EXPERIMENTAL RESULTS FROM PASSING JUVENILE CHINOOK SALMON THROUGH ARCHIMEDES LIFTS AND AN INTERNAL HELICAL PUMP AT RED BLUFF RESEARCH PUMPING PLANT, UPPER SACRAMENTO RIVER, CALIFORNIA

Red Bluff Research Pumping Plant
Report Series: Volume 9

Prepared By:

C.D. McNabb, Consultant
U.S. Bureau of Reclamation
86 Woodland Circle
Highlands Ranch, Colorado 80126-3115

S.M. Borthwick
U.S. Bureau of Reclamation
Red Bluff Fish Passage Program
P.O. Box 159
Red Bluff, CA 96080-0159

C.R. Liston
U.S. Bureau of Reclamation
Mid-Pacific Regional Office MP-400
2800 Cottage Way
Sacramento, CA 95825-1898

Prepared For:

U.S. Bureau of Reclamation
Mid-Pacific Region
Red Bluff Fish Passage Program
P.O. Box 159
Red Bluff, CA 96080-0159

August 2000

Disclaimer

The mention of trade names or commercial products in this report does not constitute endorsement of recommendation for use by the Federal Government.

The correct citation for this report is:

McNabb, C.D., S.M. Borthwick and C.R.Liston. 2000. Experimental results from passing juvenile chinook salmon through Archimedes lifts and an internal helical pump at Red Bluff Research Pumping Plant, Upper Sacramento River, California. Red Bluff Research Pumping Plant Report Series, Volume 9. U.S. Bureau of Reclamation, Denver, CO.

EXPERIMENTAL RESULTS FROM PASSING JUVENILE CHINOOK SALMON THROUGH ARCHIMEDES LIFTS AND AN INTERNAL HELICAL PUMP AT RED BLUFF RESEARCH PUMPING PLANT, UPPER SACRAMENTO RIVER, CALIFORNIA

U.S. Bureau of Reclamation
Red Bluff Fish Passage Program
P.O. Box 159
Red Bluff, California 96080-0159

Abstract. Experiments were conducted to assess mortality and injury to juvenile chinook salmon that passed through Archimedes lifts and an internal helical (Hydrostal) pump in the U.S. Bureau of Reclamation's Red Bluff Research Pumping Plant. Hatchery-reared chinook salmon were used in the experiments. Size-classes were chosen to cover the range of sizes of juveniles that outmigrate from spawning and rearing areas on the upper Sacramento River (34-74 mm fork-length). Twenty-seven trials were conducted in an experiment to compare pump-passage effects of the two Archimedes lifts. Forty trials were conducted in an experiment to compare effects of the Archimedes lifts and the internal helical pump. Approximately 128 chinook salmon were used in each trial. The two pumps used in each experiment were run concurrently during trials. *Treatment* samples were inserted in the intake of each pump. Fish in treatment samples passed through the pumps, and through their outfalls. *Control* samples were released just downstream of pump outfalls. Fish from all samples were recovered in holding tanks located on downstream fish-bypass channels.

Results of the experiments indicated that the Archimedes lifts and internal helical pump were fish-friendly. In the experiment comparing Archimedes lifts, a statistically significant pump-passage effect (treatment effect) on mortality was not detected for either lift. Mean total mortality (direct + 96-h delayed) in treatment samples and control samples used with both lifts was very low; in a range between 1.0% and 1.8%. Sub-samples of surviving post-passage fish were examined for descaling and other sub-lethal injuries. No significant pump-passage effect was observed for either lift for %-fish descaled, or %-fish with other injuries. There were no significant differences between the two lifts for %-total mortality, %-fish descaled or %-fish with other injuries. One of the two Archimedes lifts was selected randomly and run concurrently with the internal helical pump in a second experiment. A significant pump-passage effect on total mortality was not detected for the Archimedes lifts. A small, but highly significant ($P=0.001$), pump-passage effect on total mortality was obtained for the internal helical pump (2.5%). No significant pump-passage effects were observed for either type of pump for %-fish descaled, or for %-fish with other sub-lethal injuries.

Amount of descaling and types of other injuries noted on live post-passage individuals from treatment and control samples in both experiments were not debilitating; except for one juvenile salmon in the total of 267 that were examined (0.4%). Juveniles that died during plant-passage of treatment and control samples were also examined for descaling and other injuries. Multiple injuries were common on these fish. There were no indications that pump-passage caused any particular type of injury.

Turbulence at the head of channels that received the free-fall of discharges from the Archimedes lifts and the internal helical pump differed. Higher turbulence occurred at the outfall of the internal helical pump. A separate study was conducted to evaluate the role of the outfall in the elevated pump-passage effect on mortality that was observed with the internal helical pump. No significant difference was detected for mortality between chinook salmon in samples that were released through a port cut in the outfall structure just upstream of the pump's outfall, and samples that were released at the location downstream of the outfall that was used for control samples during the study reported here. The outfall, by itself, was not responsible for the elevated pump-passage effect on mortality that was obtained with the internal helical pump.

Table of Contents

List of Figures

List of Tables

List of Tables Continued.

Tables of the Appendix

Appendix of Tables Continued.

EXPERIMENTAL RESULTS FROM PASSING JUVENILE CHINOOK SALMON THROUGH ARCHIMEDES LIFTS AND AN INTERNAL HELICAL PUMP AT RED BLUFF RESEARCH PUMPING PLANT, UPPER SACRAMENTO RIVER, CALIFORNIA

INTRODUCTION

Between 1993 and 1995, the U.S. Bureau of Reclamation constructed a Research Pumping Plant on the Sacramento River at the agency's Operations and Maintenance Complex for Red Bluff Diversion Dam and the Tehama-Colusa Canal. The dam and pumping plant are located at km 391 (river mile 243) above San Francisco Bay near Red Bluff, California. The pumping plant was constructed to test new fish-protection technology that involved two Archimedes lifts, one internal helical pump, and vertical wedge-wire screens and fish-bypass structures that were located on each pump's effluent-stream (Figure 1). The project was a part of Reclamation's commitment to improve fish passage at Red Bluff Diversion Dam; particularly the passage of anadromous fishes, including adult and juvenile chinook salmon (*Oncorynchus tshawytscha*). Liston and Johnson (1992a, 1992b), working with fisheries biologists from state and federal agencies, developed a detailed plan for evaluating the engineering and fish-passage aspects of the plant. Implementation of their plan began shortly after construction was completed in June of 1995. Work presented in this report addresses one of the objectives of Liston and Johnson (1992b); namely, the objective that dealt with assessment of mortality and injury to young chinook salmon that passed through the Archimedes lifts and internal helical pump (Objective B).

McNabb et al. (1998) describe in detail the methods that were developed to assess mortality and injury that occurred among juvenile chinook salmon that were passed through pumps during the course of work presented in this report. These authors and Frizell and Atkinson (1999) provided descriptions of the design and operational features of the Red Bluff Research Pumping Plant, and two important support facilities that were put in place on the site at Red Bluff to accommodate the needs of these studies. One support facility was a wellwater laboratory in which hatchery-reared juvenile chinook were held while they awaited use in experiments. Wellwater that ran through holding tanks in this facility provided a relatively disease-free environment for the experimental fish. The second support facility was plumbed into the face of the pumping plant's intake structure on the Sacramento River. Just prior to their use in experiments, juvenile chinook salmon were acclimated in this facility to the riverine conditions they would encounter while passing through the pumping plant. Readers that find a need for more detailed information than is given below on facilities and experimental methods are referred to McNabb et al. (1998) and Frizell and Atkinson (1999).

While Archimedes lifts have been successfully employed worldwide in industrial applications for lifting water and slurries of various solids, installations of large lifts (11.58 m, 38 ft long; 3.05 m, 10 ft diameter) of the type used at Red Bluff had not previously been made. The lifts at Red Bluff had revolving barrels containing three separate flights, rotating seals at fixed intakes, fluctuating internal water-surface elevations, and they operated at a relatively high rotational speed 26.5 rev/min (Frizell and Atkinson 1999). The lifts deliver water at 2.4-2.5 m^3/s (85-90 cfs). Week et al. (1993), used a prototype Archimedes lift built for demonstration, and showed that juvenile steelhead (*Oncorhynchus mykiss*), chinook salmon (*O. tshawytscha*) and coho salmon (*O. kisutch*) could pass through such lifts without experiencing significant direct or delayed mortality. The lift that was used in their study was 3.05 m (10 ft) long and 0.76 m (2.5 ft) diameter, and delivered water at 0.02-0.03 m^3/s (0.62-1.14 cfs).

