PAP 940

Swim-Thru Fishway Evaluation Project

Brent Mefford

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RECLAMATION

Managing Water in the West

Swim-Thru Fishway[1] Evaluation Project[2]

by Brent Mefford, PE

U.S. Department of the Interior
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Water Resources Research Laboratory
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[1] Swim-Thru Fishway is a product name

[2] Following completion of the initial study, a series of additional tests were performed that are reported herein under the addendum.

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Swim-Thru Fishway Evaluation

Background

Reclamation's Snake River Area Office requested a hydraulic evaluation of a new fish passage product called Swim-Thru Fishway. The evaluation was conducted at Reclamation's Water Resources Research Laboratory (WRRL) in Denver, Colorado. The project was conducted as a cooperative research and development project to assist Swim-Thru Fishway with evaluation and development of their fish pass. Therefore, the fish pass tested was a prototype under development. The fish pass uses the concept of a rotary valve mounted in a cylindrical chamber. The valve consists of a three vane sprocket that rotates in a horizontal plane similar to a revolving door. A schematic of the valve provided by Swim-Thru Fishway is shown in figure 1. The valve's vanes are rotated by the action of an external paddle wheel drive. The vanes rotate against the flow direction on one side of the cylindrical chamber and with the flow on the opposite side. Vanes moving against the flow allows fish to enter the space between the vanes and move upstream against a rising pressure head under the aid of the rotary valve.

Prototype rotary valve

The rotary valve tested in the evaluation study is shown in figure 2. The valve was 4 ft in diameter and 1 ft high. The fish entrance was 10 in. wide by 11 in. high. The exit was a 10 in. diameter pipe. The internal rotor had three straight vanes supported by a center shaft. A Plexiglas insert mounted in the fish pass top provided a window for viewing inside the chamber during operation. Flow passes continuously through the valve as the vanes rotate. The amount of flow passing through the fish pass is dependent on the total head across the valve, volume of the valve and the clearances between the valve vanes and the chamber. The clearance between the vanes and the chamber floor could be adjusted by moving a high density polyurethane strip mounted on the bottom edge of each vane. No clearance adjustment was available along the top and side of the vanes. The measured clearances between the vanes and the chamber body were about 0.10 inches along the top, 0.08 inches on the sides and 0.07 inches on the bottom. Vane clearances were not changed during testing. Each vane also contained a 1 in. diameter hole with a one way flap valve. The flap valve allowed flow through the hole when the vane was moving against the flow and closed when the vane was moving in the flow direction. The rotary valve is powered by an overshot water wheel, figure 3. The water wheel uses water piped from the upstream barrier to drive the wheel.

Evaluation test program

The evaluation program was conducted in two phases; first a hydraulic evaluation of the rotary valve was conducted followed by a preliminary evaluation of fish and debris passage. The debris and fish passage evaluation was conducted to obtain a preliminary assessment of debris and fish passage issues that might be encountered in a longer term field application. The passage tests were not designed to evaluate fish passage performance. This will require a field test program.

Hydraulic evaluation

For the hydraulic evaluation, the valve was plumbed as shown in figures 4 and 5. A pump was connected upstream to allow the valve to be evaluated at several different heads and corresponding flow rates. Flow passing through the valve was measured using a flow meter placed between the pump and valve. A pressure gage mounted on the upstream end (fish exit) of the valve was used to monitor the exit pressure head on the valve. The water wheel drive was removed and replaced by a variable speed gear motor. The gear drive provided control of vane rotation speed independent of flow, figure 6. Tailwater elevation and entrance submergence were measured using a staff gage mounted in the fish pass entrance channel, figure 7. Pressure inside the fish pass was measured by mounting a stand alone pressure logger on a vane, figure 8. The pressure logger was programmed to record pressure and time as it rotated with the valve. During each hydraulic test, a target differential pressure across the valve was set by adjusting flow delivered to the fish pass. Tests were conducted at differential pressures across the valve of 2.0, 2.5, 3.6 and 5.5 ft. Differential pressures can be thought of as barrier height. Tests were planned for higher differential pressures; however, at upstream pressures above about 6 ft the vanes scraped the lid of the fish pass chamber. It appeared deflection in the top of the chamber was sufficient to cause loss of clearance between the outer edges of the vanes and the chamber lid. All tests were conducted at a rotational speed of about 1.35 rpm. The rotational speed was chosen based on the ability of the gear motor to drive the rotary vanes smoothly through a full cycle. Drive torque was not measured during the tests. However, loading on the drive motor clearly changed as a function of vane rotational position. During the tests, the fish pass entrance was submerged 0.5 ft by tailwater resulting in a flow depth in the entrance channel of about 1.7 ft., figure 9. Figures 10, 11, 12 and 13 give the results of the pressure measurements. The pressure response to the valve rotation was similar in all tests. The peak and valley of each cycle show a pressure change that is likely due to a vane passing the entrance or exit openings. When a vane crosses an opening the total head across the system is broken across two vanes instead of three vanes. The pressure curves shown will change if vane clearances are adjusted. For the valve configuration tested, the relationship between flow and total differential pressure is given in figure 14. For example, a differential pressure of 5 ft of water across the fish pass equates to a flow of 1.8 ft^3/s flow.

Biological evaluation

The model was changed to closer simulate a typical fish pass installation for the biological tests. The pump used for the first phase of tests was replaced by a flume that carried water past the fish pass exit similar to a fish pass located on the abutment of a small run-of-river dam, figure 15. A fish pass exit structure designed by Swim-Thru Fishway was mounted perpendicular to the upstream flume, figure 16. The exit structure serves as an interface between the stream and the exit pipe upstream of the rotary valve. During construction we noted the pipe flange on the exit structure was for an 8 inch pipe flange instead of a 10 inch flange used on the rotary valve. Because the tests were not designed to evaluate fish passage efficiency, we reduced the exit pipe from 10 inch to 8 inch to match flanges. This increased flow velocity in the exit pipe by about 56 percent.

Pond weed fouling tests - Several tests were conducted where pond weed was introduced to the stream flow and carried by the water into the fish pass. Tests were conducted at a differential head of 4 ft and at the same rotational speed used for the hydraulic evaluation. During each test, pond weed was manually feed into the model over a five minute period. The pond weed was introduced into the upstream flume (stream) adjacent to the bank containing the fish pass exit. This ensured a large percentage of the material was entrained into the fish pass by the flow. Tests were conducted with 1, 2.5, 4 and 6 gallons of tightly packed (drained wet material) pond weed fed into the model during each test. The pond weed generally passed easily through the exit structure. Some material was entrained by eddy flows that occur downstream of the "U" shaped baffle and behind the reentrant pipe. Material entrained by eddies typically persisted for the duration of each test. Debris that passed into the rotary valve was largely expelled out of the fish pass by flow. Some material was caught by the horizontal vane support rods and the center shaft. During operation, pond weed could be seen through the viewing window trapped between the vanes and the chamber body. During the short laboratory tests the material did not impact valve operation. When each vane passes the entrance and exit, the direction of flow past the vanes reverses. This reversal of flow around the vanes likely facilitates flushing of debris off the vanes. Figures 17 and 18 are photographs looking inside the rotary valve following debris tests. Passage of other types of debris including sticks or sediment was not investigated during this preliminary study.

