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Managing Water in the West

Hydraulic Laboratory Report HL-2013-04

North Battle Creek Feeder Fish Screen and Fishway Hydraulic Model Study

U.S. Department of the Interior
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Hydraulic Investigations and Laboratory Services Group
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14. ABSTRACT
A 1:4 Scale model of The North Battle Creek Feeder fish screen and fishway was built at Reclamation's Hydraulic Laboratory in Denver, Colorado to investigate solutions to allow the fish screen and fishway to operate within fish passage standards.

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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

NBCF North Battle Creek Feeder
WSE Water surface elevation
RWSE Reservoir water surface elevation
DWR California Department of Water Resources
PG&E Pacific Gas and Electric Company
BOR U.S. Bureau of Reclamation
NOAA National Oceanic and Atmospheric Administration Fisheries
MOU Memorandum of Understanding

Executive Summary

The North Battle Creek Feeder (NBCF) diversion is located in Shasta County on the North Fork of Battle Creek near Manton, California. The facility is owned and operated by Pacific Gas and Electric Company (PG&E). The fish screen, ladder and diversion have not been performing as designed. Field studies indicate velocities through the fish screen are not uniform, full diversions are not being met, and the water surface drop between pools in the fish ladder may be too large to facilitate fish passage (California DWR 2012). Design performance targets for the facility are given in Table 1.

Table 1 – North Battle Creek Feeder Canal fish screen and ladder design performance targets.

Minimum instream flow (combined fishway flow and screen bypass flow)	May-November - 47 ft^3/s December to March – 88 ft^3/s April – 67 ft^3/s
Design Diversion Flow	55 ft^3/s
Fish Screen Bypass Flow	7.5 ft^3/s
Fish Screen Design Approach Velocity	0.33 ft/s
Fish Screen Design Water Surface	2081.3
Fishway Water Surface Drop between Baffles	1 ft

A 1:4 geometric scale physical hydraulic model of NBCF Dam was constructed in Reclamation's hydraulics laboratory in Denver, Colorado in 2012. Major design features include the non-overflow portion of the dam, fish screen, diversion, return pipe, fish ladder, approximately 100 ft of the forebay, and a pool downstream of the ladder. The purpose of this study was to investigate why the NBCF facility is not performing as designed and recommend improvements, modifications, or operating procedures that will allow the facility to perform within acceptable criteria while meeting the full diversion for PG&E.

The model study identified a number of modifications that would improve facility performance for the fish screen and fishway. The major performance issues and corrective actions recommended from the model study are:

- Issue - Design diversion flow target cannot be met.
  Recommended action - Increase the fish screen design water surface to 2082.3. This requires adding a minimum of 1 ft of blanking panel above the top of screen, raising the fish ladder exit elevation 1 ft by adding an

additional ladder pool upstream of the as-built exit, reducing the fishway orifice size to 12”x15” and reducing the headloss through the diversion structure and/or raising the spillway crest elevation.

- Issue – Poor uniformity of flow passing through the screens.
  Recommended action - Add three guide vanes behind the screen and modify the diversion channel shape by reducing the lateral expansion of the diversion channel in front of the screens.

- Issue – Tailwater to fishway entrance pool water surface differences exceed 1 ft for all conditions.
  Recommended action – Lower the fishway entrance elevation 2 ft by adding two additional bays downstream of the as-built fish ladder entrance. Note, this modification was not found to fully meet the 1 ft maximum differential objective under high river flows. Options for increasing tailwater elevation were not studied due to insufficient prototype tailwater elevation and downstream bathymetry data.

- Issue – Fishway exit pool to diversion pool water surface difference can exceed the 1 ft differential target.
  Recommended action – Operate the fishway with both orifices in the exit baffle open and all downstream baffles with one orifice open. Note, characteristics of pool and chute fishways like the NBFC structure typically exhibit the formation of random standing waves in the fishway pools and water surface tuning issues at the exit.

- Issue – Fishway can’t be easily unwatered.
  Recommended action - Alternatives for closing and unwatering the fishway were not addressed in the model study. However, the model study pointed out the operational importance of providing improved access to the fishway for opening and closing orifice gates and debris removal.

Introduction

Project Background

The North Battle Creek Feeder (NBCF) diversion is located in Shasta County on the North Fork of Battle Creek near Manton, California. The facility is owned and operated by Pacific Gas and Electric Company (PG&E). The fish screen, ladder and diversion have not been performing as designed. Field studies indicate velocities through the fish screen are not uniform, full diversions are not being met, and the water surface drop between pools in the fish ladder may be too large to facilitate fish passage (California DWR 2012).

Figure 1. Location map showing the NBCF diversion.

Model Objectives

- Verify that the model correctly represents the current structure.
- Analyze and evaluate the fish screen and bypass performance over a range of flows.
- Identify and test modifications to the screen structure to achieve design flow conditions (0.4 ft/s max approach velocity) through the fish screen and bypass.
- Test the modified screen structure with modifications or operating conditions developed for the fish ladder.
- Analyze and evaluate the fish ladder performance over a range of flows. Identify operations that do not meet the design flow conditions (1 foot max drop between pools).
- Develop stage vs. discharge curves for the fish ladder for conditions of orifices open and closed.
- Develop a stage vs. discharge curve for the whole facility (diversion and fishway). Fishway flow may require additional restriction or control of flow to meet diversion objectives.
- If results of the screen model find additional control or a reduction of flow through the fishway is needed, modifications to the fish ladder baffles or a headgate structure will be evaluated.
- From the study results, recommendations for operating the fishway under different river flows will be provided.

Model Description

Model Scale

A physical hydraulic model of NBCF Dam including the non-overflow portion of the dam, fish screen, diversion, return pipe, fish ladder, approximately 100 ft of the forebay, and a pool downstream of the ladder was constructed in Reclamation's hydraulics laboratory in Denver, Colorado in 2012 (Figure 2 and Figure 3). In order to include all desired model features in the floor space available, the physical hydraulic model was built at a 1:4 (model:prototype) geometric scale. The dam's spillway was not included in the model.

Similitude between the model and the prototype is achieved when the ratios of the major forces controlling the physical processes are kept equal in the model and prototype. Since gravitational and inertial forces dominate open channel flow, Froude-scale similitude was used to establish relationships between the model and the prototype parameters. The Froude number is

$$Fr = \frac{v}{\sqrt{gd}}$$

where v = velocity, g = gravitational acceleration, and d = flow depth. When Froude-scale modeling is used, the following relationships exist between the model and prototype for the 1:4 geometric scale chosen:

Length ratio: $L_{p/m} = 4$

Velocity ratio: $V_{p/m} = (4)^{1/2} = 2$

Time ratio: $T_{p/m} = (4)^{1/2} = 2$

Discharge ratio: $Q_{p/m} = (4)^{5/2} = 32$

The 1:4 scale model will provide a very good representation of prototype headloss and turbulence. Air entrainment (white water) will be slightly different between model and prototype due to surface tension effects.

Figure 2. NBCF physical model.

Figure 3. NBCF physical model showing the original fish ladder and fish screen

Model Setup

Flow was provided to the model from a permanent laboratory pump and water measurement facility using venturi meters. At the head of the model, flow entered a model headbox where it passed through a gravel baffle diffuser and into the modeled upstream river channel.

The upstream channel geometry and all flow components of the facility except the trashrack and the fish screen fabric were modeled geometrically to scale. The trashrack was not included in the model. Flow headloss associated with the trashrack is not represented in diversion channel water surface elevations reported in the study. In the model the diversion gate was on the upstream side of the dam instead of the downstream as in the prototype. This was done for ease of construction and has negligible impact to the performance of the model. A wedgewire fish screen fabric with similar percent open area and slot opening to the prototype was used in the model. Using screen fabric of similar open area and fabric construction is important to achieving similarity of energy loss through the model screen. The prototype size slot openings were used in the model to minimize the effects of free air entrapment in the screen and surface tension.

Fish Screen and Diversion Channel **–** Screen approach and sweeping velocities were measured in front of the screen using a Nortek three-dimensional acoustic doppler velocity meter. The Nortek meter was mounted to a linear rail running parallel to the face of the screen to maintain a constant distance off the screen. Due to the size of the probe head, point velocities were measured approximately one inch (model) off the screen or 4 inches (prototype). Louver-style baffles were placed behind the screen similar to the prototype. Unlike the prototype, each section of louvers between screen piers was ganged together with a single operator. This allowed for quick adjustment of louvers, but did result in all louvers within a screen bay being set at a similar opening. A total of 14 louver panels were used in the model. The model louver panels were extended above the screen allowing easy access for making adjustments (Figure 4). The water surface elevation downstream of the screens was set using model tailboards in the downstream diversion circular flume. Tailboards were set for each diversion flow based on calculating prototype normal depth in the downstream circular flume. Diverted flow was measured using a calibrated ramp flume.

In the prototype the screen panels are 3-foot-wide and are numbered 1 through 27 with 1 being the most downstream, and 27 the farthest upstream. During the initial performance tests approach and sweeping velocities were measured at the center of each panel (both horizontally and on the 60 plane of the panel). In the model panel locations 1 through 27 were also utilized for velocity measurements.

Water surface elevation both upstream and downstream of the screen was measured using a series of floor mounted pressure taps. The taps were connected to piezometer tubes and manually read. Fish screen bypass flow was controlled using stoplog weirs similar to the prototype. Bypass flow was measured using a weir box equipped with a 45 degree V-notch measuring weir located downstream of the fish release pipe.

The total flow entering into the model was measured with the permanent laboratory control system. Flow through the screened diversion and screen fish bypass were also measured independently. The fishway flow could then be calculated by subtracting the diversion flow and bypass flow from the total river flow. The model did not account for the spillway flow that will occur on the right side of the dam and sluiceway wall at elevation of 2082.4 ft.

Figure 4. Fish screen looking downstream. Notice the louver panels, Nortek velocity meter and meter guide rail.

Fishway – The model fishway was modeled geometrically similar to the prototype including all aspects of the baffles and orifices. An area of the downstream channel surrounding the fishway entrance was modeled in a tailbox. An area approximately 60 ft long by 50 ft wide (prototype) was included in the model. Tailwater elevation in the downstream river was controlled using vertical pickets across the full width of the tailbox (Figure 5). Tailwater was set in the model based on available prototype field data (Figure 6). Few prototype water surface data were available for predicting tailwater elevation, therefore tailwater data presented herein should be considered approximate.

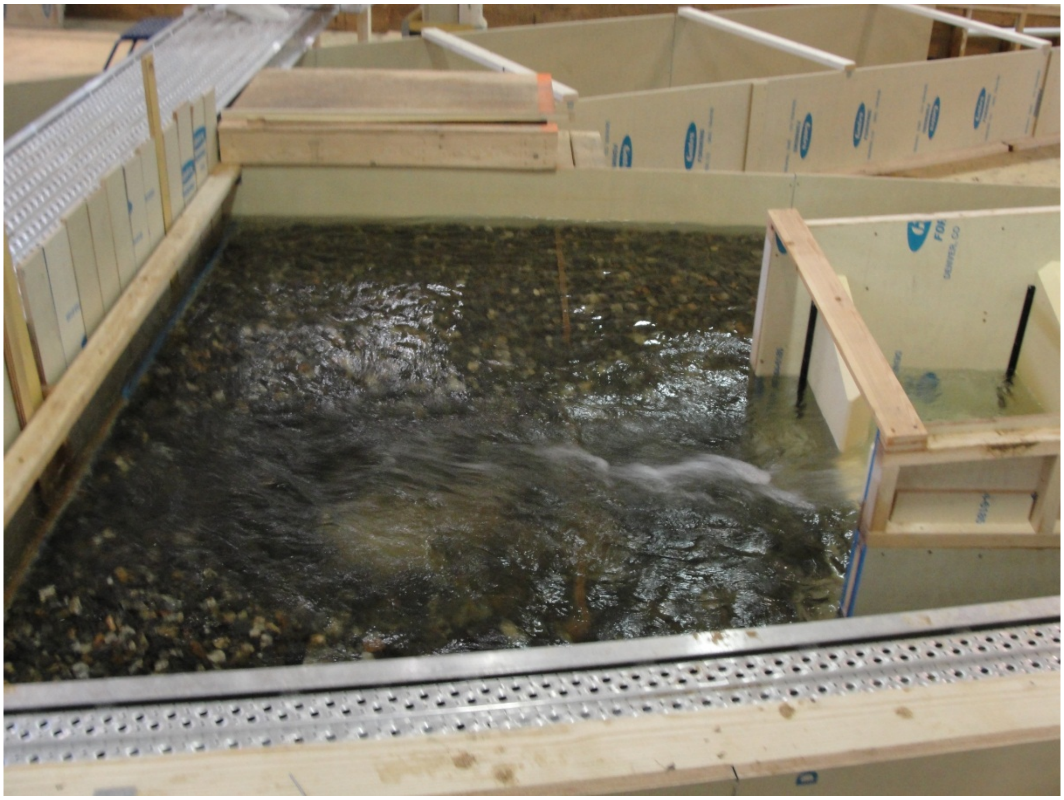


Figure 5. Tailbox and pickets (left) used to artificially raise the model tailwater to represent prototype conditions.

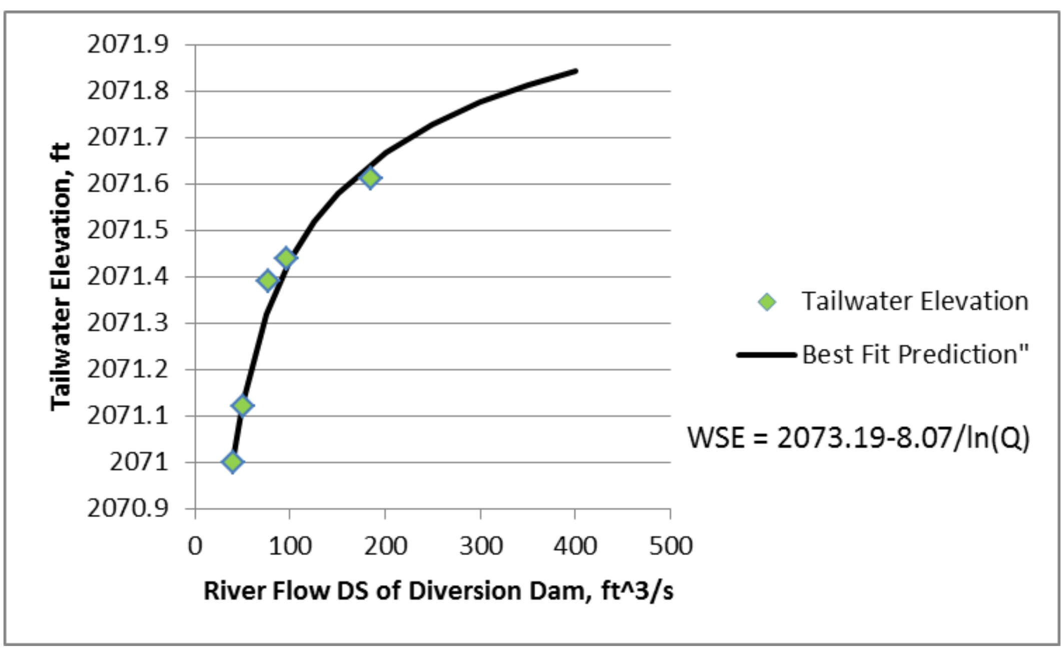


Figure 6. Available tailwater data and "best fit prediction" used in the model.

Model Verification

In the summer of 2011 approach and sweeping velocity data along the fish screen were collected to adjust louvers behind the screen and verify screen performance. In August of 2012 water surface elevations in the fish ladder and velocity data approaching the dam were collected at the NBCF facility (Figure 7). This data was used to verify that the model was correctly representing the prototype, including the performance deficiencies with the screen and ladder.

Figure 7. August 2012 field visit. DWR shown collecting velocity profiles upstream of the dam.

Velocity data along two transects upstream of the dam were collected with a total river flow of about 43 ft^3/s. The same flow condition in the model was simulated and velocity data was collected and compared to the prototype approach velocity. Figure 8 and Figure 9 compare prototype and model velocity magnitudes at different locations along each field transect. Transect A was taken perpendicular to the river flow approximately 60 ft upstream of the dam. Transect B was taken perpendicular to the river flow approximately 110 ft upstream of the dam.

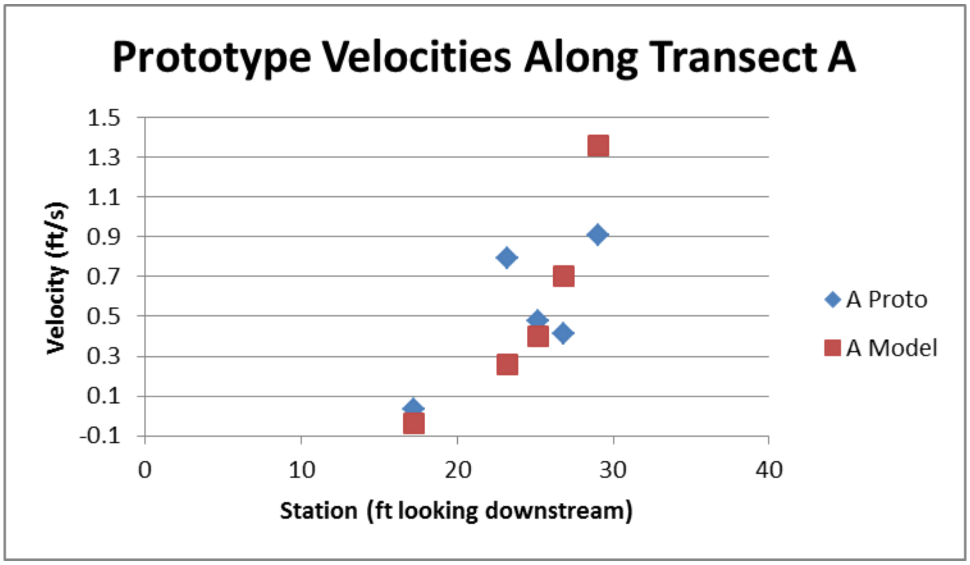


Figure 8. Comparison of prototype and model approach velocities along transect A measured 60 ft upstream of NBCF dam.

