TECHNICAL MEMORANDUM Bureau of Reclamation

Tehama-Colusa Canal Authority (TCCA) – Fish Passage Improvement Project at Red Bluff Diversion Dam

Red Bluff Pumping Plant and Fish Screen Project Hydraulics: Fish Refuge Physical Modeling (1:1 Scale)

PREPARED FOR:	Lauren Carly/Reclamation Alan Stroppini/ Reclamation Al Bernstein/ Reclamation Bob Gatton/ CH2M HILL Pete Rude/ CH2M HILL
PREPARED BY:	Dale Lentz/ Reclamation
REVIEWED BY:	Tracy Vermeyen/ Reclamation
COPIES:	Al Bernstein/Reclamation Brian Goplen/Reclamation Pete Rude/CH2M Hill Bob Gatton/CH2M Hill
DATE:	June 30, 2009

Introduction

This technical memorandum summarizes the Red Bluff Fish Screen Fish Refuge physical model at Reclamation's Hydraulics Laboratory in Denver, Colorado. This memorandum details modeling methods, results, and recommendations for the prototype fish refuge design.

Model Setup

A 1:1 scale physical model of a proposed fish refuge was built inside a 3 ft by 60 ft sloping flume (figure 1). The channel and refuge were constructed of smooth marine-grade plywood and Plexiglas®. The 3-ft-wide channel narrows to an 8 in. wide channel that extends for 14 ft before the start of the fish refuge section. The initial refuge was 10 ft long, but was eventually shortened to 8 ft and is separated

from the main channel by ¾ in. diameter horizontal bars spaced 1.75 in. on center. The distance between the bottom bar and the floor of the flume was 1.25 in. to accommodate the size of the juvenile sturgeon available for testing. The back wall of the refuge was constructed of Plexiglas and was adjusted to create different pocket depths.

Downstream from the refuge the 8-in.-wide channel extended for another 8 ft and then transitioned abruptly to the full 3 ft channel width for the last 8 ft of the flume. The water depth in the flume was controlled by tailwater boards and was held at about 20 in. deep in the refuge test section. Limitations of the model are: a maximum water depth of 24 in. and an 8 in. wide channel compared to a much deeper and wider river. The Red Bluff Pumping Plant fish screen model showed prototype sweeping velocities were 5 to 6 ft/sec. The 8 in. wide model channel allowed the model to operated at the expected velocities and it kept the passing fish in close proximity to the refuge.

A fish holding/release pen was built in the upstream transition by installing a pair of removable screens. The purpose of this fish pen was to allow the fish to acclimate to the flume flow conditions. This pen was also used to “exercise” the fish for an extended period prior to release. The exercise period was intended to fatigue the salmonids so they would be inclined to seek refuge. The velocities in this fish pen ranged from 1 to 2 ft/s. The sturgeon were not exercised for this study.

A fine meshed screen and reduced velocities at the downstream end of the flume allowed for fish holding and recovery. A high-speed video camera was used to document fish interaction and usage of the refuge.

Juvenile Chinook salmon, white sturgeon, and rainbow trout were tested in the refuge model. The test fish were held in Reclamation’s fish laboratory and were cared for by fishery biologists. The Chinook ranged in length from 3 to 4 in. The sturgeon ranged in length from 5 to 7 in. The trout ranged in length from 1 to 2 in.

During fish tests, Chinook were released into the fish holding pen and were allowed to swim/hold for one hour before being released and allowed to move downstream toward the refuge. For some tests, Chinook were also released directly into the refuge for observation. Generally, about 10 Chinook were released during a test. The sturgeon were placed into the release pen and allowed to swim for a few minutes to acclimate and to achieve bottom orientation before being allowed to move downstream. Sturgeon were also released directly into the refuge. Typically, four sturgeon were released during a test. The rainbow trout were released in different areas upstream of the refuge using an injection tube. Trout were also released directly into the refuge. Typically 14 Trout were released at a time. At the conclusion of a test, all fish were recaptured at the end of the flume.

Figure1. Red Bluff fish refuge physical model. The photograph on the left is an overview of the model. The top right photo is a side view of the refuge, where flow is from left to right. The bottom right photograph is a close up of the horizontal bars.