Fish trials – Five adult trout ranging from 12 to 16 inches in length and 10 juvenile white suckers ranging form 2 to 4 inches in length were placed in the entrance channel for the fish trials. One trout and eight of the suckers almost immediately moved into the rotary valve. The trout followed the vane for a full cycle and passed back out downstream. The trout was netted and showed not signs of physical injury. It was then returned to the entrance channel. The juvenile suckers remained in the fish pass for the 2 hour duration of the test, neither exiting nor returning downstream. The juvenile suckers could not be seen through the viewing window after they first entered the rotary valve. They likely moved into the exit pipe and held for the duration of the test. The trout were allowed to acclimate to flow in the entrance channel for one hour. They were then slowly crowed to the entrance of the rotary valve. Three moved into the valve after approaching the entrance. One fish stayed in the chamber for a full vane rotation and returned to the entrance channel. Similar to the suckers, two of the trout remained in the fish pass and were not observed to be in the rotary valve chamber. After 15 minutes, the exit flange of the rotary valve was tapped several times to provoke fish movement. The larger trout (about 15 inches) then exited the fish pass to the upstream flume. The fish was netted and visually examined for injuries, figure 20. No injuries were noted. The remaining fish were not found. After two hours of normal operation, an attempt was made to flush the remaining fish from the fish pass by lowering the tailwater and raising the upstream head as much as possible. This also failed to flush fish from the fish pass. The fish pass was then slowly dewatered. This caused the trout (about 13 inch long) to return to the entrance channel. The trout was netted and visually examined for injuries. No injuries were noted. In addition to the trout, several injured white suckers flushed out of the fish pass as the water was drawn down. The injuries were similar on all of the injured suckers. The injury looked to be a laceration approximately as wide as it was deep that was caused by a strike form a blunt object, figures 21 and 22. The injuries were generally located high on the fish's back. The obvious locations where an impact could occur in the rotary valve are at the entrance and exit pipes where the vanes close against the chamber wall. The injuries did not appear to be caused by this type of pinching action. The depth of the injury was not consistent with the small clearance (0.08 in.) between the vanes and chamber wall and the injuries were largely located on the back of the fish. This suggests the injuries may have been caused by fish being trapped between the vane's horizontal support struts and the chamber floor as the vane rotated.

Conclusions

This laboratory project was designed as a first level prototype evaluation of the Swim-Thru Fishway. The evaluation results are intended to aid Swim-Thru Fishways with product development and Reclamation with future implementation of fish passage technologies. The rotary valve concept incorporated by the Swim-Thru Fishway is viable and may offer a solution to fish passage projects where traditional methods are hampered by space, flow limitations or cost. As with any prototype device, the evaluation tests revealed several issues that negatively affected operation of the fish pass. Within the scope of the tests, no problems were identified that could not be resolved with some design modifications. Toward this objective, a list of design recommendations is provided herein.

Recommendations

The following recommendations are ideas for consideration. Some of the recommendations follow directly from issues confronted during the evaluation tests of the prototype fish pass. Other recommendations are more general and reflect ideas that could be considered as development of the rotary valve concept moves forward.

- Remove horizontal support bars between vanes. The rotary vane structure should be designed to minimize exposed structure in the fish passage chambers. This will reduce the chances of fish injury or debris fouling.
- Remove the flap valve in the vanes. Tests indicate sufficient flow can be passed by the vanes at small vane clearances under the operating heads tested.

•Add structural support to the top and bottom of the valve chamber to reduce deflection under pressure. A structural analysis of the rotary valve chamber should be conducted to ensure structural integrity as a function of the non-uniform pressure load that occurs on the top and bottom surfaces of the rotary valve.
•Change the chamber's top flange design to an external flange. The prototype uses an internal butt joint that is difficult to maintain a seal.
•Consider mounting a polyethylene brush on the right vertical wall downstream of the entrance and upstream of the exit to minimize the chances of fish being pinched against the chamber wall by the rotating vanes. Fish holding in the entrance or exit would be pushed into the brush by the moving vane and have time to move clear of the vane.
• Consider rubber leaf seals on the backside of the vanes. The seals would allow leakage in the fish passage direction and would seal under pressure on the back side of the rotation. This would help reduce the need for tight tolerances between the vanes and chamber to control flow.
•Consider using an interior support and guidance ring around the center shaft of the rotary vanes. The ring would change the shape of the passage chamber between two vanes from a pie shape to an annular segment. This might improve passage guidance at the valve exit by holding fish to the outside of the chamber and excluding them from the center apex of the pie shaped area. An interior ring could also reduce the amount of sediment or debris coming in contact with the center shaft and bearings. The ring should have brush or rubber seals on the top and bottom to minimize passage of flow and sediment into the center. Consider about a 1 ft diameter interior ring on a four ft diameter rotary valve.
•Consider a four vane design to better balance rotational torque for larger diameter designs.
•Consider "Z" aligned horizontal bar rack trash deflectors to exclude trash and bed sediment at the fish exit. Offset bar racks can be fairly effective at excluding debris and sediment if the stream velocity parallel to the bar racks is at least 10 times the velocity through the bar racks. The offset or "Z" alignment allows fish to pass through openings between individual racks.
•For some installations an undershot paddle wheel drive similar to those used on small drum screens may be a better option than the overshot wheel. It may also be possible to incorporate an auto reversing drive that reverses the direction of the rotary vane if it stops rotating. This would allow the rotary vane to backup if debris became wedged between the vane and chamber wall.
•Where feasible, consider exiting the fish pass directly into a vertical shaft. Experience with Borland fish locks and vertical shaft fish locks support using a vertical shaft design to improve fish passage. A vertical shaft could be a steel or concrete culvert mounted vertically with concrete poured around the base and the rotary valve flanged 90 degrees to the vertical shaft. The vertical shaft or pipe should be open on top with expanded metal grating to exclude large debris. A vertical shaft exit will increase light at the rotary valve exit and expand the flow area immediately at the rotary valve exit. Both conditions should encourage fish to exit the rotary valve.