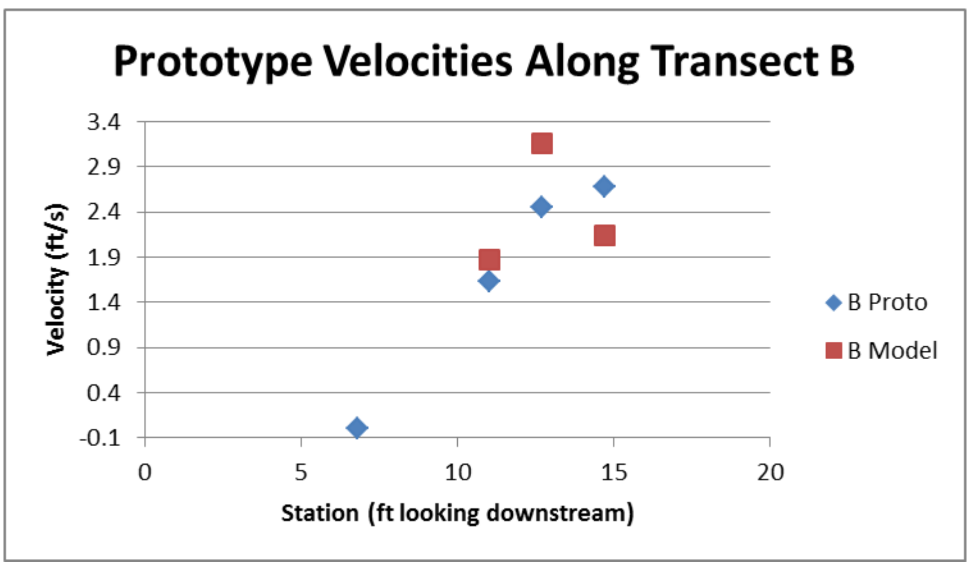


Figure 9. Comparison of prototype and model approach velocities along transect B measured 110 ft upstream of NBCF dam.

During the August 2012 field visit the survey crew measured water surface elevations in each pool in the fish ladder, including the tailwater and forebay. Water surface elevations in the model were also measured for the same flow condition. Figure 10 shows the similarity of model and prototype water surface elevation in the fish ladder.

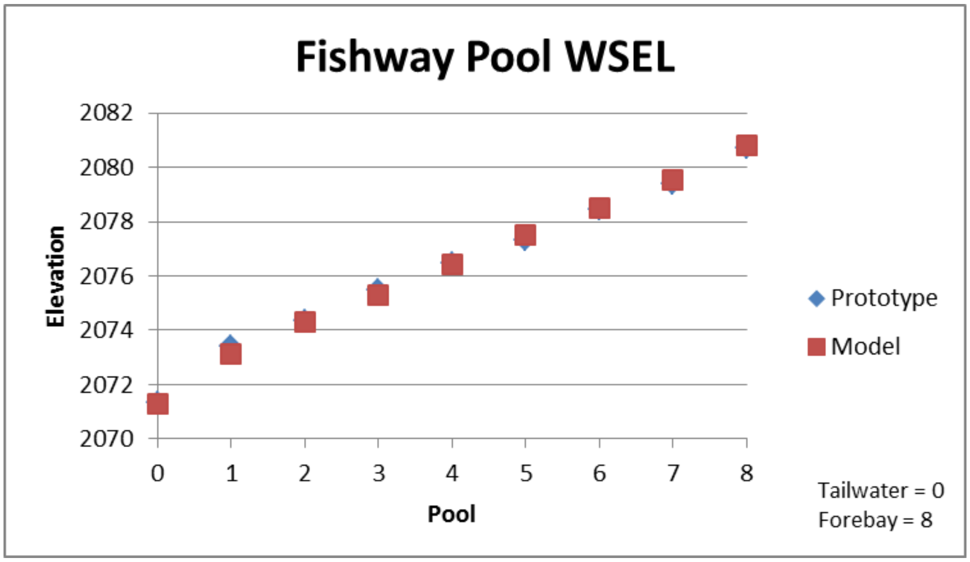


Figure 10. Comparison between the prototype and model fish ladder water surface elevations.

Fish screen velocity data collected in 2011 was used to verify similar screen performance of the model to the prototype. The flow configuration from trial 6 (California Department of Water Resources, 2011) was replicated in the model as shown in Table 2. Field Trial 6 data and simulated model data (Run 2) are given in Figure 11 and Figure 12, respectively.

Table 2 Flow configuration for the prototype trial 6 and the model run 2.

	Trial 6 2011	Model 2
Total Discharge (ft^3/s)	64	64
Diversion Discharge (ft^3/s)	44.2	40.7
Bypass Discharge (ft^3/s)	13.2	19.1
Fishway Discharge (ft^3/s)	6.6	4.17
Forebay Elevation (ft)		2082.02
Tailwater Elevation (ft)		2069.33
Diversion. WSEL (ft)	2.35	2.09
Headgate	full open	full open
Bypass weir boards		1
Fishway Right Orifice	closed	closed
Fishway Left Orifice	closed	closed
Stop logs		0
Baffle 8 stop logs		5
Baffle 7 stop logs		1

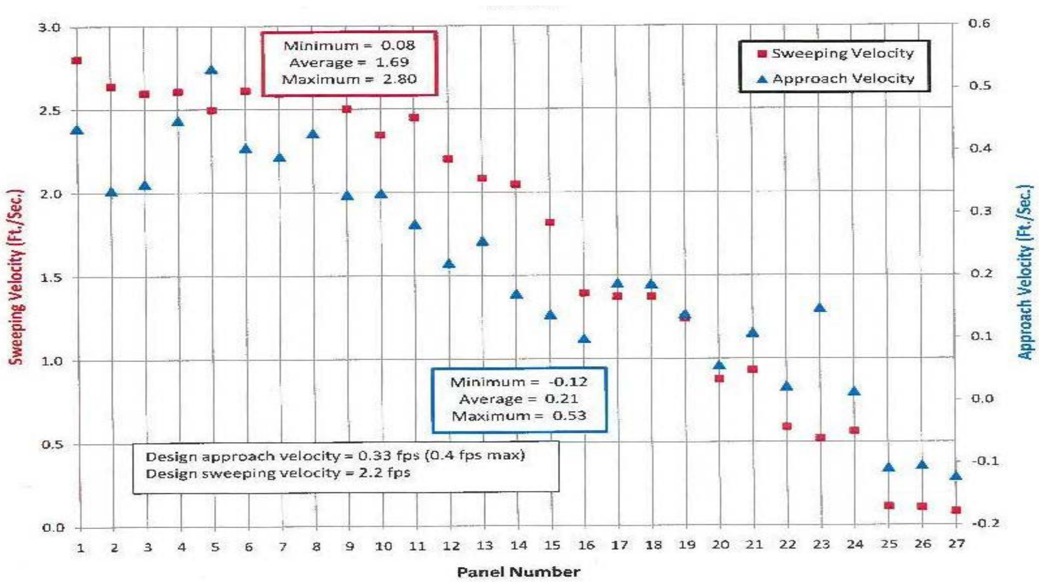


Figure 11. Sweeping and approach velocity along the fish screen from 2001 field Trial 6.

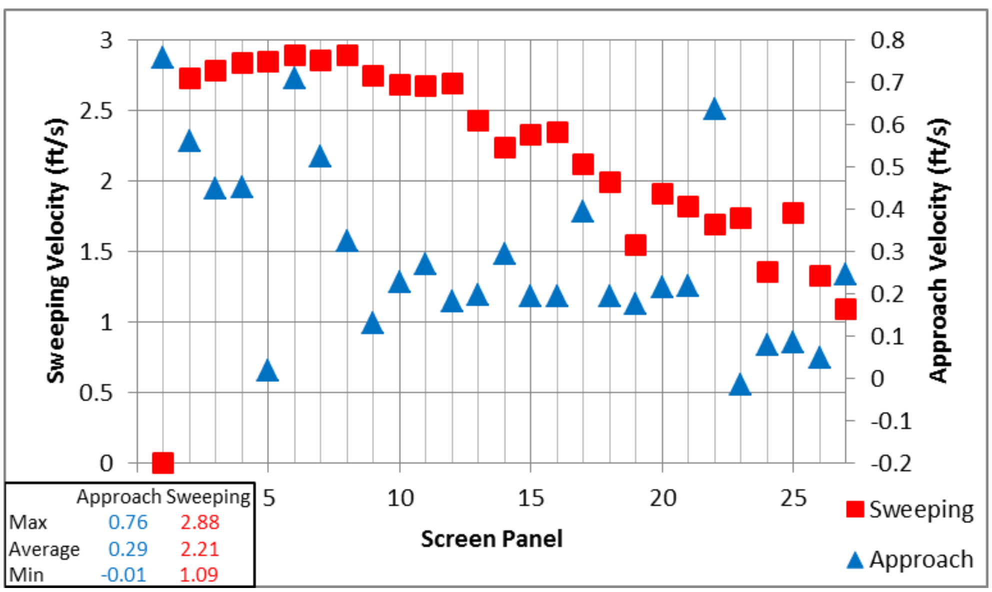


Figure 12. Sweeping and approach velocity along the fish screen from model Run 2 scaled to prototype velocity.

The initial model tests verified that the model reasonably replicated the prototype in its performance and limitations. The remainder of the model testing focused on solving operational issues identified for the as-built structure.

Diversion Operation Requirements

The NBCF Canal is operated following a set of guidelines that dictate instream flow (the sum total of fishway flow, screen bypass flow and dam overflow) and diversion flow. All diversion flow is passed through the fish screen to prevent entrainment of aquatic species larger than the screen slot width. The Memorandum of Understanding (MOU) for the Battle Creek Restoration Plan gives the following minimum instream flow requirements downstream of the NBCF Diversion Dam, assuming minimum flows are available at the dam:

- 47 ft^3/s – May to November

- 88 ft^3/s – December to March

- 67 ft^3/s – April

The diversion design flow is 55 ft^3/s. Flow can be diverted above the minimum instream flow requirement. The model study initially focused on the smallest instream requirement (47 ft^3/s) combined with the design diversion flow. For the model investigation an upstream river flow of 110 ft^3/s was used for achieving full diversion compliance to give some float for adjusting the flow split. All recommended modifications were then tested over a range of river flows.

Fish Screen Design

The screen design discharge is 55 ft^3/s. The fish screen is 3.0-ft-high by 82.25-ft-long and is inclined at 60 degrees from horizontal. The full area of the screen is 246.75 ft^2 with a vertical projected area of 213.68 ft^2. These areas correspond to average design approach velocities of 0.22 and 0.26, respectively, not including loss of screen area for screen structural support members.

Fishway Design

The fishway is a pool and chute style with eight baffles on a 9H:1V slope. The fishway is 15-ft-wide with baffles spaced on 9 ft centers and 8 ft pools between baffles. The baffles are shown on Figure 13. Each baffle contains two 20 inch gated square orifices, a 3-ft-wide by 3.5-ft-deep center weir slot and 3H:1V sloping weir crests either side of the center slot. The center slot depth of the two upstream most baffles (referred to as exit baffles) are greater with the horizontal section of the center slot being at the same elevation as the third baffle from the upstream end. The two exit baffles contain stoplog slots in the center slot for adjusting the slot invert elevation. General design guidance for this style of fishway was published by Bates in 1991.

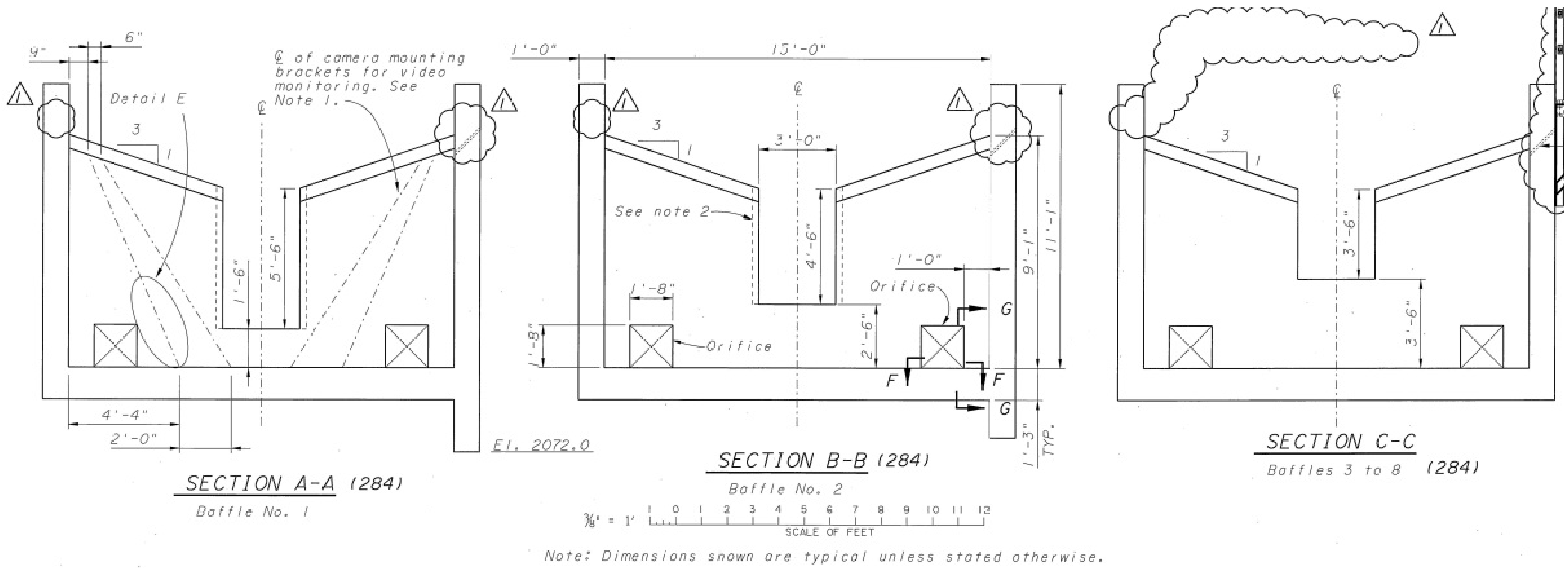


Figure 13. Baffle dimensions for the as-built fishway.

Investigation and Analysis

Fish Screen and Diversion

Tests of the as-built screen and diversion channel showed:

- A diversion flow of >~40 ft^3/s overtopped the screens.

- High approach velocities in screen bays 1-7 and low or reverse flow in bays 20-27.

- Significant large scale turbulence in the diversion channel resulting in highly unsteady approach and sweeping velocities along the upstream 1/3 of the screen.

- The flow capacity of the fishway with exit weir set at elevation 2079 (2 ft of weir boards) and orifices closed restricted diversion flows to less than 55 ft^3/s unless additional weir boards were added to the fishway.

The following screen modifications tested in the model were found to meet fish screen performance goals:

- Adding screen blanking panels above the screen to a minimum elevation of 2082.5.
- Adding 3 flow guidance vanes behind the screen.
- Adding a straight guide wall opposite the screen.
- Adding short guide walls to create a gradual expansion downstream of diversion gate.
- Adding a bullnose entrance to the diversion inlet.

Blanking Panels

Passing 55 ft^3/s diversion flow through a properly baffled screen required a WSE on the upstream side of the screen of 2082.3 or a WSE approximately 1 ft above the as-built top of screen. In order to facilitate an increase in head without overtopping the screen, blanking panels were added above the screen as shown in Figure 14.

