State of California
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Evaluation of Mortality and Injury in a Fish Release Pipe

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List of Abbreviations

ANOVA	Analysis of Variance
CDEC	California Data Exchange Center
CFD	Computational Fluid Dynamics
CHTR	Collection, Handling, Transport, Release
CVP	Central Valley Project
CVFFRT	Central Valley Fish Facilities Review Team
CWT	Coded Wire Tag
Delta	Sacramento-San Joaquin Delta
DFG	California Department of Fish and Game
DWR	California Department of Water Resources
DO	Dissolved Oxygen
EC	Electrical Conductivity
FCCL	UC Davis Fish Conservation and Culture Laboratory
FL	Fork Length
ID	Inside Diameter
IEP	Interagency Ecological Program
PVC	Polyvinyl Chloride
SDFPF	John E. Skinner Delta Fish Protective Facility
SE	Standard Error
SL	Standard Length
SWP	State Water Project
TFCF	Tracy Fish Collection Facility
TL	Total Length
USBR	United States Bureau of Reclamation
USFWS	United States Fish and Wildlife Service

Executive Summary

The State Water Project (SWP) John E. Skinner Delta Fish Protective Facility (SDFPF; Figure 1) and federal Central Valley Project (CVP) Tracy Fish Collection Facility (TFCF) were constructed in the late 1950's and 1960's to salvage fish entrained at the southern Sacramento-San Joaquin Delta (Delta) water export facilities. These facilities protect fish by using a series of behavioral dewatering louvers to concentrate fish into holding tanks where they are held for later transport back into the Delta away from the zone of influence of the water export facilities. Fish are held in these facilities until they are collected by draining each holding tank into a haul-out bucket (collection), transferred to a water tanker truck (handling), transported to release sites in the central Delta near the confluence of the Sacramento and San Joaquin Rivers (transport), and released back into the Delta at fixed release points (release; Figures 2 & 3).

In response to concerns about the survival of sensitive fish species exposed to the Collection, Handling, Transport, and Release (CHTR) processes at the state and federal delta water export facilities, the California Department of Resources (DWR) in collaboration with the California Department of Fish and Game (DFG) and U.S. Bureau of Reclamation (USBR) conducted a series of focused investigations on the CHTR phase of the salvage process. These investigations were developed to provide useful information that could serve to reduce the potential vulnerability of sensitive fish species including delta smelt (*Hypomesus transpacificus*) and Chinook salmon (*Oncorhynchus tshawytscha*) to injury and mortality during the salvage process. The results of these investigations will be used to reduce overall mortality and stress during the salvage process by making recommendations and providing baseline information for the improvement of existing fish salvage facilities and construction of new facilities.

The Department of Water Resources' contribution to this effort was to conduct a focused investigation into the release stage of the fish salvage process at the SDFPF. The release phase investigation was composed of three separate elements, each investigating a different aspect of the release phase. Element 1: an investigation of the far-field survival of salvaged fish following release, Element 2: an investigation of release site predation, and Element 3: an investigation of the physical factors influencing mortality and injury during release. The Element 1 investigation was subsequently eliminated based on peer review comments, while the results of the Element 2 investigation are available as a separate technical report. The results of the Element 3- the Evaluation of Mortality and Injury in a Fish Release Pipe are the focus of this report.

Element 3- Evaluation of Mortality and Injury in a Fish Release Pipe
Fish released at the state and federal fish salvage release sites are subjected to a variety of physical factors which may result in stress, disorientation, or direct

mortality. These factors include the hydraulics of release, presence of debris, the method of injecting flushing flow into the release pipe, and the geometry of the release pipe truck connection. In order to investigate the physical factors influencing salvaged fish mortality and injury in a fish release pipe, experimental fish releases and subsequent survival and injury assessments were made using a mock release site, a nearly full-scale replica of the SWP Horseshoe Bend release site. The mock release site included a 30.48 cm (12 in) release pipe 29.64 m (97.25 ft) long mounted on a 16% slope and equipped with a flushing system with identical specifications as the release system at the SWP Horseshoe Bend release site. In the model, the river was simulated by a 2.4 m wide by 9.1 m long by 2.6 m deep (8 ft x 30 ft x 8.6 ft) fiberglass tank.

Altogether 3,234 adult delta smelt, 49–87 mm (1.9–3.4 in) in length, were used in a total of 49 experimental releases and 4,158 juvenile Chinook salmon, 48–109 mm (1.9–4.9 in) in length, were used in 63 experimental releases investigating the interaction of fish, debris, and hydraulics during release. In each release, fish, varying levels of debris load (no debris, moderate debris, and heavy debris), and water were inserted into the transport truck and released down the mock release pipe into the receiving pool. Control fish were also inserted into the receiving pool or held in holding tanks to isolate injury and mortality specifically due to the release process.

In general, injury and mortality associated with release were low for both juvenile Chinook salmon and adult delta smelt under all scenarios. In trials with no debris, survival of fish released down the pipe was 98.7% and 99.2% for delta smelt and Chinook salmon, respectively. In trials with moderate debris, survival was 97.1% and 97.4% for delta smelt and Chinook salmon, respectively. In trials with heavy debris, survival was 95.2% and 98.4% for delta smelt and Chinook salmon, respectively. Overall, injury assessments did not reveal any consistent patterns of body damage relative to increasing debris loads. Statistical analyses demonstrated that for both species, increasing level of debris and release pipe design were not a significant factors in mortality or injury associated with the release.

Mock release site hydraulic data demonstrated that the flow from emptying the truck tank did not effectively flush the release pipe. A direct result of insufficient flushing flows in the pipe was a significant amount of debris remained in the submerged length of the release pipe after all releases with debris. Recommendations to the release facilities have been made to improve the flushing of debris and fish from the release pipe to prevent clogging. Results of this research are being used to modify the existing release sites and/or in the construction of new release facilities.

1.0 Introduction

The John E. Skinner Delta Fish Protective Facility (SDFPF; Figures 1 & 2) was built in the 1960s and designed to protect fish in the Sacramento-San Joaquin Delta (Delta) from entrainment into the California Aqueduct. The fish facility was designed with a maximum louver screening capacity of 291 m^3/s (10,300 cfs). Screened fish are bypassed into holding tanks from which they are loaded into tanker trucks for transport to release sites outside the zone of influence of the South Delta water diversions. Water and fish diverted from Old River enter Clifton Court Forebay, which is used as a regulating reservoir for the pumping plant. The water and fish drawn from the forebay first travel by an intake channel to a floating trash boom designed to intercept floating debris and guide it to a trash conveyor. Water and fish then flow through a trash rack to a series of louvers arranged in a Vee pattern. The louvers create a disturbance in the water to guide fish into the SDFPF. In the final stage of the fish salvage process, salvaged fish are then collected, handled, transported away from the influence of the export pumps, and released back into the Delta in a process known as Collection, Handling, Transport and Release (CHTR).

Figure 1-Aerial view of the SDFPF including the Primary Louvers arranged in a Vee configuration

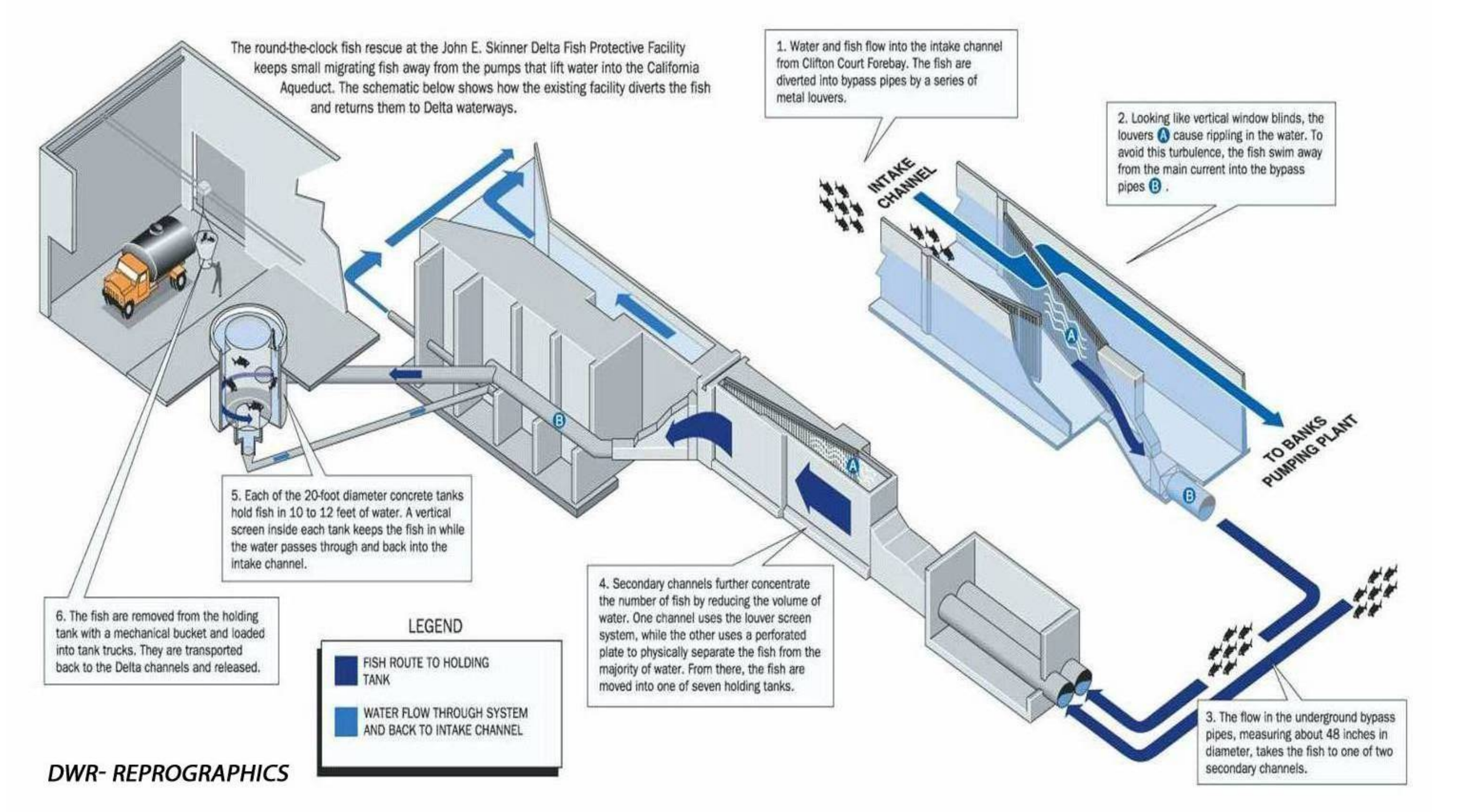


Figure 2-The fish salvage process at the John E. Skinner Delta Fish Protective Facility

Routine CHTR operations may cause stress, injury, and disorientation to salvaged fish (Raquel 1989) potentially leading to direct mortality or increased susceptibility to predation. Within the framework of the CHTR process, release begins when the knife gate attached to the outlet of the transport truck is opened, allowing water and fish to exit the fish transport truck water tank and is finished when the release truck is fully emptied. Observations of this process suggest several potential sources of stress, disorientation, and mortality to fish including:

1. Hydraulics of Release

The flow out of the tank and down a release pipe is similar to culvert flow complicated by many variables, including the inlet geometry, a 90° bend, slope, size, roughness, and approach and tailwater conditions. At the point that water traveling down the pipe as free flow meets the tailwater, a hydraulic jump is created. This results in turbulent forces that may cause injury or mortality to salvaged fish.

2. Debris

The presence of debris poses significant operational problems at the both the SWP and CVP fish salvage facilities. The CVP does not have a regulating forebay and receives river debris, which includes quantities of water hyacinth and peat; both of which clog the louvers and trashracks. At the SWP facility, the debris load has increased over the years as Clifton Court Forebay has silted in. As the forebay depth became shallower, conditions have become favorable for the production of introduced aquatic weed, particularly *Egeria densa*. At peak periods, a 2–meter (6–foot) deep mat of weed can accumulate that is dense enough for a man to walk on.

At the SDFPF, weed and debris drift along the floating trash boom where it encounters a conveyor system that lifts the debris up to a loading facility. While some of the *Egeria* is collected on the conveyor, a large portion also rolls under the trash boom and clogs the trashracks in front of the louver bays. A trash rake is used to clean the *Egeria* off the trashrack. This process breaks some of the weed into smaller pieces, which pass through the trashrack into the louver bays. This can lead to clogged louvers and is the source of the debris in the CHTR process. The only exit from the primary louver bays for the debris is through the louvers or into the fish bypass. Any debris that enters the holding tanks is transferred to the fish transport truck tanks unless manually removed by the salvage operators.

At the release sites, debris can clog the outlet after opening the knife gate on the release trucks to release fish. The debris then acts like a sieve separating fish from the flow and stranding them in the tank. Additionally, the interaction of fish and debris as they travel down the release pipe may cause injuries to salvaged fish.

3. Method of Introducing Flushing Flow

The release pipes sit unused most of the time, hence, the non-submerged length of pipe stays dry. One of the first things done when a fish transport truck arrives at a release site is to turn on a pump that sends flushing flow (auxiliary flow) down the release pipe (Figure 4). This water establishes flow in the pipe prior to the knife gate opening. The flushing flow was installed to prevent fish from sliding down a dry pipe and to flush fish and debris out of the pipe but may unintentionally injure fish as they pass near the water inlets.

4. Geometry of Release Pipe Connection

Due to site constraints, a fish transport truck cannot back up straight to the SWP release sites without major modification of the release sites, and as a result the truck must park perpendicular to the release pipe. The 90° bend in the Fish Release Pipe may increase stress, turbulence, and disorientation as fish, debris, and water interact through the bend (Figure 4). A high velocity jet of water exits the tank and travels through the bend. The flow becomes so super-elevated in the bend (that is to say that the water climbs up the side of the pipe rather than remaining at the bottom of the pipe) that it can fall back on itself. The turbulence caused by this action might injure or kill salvaged fish.

The 2000 CALFED Record of Decision identified the improvement or replacement of the existing fish salvage facilities of the State and Federal export facilities as a major objective to restore and protect fisheries resources (CALFED 2000a, 2000b). However, while proposed new screening facilities would have significant design improvements, a new or modified CHTR process may still be required to move salvaged fish away from the influence of the export facilities. Concerns that these CHTR processes may decrease survival of salvaged delta smelt (*Hypomesus transpacificus*) and other sensitive fish species, which would limit the benefits of new fish screening facilities, led to a comprehensive program designed to investigate the impacts of the CHTR process and assess the potential benefits of new CHTR technologies at the state and federal water export facilities. The Interagency Ecological Program (IEP) Central Valley Fish Facilities Review Team (CVFFRT) coordinated a series of collaborative studies designed to investigate the effectiveness of the existing fish salvage process and assess the potential benefits of new CHTR technologies at the state and federal water export facilities. The Department of Water Resources' contribution to this effort was to conduct a focused investigation into the release stage of the fish salvage process at the SDFPF. The objective of this investigation, funded by Proposition 13 bond funds and conducted with support from California Department of Fish and Game (DFG) and U.S. Bureau of Reclamation (USBR), was to determine the survival of salvaged fish being released at the existing fish release sites and to gather the necessary scientific and engineering information for the design and operation of improved fish release facilities. The investigations focused on:

1. A comprehensive evaluation of the effects of specific components of the release stage of the salvage process on the survival of delta smelt and other species of concern including physical aspects of the release

procedure

2. Collecting necessary scientific information for use in evaluating potential alternative technologies designed to reduce stress and improve survival throughout the release stage of the salvage process
3. Developing criteria for the design of new facilities or large-scale improvements to the existing release facilities

Originally, the release stage investigation had three separate elements. Element 1– an assessment of the far-field survival of salvaged fish released at both the SWP and CVP releases sites; Element 2 – examination of the abundance, composition, and behavior of predators in the receiving waters at the release sites; and Element 3 – an evaluation of the physical factors influencing mortality and injury of fish during release. The following provides a brief description of these investigations:

- Element 1 was proposed as an assessment of the far-field survival of salvaged fish following release. It was designed to develop quantitative estimates of survival of juvenile fish experimentally released at both the SWP and CVP releases sites and at control sites. The experimental design of Element 1 included mass releases of Coded Wire Tagged juvenile Chinook salmon at each salvaged fish release site and at control sites with subsequent recapture downstream using a Kodiak Trawl. Element 1 was subsequently eliminated based on IEP Management Team and peer reviewer concerns about potentially low recovery rates of marked fish using the proposed or existing trawl sampling methodology.

- Element 2, the Release Site Predation Study, examined the abundance, composition, and behavior of predators in the receiving waters at the release sites. This study involved using multiple survey methods including electrofishing and avian point counts to determine predator composition. The study included mark-recapture using Floy and acoustic tagging to determine site fidelity along with DIDSON and hydroacoustic sonar observations to determine predator behavior and abundance. In addition, a hypothetical predation risk analysis was performed using a bioenergetics approach.

- Element 3, the Evaluation or Mortality and Injury in a Fish Release Pipe presented in this report, was designed to assess the physical factors influencing mortality of fish during release. This study assessed the survival and injury of salvaged fish as they exited the release truck and traveled down a nearly full-scale replica release pipe and includes an evaluation of the hydraulic forces and debris loads associated with the release stage including release pipe hydraulics, release pipe design, and the effect of debris on sensitive salvaged fish species.