A three dimensional, 16-megahertz Micro ADV (Acoustic Doppler Velocimeter) was used to collect velocity data in the fish refuge model. For different test conditions, velocity data were taken at 3 locations along the length of the refuge. Velocities were measured in the "river" channel 3 in. away from the horizontal bars. Measurements started at 1 ft upstream of the refuge and were measured every 1 ft through the refuge section, down to 1 ft downstream of the refuge. The velocity sample area was at mid depth of the water column. Velocities were also measured in a similar manor in the refuge located 1.5 in. from the bars and 1.5 in. away from the back wall. Measurements started at 0.2 ft away from the upstream end and continued every 1 ft down until 0.2 ft. from the downstream end.

Test Configurations

Initial velocity data were taken with a 3-in-wide by 10-ft-long refuge. There was little recirculation of flow in the refuge. Dye released upstream of the refuge moved in and out of the refuge almost as fast of the dye in the channel. Dye released in the refuge was quickly washed out. A 6-in. wide refuge had more flow recirculation and slower velocities along the length of the refuge. Dye typically stayed in the refuge for 15-20 seconds before being washed out. Therefore, all subsequent tests (including all fish release tests) used a 6-in.-wide refuge. Figure 2 shows overall slower velocities in the 6-in. wide refuge compared to the 3 in. Solid lines represent velocities for the 6 in. refuge and dashed lines are for the 3-in. refuge. Lines of the same color were taken at the same location. The error bars for each data point represent turbulence measurements at that location.

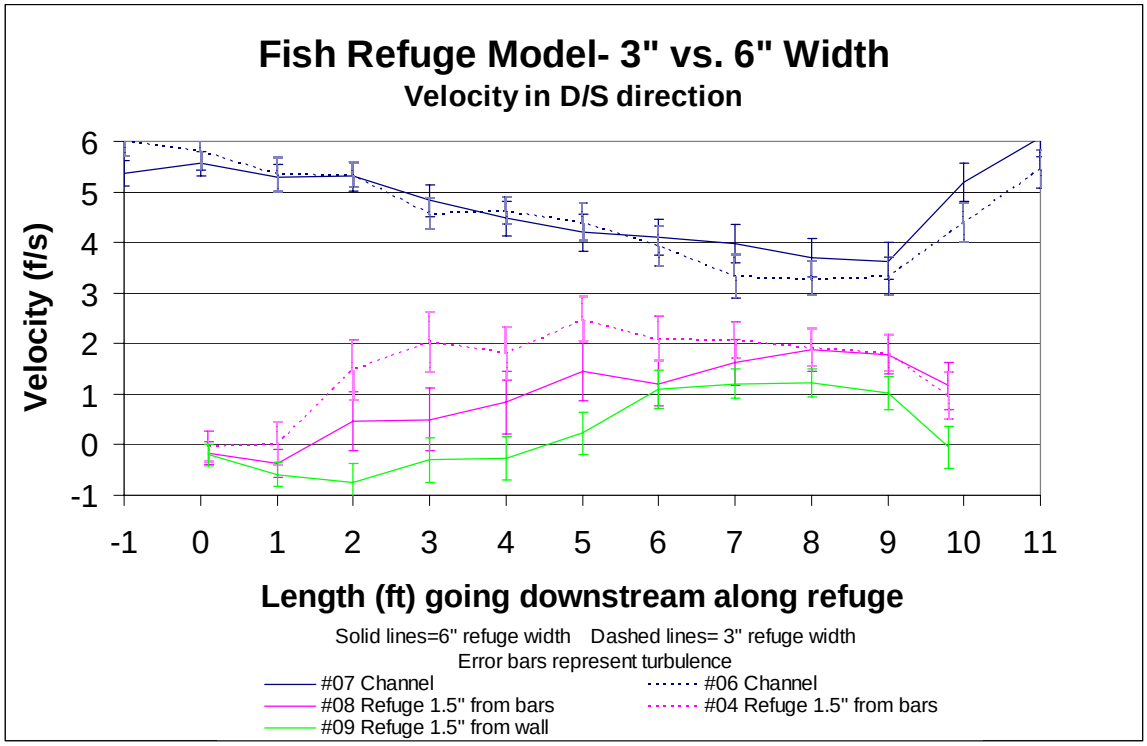

Figure 2. Velocities along the length of the refuge, 3 in. vs. 6 in. wide refuge.

