Hydraulic Laboratory Report HL-2020-03

Antioch Fish Release Site Replacement Physical Hydraulic Model

Delta Division, Central Valley Project, California
California-Great Basin Region 10

U.S. Department of the Interior September 2020

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14. ABSTRACT As part of the demolition and reconstruction of the Antioch Fish Release Site the design team requested a hydraulic model be constructed at Reclamations Hydraulics Laboratory in Denver, CO. The goal of the model was to evaluate how debris in the release pipe is flushed using the developed standard operating procedure for the release site. The primary concern in the operation was the potential for the damage of fish if the debris is not completely removed during the 10-minute “Pre-Flush” phase of the operation. Buoyant debris was chosen as the primary debris material due to its resistance to flushing and its ability to recirculate in hydraulic jumps during the “Fish Release” phase. A 1:4 scale physical model was constructed to analyze the full release operation and determine the flushing capabilities of the system. This report summarizes the physical model results.			
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Cover Photo: Physical model located in Reclamation's Hydraulics Laboratory in Denver, CO (credit: Jacob Carter-Gibb)

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Glossary

B.O.	Biological Opinions
CGB	Interior Region 10 - California-Great Basin
CVP	Central Valley Project
Delta	Sacramento-San Joaquin River Delta
DWR	State of California, Department of Water Resources
MHHW	Mean high-high water surface
MLLW	Mean low-low water surface
NAVD 88	North America Vertical Datum of 1988
Reclamation	U.S. Bureau of Reclamation
SAV	Submerged aquatic vegetation
SOP	Standard Operating Procedure
SWP	State Water Project

Executive Summary

The Antioch Fish Release Site is located near the Antioch Bridge off Highway 160 in Antioch, California. The federally owned site is used by both the John E. Skinner Delta Fish Protective Facility (operated by the State of California, Department of Water Resources (DWR)) and the Tracy Fish Collecting Facility (operated by the U.S. Bureau of Reclamation (Reclamation)) to meet Biological Opinions (B.O.) requirements for fish releases back to the San Joaquin and Sacramento Rivers upstream of the Sacramento-San Joaquin River Delta (Delta) confluence. Fish are collected at both the facilities which are located just outside of Tracy, California, on the Old River, which is the southern region of the Delta. Fish are collected before water from the Delta is pumped into the California Aqueduct and the Delta-Mendota Canal. The purpose of the Antioch Fish Release Site is to provide both collection facilities a means to deliver fish species to a point in the Delta beyond the influence of Reclamation's Central Valley Project (CVP) and DWR's State-Water Project (SWP) pumping systems.

As part of the demolition and reconstruction of the Antioch Fish Release Site, the California-Great Basin (CGB) regional design team requested a hydraulic model be constructed at Reclamation's Hydraulics Laboratory in Denver, CO. The goal of the model was to evaluate how debris in the release pipe is flushed using the developed standard operating procedure for the release site. The primary concern in the operation was the potential for the injury of fish if the existing submerged debris is not completely removed during the 10-minute "Pre-Flush" phase of the operation. A 1:4 scale physical model was constructed to analyze the full release operation and determine the flushing capabilities of the system.

This report summarizes the physical model results. Three different downstream water surface elevations were tested with three different debris loads: a mean low-low elevation, mean high-high elevation and an intermediate point. The model was tested through the full release procedure which included thru-pipe water releases of 3 ft^3/sec for 10 minutes for pre-fish release flushing, 1.75 ft^3/sec for 4 minutes for fish release, and 3 ft^3/sec for 10 minutes for post-fish release flushing. It was determined that the proposed operating procedure adequately cleared debris from the release pipe for all debris except for large amounts of small floating debris which the authors refer to as the extreme case, extreme referring to the debris that was most difficult to pass.

Project Background

The Antioch Fish Release Site is located near the Antioch Bridge off Highway 160 in Antioch, California. The federally owned site is used by both the John E. Skinner Delta Fish Protective Facility (operated by the DWR) and the Tracy Fish Collecting Facility (operated by Reclamation) to meet B.O. requirements for fish releases back to the San Joaquin and Sacramento Rivers. Fish are collected at both facilities which are located just outside of Tracy, California, on The Old River, which is the southern region of the Delta. Fish are collected from the Delta before water is pumped into the DWR's California Aqueduct and Reclamation's Delta-Mendota Canal. The purpose of the Antioch Fish Release Site is to provide both collecting facilities a means to deliver captured fish species to a point in the Delta beyond the influence of Reclamation's CVP and DWR's SWP pumping systems. Figure 1 provides the location of the Antioch release site in relation to both collection facilities.