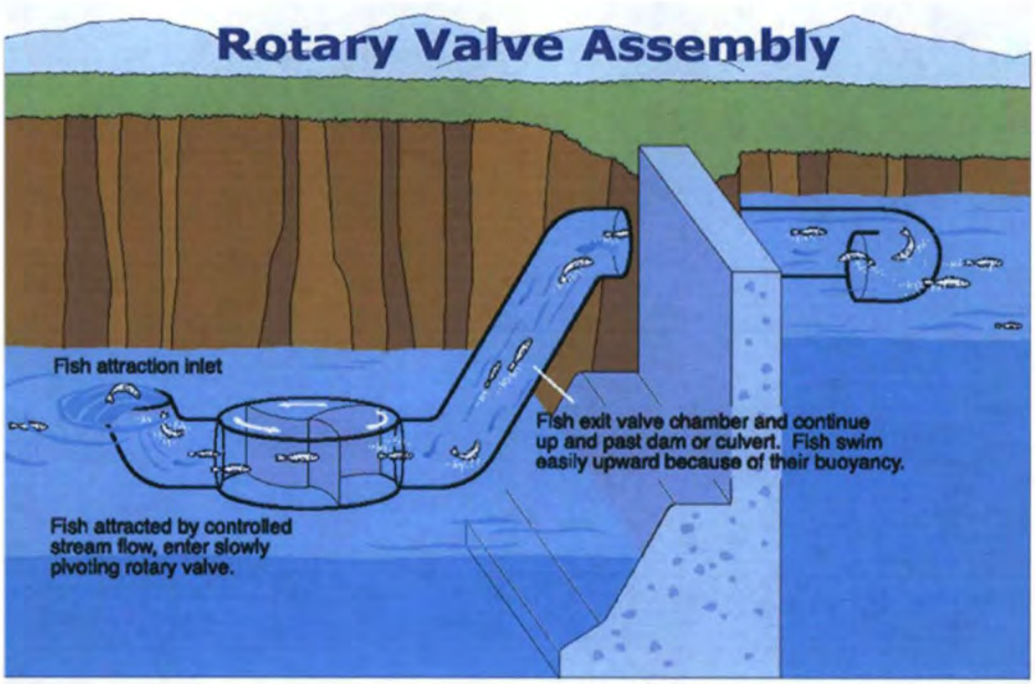

Figure 1- Schematic of Swim-Thru Fishway (Swim-Thru Fishway web site)

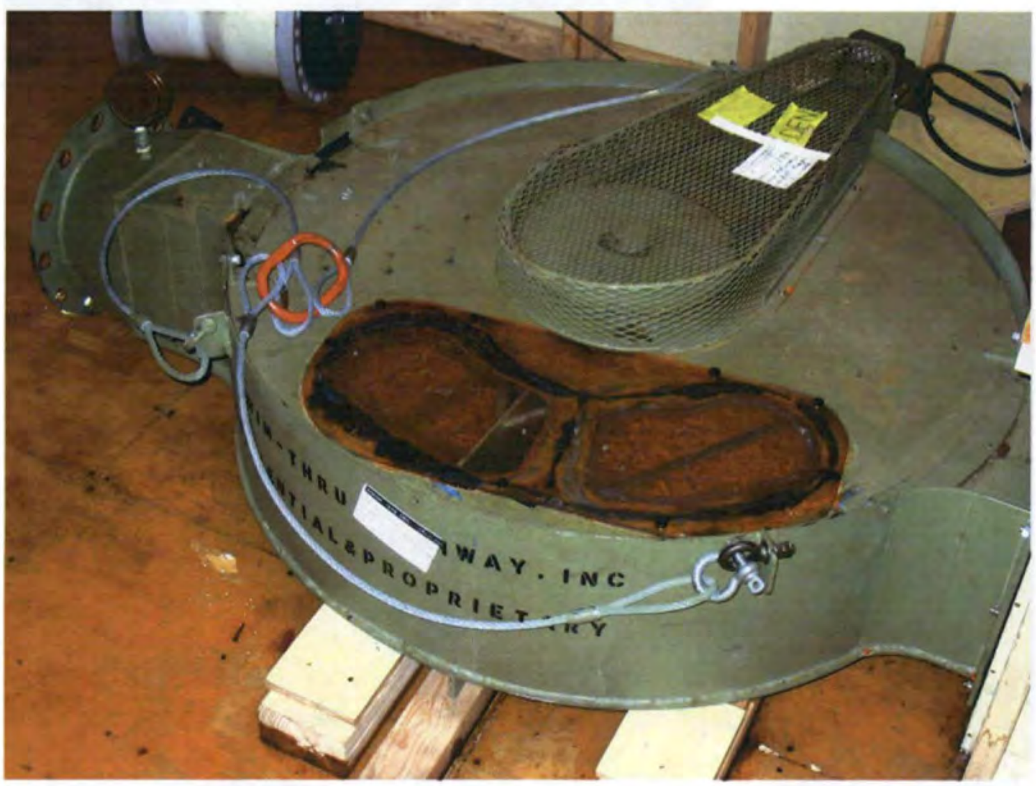

Figure 2 – Photograph of Swim-Thru Fishway tested at WRRL.

Figure 3 - View of overshot water wheel.

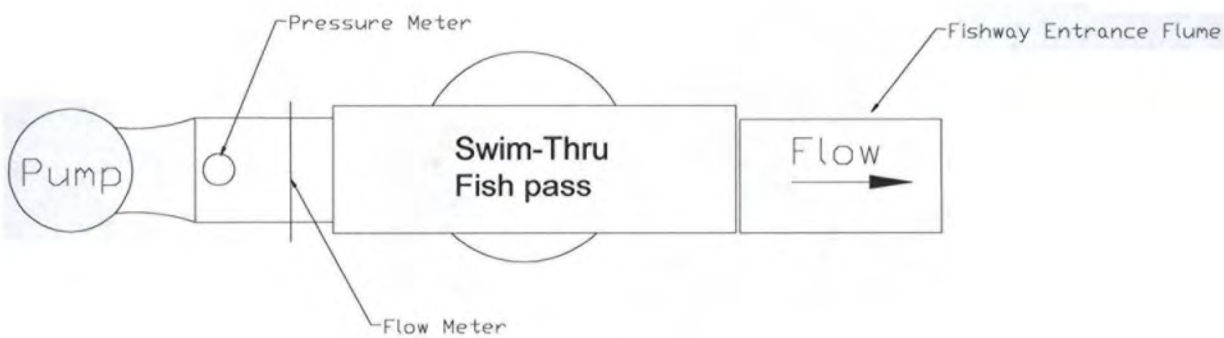

Figure 4 – Plan view of test configuration for hydraulic evaluation of Swim-Thru Fishway operation.