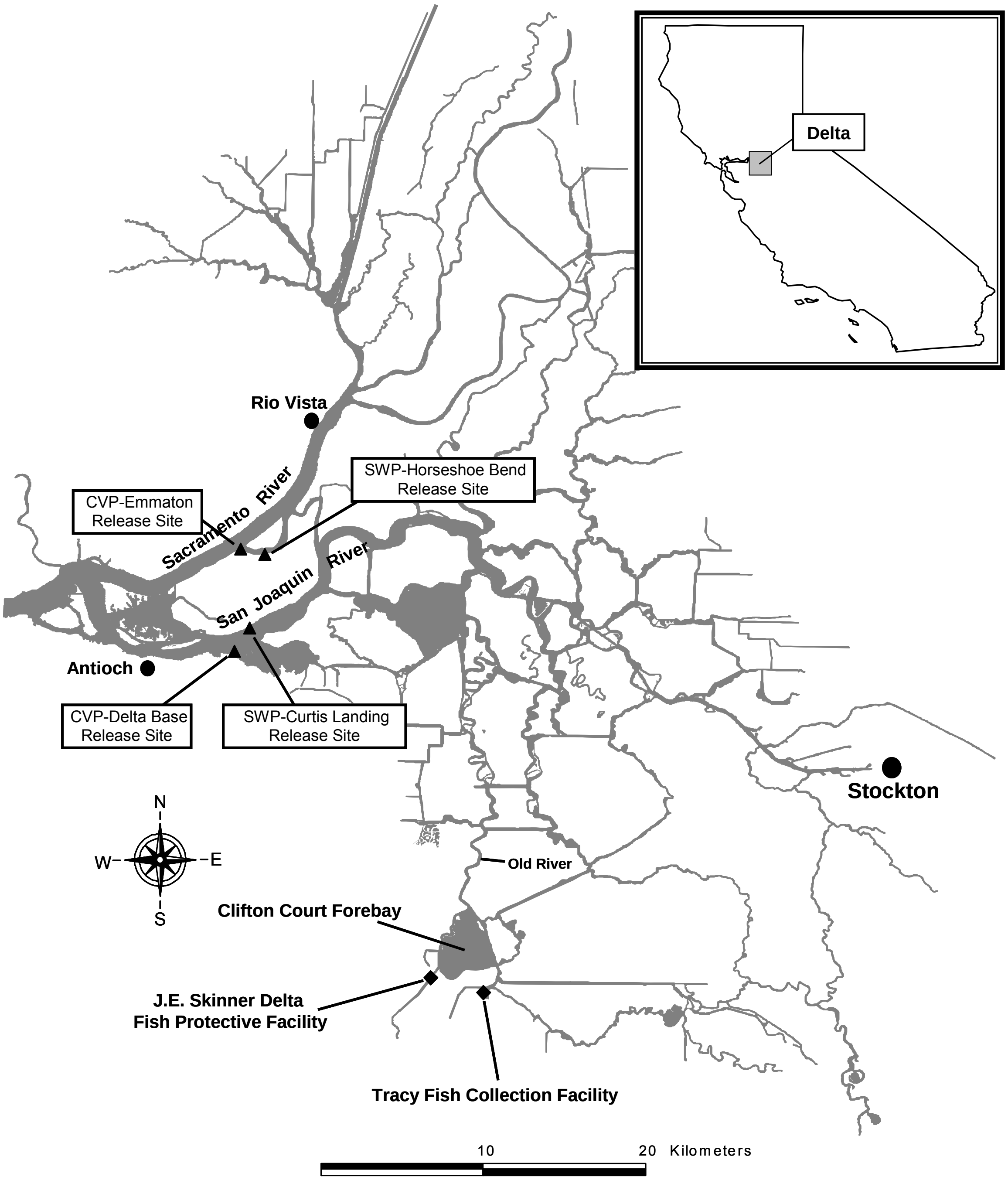
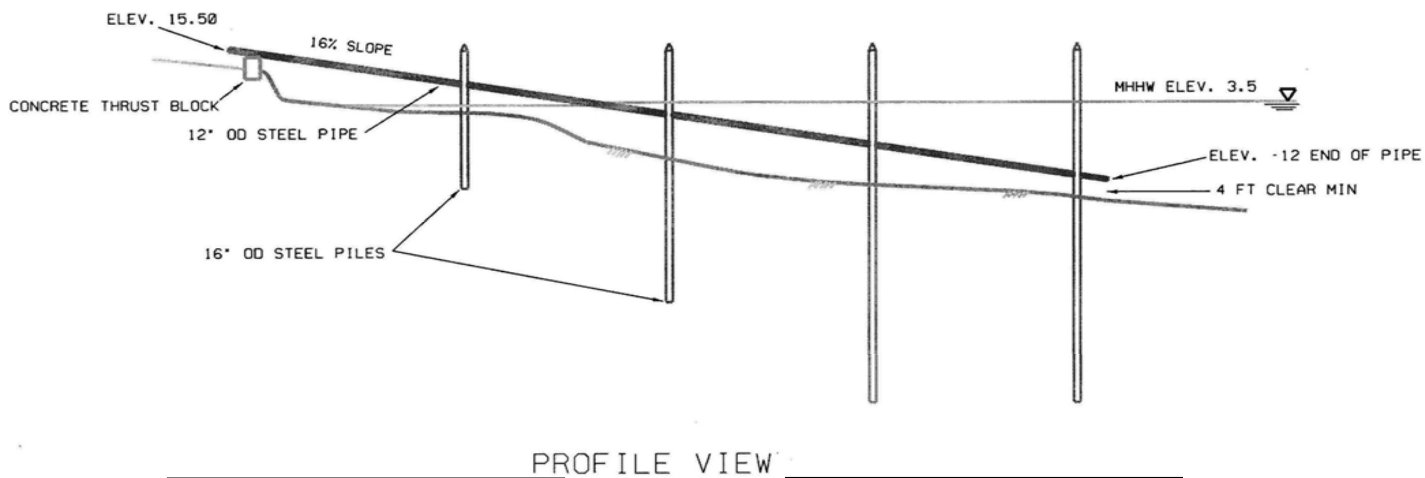


Figure 3- Map of the SWP and CVP fish salvage facilities and release sites. The release sites are a 45- to 60-minute drive from the salvage facilities.



Auxiliary flow injection system

Fish release pipe with 90 deg elbow attachment

Figure 4- Schematic of the SWP Horseshoe Bend release site on Sherman Island with photos of the auxiliary flow injection system (flushing system) and the 90º connection to the transport truck.

1.1 Objective

The primary objective of this evaluation was to experimentally determine if fish released back into the Sacramento-San Joaquin Delta (Delta) experience elevated injury or mortality as a result of their exposure to the release process and interaction with other factors such as debris loading. For this investigation, survival and injury assessments were made using a nearlyfull-scale replica, of the SWP Horseshoe Bend release facility to measure the effects of stressors on fish imposed by the physical structures and the hydraulic forces combined with debris loads that characterize the existing release method.

The results of these experiments will provide data to make informed decisions regarding recommendations for improvements. These improvements could be in the form of building new facilities, modifications to existing facilities, and alterations to operating procedures for releasing fish. If debris, coupled with release hydraulics is found to be detrimental to fish health or survival, the results will also be used to develop criteria for the amount of debris to be removed throughout the fish salvage facilities and in the CHTR process.

1.1.1 Research Questions and Hypotheses to be Tested

Research Questions

- Is there a debris limit that the release facility can accommodate without causing mortality to salvaged fish?
- Do the existing release facilities and procedures cause mortality?
- If the release facilities do cause mortalities, how can the mortalities be reduced or eliminated?

Hypotheses

Hypothesis 1: There is no threshold level of debris that causes significantly more mortality and /or injury.

> If this hypothesis is refuted, then the approximate point where debris starts to cause problems with fish can be established. This knowledge can be used to determine how much debris should be removed from the system before the salvaged fish enter the transport process.

Hypothesis 2: The existing release facility does not cause mortality or injury of fish at release.

1.2 Assumptions and Limitations

- This experiment does not account for the effects of accumulated stress responses induced from other parts of the salvage and transport process.

The experiments only quantify the impacts imposed on fish as they move through the release process.

- This experiment used cultured fish. Cultured fish may be more tolerant to handling and certain stressors than wild fish.

- The experiments used debris collected from the trash rack and holding tanks at the SDFPF and Tracy Fish Collection Facility (TFCF). It is assumed that this debris behaved in a similar manner as the debris, which regularly passes through the system to the transport truck.

- The amount of debris used as the high debris condition (referred to as 4X) was limited by the amount of debris available for use in experiments and the amount of time necessary to prepare debris for experiments. Based on input from SDFPF staff, it is assumed that the 4X condition represents an appropriately high level of debris.

1.3 Project Responsibilities

- As the project lead, the DWR Fishery Improvements Section was responsible for coordinating with the technical teams, project proposal development, experiment site construction, project oversight, and conducting experiments. DWR was also responsible for all infrastructure improvements at the mock release site, a nearly full-scale replica of the SWP Horseshoe Bend release site, and writing the final report.
- The USBR Fishery and Wildlife Resources Group was responsible for deploying and operating hydraulic instrumentation at the mock release site, developing debris protocols, assisting with experiments, data analysis and interpretation, statistical oversight, and for writing specific sections of the report.
- The DFG Fish Facilities Research Unit was responsible for assisting with experiments, collecting, evaluating, and analyzing the biological data, providing technical guidance, and for writing specific sections of the report. DFG was also responsible for transporting fish and providing fish care

2.0 Methodology

2.1 Mock Fish Release Site

DWR engineers and biologists designed and constructed a mock release site, a nearly full-scale model (Figure 5) of the SWP Horseshoe Bend release site. The objective was to investigate the effects of stressors on fish imposed by the physical structures and interacting hydraulic forces, combined with debris, that characterize the existing release method. The model was constructed at the SDFPF on a spoils pile adjacent to the fish holding tank buildings. An exhaustive search of potential sites yielded this site as the most suitable due to its accessibility, proximity to the smelt culture facility and CHTR laboratory, and minimal construction needs.

Figure 5- Mock release site constructed at the SDFPF compound.

2.1.1 Truck Tank

The fish hauling truck used during the experiments was one of two trucks used during salvage operations and serves as a backup to the slightly larger main truck (maximum capacity of 9464 L and 10599 L [2500 gal and 2800 gal] respectively). The haul truck was parked on a slope grade identical to that of the actual release site. A maximum water level indicator was mounted on the downstream truck tank portal. Prior to each test, the tank was filled to the indicator which corresponded to about 8517 L (2250 gal) (during normal SDFPF operations, the truck tank is not filled to full capacity).

2.1.2 Release Pipe and Downstream Receiving Tank

The actual SWP Horseshoe Bend release site is located within Horseshoe Bend on Sherman Island, approximately 11 km (6.8 mi) downstream of the city of Rio Vista along highway 160. The release facility consists of two 30.5-cm (12-in) diameter steel pipes (Figure 4). One pipe is approximately 54.3 m (178 ft) long and is used for the release of fish. The other pipe houses a submersible pump which feeds flushing water at 0.005 m^3/s (0.18 cfs) into the release pipe through a four inlet manifold. The pipelines are fixed to the top of the Sherman Island levee at approximately a 16% slope with a straight trajectory into the water and are supported by a series of steel piles. The end of the release pipeline extends 2 m (6 ft) beyond the last set of piles and is suspended 1.8 m (6 ft) above the channel bottom to prevent blockage due to sediment buildup. At the mean high water level, the pipe is submerged 3.7 m (12 ft). A short section of 25.4 cm (10 in) inside diameter (I.D.) flexible corrugated steel pipe containing a 90° short radius elbow is used to connect the truck tank and release pipe. The upstream end of the flex-pipe is clamped onto the truck tank knife gate discharge pipe and the downstream end is slipped inside the larger radius release pipe. The outside diameter of the flex-pipe is approximately 1.27 cm (0.5 in) less than the inside diameter of the release pipe.

In the mock release site, a 30.48 cm (12 in) I.D. clear Polyvinyl Chloride (PVC) pipe 29.64 m (97 ft) long mounted on a 16% slope was used to simulate a release pipe. Clear PVC pipe was used in the model to allow observations of hydraulic conditions and debris in the pipe. Pumped auxiliary flow can also be injected to the release pipe through a four path manifold located approximately 2.4 m (8 ft) from the upstream end of the release pipe. The manifold was constructed with identical specifications as the existing release system at SWP Horseshoe Bend with the exception of being fabricated out of clear PVC rather than steel.

Above the tailwater, the mock release site is a full-scale representation of the SWP Horseshoe Bend release facility. In the mock release site, the river is simulated by a 2.4 m x 9.1 m x 2.6 m (8 ft x 30 ft x 8.5 ft) fiberglass tank. The release pipe passes through the tank wall and extends into the pool approximately 5.5 m (18 ft). The length of submerged release pipe was shortened compared to the actual pipe to fit in the receiving tank. The mock release pipe extends about 1.28 m (4.2 ft) below the tailwater, a slope length of about 7 m (23.5 ft). The SWP Horseshoe Bend release pipes extend approximately 3 m (10 ft) below the mean water surface at a slope length of 19 m (62.5 ft).

The receiving tank was equipped with two, 2.4 m x 0.6 m x 0.6 m (8 ft x 2 ft x 2 ft) troughs separated by a flat plate fish screen on one end of the trough. The purpose of these troughs was to isolate fish and debris from the three dewatering pumps placed in one of the troughs and to allow an area for water to remain in the receiving tank, preventing stranding of fish.

2.1.3 Model Instrumentation

Pressure transducers were installed on the haul truck fish tank, and also at 3 m (10 ft) intervals along the release pipe invert and on the receiving tank to measure water depth during the release process (Figures 6 & 7). The opening of the knife gate was measured using a linear position string transducer mounted on the top of the gate leaf. An attempt was made to continuously measure release flow by mounting a strap-on acoustic flow meter on the release pipe below the tailwater at the junction of the release pipe and the tailwater tank, but this effort to measure flow proved unsuccessful due to excessive air entrainment in the flow. Alternatively, the change in truck tank volume during each time step of the release was used to determine flow. The instrumentation recorded data at 1.6 second intervals during a fish release using a 24 bit precision analog to digital multiplexer. The data for each test was downloaded directly to a laptop computer. A comprehensive report detailing the model instrumentation and hydraulics is also available (USBR, 2008).

Figure 6- Close-up view of one of the pressure transducers installed to measure flow in the release pipe.

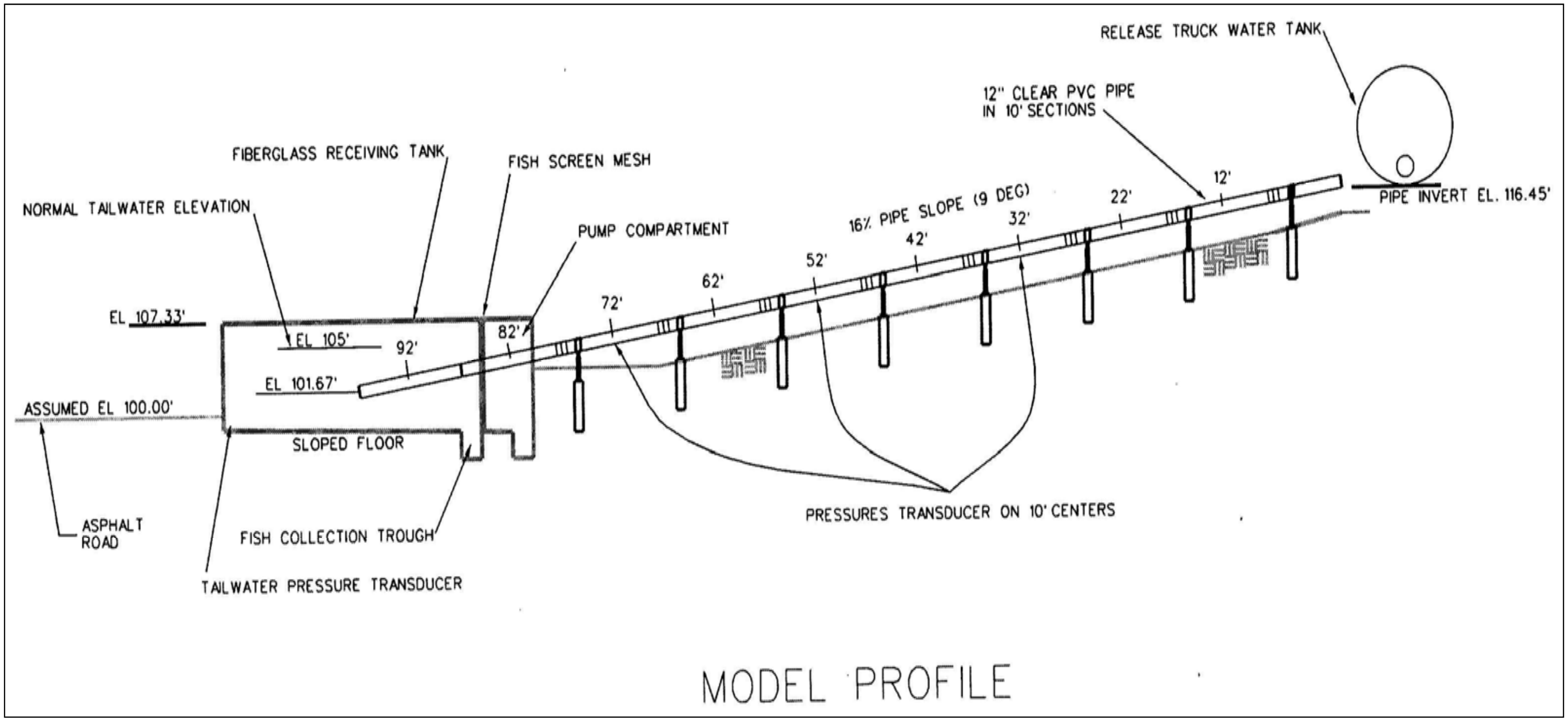


Figure 7- Profile of the mock release pipe with locations of hydraulic instrumentation shown.

2.2 Debris Collection and Preparation

2.2.1 Debris Evaluation

Prior to conducting experiments, a realistic representation of debris was established. This debris "cocktail" represented a combination of different debris types, in a ratio that is commonly found in the circular holding tanks, where collected fish are held and then transferred to the fish hauling truck. This debris cocktail had to be reproducible, so that the quantity, ratio, and type of debris could be replicated for multiple experiments.

The first step in developing a debris cocktail that would represent a typical debris load in the circular holding tank, and therefore in the fish haul truck, was to evaluate the debris loads coming into the SDFPF holding tanks. Debris coming into the circular holding tanks was separated into three main categories or types: green debris composed mostly of Brazilian elodea (*Egeria densa*) and Eurasian watermilfoil (*Myriophyllum spicatum*), woody debris (sticks, bark, and nut shells), and trash. The debris composing the trash category was composed mostly of manmade debris (trash) and natural debris such as clam shells and rocks.

To obtain relative densities of debris occurring during normal salvage operations, debris was collected and saved by personnel at the SDFPF. Debris was collected during the12, 20 minute, fish counts which occurred every two hours during each 24–hour period. Twenty, random, sprigs of green debris (*Egeria*) and twenty, random, woody branches were then measured for length from each fish count period. If less than twenty sprigs of green debris or less than twenty sticks were found in a two hour fish collection period, then all that were collected were measured. In addition, the diameter of the woody branches was also measured. The wet weight of all woody, green, and trash categories was also recorded every time a fish count was made. Using this information, an initial debris load for a 24–hour period was calculated, based only on the wet weight of the three types of debris (Table 1).

2.2.2 Debris Cocktail

An initial debris cocktail, based on wet weight, was assembled in the 1892–L (500–gal) haul-out bucket for SDFPF personnel to observe and evaluate (Figure 8). Personnel at the SDFPF collect, observe, and remove debris from the haul-out bucket on a daily basis when collecting and transferring fish to the fish hauling truck. Using their comments and suggestions the initial wet weight debris cocktail was adjusted by increasing or decreasing the three types of debris. During the week of December 10–16, 2006 many observations were made of debris loads in the haul-out bucket, by the experiment debris crew. Using only these visual observations another initial debris cocktail was assembled in the 1892–L (500–gal) haul-out bucket. This debris cocktail was also evaluated by SDFPF personnel to obtain their input. The two different initial cocktail methods (wet weight and visual) were then used to create a final debris cocktail that represented a realistic "ambient debris load" that would most often be found in the haul-out bucket. This final debris cocktail was based upon both the wet weight cocktail derived from debris collected during the fish counts and the cocktail assembled based upon visual observations made by the study crew with the help of personnel from the SDFPF (Table 1).

The final debris cocktail contained a ratio of green, woody, and trash debris, which was composed of 15 kg (33 lb) of green debris, 7.5 kg (17.5 lb) of woody debris, and 1.5 kg (3.3 lb) of trash (Figure 9, Table 2).

Table 1- Wet weight calculation and estimate of debris samples collected during twenty minute fish counts

Debris Type	Mean of 20 Minute Counts (kg)	Debris in 24hrs (one holding tank) (kg)*	Debris in 24hrs (1.5 holding tanks) (kg) **	Comments	Corrected wet weight estimate (kg)
Green	0.045	x 72 =3.24	x 1.5 =4.86	SDFPF personnel estimated 3X less than normal	4.86 x 3 = 14.58
Woody	0.156	x 72 =11.2	x 1.5 =16.80	SDFPF personnel estimated 2X more than normal	16.80/2 =8.4
Trash	0.006	x 72 =0.43	x 1.5 =0.65	SDFPF estimated 3X less than normal	0.65 x 3 =1.95

*72= number of 20-minute periods in 24 hours.
**Under normal operating conditions during the study period, an average of 1 to 2 holding tanks were used during each 24-hour period. Therefore 1.5 was used as a multiplying factor.

Figure 8- Initial debris cocktail prepared for evaluation by SDFPF personnel

Table 2- Using the two initial evaluation techniques, a standard cocktail representing normal debris (1X) at the SDFPF was developed.

