TRAVEL TIME AND CONDITION OF JUVENILE CHINOOK SALMON PASSED THROUGH ARCHIMEDES LIFTS, AN INTERNAL HELICAL PUMP, AND BYPASSES AT RED BLUFF RESEARCH PUMPING PLANT, SACRAMENTO RIVER, CALIFORNIA

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TRAVEL TIME AND CONDITION OF JUVENILE CHINOOK SALMON PASSED THROUGH ARCHIMEDES LIFTS, AN INTERNAL HELICAL PUMP, AND BYPASSES AT RED BLUFF RESEARCH PUMPING PLANT, SACRAMENTO RIVER, CALIFORNIA.

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Abstract. We evaluated travel time, the frequencies of mortalities and injuries, and the extent of descaling on juvenile chinook salmon that were passed through large pumps and associated fish bypasses at Red Bluff Research Pumping Plant (RBRPP). An internal helical pump (91 cm inlet) and two Archimedes lifts (122 cm intake) were used in this study. Vertical wedge-wire screens (2.4 mm openings) were located downstream of each pump. Fish-bypass channels led away from each screening facility. Water in these channels dropped into plunge pools before entering 46 cm diameter underground pipes. The 46 cm diameter underground pipe from each pump's fish bypass connected to the same 152 cm diameter conduit. The 152 cm conduit opened into the Sacramento River.

On average, one-quarter of the chinook salmon released into pump intakes remained within RBRPP 48 h after release. Recovery rates were significantly lower for trials begun at sunrise versus those begun at sunset (P=0.003). Passage delays occurred in screening facilities and in the 152 cm diameter pipe. Turning pumps off and back on was ineffective at flushing fish from screening facilities. Pulsing flows through the 152 cm pipe at about 4.4 m^3/s effectively moved lingering fish into the river.

Mean total 96-h mortality of juvenile chinook salmon passed through pumps and their bypasses (treatment) was nearly 4%. Mean total 96-h mortality ranged from 2.0% to 2.4% for fish passed through bypasses only (control). These mortality values include deaths that may have occurred during pre- and post-trial handling and capture of fish, and therefore may be over-estimated. The difference in mortality between treatment and control samples was not statistically significant for either pump type. Mean body surface descaled and mean frequency of chinook salmon with non-lethal injuries was <1.2% and <8.0%, respectively for both pump types, and did not differ significantly between treatment and control samples. There were no significant differences between the internal helical pump and the Archimedes lifts for mortality, descaling, or injury. Also, no differences were detected between pump bypasses for %-frequencies of mortalities and injuries, or extent of descaling. Pulsing flows through the 152 cm diameter conduit did not significantly increase the percent frequency of mortality or injury, or the extent of descaling to juvenile chinook salmon that were passed through the pumps and bypasses. Findings from this and other studies at RBRPP revealed that low mortalities, descaling, and injuries to juvenile chinook salmon that passed through RBRPP occurred mainly as fish traveled through the pumps, screening facilities, and plunge pools. Few adverse effects were associated with the 46 cm and 152 cm diameter underground bypass pipes.

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Introduction

Red Bluff Research Pumping Plant (RBRPP) was constructed to evaluate new fish passage technologies in the face of declining salmonid populations in the Sacramento River (McNabb et al. 1998). The two Archimedes lifts and the internal helical (Hidrostal) pump installed at RBRPP are the largest (122 and 91 cm intakes, respectively) of their kind constructed for passing fish (Frizell and Atkinson 1999). Extensive trials have been conducted to evaluate whether these pumps can safely pass juvenile chinook salmon and other fish entrained from the river (McNabb et al. 1998, 2000, Borthwick et al. 1999). These trials focused on pump passage effects on fish. The pumping plant also has an elaborate fish bypass system. The National Marine Fisheries Service (NMFS, 1997) defines a bypass as "a water channel which transports juvenile fish from the face of a screen to a relatively safe location in the main migratory route of the river or stream". At RBRPP the bypasses originate at the v-shaped vertical wedge-wire screens just downstream of the pump outfalls. The screens direct fish and approximately 10 percent of the pumped water into an open bypass channel. This bypass goes underground near the fish evaluation facility (Figure 1), merges with the rotary drum screen fish bypass, and terminates at an outfall structure in the Sacramento River (Figure 2).

Objective E in Liston and Johnson (1992) addresses evaluation of the underground portion of the bypass system. In 1997, pilot trials determined that the underground portion could not be evaluated without considering the stress and injury that chinook salmon experience in the plant before reaching that point. Therefore, during the December 1997 annual meeting, the RBRPP Interagency Fisheries Work Group agreed to broaden this objective to determine if pump passage affects the ability of chinook salmon to pass through the entire pumping plant to the river. This included evaluation of the entire bypass system from the vertical screens to the bypass outfall.

Past efforts at improving fish passage have often focused on upstream passage of adult fish, with less consideration for downstream passage (Monteverde 1993, Larinier 1998). In 1929 the U. S. Army Corps of Engineers (Corps) acknowledged the need to provide upstream passage to adult salmonids blocked by Corps dams on the Columbia River. When Bonneville Dam was completed in 1938 it included fish ladders, an experimental lock system for fish, and a migratory canal around the project (Monteverde 1993). Surface bypass outlets designed to pass juvenile fish were installed at the powerhouse and spillway. However, they were too small to effectively protect against turbine mortality (Ferguson et al. 1998). As more dams were constructed on the Columbia River in the 1950's and 1960's, the need to include effective juvenile bypass systems increased. Turbines, unscreened diversions, and other water project-related mortalities were being recognized as contributors to the reduction of salmonid populations. Based upon 1960's studies on turbine mortality at dams on the Columbia River, the Corps began to incorporate juvenile bypass systems into the design of new powerhouses (Ferguson 1992). Since then extensive consideration and research have assisted designs for fish-friendly juvenile bypass systems (Rainey 1985, Pearce and Lee 1991 Ferguson et al. 1998). Bell (1991) provides a fairly complete compilation of considerations in fish bypass designs based upon knowledge of fish passage and behavior. Various studies have been conducted at dams and irrigation diversions to assess the effectiveness of juvenile-bypass systems (Neitzel et al. 1988, Neitzel et al. 1990, Maule and Mesa 1994, Mueller et al.1995, Bigelow and Johnson 1997).

Portions of the RBRPP bypasses have been evaluated previously. McNabb et al. (1998, 2000) found passage delays but low mortality of juvenile chinook salmon traveling through the screening facility and open bypass channel. Evaluation of the drum screen bypass by Bigelow and Johnson (1997) found no direct mortality and less than 1 percent delayed mortality for juvenile chinook salmon. Vogel and Marine (1997) found that passage through the drum screen bypass did not cause sufficient stress to impair a juvenile chinook salmon's ability to avoid predators.

The pumps at RBRPP have multiple applications and are used to deliver water to canals while bypassing entrained fish back to the river. It was unknown if fish could be passed through these large pumps at speeds used for making water deliveries and then diverted through the bypass system unharmed. Rainey (1985) provides a detailed discussion on design aspects of juvenile bypass systems and states that the effectiveness of a juvenile bypass system is measured not only by survival of fish passed through it, but also by the time it takes for fish to move past the screen and bypass system back to the river. Therefore, we assessed travel time of juvenile chinook salmon through RBRPP as well as mortality, injury, and descaling. Passage delays were anticipated; however, it was unknown whether pulsing flows could be used to effectively flush fish from the bypass without causing additional mortality or injury. To address these uncertainties, this study included the following objectives:

1. Determine whether pump passage affects mortality, injury, and descaling of juvenile chinook salmon passed through RBRPP from pump intakes to the bypass outfall in the Sacramento River.

2. Determine passage time of juvenile chinook salmon through RBRPP during normal flows. If delays in passage occur, determine where they occur and how they can be eliminated.

3. Determine if pulsing flows can be used effectively to flush juvenile chinook salmon from areas where their passage is delayed, without causing additional mortality, injury or descaling.

Study Site

Red Bluff Research Pumping Plant (RBRPP) is southeast of Red Bluff, California, 391 km (243 miles) upriver from the mouth of the Sacramento River. The Archimedes lifts and internal helical pump divert water directly from the Sacramento River into the Tehama-Colusa canal (TCC). Vertical wedge-wire screens and fish bypasses route entrained fish back to the river (Frizell and Atkinson, 1999). The upper reaches of the fish bypasses consist of open channels while the lower reaches are underground conduits.

The Archimedes lifts, manufactured by Wheelebrator/CPC, consist of 11.5 m (38 ft) long, 3.0 m (10 ft) diameter rotating cylinders with three helical flights continuously welded along the length of the cylinder's inside walls. The lifts are unique in having a rotating, sealed inlet at their lower end allowing them to operate over a wide range of river elevations. During this study they operated at 26.5 rpm, delivering water at an average rate of 2.5 m^3/s (88 ft^3/s), and lifting it 7.6 m (25 ft). The internal helical pump, manufactured by WEMCO-Hidrostal, has an inlet diameter of 91 cm (36 in) and is the largest of its type ever constructed (Frizell and Atkinson 1999). It has a single-vane impeller cast with a rotating conical shroud. During this study it operated at 350 rpm, delivering water at an average rate of 2.4 m^3/s (86 ft^3/s), and lifting it 8.3 m (27.5 ft).

Each of the three pumps has its own screening facility, fish evaluation facility, and underground bypass (Figure 1). After passing through a pump, water and its contents are discharged into a 10.9 m (36 ft) long concrete sluiceway. The sluiceway leads to a 10.6 m (35 ft) long screening facility consisting of vertical wedge-wire screens (2.4 mm, 0.09 in openings) in a vee arrangement with continuously operating brushes. Approximately 90 percent of the water passes through the screens to the canal while the remaining 10 percent, along with fish and debris, is diverted into a 46 cm (18 in) wide, curved, open bypass channel. After traveling approximately 13.5 - 31.5 m (45 to 104 ft, depending upon the pump), water can either continue into an underground bypass to the river or be diverted into a fish evaluation facility. Water and fish diverted to the evaluation facility can be directed into either of two flow-through holding tanks or to the underground bypass. When the evaluation facility is not in use, the dewatering ramp is raised; water and fish in the open bypass channel drop into a plunge pool then enter a 46 cm (18 in) diameter underground bypass pipe where current velocities are approximately 1.8 m/s (6.0 ft/s). These pipes extend approximately 53 m (176 ft) before merging directly with a 152 cm (60 in) pipe that is part of the fish bypass system for the forebay at the Tehama-Colusa canal. The 152 cm pipe terminates at an outfall structure in the Sacramento River downstream of Red Bluff Diversion Dam (Figure 2).

The TCC fish bypass operates during the four months when gates on Red Bluff Diversion Dam (RBDD) are lowered (May 15 - September 15) and water is diverted from Lake Red Bluff into the TCC forebay. A series of 32 rotary drum screens in the forebay exclude chinook salmon from the canals. Associated with the drum screens is an underground bypass system to transport screened fish back to the Sacramento River. The bypass system consists of four 122 cm (48 in) diameter pipes with weir gates to adjust flows, a gate structure, two 152 cm (60 in) diameter pipes, and one outfall structure (Figure 2). An entrance into a 122 cm pipe is located after every eighth drum screen. At the gate structure, flows from the two upstream 122 cm pipes converge into an open chamber and are redirected into a 152 cm pipe. Similarly, flows from the two downstream 122 cm pipes converge into a second 152 cm pipe. The two 152 cm pipes run parallel, terminating at the outfall structure in the Sacramento River. The drum screen bypass was designed to pass a total flow of 6.79 m^3/s (240 ft^3/s).

During the eight months each year when RBDD gates are raised, RBRPP provides water to the TCC canal as needed. Because the drum screen bypass is not operated during this time, weir gates on each of the four 122 cm pipes are closed, and significant water movement in the 152 cm pipe is created by the pumping plant's discharge only. This discharge ranges from approximately 0.30 m^3/s to 0.90 m^3/s (10.6 - 31.9 ft^3/s) depending on the number of pumps operating. The resulting current velocities in the 152 cm pipe are very low, calculated as only 0.16 - 0.49 m/s (0.54 - 1.63 ft/s), resulting in potential refugia for fish. The proposed solution to the passage delays caused by these low velocities was to fully open the weir gates on two 122 cm pipes to release sufficient water to flush fish into the river. In part, this study was designed to assess the effectiveness of pulsing flows and to determine whether such flows caused mortality, injury, or descaling to juvenile chinook salmon.

There are other areas within RBRPP where fish passage delays occur or may occur. Pump passage experiments conducted from 1995 through 1999 revealed that fish found refugia in the screening facility (McNabb et al.1998, McNabb et al. 2000). A 4:1 ramp located at the downstream end of the vertical screens creates a recirculating eddy preventing flow from accelerating up the ramp and into the open bypass. Sweeping velocities near the bottom of the screening facility just upstream of the ramp are low (<0.61 m/s;<2.0 ft/s) providing areas for fish to hold with minimal energy expenditure (Frizell and Atkinson 1999).

The plunge pool was identified as an area where fish passage delays *may* occur (Figure 1). Water depth within the pool is normally about 30.5 cm (12 in) but can be increased by placing stop-logs downstream. Pilot trials conducted in 1997 revealed that without stop-logs injuries occurred as fish plunged into the shallow water. Therefore, during this study stop-logs were used for all three pumps creating a deeper pool and slower velocities where we hypothesized fish may take refuge.

Methods

The study was conducted from April through July 1999. It consisted of two separate experiments. The *passage experiment* was designed to assess residence time and to identify locations in the pumping plant and its fish bypass system at which fish delayed passage to the Sacramento River. The *survival experiment* was designed to assess mortality, descaling, and other injuries to fish that passed through the pumps and bypasses. Some methods were common to both experiments, and are described directly below. Other methods were unique to the individual experiments. Those are found below under the headings for each experiment.