The back wall of the refuge was made of smooth Plexiglas. To create roughness, 1.5 x 1.5 in. vertical boards were added to the back wall of the refuge, placed 6 in. on center. This modification created a lot of turbulence and small eddies near the back wall. The Chinook appeared to have a tougher time swimming in this condition. The spacing of the boards was increased to 18 in. and the width of boards that protruded into the refuge was reduced to ¾ in. This condition reduced velocities in the refuge with less turbulence than the thicker boards. For this modification, it appeared that both Chinook and sturgeon were able to swim in the refuge without much trouble. Velocity measurements plotted in figure 3 show slower velocities throughout the refuge when roughness was added to the back wall of the refuge compared to a smooth back wall. Solid lines represent velocity with a smooth back wall, and the dashed are with roughness added to the back wall of the refuge. Lines of the same color were taken at the same location. The "error bars" represent turbulence measurements at that location.

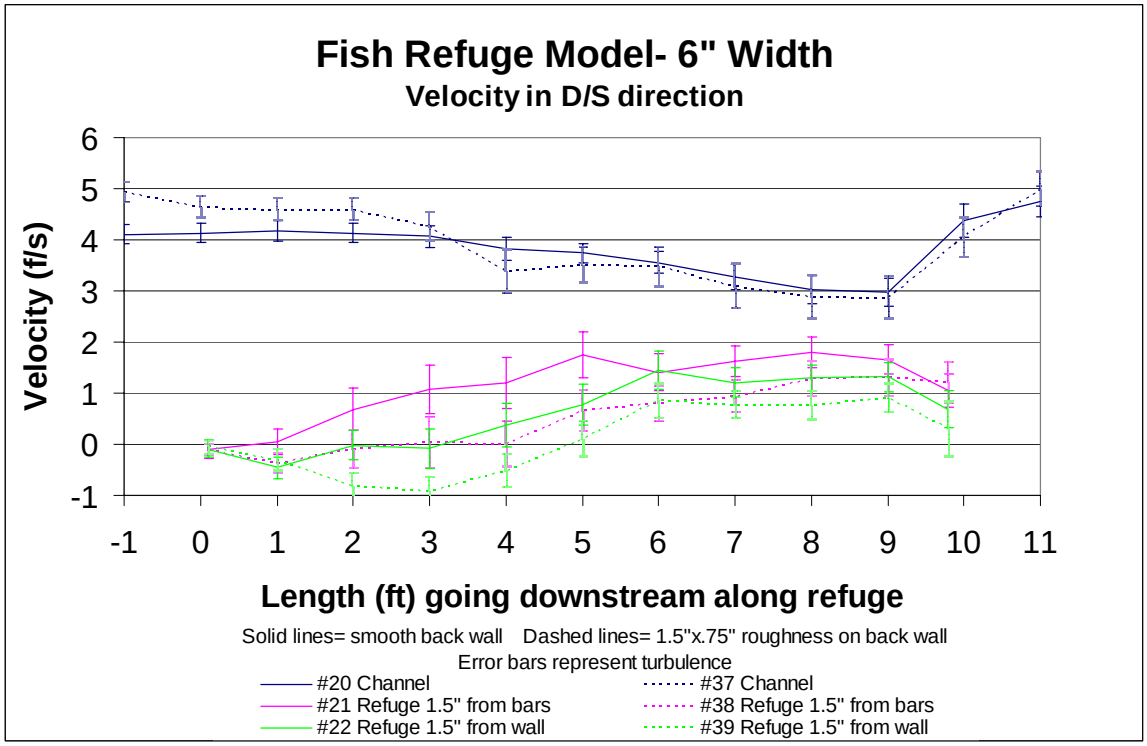

Figure 3. Velocities measured along the length of the refuge for a smooth wall and with roughness elements on back wall.

Observations from videos of the fish tests show that the majority of the fish entering the refuge did so within the 1st half of the refuge length. Therefore, tests were done with a portion of the refuge blocked off. A thin sheet of Plexiglas was clamped to the inside of the horizontal bars to block flow into the refuge. A variety of panel openings were tested.

For the 10-ft-long refuge velocity data were collected for the condition where the refuge was open for 5 ft, blocked for 4 ft and open for 1 ft. For the 8-ft-long refuge, the configuration was a 4 ft opening, 3 ft blocked, and 1 ft open. The blocking panel was raised 3 in. off the floor which allowed sturgeon to pass in and out of the refuge along its entire length. For both configurations, the panel lowered velocities in the refuge, reduced turbulence behind the panel, and created a more uniform flow through the refuge. Figure 4 shows slower velocities and lower turbulence in the refuge behind the blocked off portion compared with no panel. Solid lines are data for test condition with roughness on the back wall and a panel blocking part of the refuge opening. The dashed lines are with the refuge unblocked. Lines of the same color were taken at the same location. The error bars represent turbulence at that location.

