RECLAMATION

Managing Water in the West

Hydraulic Laboratory Technical Memorandum PAP-1087

Clark's Fork Coalition & Watson Irrigation Fish Screen Tests

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

April 2014

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

April 2014

Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

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.

Hydraulic Laboratory Reports

The Hydraulic Laboratory Report series is produced by the Bureau of Reclamation's Hydraulic Investigations and Laboratory Services Group (Mail Code 86-68460), PO Box 25007, Denver, Colorado 80225-0007. At the time of publication, this report was also made available online at **http://www.usbr.gov/pmts/hydraulics_lab/pubs/**.

Disclaimer

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Introduction

The Clark's Fork Coalition (CFC) funded the Bureau of Reclamation's (Reclamation) Hydraulics Laboratory in Denver, CO to evaluate a fish screen designed for small irrigation diversions. The subject screen was built by Watson Irrigation Inc. out of Townsend, MT. Reclamation was requested to conduct hydraulic and limited biological evaluations of the Watson screen. The screen was provided to Reclamation by CFC and Watson Irrigation. Hydraulic testing included development of a screen rating providing water depth, diversion flows, and bypass flows over the expected operating range of the screen. Limited biological testing included introducing 1-3 inch rainbow trout (*Oncorhynchus mykiss*) to the screen and visually documenting impingement on the screen and mortality that occurred from encountering the screen.

Watson Screen Description

The Watson screen was designed by Clay Watson with Watson Irrigation Inc. as a method to prevent debris and fish from entering irrigation diversions (typically piped diversions) in the area surrounding Townsend, MT. The rectangular screens are 3-ft wide by either 8- or 16-ft long, depending on the specifications of the required diversion. Eight-ft screens are used for diversion pipes up to 10-in in diameter and a maximum flow rate of 1100 gallons per minute (GPM). Sixteen-ft screens are used for diversion pipes up to 18-in in diameter and a maximum flow rate of 3500 GPM.

The screens are installed across the entire width of the channel below the headgate. Depending on the location of the diversion, the screens can be installed with an adjacent bypass channel to pass excess flow not needed for diversion. Bypass channels are typically 2-ft wide and extend the entire length of the screen but can vary in width depending on the required bypass discharge. The screen is oriented horizontally with the upstream edge raised 0.5-in per foot of screen length higher than the downstream edge, providing a slight slope (approximately 4 percent) to allow debris to easily pass over the screen. Basic dimensions of an 8-ft screen with no bypass are included in Figure 1 and Figure 2. When a bypass is added it is attached to one side of the flume and has a solid floor that is set at the same elevation as the downstream end of the screen (Figure 3).

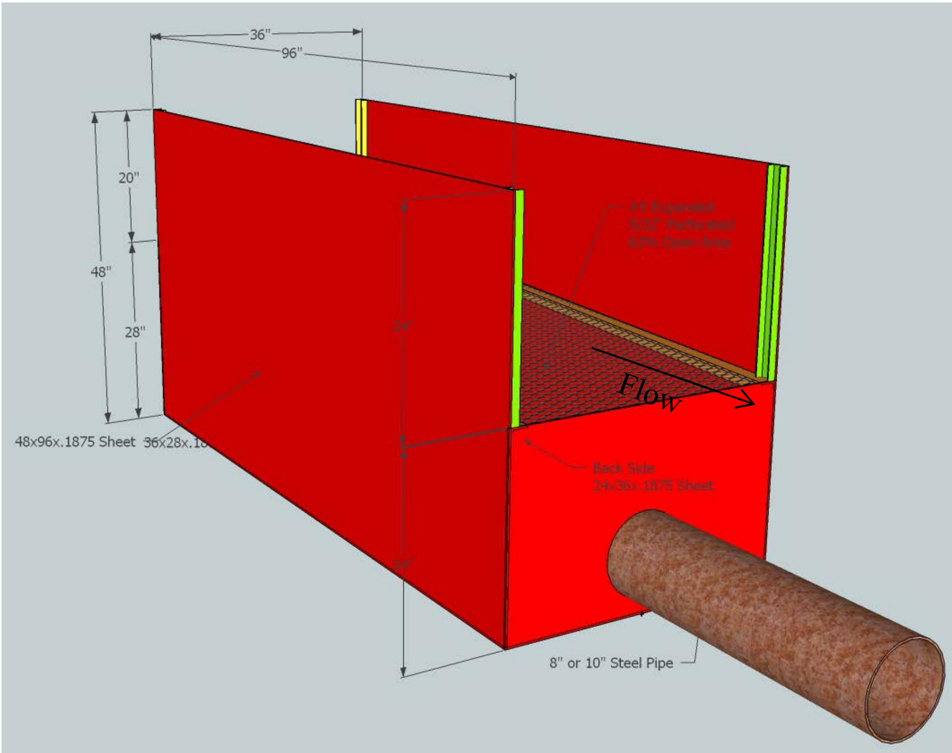

Figure 1 - 8-ft Watson screen. Flow is from top left to bottom right.

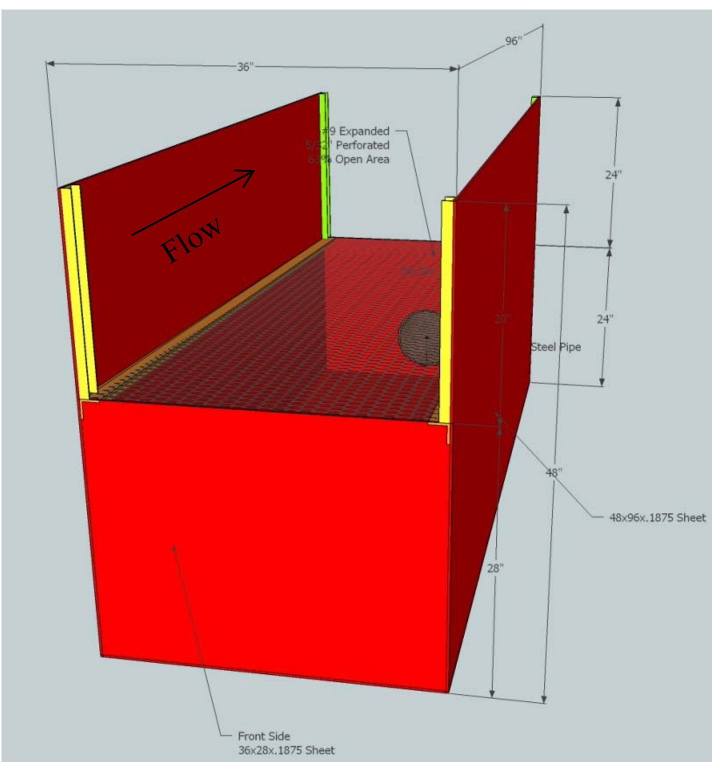

Figure 2 - 8-ft Watson screen. Flow is from bottom to top.