Debris Type	Debris Cocktail Wet Weight, kg	Debris Cocktail Visual Estimate, kg	Final Debris Value (1X), kg
Green	14.7	12.4	15
Woody	8.4	6.6	7.5
Trash	1.9	1.6	1.5

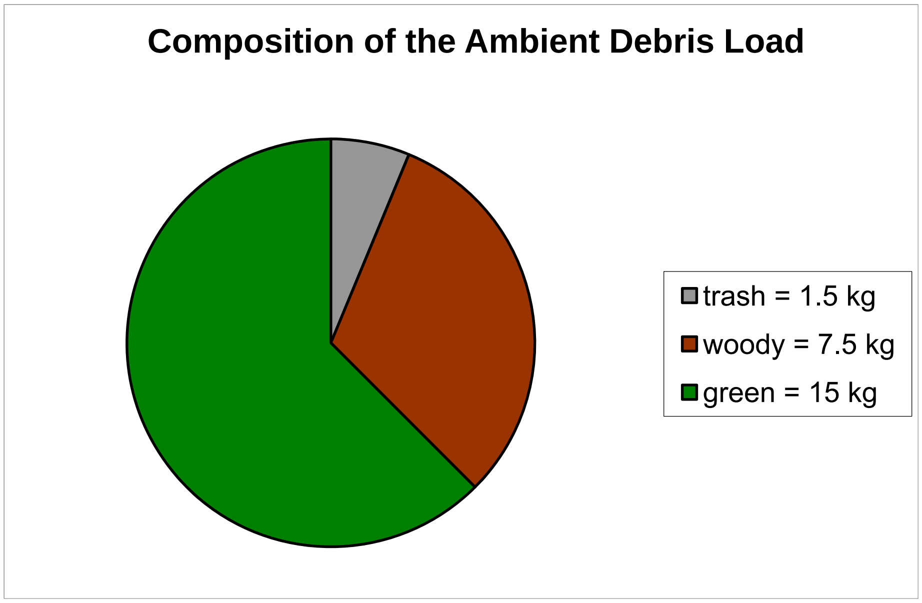


Figure 9- Composition of the ambient debris (1X) cocktail**.**

The final debris values were weighed out in three separate containers for each type of debris for equal addition to the three access hatches in the tank of the fish hauling truck. Therefore, 15 kg (33 lb) of green debris was weighed out in three buckets of 5 kg (11 lb) each. Woody debris was weighed out in three buckets of 2.5 kg (5.5 lb) each and the trash was weighed out in three bucket of 0.5 kg (1.1 lb) each. This debris load represented the normal or ambient debris load collected at the facility over a 24-hour period and was used to represent the 1X debris load in the experiments.

2.2.3 Debris Storage and Preparation

Debris was collected and stored in water-filled tanks until use (Figure 10). Debris was drained of excess water before weighing and the length of debris was limited to less than 23 cm (9 in) as much as possible. In actual operations large debris is removed from the haul-out bucket using a pitch fork prior to loading the fish in the hauling truck. Green debris was used only once per experiment because the green sprigs tend to fragment easily. A four-fold debris load (4X) was also used during the experiments composed of 60 kg (132 lb) green, 30 kg (66 lb) woody and 6 kg (13 lb) of trash debris (Figure 11). The 4X debris load was intended to represent a “heavy” debris load that might be encountered during operations at the SDFPF.

Debris prepared for the experiments was divided roughly into thirds for both of the 1X and 4X debris loads so that each third could be added to each of the three access hatches, on top of the fish hauling truck. This provided a more even and realistic distribution of debris in the tank. After the debris was inserted, it was then swirled around so that it was mixed in the tank as evenly as possible. Debris was inserted a minimum of 20 minutes prior to an experimental run.

Recovered debris collected from the receiving pool following release from the truck was separated once again into the three debris types (woody, green and trash). The green debris was discarded and the woody and trash components were saved for reuse in other experiments. The date, time, and the amount of debris used in the experiment (0 X, 1X, or 4X) were recorded for each experiment.

Figure 10- The three types of debris were kept submerged in individual 341–L (90–gal) containers.

Figure 11- View of a 4X debris load ready for insertion into the release truck.

2.3 Fish Care, Handling, and Marking

2.3.1 Fish Care and Holding

Cultured adult delta smelt used in tests were obtained from the University of California at Davis Fish Conservation and Culture Laboratory (FCCL) while cultured juvenile Chinook salmon were obtained from the DFG Mokelumne River Fish Hatchery. Experimental fish were held in the CHTR Test Building which is adjacent to the FCCL on the grounds of the SDFPF approximately 0.4 km (0.25 mi) from the test site. The test building was designed to hold fish, conduct CHTR and other fisheries experiments, and provide laboratory space. The building is outfitted with a combination of 1,135–L and 341–L (300–gal and 90–gal) holding tanks and a continuous flow-through water supply of filtered, UV treated water from the intake canal of the Banks Pumping Plant.

Delta smelt were held in the 341–L (90–gal) tanks pre-test and the 1,135–L (300–gal) tanks post-test. Chinook salmon were held in the 1,135–L tanks pre- and post-test. Pre-test fish were fed once daily. Delta smelt were fed Kyowa 1000-c (BioKyowa™, Kyowa Hakko Kogyo Co Ltd., Tokyo, Japan) and Hikari plankton feed (Kyorin Co Ltd., Himeji City, Hyogo Prefecture, Japan). Chinook salmon were fed BioOregon Bio-Vita feed (Nutreco Holding N.V., Amersfoort, Netherlands). Post-test fish were not fed. Temperature, dissolved oxygen, and specific conductance were measured daily in fish test tanks by an YSI 556 (YSI Incorporated, Yellow Springs, OH) multi-parameter system. Dissolved oxygen (DO) was measured in percent saturation (%) and milligrams per liter (mg/L), specific conductance was measured in micro-siemens (µs/cm), and temperature was measured in degrees Celsius (^{o}C).

The number of mortalities in all pre- and post-test fish tanks were recorded daily and any dead fish were removed daily. Any batch of pre-test fish experiencing 5% mortality or more in the 48 hours prior to a test or that showed signs of disease were not used in experiments. During the period from March 15 through March 23, Chinook salmon and delta smelt were held together in the same holding tanks due to rearing space limitations. However, it was discovered that the Chinook salmon were attacking the delta smelt and causing confounding injury and mortality. Consequently, delta smelt data from this time period was not included in this report.

2.3.2 Fish Marking

Experimental fish were marked by distinct fin clippings to differentiate between groups. Each test used 3 groups of 22 fish, for a total of 66 fish per experiment. In order to attain the desired number of 9 distinct fish groups, the following 9 fin clippings or clipping combinations were used: Dorsal fin (D), Anal fin (A), Dorsal lobe of Caudal fin (CDF), Ventral lobe of Caudal fin (CVF), Dorsal and Anal fins (AD), Dorsal and Ventral lobe of Caudal fin (D+CVF), Dorsal and Dorsal lobe of Caudal fin (D+CDF), Anal and Dorsal lobe of Caudal fin (A+CDF), and Anal and Ventral lobe of Caudal fin (A+CVF). Paired fins (Pelvic and Pectoral) were not clipped to avoid severely affecting swimming ability. Typically, 132 to 198 fish were needed to conduct two or three experiments per day and required the marking of approximately 900 fish per week.

Batches of five fish were lightly anesthetized in a 50 mg/L solution of MS-222 to reduce handling stress before fin clipping. Using dissecting scissors, a diagonal stroke was cut from the given fin. Fish were then placed in a black 18.9–L (5–gal) recovery bucket with NovAqua™ (Kordon LLC, Hayward, CA), 4 ppt salinity, and air diffused (Swanson and others 1996). The fish were then transferred to the appropriate pre-test holding tank. Fish were held post-clipping for a minimum of 48 hours before use in an experiment to allow for sufficient recovery from handling.

2.3.3 Fish Transport

Before fish transport, three 18.9–L (5–gal) buckets were filled 2/3 full with fresh water then 1.9 L (0.5 gal) of 100 % saturated brine solution and one capful of Novaqua were added to condition the water. Each trial consisted of 3 groups (see Section 2.4). Soft white nylon brine shrimp nets were used to move fish between tanks and buckets. Any dropped fish were excluded from the test. Two people were present when counting fish to verify the final count of 22 fish netted per bucket. To further reduce counting error, only two fish maximum were netted at a time. Care was taken to minimize handling and stress during the net collections. If a pair’s counts did not agree, then a new bucket was prepared and a new batch of fish recounted into the new bucket. Once the total number of fish was transferred, the bucket was slowly filled with water to the rim and the bucket lid replaced. The filled container prevented sloshing and helped minimize any experimental stress or injury.

The 18.9–L (5–gal) buckets with fish were transported 0.4 km (0.25 mi) by automobile to the test site in cushioned, foam insulated Tupperware containers. Efforts were made to minimize any bouncing, bumping or other physical disturbance during transport. Efforts were also made to minimize the total time fish were held in the buckets prior to testing.

2.4 Fish Mortality and Injury Assessment Procedures

Three groups of fish were used for each experiment; 2 controls (“Baseline” and “Control”) and 1 treatment group. The “Baseline” group was subjected only to the transport process from the pre-test holding tanks to the test site and back to a post-test holding tank. The “Control” group was placed directly into the receiving tank and was subjected to the transport and recovery processes. The “Treatment” group was inserted into the truck tank and was the only group subjected to the actual release process. By analyzing and contrasting these groups, injuries could be isolated to the receiving pool, pre-experiment fish condition, or fish release pipe with or without debris (Figure 12).

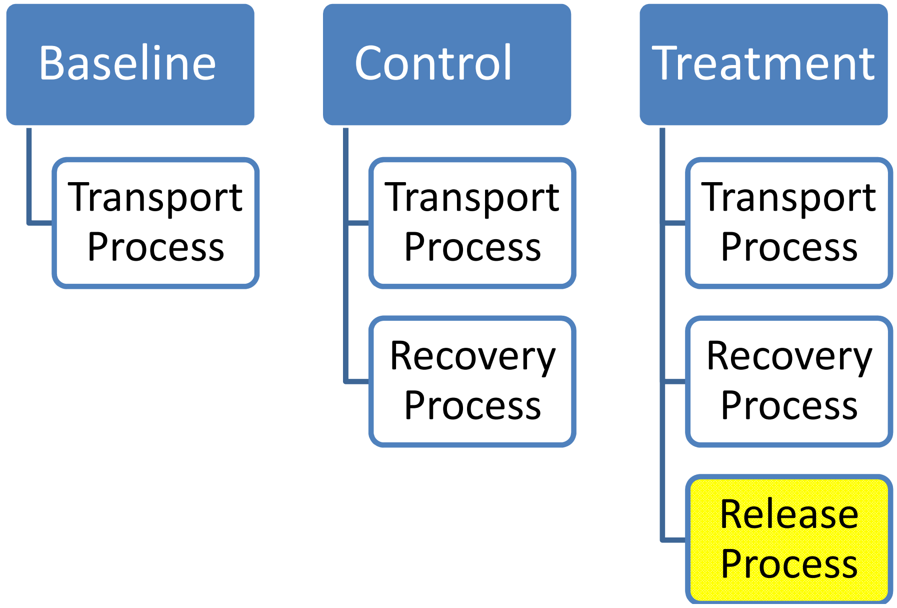


Figure 12- Breakdown of the experimental control and treatment groups used to isolate the effects of the various components of the experimental design. The critical Release Process, which includes the physical process of release from the release truck and travel down the release pipe, is highlighted for emphasis.

Mortality counts were performed immediately following each experiment, at 24 hours post-experiment, and at 48 hours post-experiment. Any dead post-test fish were examined for injury and their condition was recorded. All live fish at 48 hours were removed from post-test holding tanks and euthanized by MS-222 overdose. Fish injury assessments were performed immediately on a random sub-sample of four fish from each baseline, control, and treatment group of Chinook salmon or delta smelt per test.

The injury assessment consisted of inspecting each fish using a stereomicrosope. The head, eyes, skin, pectoral fins, pelvic fins, dorsal fin, anal fin, and caudal fin were examined for injury. Each biological variable was scored for damage using the fish injury data codes (Table 3). Fork length (mm) was measured to the nearest millimeter on a measuring board. Wet body weight was measured on an Acculab Balance VIC-4mq electronic balance to the nearest 0.001 gram (g).

Table 3- Marks and categories used in recording health assessment observations**.**

Reporting variable	Mark	Category
Fin clip	D	Dorsal
	CDF	Caudal-dorsal fork
	CVF	Caudal-ventral fork
	A	Anal
	D+CDF	Dorsal and CDF
	D+CVF	Dorsal and CVF
	A+D	Anal and dorsal
	A+CDF	Anal and CDF
	A+CVF	Anal and CVF
Mortality	D	Dead
	A	Alive
Head	0	Normal
	1	One operculum missing
	2	Both opercula missing
	3	Integument missing
	4	Hemorrhage
	5	Other injury
	6	Decapitation
	7	Bubble under skin
Eye	0	Normal
	1	One eye missing
	2	Both eyes missing
	3	Bulging eye
	4	Hemorrhage
	5	Other injury
	6	Abrasion
	7	Bubble under eye
Skin	0	Normal
	1	Bruised areas
	2	Partially de-skinned
	3	Split or open wound
	4	Hemorrhage
	5	Other injury
	6	Abrasion
	7	Bubble under skin
Pectoral fin	0	Normal
Pelvic fin	1	Discolored, frayed, < 30% erosic
Dorsal fin	2	> 30% erosion, but visible
Anal fin	3	Eroded to base
Caudal fin	4	Hemorrhage
	5	Other injury
	6	Missing
	7	Bubbles under the skin

2.4.1 Data Analysis

Data analysis was conducted in consultation with a biostatistician (Dr. Mark Bowen, USBR). Data was examined for parametric properties (normality and equal variance) prior to statistical testing. Normality of data distribution was tested using a Kolmogorov-Smirnov test. Equal variance among groups was examined using Bartlett's test of homogeneity (Zar 1984, Sokal and Rohlf 1969). The health assessment and mortality data for both delta smelt and Chinook salmon were non-parametric. Therefore, a Kruskal-Wallis test with a significance level of $P < 0.05$ was used to determine if significant differences existed between groups. Systat Version 9 (Systat Software, Inc., Chicago, IL) was used to analyze all data.

2.4.1.1 Release Pipe Fish Mortality

The overall percent survival for baseline, control, and treatment groups was calculated for descriptive purposes. The percent mortality data was converted to adjusted effect size for statistical testing purposes. This approach was used to determine if the treatment fish sustained significant mortality from exposure to varying levels of debris during release. Mortality percentages were converted to effect sizes by the following formula.

Mortality effect size = (treatment – control percentages) + C_M
where: C_M = the largest effect value in the test for each variable

This approach assumes that any difference in the results from the mortality effect size of the control and treatment scores were due to mortality caused by each treatment (debris load) since the receiving pool mortality was subtracted and consequently removed. Since negative values occurred in some experiments, the largest effect size in the test, C_M was added to ensure that all data points were positive.

2.4.1.2 Receiving Pool Health Assessment Effect

To determine if the control fish sustained significant injury in the receiving pool, the original injury observations were converted to adjusted response effect values. The data was first described as the proportion of damage per test. Each health assessment of baseline and control tests was composed of four fish so the proportion of damaged fish per test was scored as 0, 0.25, 0.50, 0.75, or 1.0. Each proportion was then converted to an effect size by the following formula.

Receiving pool effect size = (baseline – control proportions) + C_p
where: C_p = the largest effect value in the test for each variable

This procedure assumes that any difference in the results from effect size of the baseline and control scores were due to any damage caused by recovery from the receiving pool. Since negative values occurred in some experiments, the largest effect size in the test was added to ensure that all data points were positive.

2.4.1.3 Release Pipe Health Assessment Effect

The same coding used for the receiving pool health assessments was used to determine statistically if the treatment fish sustained significant injury in the mock release pipe. The data was first described as the proportion of damage per test. Each health assessment of control and treatment tests was composed of 4 fish so each fish was scored as 0, 0.25, 0.50, 0.75, or 1.0. Each test proportion was then converted to an effect size by the following formula.

Release pipe effect size = (treatment – control proportions) + C_T
where: C_T = the largest effect value in the test for each variable

This procedure assumes that that any difference in the results from effect size of the control and treatment scores were due to any damage caused by each treatment (debris load) since any experimental control effect was subtracted and consequently removed. Since negative values occurred in some experiments, the largest effect size in the test was added to ensure that all data points were positive.

2.4.2 Quality Control Procedures

Quality control procedures were done for the environmental and biological variables: dissolved oxygen, specific conductivity, water temperature, fork length, and wet weight. Quality control procedures were also used for the health assessment observations on the head, eye, skin, pectoral, pelvic, dorsal, anal, and caudal fins. Precision and accuracy were calculated by the following formulas.

Relative Precision Deviation =
(Difference between readings 1 and 2) / (mean value of reading 1 and 2) x 100%

Relative Accuracy Deviation =
(Mean value of reading 1 and 2) - (true reading) / (true reading) x 100%

Performance goals for acceptable precision and variance levels for dissolved oxygen, specific conductivity, and temperature are listed in Appendix A. Performance goals for acceptable accuracy levels for fork length and wet weight, and error rate for injury assessment observations are listed in Appendix B. Variance for injury assessment was calculated by the following formula.

Error rate=
(number of QC injury assessment readings which differed)/(total number of QC injury assessment readings) x 100%

The precision checks were performed by a lead person. Any higher deviations were reported to the Lead Biologist and triggered corrective actions.

The YSI Model 556 Multi-Probe System was calibrated for specific conductance before and after the study by inserting the probe in a 1,430 µS/cm KCL solution and using the instrument's calibration routine. Dissolved oxygen was calibrated daily by obtaining barometric pressure which was entered into the meter and used the instrument's calibration routine. A NIST traceable glass thermometer was used to obtain a reference reading for accuracy readings. The Acculab Balance VIC-4mq scale was calibrated daily with a 200 g (0.44 lb) certified weight.

2.5 Experimental Procedures

For each experiment, the release truck tank was filled with 8,517 L (2250 gal) of Delta water. Water was supplied from a high pressure line located inside one of the fish holding tank buildings at SDFPF. The water line draws its water from the main intake canal located just in front of the debris racks, and is the same water line used to fill the haul trucks during normal salvage operations. During the filling process, 30 kg (66 lb) of salt was added to the truck tank (equating to ~2 ppt salinity) to reduce fish stress and to mimic standard operating procedures at the SDFPF when delta smelt are present in the salvage. The same high pressure water source was used to fill the receiving pool at the end of the release pipe. The receiving tank was filled with approximately 47,318 L (12,500 gal) of water prior to each experiment. Salt was not added to the receiving tank since at the actual salvaged release sites salinity would be variable and tied to delta outflow and tidal conditions.

Once the truck tank was filled to the desired level, a pre-determined level of debris (0X, 1X, 4X) was added to the tank. Preparation of the different debris levels is detailed in Section 2.2 of this report. Debris was inserted at least 20 minutes prior to an experimental run. This allowed the debris to distribute vertically in the water column in the tank.

Once the truck tank and receiving tank were filled to the desired level, the pressure transducers along the release pipe were bled of air. This ensured an accurate reading of the hydraulic data being recorded. Water quality data in the truck tank and receiving tank was also recorded at this time. A water quality probe (YSI model 85, YSI Incorporated, Yellow Springs, OH) calibrated daily, was used to record water temperature (°C), dissolved oxygen (DO, mg/L), specific conductance (µs/cm), and salinity (ppt). Experiments were not conducted if any water quality parameters were outside acceptable ranges (temperature >1°C different than holding tanks or DO < 7mg/L).

The fish were gently inserted by lowering the transport bucket into the water and inverting it. This ensured a water to water transfer, minimizing stress to the fish. After insertion, fish were allowed a 10 minute acclimation period before conducting an experiment.