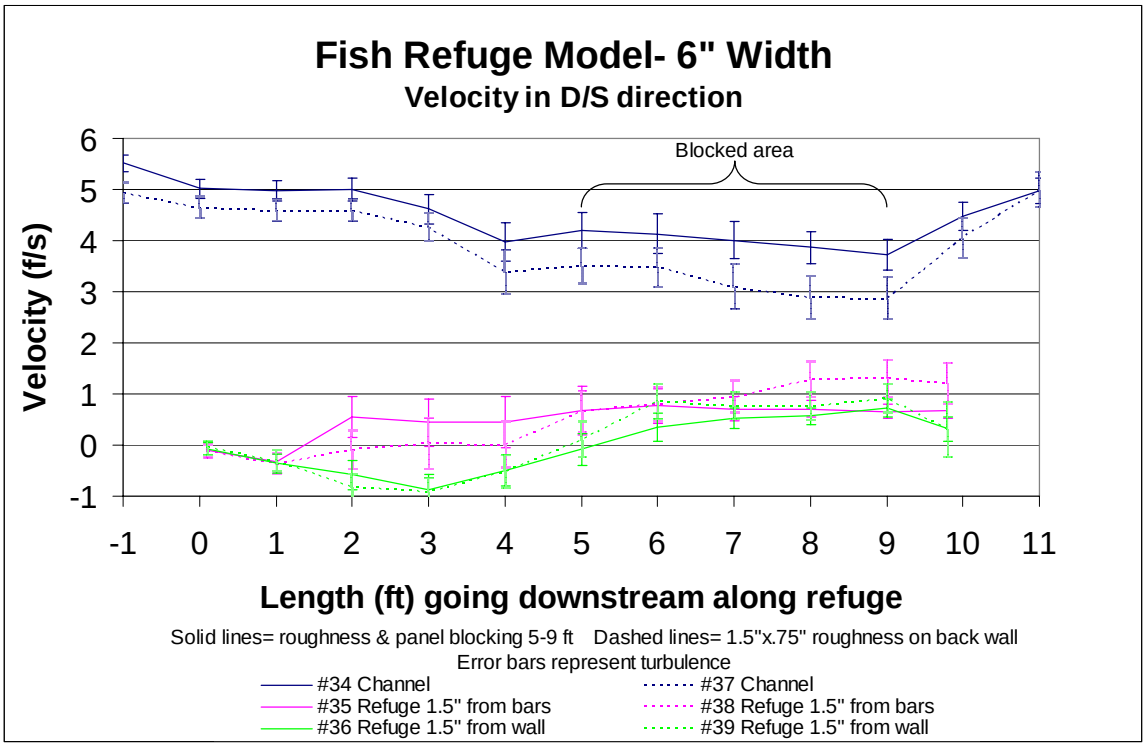

Figure 4. Velocities measured along the length of the refuge for partially blocked and unblocked conditions.

A larger downstream opening of 2.5 ft was tested. With the larger opening, flow was entering the refuge at the beginning of the downstream opening. This created a large recirculation zone and high turbulence in this area. When the downstream opening was only 1 ft long there was only flow exiting the refuge. The smaller opening reduced the recirculation zone and turbulence at the downstream end of the refuge. Observations from fish tests show that fish were able to hold position in the downstream end of the refuge easier with a 1 ft opening compared to the 2.5 ft opening.

A divider wall was placed in the refuge to create two 5-ft-long refuges. This wall made both refuges more turbulent, so the divider wall was removed in favor of a longer less turbulent refuge.

The refuge model was originally designed and built after the larger prototype refuge, 6 in. by 10 ft. All Chinook and sturgeon tests were preformed in this size model. Later the refuge model was modified to reflect the revised fish refuge design in the prototype. - a 6 in. by 8 ft. refuge. Because of the size of the growing Chinook and sturgeon, smaller rainbow trout were tested in the 8-ft-long refuge. The 8-ft-long refuge preformed similarly to the 10 ft refuge, but with slower velocities. Figures 5 and 6 contain plots for a 10-ft- and an 8-ft-long refuges, respectively.