Figure 3 - 8-ft Watson screen with bypass. Flow is from right to left.

Literature Review

The Watson screen can be most closely described as a horizontal flat plate fish screen with a slight downward slope to the screen allowing fish and debris to pass more efficiently. Horizontal flat plate screens have been investigated by Reclamation for use in small streams near the bottom (invert) of the channel. The most comprehensive details for horizontal flat plate screens can be found in Reclamations 2006 technical publication titled Fish Protection at Water Diversions. The report summarizes some of the research activities relating to horizontal screens on pages III-38-40 and section IV.B.4.c. Advantages and disadvantages of horizontal flat plate screens include (Reclamation 2006):

Advantages:

- They can be effectively applied at shallow in-river diversion sites.
- They have a simple design with no moving parts.
- They offer a cost effective positive barrier screen concept that can comply with fishery resource agency criteria.

Disadvantages:

- Debris and sediment handling characteristics may be a problem.
- Diversion flow rates will vary as a function of water surface elevation and screen fouling.
- Applications are likely limited to relatively small diversions (less than 100 ft^3/sec).
- There may be high exposure of bottom-oriented fish to the screen surface.

To achieve effective screening using horizontal flat plate screens, Reclamation advises:

- Screens should have uniform parallel flow patterns across the screens.
- When more than 25% of flow is diverted the active screen width should be reduced over the length of the screen.
- Avoid hydraulic jumps on the screen.
- Sweeping velocities of 2 to 6 ft/sec improve fish guidance and debris cleaning.
- Using approach ramps with a 10 percent slope.

The Watson screen differs from the standard definition of a horizontal flat plate screen because the downstream end of the screen in lowered to create a mild slope which helps guide fish and debris over the screen.

The Watson screen also differs because flow through the screen is controlled by an outlet pipe instead of by the screen and overflow weir as described by Reclamation (2006). This causes a shift in how the water exits the screen depending on where the pipe is located in the outlet box of the Watson screen. This may increase the need for internal baffling of the Watson screen.

Test Facility & Model Setup

Testing was conducted in Reclamation's Hydraulics Laboratory located in Denver, CO USA. A 1:1.667 geometrically scaled (prototype dimensions divided by 1.667 equals model dimensions) Watson screen was tested at the end of a 3-ft-wide and 4-ft-deep rectangular channel (Figure 4). The channel was operated as an open channel with discharge ranging from 0-3.5 ft^3/sec (model scale). Flow was pumped into the channel using a 150 horsepower centrifugal pump. Flow rates into the channel were measured using a calibrated[1] venturi meter accurate to ±0.25 percent. Flow rates through the 4-in diversion pipe were measured using a Siemens 1010 ultrasonic flow meter accurate to 1 percent of upper range discharge. Depth measurements in the upstream channel and

[1]Calibrations are performed every 2 years using a weight versus time relationship derived from a permanent volumetric weight tank. Historical performances of all venturi meters have shown little if any deviation year to year. (Hydraulic Laboratory Techniques, Denver CO 1989 available online at: http://www.usbr.gov/pmts/hydraulics_lab/pubs/manuals/HydraulicLabTech.pdf)

across the screen were obtained using a thin handheld engineering scale accurate to 0.02 inch.

Since hydraulic performance for open channel flow depends primarily on gravitational and inertial forces, Froude law scaling was used to establish a relationship between the model and the prototype. Froude law similitude produces the following relationships between model and prototype (model:protype):

Length Ratio: $L_r = 1:1.667$

Velocity Ratio: $V_r = L_r^{1/2} = 1:1.291$

Discharge Ratio: $Q_r = L_r^{5/2} = 1:3.586$

When conducting a scaled model, all dimensions are scaled geometrically except for the screen material, which is left in prototype dimensions to correctly simulate the headloss produced by the prototype screen. All data presented in the report are given in prototype dimensions unless specified otherwise.

Figure 4 – 1:1.667 scaled Watson screen attached to the end of a laboratory testing channel.

Test Procedure

Hydraulic data was collected by establishing a known flow into the upstream channel. After a few minutes the channel and screen filled, reaching steady flow conditions in less than 5 minutes. Discharge through the screen was diverted into a 6.7-in diversion pipe (4-in model scale) and measured by the Siemens ultrasonic meter. Using mass balance the difference between the channel flow and the flow going through the diversion pipe was the bypass flow (or flow that was going across the screen and back into the main channel). Once flow rates were measured, depths were obtained 1.667-ft upstream from the screen and every 10 inches over the length of the screen. During the tests dye was injected upstream of the screen to determine if resultant velocities were through the screen or parallel to the screen. Actual velocity measurements were not able to be obtained due to shallow depths, high velocities, turbulence, and the interference between velocity measurement instrumentation and the screen. Once all data was collected flows were adjusted and the process was repeated.

Hydraulic Results

All results are provided in prototype dimensions. CFC and Watson Irrigation Inc. witnessed and modified the Watson screen during a 2 day site visit. During the site visit several modifications were made to the screen by CFC and Watson Irrigation to improve the screen's debris and fish passage performance. The following hydraulic results only provide data for the initial and final evaluations.

Initial Evaluation

In the initial configuration received from CFC and Watson Irrigation, the screen consisted of a 5/32-in perforated plate on a 3/16-in staggered pattern with 63 percent open area and no baffling. A bypass channel was present but was blocked to allow all water to pass across the screen. The initial Watson screen was evaluated at various channel flow rates from 450 to 6200 GPM. Table 1 displays the data collected including flow in the upstream cannel (Q_{in}), flow through the diversion pipe (Q_{pipe}), bypass flow (Q_{out}), percentage of screen that is not submerged with water (% Dry), and water depths above the screen at each location down the centerline of the screen.

Figure 5 provides the water surface profile down the centerline of the screen. Flow rates below 1200 GPM produced large areas of the screen with no submergence. The majority of flow passed through the screen in the first two feet, leaving the remainder of the screen dry. For these flows most of the water passing through the screen was transferred through the diversion pipe leaving little to no bypass flow remaining in the channel downstream of the screen. Any flow that was bypassed to the downstream channel was done so without water above the screen, meaning the water was at or below the screen level and was bypassed out the small gap at the downstream end of the screen.

