# Design, Development, and Pilot Testing of a Laboratory-Type Fish Jumping Box

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**Introduction**

Over the last century, The Bureau of Reclamation (Reclamation) has developed a multitude of dams, canals, and spillways as a means to accomplish a mission to deliver water to the American west in an environmentally sound manner. Dams and spillways can pose a serious in-stream obstacle, if not a permanent barrier to fish, whose only means to navigate such structures is via jumping or leaping. Impassable barriers disrupt historical migration patterns and reduce available habitat for fish, which may ultimately have significant population level effects (Clay 1995; Brandt et al. 2005). As a means to mitigate such effects Reclamation has, and will likely continue to, assist in the development of fish passage structures and fish ladder systems (e.g., Battle Creek Restoration Project (CA), Link River Dam and Fish Ladder (OR), Three Miles Falls Diversion Dam (OR), etc.) in an attempt to guide fish past insurmountable in-stream barriers. Critical components to consider when developing fish passage and fish ladder systems are swimming and jumping performance of key species of concern at all impacted life-stages (Brandt et al. 2005). Though there is a plethora of available information on the swimming performance of fish (see Videler and Wardle 1991 for review), there is a definite lack of available published literature detailing fish jumping performance, which results in engineers and managers relying on trial and error when developing fish passage systems. Laboratory based adjustable waterfalls are relatively easy and economically efficient to construct, have been employed successfully for fisheries research (Brandt et al. 2005; Kondratieff and Myrick 2005), would provide Reclamation with the ability to quantify jumping performance of critical fish species affected by Reclamation facilities, and could be used to acquire data for future development of more efficient fish passage and fish ladder systems. Therefore, the primary objective of this research was to see if a laboratory-type adjustable fish jumping box could be designed, developed, and tested by Reclamation personnel at the Technical Service Center (Denver, CO).

## Materials and Methods

*Fish Source and Care* - Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) were acquired from the Mokelumne River Fish Hatchery (California Department of Fish and Wildlife, Clements, CA), and were truck-transported in 550-L tanks to Reclamation's Technical Service Center (Denver, CO), where they were maintained in continuously aerated 870-L circular tanks. Following arrival to the TSC, fish were maintained at transport water temperatures and provided a daily 2-3h prophylactic salinity (NaCl @ 6-8 ppt) and paracide green/formalin (22.5mL) bath for four days to minimize likelihood of pathogenic infection, and promote internal osmotic balance that can be compromised as a result of handling and transport procedures (Piper 1986; Wedemeyer 1996). Approximately 14 d following truck transport, fish were exposed to gradual changes in temperature, not exceeding 1.0°C/d, until target test temperature was achieved. Fish were maintained under a natural photoperiod (37° 44' 23" N) with a combination of natural and halogen light sources. Chinook salmon were fed slow sinking pellets (1.5 mm, Bio Oregon®, Longview, WA) at 2-3% body weight per day prior to replicated testing. Threadfin shad (*Dorosoma petenense*), truck transported from Reclamation's Tracy Fish Collection Facility (Byron, CA) were also used during preliminary testing. However, there was no indication they were stimulated to participate in experimentation (i.e., jump waterfall) so their use during experimentation was discontinued.

*Box Design* - The laboratory-type jumping box was designed by Reclamation Fish Biologists, based on designs reported in Kondrotief and Myrick (2005), and constructed by Reclamation Research Lab Model Makers. The jumping box (Figure 1) was constructed of marine plywood, to promote longevity and minimize water loss, and supported structurally along all edges with welded angle iron. The main jumping box (see Figure 1) was 240 cm long × 120 cm wide × 92 cm deep, and was created to permit testing of larger (< 350 mm) fish if ultimately deemed appropriate. The primary components of the jumping box were an upper waterfall box and lower plunge pool. The waterfall box, which permits water flow and the development of a flowing waterfall to provide a stimulus to promote fish jumping, was raised inside the main box and was divided into two sections. To minimize turbulence from the inflowing water, a baffle separated the inflow from the overflow compartment (Figure 2). Reducing turbulence from the incoming water helped create laminar flow across the waterfall. The two compartments of the waterfall box were 41 cm deep, and the inflow compartment was 45 cm long × 107 cm wide. The overflow compartment was 43 cm long × 107 cm wide. A cutout, 30 cm wide in the front of the waterfall box, created the waterfall. The plunge pool was 120 cm wide × 147 cm long. The depth of the plunge pool was controlled by adjusting the level of the false bottom and the height of two 3.8 cm drainpipes on the opposite end of the plunge pool. More drainpipes could be added to the design if higher water velocities are necessary for testing, but after preliminary efforts with a single 3.8 cm drainpipe, it was deemed two would be appropriate for our efforts. Plunge pool depth can be adjusted from 0-57 cm, in ~ 2.5 cm increments, allowing for future experiments to investigate effects of plunge pool depth and/or waterfall height on fish jumping success. A baffle separates the plunge pool from the area underneath the waterfall box, preventing the area underneath the waterfall box from becoming a refuge for fish.