The internal helical pump installed at Red Bluff was the largest of its kind ever built. Its inlet and outlet diameters were 0.91 m (3 ft). During work for this report the pump was run at 350-375 rev/min and delivered water in the range of 2.3-2.8 m^3/s (80-100 cfs). The predecessor of the internal helical pump (Hydrostal pump) at Red Bluff was developed several decades ago in response to the need of the fishmeal industry of coastal Peru for rapid off-loading and delivery of ocean harvest to processing plants (Stahle and Jackson 1982). Because of relatively benign patterns of flow through the enclosed helical impeller, the pump was also suitable for passing delicate fruits and various types of vegetables. Reports in the literature dealing with laboratory-scale studies (Patrick and Sim 1985, Rogers and Patrick 1985), and field studies (Patrick and McKinley 1987) have shown that the frequency of mortalities varied among species of fish passed through internal helical pumps, but tended to be low. In contrast to the internal helical pump at Red Bluff, pumps used in these studies were small with intake apertures of 15-25 cm (6.0-9.9 in), and discharge of water at 0.2 m^3/s (0.62 cfs) or less. Mortalities of 0-5% were observed in these studies at pump operating speeds ≥450 rev/min.

Information in the literature just cited, as well as experience in fish hatcheries and the aquaculture industry with safe fish-passage through small centrifugal pumps (Baldwin 1973), indicated that the two types of pumps installed at Red Bluff would indeed be fish-friendly. The purpose of work for this report was to examine that premise, and to compare the two types of pumps in regard to safe passage for juvenile chinook salmon. When experimental trials were begun in March of 1997, various features of the pumping plant were in late phases of engineering modifications aimed at improving as-built performance, including performance of the pumps themselves. To achieve the purpose of the study, two experiments were undertaken, rather than just one. This approach provided the flexibility to accommodate periodic downtime for improvements on individual pumps, and flexibility to accommodate the logistics involved in properly handling experimental fish with available fisheries facilities and personnel. Both experiments consisted of repetitious trials in which samples of experimental fish were passed concurrently through two operating pumps. The two types of pumps in the plant were compared directly in one experiment in which one of two Archimedes lifts was selected randomly, and it and the internal helical pump were operated simultaneously during fish-passage trials (Arch-helical experiment). In a second experiment, samples of experimental fish were passed during trials through each of the two Archimedes lifts (Arch-Arch experiment). The intent of the Arch-Arch experiment was to obtain information on experimental error introduced to the Arch-helical experiment by the random selection of one of two Archimedes lifts for use in that experiment.

METHODS

Studies of chinook salmon that died or sustained sublethal injuries as a result of passage through pumps at Red Bluff were made using hatchery-reared juvenile chinook as surrogates for riverine chinook that were entrained from the Sacramento River during routine pumping operations. Trials for this work were conducted during the winter, spring and early summer months of 1997, 1998 and 1999. In each of these years, trials were put on-hold during episodes of high runoff when the elevation of the Sacramento River at Red Bluff exceeded the elevation at which the pumping plant could operate (Frizell and Atkinson 1999). When the pumping plant was operable in these years, the Archimedes lifts were generally up and running and available for use. Trials for the experiment to compare the effects of passage through the Archimedes lifts were conducted in 1997 and 1998. However, the internal helical pump was unavailable for use when the pumping plant was operable during periods in the winter, spring and early summer of 1998. Because of this, trials to compare the effects of passage through the Archimedes lifts and the internal helical pump were begun in 1997 and completed in 1999.

Pre-Trial Handling

Juvenile chinook salmon used in trials were obtained periodically from the U.S. Fish and Wildlife Service at Coleman National Fish Hatchery near Anderson, California. Individual lots, each consisting of a few thousand juveniles, were removed from the hatchery's raceways and transferred to tanks in the project's wellwater facility at Red Bluff. During the move to Red Bluff, and throughout various stages of the experiments that required moving the fish, they were immersed in solutions of salt and Kordon's PolyAqua® at concentrations of 5-7 g/L and 0.13 ml/L respectively (Vogel and Marine 1995). When netting was required, the fish were out of water no longer than several seconds. These steps were taken to minimize stress and the occurrence of injuries (Nikinmaa et al. 1983, Moyle and Cech 1988, Summerfelt and Smith 1990, Wedemeyer 1992). Quality control criteria were also put in place to assure that only healthy and robust groups of hatchery-reared juveniles were used for experimental work. These criteria are shown in Table 1. It can be noted in Table 1, that chinook salmon in lots from the hatchery that showed symptoms of disease and required therapeutic treatment at Red Bluff were not used in trials. Lots with a history of excessive mortalities during pre-trial holding periods were also excluded from use.

As preparations for trials of pump-passage were begun, a trial-group of several hundred juvenile chinook salmon was selected from among all of the juveniles that were held in the wellwater facility at Red Bluff. The selected trial-group was transferred to a separate tank in the facility. Thirty individuals were then removed at random from the trial-group. Results of microscopic examination of fish in the sub-sample for abnormalities or injuries were compared to quality control criteria listed in Table 1. Confinement to raceways at Coleman National Fish Hatchery, or tanks in the wellwater facility at Red Bluff, tended to result in fraying at the edges of fins (splitting between fin rays) and erosion at the edges of opercula. Trials groups of experimental fish that had these rearing-related abnormalities were not excluded from use in experiments unless they had injuries of other kinds on the head, eye, body or fins (Table 1).

The %-frequency of fish with descaling, and the extent of descaling on affected individuals, was estimated for each trial-group by examining juveniles in the sub-sample of 30 fish. Examinations were made using a binocular microscope at magnifying powers between seven and ten. At these magnifications, individual scales on chinook salmon in trial-groups with mean fork-length ≥55 mm were seen to be well developed with distinct margins. Areas of scaled surfaces from which scales were missing were easily distinguished on these fish. Examinations showed that the frequency of individuals with patches of missing scales was high (≥ 40%). Patches of missing scales covered 1-5% of the scaled surfaces on these fish (Appendix Tables A-4 and A-9). These occurrences of missing scales were taken as a normal, pre-trial background condition for salmon in trial-groups with mean fork-length ≥55 mm. In contrast, scales on juvenile salmon from trial-groups with mean fork-length <55 mm were small, transparent and poorly developed. Attempts to reliably estimate the area over which individual scales were missing on these smaller fish were not successful.

Given the conditions just described, the extent of descaling on fish used during experimental trials was estimated in the following manner. Descaling assessments were based on the losses of scales associated with superficial abrasions (scrapes) that occurred on scaled surfaces of experimental fish as a result of handling or passage through the pumping plant. The occurrence and extent of these abrasions was readily detected on small chinook salmon (<55 mm fork-length), as well as on those in larger size-classes. The scaled surfaces on each side of experimental fish were visually subdivided into three zones. A caudal zone included the area above and below the lateral line and posterior to the posterior insertion of the dorsal fin. A dorsal zone included the area anterior to the caudal zone and above the lateral line, while an abdominal zone included the area anterior of the caudal zone and below the lateral line. These zones were also used for descaling assessments by Kostecki et al. (1987). Measurements of scaled surfaces on juvenile chinook salmon used in trials at Red Bluff showed that, on the average, the caudal zone covered approximately 33% of the area of total scaled surface on one side of the fish, while the dorsal zone covered 25% of the scaled surface, and the abdominal zone covered the remaining 42%. The percentage of each zone that was abraded on each side of the fish was estimated visually and recorded. These percentages were multiplied by the mean percentage of total scaled surface that each zone occupied. The resulting products for all six zones on a fish were then summed to obtain the fraction of each fish's total scaled surface that was descaled.

Measurements of weight and length were made on each of the juvenile chinook in each sub-sample of 30 that was taken from a trial-group. These measurements were used to calculate a condition factor (*k*) where,

$$k = W/L^3 \times 100, \quad (1)$$

W was wet weight in grams, and L was fork-length in centimeters (Bagenal and Tesch 1978, Moyle and Cech 1988). A mean *k* was obtained as an estimate of the robustness of individuals in trial-groups. Condition factors calculated in this manner are known to change during the ontogeny of fishes (Cone 1989), including chinook salmon. Values of *k* increased as fork-length of juvenile chinook salmon used in experiments at Red Bluff increased. This growth-related increase in *k* is reflected in the two values for *k* that are listed in Table 1 for limiting the use of trial-groups in experiments. Working in holding tanks at Red Bluff, Petrusso (1998) put small (44 mm mean fork-length) and large (68 mm mean fork-length) juvenile salmon from Coleman National Fish Hatchery on different rations, including 0-ration. Over 14-day intervals, *k* decreased for fish on 0-ration as they lost weight and became listless. The specific values for mean *k* listed as guidelines in Table 1 were taken from measurements of *k* and observations of fish behavior during the course of that work. Petrusso (ibid.) also obtained information on the distribution of *k* among juvenile chinook salmon in the Sacramento River where less robust individuals were presumably selected against. Data were obtained on fork-length and *k* for small (≤45 mm) and larger (≥46 mm) individuals in a total of 1204 fall-run chinook salmon. Riverine fish that were less robust than required by the limits for fork-length and *k* set in Table 1 were rare. They made up only 2% of fish ≤45 mm, and 1.3% of fish ≥46 mm.