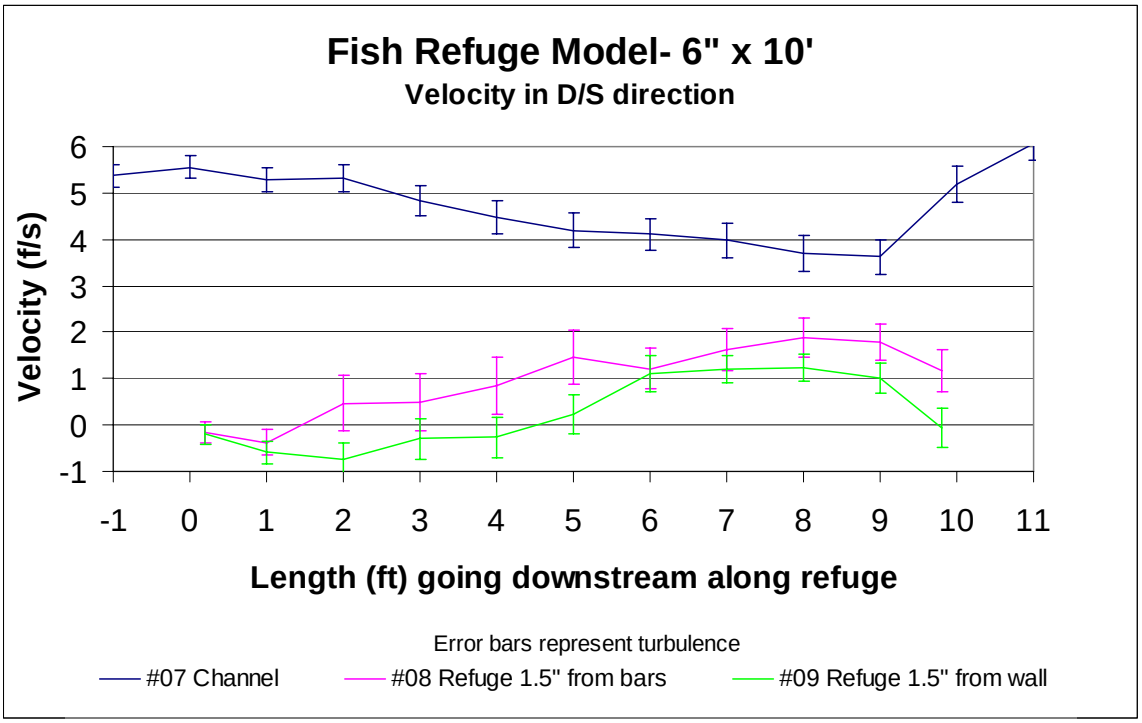

Figure 5. Typical velocities in 6 in. by 10 ft. refuge.