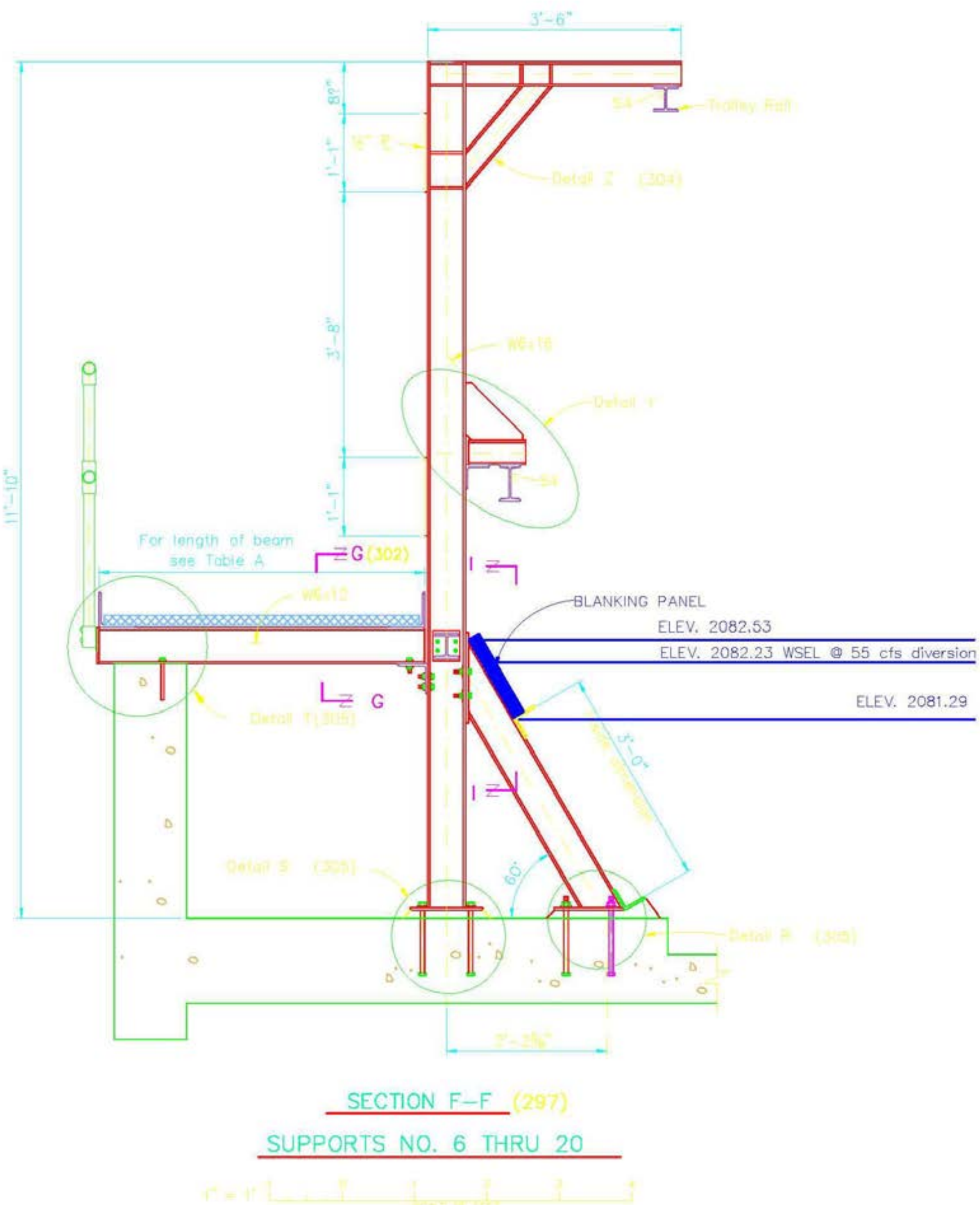


Figure 14. Drawing cross section of the as-built screen showing the addition of blanking panels above the screen.

In the model blanking panels were placed directly above the screen extending up to elevation of 2082.5 ft. The model screen baffles extended well above the screen for ease of adjustment, therefore baffles did not overtop in the model. A prototype blanking panel will need to include a horizontal plate or other method to block significant flow from passing over the screen baffles. Blanking panels providing freeboard greater than presented herein may be desirable if diversion of greater than 55 ft^3/s could occur during high flow events.

Guide Vanes Located Behind the Screen

Three guide vanes were installed and tested behind the screen to help improve uniformity of screen approach velocity (Figure 15). The three vanes essentially divide the screen into four smaller screens. The four sections are not completely hydraulically isolated, however baffling can effectively produce uniform approach conditions through the entire screen. The baffling for each section is similar to what a single screen would be. In each section the upstream baffles are open more than the downstream baffles. The upstream end of the vane is attached to the screen support structure as seen in Figure 16 and Figure 17. They are attached to piers 4, 7, and 11 as shown in Figure 15. Piers are numbered starting with the most downstream pier as number 1 and the most upstream pier as number 15. The vanes extend downstream 2 ft past where the next vane starts (see Figure 15). They are rotated 4.4 degrees from the screen.

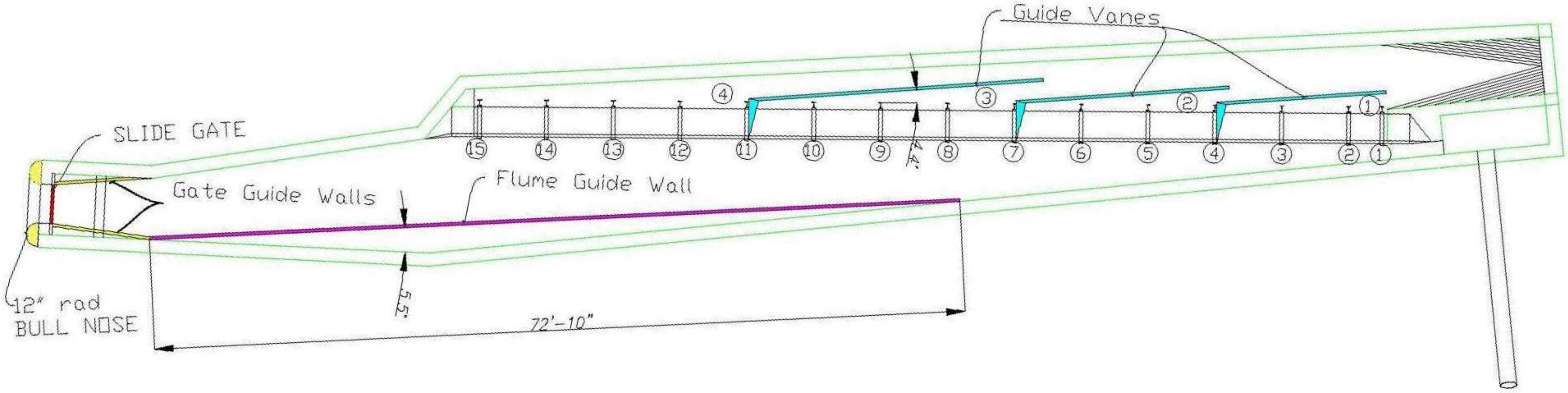
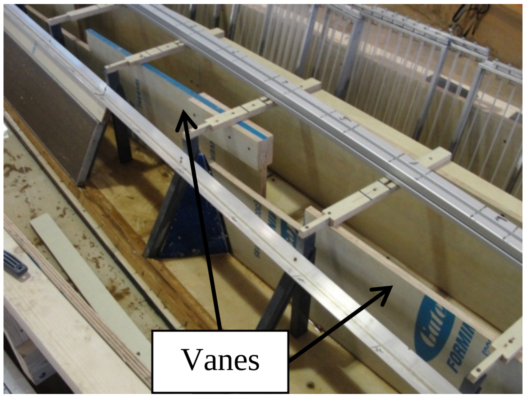


Figure 15. Diversion screen structure showing the additional guide vanes, the straightened wall opposite of the screen and the guide wall downstream of the diversion gate.



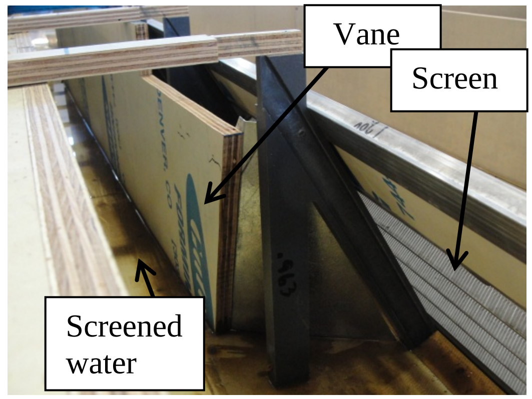


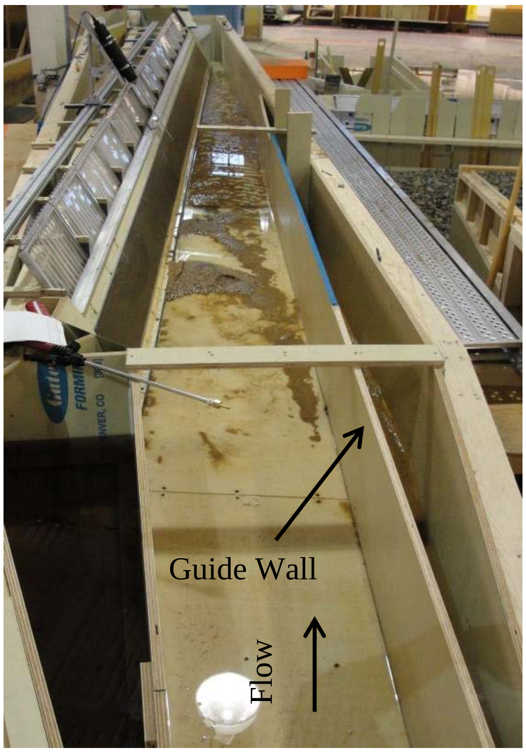
Figure 16. Model vanes behind the screen (most of the screen and baffles are removed in this photo)

Figure 17. Model vanes are attached to the screen support piers.

Guide Walls

Three guide walls were added in the diversion channel to better guide flow onto and along the screen. Downstream of the gate the left wall flares out at about 11 degrees creating a non-symmetric gradual expansion of the diversion channel upstream of the screen. This expansion enhances the development of turbulent flow patterns upstream of the screen that carry downstream onto the screen. To improve the uniformity of flow in the channel approaching the screen a straight guide wall was installed along the right wall. The proposed wall starts about 10 ft downstream of the diversion gate and extends downstream for approximately 73 ft as shown in Figure 15 and Figure 18. The proposed wall provides greater symmetry and less expansion of the channel ahead of the screen. Observation of flow patterns using dye showed the guide wall reduced the presence of large scale eddies moving along the upstream half of the screen.

To further reduce the energy loss upstream of the screen, short guide walls were added on both sides of the channel where flow leaves the diversion gate. In the as-built design the abrupt expansion causes excessive flow recirculation and energy dissipation and causes the high velocity flow to attach to one side of the channel. The side of the channel that the flow attaches to depends on the current flow conditions. The flow was observed to randomly attach to either side and switch sides during steady operation. Ten-foot-long guide walls were added on each side of the gate opening to create a more gradual expansion downstream of the gate (Figure 19 and Figure 15).



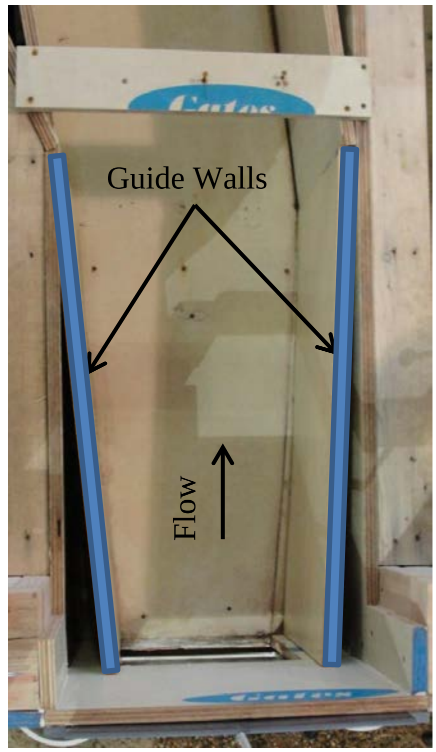


Figure 18. Guide wall on the right side of the screen channel.

Figure 19. Guide walls immediately downstream of the diversion gate. The trash rack was not modeled.

Bullnose

A 1-foot-radius (prototype) half pipe bullnose was added around the diversion entrance (Figure 20). In the model, a significant amount of headloss was measured through the diversion gated entrance due in part to flow approaching the entrance at a highly skewed angle. Flow was observed to approach the diversion entrance flowing from right to left across the face of the dam. This pattern was caused by the dominant flow entering the fishway and the layout of the two flow paths and upstream river channel. An array of guide walls in the forebay were tested in the model, however none had a significant positive effect. The bullnose was found to provide the best transition of flow into the diversion entrance, thus reducing separation on the right side of the entrance and flow impacting the left side. The simple bullnose shape was found to reduce the headloss through the entrance by about 0.3 ft. The combination of the bullnose and the guide walls reduced the RWSE by 0.39 ft for the low flow condition of 110 ft^3/s in the river and a full diversion (Table 3, compare run 16 and run 31).

Figure 20. One-foot-radius half pipe bullnose around the entrance to the diversion. In the inset picture the flow can be seen curving around the bullnose into the diversion channel.

Diversion Channel Performance with Modifications

The blanking panels, guide vanes behind the screen and the guide wall on the right side of the diversion channel all contribute to meeting fish screen approach flow criteria. With these three modifications the screen performance with 110 ft^3/s and a 55 ft^3/s diversion is shown in Figure 21. This operation yielded a maximum screen approach velocity of 0.31 ft/s and an average of 0.19 ft/s. This same configuration was tested at a total river flow of 200 ft^3/s. This operation yielded a maximum screen approach velocity of 0.33 ft/s and an average of .19 ft/s. Facility settings for these two tests are shown in Table 3 and the screen performance is shown in Figure 22 under runs 16 and 17. Performance of the fish screen is nearly independent of the fish ladder over the range of flows tested (< 250 ft^3/s).

With 110 ft^3/s in the river, achieving the design diversion requires a RWSE of 2082.76 which is higher than the dam's spillway elevation of 2082.4 ft (run 16). To achieve full diversion similar to run 16, the spillway crest in the prototype would have to be raised during low river flows above 2082.76 or headloss associated with flow through the entrance gate reduced. Studies were then conducted to investigate improving flow conditions through the diversion entrance. This investigation found that adding a bullnose entrance on the upstream dam face and short guide walls in the diversion channel at the entrance outlet reduced the headloss through the diversion gate opening by about 0.39 ft for the design flow. This is illustrated by comparing Runs 31 and 16 in Table 3. These runs were identical except the bullnose and guide walls downstream of the diversion gate were added for Run 31. These modifications reduced the required RWSE for full diversion at 110 ft^3/s river to 2082.37 ft. It should be also noted that the model did not include headloss due to the trashrack. A trashrack loss should be included during design of facility modifications. The conditions given in Run 31 provide little freeboard before flow would pass over the spillway. Therefore, providing either a spillway raise as temporary weir boards for low river flow or a permanent crest raise is needed to meet operation goals.

The screen performance between runs 16 and 31 is very similar, both yielding a maximum approach velocity of 0.27 ft/s and an average of 0.18 ft/s (Figure 23). Figure 24 shows measured water surface elevations of the reservoir, screen channel, behind the screen, and diversion flume for Run 31. The modifications and settings used in Run 31 is the recommended configuration.

Table 3. Flow configuration for runs 16, 17, and 31.

	Run 16	Run 17	Run 31
Total Discharge (ft^3/s)	110.1	200	110
Diversion Discharge (ft^3/s)	55.2	55.5	55.7
Bypass Discharge (ft^3/s)	7.9	7.2	5.6
Fishway Discharge (ft^3/s)	47	137.3	48.7
Forebay Elevation (ft)	2082.76	2085.34	2082.37
Tailwater Elevation (ft)	2070.64	2071.65	2071.27
Diversion. WSEL (ft)	2.27	2.24	2.23
Headgate	full open	1.6	full open
Bypass weir boards	5	5	5.5
Fishway Right Orifice	closed	closed	open small
Fishway Left Orifice	closed	closed	closed
Stop logs	0	0	0
Baffle 11 stop logs	2.5	2	2.25
Baffle 10 stop logs	2	2	2
Baffle 9 stop logs	1	1	1
Diversion treatment	na	na	bull nose

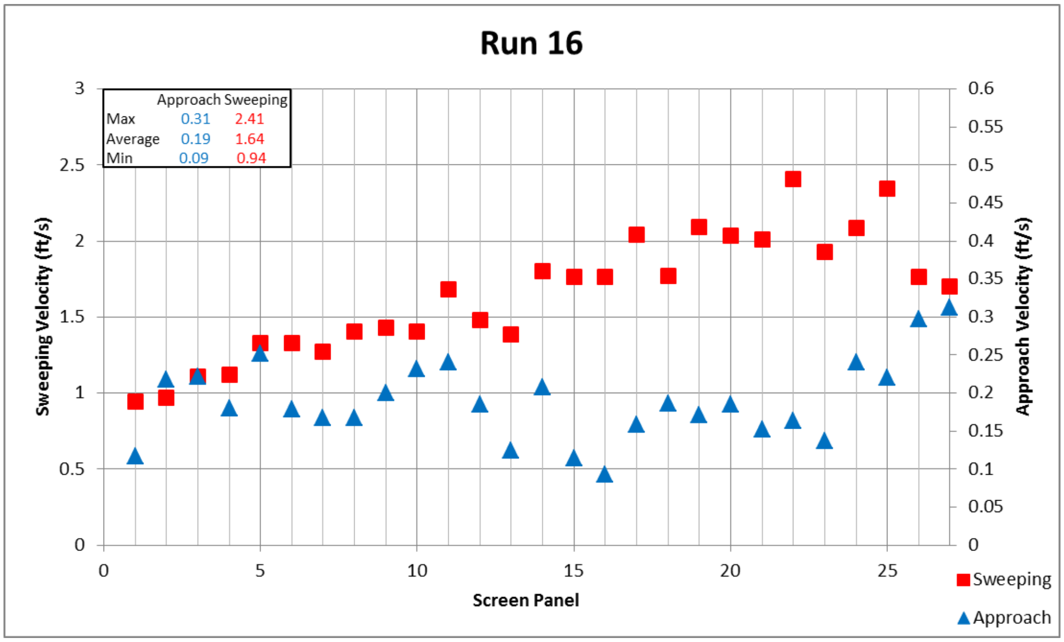


Figure 21. Screen performance with 110 ft^3/s in the river and 55 ft^3/s diversion with the blanking panels, guide vanes, and right guide wall modifications.