Figure 5 - View of test setup with a downstream flume and an upstream pipe from a pump.

(Flow passes through from right to left)

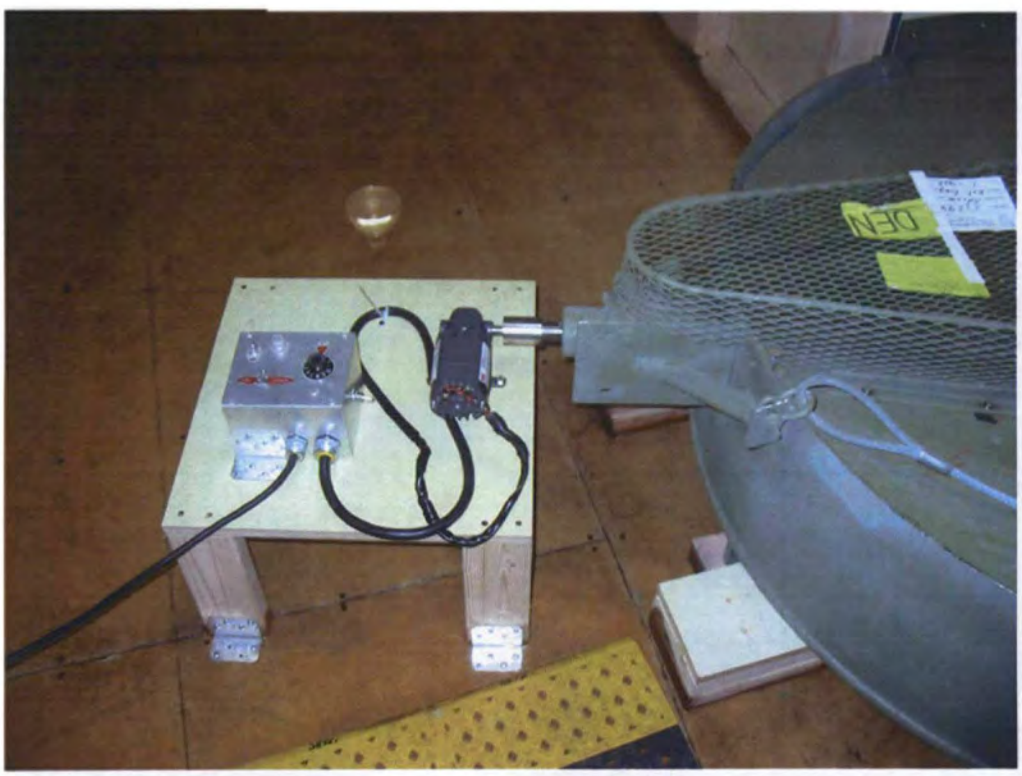

Figure 6 - View of gear motor mounted in place of the standard water wheel drive.

Figure 7 - View of entrance flume constructed for the laboratory evaluation.

(Looking upstream at the entrance to the rotary valve.)

Figure 8 - View of pressure logger mounted on a vane of the rotary valve.

Figure 9 - View looking upstream at model entrance channel.

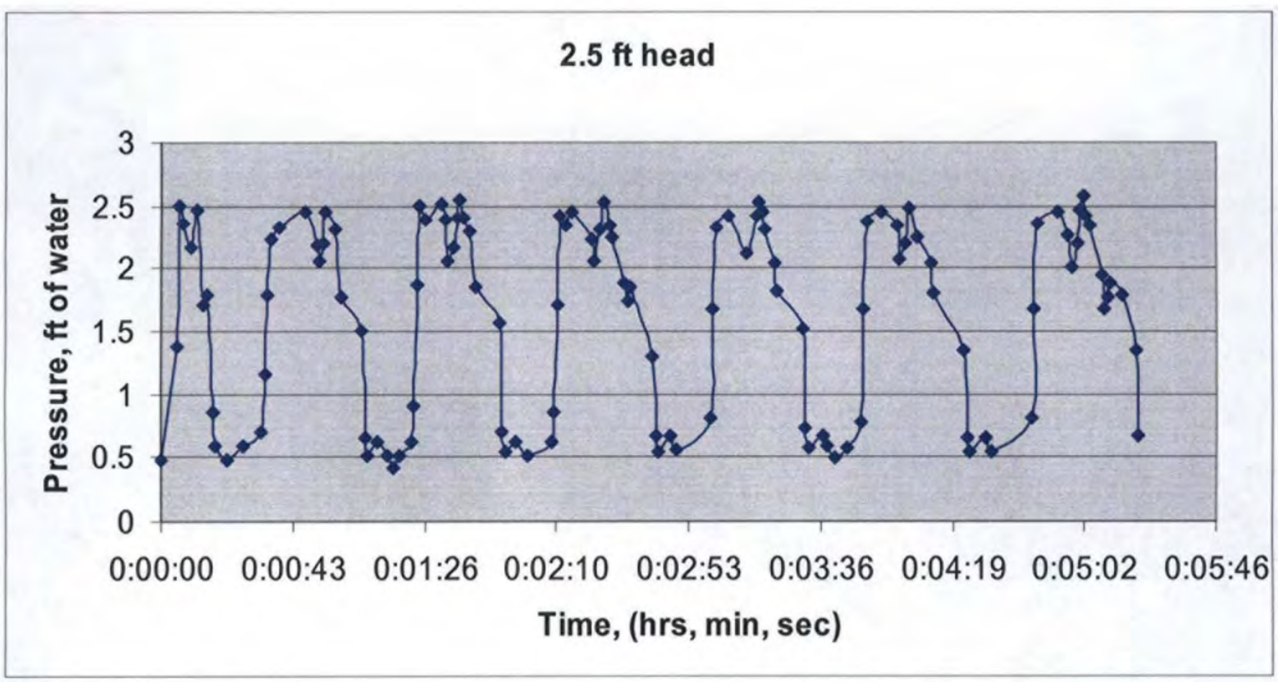

Figure 10 - Expanded view of pressure changes in fish passage chamber during valve rotation. The upstream pressure head was 2.5 ft and the total differential head was 2.0 ft.