Flows above 1200 GPM provided an uneven velocity distribution which was detected using dye as a visual indicator of whether flow was passing below the screen or coming up through the screen. Figure 6 gives a visual representation of the velocity distribution that existed with the initial tests.

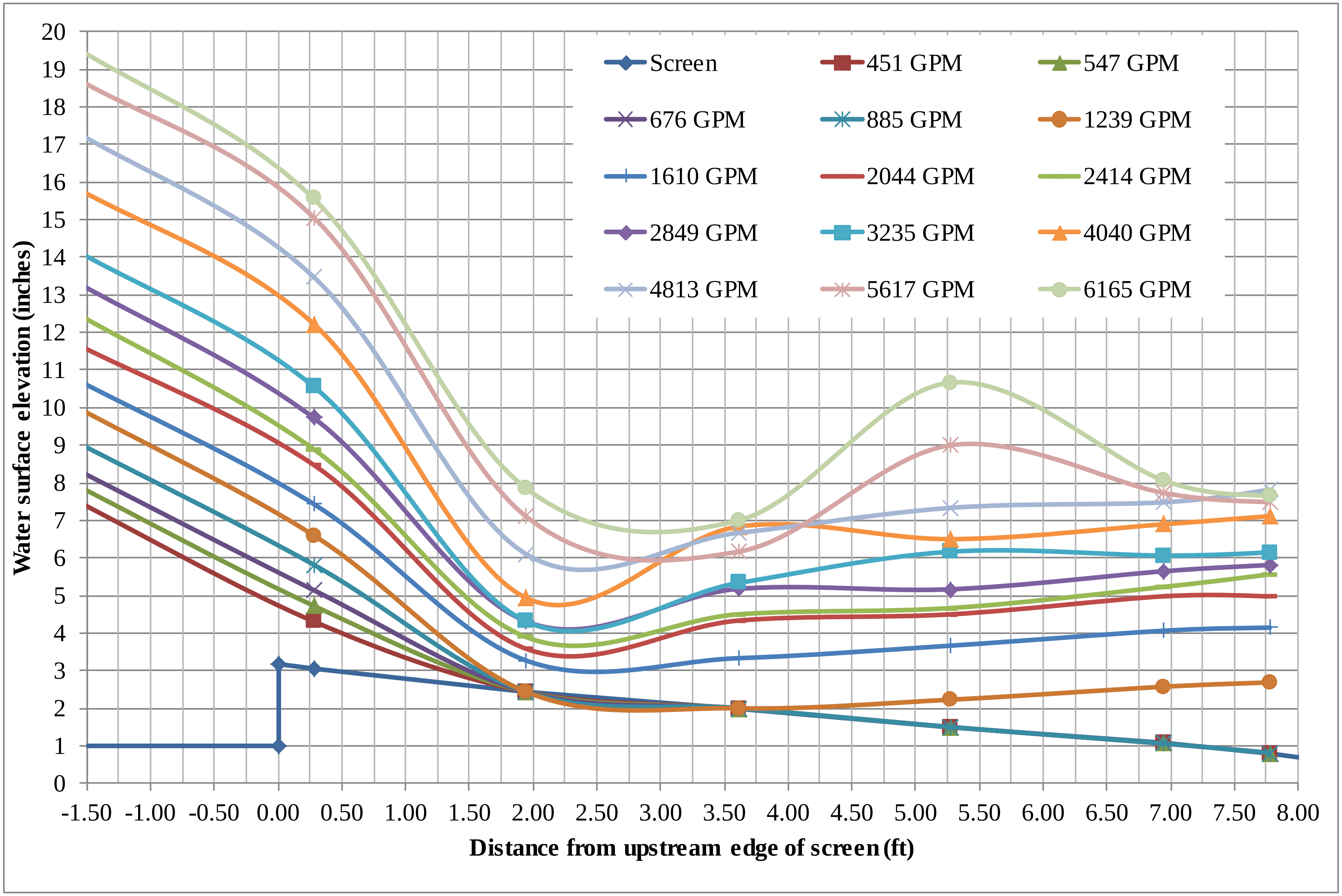

Figure 5 – Initial testing results showing centerline water surface profiles of the Watson screen.

Table 1 – Initial evaluation data including flow rates and water depths down the centerline of the Watson screen.

Q_{in} (GPM)	Q_{pipe} (GPM)	Q_{out} (GPM)	% Dry (%)	Centerline Water Depth Above Screen (in inches)						
				@ -1.67 ft	@ 0.28 ft	@ 1.95 ft	@ 3.61 ft	@ 5.28 ft	@ 6.94 ft	@ 7.78 ft
451	451	0	88.54	6.67	1.25	0.00	0.00	0.00	0.00	0.00
547	547	0	87.29	7.08	1.67	0.00	0.00	0.00	0.00	0.00
676	676	0	85.42	7.50	2.08	0.00	0.00	0.00	0.00	0.00
885	885	0	82.29	8.23	2.76	0.00	0.00	0.00	0.00	0.00
1239	901	338	30.21	9.17	3.54	0.00	0.00	0.73	1.51	1.88
1610	917	692	0.00	9.90	4.38	0.83	1.33	2.17	3.00	3.33
2044	925	1119	0.00	10.83	5.42	1.15	2.33	3.00	3.92	4.17
2414	934	1481	0.00	11.67	5.83	1.46	2.50	3.17	4.17	4.75
2849	938	1911	0.00	12.50	6.67	1.88	3.18	3.67	4.58	5.00
3235	945	2290	0.00	13.33	7.50	1.88	3.33	4.67	5.00	5.33
4040	956	3084	0.00	15.00	9.17	2.50	4.83	5.00	5.83	6.30
4813	963	3850	0.00	16.50	10.42	3.67	4.67	5.83	6.42	7.00
5617	966	4652	0.00	17.92	12.00	4.67	4.17	7.50	6.67	6.67
6165	967	5197	0.00	18.75	12.50	5.42	5.00	9.17	7.00	6.83

