraulics of the articulated fishway. Therefore, results are only shown for one tested flow rate.



Figure 12. Pools 6 and 5, upstream slope= 0.2 degrees, discharge= $0.6 \text{ ft}^3/\text{s}$. Visual flow patterns were identical for varying upstream slopes.



Figure 13. Pools 6 and 5, upstream slope= 3 degrees, discharge= $0.6 \text{ ft}^3/\text{s}$. Visual flow patterns were identical for varying upstream slopes.

Physical Model vs. Numerical Model

During physical model testing, a three dimensional computational fluid dynamic (CFD) numerical model was built and tested to evaluate if CFD modeling could replicate the complex hydraulics represented by an articulated fishway. The FLOW-3D numerical model had the same dimensions as the physical model to make comparison easy. The CFD model was set up to match one physical model setup with a constant slope of 3 degrees, a discharge of $0.9 \text{ ft}^3/\text{s}$, and no dog ears.

Velocity flow patterns in the CFD model closely resembled the physical model (Figure 14), including recirculation in the pools. Figure 15 shows the WSE measured in the physical model in each pool of the fishway compared to the calculated values in the CFD numerical model. In the physical model only one WSE was measured per pool. In the CFD, the WSE was calculated at each cell in the pool. Areas in Figure 15 without a CFD WSE indicate where the solid fishway baffles are located. These comparisons show that hydraulics in the physical model and CFD model correlate very well.

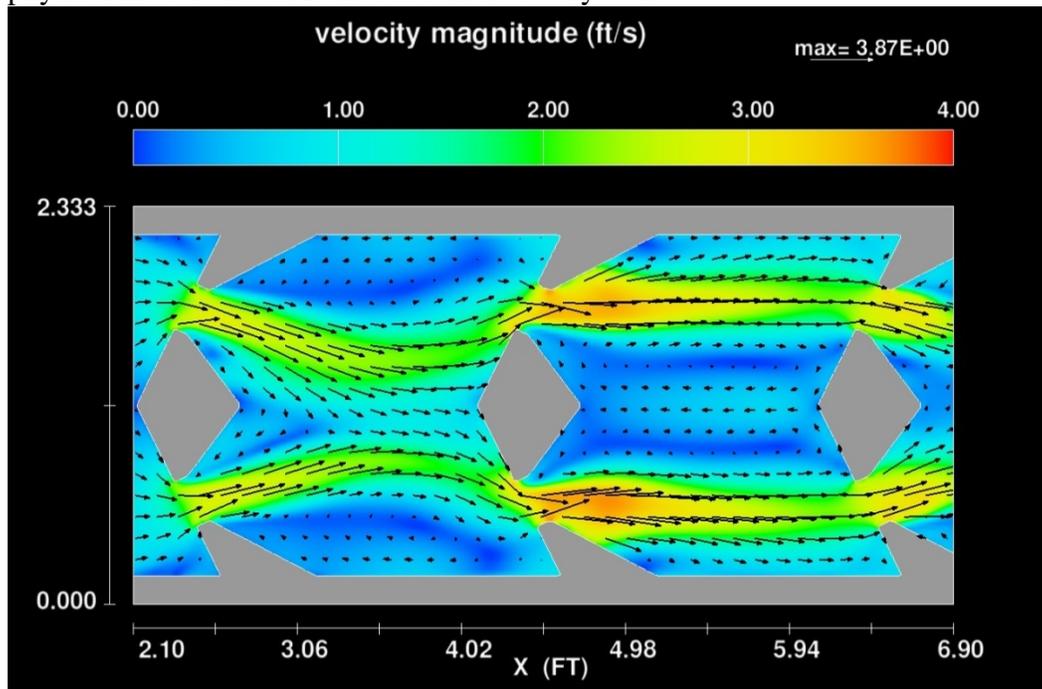


Figure 14 - Velocity flow patterns seen in the CFD model.