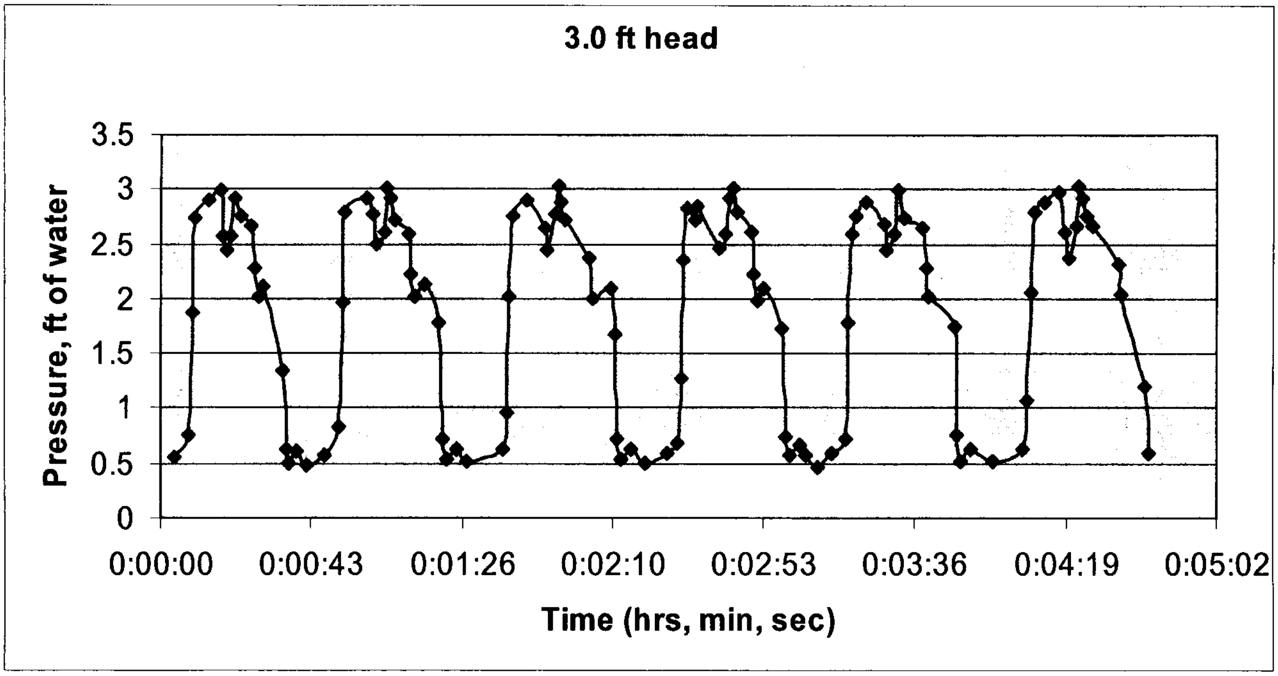

Figure 11 -Expanded view of pressure changes in fish passage chamber during valve rotation. The upstream pressure head was 3.0 ft and the total differential head was 2.5 ft.

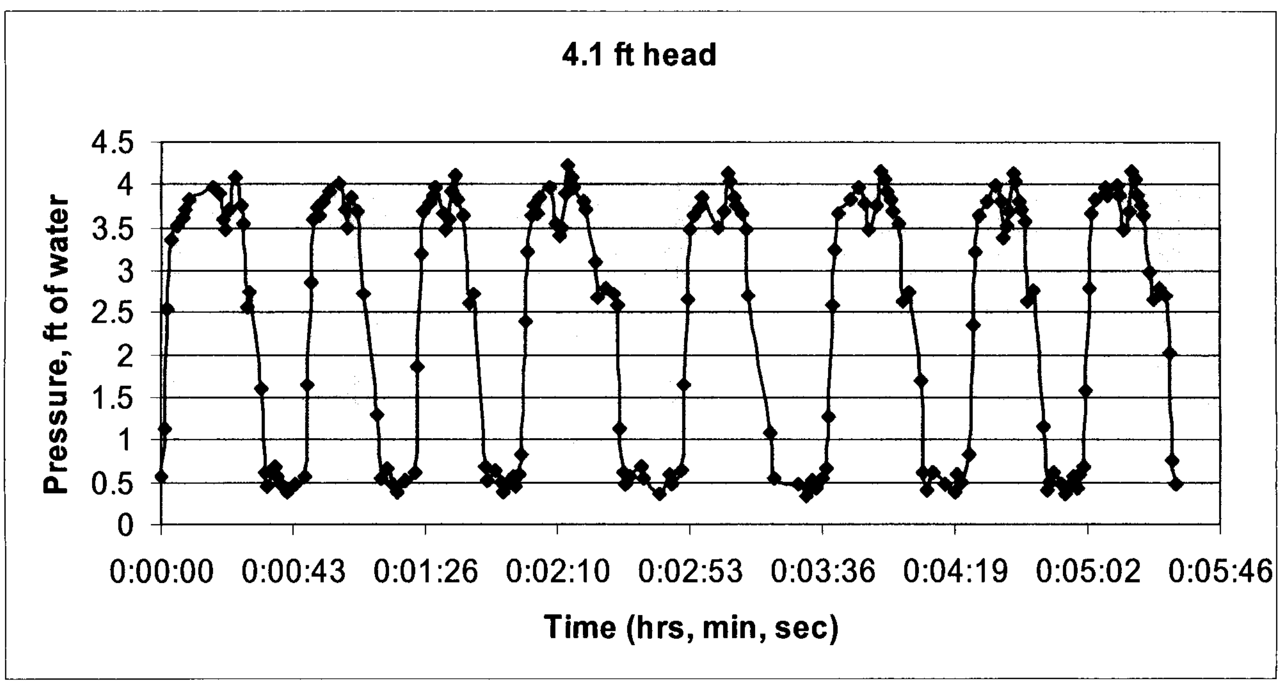

Figure 12 - Expanded view of pressure changes in fish passage chamber during valve rotation. The upstream pressure head was 4.1 ft and the total differential head was 3.5 ft.