Fall and late-fall juvenile chinook salmon were obtained from Coleman National Fish Hatchery in Anderson, CA for use in experiments. They were transported to RBRPP's well-water holding facility, acclimated to well-water conditions, and maintained prior to trials using standardized procedures described by McNabb et al. (1998). Water quality and mortality data were recorded twice daily while the fish were held at Red Bluff. During experiments, fours marks were used on juveniles in random combinations; upper or lower caudal fin-clips, and dyed or undyed with Bismarck Brown-Y. Fish were fin-clipped at least one week prior to a trial, and dyed three to six days before a trial. Dying involved immersion for 25 minutes in approximately 379 L (100 gal) of water containing 8 g of Bismarck Brown-Y (Mundie and Taber 1983). At least 48 h prior to a trial, marked fish were randomly selected and separated into samples. Samples were placed into live cages, and transferred to the project's river-water holding facility for acclimation to ambient Sacramento River conditions (McNabb et al. 1998).

During a trial, individual samples of fish were poured from their live cage into a plastic carboy fabricated specifically for releasing fish into flowstreams at RBRPP (McNabb et al. 1998). Carboys were half-filled with a solution of river water, salt (5-7 g/L) and Kordon's PolyAqua® (0.13 mL/L) to reduce stress to fish during transport to release sites in the pumping plant (Vogel and Marine 1995). At each release site, a carboy was lowered to the water level, and fish were released into the flowstream. At pump intake release sites, where fish were released into standing water within an insertion tube, a weighted 30.5 cm (12 in) diameter PVC tube with a perforated bottom was lowered to crowd the fish into the flowstream of the pump's intake pipe.

Released chinook salmon were captured in holding tanks at the plant's evaluation facility or in a net at the bypass outfall in the Sacramento River. The holding tanks were operated as flow-through systems and were fitted with 3.2 mm (0.13 in) mesh knotless nylon netting to retain juveniles. At the bypass outfall, fish were captured with a 9.1 m (30 ft) long fyke net constructed of 4.8 mm (3/16 in) mesh knotless nylon netting (Figure 3). The mouth of the net was attached to a steel frame which fit into the outfall's stop-log slots. The mouth of the net covered the entire outfall opening (1.8 x 1.8 m; 6.0 x 6.0 ft). The steel frame at the front of the net was raised and lowered using a battery-powered winch. The winch was mounted on a metal frame that was bolted to the surface of the concrete outfall structure.

A live box was attached to the cod end of the fyke net and fixed in place between the distal ends of two aluminum pontoons. The pontoons and live box were part of a rotary screw trap manufactured by E. G. Solutions®, Corvallis, Oregon. The live box (1.2 m wide x 1.8 m long x 0.5 m tall; 4 ft x 6 ft x 1.8 ft) had aluminum screens in the rear, floor, and sides to dissipate water velocities. For this study, the opening of the live box was modified to accommodate the 0.30 m (1 ft) square cod end of the fyke net. The pontoon and live box combination was attached to the bypass outfall structure by securing one end of a 6.4 mm (0.25 in) diameter aircraft cable to the front of each pontoon, and the other end to an eye on the outfall structure. To stabilize the pontoons in the river's current, a 45.5 kg (100 lb) anchor was deployed approximately 12.1 m (40 ft) off the downstream end of each pontoon (Figure 3).

During both experiments, chinook salmon were allowed to exit the plant's fish bypass outfall and move into the live box on their own volition. The length of time allowed for this movement was standardized to meet objectives of the passage experiment and the survival experiment. At the end of each standardized time period, a pulse of water was sent through the 152 cm diameter underground pipe that formed the terminal portion of the plant's fish bypass system (Figure 2). Pulsed flows were obtained by fully opening weir gates on each of two 122 cm drum-screen bypass lines that converged at the upstream end of the 152 cm line.

Bigelow and Johnson (1997) measured the total discharge from the two 122 cm bypass pipes to be 4.44 m^3 /s (157 ft^3/s). Adding discharges from fish bypasses of three operating pumps in RBRPP, an estimated flow of 5.4 m^3/s (189 ft^3/s) was obtained for the 152 cm pipe. At this discharge, the calculated velocity of water in the pipe was 2.9 m/s (9.6 ft/s). In spring 1998, velocity measurements were taken at the mouth of the bypass outfall using a Marsh-McBirney® Model 2000 flow meter. The average of 10 measurements taken with the two weir gates fully open and three pumps running in the plant was 2.8 m/s (SD = 0.3 m/s; 9.2 ft/s, SD = 1.1 ft/s). These velocities were very near to those obtained above by estimation. They were also much higher than the maximum sustained swimming speed for juvenile coho salmon (Bell 1991; 0.4 m/s for 50 mm coho; 0.5 m/s for 90 mm coho). Preliminary trials that we conducted showed that if the upstream weir gates were fully open for five minutes, current velocities in the 152 cm bypass pipe were adequate to flush resident juvenile chinook salmon from the pipe. A 10-minute pulse in the pipe, developed by fully opening the two upstream weir gates, was chosen for use during trials for this study. The actual pulse lasted 26 minutes since 8 minutes were required to fully open the weir gates, and also to close them.

During each trial physiochemical and pumping conditions were recorded. Water temperature (°C) and dissolved oxygen (ppm, percent saturation) were monitored with a YSI® Model 55 dissolved oxygen meter. Water turbidity (NTU) was measured with an HF Scientific® continuously-monitoring turbidimeter located in the river water fish facility. Measurements of river elevation (ft) and pump discharge (ft^3/s), including canal and bypass flows, were automated and continuously recorded on a computer in the pumping plant's automation facility.

Passage Experiment

Trials for the passage experiment were conducted from 4/12/99 through 5/12/99. Fall-run chinook salmon with mean fork length (FL) of 54 to 62 mm were used (Table 1). During this period gates on RBDD were raised out of the water. This allowed for free-flow of the Sacramento River, and also eliminated the hydraulic head that was otherwise used to maintain surface elevations for water in the forebay of the Tehama-Colusa canal. In this situation, weir gates on the 122 cm drum screen bypass pipes were closed. If significant flow of water occurred in the 152 cm bypass pipe, it was caused by discharge from pumps in the research pumping plant. Thus, at the time of these experimental trials, conditions for flow in the 152 cm bypass pipe were typical for times during the year when the pumping plant was operated to deliver water for irrigation and other uses in the northern Central Valley.

Time required for passage of juvenile chinook salmon through RBRPP was evaluated using *whole-plant* and *segmented-plant* trials. The purpose of whole-plant trials was to evaluate total passage time through the pumping plant. Samples of chinook salmon were released into pump intakes and recovered in the live box on the fyke net at the fish bypass outfall in the Sacramento River. The purpose of segment trials was to identify areas within the plant where fish passage might be delayed. Segment trials were conducted by releasing differentially marked chinook salmon at four different locations in RBRPP and recovering them in the holding tanks or at the bypass outfall (Figure 1). Four whole-plant and four segment trials were conducted with the general strategy of alternating trial types. One whole-plant and one segment trial was conducted each week. Whole-plant trial 2 failed due to a pump automation problem. Consequently, an additional whole-plant trial (trial 5; Table 1) was conducted. Two trials of each type (whole-plant or segment) began at sunrise and two at sunset (Table 1).

Whole-plant trials.- In each trial, a sample of fifty chinook salmon was inserted into each of the intake streams of Archimedes-1, Archimedes-2 and the internal helical pump using techniques described by McNabb et al. (1998). Markings on experimental fish used with each pump were recorded. Fish passed through the pumps and their downstream screening facilities into open bypass channels, then to plunge pools, and underground bypass conduits (Figure 1). They were collected from the live box at the bypass outfall. Fish marked for use with Archimedes-1, Archimedes-2 and the internal helical pump were enumerated at 0.5, 1, 1.5, 2, 12, 24, 36, and 48 h after insertion in pump intakes. After the 48-h collection was completed, the 152 cm bypass pipe was pulsed. Experimental fish taken in post-pulse collections were assigned by their markings to individual pumps, and then enumerated.

Segment trials.- Each segment trial used a total of ten samples, each consisting of 50 chinook salmon. Downstream portions of fish bypasses were evaluated in the following manner. Two of the three pumps in RBRPP were used simultaneously. The internal helical pump was used in all of the trials. The total number of trials conducted were split equally between the two Archimedes pumps (Table 1). With dewatering ramps on bypasses of each pump raised, a sample of fish was released under the ramp, just upstream of the plunge pool leading to the underground bypass (Figure 1). Another sample was released for each pump, downstream of the plunge pool at the entrance to underground bypasses. All samples were released in a short interval of time (minutes). Fish from these samples were collected at the bypass outfall. Those individuals belonging to each sample were identified by specific markings, or lack thereof. Fish in samples were enumerated at the bypass outfall at 0.5, 1, 1.5, 2, 12, 24, 36, and 48 h after their release. After the 48-h enumeration, the 152 cm bypass pipe was pulsed. After the pulse, the live box on the fyke net was checked, and fish recoveries were recorded. The resulting data were used to assess passage delays in downstream portions of the plant's fish bypasses, particularly in the plunge pool and 152 cm bypass pipe.

After inserting fish into downstream segments of the pumping plant, dewatering ramps on pump bypasses were lowered into place. Pump discharges were diverted into holding tanks in the plant's fish facility (Figure 1). Archimedes-1, Archimedes-2 and the internal helical pump were used in this portion of the work. A sample of fish was inserted into the intake of each pump and at the outfall of each pump. Chinook salmon in intake samples and outfall samples were distinguished from one another by different markings. The holding tanks on each pump's fish bypass were tended and experimental fish from each sample were enumerated at 0.5, 1, 1.5, 2, 12, 24, 36, and 48 h after their release. After the 48-h enumeration, pumps were turned off, then restarted to develop a pulse to move fish into tanks. After the pulse, tanks were checked, and fish recoveries were recorded. Resulting data were used to assess passage delays in upstream portions of the plant. By comparing data from samples inserted in pump intakes with data from samples released at pump outfalls, we were also able to address the question of whether passage through the pumps affected travel time.

Statistical Analysis.–Recovery trials were compared using repeated measures analysis of variance (Kuehl 1994) with two grouping factors, pump type and day/night release, and one within subjects factor, time after release. Cumulative percent recovery, the dependent variable, was measured at 0.5, 1, 1.5, 2, 12, 24, 36, and 48 h after release and after the pulse. This design was used to test recovery for whole-plant trials and for trials on each of the four subsections. Two additional repeated measures analyses of variance were conducted to evaluate potential delays caused by the pumps in the upper section of the pumping plant, or by the plunge pools in the lower section. For these analyses, release site was the grouping factor. The upper section consisted of samples released into pump intakes and samples released into pump outfalls. The lower section consisted of samples released above plunge pools and samples released below plunge pools. Time was the within subjects factor, as above. The Huynh-Feldt E was used to correct P values for deviations from compound symmetry for all repeated measures analyses (Kuehl 1994). We compared cumulative 48-h and post-pulse recovery rates among samples released during day and night using two-sample t-tests. All statistical tests were considered significant at $P \leq 0.05$.

Survival Experiment

Sixteen trials were conducted from 5/19/99 through 7/12/99 (Table 2). During this period gates on Red Bluff Diversion Dam were in the water. Drum screens in the forebay of the Tehama-Colusa canal were operating, and fish bypass pipes from the drum screens were open to the Sacramento River (Figure 2). To simulate conditions that fish encounter when gates on Red Bluff Diversion Dam are out of the water and the RBRPP is used to divert water to the Tehama-Colusa canal, flows through the drum screen bypass pipes were turned off while trials were conducted. All trials were conducted at night beginning 30 to 60 minutes after sunset to maximize recapture of fish (McNabb et al. 1998) and to simulate conditions when most wild chinook salmon are entrained (Borthwick et al. 1999).

Each trial consisted of simultaneously releasing samples of juvenile chinook salmon into the intake of each pump (treatment) and at the outfall of each pump (control). The helical pump and a randomly selected Archimedes lift were used in each trial. Chinook salmon released in samples were captured in the live box at the bypass outfall. Archimedes-1 was used in nine trials; Archimedes-2 was used in seven trials (Table 2). On the first two trial dates both fall and late-fall chinook salmon (mean FL 69 mm and 42 mm, respectively) were available. On those dates, two trials were conducted simultaneously, each trial using one of the two readily distinguishable size classes of chinook salmon. A single trial was conducted on each of the remaining 12 dates using late-fall chinook salmon. Mean fork length of the late-fall salmon increased from 44 to 58 mm during the interval in which these trials were conducted.

Four live cages, each with 55 juvenile chinook salmon, were randomly assigned to each of four release sites; the helical pump intake and outfall, and the intake and outfall of an Archimedes lift. Chinook salmon from each live cage were transferred to a separate carboy (McNabb et al. 1998) and transported to a release site. Prior to release, five fish were randomly selected from each carboy and euthanized in river water containing 200 mg/L Finquel® buffered with an equal weight of sodium bicarbonate. The euthanized fish were stored in a refrigerator until assessed for pre-passage injury and descaling. Fish remaining in the carboys were released into the flowstreams. The dewatering ramp associated with each pump was raised during trials. This allowed experimental fish to pass unimpeded through screening facilities, above-ground fish-bypass channels, and into underground portions of the plant's bypass.

Fish released in samples were captured in the live box on the fyke net attached to the bypass outfall in the Sacramento River. One hour after release of samples, experimental chinook salmon (marked) were collected from the live box and placed in a 19 L bucket containing river water. Immediately after the 1-h check, the drum screen bypass pipe was pulsed as described earlier for the passage experiment. Experimental fish in the live box after the pulse were collected and placed in a separate 19 L bucket. Fish that were dead when collected from the live box were removed from the sample and counted.

One to five chinook salmon of each mark were randomly selected from those collected at 1 h and at post-pulse. These were euthanized in the Finquel® solution, and chilled until assessed for post-passage injury and descaling. The number taken for these assessments varied with the number of fish recovered in the live box. Generally, three to five fish were taken, except when fewer than 10 fish were collected. In those cases, typically one or two fish were taken. The remaining fish in samples were transported to the project's river-water facility where fish were enumerated. These fish were transferred to live cages and held for a 96-h observation period. Salmon that were dead when collected were stored in a refrigerator to await injury and descaling analyses.