At the end of the fish acclimation period, approximately 0.005 m^3/s (0.18 cfs) of auxiliary flow was fed into the release pipe through the water jet manifold. The jet manifold system was designed to, in theory, prevent fish from being released into a dry pipe and sustaining injury from dragging along the bottom. Once the auxiliary flow was detected by the pressure transducers along the pipe, the release valve on the truck tank was opened and the experiment began. During an actual release, the operators open the knife gate incrementally in stages. If the knife gate is opened too fast or all at once, blowback will occur and send water and fish up and out the release pipe. We employed a similar procedure during our experiments, but attempted to standardize how quickly the gate was operated. However, the compressed air actuator that operates the knife gate made opening the gate to a set position difficult. To the best of our ability the following procedure was followed for every experiment: the initial gate position was 20% open for a duration of 30 seconds; the next gate position was 50% for 10 seconds; finally the gate was fully opened for the remainder of the experiment. As in the field, once the gate was in the full open position, the operator climbed up the truck tank and washed down the inside with a high pressure water hose. The auxiliary flow remained on until the truck tank was completely empty of water and debris. With the release complete, the data recorded by the pressure transducers was saved onto a file and stored on the computer.

Immediately following each release, three drain pumps for the receiving pool were turned on. The pumps drained the pool to a water depth of 30 cm (12 in) in approximately 35 minutes. Care was taken to not lower the water level further and strand fish in the debris. Personnel then entered the pool and recovered the treatment and control fish using nylon brine shrimp nets. The recovered fish were placed inside transport buckets and returned to the CHTR building where they were transferred into post-test tanks for observation. The debris recovered from the receiving pool was separated and sorted back into the three debris groups (woody, trash, and green). Woody and trash debris were reused in subsequent experiments and the green debris was discarded.

3.0 Results

3.1 Hydraulic Conditions During Fish Releases

The hydraulics of the fish release process is, by its nature, unsteady flow. As the tank drains, the driving head on the system and therefore flow continuously decrease for a fixed gate opening. Predictable relationships between gate opening, tank water depth and release flow were affected by pressure surges in the pipe caused by poor air venting and to a lesser degree, debris movement through the system. Additional variability of operation was introduced by the poor control of the truck knife gate positioning.

In the study, a total of 106 tests were conducted to investigate the influence of operation and debris load on release pipe hydraulics during the release process; 35 experiments at the normal debris (1X) and four times normal (4X) debris loads, and 36 experiments with no debris load (0X). Comprehensive hydraulic results, including data from individual experiments, are available in a separate USBR publication (USBR 2008). Figures 13, 14 and 15 present selected data measured during typical tests conducted with no debris (0X), normal debris (1X) and four times normal (4X) debris loads. The data plots illustrate how flow conditions change with time during the fish release process.

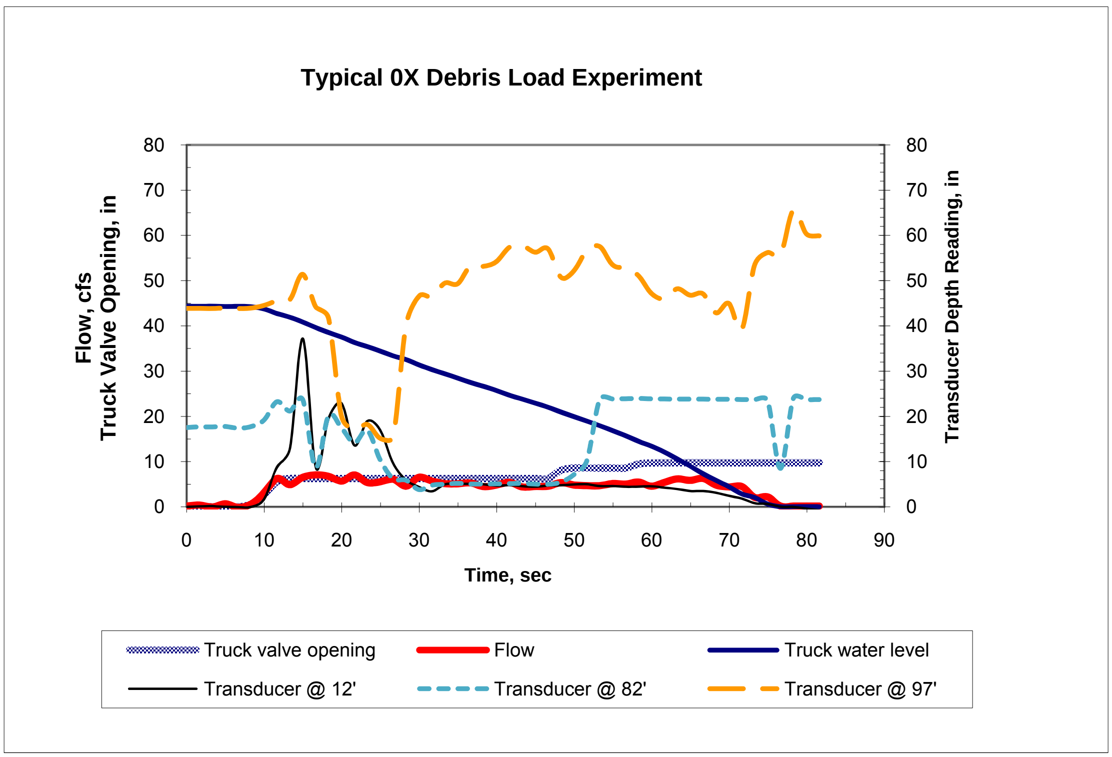


Figure 13- Plots of selected model parameters measured during a fish release test conducted with no debris. Pressure transducer readings are referenced from end of pipe invert.

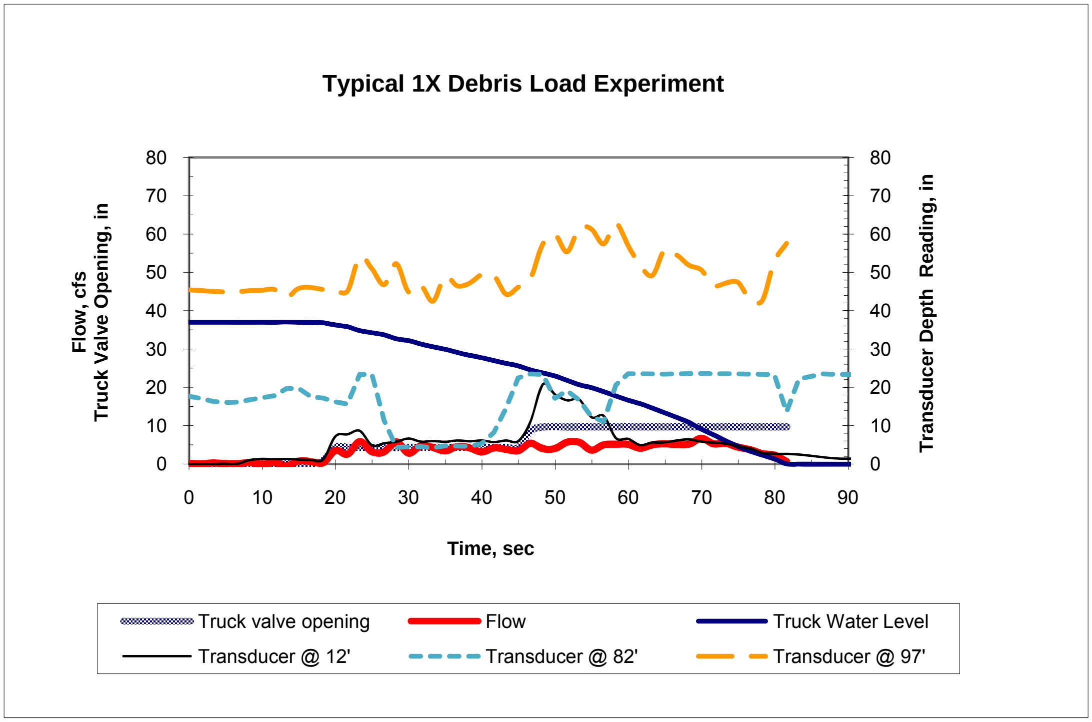


Figure 14-Plots of selected model parameters measured during a fish release conducted with an ambient (1X) debris load. Pressure transducer readings are referenced from end of pipe invert.

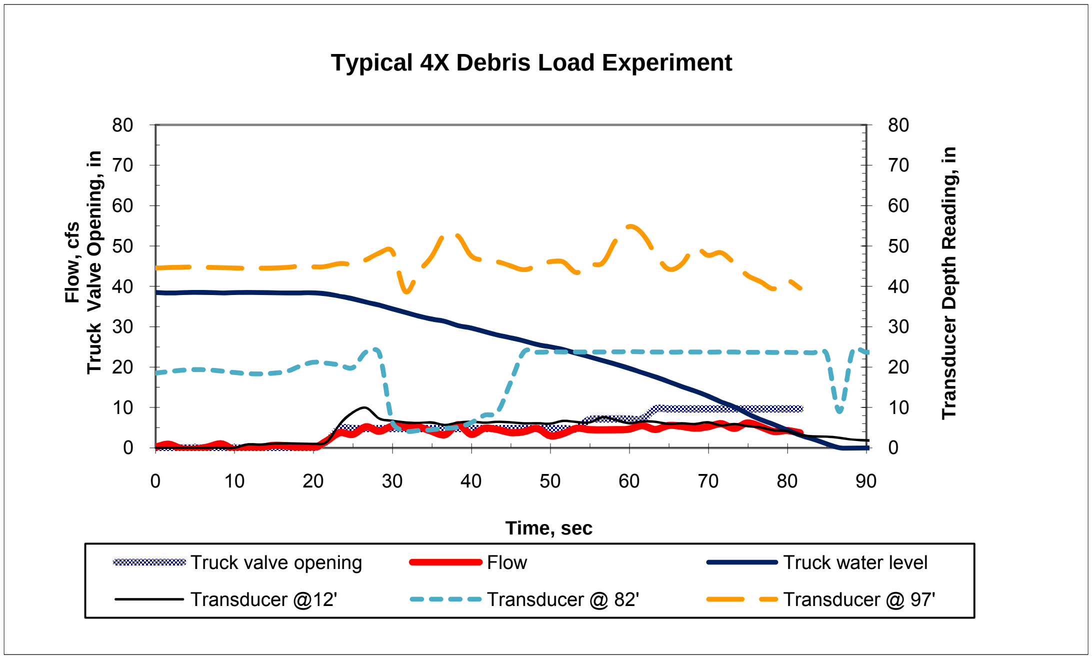


Figure 15- Plots of selected model parameters measured during a fish release test conducted with a four times ambient (4X) debris load. Pressure transducer readings are referenced from end of pipe invert.

3.1.1 Truck Tank

Flow from the tank is largely a function of the tank release gate discharge characteristics. The knife gate is a 25.4 cm (10 in) diameter pneumatic valve mounted on the back of the release truck. The bottom of the gate leaf has a radius slightly larger than the pipe diameter. The relationship of flow to truck tank water depth is estimated by the coefficient of discharge for the knife gate. Hydraulic data on similar knife gates was not found. As a reasonable substitute, the coefficient of discharge for a gate valve was used. The coefficient of discharge relationship for free flow through gate valves developed by the Army Corps of Engineers is shown in Figure 16. The relationship can be expressed by Equation 1 and is shown for various gate openings in Figure 17.

$$Q = C_d A\sqrt{2gH} \tag{1}$$

where:

Q = Flow from the tank, CFS
C_d = 0.0094*Percent Gate Opening
A = full open gate area, ft^2
g = acceleration due to gravity, 32.2 ft/s^2
H = water depth upstream of gate referenced to the center line of the gate, ft

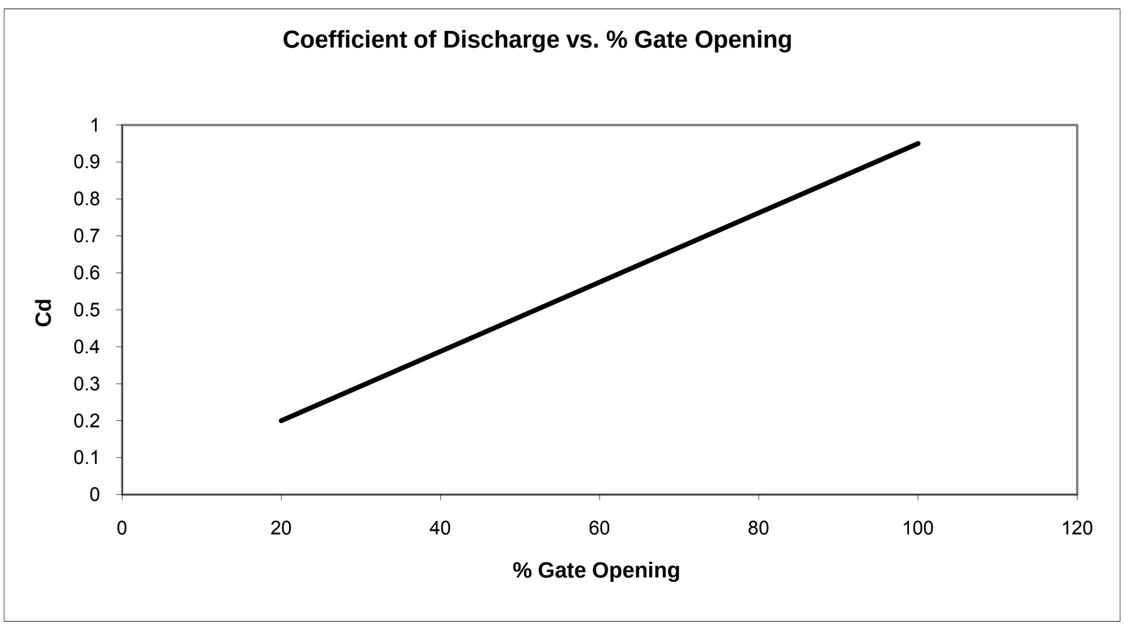


Figure 16- Coefficient of discharge for a gate valve, Corps of Engineers Hydraulic Design Chart 330-1/1.

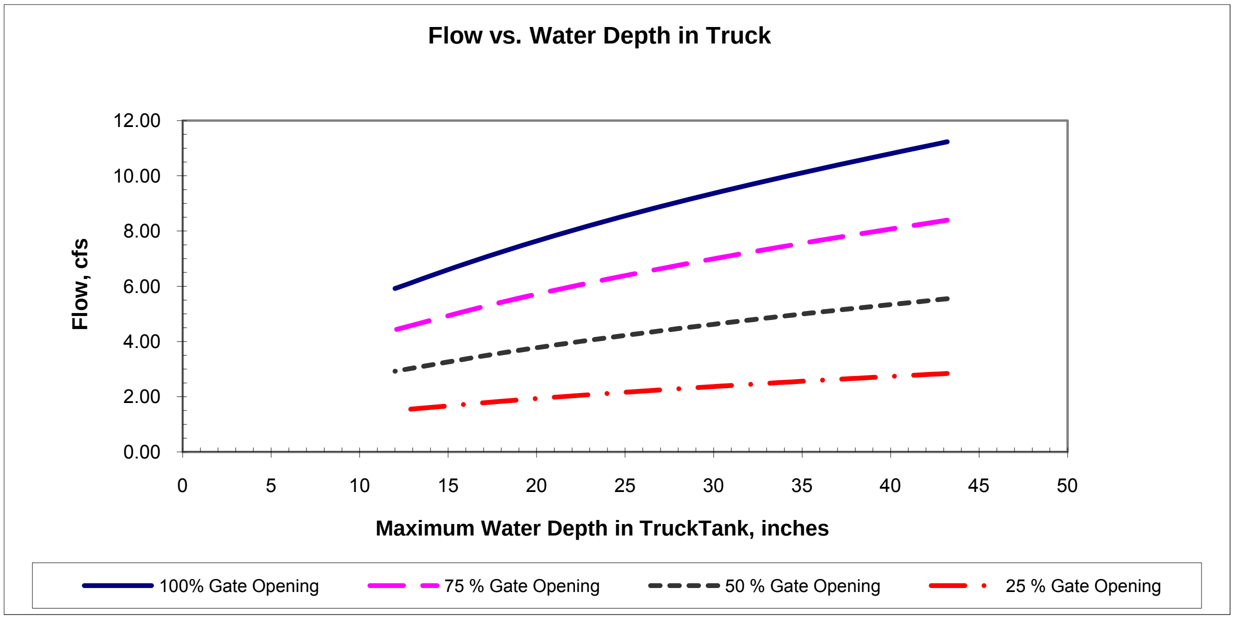


Figure 17- Estimated Flow from the truck tank outlet at four different gate openings based on equation 1.

3.1.2 Free Surface Pipe Flow

Flow from the truck tank passes down the pipe as free surface flow until intercepting the tailwater. The smooth acrylic pipe is sufficiently long to allow the flow to reach normal depth upstream of the tailwater. Flow depth and velocity at the tailwater for a known discharge can be determined by iteration from the well known Manning's equation. The Manning's Formula for uniform flow in an open channel expressed in English units is,

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2} \tag{2}$$

where: Q = discharge, ft^3/s
A = flow area, ft
n = Manning's coefficient of roughness
R = channel hydraulic radius, ft
S = slope of the energy grade line

Model flow versus normal depth in the release pipe for a Manning's *n* value of 0.01 is given in Figure 18 and average flow velocity at contact with the tailwater is given in Figure 19. Figures 18 and 19show that under free surface flow conditions with the maximum pipe flow of 0.28 m^3/s (10 cfs), the maximum velocity obtained in the pipe was 7.3 m/s (24 ft/s) at a water depth of 12.7 cm (5 in). The existing steel release pipes would be rougher than the PVC pipe used in the model. Depending on pipe condition, Manning's n values for the actual pipe would likely be in the range of 0.012 to 0.014.

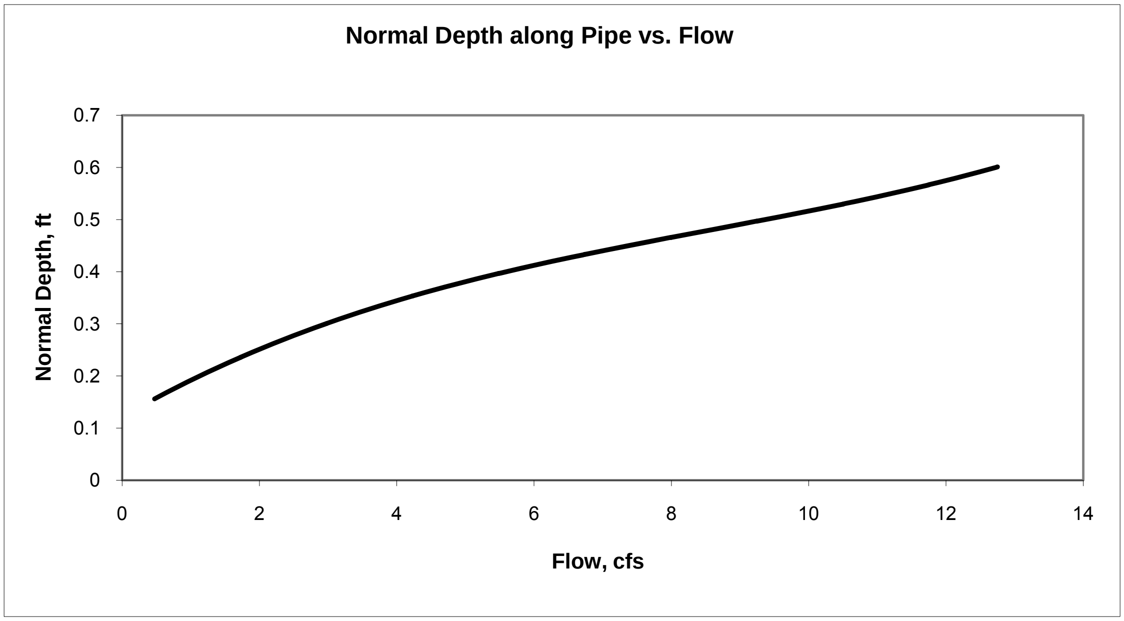


Figure 18- Normal Depth in a 12 in (30.48 cm) diameter smooth pipe. Values above 10 cfs (max flow) are extrapolated, and all values are based on the physical properties of pipe.