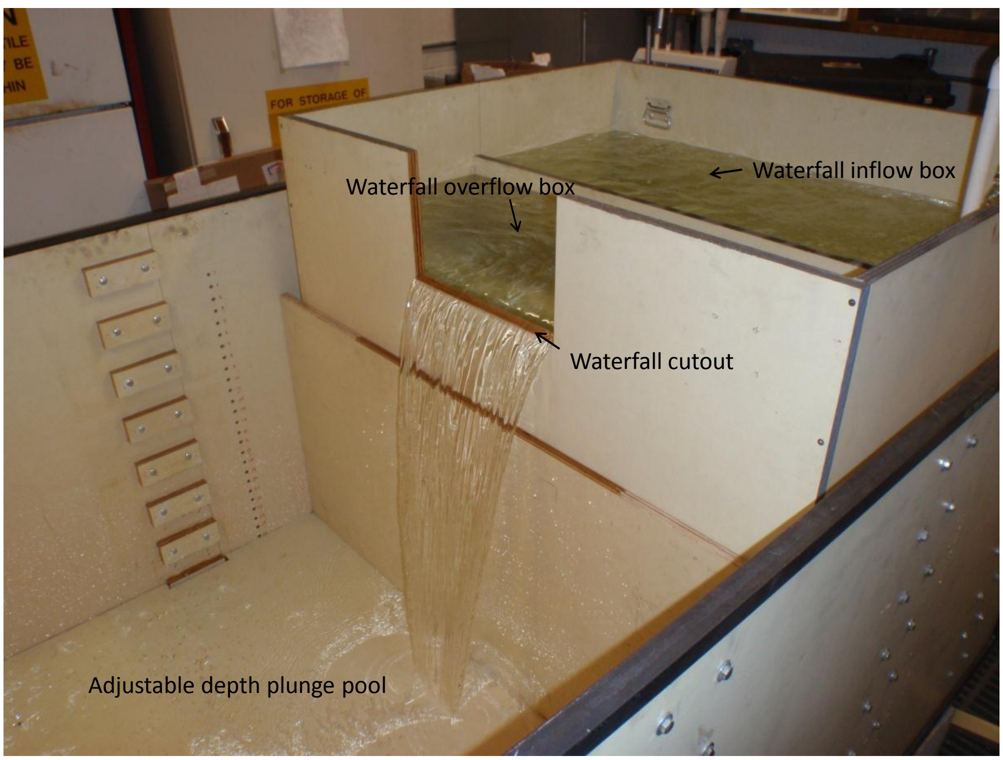


**Figure 1. -** Fish jumping box, constructed by Bureau of Reclamation Research Lab Model Makers (Denver, CO) showing the two compartments of the waterfall box and the false bottom plunge pool.