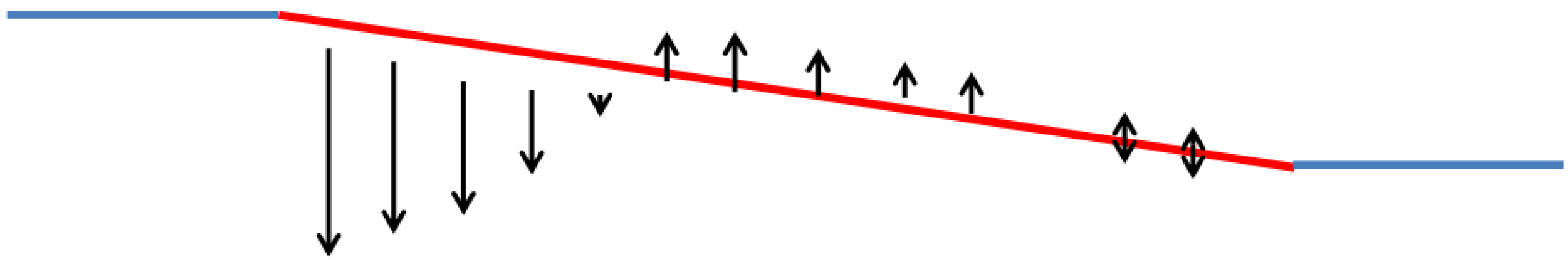

Figure 6 – Estimated velocity distribution through the screen for the initial evaluation. No physical measurements were obtained. Flow arrows are not proportionate and only represent direction and approximate magnitude. Red section is the screen, Flow is from left to right.

Final Evaluation

After CFC and Watson Irrigation modified the screen, there were 3 internal vertical baffles, a 1-ft velocity guidance plate (Figure 7) at the upstream end of the screen, and a 3/32-in perforated plate on a 5/32-in staggered pattern with 33 percent open area for the screen. Internal baffles were located at 2-, 4-, and 6-ft from the upstream end of the screen box and contained a centered single vertical slot with openings and open areas of 1.2-in (3%), 4.0-in (11%) and 4.8-in (13%) respectively (Figure 8). All Dimensions are prototype dimensions.

Figure 7 - 1-ft prototype length guidance velocity guidance plate at upstream end of screen (flow is from top to bottom)

Figure 8 - Internal vertical baffles below screen (flow is from left to right).

The final evaluation was conducted at various channel flow rates from 950 to 5150 GPM. Table 2 displays collected data, including flow in the upstream cannel (Q_{in}), flow through the diversion pipe (Q_{pipe}), bypass flow (Q_{out}), percentage of screen that is not submerged with water (% Dry), and water depths above the screen at each location down the centerline of the screen.

Figure 10 provides the water surface profile down the centerline of the screen after CFC and Watson Irrigation modified the screen. Figure 11 normalizes the screen to a zero elevation and provides depth of water above the screen. Flow rates below 950 GPM were not tested because flows were not large enough to keep the screen submerged with water. Adding the 1-ft velocity guidance plate, reducing the size of the screen open area and adding the vertical baffles all improved the debris and fish passage capability of the Watson screen. All flows tested visually showed a more uniform velocity passing though the screen. Figure 9 provides an estimate on what the velocity distribution might look like after modifications have been made. When comparing to Figure 6 the velocity distribution has improved significantly. No physical measurements of velocity were obtained and some non-uniformity at each baffle will exist.

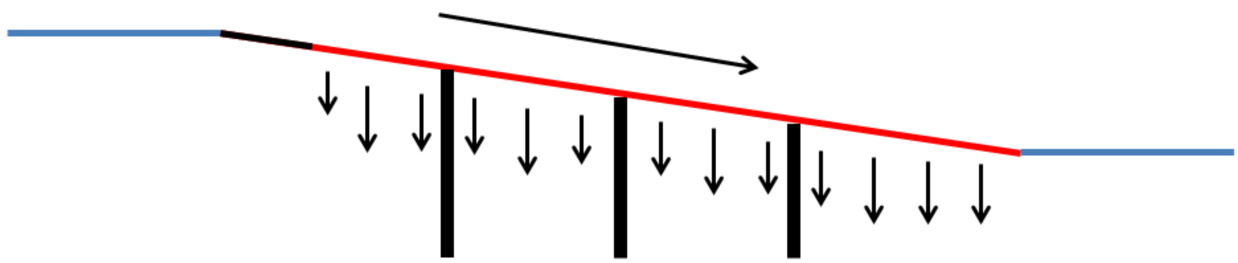

Figure 9 - Visual representation of estimated velocity distribution through the Watson screen. No actual measurements were obtained. Flow arrows are not proportionate and are only represent direction and approximate magnitude. Flow is from left to right.

Table 2 – Final evaluation data including flow rates and water depths down the centerline of the Watson screen.

Q_{in} (GPM)	Q_{pipe} (GPM)	Q_{out} (GPM)	% Dry (%)	Centerline Water Depth Above Screen (in inches) @ -1.67ft	@ 0.00 ft	@ 0.83 ft	@ 1.67 ft	@ 2.50 ft	@ 3.33 ft	@ 4.17 ft	@ 5.00 ft	@ 5.83 ft	@ 6.67 ft	@ 7.50 ft
966	885	80	0.00	8.17	3.33	2.42	1.50	0.83	0.67	0.67	0.50	0.50	0.33	0.33
1288	893	394	0.00	9.00	4.08	2.92	2.00	1.33	1.17	1.08	1.00	1.00	0.83	0.75
1610	893	716	0.00	9.83	4.75	3.50	2.33	1.67	1.50	1.50	1.50	1.50	1.17	1.17
1931	893	1038	0.00	10.67	5.50	4.17	2.83	2.25	2.00	2.00	1.83	1.83	1.50	1.50
2286	895	1391	0.00	11.33	6.17	4.67	3.33	2.67	2.42	2.25	2.17	2.17	2.00	2.00
2575	895	1680	0.00	12.00	6.83	5.25	3.83	2.92	2.75	2.58	2.50	2.50	2.33	2.33
2897	900	1997	0.00	12.75	7.58	5.67	4.17	3.25	2.92	2.75	2.67	2.67	2.67	2.67
3235	903	2332	0.00	13.33	8.00	6.25	4.58	3.67	3.33	3.17	3.08	3.08	3.08	3.08
3525	906	2619	0.00	14.00	8.50	6.83	5.00	4.08	3.67	3.67	3.50	3.50	3.50	3.50
3863	909	2954	0.00	14.50	9.17	7.17	5.50	4.33	4.00	3.92	3.83	3.83	3.83	3.83
4153	914	3238	0.00	15.00	9.67	7.75	5.67	4.67	4.33	4.17	4.00	4.00	4.00	4.00
4523	917	3605	0.00	15.67	10.83	8.50	6.00	5.00	4.67	4.67	4.50	4.50	4.67	4.67
4796	919	3877	0.00	16.25	11.33	9.00	6.33	5.17	4.83	4.67	4.67	4.67	4.67	4.67
5151	921	4230	0.00	17.00	11.67	10.00	7.33	5.67	5.17	5.00	4.83	5.00	5.33	5.33