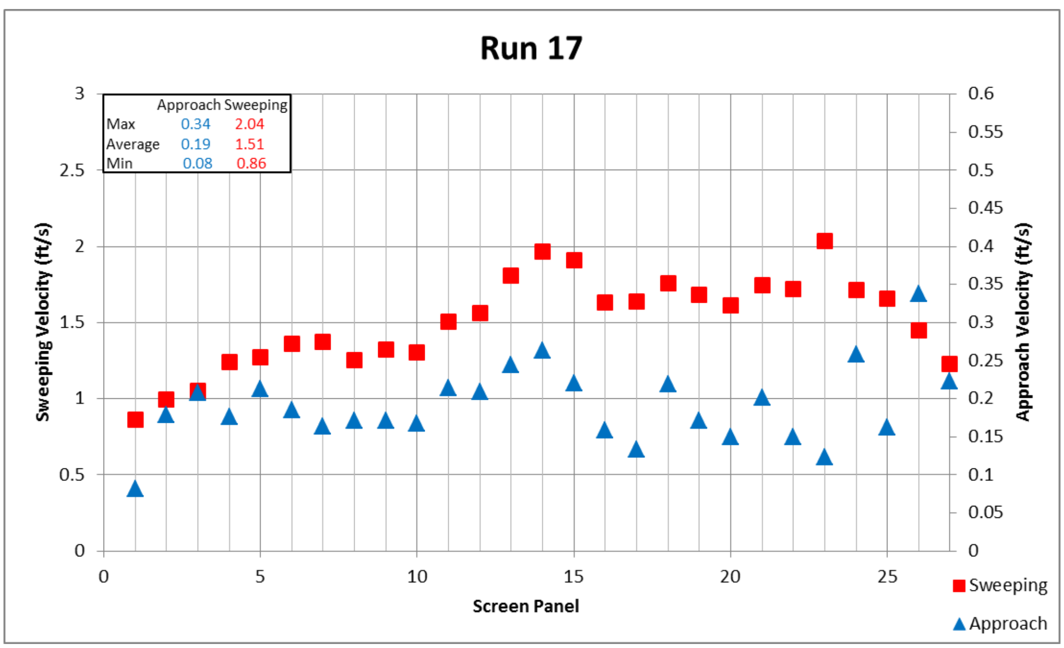


Figure 22. Screen performance with 200 ft^3/s in the river and 55 ft^3/s diversion with the blanking panels, guide vanes, and right guide wall modifications.

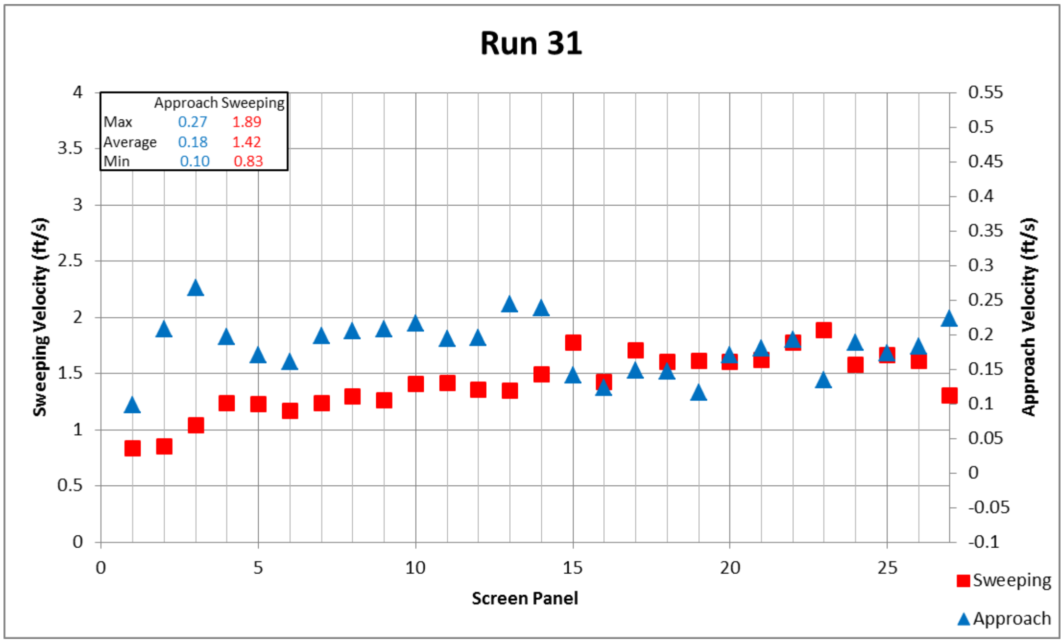


Figure 23. Screen performance with 110 ft^3/s in the river and 55 ft^3/s diversion with the blanking panels, guide vanes, and right guide wall, gate expansion guide walls and the bullnose modifications.

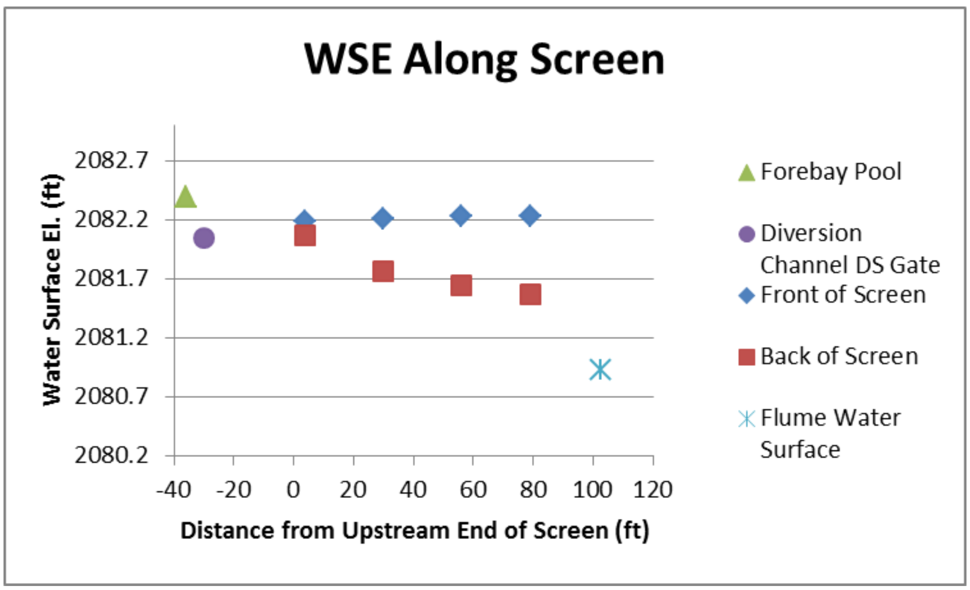


Figure 24. Water surface elevations through the screen structure, Run 31- all screen modifications.

Diversion Screen Louver Baffle Settings

NOAA fish screen design criteria requires baffles behind most large screens to control and adjust flow velocity through the screen. NOAA screen approach velocity criterion for off-river screens is 0.4 ft/s. The criterion is set to protect fish from being impinged by flow on the upstream face of a fish screen. To meet this criterion, the NBCF uses individually operated louvers. The 3-ft-long by 6-in-wide louvers are rotated to increase or decrease the flow area between the louvers. Settings for field trials 1-7 tested during the NBCF fish screen hydraulic performance tests varied from 8% to 100% open area compared to model Run 31 with louver settings that varied from 3% to 8% open area (Table 4). The smaller percent open area is required to adequately adjust the headloss through the screen-baffle system for achieving the required uniformity of screen approach velocity. Table 4 also shows the correlation between the screen panel, baffle section, and the vane section (see also Figure 15).

Table 4. Louver Baffle settings for field trials 1-7 and model Run 31.

Screen Panel	Baffle Section	Model Vane Section	Trial 1 % open	Trial 2 % open	Trial 3-7 % open	Model- Run 31 % open
1	1	1	17%	13%	8%	3%
2	2	1	17%	13%	8%	3%
3	2	1	17%	13%	8%	8%
4	3	1	19%	17%	13%	8%
5	3	1	19%	17%	13%	8%
6	4	2	21%	19%	17%	8%
7	4	2	21%	19%	17%	3%
8	5	2	25%	25%	21%	3%
9	5	2	25%	25%	21%	8%
10	6	2	29%	29%	33%	8%
11	6	2	29%	29%	33%	6%
12	7	3	33%	33%	50%	8%
13	7	3	33%	33%	50%	8%
14	8	3	50%	100%	100%	6%
15	8	3	50%	100%	100%	6%
16	9	3	60%	100%	100%	6%
17	9	3	60%	100%	100%	6%
18	10	3	70%	100%	100%	8%
19	10	3	70%	100%	100%	8%
20	11	4	80%	100%	100%	6%
21	11	4	80%	100%	100%	6%
22	12	4	90%	100%	100%	6%
23	12	4	90%	100%	100%	3%
24	13	4	100%	100%	100%	8%
25	13	4	100%	100%	100%	8%
26	14	4	100%	100%	100%	6%
27	14	4	100%	100%	100%	3%

Diversion Fish Bypass

The fish bypass structure is shown in Figure 25 and Figure 26. The bypass is designed to pass 7.5 ft^3/s flow at design conditions. Bypass discharge and flow depth on the screens are controlled by inserting six-inch-high (prototype) weir boards in the throat of the bypass. During the model study the bypass flow was varied typically within the range of approximately 10 to 15 percent of the diversion flow. Five boards (2.5-ft-high weir) were found to work well for river flows between ~130 ft^3/s and 250 ft^3/s (highest flow tested in model). For river flows between 130 ft^3/s and 80 ft^3/s, 5.5 boards (2.75-ft-high weir) were used.

Figure 25. Bypass pipe passing 7.5 ft^3/s.

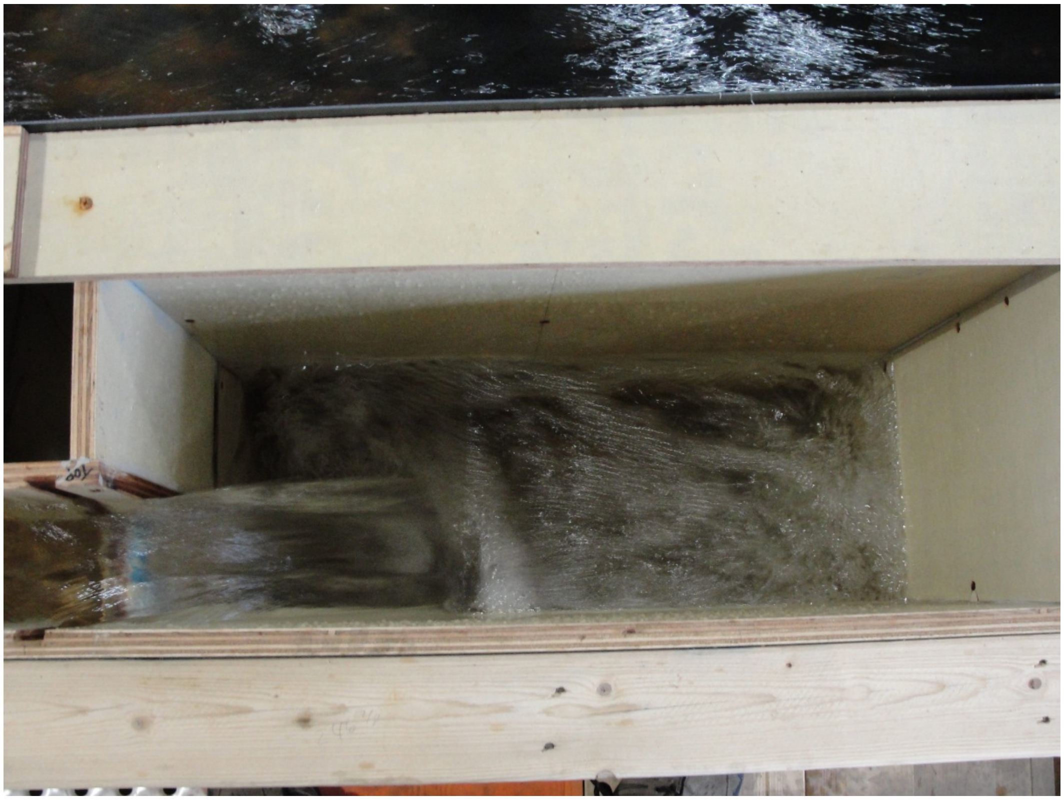


Figure 26. Bypass downwell chamber passing 7.5 ft^3/s.

A few tests of a low bypass weir and high river flow were conducted. These tests showed very strong turbulence in the downwell chamber downstream of the weir at bypass flows above ~ 9.2 ft^3/s and unsteady pressurization of the discharge pipe at flows above ~ 15.8 ft^3/s. Table 5 shows the flow conditions in the bypass pipe for different flow rates. Figure 27 plots the bypass flow rate versus the weir height, assuming a 55 ft^3/s diversion. Figure 25 and Figure 26 show the bypass pipe and downwell chamber passing 7.5 ft^3/s, corresponding to 13% of the 55 ft^3/s diversion. At this flow rate the pipe entrance is submerged, however the pipe is not pressurized.

Table 5. Flow conditions in the bypass pipe.

Run	Bypass	Diversion	WSE Screen	Weir Boards	Weir Height	Notes
#	ft^3/s	ft^3/s	ft	#	ft	
64	3.8	55.1	2082.21	6	3	Entrance not submerged, pipe is not pressurized
63	5.3	61.4	2082.40	6	3	Entrance not submerged, pipe is not pressurized

Run	Bypass	Diversion	WSE Screen	Weir Boards	Weir Height	Notes
57	7.5	56.0	2082.24	5	2.5	Entrance is submerged, pipe is not pressurized
62	9.2	49.0	2081.97	4	2	Entrance is submerged, pipe is not pressurized
58	11.2	55.5	2082.21	4	2	Entrance is submerged, upstream end of pipe is pressurized, starts to surge
59	15.8	55.4	2082.21	3	1.5	Entrance is submerged, pressurized most of the time, surges
60	21.0	56.0	2082.25	2	1	Entrance is submerged, entire pipe is pressurized
61	24.3	55.5	2082.23	1	0.5	Entrance is submerged, entire pipe is pressurized

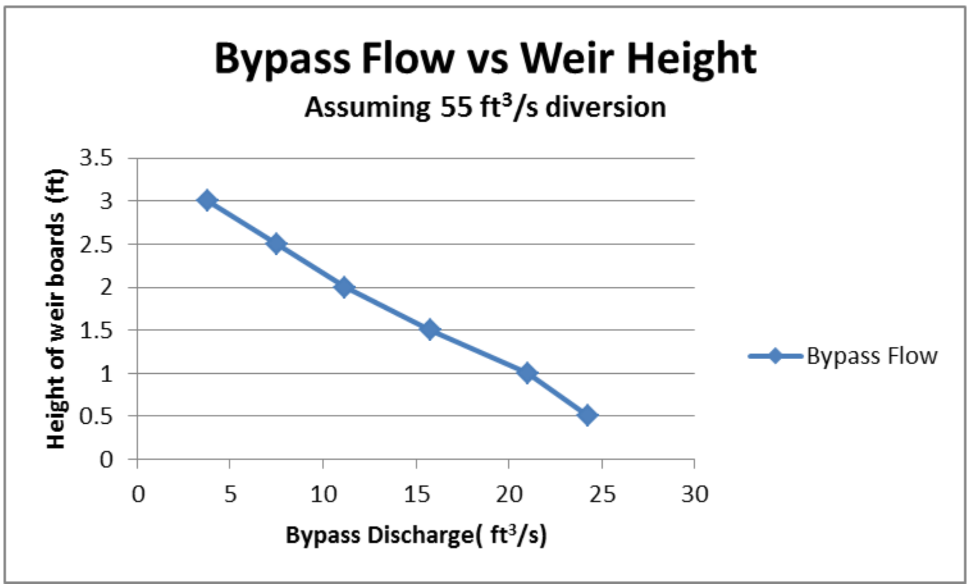


Figure 27. Bypass flow rate vs. weir height, assuming a 55 ft^3/s diversion.

As-built performance reports note the tailwater depth is often insufficient at the bypass discharge location to provide a safe return of fish to the river. There was insufficient topography and bathymetry data available below the dam to physically model downstream river conditions. Investigating methods to increase tailwater or modify the bypass outlet to provide a better condition for fish return to the river was not addressed in this study.

Fishway

Tests of the as-built fishway showed:

- The flow capacity of the fishway with the orifices open and 2 boards in the exit weir (weir elevation 2079) will not provide sufficient head on the diversion entrance to divert 55 ft^3/s during a river flow of 110 ft^3/s.
- The difference in water surface elevation between the entrance pool and the tailwater is >~2 ft.

The following fishway modifications allow the facility to meet instream and diversion flow requirements and showed improved performance of the fishway:

- Lower the fishway entrance by adding two additional downstream bays
- Reduce the maximum flow capacity of the orifices by changing the openings to 15 inches high by 12 inches wide.
- Raise the fishway exit elevation 1 ft by adding one additional upstream bay

Fishway Entrance Issues

Figure 28 shows the water surface elevation in each pool of the fishway. The larger drop between the tailwater and the first pool is cause by the insufficient submergence of the fishway entrance. The large drop between the seventh pool and the forebay is because the flow conditions approaching the exit baffle make it less efficient than the downstream baffles with equal steps for all baffle weirs.