Figure 1. Overview map of the Antioch Fish Release Site and both fish collecting facilities that utilize the site.

The current Antioch Fish Release Site was designed in the early 1980's and constructed in 1983. The site includes a 6-inch valve and pipe, a horizontal pumping unit to obtain water for the release process, and an 80-ft-long 12-inch diameter fish delivery pipeline that extends under the low water level. The site also includes the necessary structural components (concrete, electrical, asphalt, gating) to allow the fish haul trucks to access and release at the site. In 2012, the existing release pipe separated and a dive inspection determined that the steel pipe contained numerous holes and weak areas caused by the highly corrosive water quality in the area. Temporary repairs have enabled the site to continue to function while a replacement site is designed.

The proposed fish release site will replace the old infrastructure with a new pump with fish screen and a new release pipe that complies with the CVP and SWP B.O. long-term objectives and incorporates lessons learned during the recent construction of two recently completed fish release sites (Little Baja and Manzo Ranch) that were completed by DWR in 2016. The new site will be composed of a 1-foot diameter pipe running approximately 178-feet from a new concrete pad into the San Joaquin River, a new water intake pipe for auxiliary flow paralleling the release pipe, as well as all new structural components. Under high water conditions approximately 136-feet of the pipe will be submerged and under low water conditions approximately 112-feet of pipe will be submerged with an inlet elevation of 12 ft using North America Vertical Datum of 1988 (NAVD 88) and an outlet elevation of -7.5 ft (NAVD88).

Model Description

Model Objectives

The 1:4 Antioch Fish Release Site Replacement physical hydraulic model study focused on the following objectives:

- Ensure debris can be flushed with the proposed standard operating procedure (SOP); 3 ft^3/sec of flushing flow for 10 minutes, 1.75 ft^3/sec of flush flow for 4 minutes, and 3 ft^3/sec of flushing for 10 minutes) for the following design water surface elevations. The standard operating procedure was developed by a multi-agency team during the designs of the Manzo Ranch and Little Baja sites.
    - Mean High High Water (MHHW) = 5.75 ft (NAVD88)
    - Mean Low Low Water (MLLW) = 1.5 ft (NAVD88)
    - Intermediate water surface = 4.5 ft (NAVD88)
- Suggest modification to the proposed SOP if:
    - the debris is not fully cleared.
    - significant blow back into the release truck occurs.

Model Scale

Similitude between the model and the prototype is achieved when the ratios of the major forces controlling the physical processes are equal in the model and prototype. Froude-scale similitude was used to establish a kinematic relationship between the model and the prototype. The Froude number is defined as

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

where v = velocity, g = gravitational acceleration, and d = flow depth. When Froude-scale similitude is used for a 1:4 scale, the following relationships exist between the model and prototype where the r subscript refers to the ratio of model to prototype:

Length ratio: $L_r = L_{model}/L_{prototype} = 1:4$

Pressure ratio: $P_r = L_r = (4) = 1:4$

Velocity ratio: $V_r = L_r^{1/2} = (4)^{1/2} = 1:2$

Time ratio: $T_r = L_r^{1/2} = (4)^{1/2} = 1:2$

Discharge ratio: $Q_r = L_r^{5/2} = (4)^{5/2} = 1:32$

Model Features

A 1:4 scale physical hydraulic model was tested at Reclamation's Hydraulics Laboratory in Denver, CO to ensure that the operational procedure of the fish release site performed as designed and will meet B.O. recommendations to minimize injury to fish as they are released into the San Joaquin River. The model was constructed using 3-inch inside diameter acrylic pipe to represent the fish release pipe, 1.5-inch schedule 40 PVC to represent the auxiliary flow piping, and a wooden tailwater box to control the downstream water surface elevation to match the river water surface elevations. The release pipe with auxiliary flow piping can be seen in Figure 2.

Figure 2. Top down view of the auxiliary flow manifold (direction of fish release is from the bottom of the photo to the top).

Typical debris that the Tracy Fish Collecting Facility and the John E. Skinner Delta Fish Protective Facility encounters is primarily composed of biological components, most often submerged aquatic vegetation (SAV) and small woody debris, but occasionally man-made material such as pill bottles, plastic drink bottles and other synthetic debris can be collected (Garrison, 2020). An example of debris pulled from the facilities is shown below in Figure 3.