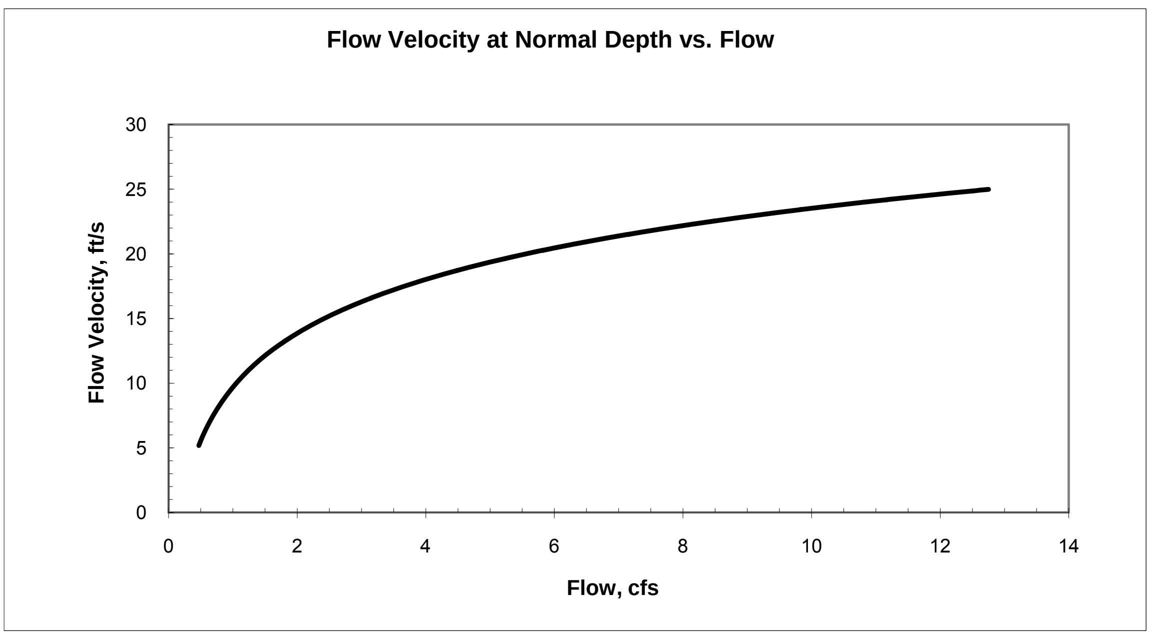


Figure 19- Flow velocity at contact with the tailwater as a function of pipe flow. Values above 10 cfs (0.28 m^3/s; max flow) are extrapolated. All values are based on physical properties of pipe.

3.1.3 Pressurized Pipe Flow

Free surface pipe flow jumps to pressurized full-pipe flow upon intercepting the tailwater in the pipe. The velocity of pressure flow downstream of the hydraulic jump is inversely related to pipe area. Average flow velocity is approximately 1.27 times flow (Figure 20). Figure 20 shows that under pressurized flow conditions, the maximum velocity in the pipe is 3.96 m/s (13 ft/s) at a full pipe (30.48 cm [12 in]).

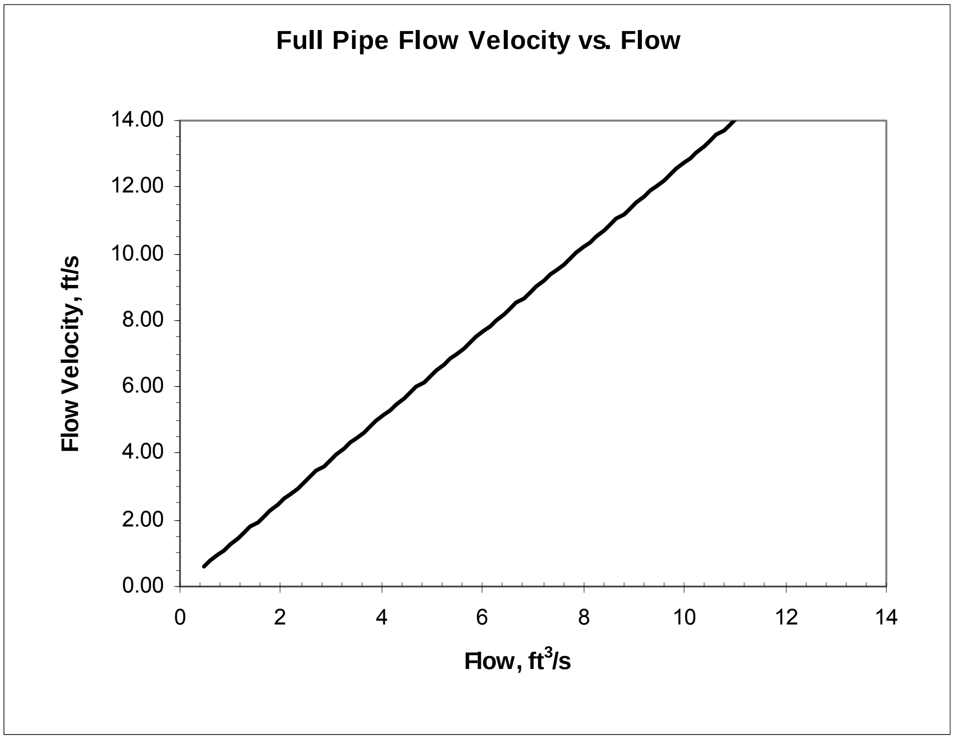


Figure 20- Full pipe flow velocity in a 30.48 cm ID (12 inch) pipe. Values above 10 cfs (0.28 m^3/s) are extrapolated.

3.1.4 Tailwater Suppression and the Hydraulic Jump

Also of note in Figures 13–15, are pressures measured at pipe stations 82 and 97. These stations are located below normal tailwater. In all three tests, the tailwater is suppressed for a period of time below pipe station 82 as indicated by a sharp drop in pressure during the release process. In Figure 13, pressures measured at station 97 indicate an initial gate opening of 60% resulted in the hydraulic jump (free flow-tailwater interface) moving to nearly the pipe terminus for about 15 seconds before retreating. Test data shown in Figures 14 and 15 with smaller initial gate openings indicate the hydraulic jump remains upstream of station 97 throughout the release. However, large pressure fluctuations at station 97 indicate the hydraulic jump length extends to the end of the pipe during much of the release.

The momentum of the free surface pipe flow upon contacting the tailwater suppresses the tailwater in the pipe below the surrounding tailwater level, moving the hydraulic jump downstream. Suppression of the jump in the release pipe is given in Figure 21 in terms of vertical and slope distances.

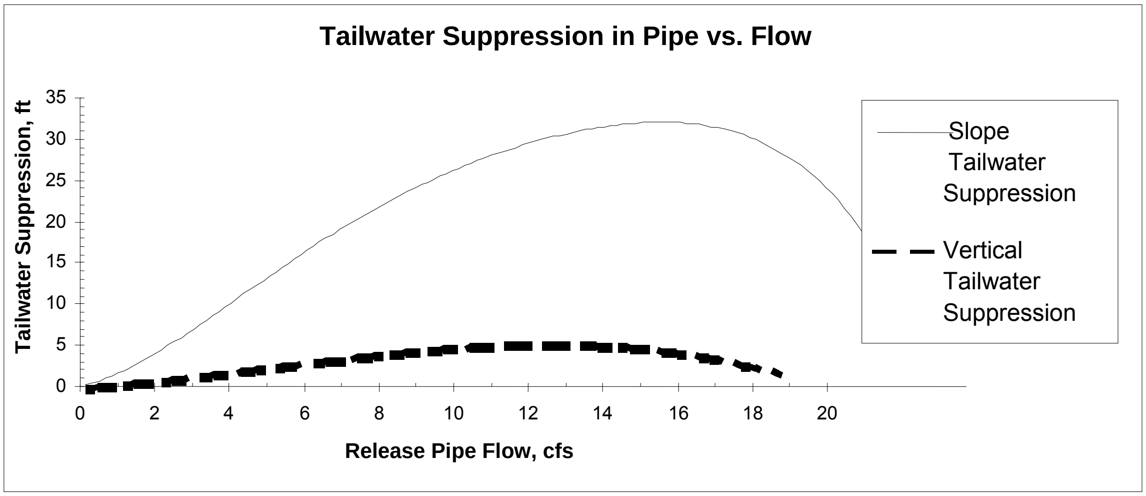


Figure 21- Location of the hydraulic jump in the fish release pipe as a function of pipe flow.

3.1.5 Hydraulic Jump Length

No studies of hydraulic jump lengths in shallow sloping pipes were found during the literature search. However, a reasonable approximation of jump length can be determined from physical model studies of jumps in horizontal pipes conducted by Stahl and Hager (1999). They defined jump length in terms of a recirculation zone and air entrainment zone. The recirculation zone (L_r) represented by equation 3, extends from the upstream jump toe downstream to the surface stagnation point. The air entrainment zone (L_a) represented by equation 4, extends from the upstream toe downstream to the point where most of the entrained air has reached the pipe crown.

$$L_r = 2h_2F_1 \tag{3}$$

where: L_r = recirculation zone
h_2 = sequent depth
F_1 = Froude number

$$L_a = 2L_r \tag{4}$$

where: L_a = air entrainment zone
L_r = recirculation zone

The hydraulic jump length is an important parameter, because it represents the linear distance of turbulence associated with the hydraulic jump. Results from our study suggest that the recirculation zone for our experimental runs was between 3.6 m and 3.9 m (11.8 ft and 12.8 ft) in length. Fish traveling down the pipe, therefore pass through the hydraulic jump and a 3.6–3.9 m (11.8–12.8 ft) length of turbulent water just after the jump. The relationship between F_1 and release pipe flow is shown in Figure 22.

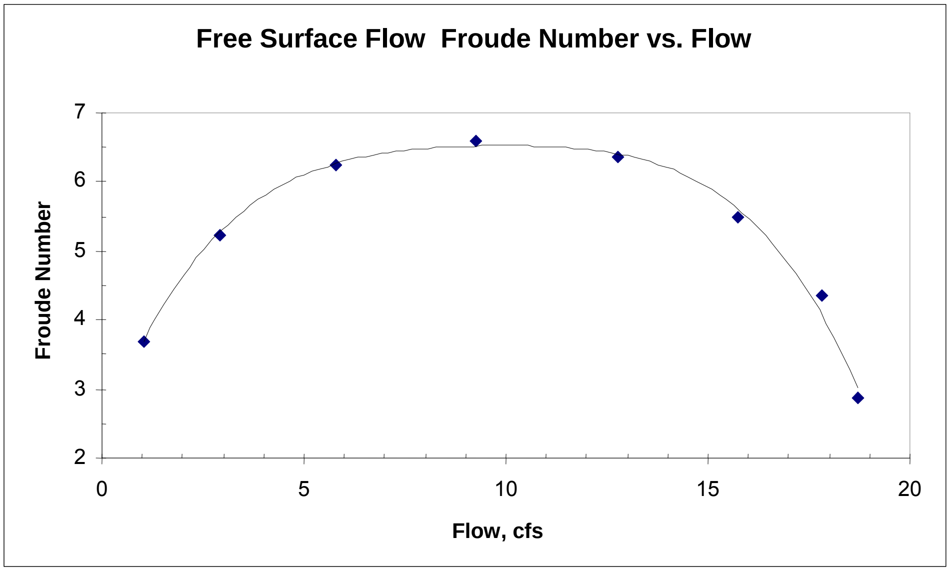


Figure 22- Froude number of free surface flow in the fish release pipe.

3.1.6 Auxiliary Flow

The amount of auxiliary flow pumped into the mock release pipe was calculated from field measurements at the SWP Horseshoe Bend fish release site. The volume of water flowing from the SWP Horseshoe Bend auxiliary system was recorded several times over a one minute time period to obtain a flow rate. The field measured auxiliary flow of 0.005 m^3/s (0.18 cfs) was supplied to the release pipe just prior to each test and continuing until several minutes after the truck tank was emptied. The small auxiliary flow had little effect on release pipe hydraulics.

3.1.7 Receiving Pool Depth

Receiving pool depth was measured using a pressure transducer mounted near the floor of the receiving pool. All flow released from the fish haul truck was retained in the receiving pool during a test. Prior to each test the initial depth was set to 1.28 m (4.2 ft) of submergence on the downstream end of the release pipe. During the tests the receiving pool depth (tailwater) increased 31.75 cm (12.5 in).

3.1.8 Air Entrainment and Venting

At the interface of free flow and pressure flow, the hydraulic jump transfers free air from upstream of the jump into the pressure flow downstream. In a sloping pipe the entrained air may be carried down the pipe by flow or travel up the pipe against the flow due to buoyancy. Falvey (1980) presented a graph of predicted movement of air bubbles in sloping pipes (Figure 23). The range of hydraulic conditions and air pocket movement that could occur during a fish release are indicated on the plot by a heavy line. The data indicates air bubbles will travel upstream when release pipe flow is less than about 0.079 m^3/s (2.8 cfs) and downstream when flows are higher. Because flow decreases as the truck tank empties, a transition will occur where air bubbles that were moving down the pipe fail to escape prior to the discharge falling below 0.079 m^3/s (2.8 cfs). Free air remaining in the pipe will then run up the pipe consolidating into larger air pockets as downstream bubbles overtake upstream bubbles. When air pockets reach the free surface the pockets contain compressed air that rapidly expands at the water surface. This action is referred to as blowback. The action of air pockets blowing back was evident in the model. Visual observation of flow in the model revealed rapid swings in the location of the hydraulic jump as the truck tank approached empty. The pressure swings observed were likely a combination of blowback and restricted air venting of the free flow zone.

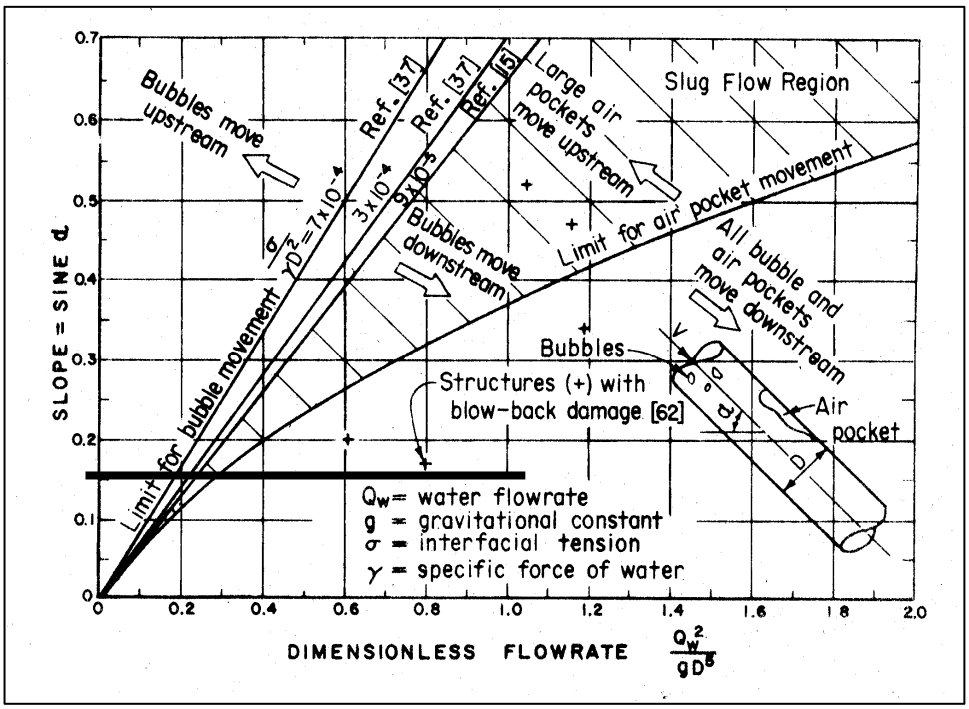


Figure 23- Air bubble movement in a sloping pipe, Falvey 1980. Range of possible conditions during a fish release are represented by the dark bold line.

Of particular note are the test data for pipe station 12 presented in Figure 13 which show a sharp rise in pipe pressure immediately following gate opening. The pressure rise is due to compression of air in the pipe caused by a rapid release of water into the pipe with restricted air venting. The pressures shown resulted from an initial gate opening of 60%. Figures 14 and 15 show a much reduced pressure rise due to air compression following initial gate openings of 40 to 45%. A rapid pressurization of the pipe results in air and water blowing back through the annulus between the fixed pipe and flex pipe used during a release and is typically avoided by operators by opening the gate less than about 40% for a period of 20 to 30 seconds while air bleeds out of the pipe.

3.1.9 Fluid Strain

The maximum rate of fluid strain in a hydraulic jump can be approximated by high velocity flow entering a pool. Rate of fluid strain is defined as the change in velocity magnitude divided by distance normal to the flow direction (Δy). Maximum velocity in the model reached about 7.62 m/s (25 ft/s; Figure 19) or a maximum rate of strain of 428 in/s/in.

3.1.10 Flushing of Debris

Flushing of debris through the release system requires material be carried by flow from the truck tank, passed through the control gate and a 90° elbow before entering the release pipe. Material must then be carried by free surface flow down the pipe to the hydraulic jump, pass through the jump and be carried in full pipe flow to the pipe exit. The addition of four times the ambient debris load was found to have little effect on release flow conveyance. Drawing direct comparisons of flow conditions with different debris loads was not possible due to our inability to closely control the truck release gate opening and differences in debris characteristics (buoyancy and consistency) between tests. To evaluate debris effects on flow conveyance, coefficient of discharge (C_d) values were calculated for a full and partial gate opening conditions under similar hydraulic heads. Ten values for tests conducted with no debris were compared to 10 tests conducted with 4X debris. The C_d values were not statistically different at a 95% confidence level. This indicates no significant reduction in flow conveyance from the truck tank due to debris at the concentrations tested. However, significant clogging was observed following several 4X debris tests at both the gate and elbow. We could not determine from the tests when clogging occurred during the release process. Clogging most likely occurred near the end of the release process when flow is rapidly declining and large quantities of floating debris are being pulled into the release pipe. On several occasions, the clogging resulted in some fish being stranded in a small pool of water in the truck until the clog could be removed.

Following all debris tests, significant debris also remained in the submerged section of pipe. The retention of debris in the pipe following a release is affected by a combination of factors including debris characteristics and flow conditions. Highly buoyant debris is likely expelled from the truck tank during the final stages of the release process when release flow is significantly reduced. Debris that is positively buoyant may either pass through the jump or become entrained in the recirculation flow that occurs on the face of the hydraulic jump. Entrapment of highly buoyant debris in the recirculation zone of a hydraulic jump is nearly independent of flow. Entrapment may persist during large and small flows. Highly buoyant debris passed through the jump can be assumed to move similar to an air pocket as discussed in the air entrainment section. Therefore, to transport highly buoyant material downstream requires a sustained flow rate greater than about 0.079 m^3/s (2.8 cfs) of sufficient time for material to travel the length of submerged pipe. Considering buoyant debris is most likely to be flushed during the final stages of a release, sufficient auxiliary flow was not provided during the model tests to flush buoyant debris.

3.1.11 3-Dimensional Computational Fluid Dynamics (CFD) Modeling

A three dimensional CFD model of the mock release site was developed to further investigate the hydraulics of the release process (Figures 24 & 25). Computer generated animations of flow conditions during the entire fish release process for both gates sequences modeled are available upon request. The CFD model included the truck tank, 25.4 cm (10 in) release gate and insertion pipe, fixed 30.48 cm (12 in) diameter release pipe, and tailwater tank. The numerical model was used to simulate the unsteady flow conditions of a release, validate the analytical prediction of tailwater suppression presented and extend the study results to include hydraulic conditions for a full gate opening release.

Two simulations of fish releases in the numerical model were conducted. The first simulation modeled a release using a stepped gate opening (Figure 24). The truck gate was initially opened to 40% of the full gate stroke for 20 seconds and then increased to 50% gate stroke for ten seconds followed by opening the gate 100%. The second simulation modeled a release where the gate is fully opened at once (Figure 25). For each simulation 0.0045 m^3/s (0.16 cfs) was added as auxiliary flow. The compression of air in the release pipe was not included in the model.