During the Arch-Arch experiment, mean *k* for fish in six trial-groups with ≤45 mm fork-length ranged from 0.81 (SD 0.05) to 0.89 (SD 0.05). Juvenile chinook in five trial-groups with mean fork-length ≥46 mm had *k*-values ranging from 0.86 (SD 0.10) to 0.96 (SD 0.07). In the Arch-helical experiment, mean *k* for fish in four trial-groups with ≤45 mm fork-length ranged from 0.73 (SD 0.07) to 0.88 (SD 0.08). Juvenile chinook in ten trial-groups with mean fork-length ≥46 mm had *k*-values ranging from 0.87 (SD 0.05) to 1.18 (SD 0.08).

On the basis of results from examination of 30 individuals from each trial-group, juvenile chinook salmon used in trials for the Arch-Arch and Arch-helical experiments met all quality control requirements shown in Table 1. Following assessments for quality control, fish in trial-groups were marked. Marking was carried out in the wellwater facility. A dye, Bismarck brown-Y, was used (Mundie and Taber 1983), or small clips were made on the margins of selected fins. Markings provided a way to distinguish experimental surrogates from juvenile chinook salmon that were entrained from the Sacramento River during trials, as well as to identify members of individual samples that were released in trials. After marking, fish in each trial-group were moved from the wellwater facility to the project's riverwater facility. There, they were released in flow-through holding tanks to begin acclimation to water quality conditions that they would encounter in the pumping plant. Prior to use in trials, these juveniles were separated into individual samples by using live-cages. Live-cages were fabricated from PVC cylinders that were 25.4 cm (10 in) in diameter. Cages were 40.6 cm (16 in) long and covered on each end with a plastic plate that had 3.2 mm (0.13 in) perforations. Perforations allowed for the circulation of water through the cages during holding periods. The plate on one end of each cage was removable to allow access. Live-cages were numbered so that individual samples of juvenile chinook could be tracked throughout pump-passage trials.

Conducting Trials

Twenty-seven trials were conducted for the experiment in which the two Archimedes lifts were compared for passage-related mortality and injury. Thirteen of these trials were done in 1997; the remaining 14 were completed in 1998. A total of 40 trials were conducted in the experiment designed to compare the effects of passage through the Archimedes lifts and the internal helical pump. Twenty-five of these trials were done in 1997; 15 were done in 1999. For the Arch-Arch experiment, the two Archimedes lifts were run simultaneously. One of the Archimedes lifts, selected randomly, and the internal helical pump were run simultaneously for trials in the Arch-helical experiment. In both experiments, the Archimedes lifts were run at 26.5 rpm and discharged an average of 2.5 m^3/s (89 cfs). In the Arch-helical experiment, the internal helical pump was run at a speed of about 360 rpm. The pump had an average discharge of 2.6 m^3/s (93 cfs).

Releasing Samples in the Pumping Plant

Four samples of juvenile chinook were used in each trial. The standard number of fish per sample was 34. On relatively rare occasions, that number was somewhat less. At the start of a trial, samples of fish were carried to the pumping plant in fabricated devices called inserters. Each inserter was made by removing the bottom of a 19 L (5 gal) plastic carboy. The carboy was then inverted. A flexible rubber plug was used to cover the interior portion of the carboy at its mouth. A sling was fit around the exterior of the carboy. A snap-clamp attached to the sling held a line that was used to lower the carboy to the water-surface at designated fish-release points in the plant. A second line was attached to the rubber plug so that it could be removed to release juvenile chinook into the water. In preparation to receive a sample of fish, an inserter with plug in place was filled to one-half capacity with the salt and PolyAqua® solution at concentrations of 5-7 g/L and 0.13 ml/L respectively. A numbered live-cage holding a sample of chinook salmon was then selected at random from among those cages with juveniles that had undergone pre-trial acclimation to riverwater. The lid on the live-cage was removed and the fish were poured gently into an inserter. The inserter was placed in a 19 L (5 gal) plastic bucket and the sample of fish was transported from the riverwater facility to the pumping plant.

Two of the four samples of juvenile chinook used in a trial were released in the intakes of the two pumps that were used for the Arch-Arch and Arch-helical experiments. These two samples were designated *treatment* samples. Release of treatment samples was carried out by using vertical standpipes that made unions with the intake pipe of each pump in the plant (Figure 1). Standpipes were 30 cm (12 in) in diameter and extended from the top of the pumping plant's intake structure downward for a distance of 11.9 m (38 ft). They opened into the intake pipe of each pump approximately 2 m (6.6 ft) upstream from where intake pipes connected to pump chambers. Elevation of the surface of water in the standpipes fluctuated with elevation of the water surface in the nearby Sacramento River. Calculated velocity of flow in the intake pipes at junctions with standpipes was about 2.4 m/s (8 ft/s).

When releasing a treatment sample, juvenile chinook in an inserter were lowered to the water surface in a standpipe. The plug in the mouth of the inserter was retrieved, and the juveniles were freed as the inserter was lifted from the standpipe. A crowder was then lowered in the standpipe to the point of junction between it and the pump's intake line. Crowders were made from sections of PCV pipe that were 41-46 cm (16-18 in) long and 25 cm (10 in) in diameter. The lower end of a crowder was covered with a perforated plastic plate. The crowders were weighted to promote their downward movement through the water in the standpipes. Neoprene rings were attached to upper and lower rims of crowders to make them fit snugly within standpipes.

In addition to treatment samples, two samples of juvenile chinook were used during each trial as controls. *Control* samples were released from inserters at the surface of the water at a point just downstream from the fallout of the discharge from each of the two pumps used in a trial. Just prior to release of each treatment and control sample, two juvenile chinook were removed from inserters at random. These juveniles were euthanized in situ using a 200 mg/L solution of Finquel® that was buffered with an equal weight of sodium bicarbonate. They were then placed on ice. Later, these juveniles were examined microscopically for descaling and other injuries in order to make estimates of the percent-frequency of pre-passage individuals that had these types of abnormalities. The amount of descaling and the types of other injuries that occurred on affected individuals were also recorded.

Recovering Samples of Released Fish

Downstream pathways along which juvenile chinook salmon from treatment and control samples moved are shown in Figure 1. Water discharged from each of the Archimedes lifts fell into a sluiceway that led to a downstream screening facility. Discharge from the internal helical pump also fell into a sluiceway upstream of a screening facility. Its sluiceway had the same configuration as those of

Archimedes lifts, but greater turbulence occurred at the fallout of this pump. The screening facility for each pump had a pair of vertical, wedgewire screens arranged in a chevron pattern. The screens were approximately 9.1 m (30 ft) in length and had 2.4 mm (0.09 in) gaps. Mechanically operated brushes ran back on forth over the full depth of the stainless steel screens to dislodge debris. The screens separated experimental fish from water delivered to the forebay of the Tehama-Colusa Canal. Screens passed approximately 90% of pumped water to the forebay of the canal, while the remaining portion (about 10%) moved into channels at the head of each pump's fish bypass system.

Fish tanks located downstream of screens were used to recover juvenile chinook salmon in samples that were released. To do that, a ramp was lowered into the fish bypass channel of each pump to intercept the total flow (Figure 1). The face of each ramp was covered with stainless steel wedgewire screening (2.4 mm, 0.09 in gap). Weirs beneath the ramps were adjusted to force a portion of the flow in bypasses along the top of the ramps. When encountering a ramp, experimental salmon moved up it, and then dropped between widely spaced bars on a debris-separator box that was located at the distal end of each ramp. From debris-separator boxes, fish in samples moved downstream in the remaining fraction of a pump's discharge and entered one of two holding tanks. The holding tanks were operated in a flow-through mode. They discharged water back into the bypass from which it came. In order to retain experimental fish, tanks were fitted with delta weight, knotless nylon nets with 3.2 mm (0.13 in) or 4.7 mm (0.19 in) mesh.