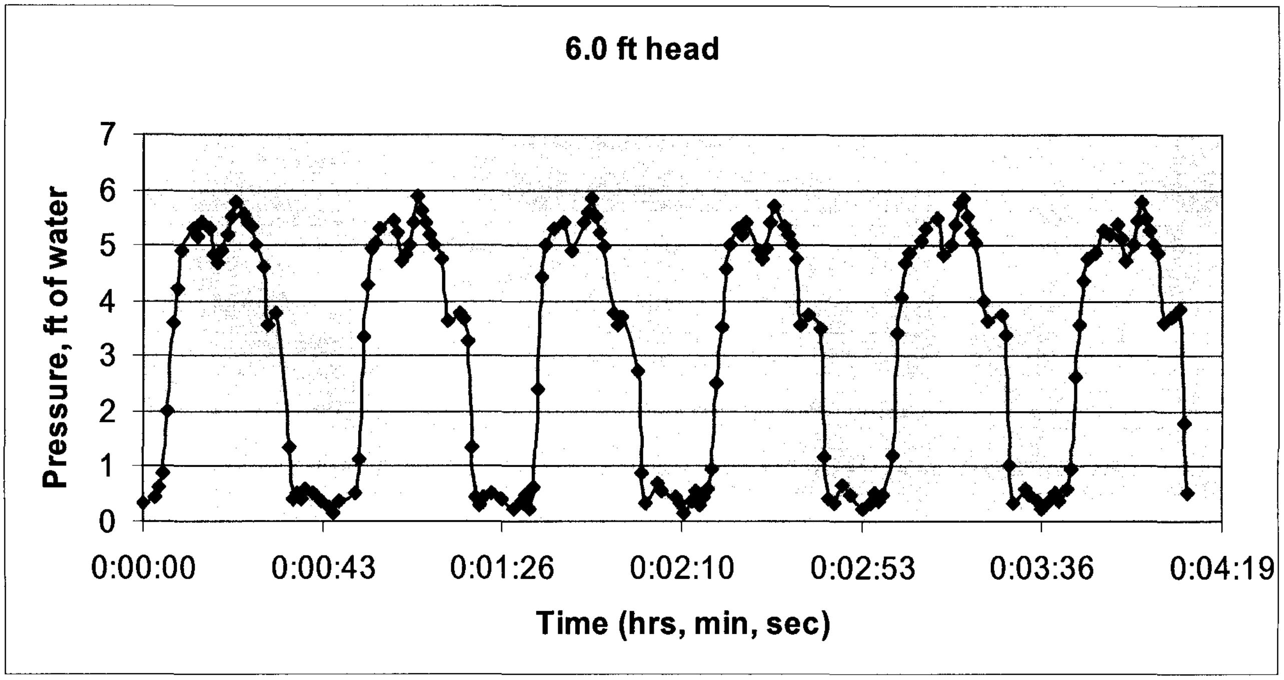

Figure 13 - Expanded view of pressure changes in fish passage chamber during valve rotation. The upstream pressure head was 6.0 ft and the total differential head was 5.5 ft.

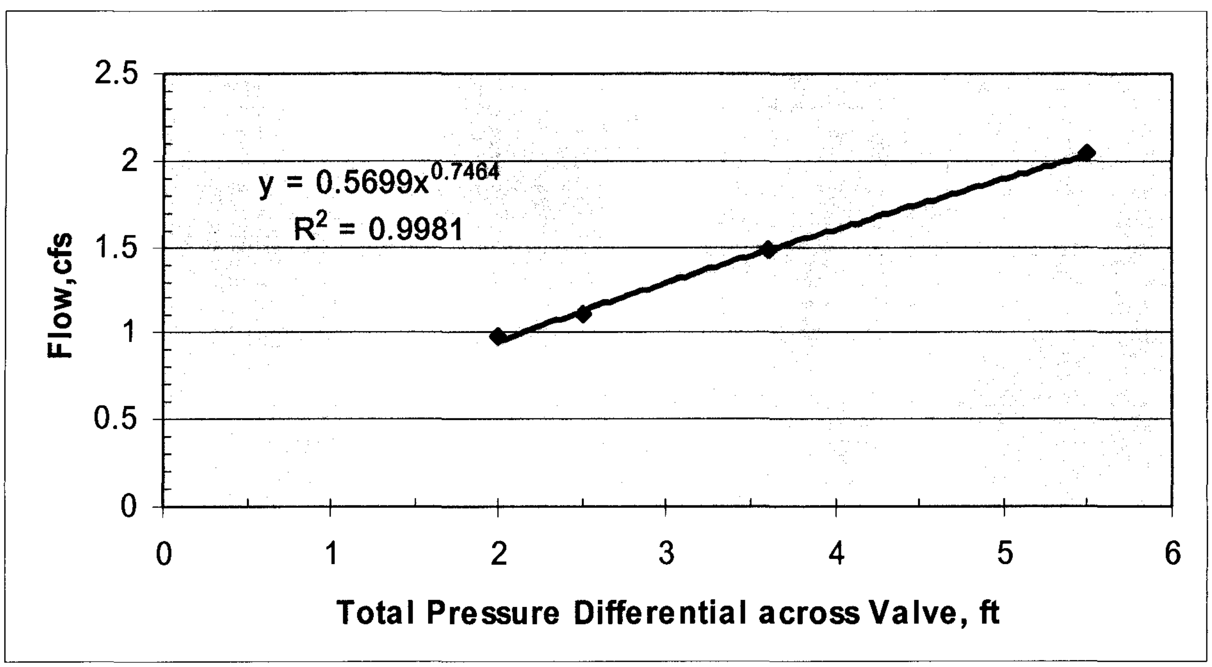

Figure 14– Relationship between total differential pressure across rotary valve and fish passage flow.