The simulations were developed to assist in understanding how the dynamics of the hydraulic jump changes through the unsteady process and the implications to flushing debris and fish. Hydraulic jump suppression predicted from the CFD modeling compared well with calculations using the specific force method. Comparing the volume of flow released with time, the stepped opening requires about 125 seconds for the tank to drain compared to about 75 seconds when the release gate is opened fully.

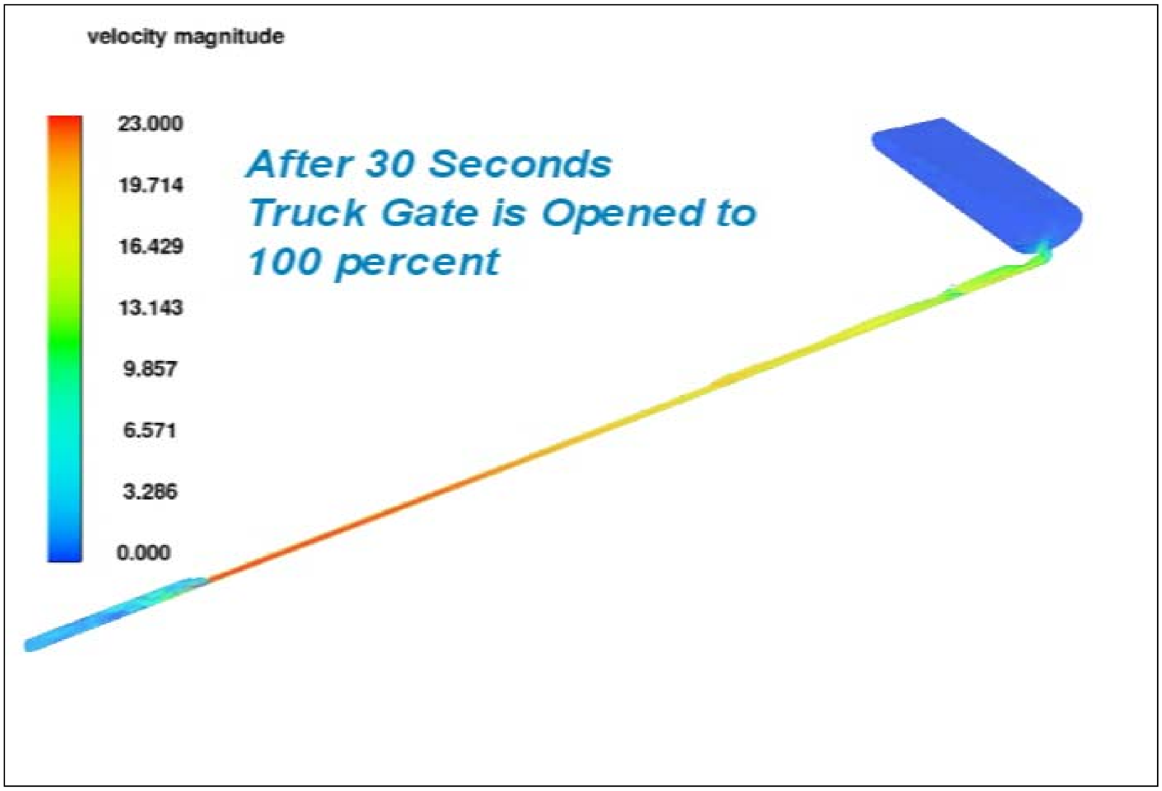


Figure 24- View showing the CFD model of the mock fish release facility during a stepped gate opening. Velocity magnitude is expressed as ft/s. The full animation of the model is available upon request.

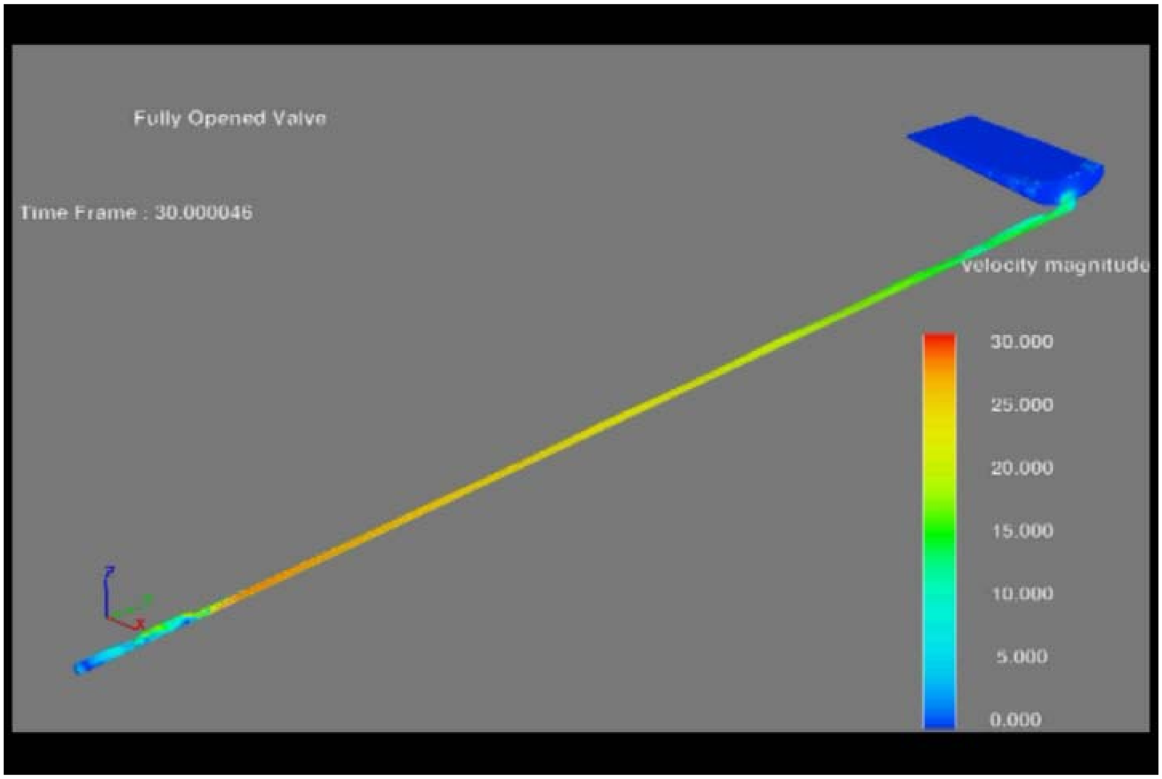


Figure 25- View showing the CFD model of the mock fish release facility during a release when the valve is fully opened at once. Velocity magnitude is expressed as ft/s. The full animation of the model is available upon request

3.2 Fish Mortality and Injury Assessment Results

A total of 21 tests were completed for each debris load, 0X, 1X, and 4X, for juvenile Chinook salmon during March and April 2007. A total of 4,158 Chinook salmon were used in tests with a mean length of 75.6 mm (2.97 in) FL and a mean wet weight of 4.96 g (0.174 oz). Seven hundred fifty-six individual fish were examined in the injury assessments (Table 4).

A total of 16 tests were completed for each of the 0X and 4X debris loads and 17 tests for 1X debris load for adult delta smelt during January and February 2007. A total of 3,234 delta smelt were used in tests with a mean length of 69.0 mm (2.71 in) FL and a mean wet weight of 2.58 g (0.091 oz). Five hundred ninety-five individual fish were examined in injury assessments (Table 4).

Table 4- Number, mean length, and mean wet weight of Chinook salmon and delta smelt.

Species	Total Number	Number Examined For Injury	Range FL (mm)	Mean Length (mm±SE)	Range Weight (g)	Mean Weight (g±SE)
Chinook salmon	4,158	756	48-109	75.6±0.32	1.08-15.04	4.96±0.07
delta smelt	3,234	595	49-87	69.0±0.25	0.88-5.65	2.58±0.03

3.2.1 Fish Mortality

Overall, fish mortality was generally low for all groups observed in both juvenile Chinook salmon and adult delta smelt experiments. Percent mortalities of Chinook salmon for all baseline (transport only) and control (transport and recovery) groups were insignificant (Table 5). Baseline mortality ranged from 0.0 to 0.2%. Control mortality ranged from 0.0 to 0.8% and treatment (transport, release, and recovery) mortality ranged from 0.8 to 2.6% with no evidence of a debris load mortality relationship for either group.

Table 5- Percent mortality of Chinook salmon and delta smelt for baseline, control, and treatment groups.

Species	Baseline			Control			Treatment		
	0X	1X	4X	0X	1X	4X	0X	1X	4X
Chinook salmon	0%	0.2%	0%	0.6%	0%	0.8%	0.8%	2.6%	1.6%
delta smelt	0%	0.3%	0.3%	0.5%	2.7%	4.0%	1.3%	2.9%	4.8%

Similar to Chinook salmon, delta smelt showed little mortality in the baseline trials. Percent mortality for baseline groups ranged from 0.0 to 0.3%. Mortality for control groups ranged from 0.5 to 4.0% and 1.3 to 4.8% for the treatment groups. It should be noted however, that while there was no significant relationship between mortality and debris load for the treatment group, mortality did increase slightly as debris load increased.

For Chinook salmon, mortality effect size was not significantly different between 0X, 1X, or 4X debris loads in the treatment groups, indicating the level of debris was not a significant factor in Chinook salmon mortality associated with the release pipe simulation (Table 6, Figure 26).

Similar to the Chinook salmon findings, the mortality effect size analysis for delta smelt did not show significant differences between 0X, 1X, or 4X debris load in the treatment groups, indicating that delta smelt mortality was not significant in the release pipe at increased debris loads (Table 6, Figure 26).

Table 6- Mean mortality effect size for Chinook salmon and delta smelt with corresponding U statistic, degrees of freedom, and probability.

Species	Mean 0X Debris load ± SE	Mean 1X Debris load ± SE	Mean 4X Debris load ± SE	U	df	*p*
Chinook salmon	4.05 ± 0.15	4.57 ± 0.24	4.22 ± 0.15	1.61	2	0.45
delta smelt	4.17 ± 0.18	4.05 ± 0.31	4.19 ± 0.36	0.01	2	0.99

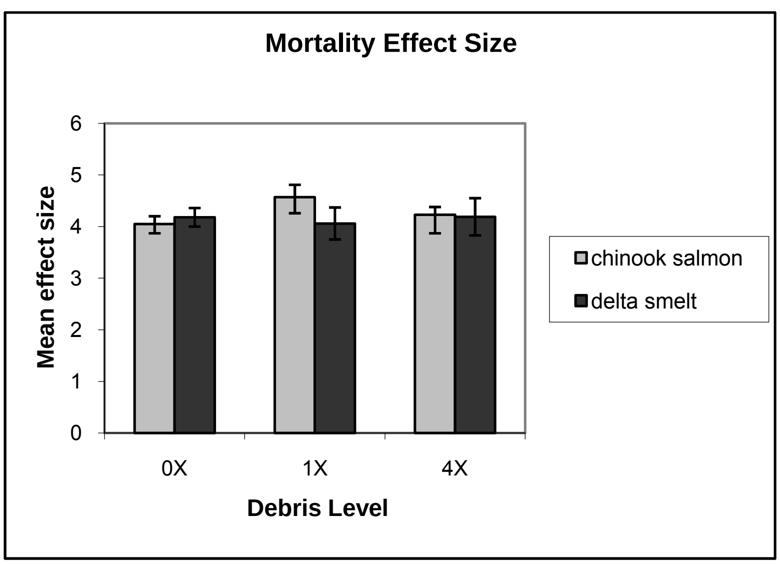


Figure 26- Mean release pipe effect size for mortality in Chinook salmon and delta smelt for three debris levels with standard error bars.

3.2.2 Fish Injury

Overall, inspection of the mean injury proportions from the Chinook salmon and delta smelt groups did not reveal any striking or consistent patterns of body damage relative to increasing debris loads. The mean baseline and control injury proportions for Chinook salmon were generally low and similar except for higher frequencies of pectoral and pelvic fin injuries (Table 7). Pectoral and pelvic fins had the highest degree of injury and increased slightly over control 1X and 4X debris loads suggesting that some minor damage to fins occurred in the receiving pool. Pectoral fin injury from the receiving pool served as a representative example (Figure 27). Eye injury served as a representative example for the remaining injury variables observed from the receiving pool trials since injury proportions were generally very similar (Figure 28). Head injury was the least frequent Chinook salmon injury.

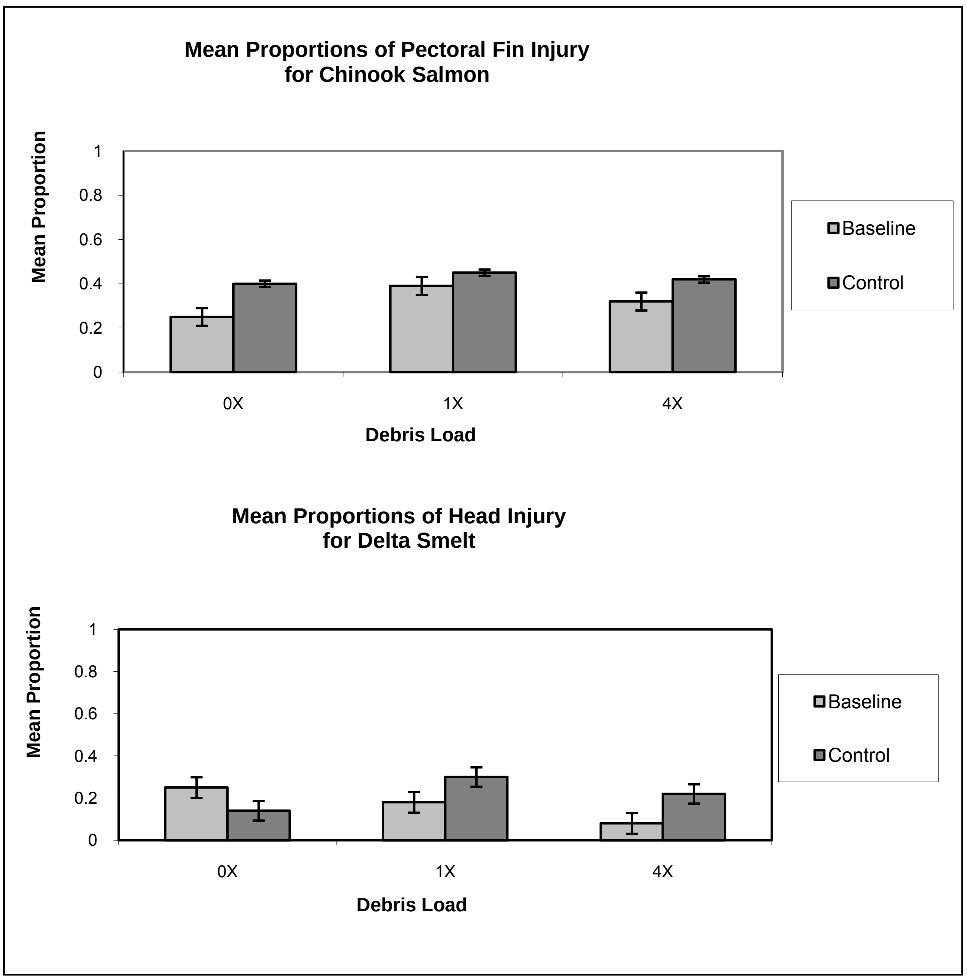


Figure 27- Mean proportions of pectoral fin injury for Chinook salmon and head injury for delta smelt baseline and control groups with standard error bars.

Table 7- Mean injury proportions for Chinook salmon experiments ± SE.

Injury Location	**Baseline**			**Control**			**Treatment**		
	0X debris load	**1X debris load**	**4X debris load**	**0X debris load**	**1X debris load**	**4X debris load**	**0X debris load**	**1X debris load**	**4X debris load**
Head	0.00 ± 0.00	0.02 ± 0.02	0.01 ± 0.01	0.02 ± 0.02	0.01 ± 0.01	0.01 ± 0.01	0.00 ± 0.00	0.01 ± 0.01	0.02 ± 0.02
Eye	0.02 ± 0.02	0.06 ± 0.03	0.08 ± 0.04	0.08 ± 0.03	0.06 ± 0.02	0.08 ± 0.04	0.04 ± 0.02	0.07 ± 0.03	0.08 ± 0.04
Skin	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.04 ± 0.02	0.00 ± 0.00	0.02 ± 0.02	0.00 ± 0.00	0.02 ± 0.02	0.07 ± 0.05
Pectoral	0.35 ± 0.08	0.39 ± 0.06	0.32 ± 0.07	0.40 ± 0.06	0.45 ± 0.07	0.42 ± 0.08	0.38 ± 0.06	0.43 ± 0.06	0.36 ± 0.08
Pelvic	0.30 ± 0.08	0.30 ± 0.05	0.29 ± 0.07	0.26 ± 0.06	0.35 ± 0.07	0.40 ± 0.08	0.27 ± 0.06	0.35 ± 0.05	0.35 ± 0.08
Dorsal	0.36 ± 0.02	0.05 ± 0.02	0.04 ± 0.02	0.08 ± 0.04	0.06 ± 0.03	0.11 ± 0.05	0.02 ± 0.02	0.06 ± 0.03	0.11 ± 0.04
Anal	0.36 ± 0.20	0.04 ± 0.02	0.04 ± 0.02	0.06 ± 0.04	0.04 ± 0.02	0.11 ± 0.05	0.07 ± 0.04	0.05 ± 0.03	0.20 ± 0.06
Caudal	0.01 ± 0.01	0.08 ± 0.03	0.12 ± 0.05	0.11 ± 0.04	0.08 ± 0.03	0.17 ± 0.05	0.11 ± 0.04	0.06 ± 0.03	0.17 ± 0.06

The mean injury proportions for delta smelt were generally low, and control mean percent proportions were similar to their respective baseline values except for head and caudal fin injuries (Table 8). In contrast to Chinook salmon, head and caudal fin injury was most prevalent for delta smelt and increased slightly over control, 1X, and 4X debris loads suggesting that some minor damage to the head and caudal fin occurred in the receiving pool. Head injury was an example of the higher injury levels in the receiving pool (Figure 27). Eye injury was representative of the lower incidence of injury for delta smelt removed from the receiving pool (Figure 28). Dorsal fin injury was the least frequent delta smelt injury.