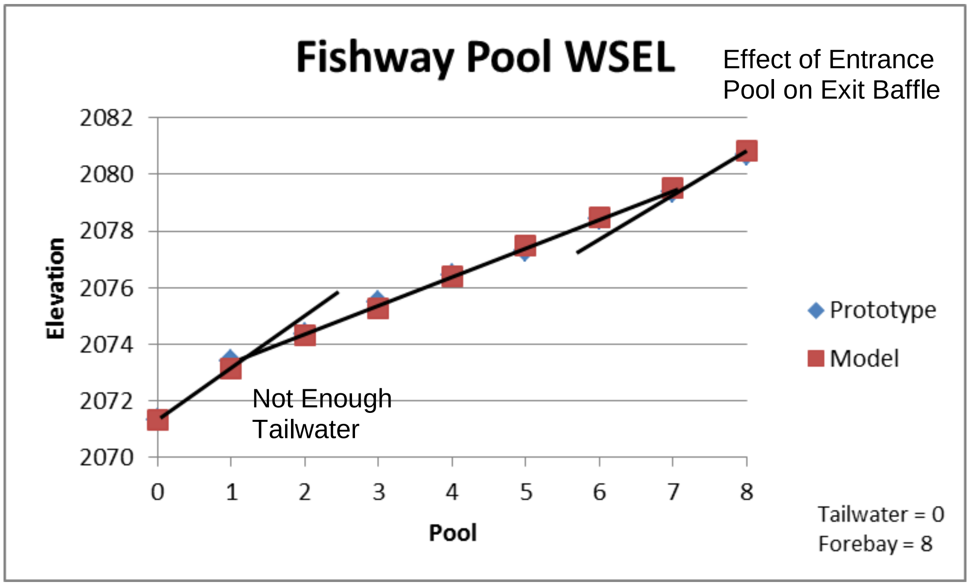


Figure 28. Fishway pool water surface elevations with a 1 ft drop between all baffle weirs. Note the large drop between the tailwater and the first pool and the drop between the seventh pool and the forebay.

To help reduce the water surface drop between the first pool and the tailwater two bays were added to the downstream end of the fishway. These two bays are the same size and on the same slope as the existing fishway. Each baffle is consecutively 1ft lower than the next upstream baffle. The baffles are the same design as the original downstream six baffles (section C-C in Figure 13). The added bays were found to greatly improve entrance conditions to the fishway. A water surface drop of 1 ft or less at the fishway entrance occurs for fishway flows below about 100 ft^3/s. As fishway flows increase above 100 ft^3/s the difference between the tailwater elevation and the first pool increase. Simulations of 180 to 200 ft^3/s fishway flow resulted in about 2 ft of difference between pool 1 and projected tailwater elevations. However, little or no prototype tailwater elevation data is available for high flows in the river. Model results relying on extrapolation of tailwater data should be considered preliminary.

15x12 inch orifices

In order to achieve the full diversion under a low flow condition, it was necessary to close all of the 20x20 inch orifices. Testing showed that these orifices were able to pass 20 to 38 ft^3/s per orifice depending on the RWSE elevation (Figure 29). During low river flow conditions the full diversion cannot be met.

A smaller 15-inch-high by 12-inch-wide orifice (NOAA 2011) was tested in an effort to reduce the flow in the fishway and increase the diversion capacity while still providing orifices as a fish passage route. The smaller orifices decreased the flow area by more than half and in turn reduced the discharge per orifice to 12 to 17 ft^3/s depending on the forebay water surface elevation (Figure 30).

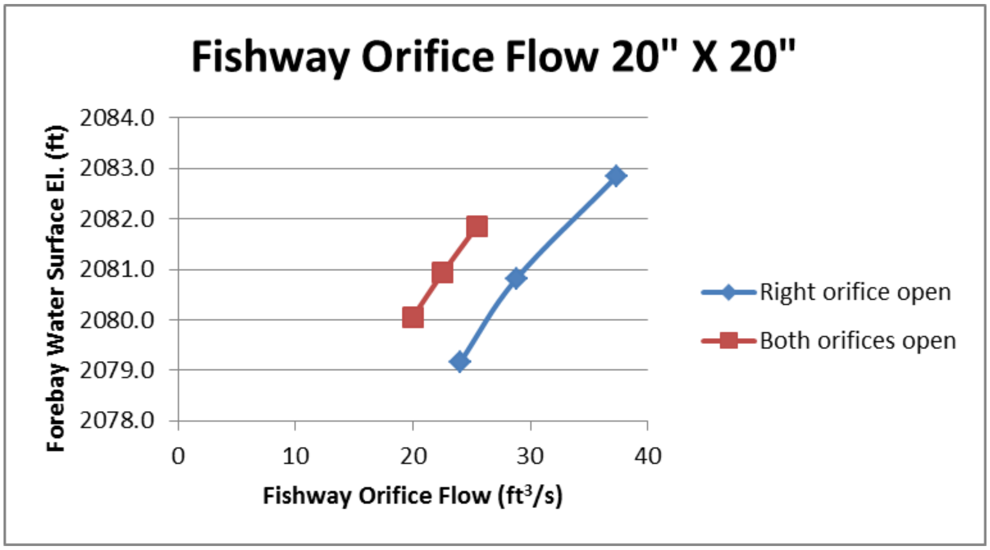


Figure 29. Fishway orifice flow for the 20x20 inch opening. Discharge is per orifice.

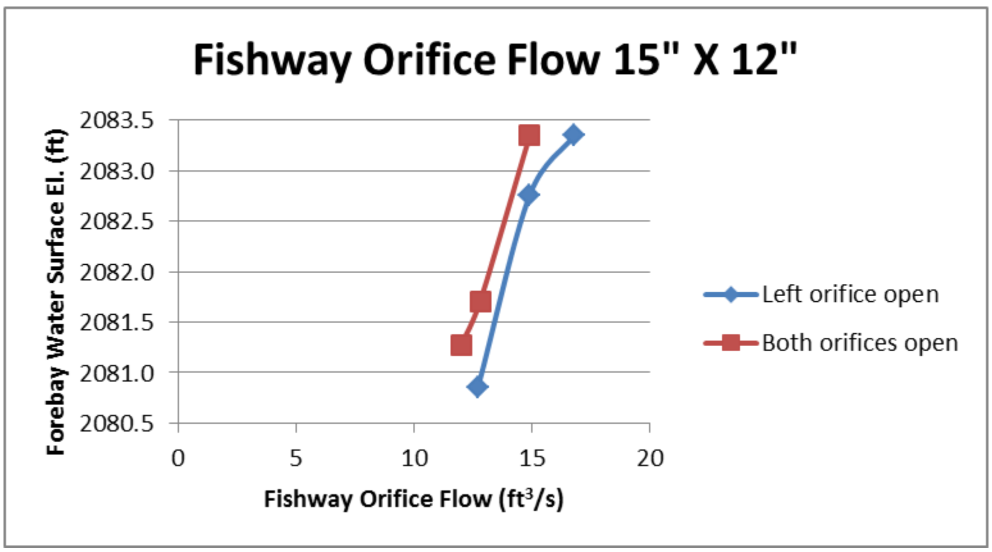


Figure 30. Fishway orifice flow for the 15x12 inch opening. Discharge is per orifice.

Figure 31 through Figure 34 document the velocity of the flow through the orifices in the fishway for both sizes of orifices and for discharges of 47 and 100 ft^3/s. The water surface drop per baffle is also plotted as the differential head across the baffle. The drop per baffle is the major factor influencing velocity. In general for all 4 tests the velocities ranged from 6.0 to 11.5 ft/s with the highest velocities always being at the exit baffle (largest water surface drop). Orifice velocity trend is about the same or decreases slightly for the 15x12 inch orifices compared to the 20x20 inch orifices.

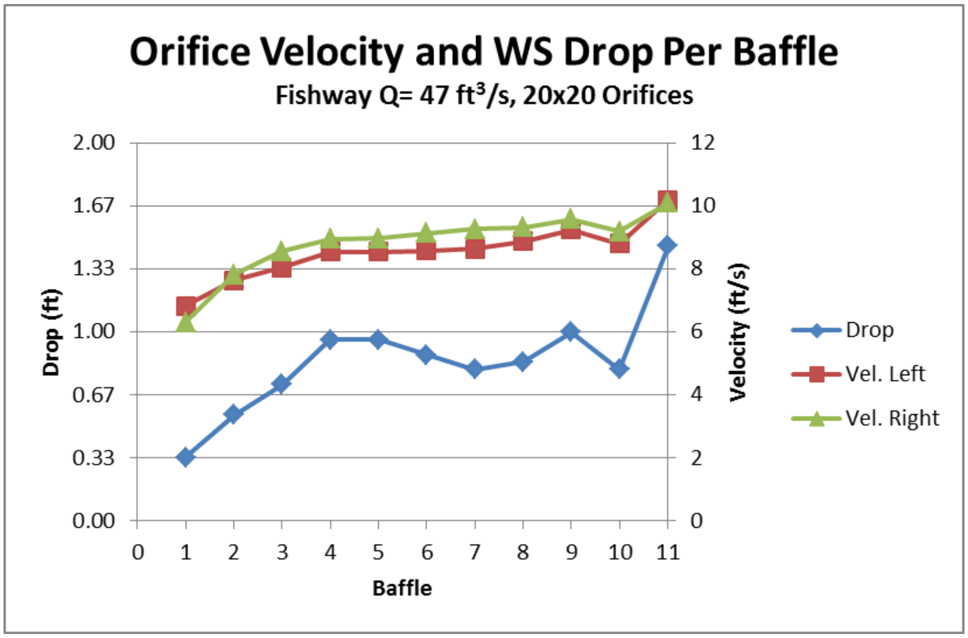


Figure 31. Orifice velocity and water surface drop per baffle with the 20x20 inch orifices. Fishway flow is 47 ft^3/s.

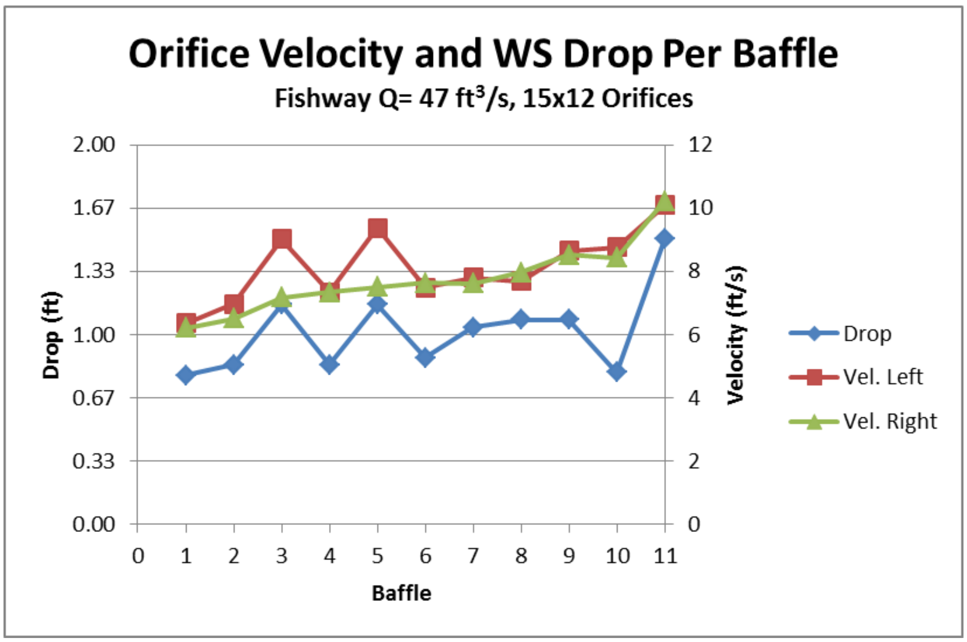


Figure 32. Orifice velocity and water surface drop per baffle with the 15x12 inch orifices. Fishway flow is 47 ft^3/s.

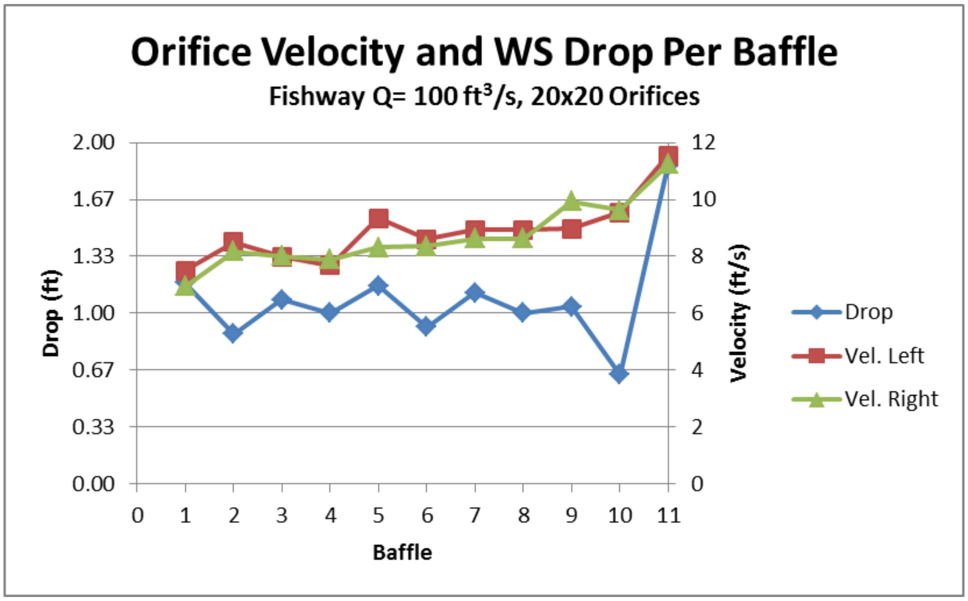


Figure 33. Orifice velocity and water surface drop per baffle with the 20x20 inch orifices. Fishway flow is 100 ft^3/s.

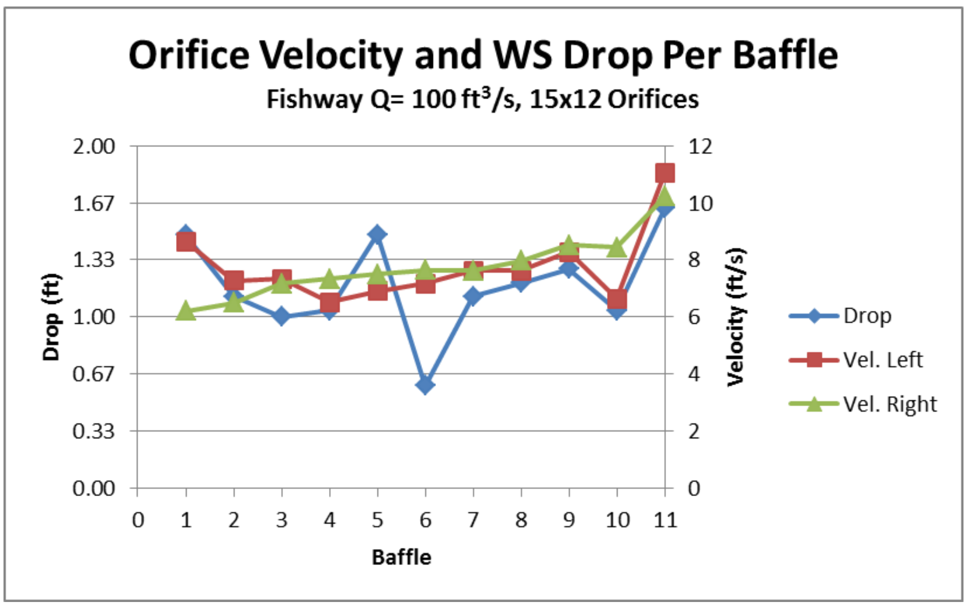


Figure 34. Orifice velocity and water surface drop per baffle with the 15x12 inch orifices. Fishway flow is 100 ft^3/s.

Fishway Exit

In order to achieve good screen uniformity with a diversion of 55 ft^3/s at a river flow of 110 ft^3/s, the required forebay WSEL is 2082.37 with the proposed modifications to the diversion structure (Run 31 Table 3). At low river flows the as-built fishway passes too much water to achieve the necessary diversion WSEL. To reach the needed forebay operation level at110 ft^3/s river flow,the fishway orifice size was reduced and the fishway exit was raised. The exit elevation of the fishway was raised 1 ft by adding a bay to the upstream end of the fishway. This bay is the same size and on the same slope as the existing ladder (Figure 35). The new exit baffle is the same design as the original exit baffle (section A-A in Figure 13). It also is designed with slots for inserting weir stop logs similar to the as-built two upstream baffles. All tests of exit modifications included herein were conducted using the 15 inch by 12 inch orifices.