The following terminology was developed to express the frequencies of mortalities that were observed in post-passage samples collected during each trial. Percent *direct mortality* at 1 h, and at post-pulse, was calculated as the number of dead fish collected from the live box at 1 h and at post-pulse, divided by the number of fish captured at each of those times. *Total* direct mortality was calculated as the sum of the number of dead fish collected at 1 h and at post-pulse, divided by the sum of the number of fish captured (dead and alive) at 1 h and at post-pulse. Percent *delayed mortality* at 1 h, and at post-pulse, was calculated as the number of fish in each of these samples that died during the 96-h period divided by the number of live salmon in each of these samples that were held for 96-h post-trial observation. *Total* delayed mortality (%) was obtained from the total number of fish in the 1-h and post-pulse samples that died during 96 h of post-trial observation divided by the total number of fish from 1-h and post-pulse collections that were held for 96 h. *96-h mortality* was calculated at 1 h and at post-pulse as the sum of direct mortality and delayed mortality. *Total 96-h mortality* was calculated as the sum of total direct and total delayed mortality.

To determine if pulsing flows through the 152 cm drum screen bypass pipe adversely affected chinook salmon, percentages for direct, delayed, and 96-h mortality for 1-h samples and post-pulse samples were compared statistically to detect significant differences. Due to different sample sizes (i.e., number of fish recovered) at each collection time, values were calculated and presented as weighted means. Descaling and injury of fish collected at 1 h and post-pulse were also compared. Because we wanted to assess the cumulative effects of pump passage, bypass passage, and pulsing flows that wild fish entrained from the river experience, only data from treatment samples were analyzed here for pulsing effects.

Prior to conducting trials, 30 chinook salmon were randomly selected from among all of those that had been marked and moved to the river-water facility for acclimation. Each fish was measured for fork length (mm) and wet weight (g), and then inspected for descaling and injury. Results were compared to criteria developed by McNabb et al. (1998) to evaluate the health and condition of chinook salmon that were used in pump-passage experiments at RBRPP (Table 3). On the basis of results from these sub-samples of 30 fish, each group of salmon that was marked, acclimated, and used in this survival experiment met the quality control requirements in Table 3. This provided some assurance that healthy and robust fish were used in each trial.

Fish collected for pre-passage and post-passage injury and descaling analyses were inspected within 18 h. To minimize observer bias, two individuals conducted all the analyses. They were unaware of the identity of samples that they analyzed (i.e., blind analysis). Each fish was inspected for injuries to the head, eyes, skin, and fins. Descaling was evaluated by summing ocular estimates of the percent area descaled in each of six zones on a fish as described by Kostecki et al. (1987) and used by McNabb et al. (2000). Dissecting microscopes were used for this work at magnifications of 7 and 10. Areas where individual scales were missing could not be reliably estimated for chinook salmon with <55 mm fork length. Scales on these fish were too small and undeveloped to consistently detect descaling. Therefore, percent of scaled body surface abraded was estimated for juveniles <55 mm on the assumption that abraded areas would be descaled.

Statistical Analyses.– Our null hypotheses were: (1) no difference in the %-frequency of mortality or injury, or the extent of descaling, between treatment (pump and bypass passage) and control (bypass passage) samples collected at the bypass outfall, (2) no difference in the %-frequency of mortality or injury, or the extent of descaling, between fish passed through the helical pump or Archimedes lifts, or fish passed through their bypasses, (3) no difference in the %-frequency of mortality or injury, or the extent of descaling, between fish collected at 1 h and fish collected post-pulse.

Multi-response permutation procedures (MRPP) were used to test our null hypotheses, with differences between means considered statistically significant at $P \leq 0.05$. These permutation procedures use normed distances between measurements as the units of analysis, rather than the actual individual measurement as in parametric statistical procedures (Mielke et al. 1981, Mielke 1984, Mielke 1985). The inferential results from MRPP are solely dependent on randomization and permutations of the measured data sets. These procedures were appropriate for our data because of the low incidence of mortality, descaling, and injury expected as a result of observations made in pilot studies, and the resulting non-normal distribution of our data. The MRPP avoid decisions about goodness of fit of univariate or multi-variate distributions, and avoids the standard assumptions of ANOVA, such as normality and heterogeneity of variances.

Results

Passage Experiment

Whole-plant trials.– Large fractions of the whole-plant experimental samples remained within RBRPP after two hours and, on average, over one-quarter remained after 48 h (Figure 4). Recovery rates differed significantly between trials begun at sunrise versus those begun at sunset (*P*=0.003; Figure 4A). Not only did samples released at sunrise exhibit lower recovery rates during the initial daylight period than samples released at sunset, but also they failed to attain the same fraction of recoveries over two successive nights (Figure 4A). Recovery rates differed significantly between sunrise and sunset samples even after 48 h (*P*=0.030). The pump utilized did not significantly affect passage time (*P*=0.514; Figure 4B).

Segment trials.– In contrast to whole-plant experiments, sunrise versus sunset trials did not differ significantly for any of the four subsections tested (Figure 5; ANOVA tables listed in Appendix 2). Trial 3 (sunrise) exhibited lower recovery rates than trials 2 and 4 (sunset) in each segment of RBRPP; however, Trial 1 (sunrise), which was conducted under high turbidity (Table 1), exhibited similar recovery rates to those begun at sunset (Figure 5). No other comparison among samples released into different pumps, pump outfalls, or pump bypass channels was significant (Appendix 2).

The patterns of recovery of samples inserted into the pump intakes did not differ significantly from those inserted into pump outfalls (*P*=0.863; Figure 5, A compared to B). Likewise, the recovery patterns of samples inserted above the plunge pools were not significantly different from those inserted below (*P*=0.988 Figure 5, C compared to D). These results indicate that pump passage did not have an appreciable effect on subsequent passage time through the vertical screen area, nor did fish hold up in the plunge pool downstream of the dewatering ramp.

Recovery trends.– Most fish were delayed in the drum screen bypass to the river outfall, as indicated by the recovery of a mean cumulative 98% (SE ±2; Figures 4, 5) of samples following pulsing in lower segment and whole-plant trials. Segment trials also indicated small fractions of fish were delayed in the vertical screen area (Figure 5). The vertical screen pulse was minimally effective at moving fish out of the area, as indicated by the similar 48-h and pulse recovery rates (Figure 5). Missing fish were presumed still within RBRPP. Mean mortality for all samples was 1.0% (± 0.004 SE) and ranged 0-4% (0-2 fish died) except for one sample, which exhibited 20% mortality (Trial 3, pump 3; 10 fish died).

Survival Experiment

Recapture of Fish

Eighty-four to 86 percent of chinook salmon released during a trial were captured at the bypass outfall (Table 4). The mean percent captured ranged from 35 to 42 at 1 h and 44 to 49 post-pulse; however, variation among trials was high (Table 5 and Appendix 3). For both the Archimedes lift and the internal helical pump, there were no significant differences in the number of treatment versus control fish captured at the 1 hr or post-pulse collections (Wilcoxan sign-ranked test; $P > 0.05$). There was no evidence that those fish which were not recovered during a trial were dead. Results from this study's passage experiment, and those of McNabb et al. (2000), showed that missing fish resided in screening facilities for several hours to several days before exiting the pumping plant.

No differences were detected in the percent of chinook salmon in the treatment samples recovered at 1 h versus post-pulse for the Archimedes lift or for the helical pump (Wilcoxan sign-ranked test; $P=0.21$ and $P=0.68$, respectively). Chinook salmon captured at 1 h exited the bypass outfall and entered the live box on their own volition. Chinook salmon captured post-pulse moved as far as the 152 cm bypass pipe within an hour, but did not move into the live box until forced to do so by pulsing flows. Due to the high velocities (1.8 m/s, 6.0 ft/s) and lack of refugia in each pump's 46 cm underground bypass pipe, fish not recovered after the pulse were presumed to be alive and residing in the above-ground bypass.

Four trials conducted on 5/19 and 5/26 with small (<45 mm) and large (>65 mm) chinook salmon released simultaneously under the same environmental conditions allowed us to evaluate the relationship between fish size and capture time. Small chinook salmon moved through the plant quickly with more than 75% exiting within 1 h. In contrast, large chinook salmon passed more slowly with less than 50% captured at 1 h. When evaluating data from all trials, however, linear regressions of fork length and percent captured at each sample time revealed a weak relationship for both pump types ($r^2 < 0.20$). Fish size may be confounded with other conditions affecting travel time, particularly degree of darkness. Varying phases of the moon, sky conditions, and release times (27 to 58 minutes post-sunset) affected darkness during trials.

Passage Effects

Mortality. – Mean total 96-h mortality of fish passed through a pump and bypass (treatment) was similar between the Archimedes lift and helical pump (3.8% and 3.9%, respectively; Table 4). Mortality of fish passed through the bypass only (control) was 2.4% and 2.0% for the Archimedes lift and helical pump, respectively. Mortality attributed to pump passage, calculated as the difference between treatment and control samples, was 1.4% and 1.9% for the Archimedes lift and helical pump, respectively (Table 4). This pump passage mortality was not statistically significant ($P > 0.05$) for the Archimedes lift or the helical pump.

Differences in total direct, delayed, and 96-h mortality between treatment and control samples was evaluated for each pump (Table 4). There were no significant differences for total delayed or total 96-h mortality. There also was no significant difference in total direct mortality between treatment and control samples for the Archimedes lift ($P = 0.78$), but there was for the helical pump ($P = 0.01$). Because the only difference between treatment and control samples was pump passage, this difference represented a helical pump passage effect of 2.0 % direct mortality. When comparing the two pump types, however, no significant differences were found in total direct, delayed, or 96-h mortality for treatment or control samples.

Separate evaluations of differences in mortality between treatment and control samples were made for fish that exited the outfall on their own volition (1 h) and those that exited with pulsing flows (post-pulse). To account for the different sample sizes (i.e., number of fish recovered) at 1 h and post-pulse, percent mortality values were expressed as weighted means (Table 5). The only statistically significant differences in mortality between treatment and control samples were with the helical pump at 1 h (direct and 96-h mortality; P=0.004 and P=0.05, respectively).

Treatment samples were evaluated for the effects of pulsing flows on mortality of juvenile chinook salmon. No significant differences were found in direct, delayed, or 96-h mortality between juvenile chinook salmon that exited the outfall within 1 hour versus those that exited post-pulse (Table 5). For the Archimedes lift, 96-h mortality of treatment fish was actually higher at 1 h than post-pulse (4.1% versus 3.8%). For the helical pump, chinook salmon pulsed from the bypass had higher 96-h mortality than fish that exited on their own (4.4% versus 3.5%). Neither pump type showed a relationship between fork length and 96-h mortality of chinook salmon captured at 1 h or post-pulse (r^2<0.10; Figure 6).

Descaling and Other Injuries. – Mean percent of body surface descaled for chinook salmon collected pre-trial, 1 h, and post-pulse was <1.2 for treatment and control samples from both pump types (Table 6). No significant differences were found in percent descaled between treatment and control samples collected pre-trial, at 1 h, or post-pulse for either pump type ($P > 0.05$). When comparing the Archimedes lift and the helical pump, no differences in descaling were detected ($P > 0.05$) for either treatment or control samples at any of the sample times. In contrast to chinook salmon captured alive, dead chinook salmon collected from the live box generally had a higher degree of descaling (0 - 41 percent of body; Table 7).

The mean percentage of chinook salmon in collections made pre-trial and at 1 h and post-pulse with non-lethal injuries ranged from 1.3 to 7.5 (Table 6). There were no significant differences in the percent frequency of injuries between treatment and control samples at any of the three sampling times ($P > 0.05$). Injuries to skin and fins were most common for the Archimedes lift and helical pump, respectively (Table 6). Specifically, these injuries consisted of hemorrhages, bruises, open wounds, and eroded or missing fins. Eye injuries were infrequent and consisted of hemorrhaging or partially dislodged eyes. There were no head injuries (e.g., missing opercula, decapitation). No differences were detected ($P > 0.05$) in the mean percentage of fish injured in the Archimedes lift versus the helical pump for either treatment or control samples at any of the three sampling times. Most (60 - 100%) dead fish collected from the live box exhibited injuries to the head, skin, eyes or fins (Table 7).

Pulsing flows through the 152 cm diameter pipe did not increase the percent frequency of descaling or injury to chinook salmon. Mean percent body surface descaled was <0.5 for chinook salmon collected from treatment samples pre-trial, at 1 h, and post-pulse. There were no significant differences detected in percent descaling among the three types of samples for the Archimedes lift (P=0.43) or the helical pump (P= 0.47). There also were no significant differences detected in percent of fish injured among the three types of samples for the Archimedes lift (P=0.42) or the helical pump (P= 0.33). In fact, for both pump types the mean percent of chinook salmon injured was less in samples collected post-pulse than in samples collected at 1 h (Table 6).

Discussion

Passage Experiment

Our data indicate a portion of fish passing through RBRPP experience a relatively long delay, particularly in the drum screen bypass pipe where velocities are low (<0.5 m/s, < 1.7 ft/s). If this delay is deemed harmful to fish, periodic pulsing appears to be an effective method of returning fish to the river without causing additional mortality, descaling, or injury. Delay in the bypass, however, could be viewed as a positive behavior. Holding in the bypass appears voluntary, as demonstrated by the difference between day and night passage times. The cover and darkness provided by the bypass may allow fish to safely reorient and recover from any stress experienced by pump and bypass passage (Weber and Borthwick 2000). Based on the high survival rates observed in the passage trials, even after 48 h, and the relatively low occurrence of predators around the river outfall (Tucker et al. 1998), we believe the risk of predation to be low for juvenile fish holding in the bypass. Further, during our passage and survival experiments large-sized predators (>200 mm) rarely emerged from the bypass outfall during pulsing flows.