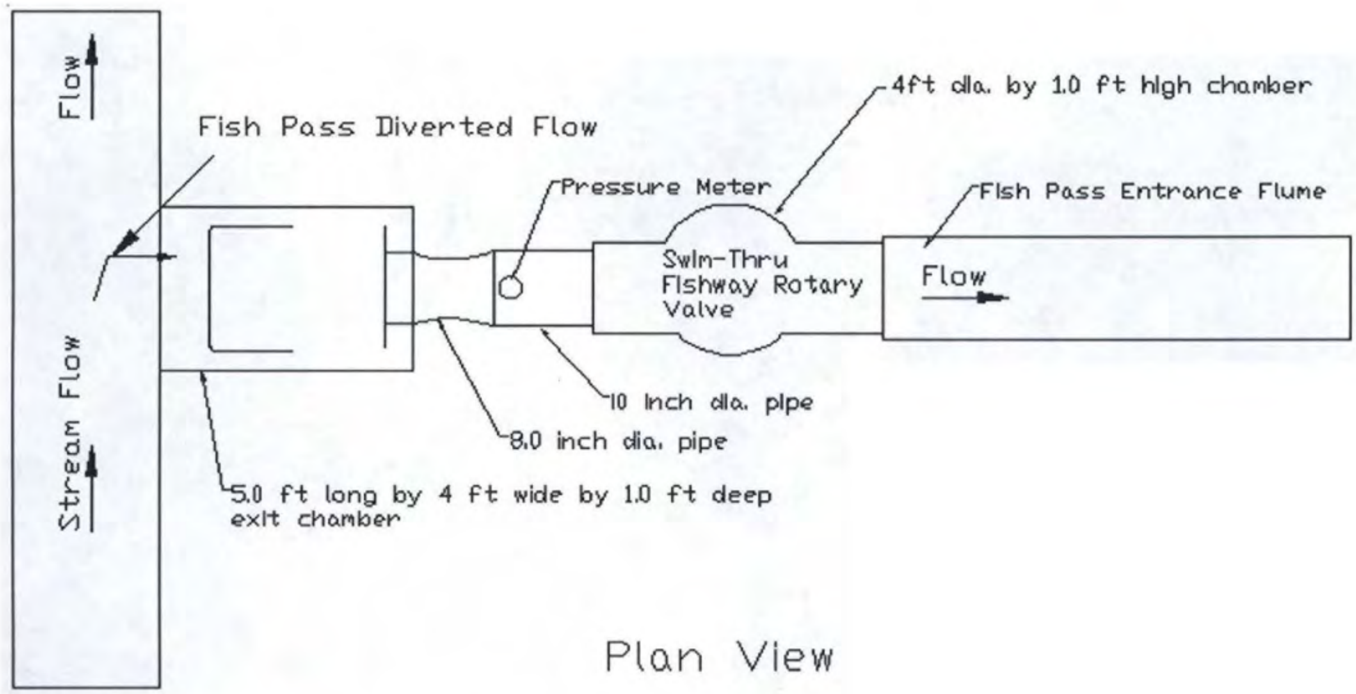

Figure 15- Schematic of model test apparatus for biological evaluation.

Figure 16- View of Swim-Thru Fishway exit chamber.

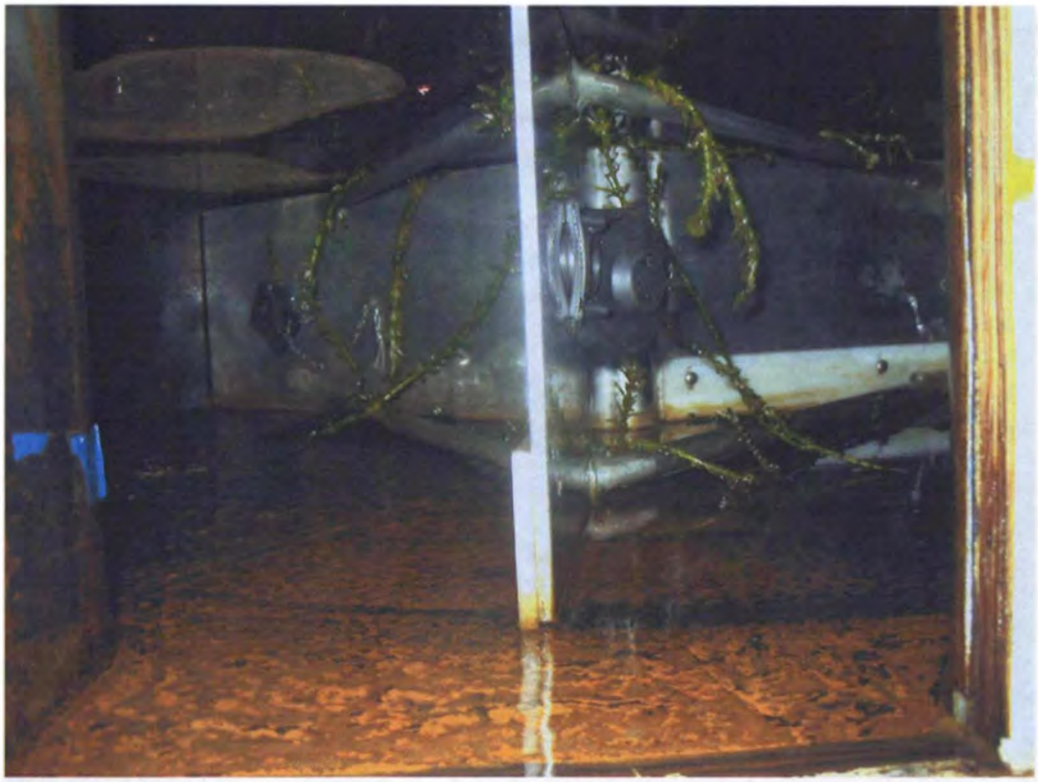

Figure 17 – View looking in side rotary valve directly at a vane following tests of aquatic pond weed entrainment.

Figure 18– View looking at center of rotary vane. Note pond weed on vane support struts.

Figure 19– View of fish in entrance channel looking upstream.

Figure 20 - Rainbow trout passed through Swim-Thru Fishway during laboratory fish passage tests.

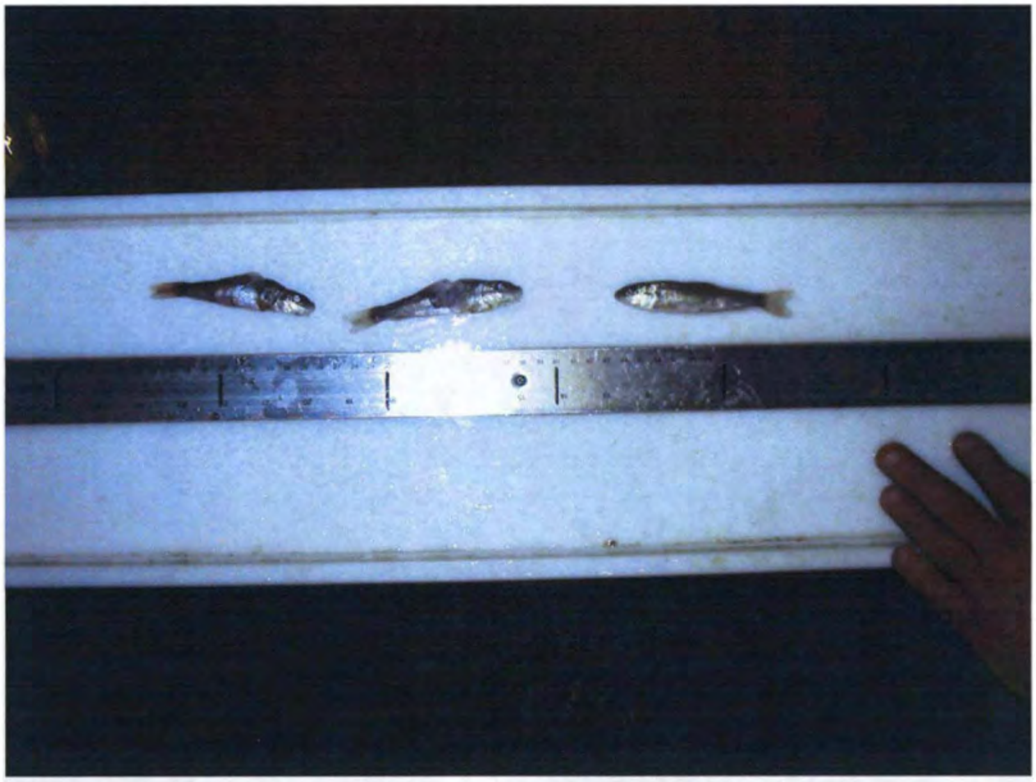

Figure 21 – Juvenile white suckers injured during laboratory fish passage evaluation tests.