Holding tanks were tended following the release of each of the four samples used in each trial. Juveniles in samples were removed from tanks with handnets, and placed in the live-cages that carried each sample's identification number. These live-cages were submersed in 19 L (5 gal) plastic buckets that held riverwater. Collections were made from holding tanks at intervals of 10, 20 and 30 minutes post-release, and the number of experimental fish taken at each interval was recorded. Immediately after each 30-minute collection, juveniles lingering in the channel between a debris-separator box and a holding tank were gently swept into the tank. Individuals collected at *sweep* were counted, and placed in the live-cage with their cohort. Dead individuals in each sample were then removed and counted. Following that, two live juveniles were removed from each sample. They were euthanized in a solution of 200 mg/L Finquel® that was buffered with an equal weight of sodium bicarbonate, placed on ice, and later examined microscopically. Results of examinations with these fish were used to estimate the percent-frequency of post-passage individuals with descaling and other sublethal injuries. The extent of descaling and the types of other injuries were recorded as well.

During some trials included in this report, less than 100% of fish released in a treatment or control sample were recovered in a 30-minute interval and the subsequent sweep. The number of individuals not recovered in this time-frame was entered in the record under the designation of *missing*. All, or some fraction of missing individuals, were recovered from holding tanks while conducting trials that followed one another in a single series, or while making collections of fish at the subsequent sunrise or sunset for 24-h studies of entrainment from the Sacramento River that were underway concurrently (Borthwick et al. 1999). Because experimental chinook had been marked with Bismarck brown-Y or fin-clips, juveniles arriving late could be associated with particular samples. The number of chinook recovered after sweep was entered in the record of the appropriate sample under the designation of *late*. The total number of dead individuals among those collected from each sample at 30 minutes plus sweep and late was noted in the record under the heading of *direct mortalities*. Injuries that each of these dead fish had were noted.

On occasion, juveniles released in a sample were never recovered in a holding tank. The number of these individuals in each sample was entered in the record under the designation of *holdouts*. Extensive efforts were undertaken in 1997 and 1998 to recover *holdouts*. That work indicated that *holdouts* avoided recapture by lingering near pump outfalls or in screening facilities in the plant for periods of time longer than those periods used for recovering late individuals.

The Environment During Trials

During preliminary work conducted in 1995 and 1996, data collected in a manner similar to that described above showed that there was a difference between night and day travel-times from points where samples of juveniles were released to holding tanks where they were recovered (McNabb et al. 1998). In the spring of 1997, standardized release and recapture techniques were used to illustrate this difference. Results of that work are given in Table 2. Data in Table 2 show that experimental fish tended to linger upstream of holding tanks to a greater degree in daylight than at night. Late arriving individuals and holdouts were approximately three times more common when samples were released in daylight. Results of studies on entrainment of juvenile chinook salmon from the Sacramento River (McNabb et al. 1998, Borthwick et al. 1999) also showed that the great majority (73%-81%) of riverine chinook salmon entered holding tanks in the pumping plant at night. As a result of these observations, and in order to facilitate high percentage post-passage recovery of juveniles in a relatively short period of time, all trials for experiments in this report were conducted at night.

Several measurements were made during trials to describe characteristics of the environment into which experimental fish were released. A YSI® Model 55 meter was used to obtain dissolved oxygen concentrations and water temperature. Estimates of total dissolved gas saturation were obtained using a Sweeney® Model DS1-A saturometer. Turbidity in the water was taken from the continuous record of an HF Scientific® turbidimeter operated in a dedicated flowstream from an intake on the face of the pumping plant's intake structure.

Intakes of pumps at Red Bluff drew water from the bottom of the Sacramento River. With it came items of debris that could pass through the plant's trash racks. Small sticks, leaves of deciduous trees, fragments of aquatic macrophytes and filamentous algae were common components of entrained debris. While episodes of gravel entrainment occurred during seasons of high discharge in the Sacramento River, gravel entrainment was not observed during trials.

Estimates of quantities of debris coming into the pumping plant were made during nights on which a total of 35 trials in the Arch-Arch and Arch-helical experiments were conducted. Amounts of debris that accumulated in holding tanks between sunset and sunrise were measured. Wet debris was removed from holding tanks at sunrise with dip-nets. Water was drained from it. Debris was transferred to a 19 L (5 gal) bucket that had been filled to a marked waterline. A measurement was made of the difference between the marked waterline and the waterline after addition of debris. This measurement was used with area of the bucket's cross section to estimate the volume of debris. The volume of debris (cc) was used with records of time between sunset and sunrise to obtain an estimate of cubic centimeters of debris that accumulated in holding tanks per hour. Volumes of debris that accumulated in fish holding-tanks per hour were used as an index of the abundance of debris that accompanied experimental fish as they moved from points of their release into holding tanks. The relationship between that index (cc/h debris) and percent-frequency of mortality among fish in samples used for trials was examined using regression analysis.

Post-Trial Handling

At the end of each trial, four numbered live-cages were on hand. Two of these held fish from treatment samples; one from each of two pumps used in the trial. The other two live-cages held control samples. Each cage contained the number of live juvenile chinook that were collected from holding tanks at 30 minutes post-release plus the following sweep, minus two post-passage fish that were removed for tallies of descaling and other injuries. The four live-cages were transported from the pumping plant to the project's nearby riverwater facility. There, live-cages were submersed in holding tanks in an arrangement that assured good circulation of water through perforated plates on their endwalls. The live-cages were opened daily over the following 96 hours, and tallies were made of dead individuals. These individuals were reported as *delayed* mortalities. Late individuals belonging to samples were also held and observed daily to the end of the 96-h period. Mortalities that occurred among late individuals were included in reports of delayed mortalities.

Statistical Treatments

Null hypotheses for the Arch-Arch and Arch-helical experiments were as follows:

I. Archimedes-1 and Archimedes-2 differed in regard to the percentages of juvenile chinook salmon that experienced mortalities, descaling or other sub-lethal injuries as a result of pump-passage.

II. The Archimedes lifts and internal helical pump did not differ in regard to the percentages of juvenile chinook salmon that experienced mortalities, descaling or other sub-lethal injuries as a result of pump-passage.

Null hypotheses were addressed in the following manner. Numerical data obtained for treatment and control samples used in the experiments were expressed as percentages of affected fish per trial for direct mortality, delayed mortality, fish descaled and fish with other sub-lethal injuries. Percentages of direct mortality and percentages of delayed mortality were summed for each trial to yield estimates for total 96-h mortality. Percentages of total 96-h mortality, fish-descaled, and fish-injured per trial were compared for treatment and control samples that were used with each of two pumps during each experiment. Multi-response permutation procedures (MRPP) were the statistical methods used to make comparisons (Mielke at al. 1981, Mielke 1984, Mielke 1985). Probability (P) $\leq$0.05 was taken to indicate a statistically significant difference between treatment and control samples. A pump-passage effect (treatment effect) was indicated where means for treatment samples were greater than means for control samples, and the difference between the treatment samples and control samples was statistically significant. Pump-passage effects of the two pumps used in each experiment, or lack thereof, were examined to detect differences between pumps. This was done by comparing data from treatment samples used with each lift in the Arch-Arch experiment, and data from control samples used with each lift. In like manner, data were compared for treatment samples used with each type of pump in the Arch-helical experiment, as well as data from control samples used with each type of pump.

RESULTS

Environmental Conditions During Pump-Passage Trials

Trials for experiments on pump-passage were conducted in winter, spring and early summer of 1997, 1998 and 1999. During each trial, measurements were made on environmental features of riverwater in which chinook salmon moved from points of their release to holding tanks where they were collected. During the Arch-Arch experiment, water temperatures ranged from a low of 11.1°C in trials conducted in March to 13.6°C during trials in May. The range for dissolved oxygen concentration was 8.2-10.7 mg/L. The range for total gas saturation was 99.8-104.6%. Turbidity ranged from 8.8 NTU to 37.7 NTU. Mean turbidity was 17.9 NTU with SD of 8.5 units. These conditions were much the same during trials for the Arch-helical experiment. Water temperatures ranged from a low of 8.4°C during trials in January to 14.0°C during trials in June. The range for dissolved oxygen concentration was 9.2-11.9 mg/L. Because of an instrument failure in 1999, data for total gas saturation during the Arch-helical experiment were available only for trials conducted in 1997. The range for total gas saturation in 1997 was 99.0-105.6%. During trials in the Arch-helical experiment in 1997 and 1999, turbidity ranged from 3.8

NTU to 38.1 NTU. The mean was 10.7 NTU with SD of 7.0 units. There were no indications in these data that water temperature, dissolved oxygen concentration, total gas saturation or turbidity was an impairment to experimental fish as they moved from points of their release to holding tanks.