Our data and McNabb et al. (1998) indicate that delays in juvenile salmon passage through RBRPP also occur in the screening facility, particularly during daylight. The observation that fish released during daylight emigrated in smaller numbers than their night-released counterparts over extended, 48-h periods (Figure 4A), however, had not been previously documented. We speculate these fish located low-velocity refugia, which allowed them to efficiently hold position. Rather than exit the bypass outfall, these fish preferred to remain within the cover of the drum screen bypass. Fish released in the darkness were probably less likely to seek refugia and, thus, more likely to emigrate during the first night following release. Frizell and Atkinson (1999) suggest that the passage delays in the screening facility are due to the ramp located at the downstream end creating a recirculating eddy preventing flow from accelerating into the open bypass channel. According to NMFS screening criteria for anadromous salmonids (NMFS 1997), "a gradual and efficient acceleration into the bypass is required to minimize delay of outmigrants". The ramp actually creates a zone of deceleration with sweeping velocities near the bottom very low, ranging from approximately 0.12 to 0.61 m/s (0.4 to 2.0 ft/s) for a distance of 2.4 m (8 ft) upstream of the bypass entrance (Frizell and Atkinson 1999). Juvenile salmon of the size used in our trials can maintain their position in these velocities (Bell 1991). Therefore, the screening facility provides an opportune refuge for chinook salmon to reside. Also, juvenile salmonids can sense changes in velocity, and may avoid moving from one gradient to another, especially from a lower to a higher gradient (Bell 1991). Therefore, chinook salmon that encounter low velocity zones in the screening facility likely resist moving back into high velocity waters.

There was no significant difference in passage time of juvenile salmon released upstream and downstream of the plunge pool. Apparently, salmon are unable to find refuge in the plunge pool or prefer to move out of the somewhat turbulent plunge pool flows into the more laminar flows of the underground bypass pipe.

Passage trials were conducted over a relatively short time period following spring storm events (when river stage allowed work on the bypass outfall) but prior to gates-in operation of RBDD and the drum screen fish bypass. Consequently, the size range of salmon used was small and the full range of river conditions (i.e., temperature, turbidity, discharge) under which RBRPP could be operated was not tested. Although the similarity in conditions among trials allowed valid comparisons, passage characteristics may vary under different conditions or for fish of different size classes.

Survival Experiment

Juvenile chinook salmon that passed through a pump and then the bypass (treatment) consistently had higher mortality than chinook salmon that only passed through the bypass (control). This finding was expected since 96-h mortality of juvenile chinook salmon attributable to pump passage was 1.0% and 2.5%, respectively, for the Archimedes lift and helical pump in 40 trials conducted by McNabb et al. (2000). Compared to McNabb et al (2000), total 96-h mortality attributable to pump passage in our study was slightly higher for the Archimedes lift (1.4%), but lower for the helical pump (1.9%; Table 4). Whereas McNabb et al. (2000) found a significant pump passage effect for 96-h mortality with the helical pump ($P < 0.01$), we did not ($P = 0.28$). In our study, the only case in which total mortality of treatment samples significantly exceeded control samples was for direct mortality with the helical pump ($P = 0.01$). McNabb et al. (2000) also found a significant pump passage effect for direct mortality with the helical pump.

Our findings of low %-frequencies for mortality and injury, and low % body surface descaled to fish passed through an Archimedes lift and helical pump are consistent with results from other studies (Griffith 1985, Patrick and Sim 1985, Rodgers and Patrick 1985, Patrick and McKinley 1987, Week et al. 1993, McNabb et al. 1998, 2000, Helfrich et al. in prep.). Studies done at RBRPP, however, were unique in that an Archimedes lift and a helical pump were evaluated while running simultaneously. Similar environmental conditions existed for fish passing through each type of pump. We evaluated whether %-frequencies of mortality and injury, and %-body surface descaled differed between the two pump types for fish passed through a pump and bypass (treatment), and for fish passed only through a pump's bypass (control). We found no significant differences between pump types for treatment or control samples.

Mortality of chinook salmon pulsed from the 152 cm diameter pipe did not differ from mortality of fish that exited on their own volition. This finding was consistent with the assessment of Bigelow and Johnson (1997) on mortality and injury to juvenile chinook salmon passed through the 152 cm drum screen bypass pipes. No direct mortality occurred in treatment (*N*=5,253) or control (*N*=6,080) chinook salmon which experienced bypass flows similar to pulsed flows used in our study. Three days after passage, mortality was lower for treatment (0.6%) than for control (0.8%) samples indicating no delayed effect on chinook salmon passing through the drum screen bypass. Percent frequency of injury and extent of descaling were also very low and similar between treatment and control samples.

Percent of body surface descaled on fish was particularly low in this study for both treatment and control samples (Table 6). Sixty-four percent of chinook salmon collected for injury and descaling analyses were <55 mm with scales too undeveloped to detect. Therefore, percent area abraded rather than descaled was assessed. Larger fish with detectable scales typically lose scales due to handling or natural sloughing. Because such a high fraction of chinook salmon in this study had undeveloped scales, they were not subject to scale loss from handling or natural sloughing. Also, abrasions due to handling were very rare. This resulted in particularly low values for percent body surface descaled in our study (mean <1.2).

Total direct mortality attributed to passage through the bypass system (pump outfall to bypass outfall) was 1.1% for the Archimedes lift and 1.0% for the helical pump (Table 4). Percent frequency of injuries and amount of descaling were low (Table 6). Similarly, in a review of unpublished NMFS reports, Williams (1998) found that direct mortality was generally less than 2% for juvenile chinook salmon passed through bypass systems constructed at dams on the Columbia River. Total 96-h mortality attributed to bypass passage in our study was 2.4% for the Archimedes lift and 2.0% for the helical pump. Data from McNabb et al. (2000), Bigelow and Johnson (1997), this study's passage experiment, and Reclamation bypass trials from previous years provide insight into where mortality and injury occurred within the bypass system of RBRPP.

In trials comparing the Archimedes lift and helical pump, 96-h mortality in the bypass segment between the pump outfall and the holding tanks was 0.5% and 1.1%, respectively (McNabb et al. 2000). In trials conducted by these authors to compare Archimedes-1 and Archimedes-2, mortality through this segment was somewhat higher (1.8% and 1.0%, respectively). This section of the bypass included screening facilities consisting of vertical wedge-wire screens (2.4 mm, 0.9 in openings) with continuously operating brushes that moved up and downstream. Baffles installed behind the screens reduced approach velocities to meet criteria established by NMFS (1997) at 98 to 99 percent of the points along the screens. Areas in which the criteria were exceeded were near the surface and likely resulted from surface waves impacting the screens (Warren Frizell, Bureau of Reclamation, Denver Technical Service Center, personal communication). Also, the brushes were not always effective at cleaning debris from the screens. This disrupted the uniform velocity profile along the screens resulting in high velocity zones where fish may have become impinged. If impinged on the screen, a fish would have had difficulty avoiding a brush. Even an unimpinged fish could have been injured. As a brush moved downstream, the upstream-oriented fish could likely perceive and avoid it. When the brush travels upstream, however, it would have approached the fish from behind making it more difficult for the fish to detect and increasing its chance of being struck.

Data collected during this study's passage experiment on juvenile chinook salmon passage through the middle section of the RBRPP suggest that mortality resulted from the high velocity, 1.5 to 2.1 m (5 - 7 ft, depending upon water depth) fall fish experienced as they entered the plunge pool. During our passage experiment, simultaneous trials (N=4) were conducted in which samples of 50 chinook salmon each were released upstream of the plunge pool and immediately downstream of the plunge pool at the entrance to the 46 cm underground bypass pipe. Both samples of fish were collected at the bypass outfall. Mean mortality of fish released upstream of the plunge pool was 0.9 and 1.7 percent for the Archimedes lift and helical pump bypasses, respectively, while mean mortality of fish released downstream of the plunge pool was zero for both pump bypasses. During our trials, stop-logs were in place to deepen the pool that fish plunged into. Even with this precaution, mortality occurred.

Based upon Bigelow and Johnson (1997) and passage trials conducted by Reclamation during this study and in 1996 (unpublished Bureau of Reclamation data), the underground portion of the RBRPP bypass contributed very little, if any, to fish mortality. In seven trials conducted by Reclamation in 1996 and 1999, juvenile chinook salmon released at the entrance to the plant's 46 cm underground bypass pipe and collected at the bypass outfall experienced no mortality. Bigelow and Johnson (1997) reported zero net mortality (i.e., treatment minus control) of juvenile chinook salmon 3 d after passing through the 152 cm drum screen bypass pipes operated at flows similar to pulsed flows used in this study. Frequencies of injury and extent of descaling also were low (mean, <3% and <8%, respectively) with no significant differences between treatment and control samples. Also, Vogel and Marine (1997) found that passage through the 152 cm pipe did not cause sufficient stress to impair a juvenile chinook salmon's ability to avoid predators.

Some mortalities attributed to bypass passage may have resulted from pre-trial handling, capture, and post-trial handling and holding of fish. However, these possible sources of mortality were not assessed in this experiment. We know that some mortality at the post-pulse capture time was due to the sampling gear (i.e., fyke net and live box). In three trials conducted on 5/26/99 and 6/10/99, cables securing the pontoon to the outfall structure were not adjusted to accommodate stretching of the net during the pulse. Rather than straightening out during the pulse, the net formed pockets where chinook salmon were observed to be trapped. When they entered the live box several were dead or abraded resulting in a higher percent frequency of direct and delayed mortality, injury, and degree of descaling than in other trials (Appendix 3). These mortalities are included in the percent mortality values reported in this study thus resulting in an over-estimate of passage mortality. Although no obvious problems occurred with the net at any 1 h collections, capture and handling effects may have occurred.

Conclusions

1. On average, over one-quarter of the juvenile chinook salmon released into intakes of all pumps remained within RBRPP 48 h after release.

2. Passage delays of juvenile chinook salmon through RBRPP occurred in the screening facility and in the drum screen bypass pipe. Delays did not occur in the plunge pool. Pulsing the pumps (i.e., turning them off and on again) was ineffective at moving chinook salmon out of the screening facility into the open bypass channel. Pulsing flows (approximately 4.4 m^3/sec, 157 ft^3/s) through the drum screen bypass for 10 minutes was effective at moving fish into the river.

3. Passage delays were significantly greater for chinook salmon released into the plant during daylight than during darkness (P=0.003).

4. Total 96-h mortality of juvenile chinook salmon passed through pumps and associated bypasses (treatment) was 3.8% and 3.9% for the Archimedes lift and helical pump, respectively. Total 96-h mortality of fish passed through bypasses only (control) was 2.4% and 2.0% for the Archimedes lift and helical pump, respectively. In addition to plant passage, these mortality values include that due to pre-trial handling, capture in the fyke net, collection from the live box, transfer to the river water facility, and 96-h post-trial holding. Mortalities due to these activities may have occurred but were not assessed.

5. No significant differences were found in total delayed or total 96-h mortality between treatment (pump and bypass passage) and control (bypass passage) samples for either pump type. There was no significant difference in total direct mortality for the Archimedes lift ($P = 0.78$). There was a significant difference ($P = 0.01$) in total direct mortality for the helical pump.

6. Mean percent body surface descaled and mean percent of chinook salmon injured were low (<1.2 and < 8.0, respectively) for both pumps and not different between treatment and control samples.

7. There were no significant differences between pump types in total mortality (direct, delayed, and 96-h), percent body surface descaled, or percent of fish injured for treatment samples or control samples.

8. The low levels of mortality, descaling, and injury to chinook salmon passed through RBRPP occurred mainly as fish traveled through the pumps, screening facilities, and plunge pools. Few,

if any, adverse effects were associated with the plant's 46 cm diameter underground bypass pipes or the 152 cm diameter drum screen bypass pipe. Mortality and injury in the screening facility may have resulted from the brushes or from zones of high approach velocities which develop when debris obstructs water passage through the screens. The force of impingement from the high velocity, vertical drop was suspected of causing mortality in the plunge pool.

9. There were no adverse effects on survival, descaling, or injury from pulsing flows (approximately 4.4 m^3/s, 157 ft^3/s) through the 152 cm diameter drum screen bypass pipe to flush fish into the river. Mean total 96-h mortality of chinook salmon passed through the Archimedes lift and its bypass was 4.1% and 3.8% at 1 h and post-pulse, respectively; for the helical pump, mean total 96-h mortality was 3.5% and 4.4%, respectively.

10. In contrast to pump passage experiments which attempt to isolate the effects of the pumps only, this evaluation addressed the entire RBRPP. Therefore, these results are applicable mainly to RBRPP in its current configuration. If additional pumps are installed at Red Bluff, the greater volume of water passing through the bypass could change passage time and perhaps mortality. The information learned about the pumps and other components of RBRPP plant, however, has application to fish-friendly passage technology being developed at other locations.

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Table 1. Trial information and environmental characteristics during an experiment conducted to evaluate passage time of juvenile chinook salmon (54 - 62 mm FL) through Red Bluff Research Pumping Plant (SE in parentheses).

Trial	Dates	Release Time	Trial Type	Pumps Tested[1]	Turbidity (NTU)	River Temperature (°C)	Sky Conditions	Moon
1	4/12 – 4/14/99	Sunrise	Segment	2,3	25.5 (15.0)	12.5 (0.5)	Clear	New
	4/14 – 4/16/99	Sunrise	Whole	1,2,3	11.6 (0.6)	13.3 (0.2)	Clear	New
2	4/19 – 4/21/99	Sunset	Segment	1,3	12.2 (1.1)	13.4 (0.3)	Clear	Half
3	4/26 – 4/28/99	Sunrise	Segment	1,3	8.7 (0.5)	13.5 (0.4)	Clear - Partly Cloudy	Full
	4/28 – 4/30/99	Sunrise	Whole	1,2,3	8.9 (0.1)	12.6 (0.9)	Clear - Partly Cloudy	Full
4	5/3 – 5/5/99	Sunset	Segment	2,3	6.0 (0.5)	12.7 (0.3)	Clear	Half
	5/5 – 5/7/99	Sunset	Whole	1,2,3	5.9 (0.0)	13.4 (0.3)	Clear	Half
5	5/10 – 5/12/99	Sunset	Whole	1,2,3	6.4 (0.5)	13.1 (0.1)	Clear	New

[1] 1=Archimedes 1; 2=Archimedes 2; 3=Internal Helical.

Table 2. Trial information and environmental characteristics during an experiment conducted to evaluate mortality, injury, and descaling to juvenile chinook salmon passed through Red Bluff Research Pumping Plant.