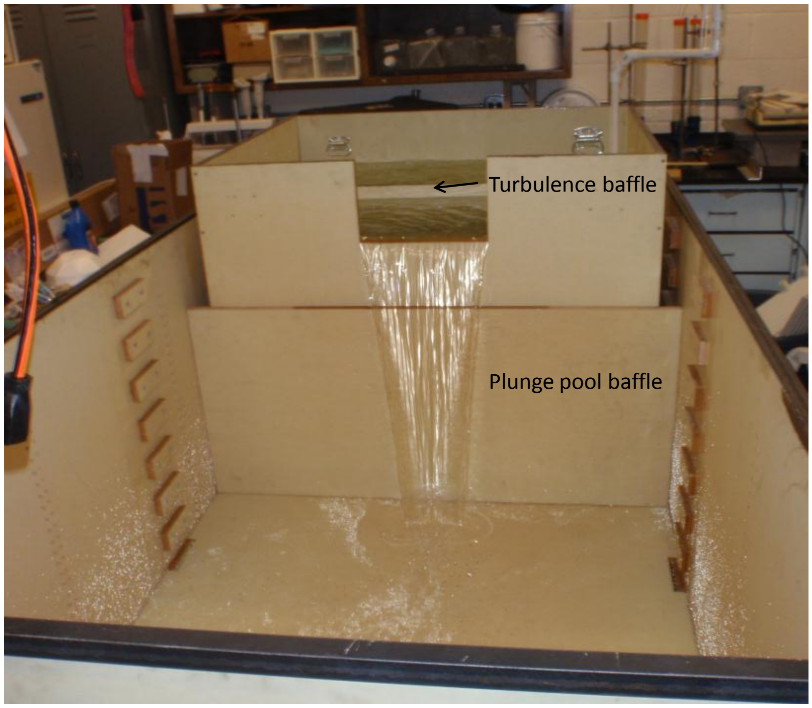


**Figure 2. -** Fish jumping box showing upper waterfall box with turbulence baffle separating inflow compartment and overflow compartment. Also shown is the lower plunge pool with baffle which prevents fish from swimming underneath the waterfall box.

*Experimental Setup* – Water flow was controlled by two 1” inlet pipes located at opposite sides within the inflow compartment of the waterfall box. To improve laminar flow, the inlet pipes were perforated with multiple aligned 1/8” holes. Much of the preliminary pilot testing of the jumping box was completed to determine an adequate design to control flow and produce a somewhat laminar flow across the waterfall, and to see if multiple variations in plunge pool depth would still promote a suitable waterfall. Prior to each replicate, a 20-L bucket was placed below each inlet pipe, and the time to fill each bucket was measured (n=3). The mean time to fill the buckets was calculated and a corresponding, cumulative flow rate (L/min) was determined. Temperature during experimentation was not controlled, and was dependent on the temperature of incoming laboratory water. At the initiation of each replicate, twenty fish were transferred from the holding tank to a 20-L bucket via soft-mesh dip net. Fish were then transferred to the plunge pool by slowly inverting the bucket in the plunge pool to minimize stress during transfer. Fish were transferred between 08:00 and 09:00 for each trial. Initial pilot tests were conducted to determine whether or not the test fish would cross the waterfall. For all replicates, the waterfall height was maintained at 4cm and the plunge pool depth was maintained at 15 cm. Preliminary trials were conducted on July 28 and 29, 2010. After a 24-hour period, the total number of fish above the waterfall and those remaining in the plunge pool was recorded. An arbitrary flow of 41.5 L/min was selected for the first pilot, and then increased to 81.0 L/min for the second. Later experiments were conducted once it was established the test fish would navigate the waterfall. During these experiments, three replicates each were conducted at two flows. The first flow was 57.6 L/min. These trials took place August 25-27, 2010. The second flow was 128.0 L/min. These three replicates took place September 1-3, 2010. These flows, including pilot flows, incorporated the approximate lowest and highest flows we felt attainable given the described setup. All other conditions remained similar to the preliminary trials. Total fish above and below the waterfall were recorded after 24 hours.

**Results and Discussion**

Initial efforts focused on stabilizing flows and creating laminar flows at the waterfall crest, which included incorporating plunge pool and turbulence baffles, as well as adjusting the number and size of drainage pipes and changing the size design of water inflow pipes. After initial adjustments were made, the hydraulic components (i.e., waterfall and water flow through), as well as the structural integrity of the jumping box, worked well. Water temperature during all testing was between 17.1 and 18.9°C. Chinook salmon mean total length (mm) and wet weight (g; ± standard deviation) were 69.8 ± 5.7 and 2.6 ± 0.6 g, respectively. It appeared the majority of salmon were feeding and seemed healthy prior to, and during, experimentation. Also, no mortalities were observed in the jumping box during experimentation. During initial pilot phase testing (n =2), with a mean flow rate of 41.5 L/min, total salmon observed in the waterfall box at 24h in both replicates was 25% of the total (15 of 20 fish). During subsequent experimental efforts, with increased mean velocities of 57.6 and 128.0 L/min, mean percentage of fish in the waterfall box were 5 and 5%, respectively (Table 1). Interestingly, even following the incorporation of a small baffle, periodic observations of the experimental system indicated salmon that had initially navigated up the waterfall would sometimes later traverse downstream back into the plunge pool box.