Figure 3. Brazilian Elodea and woody debris composed of sticks, twigs, roots, bark, seeds and peat encountered during the salvage process at the Tracy Fish Collection Facility (Wu and Bridges, 2014).

To model the SAV, plastic aquarium plant strings (Figure 4) were used. Buoyant woody debris and the other synthetic debris was modeled using round Styrofoam beads. The average particle size of the small, medium, and large Styrofoam beads was 0.2, 0.95 and 1.92 inches in diameter respectively., (Figure 7 and 8). While the Styrofoam beads do not match the exact shape and size of the debris that would be expected at the site, a spherical object will maximize the buoyant force while minimizing the surface area and shear force that it could experience. This will create a conservative estimation of the flushing potential of the SOP. During shakedown testing it was found that neutrally/negatively buoyant material would pass very quickly (within a minute) at both the flushing discharges and fish release discharge. For this reason, buoyant particles were chosen to be primary debris modeled as they represented the worst case for debris passage and did not necessarily simulate the worst case debris loading from the facility (which would be very large quantities of weeds and saturated woody material that are typically bottom oriented..

Figure 4. An example of the plastic aquarium plant strings that were used to represent the submerged aquatic vegetation. The aquarium plant strings varied in length from 3 to 10-inches (model scale, equivalent to 12 to 40 in. prototype scale).

Instrumentation

A small pump mounted at the intake of the model provided discharge to the model. Water was recirculated through a 240,000-gallon storage reservoir which runs the length of the laboratory. The discharge was controlled using a vertical slide gate mounted to the inflow pipe and a variable frequency drive controlling the pump motor. Discharge was measured using a Siemens magnetic flow meter with an accuracy of ±0.25%. (Figure 5)

Figure 5. (Left) Vertical pump and controlling slide gate used to regulate the flow into the release pipe. (Right) Magnetic flow meter used to measure the flow entering through the auxiliary flow manifold.

The downstream water surface elevation in the model was controlled with a tailwater box that had an adjustable overflow weir. An ultrasonic down-looker was connected to a stilling well inside the tailwater box that was monitored continuously using a personal data acquisition system. This allowed for adjustment of the tailwater to match the required range of river surface elevations. The overflow weir can be seen in Figure 6, the gate was controlled using a hydraulic actuator allowing for consistent changes in elevation.

Figure 6. The downstream slide gate looking upstream. This allows for control of the tail water elevation to match simulated river water surface elevations over the desired range of operation.

Testing Procedure

The model was tested across the entire range of expected operations following this testing procedure:

- The downstream water surface was first brought up to one of the three test elevations and allowed to stabilize.
- The discharge was reduced to zero to allow the debris to be introduced into the pipe. This simulates any remaining debris in the pipe after a prior release was completed or any debris deposited by natural river conditions through the downstream end of the pipe.
- For each downstream water surface elevation, the following amounts of debris were added:
    - Low, 1 string of aquarium plant and 8.5-ounces each of small and medium Styrofoam balls. (Figure 7)
    - High, 6 strings of aquarium plant and 17-ounces each of large, medium, and small balls. (Figure 7)
    - Extreme/worst case scenario, 50-ounces of small foam beads.
        - During shakedown testing the small beads took the longest time to clear from the release pipe (Figure 8). This was considered the worst case from a debris passage standpoint, although it does not represent the typical debris type at the collection facilities.
- The flow was then turned on to the pre-flush flow of 0.094 ft^3/sec for 5 minutes (model scale, equivalent to 3.0 ft^3/sec for 10 minutes, prototype scale). When the last piece of debris cleared the pipe and entered the tailwater box, the total passage time was recorded.
- During the fish release phase, the pump was set to deliver 0.055 ft^3/sec for 5 minutes (model scale, equivalent to 1.75 ft^3/sec for 10 minutes, prototype scale), and 12 strands of vegetative

debris and 3 cups of neutrally buoyant particles were added to the release pipe. The truck release discharge was simulated as a constant inflow using a 5/8-inch hose.

- The post-flush phase the discharge was set to 0.094 ft^3/sec for 5 minutes (model scale, equivalent to 3.0 ft^3/sec for 10 minutes, protype scale). In the prototype release structure this allows for any excess debris or fish to be cleared that may be remaining in the pipe.

Figure 7. Typical low debris load (Left) and high debris load (Right) introduced into the physical model.