Rates at which debris accumulated in holding tanks during trials (cc/h) were used as an index of the amounts of debris that accompanied experimental fish through the pumping plant to the holding tanks. Rates at which debris accumulated in holding tanks were available in the project's database for dates of 13 trials in the Arch-Arch experiment. Rates of debris accumulation for the two lifts involved in these trials ranged from 26 to 706 cc/h. Rates at which debris accumulated in holding tanks were available for 21 trials in the Arch-helical experiment. During these 21 trials, rates of debris accumulation for the two pumps involved in the trials ranged from 4 cc/h to 267 cc/h). Rates of debris accumulation and percent-mortality among experimental fish were obtained for each pump and each trial in the Arch-Arch and Arch-helical experiments. These data for Archimedes-1, Archimedes-2 and the internal helical pump were combined and used in linear regression analysis (n=35) to examine the relationship between rate of debris accumulation and percent total 96-h mortality among experimental fish. The analysis showed that these variables were poorly correlated ($r^2 = <0.001$). The regression was not significant ($P=0.473$).

Additional data for these trials indicated that amounts of debris that accompanied chinook salmon as they moved through the pumping plant and into holding tanks were very small. Information was available in the project's database for discharge of water (m^3/s) from screening facilities into bypass channels that led downstream to holding tanks. Estimates for rates at which debris entered holding tanks during each trial (cc/s) were used with coinciding measurements of discharge to obtain concentrations (cc/m^3) of debris in the channels. Mean debris loads in fish-bypass channels upstream of holding tanks of the lifts used in the Arch-Arch experiment were similar; 0.20 cc/m^3 (SE 0.06) for Archimedes-1 and, 0.17 cc/m^3 (SE 0.06) for Archimedes-2. The fish-bypass channel of the internal helical pump carried a lower mean load of debris (0.07 cc/m^3, SE 0.03) than fish-bypass channels of the Archimedes lifts used in the Arch-helical experiment (0.16 cc/m^3, SE 0.04). During the trials, a mean of 89.2% (SD 1.4) of pumped water was exported to the forebay of the Tehama-Colusa Canal in screening facilities of the Archimedes lifts and internal helical pump. Debris in flowstreams of pumps was carried out of screening facilities into fish-bypass channels in approximately 11% of water that was pumped. As a result, concentrations of debris that accompanied experimental fish through pumps and screening facilities in the plant were likely much less than concentrations estimated for the fish-bypass channels. It appears from these observations that concentrations of debris were too low to have substantial physical impacts on experimental fish as they moved to holding tanks. Holding tanks were continuously tended during trials, and debris was moved from tanks as it arrived. Experimental fish were also removed from tanks as they arrive. This approach minimized interactions in tanks between debris and fish.

Time-In-Travel and Holdouts

Tallies were made of number of chinook salmon from each treatment and control sample that reached holding tanks at 10, 20 and 30 minutes post-release. Estimates of time-in-travel were obtained from these tallies. Information on time-in-travel is summarized in Tables A-1 and A-2 of the Appendix.

During the Arch-Arch experiment, between-year differences occurred in time-in-travel for chinook salmon in treatment samples. In 1997, juveniles released in treatment samples entered holding tanks on the bypasses of both lifts promptly. On the average, 92% of fish reached tanks in 10 minutes, 96% in 20 minutes, and 98% in 30 minutes. These results were in sharp contrast to results obtained during 1998. In 1998, juveniles released in treatment samples with both Archimedes lifts lingered in screening facilities and bypass channels, and delayed their movement to holding tanks. About 44% of fish reached tanks in 10 minutes, 65% in 20 minutes, and 73% in 30 minutes. Juvenile salmon released in control samples used with the lifts did not exhibit a large between-year difference in time-in-travel (Table A-1). The same trends, though less pronounced, were present in data from trials conducted in 1997 and 1999 for the Arch-helical experiment (Table A-2).

During months between experimental trials in 1997 and 1998, changes were made to reduce sweeping and approach velocities in screening facilities of the Archimedes lifts and internal helical pump (Frizell and Atkinson 1999). Elevations of water levels were raised several inches to cover the full depth of screens. Screens were also fully baffled. Water velocities through screening facilities as a whole were reduced. Implementation of these actions coincided with changes to slower rates for time-in-travel of chinook salmon used in treatment samples during 1998 and 1999.

On occasion, all of the experimental fish released in treatment and control samples used for a trial were not recovered in holding tanks. These fish lingered in screening facilities and channels upstream of holding tanks for periods of time longer than periods during which tanks were tended to recover them. These holdouts were not included in calculations used to obtain percent-frequencies of mortalities among fish in samples. Data in Table 3 show that percentages of holdouts in control samples were essentially the same for each of the two Archimedes lifts in both years of the Arch-Arch experiment. Perusal of Table 4 also shows that percentages of holdouts in control samples used with each of the two pumps in the Arch-helical experiment were much the same in both years that trials were conducted. For treatment samples, however, the percentages of holdouts increased between trials in 1997 and 1998 for the Arch-Arch experiment; and increased between trials in 1997 and 1999 for the Arch-helical experiment (Tables 3 and 4). These between-year increases in percentages of holdouts from treatment samples were associated with between-year differences for time-in-travel that are presented in paragraphs above.

Mortalities in the Arch-Arch and Arch-Helical Experiments

Full sets of data that were obtained to assess the frequencies of mortalities during the Arch-Arch and Arch-helical experiments are presented in Table A-3 and Table A-8 of the Appendix. Results for total 96-h mortality from the Arch-Arch experiment are summarized in Table 5 of the text. As shown in the Table 5, mean %-frequency for mortalities among experimental fish in all treatment and control samples was very low; between 1.0% and 1.8%. A pump-passage effect was not detected for either of the two lifts. There were also no statistically significant differences between treatment samples used with Archimedes-1 and Archimedes-2 ($P=0.80$), nor between control samples used with Archimedes-1 and Archimedes-2 ($P=0.72$). These results indicated there was no significant difference between the lifts. The low incidence of total 96-h mortality associated with passage of fish from treatment and control samples was essentially the same for both units.

Results on total 96-h mortality from trials conducted in the Arch-helical experiment are summarized in Table 6. Results in Table 6 show that no statistically significant difference occurred for total 96-h mortality in treatment and control samples used with the Archimedes lifts ($P=0.13$). In contrast, a highly significant difference was found between treatment and control samples used with the internal helical pump ($P=0.001$). There was also a highly significant difference between treatment samples used with the Archimedes lifts and internal helical pump ($P=0.003$). However, no difference was detected between control samples used with the two types of pumps ($P=0.22$). While no pump-passage effect existed in the data for the Archimedes lifts, the estimated pump-passage effect on total 96-h mortality of chinook salmon that were inserted in the intake of the internal helical pump was 2.6%.

Data from the Arch-helical experiment were examined for evidence of size-related mortality among chinook salmon that were used in trials. Mortalities were tallied among a grand total of 4,872 experimental fish that were collected from holding tanks following their passage through the pumping plant. Because of the experimental design used for conducting trials, approximately one-quarter of all fish used for tallies were in treatment samples that were used with the Archimedes lifts, in control samples used with the Archimedes lifts, or in treatment samples and control samples that were used with the internal helical pump. The full range of sizes of experimental fish that were used for tallies was divided into three size-classes based on fork-length; small (34-42 mm), medium (43-56 mm) and large (58-74 mm). During the experiment, 12 trials were conducted with chinook salmon in size-class 34-42 mm. Thirty-percent of all fish used for tallies of mortality were in this smallest size-class. Fourteen trials were conducted with fish in size-class 43-56 mm. Fourteen trials were also conducted with fish in size-class 58-74 mm. The number of fish used in each of these last two size-classes made up 35% of all fish used in tallies of mortality. Total 96-h %-mortality was obtained per trial for treatment and control samples used in each size-class of fish with each type of pump. Multi-response permutation procedures were used to test for the occurrence of statistically significant pump-passage effects within size-classes.

Results of analyses on total 96-h mortality within size-classes used for trials in the Arch-helical experiment are displayed in Table 7. Data in Table 7 show that statistically significant size-related pump-passage effects were not detected for trials with the Archimedes lifts. A highly significant pump-passage effect ($P=0.003$) was found for large (58-74 mm) salmon used in trials with the internal helical pump. Significant effects were not detected for the internal helical pump with fish in the smallest and medium size-classes. Similar data are displayed in Table 8 for size-classes used trials for the Arch-Arch experiment. Significant size-related pump-passage effects were not detected in this experiment for either Archimedes-1 or Archimedes-2.