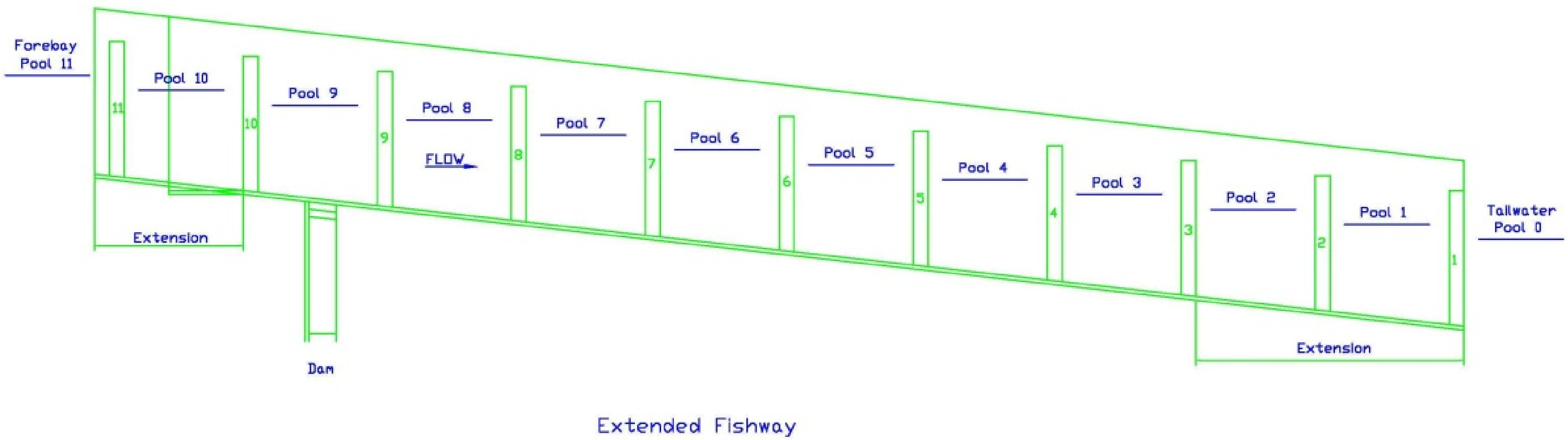


Figure 35. The model fishway showing the additional two downstream bays and one upstream bay for a total of 11 baffles.

Pool-and–chute fishways produce a rapid change in flow conditions from upstream to downstream of the exit baffle. This results in a different head-discharge relationship for the exit baffle compared to downstream baffles. Generally, more head drop or baffle flow area is required to pass the same amount of flow through the exit baffle as downstream baffles. Figure 36 plots the pool-to-pool water surface drop across each baffle versus the fishway flow with all baffles set to a 1 ft elevation difference. The additional head drop required across the exit baffle is clearly shown.

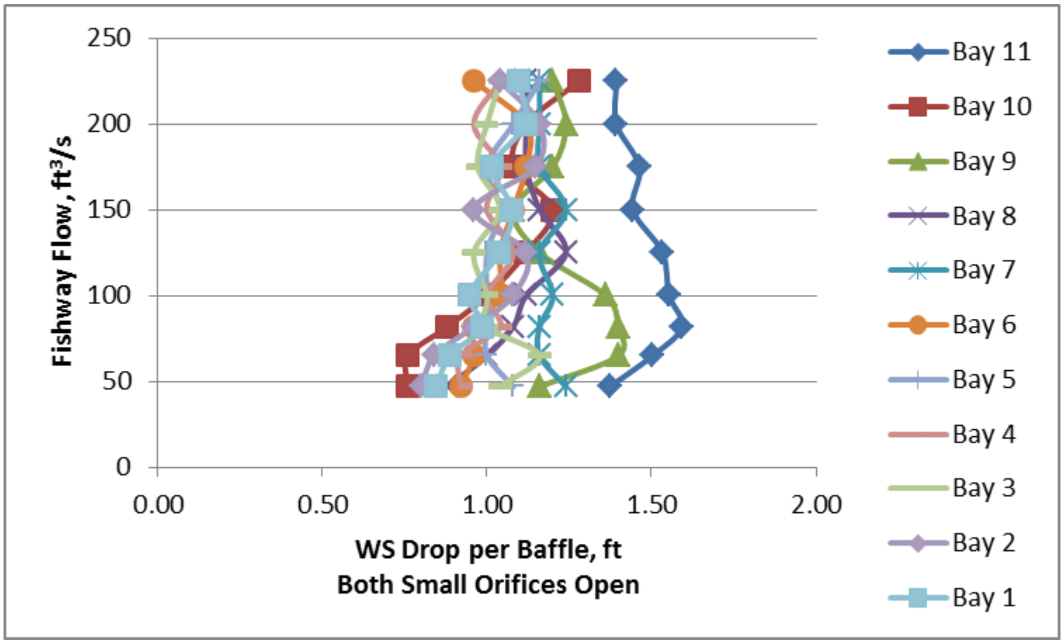


Figure 36. Fishway pool-to-pool water surface change vs. fishway flow for all baffles set at a 1 ft difference. Note at flows greater than100 ft^3/s the tailwater was adjusted to create a 1 foot drop.

Bates (1991) recommends the height of the horizontal weir of the upstream most two baffles be lower than downstream baffles, for the original fishway design (Figure 13). This increases the baffle flow area and decreases the head required to pass flow through the exit baffle. Bates suggests lowering the exit baffle weir by the gain in velocity head between the exit baffle and the third baffle from the exit. The second baffle weir is lowered one-half the difference.

Fishway Configuration #1 – Added 1 baffle upstream and 2 baffles downstream of original fishway. Baffle stop logs for baffles 11, 10, and 9 are 0 ft, 1 ft, and 1 ft, respectively (as Bates recommends). Both 15x12 inch orifices are open on all baffles.

In fishway configuration #1, one baffle was added upstream and two baffles were added downstream of the original fishway. Following Bates' guideline, for the extended fishway, the upstream two baffle weirs were set at elevation 2078. In order to set the proper elevation, the exit baffle did not require any stop log boards, the second baffle required one stop log board, and the third baffle required one stop log board.

Tests results for several fishway flows using this configuration are given in Figure 37 through Figure 41. These tests show a WSEL drop between bays of about 1ft ± 0.25 ft within the fishway. Standing waves which appeared to set up randomly within the fishway accounted for the larger variations in pool depth shown in the plots. During fishway flows above about 100 ft^3/s, differences as high as 2.7 ft were measured at the fishway entrance suggesting additional tailwater is needed during high flows.

Bates's recommended configuration was also tested for a river flow of 110 ft^3/s to determine if the fishway and diversion could be operated to meet instream and diversion objectives. The 110 ft^3/s river flow test resulted in a forebay WSEL of 2081.8 and a flow split of 65 ft^3/s fishway, 40 ft^3/s diverted and 5 ft^3/s of bypass flow. Therefore, the full 55 ft3/s diversion cannot be met with this fishway configuration. An additional 0.6 ft of forebay elevation would be needed at 110 ft^3/s river flow to meet operation objects.

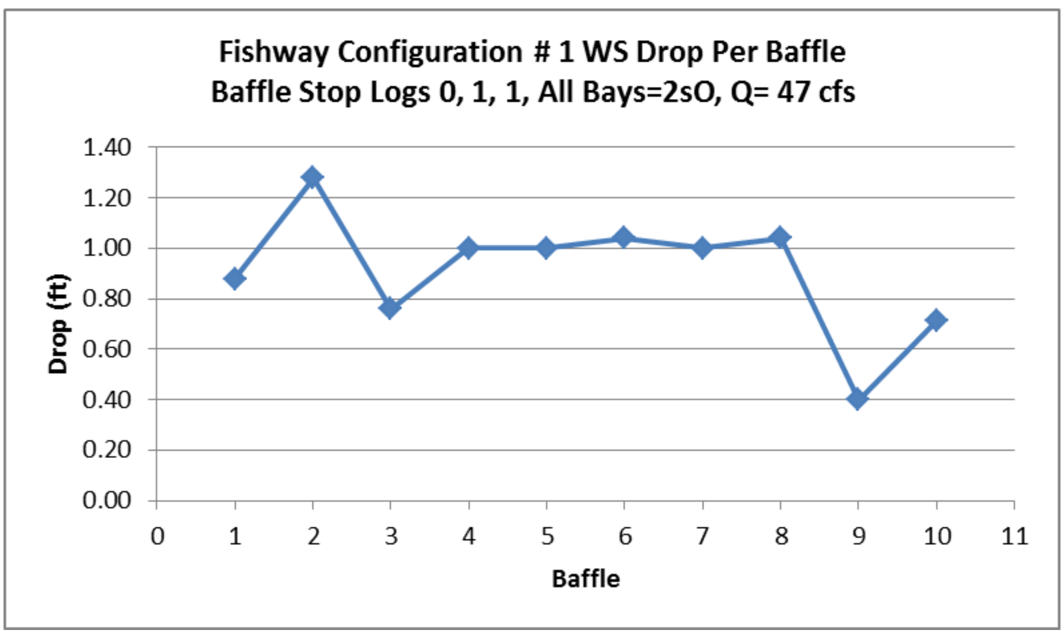


Figure 37 Fishway configuration #1 water surface drop per baffle at a fishway flow of 47 ft^3/s. All bays have 2 small orifices open. Baffle stop logs for baffles 11, 10, and 9 are 0 ft, 1ft, and 1foot respectively.

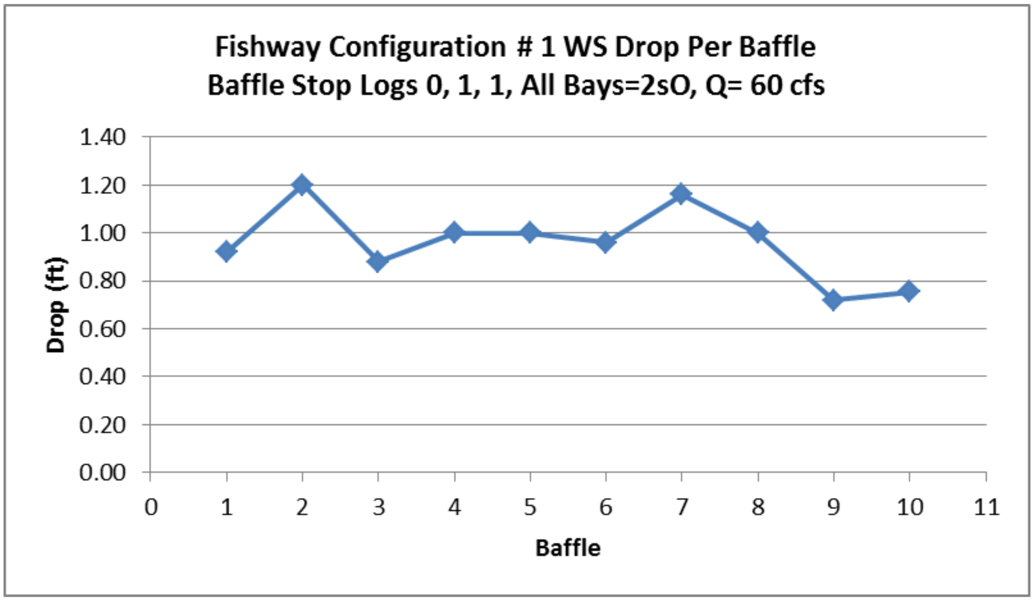


Figure 38 Fishway configuration #1 water surface drop per baffle at a fishway flow of 60 ft^3/s. All bays have 2 small orifices open. Baffle stop logs for baffles 11, 10, and 9 are 0 ft,1ft, and 1foot respectively.

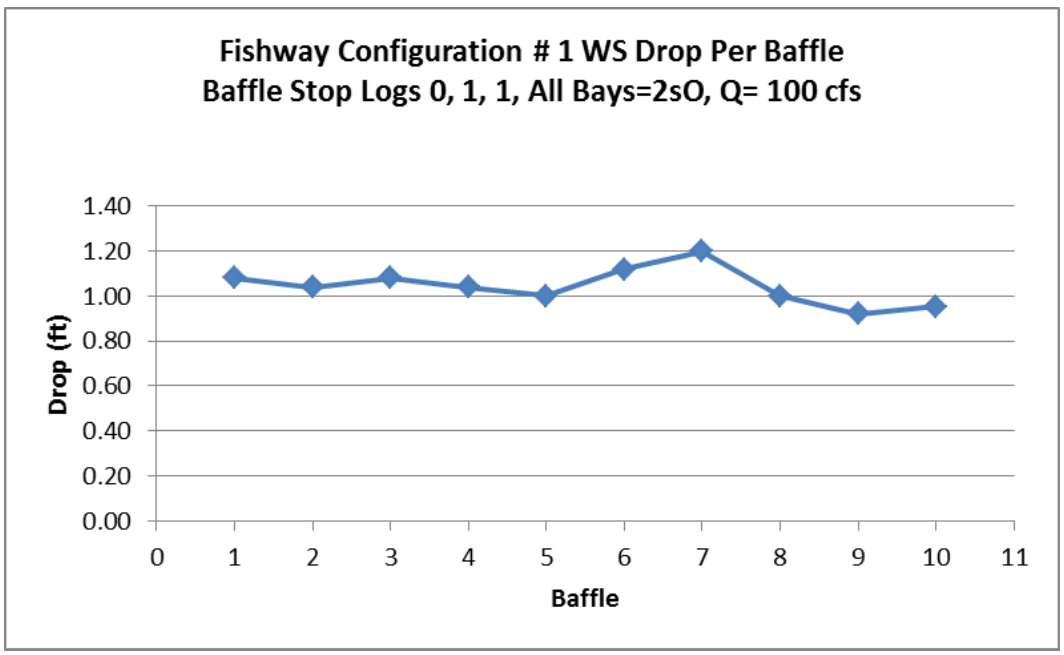


Figure 39 Fishway configuration #1 water surface drop per baffle at a fishway flow of 100 ft^3/s. All bays have 2 small orifices open. Baffle stop logs for baffles 11, 10, and 9 are 0 ft,1ft, and 1foot respectively.

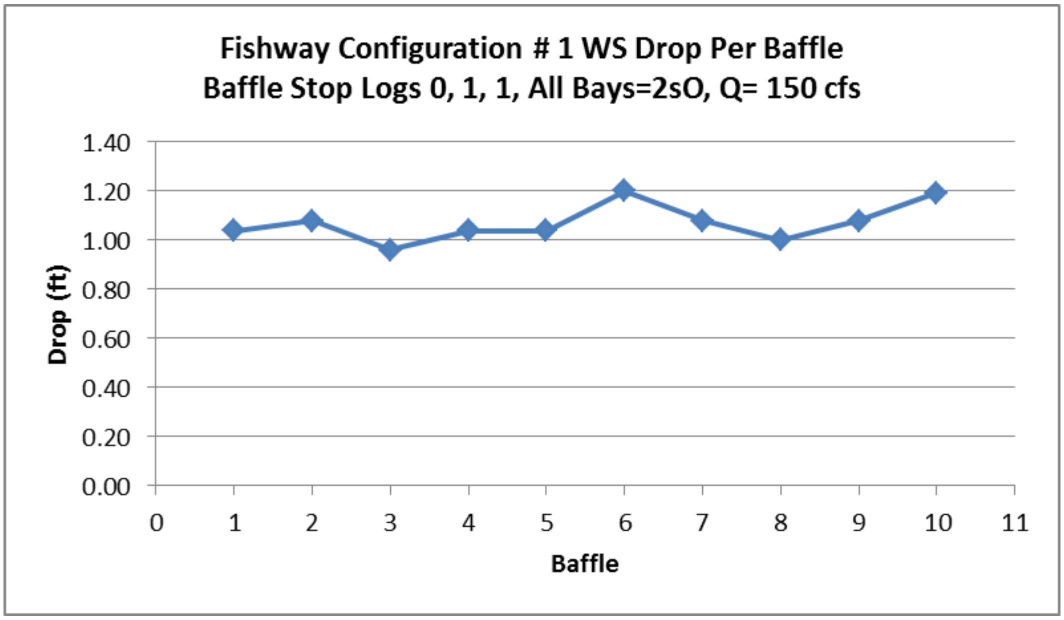


Figure 40 Fishway configuration #1 water surface drop per baffle at a fishway flow of 150 ft^3/s. All bays have 2 small orifices open. Baffle stop logs for baffles 11, 10, and 9 are 0 ft, 1ft, and 1foot respectively.

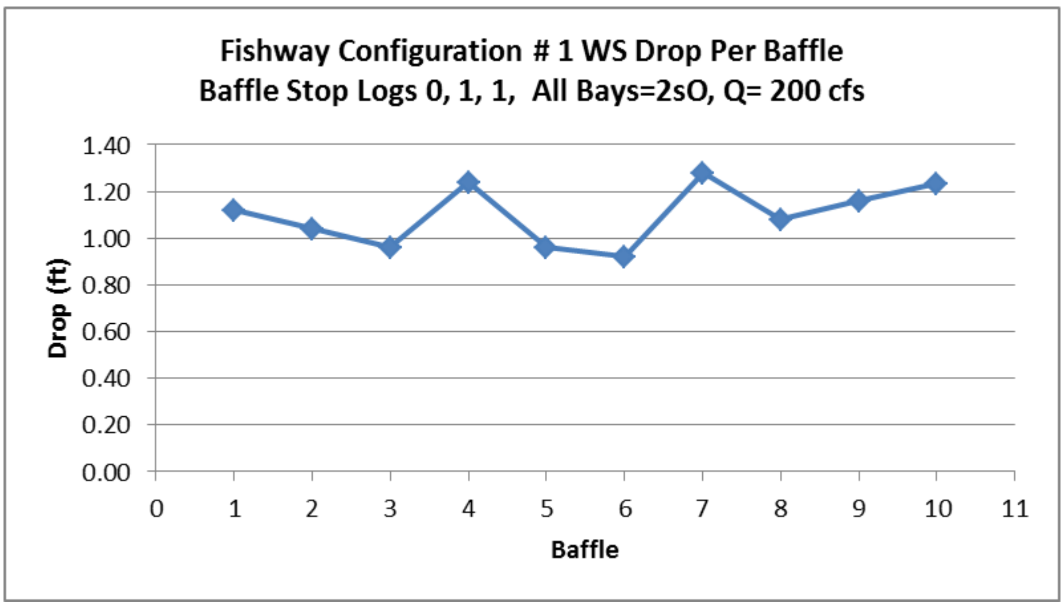


Figure 41. Fishway configuration #1 water surface drop per baffle at a fishway flow of 200 ft^3/s. All bays have 2 small orifices open. Baffle stop logs for baffles 11, 10, and 9 are 0 ft, 1 ft, and 1 foot respectively.