**Table 1**.- Results of 24-hour juvenile Chinook salmon jumping experiments. These simple experiments were conducted to evaluate a fish jumping box developed by Bureau of Reclamation (Denver, CO). Twenty fish were placed in the lower plunge pool and the final location of all fish in the waterfall box (above) and plunge pool (below) is reported.

| **Flow:** | **57.6 L/min** | | |
|---|---|---|---|
| Replicate: | Date: | Fish Above: | Fish Below: |
| 1 | 25-Aug | 1 | 19 |
| 2 | 26-Aug | 2 | 18 |
| 3 | 27-Aug | 0 | 20 |

| **Flow:** | **128.0 L/min** | | |
|---|---|---|---|
| Replicate: | Date: | Fish Above: | Fish Below: |
| 1 | 1-Sep | 3 | 17 |
| 2 | 2-Sep | 0 | 20 |
| 3 | 3-Sep | 0 | 20 |

In an attempt to better identify the percentage of fish that moved back and forth, from the waterfall box back to the plunge pool, we tried to incorporate a VAKI Riverwatcher Fish Counter (Vaki Aquaculture Systems Ltd., Kópavogur, Iceland). This module is designed to monitor fish in rivers and lakes, typically funneled through the unit using a weir. As fish pass through the unit, infrared beams are interrupted and the scanner unit records the object passing through (Figure 3). Given appropriate conditions, the VAKI unit can provide evidence of fish directionality (movement up or downstream). Though the unit seemed to work when completely submersed and tested in an 870-L tank, it was less effective at capturing fish images when the water level in the tank was lowered and the VAKI was not fully submerged. Ultimately, it proved to be too bulky to install properly with the current setup, and, based on tank testing, there were concerns with the low water levels and turbulence at the waterfall crest creating false readings.


**Figure 3. –** Reclamation personnel using a VAKI Riverwatcher Fish Counter in an attempt to better quantify movements of fish, within a fish jumping box at Reclamation's Technical Service Center (Denver, CO).

Ultimately, not quantifying or obtaining a thorough understanding of the portion of fish that moved up, and then back down, the waterfall proved to be the downfall of the current jumping box setup. Kondratieff and Myrick (2005) had success using a one-way weir in a similar waterfall box design. However, our attempt to construct a one-way baffle to allow upstream travel while preventing fish from swimming back downstream was unsuccessful. Cost effective means that could be incorporated in future efforts could include developing an effective one-way weir. Also, a simple video camera system could be used to monitor fish passage attempts, to quantify jumping success (# attempts: # successful jumps). However, the use of recorded video would require extensive labor for post-processing. Alternatively, a simple PIT tag antennae system may be able to record movements of fish in our experimental system. PIT (Passive Integrated Transponder) tags are battery free, thus having a long-life, and contain a unique code that is activated as it passes through an antenna's electrical field, which is detected and stored by a receiver. However, this would require inserting a PIT tag into all test fish, and though research suggests PIT tags do not impact swimming performance of juvenile salmonids (Newby et al. 2007), to our knowledge there is no published data to suggest it doesn't impact jumping ability.

Kondratieff and Myrick (2005) noted critical depths at the waterfall crest can restrict movement of cutthroat trout. The design of our jumping box, including being able to adjust for varying waterfall heights and plunge pool depths, should permit an evaluation of species specific critical waterfall and plunge pool depths. However, water temperature has been shown to affect swimming and jumping performance in salmonids (Uchida et al. 1990; Larinier 2002). Water flow and temperature in the jumping box, given the current setup, were dependent on the temperature of the incoming water from the building supply lines and limited by the size of the inflow pipes. Future efforts to control these variables could involve incorporating an adjustable pump and chiller into the design. Plumbing that re-circulates the water could also be installed. This would increase the versatility of the setup. Flow would be able to be controlled by adjustable valves in the plumbing, and temperature would be controlled by a water heater/chiller. In addition, this setup would be more mobile, being less dependent on the location of the source water and drain lines.

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