Trial	Date	Pumps Tested[1]	Fish Mean FL (mm)	Turbidity (NTU)	River Temperature (°C)	Sky Conditions	Moon
1,2[2]	5/19/99	2,3	65, 40	4.2	14.1	Clear	Half
3,4[2]	5/26/99	1,3	73, 44	5.7	14.1	Clear	Full
5	5/27/99	1,3	43	4.9	14.2	Clear	Full
6	6/1/99	2,3	43	5.0	12.8	Cloudy	Full
7	6/3/99	1,3	44	5.5	11.3	Mostly Cloudy	Full
8	6/7/99	1,3	46	3.9	13.4	Partly Cloudy	Half
9	6/10/99	2,3	47	3.7	13.5	Clear	New
10	6/22/99	2,3	52	3.2	14.4	Clear	Half
11	6/24/99	1,3	53	3.4	14.0	Clear	Full
12	6/28/99	1,3	56	4.8	13.5	Clear	Full
13	7/1/99	2,3	57	4.8	14.0	Clear	Full
14	7/6/99	1,3	58	5.2	14.0	Clear	Half
15	7/8/99	2,3	57	4.2	13.6	Clear	Half
16	7/12/99	1,3	55	4.2	14.1	Clear	New

[1] 1=Archimedes 1; 2=Archimedes 2; 3=Internal Helical.

[2] Two trials were conducted simultaneously; one using small, late-fall chinook salmon and another using large, fall chinook salmon. All subsequent trials used late-fall chinook salmon.

Table 3. Guidelines for making quality control assessments on different groups of hatchery-reared juvenile chinook salmon used in bypass trials at Red Bluff Research Pumping Plant. Limits listed in the table were used to eliminate sub-standard groups of juveniles from trials. Sizes for juveniles in table are for fork length (mm). (Table modified from McNabb et al. 1998).

ELEMENTS	RECORDED INFORMATION	LIMITS FOR ELIMINATION	NOTES
Disease	Outbreaks of Disease	>0	For outbreaks of disease in holding tanks in the project's well-water facility (not outbreaks at Coleman). An outbreak was defined as a condition in holding tank(s) requiring therapeutic treatment.
Mortality	Cumulative Mortality	>2%	Cumulative mortality in each group of fish obtained from Coleman Hatchery from the time of delivery to Red Bluff to the time of use in an experiment.
External Abnormalities	Damage to Fins of Individual Fish	>30% of fin area frayed or eroded on >5% of the fish	Confinement to raceways at Coleman Hatchery and tanks in the well-water facility at Red Bluff tended to result in fraying at the edges of fishes' fins (splitting between fin rays) and erosion of the edges of opercula. Fin damage was not allowed above the limit shown.
	Damage to Head, Eyes, and Skin of Individual Fish	>4% of fish	For damage to head, eyes and skin the limit for elimination was 4% of fish, except that erosion along the edges of the opercula was allowed.
Descaling	% of Scaled Body Surface That Was Descaled on Individual Fish.	>5% descaling on >7% of fish	Percent of scaled body surface descaled was estimated for fish ≥ 55 mm. Scales on fish <55 mm were too small and transparent to detect. Therefore, percent of scaled body surface abraded was estimated for juveniles <55 mm on the assumption that abraded areas are descaled.
Condition Factor	Weight and Fork Length for Individual Fish	<45 mm juveniles: mean <0.70 $\geq$45 mm juveniles: mean <0.85	Condition factor *(k)* was calculated from: $k = W/L^3 \times 100$ where W was weight in grams and L was fork length in centimeters.

Table 4. Mean percent captured and mean total mortality (SE in parentheses) of juvenile chinook salmon passed through pumps and bypasses (treatment) and bypasses only (control) during 16 trials conducted at RBRPP. Fifty treatment and 50 control fish were released in each trial and captured at the bypass outfall 1 h after release and post-pulse. Also shown, the proportion of total 96-h mortality due to pump passage and bypass passage. Significant differences between treatment and control samples are indicated with an asterisk (MRPP; $P \leq 0.05$). There were no significant differences in total direct, delayed, or 96-h mortality between pump types for treatment or control samples.

			Mean Total Mortality (% and SE)[1]			Mean Total 96-h Mortality (%) Due To:	
Pump	Group	Mean Percent Captured	Direct	Delayed	96-h	Pump Passage	Bypass Passage[2]
Archimedes	Treatment	84.1 (2.6)	1.6 (0.6)	2.2 (1.1)	3.8 (1.7)	1.4	2.4
	Control	86.0 (2.3)	1.1 (0.5)	1.3 (0.7)	2.4 (1.2)		
Internal Helical	Treatment	84.3 (2.3)	3.0 (0.7)*	0.9 (0.7)	3.9 (1.4)	1.9	2.0
	Control	85.3 (2.5)	1.0 (0.6)*	1.0 (0.4)	2.0 (1.0)		

[1] Total direct mortality was calculated for each trial as the number of dead fish collected from the live box at 1 h and post-pulse, divided by the cumulative number of fish captured (dead and alive) at 1 h and post-pulse. Total delayed mortality was calculated as the number of dead fish from the 1 h and post-pulse samples at 96 h divided by the total number of fish from 1 h and post-pulse collections that were held for 96 h. Total 96-h mortality was calculated as the sum of total direct and total delayed mortality.

[2] Includes mortality due to pre-trial handling, handling at capture, and post-trial handling.

Table 5. Cumulative mean percent captured (SE in parentheses) and weighted mean percent mortality at 1 h and post-pulse for juvenile chinook salmon passed through pumps and bypasses (treatment) and bypasses only (control) during 16 trials conducted at RBRPP. Fifty treatment and 50 control fish were released in each trial and captured at the bypass outfall 1 h after release and post-pulse. Significant differences between treatment and control samples are indicated with an asterisk (MRPP; $P \leq 0.05$).

Pump	Sample[2]	Group	Cumulative Mean (SE) Percent Captured	Weighted Mean Percent Mortality[1]		
				Direct	Delayed	96-h
Archimedes	1 h	Treatment	35.2 (6.6)	1.8	2.3	4.1
		Control	37.8 (7.1)	1.7	0.4	2.1
	Post-pulse	Treatment	84.1 (2.6)	1.3	2.5	3.8
		Control	86.0 (2.3)	0.8	1.9	2.7
Internal Helical	1 h	Treatment	40.6 (6.7)	3.1*	0.4	3.5*
		Control	41.7 (8.0)	0.3*	0.4	0.7*
	Post-pulse	Treatment	84.3 (2.3)	2.9	1.5	4.4
		Control	85.3 (2.6)	1.4	1.4	2.8

[1] Direct mortality was calculated at 1 h and post-pulse as the number of dead fish collected from the live box at each of those times divided by the total number of fish captured at each time. Delayed mortality at 1 h and post-pulse was calculated as the number of fish that died during the 96-h post-trial observation period divided by the total number of live salmon in each of these samples that were held for 96-h. 96-h mortality was calculated at 1 h and at post-pulse as the sum of direct mortality and delayed mortality.

[2] There were no statistically significant differences in direct, delayed, or 96-h mortality between treatment fish collected at 1 h and post-pulse for either pump (MRPP; $P \leq 0.05$).

Table 6. Mean percent of body surface descaled (SE), percent of fish with other injuries (SE), and percent of inspected fish with each type of injury for samples of treatment (pump and bypass passage) and control (bypass passage) fish collected alive pre-trial, 1 h after release and post-pulse. Some fish had more than one type of injury. N equals the total number of fish inspected; the number per trial was 5 for pre-trial samples, and 1 to 5 for the 1 h and post-pulse samples. Sixteen trials were conducted.

						Injury By Type (% of Fish)			
Pump	Group	Sample	N	Mean Descaling (% body)	Other Injury (% of Fish)	Head	Skin	Eye	Fins
Archimedes	Treatment	Pre-trial	70	0.0 (0.0)	6.3 (3.0)	0	1.4	0	5.7
		1 h	53	0.4 (0.3)	3.0 (2.1)	0	3.8	0	0
		Post-pulse	63	0.3 (0.2)	2.2 (2.2)	0	1.6	0	0
	Control	Pre-trial	70	0.1 (0.1)	1.3 (1.3)	0	1.4	0	0
		1 h	53	1.1 (0.7)	7.4 (4.5)	0	3.8	0	3.8
		Post-pulse	64	0.4 (0.2)	5.0 (2.9)	0	1.6	1.6	1.6
Internal Helical	Treatment	Pre-trial	70	0.0 (0.0)	1.3 (1.3)	0	0	0	1.4
		1 h	53	0.2 (0.1)	6.2 (3.3)	0	1.9	5.7	0
		Post-pulse	64	0.3 (0.2)	2.2 (2.2)	0	0	0	1.6
	Control	Pre-trial	70	0.1 (0.1)	2.7 (1.8)	0	0	0	2.9
		1 h	56	0.2 (0.1)	7.5 (6.3)	0	0	0	3.6
		Post-pulse	66	0.1 (0.1)	1.3 (1.3)	0	0	0	1.5

Table 7. Mean percent of body surface descaled (SE), percent of fish with other injuries, and percent of fish with each type of injury for treatment (pump and bypass passage) and control (bypass passage) chinook salmon collected dead from the live box 1 h after release and post-pulse. Some fish had more than one type of injury. N equals the total number of fish inspected. Sixteen trials were conducted.

						Injury by Type (% of fish)			
Pump	Group	Capture Time	N	Mean Descaling (% body)	Other Injury (% of Fish)	Head	Skin	Eye	Fins
Archimedes	Treatment	1 h	5	6.3 (4.7)	100	20	40	40	100
		Post-pulse	5	13.6 (13.6)	60	20	20	40	20
	Control	1 h	6	17.9 (13.3)	83	33	67	50	83
		Post-pulse	3	40.9 (24.0)	67	0	67	67	67
Internal Helical	Treatment	1 h	12	11.6 (5.6)	83	8	58	67	50
		Post-pulse	10	7.5 (4.9)	80	20	70	20	40
	Control	1 h	1	0.0	100	0	100	100	100
		Post-pulse	5	1.4 (1.4)	100	20	60	40	80

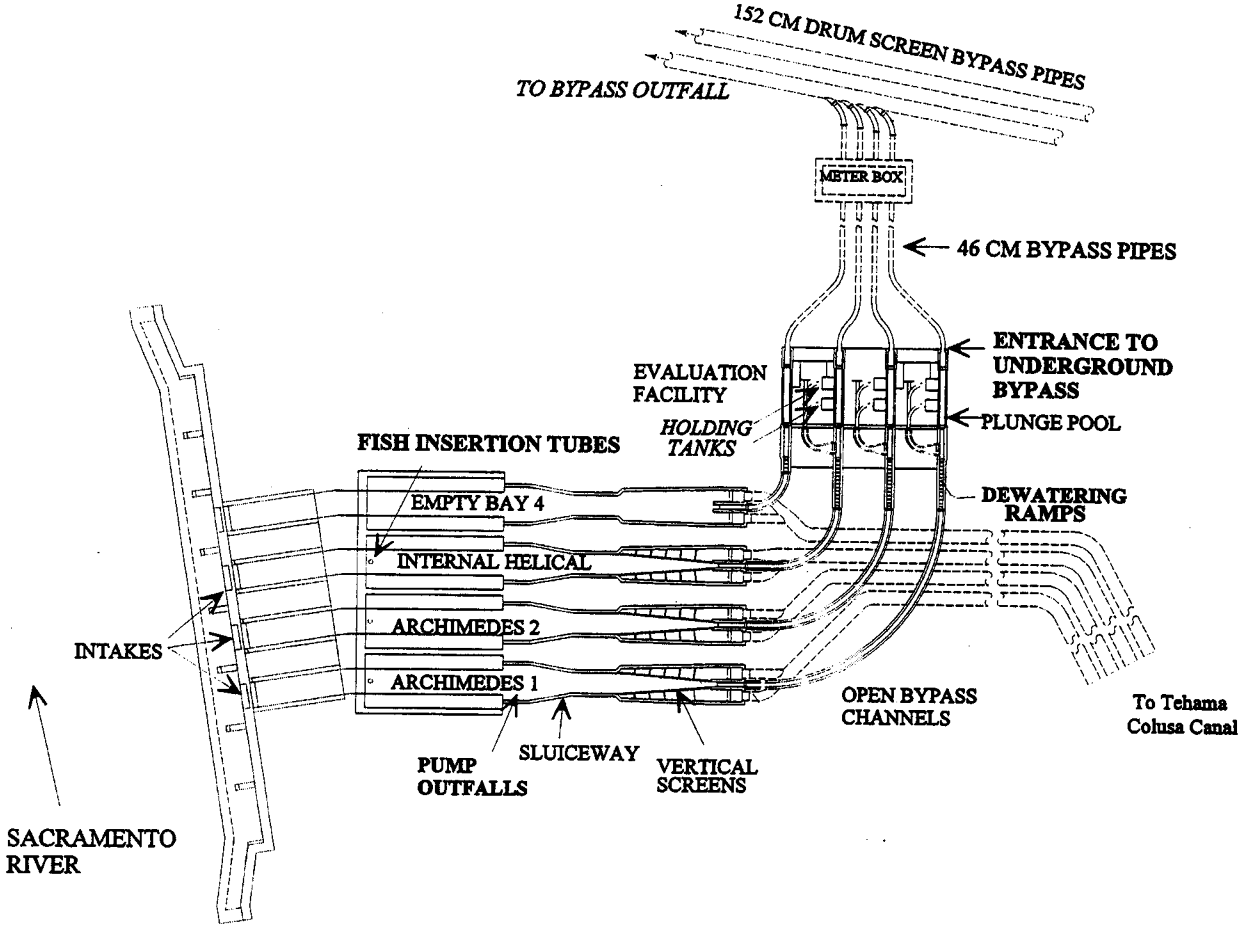


Figure 1. Schematic of Red Bluff Research Pumping Plant. Release locations for fish used in passage and survival experiments are in bold; capture locations are italicized.