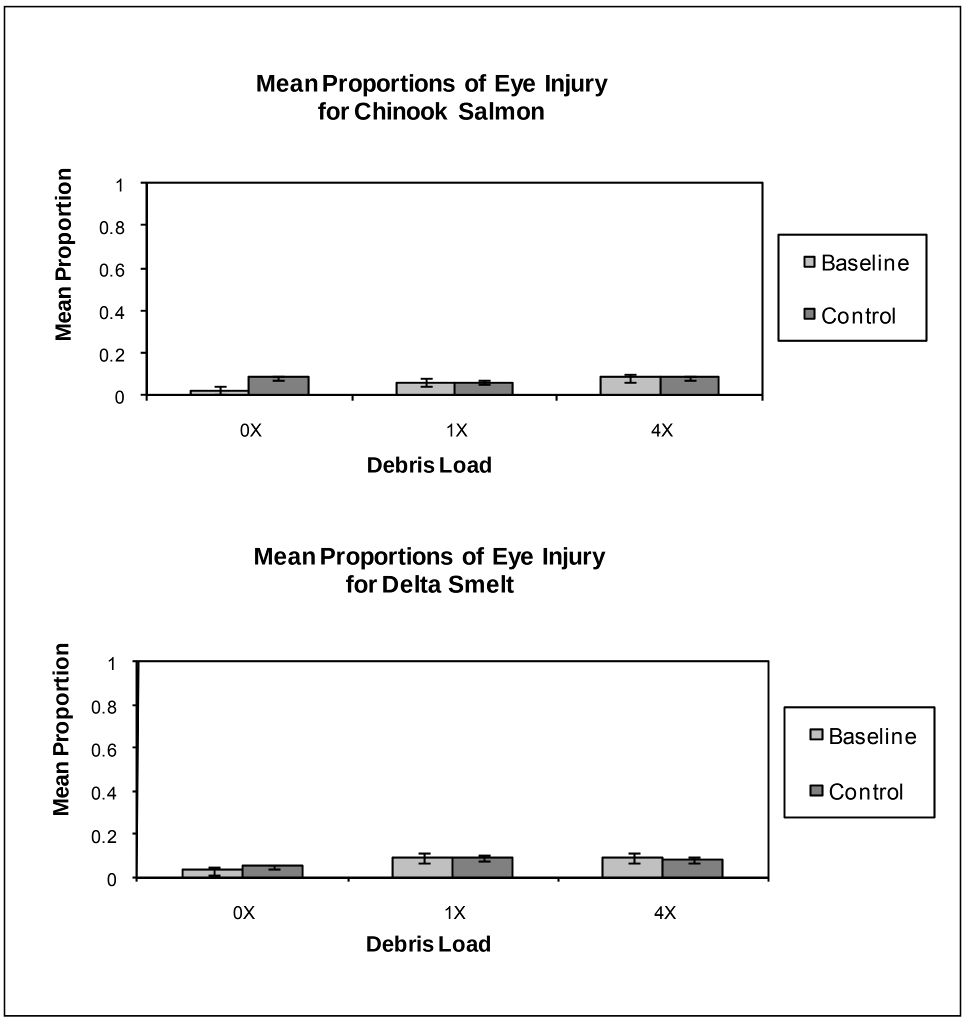


Figure 28- Percent proportion of eye injury for Chinook salmon and delta smelt for different debris loads with standard error bars.

Table 8- Mean injury proportions for delta smelt experiments ± SE.

	Baseline			Control			Treatment		
Injury Location	**0X debris load**	**1X debris load**	**4X debris load**	**0X debris load**	**1X debris load**	**4X debris load**	**0X debris load**	**1X debris load**	**4X debris load**
Head	0.25± 0.06	0.18± 0.05	0.08± 0.04	0.14± 0.05	0.30± 0.06	0.22± 0.07	0.23± 0.04	0.26± 0.05	0.25± 0.07
Eye	0.03± 0.03	0.09± 0.05	0.09± 0.05	0.05± 0.03	0.09± 0.04	0.08± 0.04	0.09± 0.06	0.07± 0.04	0.14± 0.05
Skin	0.03± 0.03	0.03± 0.03	0.02± 0.02	0.02± 0.02	0.06± 0.03	0.03± 0.02	0.03± 0.02	0.01± 0.01	0.03± 0.03
Pectoral	0.05± 0.03	0.03± 0.02	0.03± 0.03	0.05± 0.03	0.04± 0.03	0.02± 0.02	0.05± 0.03	0.06± 0.03	0.03± 0.02
Pelvic	0.05± 0.03	0.03± 0.02	0.03± 0.03	0.05± 0.03	0.04± 0.03	0.02± 0.02	0.05± 0.03	0.04± 0.02	0.03± 0.02
Dorsal	0.00± 0.00	0.01± 0.01	0.02± 0.02	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.00± 0.00	0.09± 0.06	0.01± 0.01
Anal	0.00± 0.00	0.03± 0.02	0.03± 0.02	0.00± 0.00	0.01± 0.01	0.02± 0.02	0.00± 0.00	0.01± 0.01	0.01± 0.01
Caudal	0.02± 0.02	0.10± 0.05	0.02± 0.02	0.03± 0.02	0.16± 0.05	0.06± 0.04	0.11± 0.05	0.09± 0.03	0.07± 0.04

3.2.2.1 Injury Effect Size Analysis

Receiving Pool

Statistical testing using the receiving pool effect size data showed no evidence that fish injury were related to different debris loads when baseline and control groups were examined. The mean receiving pool effect sizes for Chinook salmon were not significantly different between 0X, 1X, or 4X debris load tests for head, eye, skin, pectoral, pelvic, dorsal, anal, or caudal fins indicating that the injuries were not significant in the receiving pool at increased debris loads (Table 9).

Table 9-Mean receiving pool effect size for Chinook salmon with corresponding U statistic, degrees of freedom, and probability.

Injury Location	Mean 0x debris load ± SE	Mean 1x debris load ±SE	Mean 4x debris load ± SE	U	df	P
Head	1.02 ± 0.02	0.99 ± 0.01	1.00 ± 0.02	0.30	2	0.86
Eye	1.06 ± 0.03	1.00 ± 0.03	1.00 ± 0.05	0.05	2	0.97
Skin	1.02 ± 0.02	0.98 ± 0.01	1.01 ± 0.03	0.30	2	0.86
Pectoral	1.04 ± 0.07	1.06 ± 0.08	1.09 ± 0.08	0.50	2	0.77
Pelvic	0.96 ± 0.06	1.05 ± 0.07	1.12 ± 0.08	0.37	2	0.83
Dorsal	1.05 ± 0.05	1.01 ± 0.04	1.07 ± 0.06	0.05	2	0.97
Anal	1.02 ± 0.05	1.00 ± 0.02	1.07 ± 0.04	0.91	2	0.63
Caudal	1.10 ± 0.04	1.00 ± 0.04	1.05 ± 0.05	1.46	2	0.48

No consistent pattern was seen for injury assessment injuries between 0X, 1X, and 4X debris loads and mean 0X debris load percent injuries were often higher than 1X and 4X debris loads including head, eye, skin, and caudal fin injuries. Mean receiving pool effect size distribution was generally uniform among all debris loads and receiving pool effect size variables and mean head injury receiving pool distribution is shown as a representative example (Figure 29).

Similar to Chinook salmon, the mean effect sizes from receiving pool comparisons found no significant differences between debris loads and injury to head, eye, skin, pectoral, pelvic, dorsal, anal, or caudal fins for delta smelt (Table 10). Results indicate that delta smelt injury was not significant in the receiving pool at increased debris loads. No consistent pattern was seen for fish injuries between 0X, 1X, and 4X debris loads. Mean receiving pool effect size distribution was generally uniform among all debris loads and receiving pool effect size variables. The mean head injury receiving pool distribution is presented as a representative example (Figure 29).

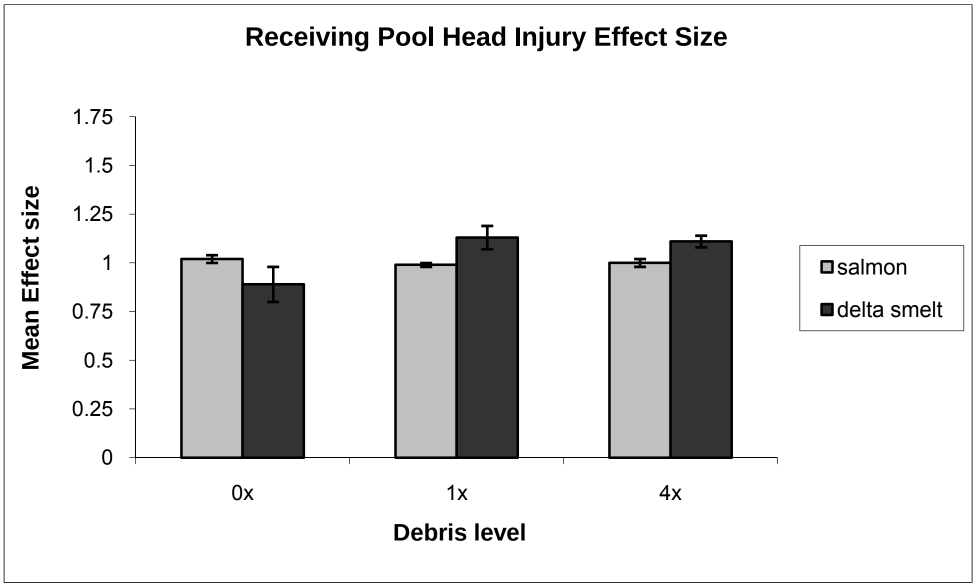


Figure 29- Mean receiving pool effect size for head injuries to Chinook salmon and delta smelt at three debris levels with mean values and standard error bars.

Release Pipe

Release pipe effect size evaluations indicate that fish injury was not significant in the mock release pipe at increasing debris loads. Mean effect sizes for Chinook salmon in the release pipe comparisons were not significantly different between 0X, 1X, or 4X debris load tests for head, eye, skin, pectoral, pelvic, dorsal, anal, or caudal fins (Table 11). Chinook salmon exhibited increased injuries for eye and dorsal at 1X debris loads while head, skin, and anal fin injuries were more predominant in 4X debris loads. Mean release pipe effect size distribution was generally uniform among all debris loads and release pipe mean head injury effect size serves as a representative example (Figure 30).

Table 10- Mean receiving pool effect size for delta smelt with corresponding U statistic, degrees of freedom, and probability.

Injury Location	Mean 0X debris load ± SE	Mean 1X debris load ± SE	Mean 4X debris load ±SE	U	df	P
Head	0.89 ± 0.08	1.13 ± 0.06	1.11 ± 0.09	5.06	2	0.08
Eye	0.02 ± 0.04	1.00 ± 0.05	1.01± 0.06	0.81	2	0.67
Skin	0.98 ± 0.02	1.02 ± 0.01	1.02 ± 0.03	2.60	2	0.27
Pectoral	1.00 ± 0.03	1.01 ± 0.04	0.98 ± 0.04	0.01	2	0.97
Pelvic	1.0 ± 0.03	1.01 ± 0.04	0.98 ± 0.04	0.01	2	0.97
Dorsal	1.00 ± 0.00	0.98 ± 0.01	0.98 ± 0.02	0.99	2	0.61
Anal	1.00 ± 0.00	0.99 ± 0.03	0.98 ± 0.02	0.52	2	0.77
Caudal	1.02 ± 0.03	1.06 ± 0.03	1.05 ± 0.04	0.65	2	0.72

Table 11- Mean release pipe effect size for Chinook salmon with corresponding U statistic, degrees of freedom, and probability.

Injury Location	Mean 0X debris load ± SE	Mean 1X debris load ± SE	Mean 4X debris load ± SE	U	df	P
Head	0.98 ± 0.02	1.00 ± 0.02	1.01 ± 0.03	1.31	2	0.52
Eye	0.95 ± 0.03	1.01 ± 0.04	1.00 ± 0.06	1.11	2	0.57
Skin	0.96 ± 0.02	1.02 ± 0.04	1.04 ± 0.06	5.30	2	0.07
Pectoral	1.00 ± 0.06	0.98 ± 0.08	0.94 ± 0.07	0.30	2	0.86
Pelvic	1.01 ± 0.06	1.00 ± 0.06	0.94 ± 0.07	0.42	2	0.81
Dorsal	0.94 ± 0.03	1.00 ± 0.04	1.00 ± 0.06	2.99	2	0.22
Anal	1.01 ± 0.04	1.01 ± 0.04	1.10 ± 0.06	1.15	2	0.56
Caudal	1.00 ± 0.05	0.98 ± 0.02	1.00 ± 0.07	0.41	2	0.81

Lack of significant differences between the mean effect sizes for delta smelt were also observed in the release pipe tests. Release pipe effect size was not significantly different between 0X, 1X, or 4X debris load tests for head, eye, skin, pectoral, pelvic, dorsal, anal, or caudal fins injuries (Table 12). No consistent pattern was seen for injuries between 0X, 1X, and 4X debris loads and mean 0X debris load percent injuries were often higher than 1X and 4X debris loads including head, eye, skin, pelvic, and caudal fin injuries. Similar to Chinook salmon, the mean release pipe effect size distribution was generally uniform among all debris loads and release pipe effect size variables and mean head injury release pipe distribution served as a representative example (Figure 27).

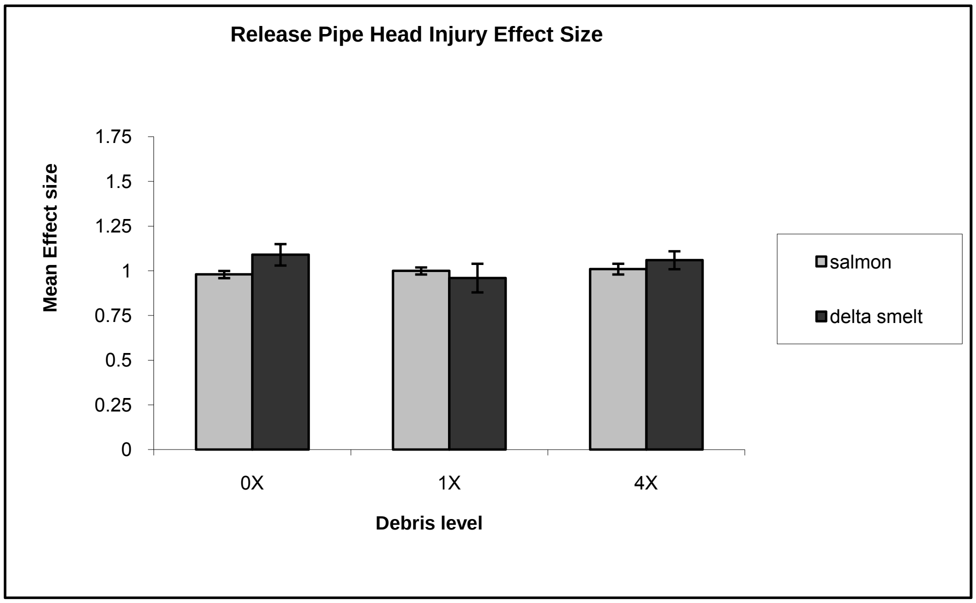


Figure 30- Mean release pipe effect size for head injury to Chinook salmon and delta smelt at three debris levels with mean values and standard error bars.

Table 12- Mean release pipe effect size for delta smelt with corresponding U statistic, degrees of freedom, and probability.

Injury Location	Mean 0X debris load ± SE	Mean 1X debris load ± SE	Mean 4X debris load ± SE	U	df	P
Head	1.09 ± 0.06	0.96 ± 0.08	1.06 ± 0.05	2.13	2	0.34
Eye	1.05 ± 0.04	0.99 ± 0.03	1.00 ± 0.05	1.27	2	0.53
Skin	1.02 ± 0.02	0.96 ± 0.03	1.00 ± 0.04	2.67	2	0.26
Pectoral	1.00 ± 0.03	1.01 ± 0.05	1.02 ± 0.03	0.39	2	0.82
Pelvic	1.02 ± 0.04	0.99 ± 0.04	1.00 ± 0.04	0.34	2	0.84
Dorsal	1.00 ± 0.00	1.09 ± 0.06	1.02 ± 0.02	3.52	2	0.17
Anal	1.00 ± 0.00	1.00 ± 0.02	1.00 ± 0.00	0.00	2	1.00
Caudal	1.08 ± 0.04	0.93 ± 0.05	1.03 ± 0.06	3.97	2	0.14

3.2.3 Quality Control Results

Dissolved oxygen, specific conductivity, and water temperature precision and accuracy samples for the fish holding tanks underwent quality control procedures and all measurements were within their specified precision and accuracy range which met quality control expectations. Chinook salmon and delta smelt fork length and wet weight accuracy samples underwent quality control procedures and all measurements were within their specified precision and accuracy range which met quality control expectations.

Chinook salmon injury assessment attribute underwent quality control procedures and all measurements were within their specified relative deviation range, which met quality control expectations, except for pectoral and caudal fin measurements. As a corrective action, the field crew was given additional training, but it was still difficult to distinguish between recent fin damage and old fin damage since hatchery Chinook salmon smolts commonly have cuts and erosion to fins. Delta smelt injury assessment attribute underwent quality control procedures and all measurements were within their specified relative deviation range, which met quality control expectations.

4.0 Discussion

4.1 Fish Mortality

The lack of significant mortality for Chinook salmon and delta smelt associated with mock fish release with varying debris loads where treatment survival rates ranged from 95.2 to 99.2% was comparable to other similar fish handling or passage research. Similar to our study, Helfrich and others (2001) also found no significant mortality of Chinook salmon in a Hidrostal pump with survival rates ranging from 98.7 to 100.0% after 96 hours. McNabb and others (2003) also found no significant mortality for Chinook salmon in a Hidrostal pump or Archimedes lift with survival rates ranging from 85.2 to 100.0% with a mean survival of 96.5% in the Hidrostal pump and 85.7 to 100.0% with a mean survival of 98.6% in the Archimedes lift after 96 hours. Raquel (1989) found Chinook salmon survival rates ranging from 98.7 to 100.0% after 24 hours in the handling phase (equivalent to the trucking and handling part of the CHTR phase) at the SDFPF. Helfrich and others (2003) also found no significant mortality of delta smelt in a Hidrostal pump with survival rates ranging from 86.4 to 89.8% after 96 hours. As in our study, Helfrich and others (2003) did not find any significant mortality of delta smelt at different debris loads. Studies on the acute mortality and injury of adult delta smelt undergoing CHTR in 2005-2006 at the SDFPF observed survival rates (90–100%) similar to our study in the absence of mechanical loss or predation (Morinaka 2006).

4.2 Injury Due to Experimental Handling

The receiving pool effect size results indicate that fish injury due to experimental transport and recovery from the release in the presence of varying debris loads did not cause any significant injuries to either Chinook salmon or delta smelt. The lack of significant levels of injury of the control fish suggests that our recovery procedures did not significantly bias our treatment injury assessments and these procedures met the original objective of the control group.

4.3 Injury Due to Release and Debris Load

The release pipe effect size results indicate that the release pipe was suitable in passing Chinook salmon and delta smelt at increased debris loads without significant increases in injury rates. Although not significant, increased debris loads in the release pipe did cause a slight increase in injuries to Chinook salmon head, eye, skin, dorsal, and anal fins but not pectoral, pelvic or caudal fins. It is interesting to note that these increases in injuries equate to the anterior, dorsal, and the sides of young salmon, but not to underside or caudal areas. This is most likely due to upstream orientation of the head (positive rheotaxis) as they traveled down the pipe during our experiments. Positive rheotaxis of juvenile Chinook salmon with water flow has been reported in fish screen and pump intake evaluations (Cech and others 2001, Coutant and Whitney 2000). This level and pattern of injuries were not observed for delta smelt despite information showing that this species also exhibits positive rheotaxis (White and others 2007).

A hypothesis for the slight increase in injuries to Chinook salmon but not delta smelt at increased debris loads is due to debris type. The main type of debris in this study was *Egeria*, a filamentous long stemmed plant. *Egeria* does not fully compact or form a solid mass in water, but rather provides small spaces between individual stems and leaves of the plants which may be large enough for slightly smaller delta smelt (49–87 mm [1.93–3.43 in]) to inhabit without physical contact and injury while the larger bodied Chinook salmon (48–109 mm [1.89–4.3 in]) may have been impacted by physical contact with the plants.

Similar results to this study can be found in injury assessment studies of fish passage using Hidrostal pumps and Archimedes lifts which have proven successful in transporting fish past dams and in-water diversions (Patrick and Sims 1985, McNabb and others 2003). Helfrich and others (2001) found that injuries to hatchery Chinook salmon smolts inserted into the entrance and compared with smolts inserted into the exit of a Hidrostal pump (discharge ranged from 0.17–0.4 m^3/s [6–14.125 cfs] with an enclosed screw type pump impeller with a 41 cm (16 in) diameter pipe at Tracy Fish Collection Facility, did not significantly differ. The injury variables assessed were similar to health assessment variables in our study including injuries to head, eyes, skin, and all fins combined. No debris loads were reported for this study. Helfrich and others (2003) also found that injuries to hatchery delta smelt inserted into the entrance and compared with delta smelt inserted into the exit of the same Hidrostal pump (discharge ranged from 0.179–0.3 m^3/s [6.35–10.59 cfs]) did not significantly differ. The injury variables assessed remained the same as in Helfrich and others (2001). Debris levels in this study varied between 125 –1,800 g (0.275–3.97 lb) per trial.