Descaling Studies

During trials, two chinook salmon were collected at random from each treatment and control sample just prior to release of these samples into flowstreams of pumps. Salmon in these pre-passage collections were examined for superficial abrasions on scaled surfaces. The results of this work are presented in Tables A-5 and A-10 of the Appendix.

Statistical analyses on data from the Arch-Arch experiment showed no significant difference for %-fish descaled between pre-passage collections from treatment samples and pre-passage collections from control samples that were used with either Archimedes-1 or Archimedes-2. In addition, pre-passage collections from treatment samples that were used with the two lifts were not significantly different, nor were pre-passage collections from control samples that were used with the two lifts. Analyses of data from the Arch-helical experiment yielded the same results. There were no significant differences for %-fish descaled between pre-passage collections from treatment samples and pre-passage collections from control samples that were used with either the Archimedes lifts or the internal helical pump. In addition, pre-passage collections from treatment samples that were used with the two types of pumps were not significantly different, nor were pre-passage collections from control samples that were used with the two types of pumps. Given the lack of significant differences in these collections, pre-passage data from all treatment and control samples were combined to obtain grand means. A grand mean for %-fish descaled for all pre-passage collections made during trials in the Arch-Arch experiment was 1%. Mean area of scaled surface descaled on the affected fish was 7% (SD 10%). A grand mean %-fish descaled for all pre-passage collections in the Arch-helical experiment was 2%. Mean area of scaled surface descaled on the affected fish was 7% (SD 4%).

Descaling data obtained from post-passage collections of chinook salmon used in the Arch-Arch and Arch-helical experiments are summarized in Table 9 and Table 10 of the text. Data in these tables suggests that passage through the pumping plant, and handling associated with collecting experimental fish from holding tanks, tended to elevate the percentage of fish with descaling above the level of grand means (1-2%) obtained for pre-passage fish. However, no statistically significant differences were detected between treatment and control samples used with pumps in either of the two experiments. As a consequence, there were no pump-passage effects on the frequencies of descaled fish. There were also no significant differences between treatment samples used with lifts in the Arch-Arch experiment (P=0.61), nor between control samples used with the two lifts (P=0.18). No significant differences were observed between treatment samples used with the two types of pumps in the Arch-helical experiment (P=0.31), nor between control samples used with the two types of pumps (P=0.18). These results indicate there were no significant differences between the two pumps used in either of the two experiments for %-fish descaled.

Data from trials showed that small experimental fish were more susceptible to descaling (abrasions) than larger ones. All chinook salmon that had descaling were from samples with mean fork-length ≤54 mm (Tables A-5 and A-10). Mean frequency of descaled fish in treatment samples used in the Arch-Arch experiment was 17% for Archimedes-1 and 11% for Archimedes-2 (Table 9). Fish used for 27 trials in this experiment were predominantly small-sized. Twenty-four trials were conducted with chinook that were 37-52 mm mean fork-length, while the remaining three trials used juveniles in size-class 55-65 mm (Table 8). In contrast, mean frequency of descaled fish in treatment samples used in the Arch-helical experiment was 5% for Archimedes lifts and 8% for the internal helical pump (Table 10). Fish used for trials in this experiment were spread almost equally among small, medium and large size-classes (Table 7). The elevated mean %-fish descaled observed in treatment samples for the Arch-Arch experiment was due to poor representation of large fish (>55 mm fork-length).

Descaled (abraded) areas on 99.6% of all affected fish from treatment and control samples used in both experiments were ≤35% of total scaled surfaces. Mean descaling on these fish was 11% (SD 9%); not unlike the extent of mean descaling (7%) noted above for collections of pre-passage salmon. A single fish, taken in a post-passage treatment collection, had an exceptional amount of descaling. It was descaled over 75% of its scaled surfaces. Unlike any of the other descaled individuals observed in the Arch-Arch and Arch-helical experiments, that fish also had other potentially debilitating injuries to the head and body. Its physical condition was similar to that observed among fish that died during 96-h post-passage periods in which delayed mortalities were tallied.

Studies of Other Sub-Lethal Injuries

Chinook salmon in pre-passage and post-passage collections that were used for assessments of descaling were also examined microscopically for other injuries or abnormalities on the head, eye, body and fins. Results of examinations made for injuries during the Arch-Arch and Arch-helical experiments are given in Table A-7 and A-12 of the Appendix.

Statistical analyses on data from the Arch-Arch experiment showed no significant difference for %-fish injured between pre-passage collections from treatment samples and pre-passage collections from control samples that were used with either Archimedes-1 or Archimedes-2. In addition, pre-passage collections from treatment samples that were used with the two lifts were not significantly different, nor were pre-passage collections from control samples that were used with the two lifts. Analyses of data from the Arch-helical experiment yielded the same results. There were no significant differences for %-fish injured between pre-passage collections from treatment samples and pre-passage collections from control samples that were used with either the Archimedes lifts or the internal helical pump. In addition, pre-passage collections from treatment samples that were used with the two types of pumps were not significantly different, nor were pre-passage collections from control samples that were used with the two types of pumps. Given the lack of significant differences in these collections, pre-passage data from all treatment and control samples were combined to obtain grand means. A grand mean for %-fish injured for all pre-passage collections made during trials in the Arch-Arch experiment was 4%. A grand mean for %-fish injured for all pre-passage collections in the Arch-helical experiment was also 4%.

Injury data obtained from post-passage collections of chinook salmon used in the Arch-Arch and Arch-helical experiments are summarized in Table 11 and Table 12 of the text. Data in Table 11 and Table 12 suggests that passage through the pumping plant, and handling associated with collecting experimental fish from holding tanks, tended to elevate the percentage of fish with injuries slightly above the level of grand means (4%) obtained for pre-passage fish. However, no statistically significant differences were detected between post-passage treatment and control samples used with either of the two pumps in either of the two experiments. As a consequence, no pump-passage effects on the frequencies of fish with sub-lethal injuries were detected. There were also no significant differences between post-passage treatment samples used with lifts in the Arch-Arch experiment ($P=0.64$), nor between means for post-passage control samples used with the two lifts ($P=0.37$). Likewise, no significant differences were observed ($P=0.61$) between treatment samples used with pumps in the Arch-helical experiment, nor between control samples used with the two types of pumps ($P=0.91$). These results for %-fish with sublethal injuries indicated there were no significant differences between the two pumps that were used in either of the two experiments.

Types of injuries or abnormalities that each affected fish from the Arch-Arch and Arch-helical experiments had are listed in footnotes of Table A-7 and A-12 respectively. Abrasions and bruises on opercula, and minor hemorrhages around opercula were common injuries. Bulging eyes and bruises on the body also occurred. Fins of experimental fish were seldom injured. It is important to note, that common injuries listed in footnotes of Tables A-7 and A-12 were found both on fish from pre-passage samples as a result of pre-trial handling and rearing, and on fish collected from post-passage samples. Perusal of the footnotes and making comparisons of the types of injuries observed among fish from pre-passage and post-passage collections from treatment and control samples, shows no indication that any particular type(s) of sub-lethal injury was associated with passing through pumps in the plant.

DISCUSSION

Conditions for Trials

Four runs of adult chinook salmon occur in the upper Sacramento River near Red Bluff Diversion Dam. Successful spawning and emergence from redds in the mainstem of the river and its tributaries have resulted in a year-around presence of juveniles in the Red Bluff reach of the river (Vogel and Marine 1991). This annual presence is periodically augmented by releases of juvenile chinook salmon from Coleman National Fish Hatchery. Borthwick et al. (1999) summarized the abundances of juvenile chinook salmon that were entrained from the Sacramento River by the Research Pumping Plant during times that it operated in 1997 and 1998. These authors showed a frequency distribution for entrained juveniles using size-classes based on fork-length. Hatchery-reared chinook salmon used in the Arch-Arch and Arch-helical experiments covered the range of size-classes that they reported for riverine juveniles. Borthwick et al. (ibid.) also found that 81% of chinook salmon that were collected from holding tanks during 24-h periods entered the tanks at night. McNabb et al. (1998) reported similar high percentages for nighttime capture of entrained salmon. Daytime trials with experimental chinook salmon released in treatment or control samples resulted in fish avoiding sunlight by seeking refuge in shadowed portions of pump outfall areas and screening facilities. Recovery of fish from individual samples was prolonged and partial. For these reasons, all trials for this report were conducted at night.