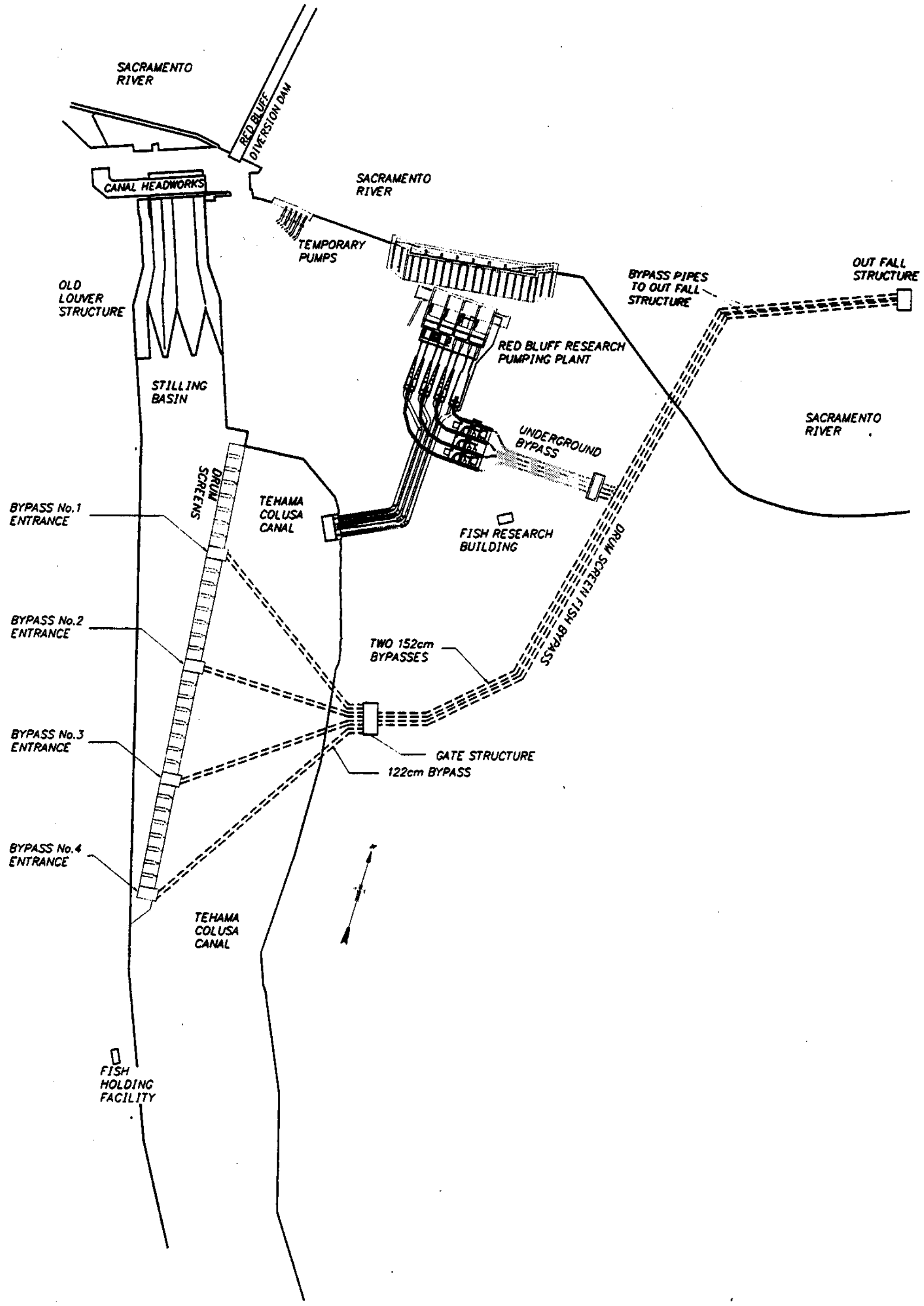


Figure 2. Relationship between Red Bluff Research Pumping Plant and the drum screen bypass system including bypass entrances, 122 and 152 cm bypass pipes, gate structure, and outfall structure.

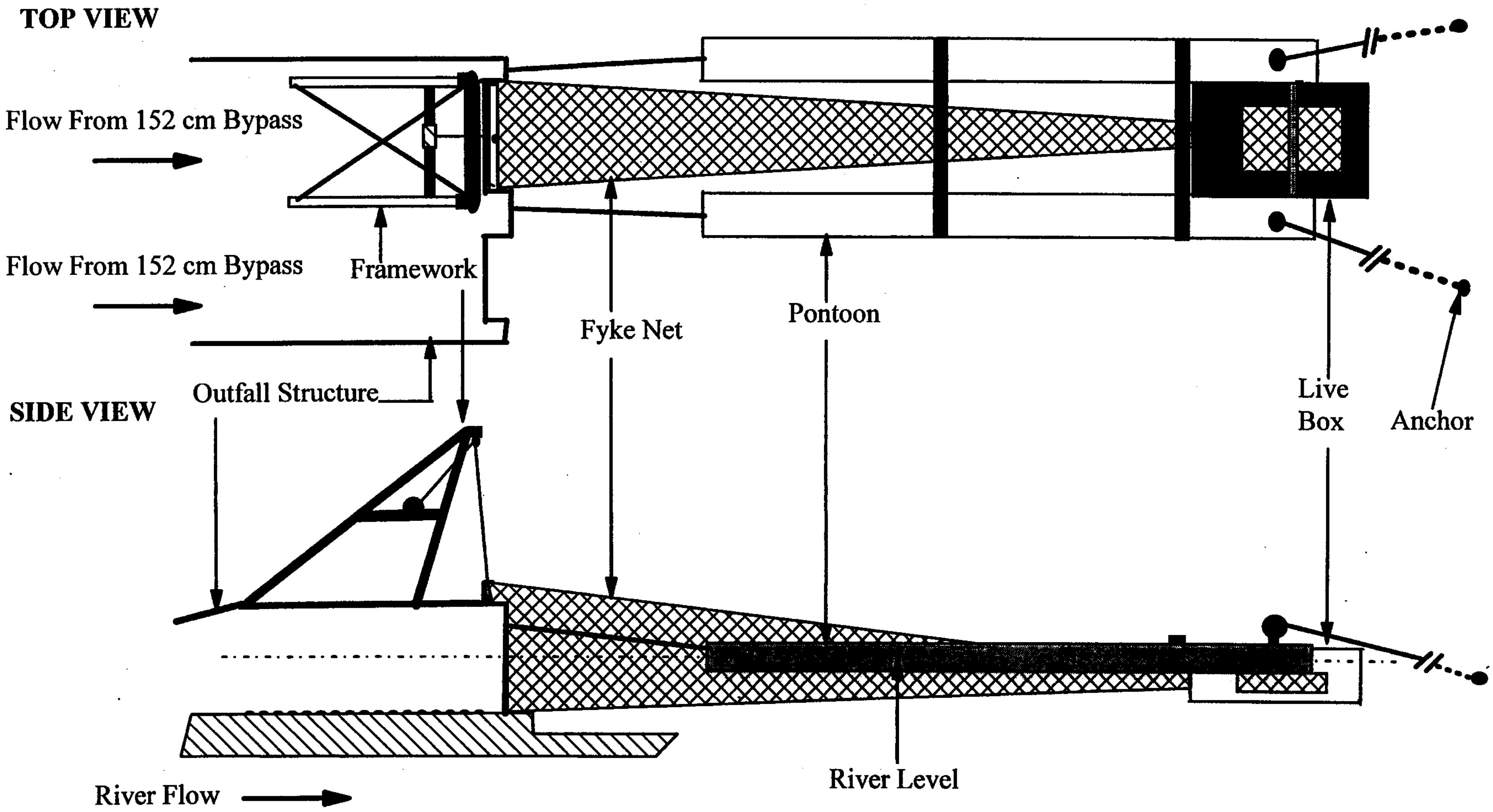
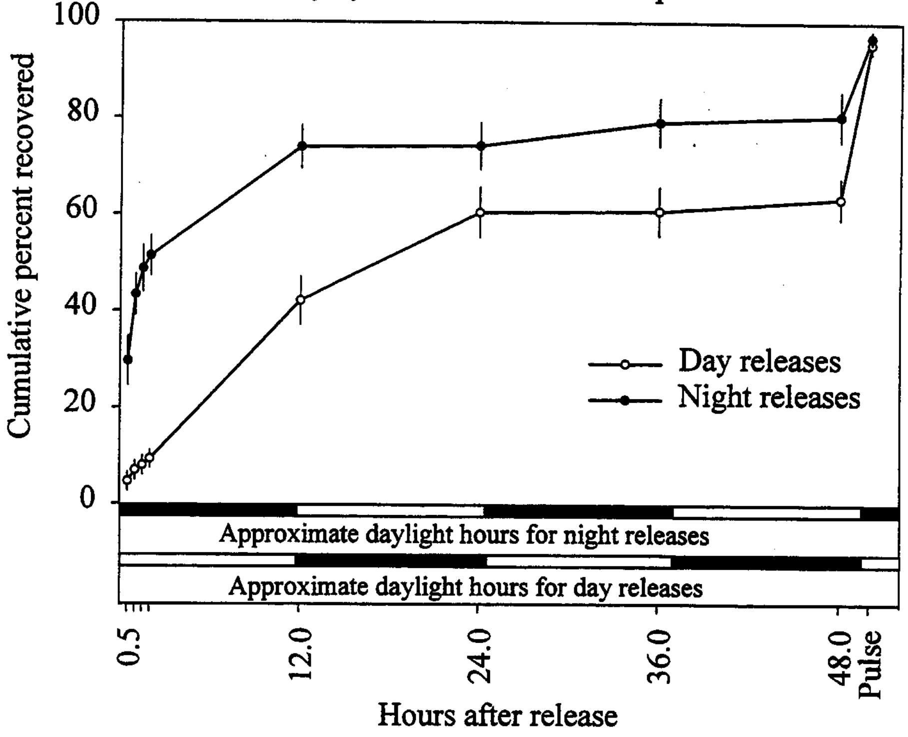


Figure 3. Top and side view of the fyke net and live box used to capture fish exiting the bypass outfall structure in the Sacramento River.

A. Chinook salmon recovery by release time in whole-plant trials.



B. Chinook salmon recovery by pump in whole-plant trials.

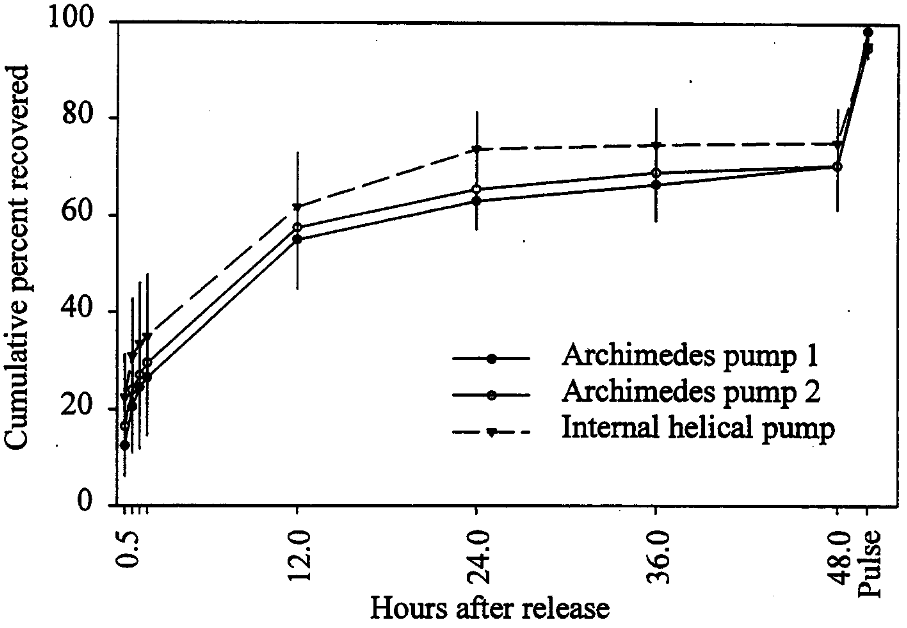


Figure 4. Mean cumulative percent of juvenile chinook salmon samples (50 per sample) recovered at Red Bluff Research Pumping Plant bypass outfall. Fish were enumerated at the outfall 0.5, 1, 1.5, 2, 12, 24, 36, and 48 h after insertion into the pumps, and following a ten-minute pulse of the bypass after 48 h. Recovery is grouped by (A) day versus night release, and (B) pump into which fish were inserted. Bars beneath graph A indicate approximate daylight (white) versus darkness (black) hours. Error bars indicate ± 1 SE.