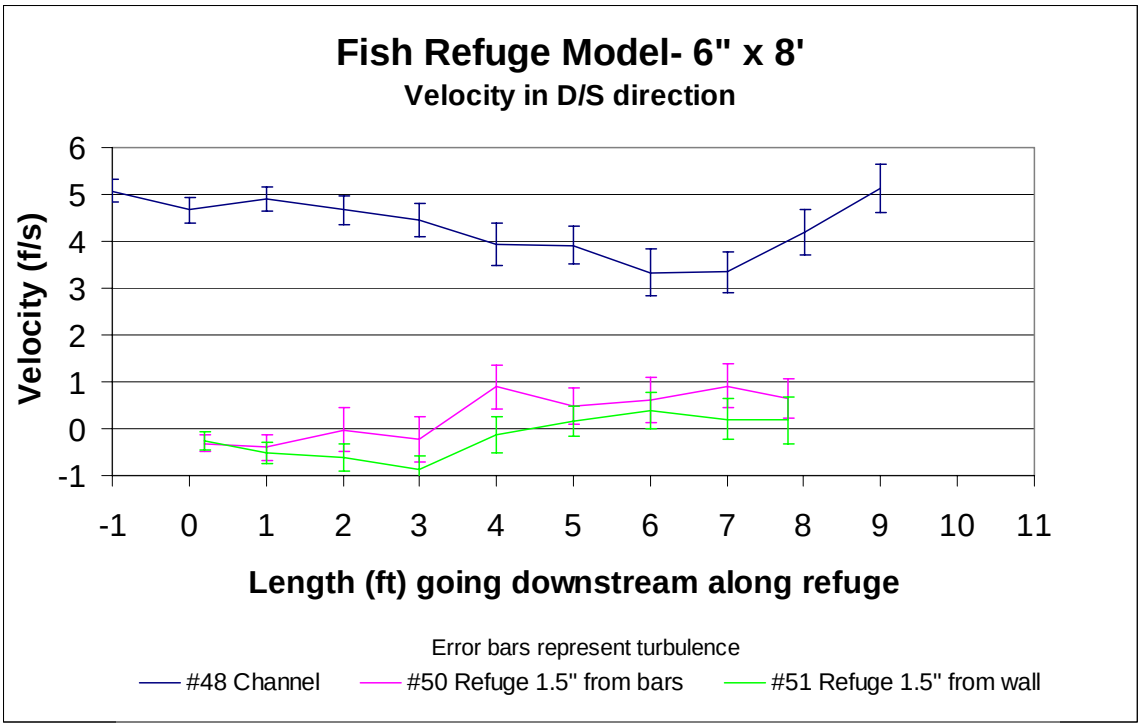

Figure 6. Typical velocities in 6 in. by 10 ft refuge.

Dye released upstream of the refuge shows that flow right next to the fish screen moves into the refuge (figure 7). This suggests that a fish traveling right along on the screen might be carried into the refuge.

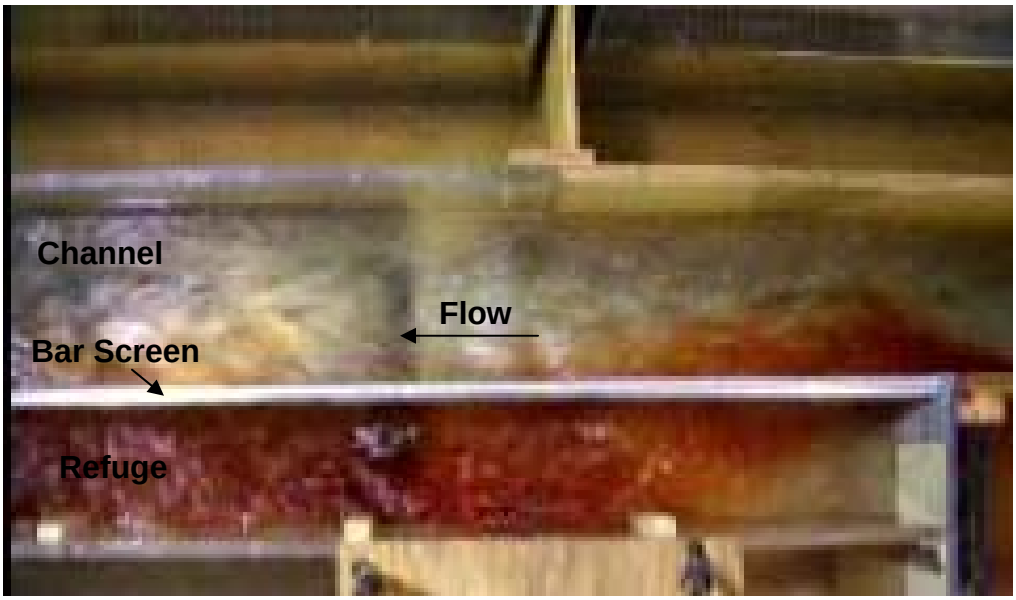

Figure 7. Plan view of dye released at upstream end of refuge, 6 in. by 10 ft refuge with panels blocking.

Fish Test Observations

Chinook Salmon - Chinook refuge tests were conducted with channel velocities between 4 and 5 ft/s. Channel velocities were measured at mid-depth, half way down the length of the refuge. Chinook were released at the upstream end of the flume and directly into the refuge. Chinook test observations are as follows:

- Juvenile Chinook had no difficulty freely moving through the horizontal bars and they easily passed in and out of the refuge.
- Chinook could easily hold position near the channel bed and to a lesser degree in the entire water column.
- Fish entering the refuge test section along the wall representing the fish screen structure were more apt to move directly into refuge.
- Fish holding position in the channel several inches from the horizontal bars did not prefer entering the refuge over holding position or moving downstream. However, if we approached or walked past the Plexiglas wall, the fish would move into the refuge.
- Chinook had little difficulty staying in the refuge, but they preferred the low velocity and less turbulent flow conditions found at the upstream end of the refuge.
- Chinook placed directly into the upstream end of refuge maintained position in that location for long periods of time. Fish that moved downstream were often swept out or swam out of the refuge and were carried downstream.