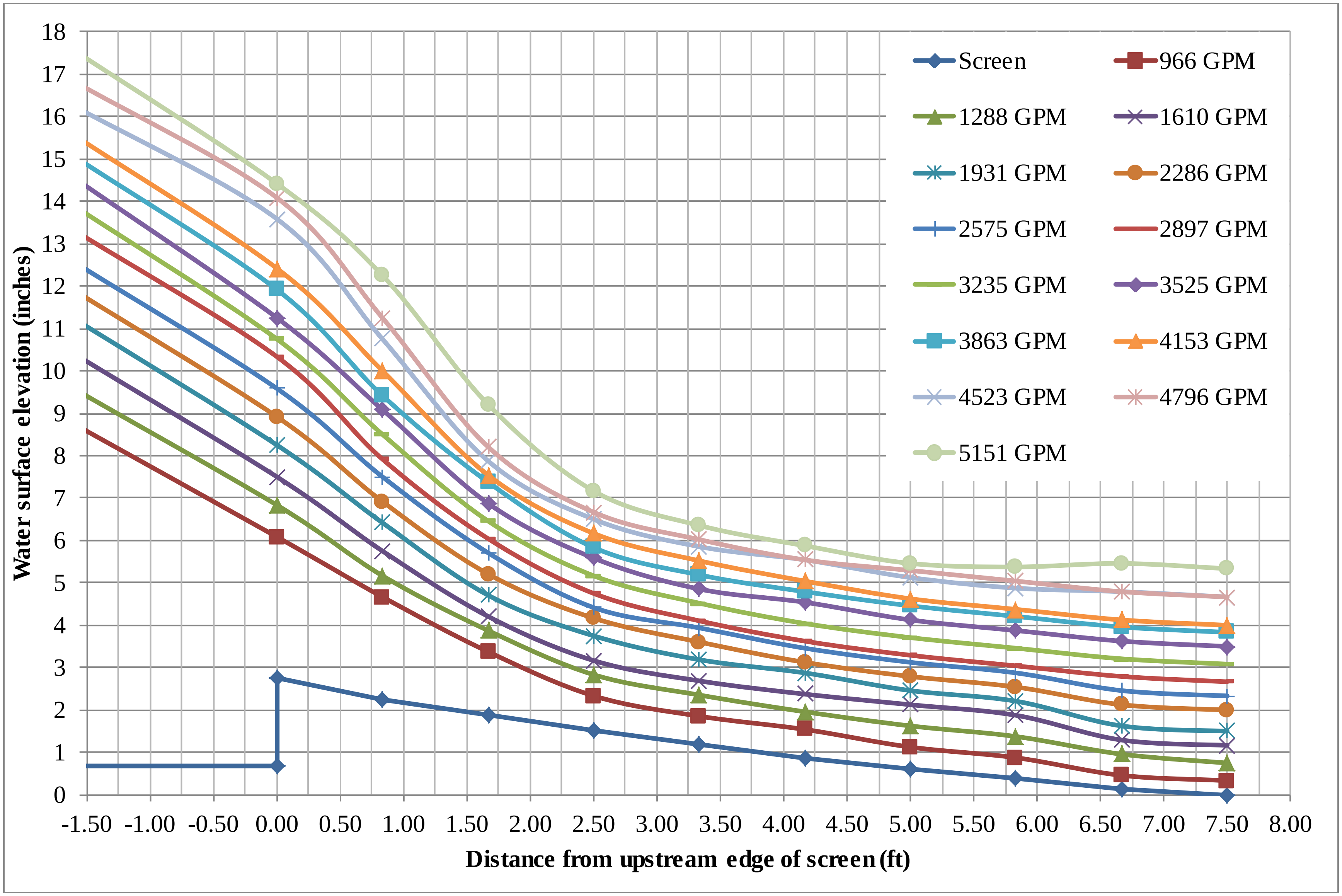

Figure 10 - Water surface profiles down the centerline of the Watson screen for multiple flow rates after baffling.