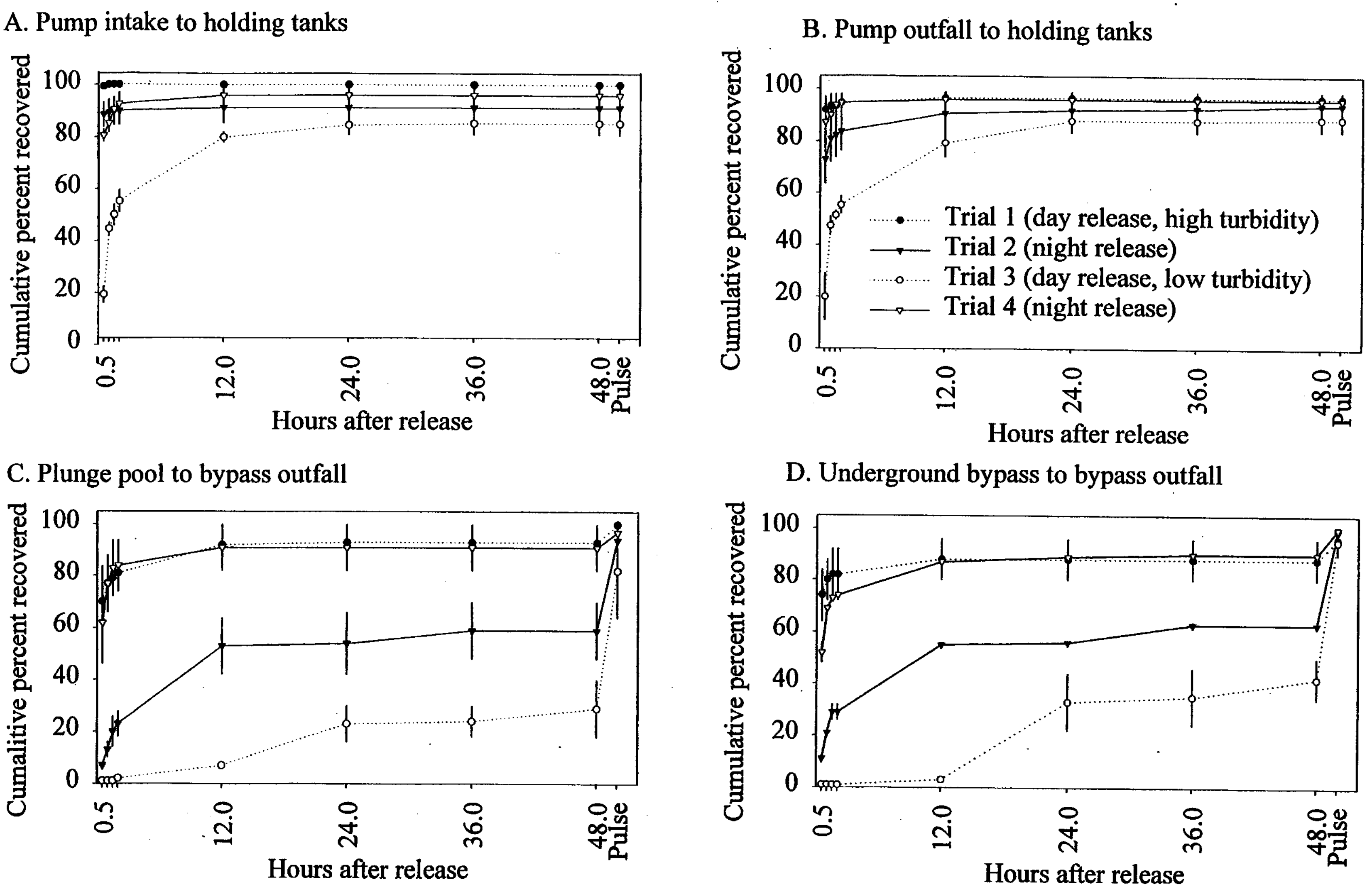


Figure 5. Mean cumulative percent of juvenile chinook salmon samples (50 per sample) recovered at Red Bluff Research Pumping Plant holding tanks or bypass outfall after release into four different sections of the plant. Fish were enumerated 0.5, 1, 1.5, 2, 12, 24, 36, and 48 h after release and following a ten-minute pulse of the bypass after 48 h. Error bars indicate ± 1 SE.

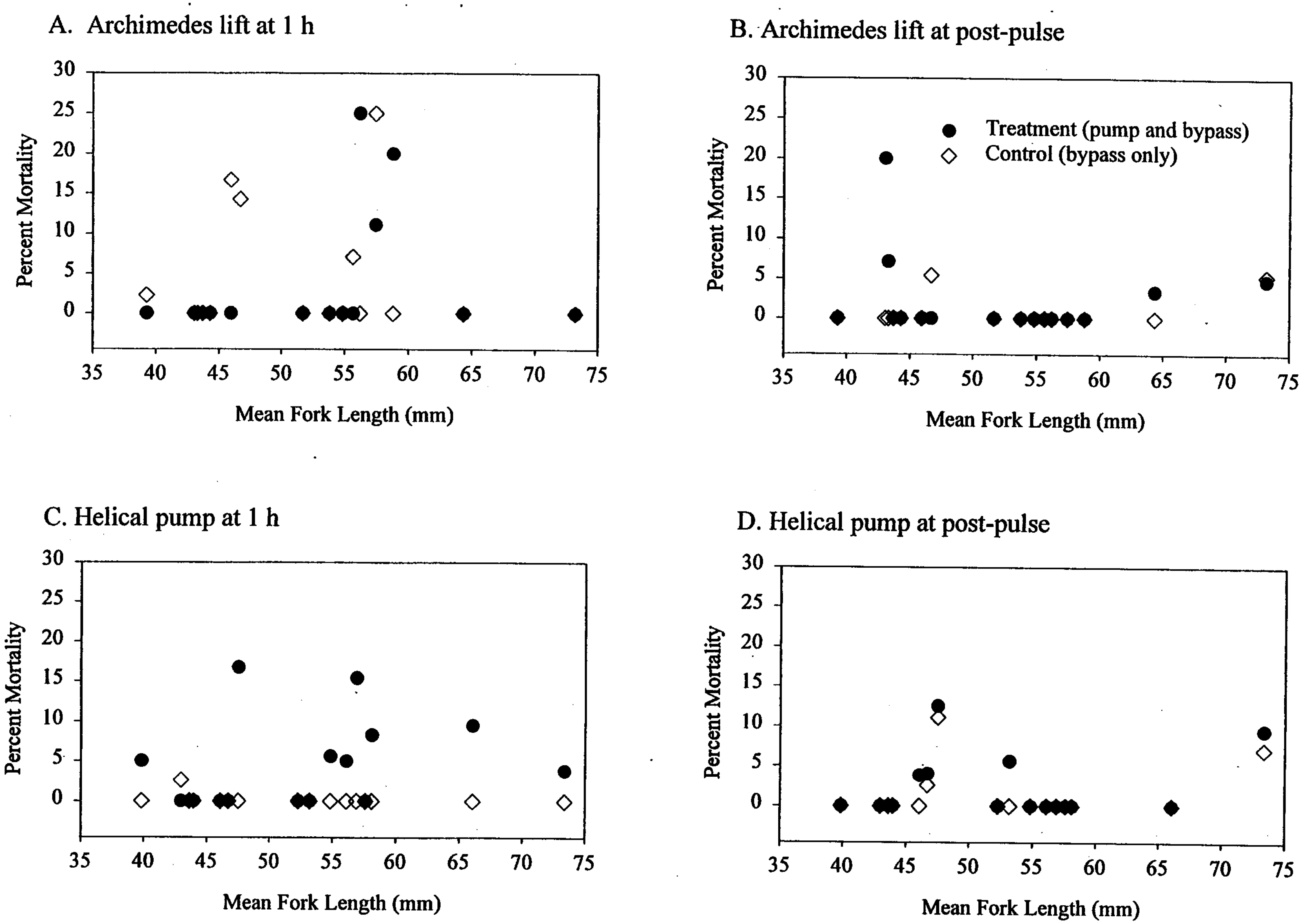


Figure 6. 96-h mortality (%) as a function of fork length for juvenile chinook salmon samples passed through pumps and bypasses, and collected at the bypass outfall 1 h after release and post-pulse. Sixteen trials were conducted.

Appendix 1. Characteristics of juvenile chinook salmon used in quality control assessments for each week of trials during the bypass survival experiment. Values for each criteria were compared with guidelines established to eliminate sub-standard groups of juveniles from the survival experiment. See Table 3 for the guidelines used.

Trial Dates	Chinook Salmon Run	Number of Fish Inspected	Mean Fork Length (mm)	Mean Weight (g)	Mean Condition Factor	Cumulative Percent Mortality[1]	% of Fish With >5% Descaling	% of Fish With Damage to Head, Eyes, Skin	% of Fish With >30% Fin Area Frayed
5/19/99	Fall	29	67	3.14	1.03	0.04	0	0	0
	Late-fall	30	40	0.52	0.78	0.10	0	0	0
5/26/99	Fall	30	72	3.86	1.01	0.0	0	3.3	0
5/27/99	Late-fall	30	42	0.65	0.87	0.10	0	0	0
6/01/99 6/03/99	Late-fall	26	48	0.94	0.85	0.20	0	3.8	0
6/07/99 6/10/99	Late-fall	29	47	1.04	1.00	0.08	0	0	0
6/22/99 6/24/99	Late-fall	30	54	1.57	0.97	0.06	6.7	0	0
6/28/99 7/01/99	Late-fall	30	55	1.84	1.11	0.07	0	0	3.3
7/06/99 7/08/99	Late-fall	29	60	2.11	0.95	0.12	0	3.4	3.3
7/12/99	Late-fall	30	61	2.21	0.96	0.10	0	0	3.3

[1] Cumulative mortality in each group of fish obtained from Coleman National Fish Hatchery from the time of delivery to Red Bluff to the time of use in an experiment.

Appendix 2. Repeated measures analyses of variance used to test for effects of pump and sunrise or sunset insertion on cumulative percent recovery (the dependent variable) of samples of 50 hatchery-reared juvenile chinook salmon inserted into Red Bluff Research Pumping Plant. Huynh-Feldt Epsilon corrected *P* values are reported for all within subject tests.

1. Whole-plant trials:

Between Subjects

Source	df	*P*
Pump	2	0.514
Sunrise/Sunset Insertion	1	0.003
Pump x Sunrise/Sunset Interaction	2	0.752
Error	6	-

Within Subjects

Source	df	*P*
Time	7	<0.001
Time x Pump Interaction	14	0.991
Time x Sunrise/Sunset Interaction	7	0.001
Time x Pump x Sunrise/Sunset Interaction	14	0.840
Error	42	-

2. Pumps to holding tanks:

Between Subjects

Source	df	*P*
Pump	2	0.595
Sunrise/Sunset Insertion	1	0.395
Pump x Sunrise/Sunset Interaction	2	0.904
Error	6	-

Within Subjects

Source	df	*P*
Time	7	0.006
Time x Pump Interaction	14	0.995
Time x Sunrise/Sunset Interaction	7	0.259
Time x Pump x Sunrise/Sunset Interaction	14	0.967
Error	42	-

Appendix 2.-- Continued.

3. Pump outfalls to holding tanks:

Between Subjects

Source	df	*P*
Pump	2	0.933
Sunrise/Sunset Insertion	1	0.441
Pump x Sunrise/Sunset Interaction	2	0.907
Error	6	-

Within Subjects

Source	df	*P*
Time	7	0.029
Time x Pump Interaction	14	0.996
Time x Sunrise/Sunset Interaction	7	0.254
Time x Pump x Sunrise/Sunset Interaction	14	0.987
Error	42	-

4. Plunge pools to river outfall:

Between Subjects

Source	df	*P*
Pump Bypass Line	2	0.541
Sunrise/Sunset Insertion	1	0.702
Pump Bypass Line x Sunrise/Sunset Interaction	2	0.961
Error	2	-

Within Subjects

Source	df	*P*
Time	7	<0.001
Time x Pump Bypass Line Interaction	14	<0.001
Time x Sunrise/Sunset Interaction	7	0.001
Time x Pump Bypass Line x Sunrise/Sunset Interaction	14	0.002
Error	14	-

Appendix 2. --Continued.

5. Bypass entrance to river outfall:

Between Subjects

Source	df	*P*
Pump Bypass Line	2	0.643
Sunrise/Sunset Insertion	1	0.778
Pump Bypass Line x Sunrise/Sunset Interaction	2	0.980
Error	2	-

Within Subjects

Source	df	*P*
Time	7	<0.001
Time x Pump Bypass Line Interaction	14	0.062
Time x Sunrise/Sunset Interaction	7	0.040
Time x Pump Bypass Line x Sunrise/Sunset Interaction	14	0.667
Error	14	-

6. Pumps to holding tanks versus pump outfalls to holding tanks:

Between Subjects

Source	df	*P*
Release site	1	0.863
Error	14	-

Within Subjects

Source	df	*P*
Time	7	<0.001
Time x Release Site Interaction	7	0.738
Error	98	-

Appendix 2.--Continued.

7. Plunge pools to river outfall versus bypass entrances to river outfall:

Between Subjects.

Source	df	*P*
Release site	1	0.988
Error	14	-

Within Subjects

Source	df	*P*
Time	7	<0.001
Time x Release Site Interaction	7	0.902
Error	98	-

Appendix 3. Data on number of juvenile chinook salmon in each release group and the number captured, number dead at capture, and number dead 96 h after capture for each capture time in trials conducted during the 1999 bypass survival experiment at Red Bluff Research Pumping Plant.