White Sturgeon - Sturgeon tests were conducted at channel velocities of 2, 3, 4, and 5 ft/s. Sturgeon were released from the holding pen at the upstream end of the flume. Sturgeon test observations are as follows:

- In general, sturgeon were more apt to use the refuge when they could maintain bottom orientation and control their position through the refuge test section.
- Sturgeon facing upstream and orientated near the channel bottom were observed to freely move into and out of the refuge.
- Sturgeon passing through the refuge section higher in the water column were unable to move into the refuge because they could not hold a horizontal position in the higher velocity flow.
- Sturgeon primarily moved into the refuge by moving between 1.25 in. gap between the bottom horizontal bar and the flume floor.
- Once inside the refuge the sturgeon stayed there for long periods of time. Like the Chinook, they preferred the low velocity and less turbulent flow conditions found at the upstream end to the refuge.
- Turbulent flow in the downstream portion of the refuge made it difficult for the sturgeon to maintain position on the channel bottom.

Rainbow Trout - Trout tests were conducted at channel velocities of 4 to 5 ft/s. Trout were released into the refuge using an injection tube. Release locations varied from 3 ft upstream of the refuge to 15 ft upstream. Fish were released along the wall representing the fish screen structure and the far flume wall, and directly into the refuge. Rainbow trout test observations are as follows:

- Once in the refuge, trout could easily hold position for long periods of time.
- The majority the trout preferred to hold in the upstream end of the refuge, but a few would hold position at the downstream end when the blocking panel was in place.
- If trout did not go into the refuge they were quickly washed downstream pass the refuge.
- Trout generally entered the refuge in the bottom half of the water column, but a few did enter the refuge from the upper half of the water column.
- Trout released 3 ft upstream from the refuge had a higher percentage that entered the refuge than when fish were released 15 ft upstream
- Trout released with part of the refuge blocked had a higher percentage that went into the refuge than without blocking panels.

Conclusions and Recommendations

A 6 in. wide refuge had better flow conditions when compared to the 3 in. wide refuge. Wider refuges were not tested because of the design width limitation in the fish screen blowout panels where some of the refuges will be located. Although the vertical roughness elements on the back wall of the refuge did reduce velocities in the refuge, they were deemed unnecessary when a blocking panel was used. Blocking panels were more effective at reducing velocities in the refuge and created uniform flow conditions with less turbulence. The blocking panel configuration that provided the best flow condition was a 5 ft opening, 4 ft blocked and a 1 ft opening for the 10-ft-long refuge. For an 8-ft-long refuge a 4 ft opening with 3 ft blocked, and a 1 ft opening created uniform flow through the refuge. Model tests showed that an 8 ft. long refuge preformed similar to a 10 ft.

Based on limited laboratory testing, this fish refuge concept appears feasible for the Red Bluff Pumping Plant fish screen. Additional field research will be necessary to evaluate debris and sedimentation accumulation in the fish refuge. Field evaluation of blocking panels will be necessary to verify their utility. Field observations of juvenile Chinook and sturgeon and predators would be of interest.

Appendix A. Fish test log

Video filename	Fish Species	Channel Velocity	Release location	Refuge Configuration	released	Initial # in refuge	Final # in refuge
fishtest2	Chinook	4	upstream		nr	nr	nr
fishtest4	Chinook	4	refuge		nr	nr	nr
fishtest5	Chinook	4.9	upstream		nr	nr	nr
fishtest6	Chinook	4.9	refuge		nr	nr	nr
fishtest7	Sturgeon	2	upstream		nr	nr	nr
fishtest8	Sturgeon	3.2	upstream		nr	nr	nr
fishtest9	Sturgeon	3.9	upstream		nr	nr	nr
fishtest10	Sturgeon	5	upstream		nr	nr	nr
fishtest11release	Chinook	4.3	upstream	1.5x1.5 vertical boards on back wall 6" on center	nr	nr	nr
fishtest11hold	Chinook	4.3	refuge	1.5x1.5 vertical boards on back wall 6" on center	nr	nr	nr
fishtest12hold	Chinook	4.3	refuge	1.5x1.5 vertical boards on back wall 18" on center	nr	nr	nr
fishtest13hold	Sturgeon	3	refuge	1.5x1.5 vertical boards on back wall 18" on center	nr	nr	nr
fishtest14release	Chinook	4.3	upstream	1.5x.75 vertical boards on back wall 18" on center & wedge placed upstream of refuge to increase eddy in refuge	nr	nr	nr
fishtest14hold	Chinook	4.3	refuge	1.5x.75 vertical boards on back wall 18" on center & wedge placed upstream of refuge to increase eddy in refuge	nr	nr	nr
fishtest15release	Chinook	4.5	upstream	1.5x.75 vertical boards on back wall 18" on center.	nr	nr	nr
fishtest15hold	Chinook	4.5	refuge	1.5x.75 vertical boards on back wall 18" on center.	nr	nr	nr
fishtest16release	Sturgeon	3.8	upstream	1.5x.75 vertical boards on back wall 18" on center.	nr	nr	nr
fishtest16hold	Sturgeon	3.8	refuge	1.5x.75 vertical boards on back wall 18" on center.	nr	nr	nr
fishtest17release	Chinook	~4.5	upstream	1.5x.75 vertical boards on back wall 18" on center. Panel 5' open, 2.5' closed, 2.5' open. Panel is 3" off floor	nr	nr	nr
fishtest18release	Chinook	~4.5	upstream	1.5x.75 vertical boards on back wall 18" on center. Panel 6.5' open, 2.5' closed, 1' open. Panel is 3" off floor	nr	nr	nr