During the interval 1995-1997, procedures for handling and holding experimental chinook salmon at Red Bluff were under development (McNabb et al 1998). Episodes of disease occurred in fish stocks at Coleman National Fish Hatchery, and in tanks in the fish holding facilities at Red Bluff. Losses of electrical power at Red Bluff, and associated losses of oxygen and temperature controls, resulted in partial mortalities among experimental salmon. Fish that survived were stressed. These experiences lead to development of quality control guidelines that would, over the years in which trials were conducted, eliminate sub-standard groups of salmon from use in experiments.

The research pumping plant at Red Bluff was designed to operate in relatively dry portions of the year when deliveries of water were needed for irrigation, and stage-height and discharge of the Sacramento River were relatively low (Frizell and Atkinson 1999). Under these conditions, downstream transport of suspended debris and bedload materials was expected to be low. Visual observations in screening facilities and fish-bypass channels, and measurements of debris that accumulated in holding tanks during preliminary trials (1995-1997), indicated that amounts of debris entrained with fish from the Sacramento River during portions of the year when the plant was operable did, in fact, tend to be low. Pulses of high debris were rare and short-lived. Common components of debris were fragments of aquatic plants, woody twigs, leaves of deciduous trees and filamentous algae. Information was available in the project's database to provide a quantitative indication of debris loads that were present during trials conducted in 1997-1999 for this report. During 13 trials in the Arch-Arch experiment and 21 trials in the Arch-helical experiment, the maximum load of debris that accompanied experimental fish through fish-bypass channels upstream of holding tanks was estimated at 0.6 cc/m^3. Estimates of mean debris loads in these channels on fish bypasses of Archimedes-1, Archimedes-2 and the internal helical pump varied from 0.1 cc/m^3 to 0.2 cc/m^3. Because irrigation water was exported from screening facilities in the plant, debris entering these channels from screening facilities was carried in only 10% to 11% of water that was pumped. This observation suggested that concentrations of debris that passed through pumps with experimental fish were, on the average, much less than the 0.2 cc/m^3. The frequency of mortalities among chinook salmon used in trials was not related to the small amounts of debris that were present during trials. This conclusion was based on regression analysis (n=35) that showed frequencies of mortalities during trials were not significantly related to rates at which debris accumulated in holding tanks during the trials (r^2= <0.001, P=0.473). Water temperature, dissolved oxygen concentration, total gas saturation and turbidity were measured during each trial. There were no indications that any of these features of water quality were detrimental to experimental fish as they passed through the pumping plant.

Pump Outfalls and the Pump-Passage Effect

Pump-passage effects on mortality and injury were evaluated by comparing results obtained for treatment and control samples of fish. Different conditions surrounded the release of treatment and control samples into flowstreams of pumps. Treatment samples were released from inserters into water in standpipes (Figure 1). Crowders were then used to move fish into pump intake pipes. Control samples were released from inserters at the water-surface downstream from pump outfalls. Significant pump-passage effects that are reported for this study include mortalities or injuries that might have been associated, not only with passage through pumps, but also passage of fish in treatment samples through standpipes and pump outfalls.

There were no indications during trials that conditions for releasing treatment samples in standpipes differed between pumps. The absence of statistically significant differences in total 96-h mortality between treatment and control samples with Archimedes lifts in the Arch-Arch and Arch-helical experiments indicated that chinook salmon passed safely, not only through the lifts, but also through their outfalls. Visually different fields of turbulence existed in channels in the pumping plant that received discharge from the Archimedes lifts and internal helical pump. Frizell and Atkinson (1999) assigned at least of portion of this turbulence to the location of the helical pump's discharge aperture in an off-center position relative to configuration of the sluiceway.

In winter and early spring of 2000, a fish-insertion port was cut in the metal discharge structure of the internal helical pump upstream of its outfall. A study was conducted (Borthwick unpublished) to evaluate the role that passing through the outfall of the pump had on the elevated %-mortality (2.5%) that was obtained for the internal helical pump during work for this report. Twelve trials were conducted at night using techniques described here in the section entitled *METHODS*. Samples were made up of 31-32 chinook salmon in two size-classes; 39 mm and 61 mm mean fork length. During each trial, fish were released in intake of the internal helical pump, through the fish-insertion port on the pump's discharge structure, and in the location downstream of the outfall that was used for control samples during trials conducted in 1997-1999 for this report. Fish released in samples were collected from holding tanks, and tallies were made for direct and delayed mortalities. There were no statistically significant differences for total 96-h mortality between size-classes of salmon in treatment samples, or in samples released through the fish-insertion port and those released downstream of the outfall. Mean total 96-hour mortality for all fish inserted in the pump intake was 4.7%. Mean total 96-hour mortality for all fish inserted in the port and at the location downstream of the outfall was 0.3% at both locations. There was no statistically significant difference between samples released through the port and samples released downstream of the outfall ($P=0.80$). Total 96-h mortality was significantly higher in samples that passed through the pump than samples release through the port ($P=0.006$), or samples that were released downstream of the outfall ($P=0.006$). These results indicate that passage through the outfall of the pump, by itself, did not contribute to the elevated %-mortality observed with the internal helical pump in the Arch-helical experiment. However, the question of whether fish that pass through the pump make their way safely through the pump's outfall in the same manner as those that were inserted in the port on the pump's outfall structure remains unanswered. It is clear that a significant pump-passage effect was obtained in the Arch-helical experiment for the configuration used at Red Bluff for installation of the internal helical pump and its outfall.

Statistical Procedures (MRPP)

Multi-response permutation procedures (MRPP) were used in this study to detect statistically significant differences between samples of treatment and control fish. In contrast to parametric statistical techniques, MRPP used normed distances between measurements as the unit of analysis. The experimental data were permuted (rearranged) repeatedly according to random assignments. This process yielded inferential results solely dependent on randomization and permutations of the measured data sets. The procedures avoided decisions about goodness of fit of univariate or multi-variate distributions. The permutation analyses also avoided the standard assumptions of ANOVA, such as normality and heterogeneity of variances. Multi-response permutation procedures were especially appropriate for the Arch-Arch and Arch-helical experiments because of the exceptionally low incidence of mortalities and injuries that were expected from preliminary studies (McNabb et al. 1998), and the consequent non-normal distribution of mortality and injury data that were obtained.

The Question of Holdouts

The frequency of mortalities among chinook salmon released during trials was estimated from tallies made of individuals that were dead when they arrived in holding tanks (direct), and those that died during a 96-h post-passage period (delayed). The fate of holdouts was not included in these tallies. Results for trials conducted specifically to determine the location of holdouts showed that they lingered in screening facilities or in the vicinity of pump outfalls; some for as long as 72 h post-release. There were no indications over the course of the study that frequency of mortalities among holdouts was as high or higher than mortalities among experimental fish that were recovered in holding tanks. Individuals that did die during passage were promptly carried by currents into holding tanks. Holding tanks were tended regularly to retrieve them, not only in this study, but also in concurrent studies of fish entrainment from the Sacramento River. A total of 3,368 chinook salmon were released in treatment and control samples during the Arch-Arch experiment. Holdouts were 4.4% of this total. During the Arch-helical experiment, a total of 5,051 chinook salmon were released in treatment and control samples. Holdouts were 3.5% of this number. For all samples released in both experiments, two of a total of 325 holdouts were known to have died (0.6%). The remainder of these holdouts had access to fish-bypass channels leading to the Sacramento River when dewatering ramps were raised in intervals between experimental trials.

Direct and Delayed Mortalities

Percentages of direct and delayed mortalities were summed in this study to obtain estimates of total 96-h mortality. Data in Table 13 and Table 14 show the partitioning of direct and delayed mortality among treatment and control samples that were used in the experiments. As shown in the tables, mean delayed mortality for all treatment and control samples used in the Arch-Arch and Arch-helical experiments was very low; in a range of 0.4 to 1.0%. There were no statistically significant differences for delayed mortality between treatment and control samples used with any of the pumps involved in the two experiments. As a result, delayed mortality did not contribute significantly to total 96-h pump-passage effects (treatment effects) in either the Arch-Arch or Arch-helical experiment.