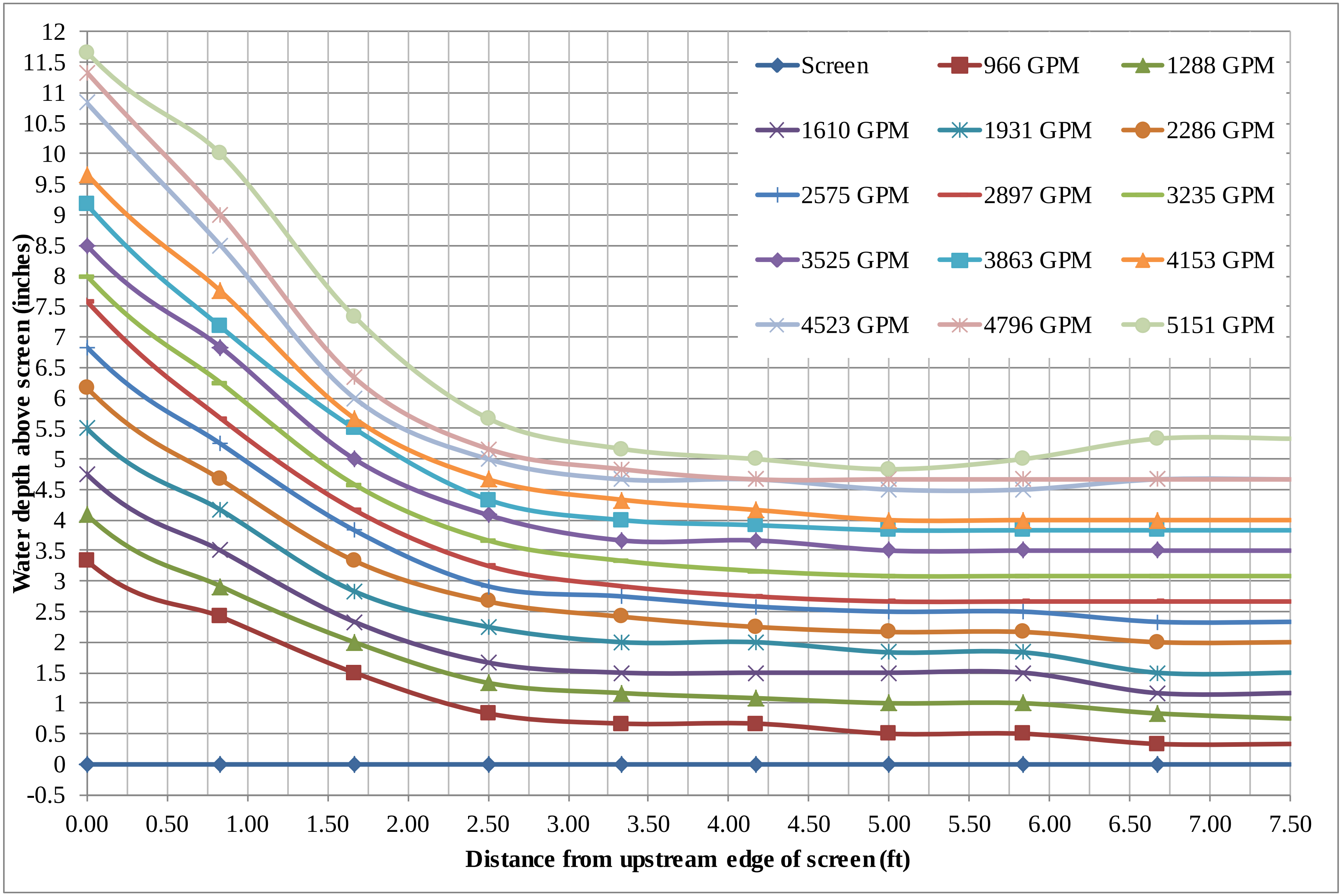

Figure 11 - Water depth above the Watson screen for several different flow rates (screen has been normalized to a zero elevation to provide water depth above screen

Biological Results

Biological testing was performed on the Watson screen using the final screen configuration. One-to three-in-long (model scale) rainbow trout were introduced into the model upstream of the fish screen. Fish introduced upstream would not voluntarily pass across the screen; as such fish were crowded onto the screen. Video was collected and analyzed to determine fish response to the screen. Observations of screen impingement were recorded and fish were monitored for 1 week after the tests with no mortality occurring. No statistical or physical damage estimates were obtained during the biological tests due to the limited scope and budget.

Around 200 fish were introduced to the screen at several different flow rates and configurations. Tests were performed with and without the 1-ft-long velocity guidance plate. Figure 12 through Figure 17 provide screen shots from video showing fish being pulled down against the screen for both 1850 GPM and 4000 GPM at the upstream transition when no plate is present.

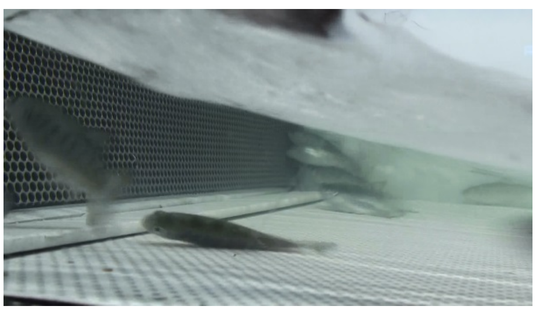

Figure 12 - Fish being pulled against screen (1850 GPM, no guidance plate)

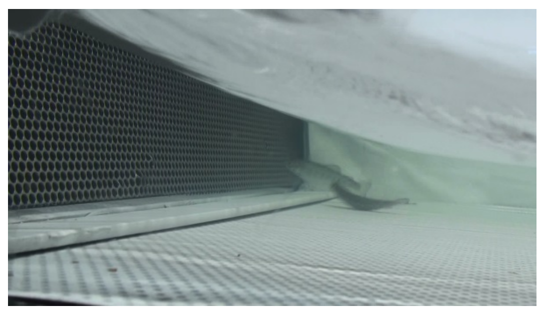

Figure 13 - Fish being pulled against screen (1850 GPM, no guidance plate)

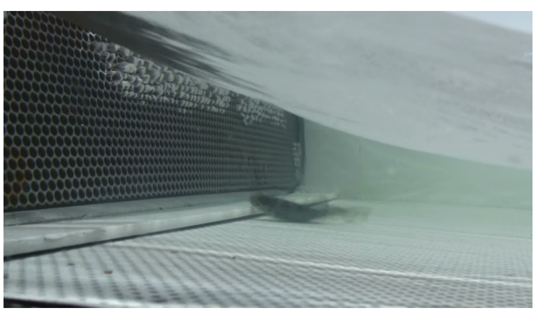

Figure 14 - Fish being pulled against screen (1850 GPM, no guidance plate)

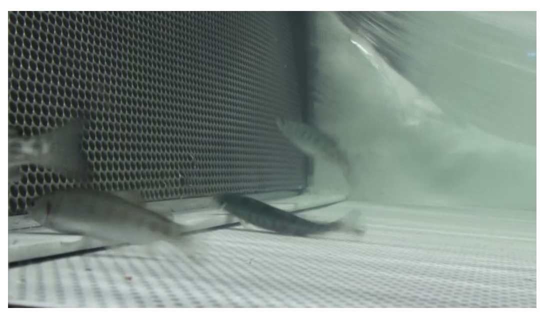

Figure 15 - Fish being pulled against screen (4000 GPM, no guidance plate)

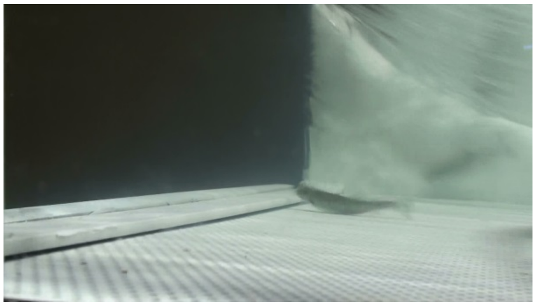

Figure 16 - Fish being pulled against screen (4000 GPM, no guidance plate)

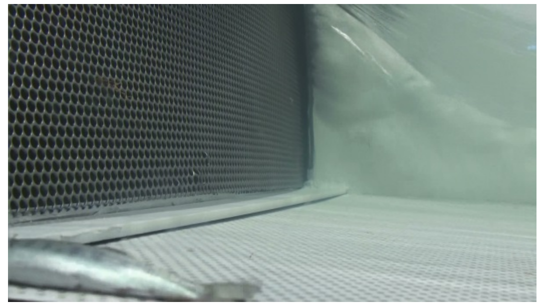

Figure 17 - Fish being pulled against screen (4000 GPM, no guidance plate)