fishtest19release	Chinook	~4.5	upstream	1.5x.75 vertical boards on back wall 18" on center. Panel 5' open, 4' closed, 1' open. Panel is 3" off floor	nr	nr	nr
fishtest20releasetube	Trout	4.5	3' us near wall, mid depth	6" x 8' refuge panel 4' open, 3' closed 1' open	10	8	7 us, 1 ds
fishtest21releasetube	Trout	4.5	3' us near wall, bottom	6" x 8' refuge panel 4' open, 3' closed 1' open	14	11	11 us
fishtest22releasetube	Trout	4.5	15' us near wall, bottom	6" x 8' refuge panel 4' open, 3' closed 1' open	14	12	12 us
fishtest23releasetube	Trout	4.5	15' us far wall, bottom	6" x 8' refuge panel 4' open, 3' closed 1' open	13	7	7 us
fishtest24releasetube	Trout	4.5	15' us near wall, bottom	6" x 8' refuge no panel	14	5	5 us
fishtest25releasetube	Trout	4.5	15' us near wall, bottom	6" x 8' refuge no panel	14	5	5 us
fishtest26releasetube	Trout	4.5	15' us far wall, bottom	6" x 8' refuge no panel	14	6	6 us
fishtest27releasetube	Trout	4.5	15' us far wall, surface	6" x 8' refuge no panel	15	9	9 us
fishtest28releasetube	Trout	4.5	3' us near wall, bottom	6" x 8' refuge no panel	14	7	7 us
fishtest29releasetube	Trout	4.5	3' us near wall, bottom	6" x 8' refuge no panel	14	11	11 us
fishtest30releasetube	Trout	4.5	15' us near wall, bottom	6" x 8' refuge panel 4' open, 3' closed 1' open	13	8	8 us
fishtest31releasetube	Trout	4.5	15' us near wall, bottom	6" x 8' refuge panel 4' open, 3' closed 1' open	14	7	6 us, 1 ds
fishtest32releasetube	Trout	4.5	15' us near wall, bottom	6" x 8' refuge panel 4' open, 2.5' closed 1.5' open	14	3	2 us, 1ds
fishtest33releasetube	Trout	4.5	15' us near wall, bottom	6" x 8' refuge panel 4' open, 2.5' closed 1.5' open	14	7	7 us

PEER REVIEW DOCUMENTATION

Hydraulic Investigations and Laboratory Services Group, 86-68460

Project and Document Information

Project Name: Tehama-Colusa Canal Authority (TCCA) – Fish Passage Improvement Project at Red Bluff Diversion Dam

WOID: RBTLT

Document Title: Red Bluff Pumping Plant and Fish Screen Project Hydraulics: Fish Refuge Physical Modeling (1:1 Scale)

Document Author(s)/Preparer(s): Dale Lentz, P.E. Hydraulic Engineer

Peer Reviewer(s): Tracy B. Vermeyen, P.E. Hydraulic Engineer

Review Certification

Peer Reviewer: I have reviewed the above document and believe it to be in accordance with the project requirements, standards of the profession, and Reclamation policy.

Reviewer: /s/ Tracy B. Vermeyen Date reviewed: 7/15/2009
(Signature)

Preparer: I believe that this document has been reviewed and approved in accordance with Reclamation policy, and is complete and ready for distribution.

Lead Author: /s/ Dale J. Lentz Date: 7/16/2009
(Signature)