Fishway Configuration #2 – Added 1 baffle upstream and 2 baffles downstream of original fishway. Baffle stop logs for baffles 11, 10, and 9 are 2.25 ft, 2 ft, and 1 ft, respectively. Both 15x12 inch orifices are open on all baffles

Weir boards were added to the uppermost two fishway baffle weirs to increase the forebay pool elevation until both instream and diversion flows could be achieved at 110 ft^3/s river flow. Tests revealed 2.25 ft of boards were needed in the exit baffle and 2 ft in the second baffle downstream. Adding weir boards increased the water surface drop across the exit baffle as shown collectively in Figure 36 and individually in Figure 42 through Figure 44.

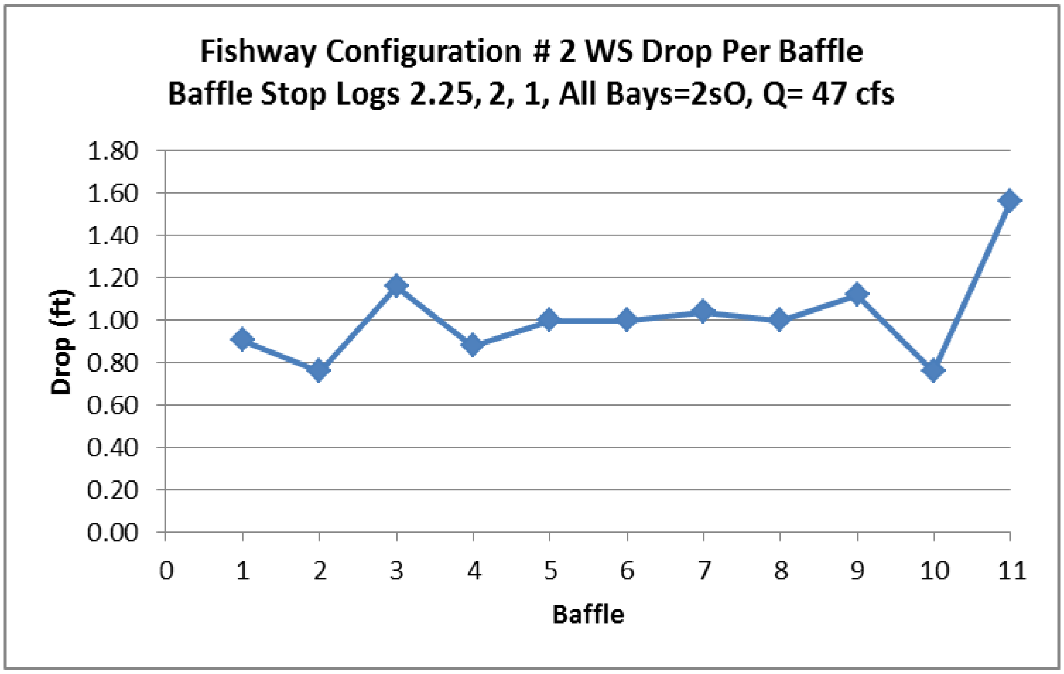


Figure 42. Fishway configuration #2 water surface drop per baffle with a fishway flow of 47 ft^3/s. All bays have 2 small orifices open. Baffle stop logs for baffles 11, 10, and 9 are 2.25 ft, 2 ft, and 1 foot respectively.

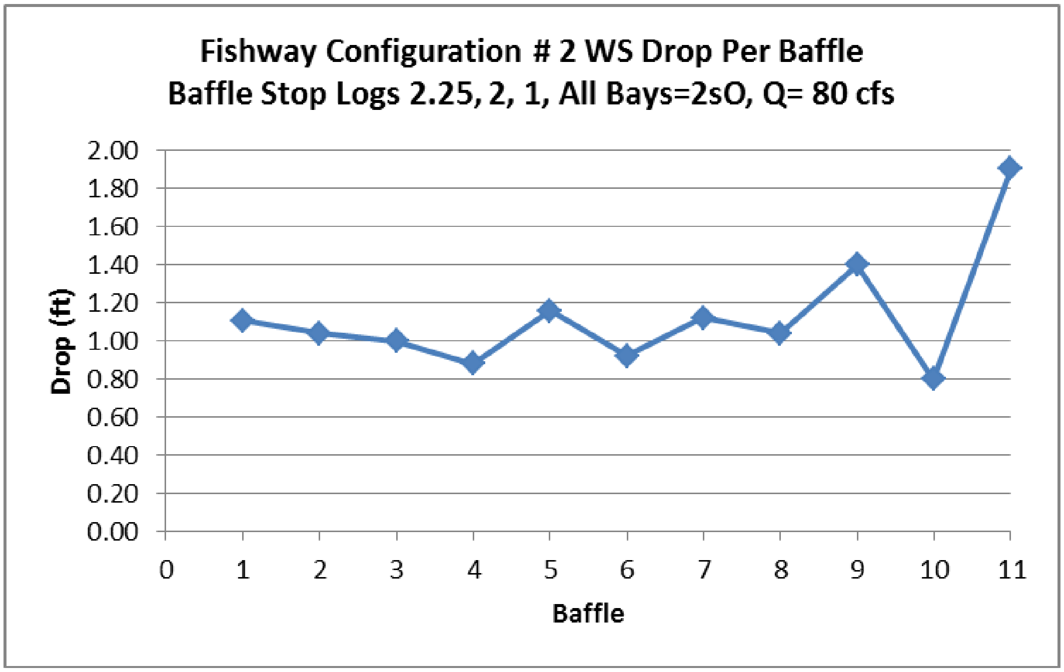


Figure 43. Fishway configuration #2 water surface drop per baffle with a fishway flow of 80 ft^3/s. All bays have 2 small orifices open. Baffle stop logs for baffles 11, 10, and 9 are 2.25 ft, 2 ft, and 1 foot respectively.

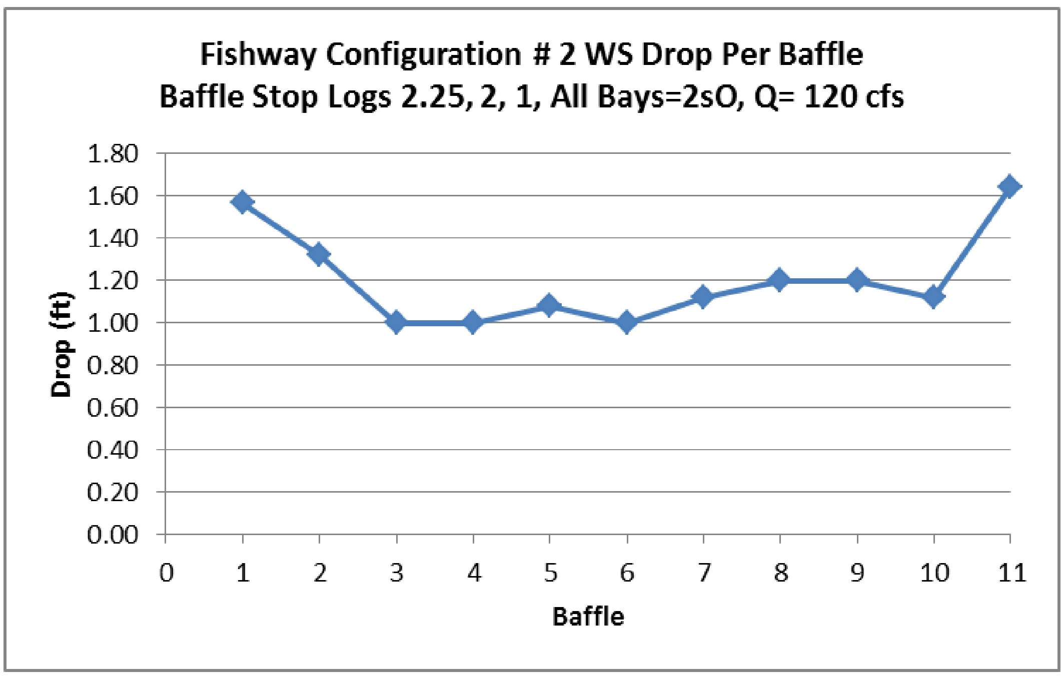


Figure 44 Fishway configuration #2 water surface drop per baffle with a fishway flow of 120 ft^3/s. All bays have 2 small orifices open. Baffle stop logs for baffles 11, 10, and 9 are 2.25 ft, 2 ft, and 1 foot respectively.

Fishway Configuration #3 – Added 1 baffle upstream and 2 baffles downstream of original fishway. Baffle stop logs for baffles 11, 10, and 9 are 2.25 ft, 2 ft, and 1 ft, respectively. Both 15x12 inch orifices are open on the exit baffle and 1 orifice open for all other baffles.

To reduce the water surface drop across the exit baffle both orifices in baffle 11 were opened and only one orifice was opened in baffles 1- 10. This configuration resulted in about the same fishway discharge as having all the orifices open as shown in Figure 50, but reduced the water surface drop across the exit baffle (Figure 45 through Figure 49).

The final configuration with all the modifications identified for both the screen and fishway was tested over a range of total river flow of 85 to 250 ft^3/s. Flow parameters are listed in Table 6 and the water surface drop per pool is shown in Figure 45 through Figure 49. For flows ≥~100 ft^3/s the tailwater is estimated based on available data. Insufficient tailwater at high flows is reflected by the large drop in water surface across the entrance baffle in Figure 48 and Figure 49.

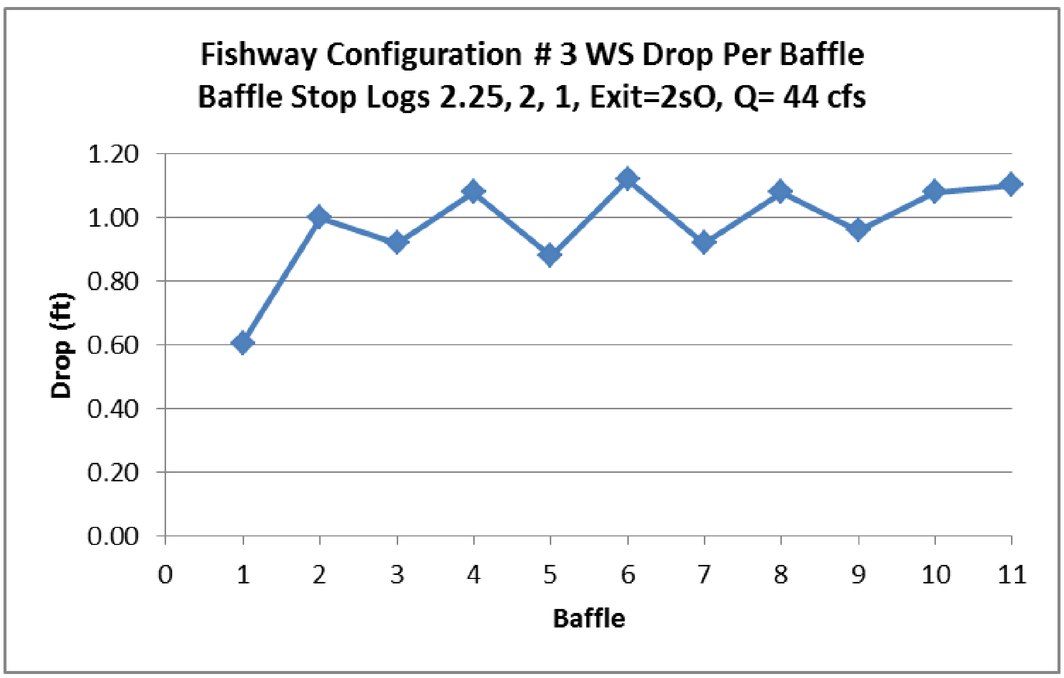


Figure 45. Fishway configuration #3 water surface drop per baffle, fishway flow is 44 ft^3/s. Exit baffle has 2 small orifices open, baffles 1-10 have 1 small orifice open. Baffle stop logs for baffles 11, 10, and 9 are 2.25 ft, 2 ft, and 1 foot, respectively.

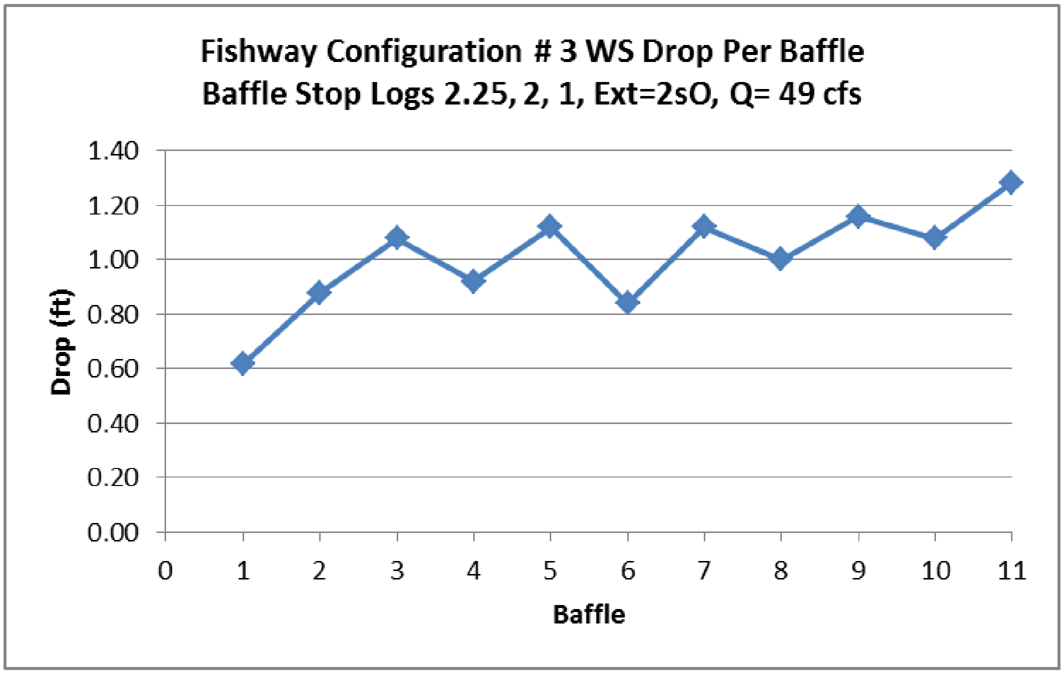


Figure 46. Fishway configuration #3 water surface drop per baffle, fishway flow is 49 ft^3/s. Exit baffle has 2 small orifices open, baffles 1-10 have 1 small orifice open. Baffle stop logs for baffles 11, 10, and 9 are 2.25 ft, 2 ft, and 1 foot, respectively.

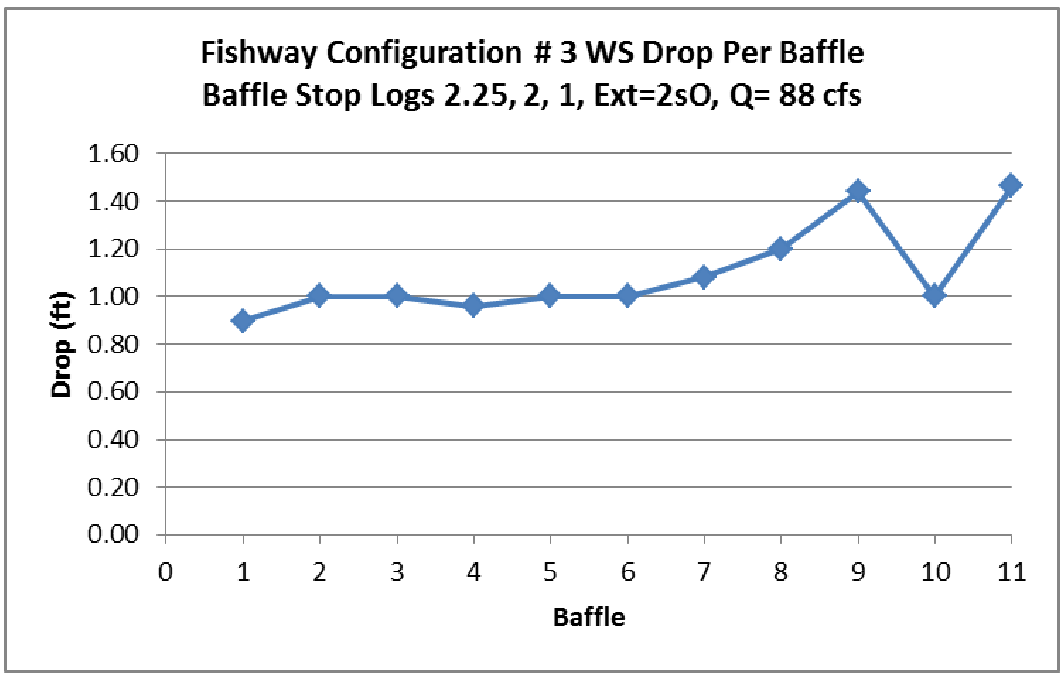


Figure 47. Fishway configuration #3 water surface drop per baffle, fishway flow is 88 ft^3/s. Exit baffle has 2 small orifices open, baffles 1-10 have 1 small orifice open. Baffle stop logs for baffles 11, 10, and 9 are 2.25 ft, 2 ft, and 1 foot, respectively.