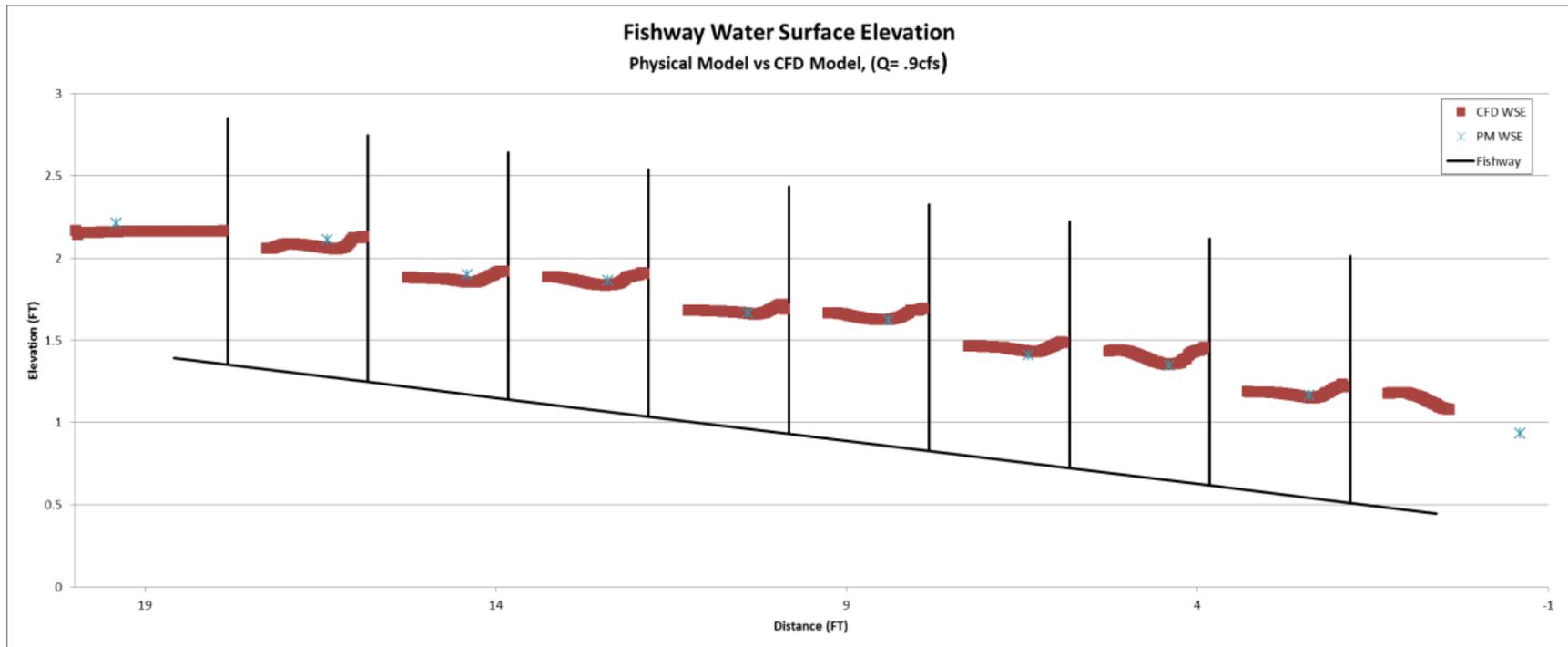


Figure 15. Water surface elevation measurements in each pool of the fishway in the physical model (PM) vs. CFD.

For feasibility and evaluation purposes, the physical and CFD model build and run times were compared. It took approximately 30 staff days to build the physical model and each flow condition took 20 minutes to setup, run, and collect data. The CFD model took approximately 2 staff days to build by an experienced modeler and approximately 4 hours to run one flow configuration. This was a conceptual level CFD model. It should be noted that the CFD simulation was not put through any grid resolution or uncertainty routines which are commonly done to ensure the model represents the flow adequately. Doing these types of routines typically adds several staff days to a CFD study. It is anticipated that each additional CFD configuration would take 2 hours to set up and 4 hours to run.

Self-Regulating Fishway

A typical installation of this fishway will be on low head dams with reservoir WSEs that fluctuate by less than 3 ft. This type of a fishway will only be successful if it can self-regulate as the upstream water surface changes.

The upstream end of the fishway is subjected to buoyancy forces. When the upstream end of the fishway is at a low slope the buoyancy force is small; inversely, at a steep slope the buoyancy force is large. During the initial laboratory test a chain hoist was used to adjust the upstream slope (see Figure 16). The 2-foot wide by 10-foot long upstream half of the laboratory model weighed approximately 400 lbs. During testing with steep slopes extra weight had to be added to the fishway to keep it from floating.



Figure 16. Laboratory setup with a chain hoist being used to adjust the upstream half of the fishway.

A self-regulating fishway could be designed in a few different ways:

- Automatic hoist with an associated water level sensor
- Large floats attached to the sides of the upstream end of the fishway

A water level sensor that is attached to a Programmable Logic Controller (PLC) will measure the changes in reservoir water surface and will direct the hoist to adjust the upstream end of the fishway accordingly to maintain a constant flow. Given the minimal power requirements of the hoist and PLC, this setup could be powered by rechargeable battery and solar panel.

In the laboratory small floats were added to the fishway in an attempt to self-regulate the upstream fishway elevation. The fishway would not stabilize at a specific elevation, but would either sink or float. Once the fishway started to float, the buoyancy would increase and it would rise to the surface quickly. The inverse is true as it started to sink. Given the fishway setup location in the laboratory it was not possible to attach large floats. Attaching large floats (55 gallon drums) to the sides of the fishway may allow for successful self-regulation.

Both of these ideas would eliminate the need to run power to the site and would operate successfully with minimal operator assistance. Further testing of the float method should be completed in the laboratory before field testing.

Conclusions

- The duel vertical slot fishway requires the use of dog ears to produce uniform flow conditions through the fishway.
- Throughout the range of slopes and flow rates tested, there were no adverse hydraulic conditions that would hinder fish passage caused by this duel vertical slot fishway with 2 slopes. The fishway should be designed so that the maximum pool drop and velocity does not exceed the target species design criteria.
- CFD modeling of the fishway accurately represented the hydraulic flow patterns, WSEs, and velocities in the physical model.
- Self-regulation of the fishway could be accomplished with a PLC and electric hoist system. Further testing of the float system in the laboratory is desired before field testing.