Figure 22 – Close-up of injury to juvenile white sucker.

Test Program Addendum – January, 2005

Background

A hydraulic evaluation of a new fish passage product called a Swim-Thru Fishway was conducted at Reclamation's Water Resources Research Laboratory (WRRL) in Denver, Colorado in September 2004. The project was conducted as a cooperative research and development study to assist Swim-Thru with evaluation and development of their fish pass. The initial evaluation program included a limited set of fish trials. These fish trials were intended to provide incite into fish passage issues that might be encountered with passage through the rotary valve. The trials were not structured to evaluate fish passage efficiency or statistically evaluate fish injury. These issues were left to future investigations of fish passage performance. The fish trials were conducted using a differential head of about 4 ft across the fish pass. Results of the trials revealed large trout (10 to 16 inch fork length) that entered the valve passed through (exiting upstream or remaining in the valve and passing back downstream) with no visual indications of injury. A similar set the trials with juvenile white suckers (2 to 4 inches in fork length) found several fish with back injuries. The injuries appeared to be caused by contact with horizontal reinforcing bars that supported the vanes of the rotary valve, see photograph 1 (addendum). National Oceanic and Atmospheric Administration (NOAA) Fisheries, in response to a Section 10 permit request from Swim-Thru Fishway, requested Reclamation conduct a second set of fish trials with the reinforcing bars removed to determine if the injuries believed to be caused by the bars during the first tests were eliminated. This addendum covers the additional fish trials that were conducted for the NOAA request.

Modifications to the Test Apparatus

The rotary valve was disassembled and the reinforcement bars were cut off the vanes. The vanes were then ground smooth at the point of attachment. The support rods were not required for structural support when operating the valve at the three to four foot head level tested in the laboratory. In addition to removing the support rods, two other recommendations listed in the initial study were implemented. A 1/16 inch thick rubber flap was mounted to the back side of each vane along the bottom, side and top. The thin rubber seals allowed better control of flow past the vanes while enabling the vane to rotate without the metal part of the vane scraping the chamber top or bottom, see photograph 2 (addendum). Another recommendation implemented was the addition of a vertical wet well at the exit of the rotary valve, photograph 3 (addendum). The wet well concept was implemented in the laboratory tests as it allowed for observation of fish at the exit of the rotary valve.

Fish Trials

Fish trials were conducted similar to previous tests described in the September, 2004 evaluation study. Fish available at the WRRL at the time of the study were used for the tests. Three fish species were used for tests of the modified valve. Five large cutthroat trout (6 to 14 inch fork length), ten small white suckers (3 to 5 inch fork length) and thirty small (2 to 3 inch fork length) stripped bass (photograph 4 addendum) were placed in an approach channel to the Swim-Thru Fishway. Fish were allowed to acclimate to the flowing water in the approach channel for 30 minutes. Following the acclimation period, approximately three to five fish at a time were crowded into the fish pass rotary valve. No attempt was made to test fish by species. Groups of fish in a trial generally contained mixed species. Trout were reused during the tests; all other fish were used one time. After fish entered the rotary valve, visual observations were made through the Plexiglas view ports located in the top of the valve chamber, looking down the wet well at the rotary valve exit and at the approach channel entrance. Fish exiting the valve upstream or returning downstream after cycling through the valve were netted and visually examined for injury. A total of 10 trials were conducted.

Results and Observations – Cutthroat trout of the length tested can swim at a sustained swimming speed of between 3 to 7 ft/s. The trout showed no visual indication of damage resulting from movement through the rotary valve. Eight of the trials contained one or two trout. Individual fish were not marked. Therefore, tracking a fish's movement was difficult and resulted in estimates of fish movement through the valve. About twenty percent of the trout passed directly through the valve to the wet well. About forty percent of the fish remained in the rotary valve for more than one cycle and about forty percent returned to the approach channel at the end of the first cycle. Some trout remained in the valve for extended periods.

White suckers were used in a single trial then removed and examined. White suckers of the length tested can swim at a sustained swimming speed of between 1 to 3 ft/s. The back injuries reported during the first tests in September 2004 were not found during these tests. The only injury noted was to a fish's tail area. One sucker was observed through the chamber view port with its tail partially pinched between the bottom of the chamber and the rubber seal on the bottom of the vane. The fish was able to free itself and return to the entrance channel. The fish showed signs of scale loss and some bruising near the tail. No suckers exited the valve into the wet well. All suckers tested returned to the entrance channel after one or more valve cycles. Some suckers remained in the valve for four cycles. The suckers appeared to have trouble holding swimming orientation in the valve chambers. They were frequently observed through the chamber view port being rolled by turbulent flow behind the vanes.

Because of availability, young juvenile stripped bass were used in the fish trials to observe the interaction of flow conditions in the valve with young life stages or small bodied fish. Juvenile stripped bass of the length tested can swim at a sustained speed of about 1 ft/s and can dart at speeds of up to 2 ft/s. No injuries to the stripped bass were observed during the tests. However, flow conditions in the valve chambers were difficult for the small fish to negotiate. Similar to the juvenile white suckers, the juvenile stripped bass were frequently rolled by turbulent flow behind the vanes. No stripped bass passed into the wet well. Most returned to the entrance channel at the end of the first cycle.

Conclusions

Injuries to the backs of fish observed during the first tests of the rotary valve were not found following removal of the support bars from between the valve vanes. The only injury noted during tests of the modified valve occurred when the tail of one fish was pinched between the vane seal and the floor of the valve chamber. The injury resulted in scale loss and visual bruising to the tail area.

The thin rubber flaps attached to the back of each vane allowed the vane to rotate without the metal part of the vane scraping the chamber top or bottom. The scope of the tests did not allow for evaluating the hydraulic performance of the flap seals. During the upstream stroke, flow passing around the vanes past the flap seals was sufficient to cause weaker swimming fish (smaller white suckers and stripped bass) to lose swimming orientation in the turbulent flow downstream of valve vanes. Improving flow conditions in the chambers between vanes is an issue that warrants further study.

Photograph 1– View of horizontal support rods between vanes. A 3/8 inch diameter rod is shown laying under the rod.

Photograph 2– View of vane with support bars removed. Also note metal strips holding rubber flaps at the vane edges.

Photograph 3– View of model showing wet well at the upstream exit of the rotary valve. Plastic tubes shown on at the surface of the wet well were used to view fish exiting the valve.

Photograph 4 - View of 2 to 3 inch long juvenile stripped bass.