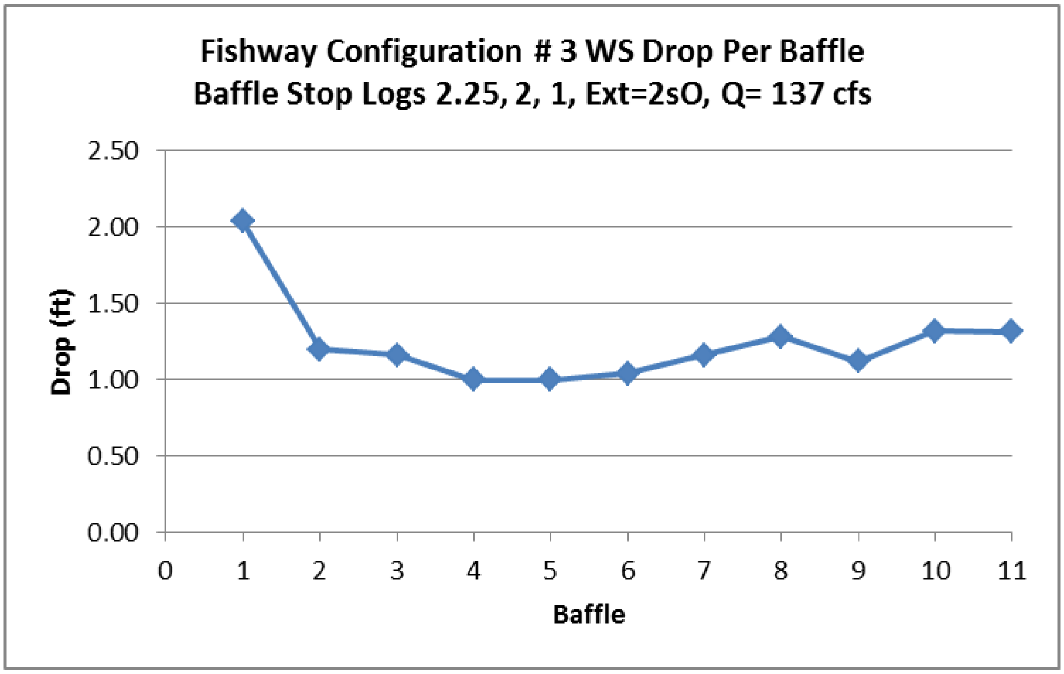


Figure 48. Fishway configuration #3 water surface drop per baffle, fishway flow is 137 ft^3/s. Exit baffle has 2 small orifices open, baffles 1-10 have 1 small orifice open. Baffle stop logs for baffles 11, 10, and 9 are 2.25 ft, 2 ft, and 1 foot, respectively. The large drop at baffle 1 is caused by insufficient tailwater.

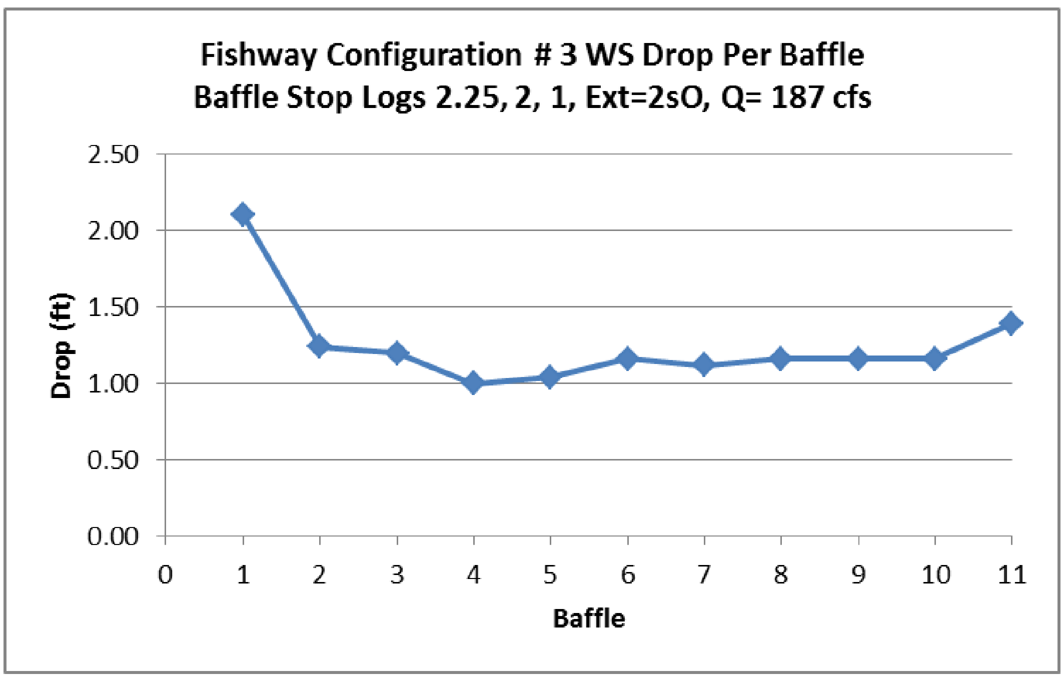


Figure 49. Fishway configuration #3 water surface drop per baffle, fishway flow is 187 ft^3/s. Exit baffle has 2 small orifices open, baffles 1-10 have 1 small orifice open. Baffle stop logs for baffles 11, 10, and 9 are 2.25 ft, 2 ft, and 1 foot, respectively. The large drop at baffle 1 is caused by insufficient tailwater.

Table 6. Test results of the recommended facility configuration. In the fishway baffle 11 has both 15x12 inch orifices open and baffles 1-10 have one 15x12 inch orifice open. The baffle stop logs for baffles 11, 10, and 9 are 2.25 ft, 2 ft, and 1 foot respectively (configuration 3). The bypass weir boards at the end of the fish screen were set at 3.5 ft. (Tests with forebay elevations higher than 2082.4 ft do not account for spillway discharge.)

Run	35	31	32	33	34
Total Discharge (ft^3/s)	85.1	110	149.8	200	250.2
Diversion Discharge (ft^3/s)	38.1	55.7	54.6	55.4	55.3
Bypass Discharge (ft^3/s)	3.2	5.6	7.5	7.8	7.7
Fishway Discharge (ft^3/s)	44	48.7	87.7	136.8	187.2
Forebay Elevation (ft)	2081.79	2082.37	2083.67	2085.04	2085.76
Tailwater Elevation (ft)	2071.04	2071.27	2071.63	2071.41	2072.02
Headgate Open (ft)	2.70	4.00	2.03	1.54	1.40

Fishway Discharge Rating

Discharge rating curves based on forebay elevation for several different orifice and exit weir heights are given in Figure 50. The rating for the recommended weir height and orifice configuration is plotted separately in Figure 51. In this case, discharge versus flow depth over the exit weir is shown for use with field staff gage measurements. An extrapolated flow split for the fishway and as-built spillway is shown in Figure 52. This plot assumes a constant diversion of 55 ft^3/s and applies the fishway rating curve in Figure 51. Spillway flow shown was calculated numerically using a broad crested weir equation.

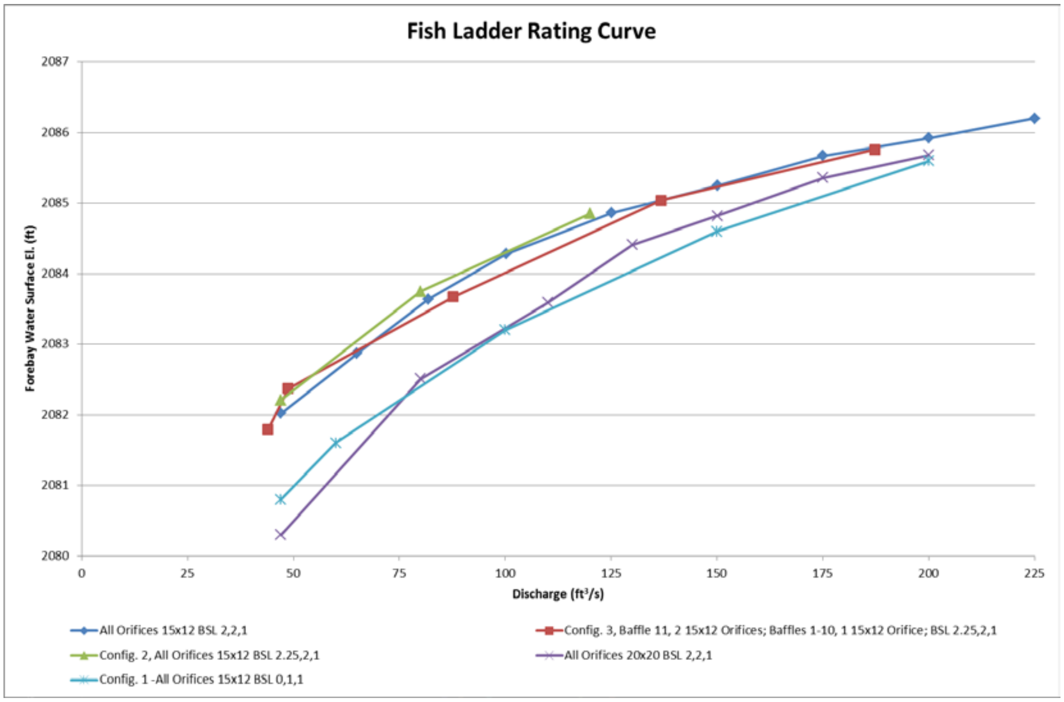


Figure 50 Fish ladder rating curve with different orifice and stop log settings.

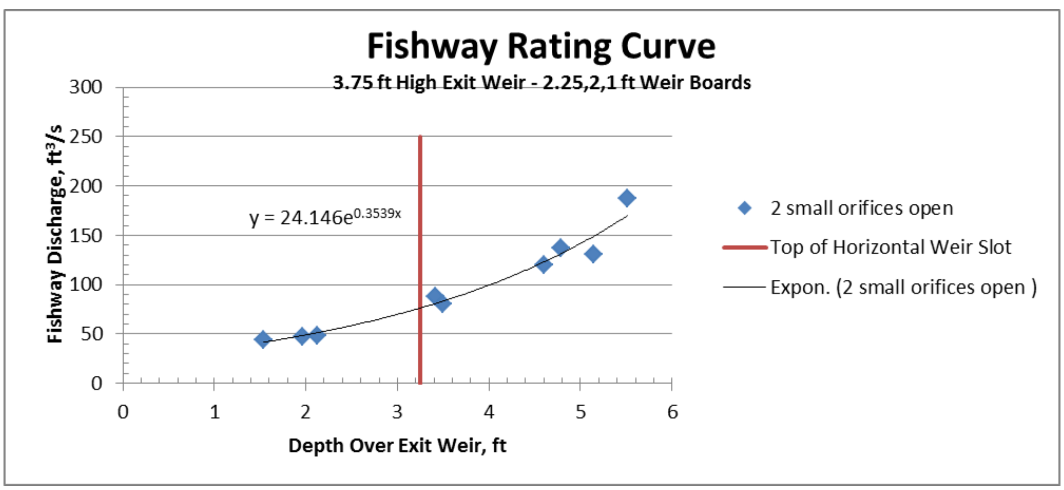


Figure 51 Fishway discharge rating for the preffered alternative, Fishway Configuration #3. 11 bays with 2.25 ft of weir boards in the exit baffle and two small orifices open in the exit baffle, one orifice open in all downstream baffles.

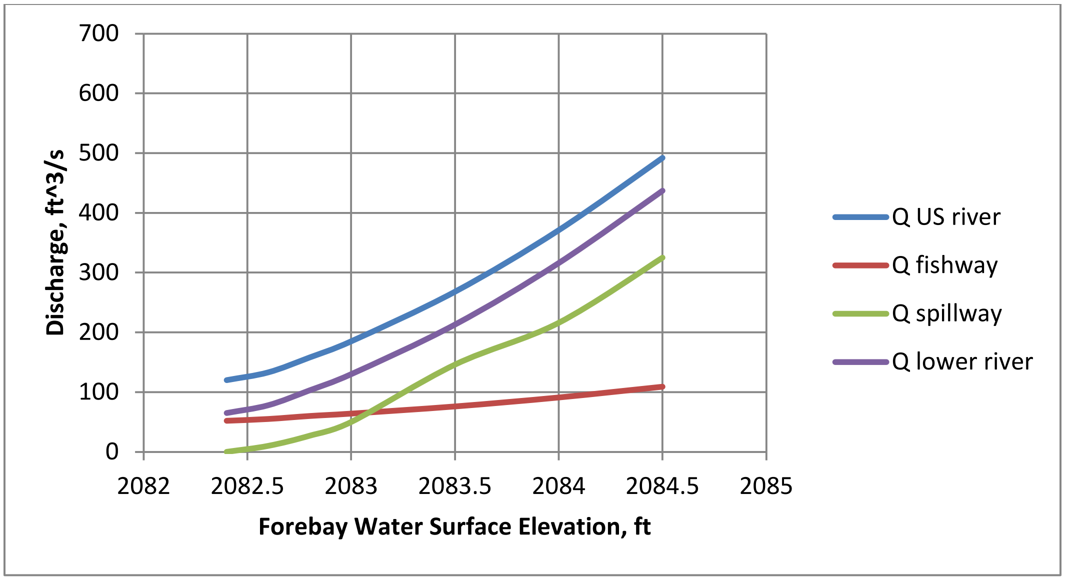


Figure 52. Extrapolated flow splits for fishway and spillway, assuming 55 ft^3/s diversion and an effective dam crest length of 35.6 ft at elevation 2082.4 ft.

Conclusions

The model study identified a number of modifications that would improve facility performance for the fish screen and fishway. The major performance issues and corrective actions recommended from the model study are:

- Issue - Design diversion flow target cannot be met.
  Recommended action - Increase the fish screen design water surface to 2082.3. This requires adding a minimum of 1 ft of blanking panel above the top of screen, raising the fish ladder exit elevation 1 ft by adding an additional ladder pool upstream of the as-built exit, reducing the fishway orifice size to 12"x15" and reducing the headloss through the diversion structure and/or raising the spillway crest elevation.

- Issue – Poor uniformity of flow passing through the screens.
  Recommended action - Add three guide vanes behind the screen and modify the diversion channel shape by reducing the lateral expansion of the diversion channel in front of the screens. Initially set the screen baffles following the percent opening given in Table 4, model test 31.

- Issue – Tailwater to fishway entrance pool water surface differences exceed 1 ft for all conditions.

Recommended action – Lower the fishway entrance elevation 2 ft by adding two additional bays downstream of the as-built fish ladder entrance. Note, this modification was not found to fully meet the 1 ft maximum differential objective under high river flows. Options for increasing tailwater elevation were not studied due to insufficient prototype tailwater elevation and downstream bathymetry data.

- Issue – Fishway exit pool to diversion pool water surface difference can exceed the 1 ft differential target.
  Recommended action – Operate the fishway with both orifices in the exit baffle open and all downstream baffles with one orifice open. Note, characteristics of pool and chute fishways like the NBFC structure typically exhibit the formation of random standing waves in the fishway pools and water surface tuning issues at the exit.

- Issue – Fishway can't be easily un-watered.
  Recommended action - Alternatives for closing and unwatering the fishway were not addressed in the model study. However, the model study pointed out the operational importance of providing improved access to the fishway for opening and closing orifice gates and debris removal.

Fish Screen Findings

- Diverting 55 ft^3/s requires a reservoir pool elevation >~ 2082.4 and a diversion channel WSE of ~ 2082.25 (top of screens=2081.46).
- The model study confirms field tests indicating highly non-uniform approach flow conditions on the screen.
- Headloss through the entrance gate can be reduced ~ 0.4 ft by adding a bullnose transition to the upstream entrance. Adding transition guide walls downstream of the gate can provide an additional ~ 0.1 ft headloss savings.

Fish Screen Issues not Addressed by the Model Study

- The fish bypass outfall has insufficient tailwater to perform as intended. A modification of the outfall design or increasing tailwater is needed.

Fishway Findings

- The as-built fishway conveys 80 ft^3/s flow with 2-1 ft weir boards installed in the exit baffle at forebay elevation 2082.4 (elevation required for full diversion).

- Operating the fishway with 2 small orifices open in baffle 11 and one small orifice open in baffles 1-10 allows diversion flows to be achieved at 110 ft^3/s with forebay WSE of 2082.4.

- As-built orifices pass ~ 50 ft^3/s (2 open per baffle) or 35 ft^3/s (1 open per baffle) for a 1 ft drop across the baffles.

- A 12inch by 15inch orifice pass about pass ~ 24 ft^3/s (2 open per baffle) or 17 ft^3/s (1 open per baffle) for a 1 ft drop across the baffles.

- The exit baffle is less efficient than downstream baffles due to difference in approach flow. This results in a greater WS drop at the exit compared to downstream baffles.

- No large scale flow instability has been seen for fishway flows <250 ft^3/s (tested range).

Fishway Issues not Fully Addressed by the Model Study

- WS pool-to-pool differences of 1 ft to 1.5 ft may occur at the exit even with the added bays.

- For high river flows, tailwater elevation is unknown. During high fishway flows, tailwater elevation may be too low to achieve a maximum of a 1 ft drop in water surface at the fishway entrance, even with lowering the entrance by 2 ft (with the addition of two bays).

- Small spillway flows carrying smolts may occur frequently during river flows from 100 ft^3/s to ~150 ft^3/s with the modifications identified and the as-built spillway crest elevation.

References

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