McNabb and others (2003) also reported that injuries to hatchery Chinook salmon smolts inserted into the entrance of a Hidrostal pump (discharge ranged from 2.3– 2.8 m^3/s [81.22–98.88 cfs]) with a 91 cm (36 in) diameter pipe and an Archimedes lift, compared with smolts inserted into the outfall of the pumps at the Red Bluff Research Pumping Plant, did not significantly differ for either fish pump. The Archimedes lift was a large pump with internal rotating barrels and 3 separate flights which lifted the water through a 3.048 m (10 ft) diameter pipe at discharge rates from 2.4–2.5 m^3/s (84.75–88.29 cfs). The injury variables assessed were head, eyes, skin, and fins. No debris loads were reported for this study. This study also attributed most of the biological injuries to fish such as cuts and abrasions from the internal moving parts in the pump rather than from the pipe itself.

4.4 Injury Attributes

Chinook salmon injuries from our study were similar to Helfrich and others (2001) but differed somewhat from McNabb and others (2003). Helfrich and others (2001) found that Chinook salmon combined fin injuries (all fin injuries pooled in analysis) were the most frequent injuries in a Hidrostal pump. Although our study reported fin injury by each fin, our study also found Chinook salmon injury frequency of fins predominant to eye, skin, and head injuries. McNabb and others (2003) found a different pattern in Chinook salmon injury frequency in Hidrostal pumps and Archimedes lifts where head and skin injuries were the most predominant. McNabb and others (2003) also found that fin injuries were rare.

Chinook salmon injuries could have occurred in the hatchery of origin or in the experimental handling prior to the experiments. McNabb and others (2000) obtained Chinook salmon from Coleman National Fish Hatchery, California, while Helfrich and others (2001) and our study obtained Chinook salmon from DFG Mokelumne River Fish Hatchery, California. Injuries could have varied between hatcheries based upon raceway material and design. McNabb and others (2000) also reported that injuries prior to experiments were generally the same as found in post-experiment measures indicating that injury may have occurred prior to experiments. Our study also indicated that Chinook salmon and delta smelt type and frequency of injuries were generally the same between baseline, control, and treatment which may indicate that the majority of injuries occurred prior to testing. Except for delta smelt dorsal fin injury, the lack of significant differences in receiving pool and release pipe test would indicate that the majority of Chinook salmon and delta smelt injuries occurred when handling the fish (tagging, moving fish, and preparing fish for trials). The experimental handling was relatively consistent between baseline, control, and treatment for all debris loads.

Helfrich and others (2003) found a higher degree of fin injury in delta smelt than our study where head and eye injuries were the most predominant injury. The contrast between these two results are somewhat perplexing since the hatchery delta smelt used in both studies originated from the FCCL and injuries in our study were similar between baseline and treatment except for dorsal fin injury which indicates that the injuries may be pre-treatment. However, delta smelt in Helfrich and others (2003) were held at the TFCF where fish were held for as long as 3 months which could have caused different pre-experiment type and level of injuries which differed from injuries from the FCCL (B. Bridges, personal communication 2007). The TFCF is not able to provide as adequate care for delta smelt as the FCCL which in the past has resulted in an increase in pre-experiment injuries.

4.5 Shear

Exposing fish to excessively strong shear forces has been shown to result in scale loss, bruising, and/or mortality (DOE 2000). The maximum rate of fluid strain in a hydraulic jump can be approximated by high velocity flow entering a pool. Rate of fluid strain is defined as the change in velocity magnitude divided by distance normal to the flow direction (Δy). In the DOE study, shear effects on multiple salmonid fingerlength and juvenile age classes and yearling American shad were tested. All strain rates were based on a Δy of 1.78 cm (0.7 in), the approximate width of a juvenile salmonid fish. The study found no significant injuries to fish occurred at strain rates < 517 in/s/in. A rate of strain of 517 in/s/in at 1.78 cm (0.7 in) would require a flow velocity of about 9.144 m/s (30 ft/s) entering a still pool. Since the maximum velocity in the mock release only reached about 7.62 m/s (25 ft/s) or a maximum rate of strain of 428 in/s/in., according to the results of the DOE study, fish exposed to the release process would not be exposed to shear forces high enough to cause injury. However, the results of a limited number of predation tests on rainbow trout indicated that increased susceptibility to predation occurred at lower strain rates than the onset of injuries. These results suggest that even though our hydraulic results indicate that the threshold for injury to occur as a direct result of shear has not been reached, there is the possibility that the release process will leave salvaged fish susceptible to predation in the receiving waters due to the stress and disorientation caused by the release and/or the cumulative effects of the salvage process.

5.0 Synthesis

These tests provided significant insight into the hydraulics and debris-fish interaction in terms of mortality and injury of fish released by the SWP fish salvage operations. The testing identified several issues that affect the performance of the release process and identified several areas that require additional investigation to fully understand the complex interaction between elements of release operations, fish, and debris.

All mock release site results presented should not be assumed to fully represent true field release pipe conditions. Non-similarity of submerged pipe length between mock and real release pipe will affect some results related to flushing of debris and fish from the release pipe. The flushing efficiency of the real SWP Horseshoe Bend release pipe (significantly longer submerged length of pipe) would likely be less than observed in the mock pipe. The length of the hydraulic jump in the mock pipe generally extended to the end of the mock pipe whereas in the actual release facilities, the jump would always reside fully in the pipe. This non-similarity of the mock release site, however, does not affect the general findings of the study.

The goal of this experiment was to determine first, if the existing release facility does or does not cause significant mortality or fish injury at release, and secondly, is there a threshold level of debris that causes significantly more problems (injury and/or mortality) to salvaged fish at release. The results of our analysis answered these questions and demonstrated that:

- Neither Chinook salmon or delta smelt mortality and injury were significant in the mock release pipe, and was generally low for all groups observed in both juvenile Chinook salmon and adult delta smelt experiments. In trials with zero debris, survival of treatment groups was 98.7% and 99.2% for delta smelt and Chinook salmon respectively. In 1X debris trials, survival was 97.1% and 97.4% for delta smelt and Chinook salmon respectively. In 4X debris trials, survival was 95.2% and 98.4% for delta smelt and Chinook salmon respectively.

- Chinook salmon and delta smelt mortality rates in this study were low and similar to results of studies examining other CHTR phases, pumps, and shear effects including DOE (2000), Helfrich and others (2003), Helfrich and others (2001), and McNabb and others (2003).

- Injuries to Chinook salmon and delta smelt may have occurred during pre-experiment handling since injuries were similar between baseline and treatment.

- The results of the effect size analyses showed that at the levels tested, increasing debris levels did not appear to have a significant impact on the survival and injury of salvaged fish.

- Prior to construction of the mock release site there was concern that the introduction of the flushing flow may have been causing injury and mortality, but field measurements at the SWP Horseshoe Bend release site showed that very little water is actually injected into the pipe.

The results from the hydraulic investigation of the mock release pipe also identified several problems with the current features of release facilities and provided recommendations for improvements. The hydraulic investigation and modeling results found that:

- A significant amount of debris remains in the submerged length of pipe after each release as a direct result of insufficient auxiliary flows in the pipe. Effective flushing of the pipe would require a minimum of approximately 0.1 m^3/s (3.5 cfs) of flushing flow sustained for 5 minutes after each release.

- Efficient operation of the current pipe is limited by the effects of blowback which is a result of poor air venting in the pipe.

6.0 Recommendations

According to the observational data and experimental results obtained from this study, where no significant injuries or mortality occurred in the release phase for either Chinook salmon or delta smelt, it is not necessary to make significant changes to release protocols or modifications to the release pipe for the purposes of increasing fish survival. However, results of the hydraulic studies indicate that there are several changes to the current release pipe design and operating procedures that would improve debris handling and ensure complete flushing of fish and debris from the pipe.

1. An air relief valve or gooseneck vent pipe should be installed on the crown of the release pipe downstream of the auxiliary flow manifold. Installing an air vent would allow the truck tank gate to be rapidly opened to 100%, improving debris flushing. Flow conditions during a rapidly opened gate release were estimated by relating the previously described flow and facility relationships derived from the model tests in a time step simulation. A spreadsheet was setup to simulate a stepped gate opening release similar to existing practice and a rapid gate opening release. Benefits to pipe flushing will result from rapidly opening the release gate which provides the maximum peak flow, maximum tailwater suppression and maximum full pipe flow velocity that can be achieved independent of auxiliary flow. Efforts are underway to retrofit both SWP release sites in accordance with this recommendation.

2. Gate actuators on the fish haul trucks should provide consistent gate control and allow rapid full opening as mentioned in Recommendation 1. This would prevent the gate from stopping as much as 10% short of full open and improve the responsiveness of the actuator. Both the SWP and CVP salvage facilities have recently purchased and are transitioning to new fish haul trucks that incorporate this recommendation.

3. Auxiliary flow should be increased following a release to approximately 0.1 m^3/s (3.5 cfs) and sustained for a minimum of five minutes to effectively flush the submerged length of release pipe. Efforts are underway to retrofit both SWP release sites in accordance with this recommendation.

4. The 90° mitered elbow at the SWP release sites should be eliminated or replaced with a longer radius bend that is permanently attached to the fixed release pipe. Though the elbow did not have any discernable impact on fish mortality or injury, removing the elbow would reduce or eliminate clogging of the elbow that was observed during model testing. Efforts are underway to retrofit both SWP release sites in accordance with this recommendation.

7.0 Future Research Questions

This study uncovered a number of topics that could benefit from further research. Research on these topics could lead to additional recommendations or guidelines to further improve survival and reduce injury of salvaged fish.

1. What would the magnitude of injury and mortality be for wild fish and/or fish of decreased health?
    - This study utilized fish of hatchery origin and of good health; however, fish with injuries or poor health are often encountered during salvage operations.

2. What is the survival of other important species encountered during salvage operations, in particular sensitive species and species typically salvaged in large quantities?
    - This study focused on salmon and delta smelt. Other species to be considered include juvenile green and white sturgeon, splittail, longfin smelt, and steelhead,.

3. What are the cumulative effects on injury and survival of fish through the salvage process?
    - This and previous CHTR studies, have primarily focused on specific parts of the salvage process and have shown little or no mortality or injury, yet the combined effects of the salvage process, including collection at the primary and secondary louvers, time held and conditions in the holding tanks, and CHTR, may have substantial injury and mortality associated with it.

4. What is the magnitude of increased susceptibility to predation of salvaged fish at the terminus of the salvage process?
    - While the results of this experiment show very little direct mortality or injury from release, the stress and disorientation caused by the release and/or the cumulative effects of the salvage process may leave otherwise healthy fish susceptible to predation in the receiving waters of the Delta.

5. What is the role of pipe roughness in improving salvaged fish survival?
    - The mock release pipe used in the experiments was constructed of smooth PVC pipe (Manning's *n* value of 0.01), while the pipes used in the field are constructed of steel and are somewhat corroded (Manning's *n* value of 0.012 to 0.014). While this difference may not significantly influence pipe hydraulics, the additional roughness may create risk for additional injury for fish.

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10.0 Appendices

Appendix A- Calibration frequency, accuracy and precision check frequency, and percent error allowed for environmental variables.

Variable	Calibration frequency	Accuracy check frequency	Precision check frequency	Allowable error
Dissolved O_2	daily	every 1st and 20th measurement daily during trail period	every 1st and 20th measurement daily during trail period	5%
Specific conductance	before and after each trial period	before and after each trial period	every 1st and 20th measurement daily during the trial period	5%
Water temperature	before and after each trial period	before and after each trial period	every 1st and 20th measurement	5%

Appendix B- Precision check frequency and percent error allowed for fish length, fish weight, and health assessment variables including head, eye, skin, pectoral, pelvic, dorsal, anal, and caudal fins.

Variable	Precision check frequency	Allowable error
Fish length	repeat measure for every 5th fish at 48 hour of the experiment	10%
Fish weight	repeat measure for every 5th fish at 48 hour of the experiment	10%
Health assessment variables	repeat measure for every 5th fish at 48 hour of the experiment	10%

Appendix C- Frequency of head injuries for Chinook salmon.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal	100.0	97.6	98.8	97.6	98.8	98.8	100.0	98.8	97.6
One operculum missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Both operculums missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Integument missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	0.0	1.2	0.0	0.0	0.0	0.0	0.0	1.2	2.4
Other injury	0.0	1.2	1.2	2.4	1.2	1.2	0.0	0.0	0.0
Decapitation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix D- Frequency of eye injuries for Chinook salmon.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal	97.6	94.0	91.7	91.7	94.0	91.7	96.4	92.9	91.7
One missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
Both missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bulging	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	2.4	6.0	8.3	8.3	6.0	8.3	3.6	7.1	7.1
Other injury	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Abrasion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under lens	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix E- Frequency of pelvic fin injuries for Chinook salmon.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal well-shaped	69.1	64.3	61.9	65.5	63.1	54.8	69.1	60.8	59.5
Discolored, frayed, < 30% erosion	20.2	25.0	22.6	19.0	29.7	33.3	20.2	21.4	28.6
> 30% erosion, but visible	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eroded to the base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	10.7	10.7	11.9	14.3	6.0	11.9	10.7	16.6	10.7
Other injury	0.0	0.0	3.6	1.2	1.2	0.0	0.0	1.2	1.2
Fin missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix F- Frequency of pectoral fin injuries for Chinook salmon.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal well-shaped	63.1	54.8	60.7	53.6	56.0	53.5	57.1	50.1	60.2
Discolored, frayed, < 30% erosion	22.6	32.1	25.0	32.1	35.7	31.0	28.6	32.1	29.1
> 30% erosion, but visible	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0
Eroded to the base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	14.3	13.1	4.8	13.1	7.1	13.1	14.3	16.6	9.5
Other injury	0.0	0.0	9.5	1.2	1.2	1.2	0.0	1.2	1.2
Fin missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix G- Frequency of pelvic fin injuries for Chinook salmon.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal well-shaped	69.1	64.3	61.9	65.5	63.1	54.8	69.1	60.8	59.5
Discolored, frayed, < 30% erosion	20.2	25.0	22.6	19.0	29.7	33.3	20.2	21.4	28.6
> 30% erosion, but visible	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eroded to the base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	10.7	10.7	11.9	14.3	6.0	11.9	10.7	16.6	10.7
Other injury	0.0	0.0	3.6	1.2	1.2	0.0	0.0	1.2	1.2
Fin missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix H- Frequency of dorsal fin injuries for Chinook salmon.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal well-shaped	96.4	95.2	96.4	91.7	94.0	89.3	97.6	94.0	86.9
Discolored, frayed, < 30% erosion	3.6	4.8	3.6	8.3	6.0	10.7	2.4	6.0	13.1
> 30% erosion, but visible	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eroded to the base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other injury	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fin missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix I- Frequency of anal fin injuries for Chinook salmon.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal well-shaped	97.6	96.4	96.4	94.0	96.4	89.3	92.9	95.2	81.0
Discolored, frayed, < 30% erosion	2.4	3.6	3.6	6.0	2.4	9.5	7.1	3.6	19.0
> 30% erosion, but visible	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eroded to the base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	0.0	0.0	0.0	0.0	1.2	1.2	0.0	1.2	0.0
Other injury	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fin missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix J- Frequency of caudal fin injuries for Chinook salmon.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal well-shaped	98.8	91.7	88.1	89.3	91.7	83.3	89.3	94.0	84.5
Discolored, frayed, < 30% erosion	1.2	8.3	11.9	10.7	7.1	16.7	10.7	6.0	15.5
> 30% erosion, but visible	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eroded to the base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other injury	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0
Fin missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix K- Frequency of head injuries for delta smelt.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal	74.6	86.3	89.7	86.8	71.6	83.9	73.5	70.7	79.3
One operculum missing	4.4	1.5	2.9	2.9	4.4	2.9	4.4	4.4	7.4
Both operculums missing	0.0	0.0	1.5	0.0	4.4	2.9	4.4	0.0	1.5
Integument missing	1.5	0.0	1.5	0.0	1..5	2.9	4.4	4.4	1.5
Hemorrhage	4.8	4.8	2.9	2.9	7.4	7.4	5.9	2.9	1.5
Other injury	14.7	7.4	1.5	7.4	10.7	0.0	7.4	17.6	8.8
Decapitation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix L- Frequency of eye injuries for delta smelt.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal	73.1	91.1	92.6	96.6	91.2	94.1	91.1	91.2	86.8
One missing	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Both missing	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bulging	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	0.0	0.0	7.4	2.9	0.0	5.9	7.4	5.9	13.2
Other injury	0.0	7.4	0.0	1.5	8.8	0.0	1.5	2.9	0.0
Abrasion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under lens	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix M- Frequency of skin injuries for delta smelt.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal	93.2	96.6	98.3	96.6	93.2	96.6	96.6	98.3	93.2
Bruised area	3.4	1.7	1.7	3.4	1.7	1.7	1.7	0.0	3.4
Partially de-skinned	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Split or open wound	0.0	1.7	0.0	0.0	1.7	0.0	1.7	0.0	1.7
Hemorrhage	3.4	0.0	0.0	0.0	3.4	0.0	0.0	1.7	1.7
Other injury	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Abrasion	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0

Appendix N- Frequency of pectoral fin injuries for delta smelt.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal well-shaped	91.1	97.1	97.1	95.6	95.6	98.5	95.6	94.2	97.1
Discolored, frayed, < 30% erosion	1.5	0.0	2.9	2.9	0.0	1.5	1.5	2.9	2.9
> 30% erosion, but visible	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eroded to the base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	4.4	2.9	0.0	1.5	4.4	0.0	2.9	2.9	0.0
Other injury	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fin missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix O- Frequency of pelvic fin injuries for delta smelt.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal well-shaped	94.1	95.6	95.6	94.1	96.6	98.5	95.6	95.6	97.1
Discolored, frayed, < 30% erosion	1.5	0.0	4.4	4.4	0.0	1.5	1.5	2.9	2.9
> 30% erosion, but visible	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eroded to the base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	4.4	4.4	0.0	1.5	4.4	0.0	2.9	1.5	0.0
Other injury	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fin missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix P- Frequency of dorsal fin injuries for delta smelt.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal well-shaped	100.0	98.5	98.5	100.0	100.0	100.0	100.0	91.2	98.5
Discolored, frayed, < 30% erosion	0.0	1.5	1.5	0.0	0.0	0.0	0.0	2.9	1.5
> 30% erosion, but visible	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	0.0
Eroded to the base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other injury	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fin missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix Q- Frequency of anal fin injuries for delta smelt.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal well-shaped	100.0	97.1	97.0	100.0	98.5	98.5	100.0	98.5	98.5
Discolored, frayed, < 30% erosion	0.0	2.9	1.5	0.0	0.0	1.5	0.0	0.0	1.5
> 30% erosion, but visible	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eroded to the base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	0.0	0.0	1.5	0.0	1.5	0.0	0.0	0.0	0.0
Other injury	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0
Fin missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix R- Frequency of caudal fin injuries for delta smelt.

Category	Baseline 0x	Baseline 1x	Baseline 4x	Control 0x	Control 1x	Control 4x	Treatment 0x	Treatment 1x	Treatment 4x
Normal well-shaped	98.5	89.5	98.5	97.0	83.5	94.0	86.5	91.0	92.5
Discolored, frayed, < 30% erosion	1.5	3.0	0.0	0.0	9.0	4.5	6.0	6.0	7.5
> 30% erosion, but visible	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0
Eroded to the base	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemorrhage	0.0	3.0	1.5	0.0	3.0	0.0	6.0	1.5	0.0
Other injury	0.0	4.5	0.0	3.0	4.5	1.5	0.0	1.5	0.0
Fin missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bubble under skin	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0