Figure 8. Extreme worst-case debris load, the smaller debris particles took longer to clear from the release pipe during shakedown testing of the model and were selected for a worst-case debris load.

Model Results

Low Debris Load

The low debris load was easily cleared by the pre-flush discharge of the SOP, 0.055 ft^3/sec for 5 minutes (model scale, equivalent to 1.75 ft^3/sec for 4 minutes, prototype scale). Debris would recirculate in the upper portion of the pipe as it made its way through a series of hydraulic jumps before entering smoother flow in the lower section. The smaller particles were susceptible to getting caught in the recirculation currents of the hydraulic jumps resulting in a similar clearing time for the low debris load and the high debris load. One of these hydraulic jumps can be seen in Figure 9.

Figure 9. A hydraulic jump forming during the beginning of the pre-flushing phase

As seen in Table 1, for every tested downstream water surface elevation the debris cleared the pipe within the 10-minute pre-flushing portion of the release procedure. At the intermediate downstream water depth of 4.5 ft a small cluster of small beads were stuck to the inside of the pipe in a recirculating eddy that took the longest to clear (Figure 10). This was seen across both trials of the low debris load at the 4.5 ft water surface elevation.

Table 1. Low debris load results, all times listed are in prototype units.

Downstream water surface elevation (ft)	Debris load	Debris cleared during pre-flush?	Time to clear debris (min)
1.5	Low	Yes	5:00
4.5	Low	Yes	6:00 for 90% 8:00 for 100%
5.75	Low	Yes	5:20

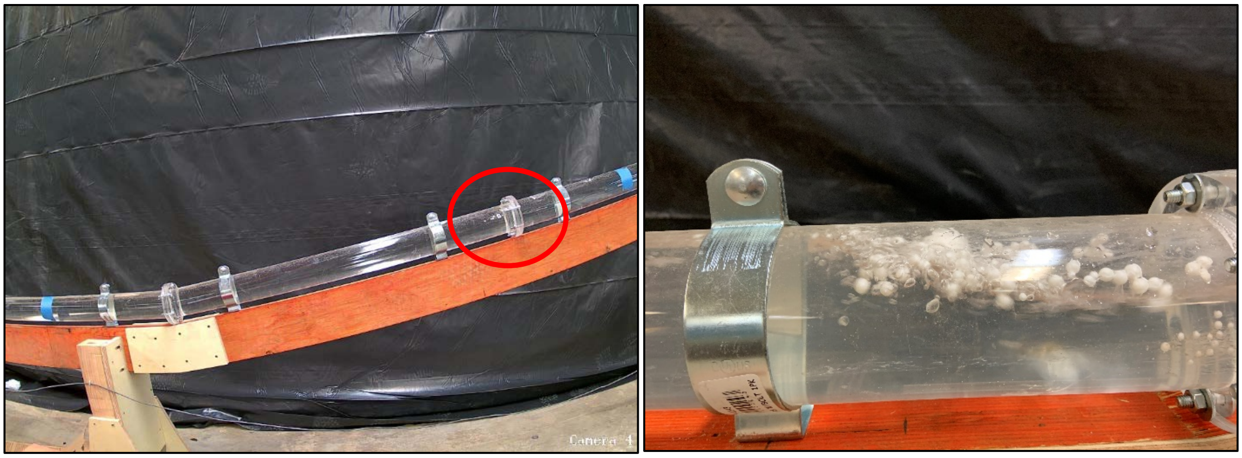

Figure 10. Small cluster of beads stuck in a recirculating hydraulic jump when the tailwater is set at 4.5 ft.

High Debris Load

The limiting factor for the high debris load clearance time was the smaller debris particles getting stuck in the entrained air pockets and recirculating through the hydraulic jumps while the large particles and SAV cleared the pipe relatively quickly. Despite the increase in overall volume the clearance time for the high debris load was similar to that of the low debris load.

Table 2. High debris load results, all times are listed in prototype units.

Downstream water surface elevation (ft)	Debris load	Debris cleared during pre-flush?	Time to clear debris (min)
1.5	High	Yes	5:00
4.5	High	Yes	6:00
5.75	High	Yes	4:40

Worst Case (from a passing standpoint) Debris Load

Once the other debris loads were easily cleared, a worst-case scenario was developed based on the observed behavior of the debris particles. The smallest Styrofoam beads were found to recirculate the most during the pre-flush phase and thus were used in excess for this trial. The amount of small Styrofoam beads can be seen relative to the other trials in Figure 8, this volume of debris is likely excessive for what the system could encounter and was used to help find the limit of the pre-flushing phase as well as the behavior of debris during the fish release phase.