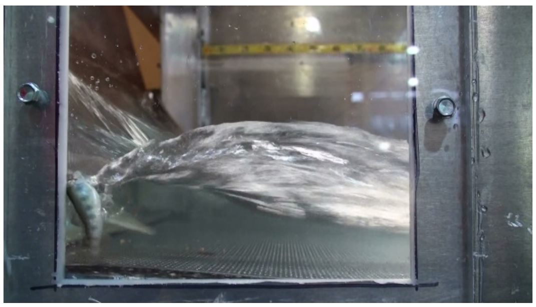

Figure 18 - Fish caught in a recirculation zone just downstream of the stop block slots (1850 GPM, no guidance plate)

Figure 19 through Figure 23 are screen shots taken of the same flow rates but with the velocity guidance plate installed. Screen shots are of both the transition onto the velocity plate and from the velocity plate onto the fish screen. Video footage clearly depicts that when the velocity guidance plate is installed the fish are not impinged against the screen at the transitions.

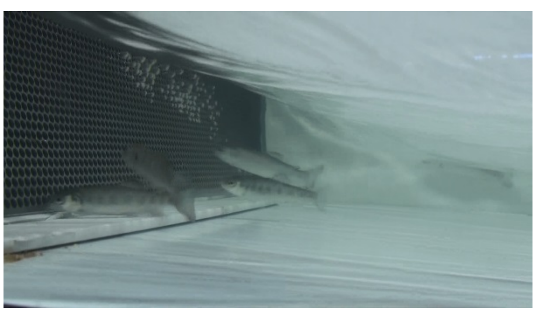

Figure 19- Fish swimming at the transition onto the guidance plate (1850 GPM, guidance plate)

Figure 20 - Fish swimming at the transition from the guidance plate to the screen (1850 GPM, guidance plate)

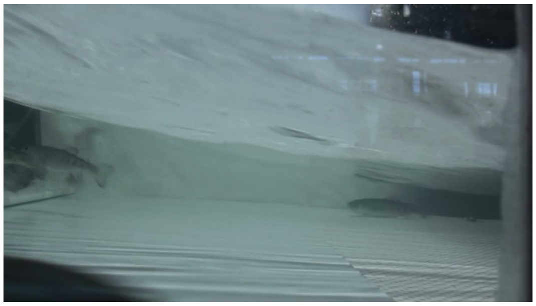

Figure 21 - Fish swimming at the transition from the guidance plate to the screen (1850 GPM, guidance plate)

Figure 22 - Fish swimming at the transition from the guidance plate to the screen (4000 GPM, guidance plate)

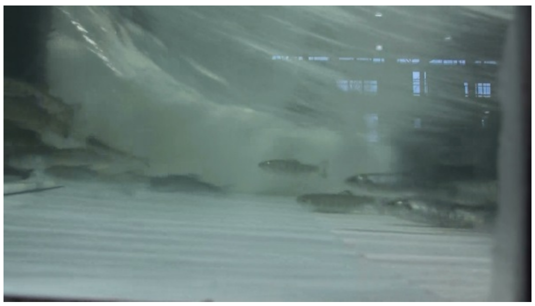

Figure 23 - Fish swimming at the transition from the guidance plate to the screen (4000 GPM, guidance plate)

Other observations that were made from biological testing included:

- Stop block at the upstream end of the screen creates a recirculation zone that many fish were caught in (Figure 18). These were removed.
- Even when very little water was present across the screen, the fish were able to swim and overcome the velocity for short periods of time.
- Stop block slots at the downstream end of the screen protrude into the flow path and create a potential impact zone which can damage fish.
- Fish encountering the screen tend to move to the sides of the screen channel. If sharp edges are present where the screen meets the walls of the channel, fish could become damaged.
- At flows below 1850 GPM water depths may become inadequate for tested fish to swim entirely within the water column.
- When depths are less than a fish body height, the fish will impact with the screen.
- When debris is present at shallow depths portions of the screen may be dry due to clumping of debris.
- Most fish introduced to the screen at all water depths were able to swim temporarily in the upstream direction. Very little observance of fish tumbling down the screen was noticed regardless of flow depth.

When the screen was dry (diversion flow = channel flow with no bypass out the end of the screen) fish were able to “flop” towards the downstream end of the screen. Most were not able to reach the downstream channel. A larger slope would aid fish in flopping towards the downstream channel.

Conclusions

Reclamation’s Hydraulics Laboratory was asked to preform hydraulic and biological testing on a debris and fish screen constructed by Watson Irrigation Inc. The tests were funded by the CFC with the intent to improve screen performance for debris and fish passage. Initial hydraulic evaluations were performed on the screen in the condition it was received. After initial testing, CFC and Watson Irrigation made screen modifications to provide better passage for debris and fish. Modifications included installing internal vertical baffles, changing the screen hole size and open area, and installing a velocity guidance plate. The modifications improved the passage of debris and fish through the screen by creating a more uniform through-velocity and providing submergence across the entire screen. Biological tests showed that the new configuration can pass fish without impingement occurring. Two hundred fish were passed over the screen and no mortality occurred after 1 week. Physical damage to fish is possible from downstream stop block slots and sharp screen edges on the sides of the channel. Additionally if the fish screen is un-baffled the screen can be dry over the majority of its length and can cause significant mortality to fish.

Reference

U.S. Bureau of Reclamation, (2006). Fish Protection and Water Diversions, A Guide for Planning and Designing Fish Exclusion Facilities. U.S. Department of the Interior, Denver CO 80225. Online at: http://www.usbr.gov/pmts/hydraulics_lab/pubs/manuals/fishprotection/Fish%20Protection%20at%20Water%20Diversions.pdf

Appendix A

Comments and Responses to Client Review

Appendix A contains response to a memorandum from Will McDowell (Cark Fork Coaltion), Casey Hackathorn (Trout Unlimited) and Clay Watson (Watson Irrigation Inc) regarding a draft copy of the report. To best address their comments and concerns Reclamation elected to include their memorandum and the appropriate responses in this Appendix. Responses to each request are presented in italic type.

MEMORANDUM

18 February, 2014

TO: Bryan Heiner, BOR

FROM: Will McDowell, Clark Fork Coalition; Casey Hackathorn, Trout Unlimited

RE: COMMENTS on "Clark Fork Coalition and Watson Irrigation Fish Screen Tests," by Bureau of Reclamation Hydraulic Laboratory, Denver, CO, January, 2014.