Date	Pump	Release Group	Run	No. Released	Capture Time	No. Captured	Cumulative % Captured	No. Dead @ Capture	% Mortality @ Capture	No. Taken For Injury Analysis	No. Assessed for 96-h Mortality	No. Dead @ 96 h	% Mortality @ 96 h
5/26/1999	Arch1	Treatment	Fall	50	1 h	27	54	0	0.0	3	24	2	8.3
5/26/1999	Arch1	Treatment	Fall	50	1 h + pulse	21	96	1	4.8	3	17	5	29.4
5/26/1999	Arch1	Control	Fall	50	1 h	29	58	0	0.0	3	26	0	0.0
5/26/1999	Arch1	Control	Fall	50	1 h + pulse	19	96	1	5.3	3	15	3	20.0
5/26/1999	Arch1	Treatment	Latefall	50	1 h	32	64	0	0.0	3	29	0	0.0
5/26/1999	Arch1	Treatment	Latefall	50	1 h + pulse	10	84	2	20.0	1	7	0	0.0
5/26/1999	Arch1	Control	Latefall	50	1 h	43	86	0	0.0	3	40	0	0.0
5/26/1999	Arch1	Control	Latefall	50	1 h + pulse	2	90	0	0.0	2	0		
5/27/1999	Arch1	Treatment	Latefall	50	1 h	31	62	0	0.0	3	28	2	7.1
5/27/1999	Arch1	Treatment	Latefall	50	1 h + pulse	14	90	1	7.1	3	10	0	0.0
5/27/1999	Arch1	Control	Latefall	50	1 h	28	56	0	0.0	3	25	0	0.0
5/27/1999	Arch1	Control	Latefall	50	1 h + pulse	16	88	0	0.0	3	13	0	0.0
6/3/1999	Arch1	Treatment	Latefall	50	1 h	16	32	0	0.0	5	11	0	0.0
6/3/1999	Arch1	Treatment	Latefall	50	1 h + pulse	28	88	0	0.0	5	23	0	0.0
6/3/1999	Arch1	Control	Latefall	50	1 h	18	36	0	0.0	5	13	1	7.7
6/3/1999	Arch1	Control	Latefall	50	1 h + pulse	22	80	0	0.0	5	17	0	0.0
6/7/1999	Arch1	Treatment	Latefall	49	1 h	2	4	0	0.0	2	0		
6/7/1999	Arch1	Treatment	Latefall	49	1 h + pulse	36	78	0	0.0	5	31	0	0.0
6/7/1999	Arch1	Control	Latefall	50	1 h	6	12	0	0.0	2	4	0	0.0
6/7/1999	Arch1	Control	Latefall	50	1 h + pulse	41	94	0	0.0	5	36	0	0.0
6/24/1999	Arch1	Treatment	Latefall	50	1 h	4	8	0	0.0	3	1	0	0.0
6/24/1999	Arch1	Treatment	Latefall	50	1 h + pulse	42	92	0	0.0	5	37	0	0.0
6/24/1999	Arch1	Control	Latefall	50	1 h	7	14	0	0.0	3	4	0	0.0
6/24/1999	Arch1	Control	Latefall	50	1 h + pulse	28	70	0	0.0	5	23	2	8.7
6/28/1999	Arch1	Treatment	Latefall	50	1 h	9	18	1	11.1	4	4	1	25.0
6/28/1999	Arch1	Treatment	Latefall	50	1 h + pulse	33	84	0	0.0	5	28	0	0.0
6/28/1999	Arch1	Control	Latefall	50	1 h	11	22	0	0.0	4	7	0	0.0
6/28/1999	Arch1	Control	Latefall	50	1 h + pulse	29	80	0	0.0	5	24	0	0.0
7/6/1999	Arch1	Treatment	Latefall	50	1 h	5	10	1	20.0	4	0		
7/6/1999	Arch1	Treatment	Latefall	50	1 h + pulse	36	82	0	0.0	5	31	0	0.0
7/6/1999	Arch1	Control	Latefall	50	1 h	2	4	0	0.0	2	0		
7/6/1999	Arch1	Control	Latefall	50	1 h + pulse	35	74	0	0.0	5	30	1	3.3
7/12/1999	Arch1	Treatment	Latefall	50	1 h	12	24	3	25.0	4	5	0	0.0
7/12/1999	Arch1	Treatment	Latefall	50	1 h + pulse	19	62	0	0.0	5	14	0	0.0
7/12/1999	Arch1	Control	Latefall	50	1 h	14	28	1	7.1	4	9	0	0.0

Appendix 3.--Continued.

Date	Pump	Release Group	Run	No. Released	Capture Time	No. Captured	Cumulative % Captured	No. Dead @ Capture	% Mortality @ Capture	No. Taken For Injury Analysis	No. Assessed for 96-h Mortality	No. Dead @ 96 h	% Mortality @ 96 h
7/12/1999	Arch1	Control	Latefall	50	1 h + pulse	27	82	0	0.0	5	22	0	0.0
5/19/1999	Arch2	Treatment	Fall	50	1 h	22	44	0	0.0	3	19	0	0.0
5/19/1999	Arch2	Treatment	Fall	50	1 h + pulse	29	102	1	3.4	3	25	0	0.0
5/19/1999	Arch2	Control	Fall	50	1 h	17	34	0	0.0	3	14	0	0.0
5/19/1999	Arch2	Control	Fall	50	1 h + pulse	31	96	0	0.0	3	28	0	0.0
5/19/1999	Arch2	Treatment	Latefall	50	1 h	45	90	0	0.0	3	42	0	0.0
5/19/1999	Arch2	Treatment	Latefall	50	1 h + pulse	3	96	0	0.0	1	2	0	0.0
5/19/1999	Arch2	Control	Latefall	50	1 h	43	86	1	2.3	3	39	0	0.0
5/19/1999	Arch2	Control	Latefall	50	1 h + pulse	6	98	0	0.0	3	3	0	0.0
6/1/1999	Arch2	Treatment	Latefall	45	1 h	32	71	0	0.0	3	29	0	0.0
6/1/1999	Arch2	Treatment	Latefall	45	1 h + pulse	7	87	0	0.0	3	4	0	0.0
6/1/1999	Arch2	Control	Latefall	50	1 h	44	88	0	0.0	3	41	0	0.0
6/1/1999	Arch2	Control	Latefall	50	1 h + pulse	4	96	0	0.0	3	1	0	0.0
6/10/1999	Arch2	Treatment	Latefall	49	1 h	0	0			0	0		
6/10/1999	Arch2	Treatment	Latefall	49	1 h + pulse	35	71	0	0.0	5	30	2	6.7
6/10/1999	Arch2	Control	Latefall	50	1 h	7	14	1	14.3	2	4	0	0.0
6/10/1999	Arch2	Control	Latefall	50	1 h + pulse	37	88	2	5.4	5	30	0	0.0
6/22/1999	Arch2	Treatment	Latefall	50	1 h	14	28	0	0.0	3	11	0	0.0
6/22/1999	Arch2	Treatment	Latefall	50	1 h + pulse	20	68	0	0.0	3	17	0	0.0
6/22/1999	Arch2	Control	Latefall	50	1 h	7	14	0	0.0	3	4	0	0.0
6/22/1999	Arch2	Control	Latefall	50	1 h + pulse	28	70	0	0.0	3	25	0	0.0
7/1/1999	Arch2	Treatment	Latefall	50	1 h	10	20	0	0.0	5	5	0	0.0
7/1/1999	Arch2	Treatment	Latefall	50	1 h + pulse	33	86	0	0.0	5	28	1	3.6
7/1/1999	Arch2	Control	Latefall	50	1 h	8	16	2	25.0	5	1	0	0.0
7/1/1999	Arch2	Control	Latefall	50	1 h + pulse	36	88	0	0.0	5	31	0	0.0
7/8/1999	Arch2	Treatment	Latefall	50	1 h	17	34	0	0.0	5	12	0	0.0
7/8/1999	Arch2	Treatment	Latefall	50	1 h + pulse	24	82	0	0.0	5	19	0	0.0
7/8/1999	Arch2	Control	Latefall	50	1 h	18	36	0	0.0	5	13	0	0.0
7/8/1999	Arch2	Control	Latefall	50	1 h + pulse	25	86	0	0.0	5	20	0	0.0
5/19/1999	Helical	Treatment	Fall	50	1 h	21	42	2	9.5	3	16	0	0.0
5/19/1999	Helical	Treatment	Fall	50	1 h + pulse	28	98	0	0.0	3	25	0	0.0
5/19/1999	Helical	Control	Fall	50	1 h	16	32	0	0.0	3	13	0	0.0
5/19/1999	Helical	Control	Fall	50	1 h + pulse	26	84	0	0.0	3	23	1	4.3
5/19/1999	Helical	Treatment	Latefall	50	1 h	40	80	2	5.0	3	35	0	0.0
5/19/1999	Helical	Treatment	Latefall	50	1 h + pulse	6	92	0	0.0	3	3	0	0.0

Appendix 3.--Continued.

Date	Pump	Release Group	Run	No. Released	Capture Time	No. Captured	Cumulative % Captured	No. Dead @ Capture	% Mortality @ Capture	No. Taken For Injury Analysis	No. Assessed for 96-h Mortality	No. Dead @ 96 h	% Mortality @ 96 h
5/19/1999	Helical	Control	Latefall	50	1 h	50	100	0	0.0	3	47	0	0.0
5/19/1999	Helical	Control	Latefall	50	1 h + pulse	4	108	0	0.0	3	1	0	0.0
5/26/1999	Helical	Treatment	Fall	50	1 h	26	52	1	3.8	3	22	1	4.5
5/26/1999	Helical	Treatment	Fall	50	1 h + pulse	21	94	2	9.5	3	16	3	18.8
5/26/1999	Helical	Control	Fall	50	1 h	33	66	0	0.0	3	30	0	0.0
5/26/1999	Helical	Control	Fall	50	1 h + pulse	14	94	1	7.1	3	10	1	10.0
5/26/1999	Helical	Treatment	Latefall	48	1 h	43	90	0	0.0	3	40	0	0.0
5/26/1999	Helical	Treatment	Latefall	48	1 h + pulse	4	98	0	0.0	3	1	0	0.0
5/26/1999	Helical	Control	Latefall	50	1 h	45	90	0	0.0	3	42	0	0.0
5/26/1999	Helical	Control	Latefall	50	1 h + pulse	3	96	0	0.0	3	0		
5/27/1999	Helical	Treatment	Latefall	50	1 h	40	80	0	0.0	2	38	0	0.0
5/27/1999	Helical	Treatment	Latefall	50	1 h + pulse	6	92	0	0.0	3	3	0	0.0
5/27/1999	Helical	Control	Latefall	50	1 h	39	78	1	2.6	3	35	0	0.0
5/27/1999	Helical	Control	Latefall	50	1 h + pulse	8	94	0	0.0	3	5	0	0.0
6/1/1999	Helical	Treatment	Latefall	50	1 h	37	74	0	0.0	3	34	0	0.0
6/1/1999	Helical	Treatment	Latefall	50	1 h + pulse	5	84	0	0.0	3	2	0	0.0
6/1/1999	Helical	Control	Latefall	50	1 h	42	84	0	0.0	3	39	0	0.0
6/1/1999	Helical	Control	Latefall	50	1 h + pulse	7	98	0	0.0	3	4	0	0.0
6/3/1999	Helical	Treatment	Latefall	50	1 h	16	32	0	0.0	5	11	0	0.0
6/3/1999	Helical	Treatment	Latefall	50	1 h + pulse	25	82	1	4.0	5	19	0	0.0
6/3/1999	Helical	Control	Latefall	50	1 h	21	42	0	0.0	5	16	0	0.0
6/3/1999	Helical	Control	Latefall	50	1 h + pulse	27	96	0	0.0	5	22	0	0.0
6/7/1999	Helical	Treatment	Latefall	50	1 h	8	16	0	0.0	1	7	0	0.0
6/7/1999	Helical	Treatment	Latefall	50	1 h + pulse	26	68	1	3.8	6	19	0	0.0
6/7/1999	Helical	Control	Latefall	50	1 h	2	4	0	0.0	2	0		
6/7/1999	Helical	Control	Latefall	50	1 h + pulse	39	82	1	2.6	5	33	1	3.0
6/10/1999	Helical	Treatment	Latefall	49	1 h	6	12	0	0.0	3	3	0	0.0
6/10/1999	Helical	Treatment	Latefall	49	1 h + pulse	32	78	4	12.5	5	23	1	4.3
6/10/1999	Helical	Control	Latefall	50	1 h	6	12	0	0.0	1	5	0	0.0
6/10/1999	Helical	Control	Latefall	50	1 h + pulse	27	66	3	11.1	4	20	0	0.0
6/22/1999	Helical	Treatment	Latefall	50	1 h	11	22	0	0.0	3	8	0	0.0
6/22/1999	Helical	Treatment	Latefall	50	1 h + pulse	23	68	0	0.0	3	20	0	0.0
6/22/1999	Helical	Control	Latefall	49	1 h	16	33	0	0.0	4	12	0	0.0
6/22/1999	Helical	Control	Latefall	49	1 h + pulse	20	73	0	0.0	3	17	0	0.0
6/24/1999	Helical	Treatment	Latefall	50	1 h	6	12	0	0.0	3	3	0	0.0

Appendix 3.--Contined.

Date	Pump	Release Group	Run	No. Released	Capture Time	No. Captured	Cumulative % Captured	No. Dead @ Capture	% Mortality @ Capture	No. Taken For Injury Analysis	No. Assessed for 96-h Mortality	No. Dead @ 96 h	% Mortality @ 96 h
6/24/1999	Helical	Treatment	Latefall	50	1 h + pulse	36	84	2	5.6	5	29	0	0.0
6/24/1999	Helical	Control	Latefall	50	1 h	1	2	0	0.0	1	0		
6/24/1999	Helical	Control	Latefall	50	1 h + pulse	36	74	0	0.0	5	31	0	0.0
6/28/1999	Helical	Treatment	Latefall	50	1 h	20	40	1	5.0	4	15	0	0.0
6/28/1999	Helical	Treatment	Latefall	50	1 h + pulse	22	84	0	0.0	5	17	0	0.0
6/28/1999	Helical	Control	Latefall	49	1 h	9	18	0	0.0	4	5	0	0.0
6/28/1999	Helical	Control	Latefall	49	1 h + pulse	30	80	0	0.0	5	25	1	4.0
7/1/1999	Helical	Treatment	Latefall	50	1 h	6	12	0	0.0	5	1	0	0.0
7/1/1999	Helical	Treatment	Latefall	50	1 h + pulse	36	84	0	0.0	5	31	0	0.0
7/1/1999	Helical	Control	Latefall	50	1 h	9	18	0	0.0	5	4	1	25.0
7/1/1999	Helical	Control	Latefall	50	1 h + pulse	29	76	0	0.0	5	24	0	0.0
7/6/1999	Helical	Treatment	Latefall	50	1 h	12	24	1	8.3	5	6	0	0.0
7/6/1999	Helical	Treatment	Latefall	50	1 h + pulse	27	78	0	0.0	5	22	0	0.0
7/6/1999	Helical	Control	Latefall	50	1 h	9	18	0	0.0	5	4	0	0.0
7/6/1999	Helical	Control	Latefall	50	1 h + pulse	32	82	0	0.0	5	27	0	0.0
7/8/1999	Helical	Treatment	Latefall	50	1 h	13	26	2	15.4	5	6	0	0.0
7/8/1999	Helical	Treatment	Latefall	50	1 h + pulse	25	76	0	0.0	5	20	0	0.0
7/8/1999	Helical	Control	Latefall	50	1 h	16	32	0	0.0	5	11	0	0.0
7/8/1999	Helical	Control	Latefall	50	1 h + pulse	25	82	0	0.0	5	20	0	0.0
7/12/1999	Helical	Treatment	Latefall	50	1 h	18	36	1	5.6	4	13	0	0.0
7/12/1999	Helical	Treatment	Latefall	50	1 h + pulse	27	90	0	0.0	5	22	0	0.0
7/12/1999	Helical	Control	Latefall	50	1 h	19	38	0	0.0	4	15	0	0.0
7/12/1999	Helical	Control	Latefall	50	1 h + pulse	25	88	0	0.0	5	20	0	0.0