Table 3. Extreme debris load, all times are listed in prototype units. Note that the debris was not fully cleared during the pre-flushing phase.

Downstream water surface elevation (ft)	Debris load	Debris cleared during pre-flush?	Time to clear debris (min)
1.5	Extreme	No	28:00
4.5	Extreme	No	24:00
5.75	Extreme	No	20:00

As the debris moved downstream it formed a slug at the crown of the pipe that was relatively stable once it passed through the hydraulic jumps in the upper section of the pipe (Figure 11). When the slug entered the downstream section of pipe with no hydraulic jumps it would slough off a layer at the leading edge that would roll down the length of the slug until reaching the downstream end. During the fish release phase of the testing, the discharge was insufficient to create the shear forces necessary to slough off the leading edge and the slug was stationary in the lower section of the release pipe. Once the post-flush discharge was ramped up, the plug would continue working its way down the pipe until finally exiting the pipe at the time indicated in Table 3. Although this large debris plug would not clear completely during the pre-flushing phase it would stay clumped together in the lower section of the pipe, out of the hydraulic jumps, during the fish release phase and likely provide adequate passage below the debris slug for fish to pass. The amount of floating debris to create this situation would be extremely unlikely to ever occur from either fish collecting facility because the majority of the debris that will be encountered at the release site will be neutrally/negatively buoyant and flush very rapidly.

Figure 11. An example of a small stable debris slug moving downstream in the release pipe. The large debris slug encountered during the extreme debris load can be seen in Figure 12.

Worst Case (Realistic from Facility) Debris Load

Realizing that the worst case tested from a debris passage perspective was not representative of the main type of debris that is currently collected at either facility the researchers wanted to see how a large amount of woody debris and vegetation might pass the facility. The closest thing to the woody debris that the researchers could recreate in the laboratory was saturated sawdust. When filling the model with 5 gallons of a saturated sawdust mixture it passed within 30 seconds at the fish release discharge (representative of when this debris might be entering the facility). Similar passage times occurred with any submerged aquatic vegetation that was tested.

Fish Passage

The fish release phase was modeled as a portion of the total operation using neutrally buoyant particles with model SAV, but the passage time may not be representative of the time required to allow fish to pass through the release pipe. Fish will often resist the current and pass at a slower rate than neutrally buoyant particles. The hydraulic conditions during the release were such that there were only one or two hydraulic jumps in the pipe depending on the “truck” flow rate. During the testing, any objects that were neutrally buoyant or only slightly buoyant, such as the model SAV, moved through the pipe rapidly. When timed during the low flow conditions of the release phase, the particles and model SAV were able to traverse the entire pipe length in 20 – 30 seconds (model scale, equivalent to 40-60 seconds prototype.)

The only trials where neutrally buoyant particles were in the release pipe at the same time as buoyant debris was during the extreme debris load scenario. As mentioned above, the debris slug was stationary during this phase of the release and theoretically should not be able to damage fish moving downstream as it was not recirculating. This behavior can be seen in Figure 12 below.

Figure 12. (Top) The black neutrally buoyant particles moving rapidly through the pipe at the bend. (Bottom) The neutrally buoyant particles moving under the stable Extreme Debris Load slug floating at the crown of the pipe (discharge is from right to left in both images).

Conclusion

A 1:4 Froude scale physical model of the proposed Antioch Fish Release Site replacement was constructed by the Hydraulic Investigations and Laboratory Services Group of Reclamation's Technical Service Center. The model contained a portion of the downstream river, the pipe and the auxiliary flow manifold and the intake for the release truck. The model was tested at three different downstream water surface elevations and three primary debris loads to evaluate the clearing capability of the SOP. The pre-flush discharge easily cleared the low and high debris loads before the fish release portion of the SOP for all realistic debris loading scenarios.

Under a very high worst-case debris load the SOP was unable to clear the debris in the pre-flush phase but due to the nature of the debris slug it was found to be relatively stable as it traveled down the release pipe forming a group of debris on the crown of the pipe that would likely allow fish to pass below the debris during releases. Furthermore, based on the comments received from the field office, the extreme quantities of buoyant particles were unrepresentative of debris loading at either fish collection facility. It is more likely that large amounts of saturated vegetation and woody debris would be encountered. The large amounts of this type of debris should pass the facility quickly as was shown when saturated sawdust was used in the model.

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