1. The draft report covers the results of the work done in a concise and useful format with graphics which are particularly apt.

2. The modifications made to the screen during the evaluation period at the lab improved its performance for both passing fish unharmed and moving debris efficiently over the screen. Improvements were observed in flow distribution through the screen as well as depth and hydraulic conditions over the screen.

3. We would like to see a small section added to the report which references what the BOR considers the most relevant recent reports on horizontal fish screens, and makes specific interpretative comments on the structure and performance of the modified Watson screen relative to those criteria. For example, it would be very useful to have the BOR's interpretation of how the modified Watson screen's hydraulic characteristics relate to the general recommendations for flat-plate screens in the 2004 BOR report by Frizzell and Mefford (page 9). Also, we would like to see a comment on the existing bypass channel configuration and need for re-design to improve fish passage out of the structure.

See "Literature Review" section. The main document discussed in the review uses information developed from the 2004 report mentioned above.

4. We would like to know if there is any way to mathematically extrapolate from the laboratory hydraulic results. First, can the range of flows or flow conditions be extrapolated in any way from the testing done so far? Second, is there any way to mathematically "scale up" any of the results to a 16 ft. screen length? If so, we would very much like to see that included in the report.

Mathematically extrapolating the data to a 16 ft screen would not be recommended as baffling requirements and screen hydraulics will change significantly. During the tests the through screen discharge control was the diversion pipe. More flow could pass through the screen given a large pipe. Consequently as more flow is passed through the diversion it will become increasingly difficult to maintain depth across the entire length of the screen. Each case is unique as different sizes of diversion pipe and systems demands can change the screen hydraulics. Maintaining adequate depths across a 16-ft screen will likely be a difficult task.

5. At a more specific level, there are very interesting video shots of fish in the modified screen at 1850 GPM inflow (which translates to 53% flow as Qout, or passing over the screen). Are there any video of fish at any of the lower flow levels, e.g. 1000-1300 GPM, where the Qout is much smaller, say <30%). I ask because I believe that in many real irrigation situations, the Qout will be in the lower end of the range tested. It would be extremely handy to have a representative screen shot and short description of observed effects on fish for each flow rate tested.

Video footage was obtained at 1850 GPM and 4000 GPM as two representative flow rates. Limited biological evaluations were funding under the original agreement. Video documentation was determined as the best method to portray fish response during testing. Reclamation chose 1850 GPM as it provided adequate depth to video the fish at the entrance of the screen with and without the guidance plate. 1850 GPM also provided what Reclamation felt was adequate depth across the length of the screen to provide fish with swimming room within the water column. Depths below 1850 GPM became too shallow for good video footage. A copy of all video files are available upon request.

6. Given the lack of empirical data on three-dimensional velocity, can the report say anything more specific about approach velocity and sweeping velocity of the modified Watson screen, based on BOR experience, visual observation of the model, and the test parameters? For example, can we use the NMFS definition of approach velocity calculated as "maximum screened flow amount by vertical projection of effective screened area"? Can we estimate a sweeping velocity and the downstream edge of screen thru Q=VA by taking the depth, width and flow rate? In short, please include a discussion of calculated approach and sweeping velocities based on the lab tests.

*Sweeping velocity can be <u>estimated</u> at the downstream end using Q=V*A where Q is defined as the flow leaving the end of the screen (Qout) and A is defined as the depth at the downstream end (ft) X width of the screen (ft) for sweeping velocity at the downstream end of the screen.*

*Q=V*A can be used at the upstream end of the screen where Q is the channel flow(Qin) and A is the depth at 0.00 ft (ft) X width of the screen (ft).*

*Average approach velocity can also be estimated using Q=V*A where Q is defined as the diversion flow rate (Qpipe) and A is defined as the gross area of the screen. .*

The estimate of sweeping velocity using this approach is high as the depth of water decreases down the screen.

The estimate of approach velocity using this approach will present an average approach velocity and will not account for any high or low velocity zones which may occur. It is assumed that some decrease in approach velocity will happen near each baffle and at the upstream and downstream ends of the screen.

Values using the above assumptions are contained in the below table.

Qin GPM	Qpipe GPM	Qout GPM	Average Approach Velocity (Qpipe/ScreenArea) ft/sec	Sweeping Velocity at 0.00 ft (Upstream End) ft/sec	Sweeping Velocity at 7.5 ft (Downstream end) ft/sec
966	885	80	0.094	2.582	2.15
1,288	893	394	0.095	2.810	4.69
1,610	893	716	0.095	3.020	5.47
1,931	893	1,038	0.095	3.130	6.17
2,286	895	1,391	0.095	3.303	6.20
2,575	895	1,680	0.095	3.359	6.42
2,897	900	1,997	0.095	3.405	6.68
3,235	903	2,332	0.096	3.604	6.74
3,525	906	2,619	0.096	3.696	6.67
3,863	909	2,954	0.096	3.756	6.87
4,153	914	3,238	0.097	3.828	7.22
4,523	917	3,605	0.097	3.721	6.89
4,796	919	3,877	0.098	3.772	7.40
5,151	921	4,230	0.098	3.934	7.07

7. Can the report say anything more about the hydraulic conditions on the screen face based on observations and the depth measurements?

See item 6 above and the clarity added to Figures 6 & 9 in the text. To avoid any misrepresentation of physical data no other information is provided.

8. Please expand the biological results section to include an assessment of screen impacts to test fish over the entire range of tested flow conditions. What is the opinion of BOR engineers about the swimming ability/impingement risk of the 1"-3" test fish at the lower depths during the low-range flow end of the tests of the modified screen? (see comment #5).

See "Biological Results" section. More bullet points were added to the other observations that were made form biological testing list.

9. Please provide a short conversion table (gpm test to gpm scaled up to cfs scaled up) in the report to help avoid confusion.

To avoid confusion all data provided in the report are in Prototype dimensions. No scaled values are presented in the report except for use in describing the physical model setup. The report indicates that results are presented in prototype units. Adding a conversion table will likely add confusion. As such no conversion table is provided. If individuals want to know the scaled values, they can calculate them based on the information provided on page 7, however, these values will be of little use to most individuals as the screens are never build smaller than 8-ft long and 3-ft wide.

10. The copy of the report attached has some minor edits in "Track Changes."

The minor changes were addressed.

CC: Casey Hackathorn, TU; Clay Watson, Watson Irrigation