With one exception, frequencies of direct mortalities were also very low in treatment and control samples used in both experiments (Table 13 and Table 14). Means for both treatment and control samples generally ranged from 0.1% to 0.8%. The exception in these data was a direct mortality of 2.8% obtained for treatment samples used in the Arch-helical experiment with the internal helical pump. Data in Table 14 show that significant pump-passage effects on direct mortality were obtained in the Arch-helical experiment with both the Archimedes lifts and the internal helical pump. However, treatment samples used with the two kinds of pumps in the Arch-helical experiment were significantly different ($P=0.001$), while control samples were not ($P=0.44$). As a result, the pump-passage effect of the internal helical pump for direct mortality (2.3%) was significantly larger than the pump-passage effect of the Archimedes lifts (0.7%). This difference in direct mortality data, combined with a lack of such a difference noted above in delayed mortality data, resulted in a significant difference between the two types of pumps in regard to total 96-h mortality (Table 6).

Experimental fish that were dead, when treatment and control samples were recovered from holding tanks (direct mortalities), were examined for external injuries. Results of this work are summarized in Table 15. The great majority (97%-100%), but not all, of these dead salmon had visible injuries. Multiple injuries on individual fish were the rule. Extensive descaling was common. Many of these fish were descaled on ≥60% of their scaled surfaces. Open wounds on the head were common. In these cases, organs were often extruded. Eyes were missing. Bruising and hemorrhaging occurred around opercula. Body cavities were torn open to expose internal organs. Fins were dislocated and torn. Overall, similar types of injuries were observed on fish from treatment and control samples. There was no pattern to suggest that a certain type(s) of injury was related to pump-passage.

Reaching Objectives of the Study

One objective of this study was to examine the premise that the Archimedes lifts and internal helical pump that were installed in the Research Pumping Plant in Red Bluff were fish-friendly. That premise was based on earlier work that was conducted with several species of fish using pumps of these types that were much smaller and delivered much less water (Stahle and Jackson 1982, Patrick and Sim 1985, Rogers and Patrick 1985, Patrick and McKinley 1987, Week et al. 1993). During the experiments, care was taken to maintain quality control in samples of experimental fish. Procedures were used to minimize experimental error in data that were obtained. Juvenile chinook salmon used in trials were healthy and robust. During each trial, the two pumps involved in an experiment were both put into operation. This approach brought water of similar quality into each of the two units during passage of experimental fish. Treatment samples and control samples used for each trial were released in the flowstreams of the two types of pumps concurrently. Chinook salmon in treatment and control samples used with each pump had the same history of rearing at Coleman National Fish Hatchery. They also had the same history of holding and rearing in facilities at Red Bluff. During preparations for trials, they were processed as a group for marking, and handled as a group while making up samples. Before their release in the pumping plant, fish used in each trial were acclimated as a group to the riverwater they would encounter when release in the plant. All trials were conducted at night to mimic the tendency for riverine chinook salmon to enter the pumping plant at night. Measurements of water quality were made during trials. Water temperatures, dissolved oxygen concentrations and turbidity were all within ranges that were entirely satisfactory for transit of experimental fish through the pumping plant. Concentrations of debris that accompanied the fish through pumps and along channels to holding tanks were very low; estimated at <1 cc/m^3. Experimental fish were recovered from holding tanks as they arrived. Interactions between the fish and debris that tended to accumulate in the tanks was thus minimized.

Twenty-seven trials were conducted in the Arch-Arch experiment. There were no pump-passage effects on total 96-h mortality among salmon used in trials with either of the two lifts. Mean %-frequency of mortality in all treatment and control samples used with both lifts was very low; in a range from 1.0-1.8% (Table 5). There was no evidence in the data (Table 8) that salmon in a small size-class (37-41 mm fork length) were more susceptible to mortality while passing through the lifts than larger salmon (44-52 mm). Live salmon were taken randomly post-passage from treatment and control samples and examined for descaling and other sub-lethal injuries. No pump-passage effects were detected for %-fish descaled (Table 9), or for %-fish with other sub-lethal injuries (Table 11). Only one fish in a total of 267 (0.4%) that were taken from post-passage samples during both experiments had descaling and other sub-lethal injuries that appeared to be debilitating.

The objective of the Arch-Arch experiment was to obtain information on experimental error introduced to the Arch-helical experiment by random selection of one of the two Archimedes lifts for use in that experiment. Results for the Arch-Arch experiment showed that the two Archimedes lifts did not differ significantly from one another in regard to total 96-h mortality, %-frequency of post-passage fish descaled, or %-frequency of post-passage fish with other sub-lethal injuries. As a result, experimental error associated with random selection of one of the two lifts for use in trials for the Arch-helical experiment was expected to be non-significant.

A second objective for this study was to compare the Archimedes lifts and internal helical pump in regard to safe passage for juvenile chinook salmon. Data to compare the two types of pumps were obtained from 40 trials. Results from trials showed that both types of pumps were fish-friendly. No pump-passage effect on total 96-h mortality was detected for the Archimedes lifts and their outfalls. A very low, but highly significant ($P=0.001$), pump-passage effect was obtained (2.5%) for the internal helical pump and its outfall (Table 6). Statistical analyses showed that treatment samples used with the two types of pumps differed significantly in regard to total 96-h mortality ($P=0.003$), while no difference was detected between control samples ($P=0.22$). Pump-passage effects on mortality were examined for chinook salmon in small (34-42 mm fork length), medium (43-56 mm) and large (58-74 mm) size-classes. Small individuals were no more susceptible to mortality while passing through the pumps than were medium-sized or large fish (Table 7). Pump-passage effects by size-class were not statistically significant in the Arch-helical experiment, except for large fish that were used with the internal helical pump ($P=0.003$).

Examinations of live salmon, taken randomly post-passage from each treatment and control sample used in trials for the Arch-helical experiment, showed no significant pump-passage effect on

%-fish descaled for either type of pump (Table 10). Data from examination of the post-passage fish also showed no significant pump-passage effect for %-fish injured for either of the two types of pump (Table 12). Descaling and injuries noted on affected post-passage individuals from both experiments were not debilitating, except for one juvenile salmon in the total of 267 (0.4%) were examined. Unlike the case for total 96-h mortality, there were no significant differences between the Archimedes lifts and internal helical pump for descaling and other types of injuries.

Liston and Johnson (1992a) described design criteria and the environmental setting for a research pumping plant to be installed on the Sacramento River near Red Bluff, California. They suggested that large Archimedes lifts and a large internal helical pump be installed in the plant. They predicted that these types of pumps would be fish-friendly. With construction on-going, the research pumping plant became a reality between 1993 and 1995. Engineering difficulties with the original designs for the Archimedes lifts and internal helical pump were largely overcome between 1995 and 1997. Results from experiments presented in this report were obtained between 1997 and 1999. The fish-friendly attributes of the Archimedes lifts and internal helical pump, expected in early planning stages of pumping plant program (Liston and Johnson 1992a, 1992b), have been verified by data reported here.

ACKNOWLEDGEMENTS

A large team of people was responsible for successful completion of the work for this report. Special thanks go to Max Stodolski, Chief of USBR Red Bluff Division and manager of Reclamation's Red Bluff Fish Passage Program. Without his day-to-day support and leadership on-site, and his professional insights on acquisition and quality control of data, the work on experiments for this report would not have been successful. Special thanks also go to Richard Corwin, biological technician on-staff at Red Bluff, for making examinations for descaling and injuries on experimental fish, constructing and maintaining the database for this and other segments of the program, and for serving as leader during nighttime trials. Rich Crouch, Zachary Wilson, Drea Traeumer, Jeremy Brasch, Marie-Christine Daems, Sharon Nowak and Christy Skelton all spent nights assisting with execution of experimental trials. They also entered data from the experiments into a computer database and check it for accuracy. Ed Weber assisted with these tasks, and his expertise in quantitative biology added immeasurably to the quality of data presentations in this report. Judy Lyons, Rick Wydoski, Tom LaCasse, Andrew Montanyo and Johnnie Boutwell from the Fisheries Applications Research Group at Reclamation's Technical Service Center in Denver helped on-site staff with trials and data entry during particularly busy periods of the year. Jon Medina, also attached to the Technical Service Center, made a major contribution to the program by consulting on experimental design, and providing and utilizing computer software to analyze the data. The diligence of Robert Bagshaw, Paul Freeman, Lester Mahan, Steve Quitiquit, Wayne Stokes and Bill Warner, Red Bluff Operations and Maintenance Staff, kept physical features of the pumping plant and fish-holding facilities operating in a fish-friendly mode. Warren Frizell and Steve Atkinson shared results of engineering studies they conducted during the course of our work. Their studies provided valuable insights on hydraulic features of flow-streams along which experimental fish traveled from pump intakes to holding tanks. Excellent cooperation was given by Roger Shudes and the staff at Coleman National Fish Hatchery to supply juvenile chinook salmon for our experiments in a timely fashion. Helpful insights that they provided on the husbandry of these juveniles were very much appreciated. We would also like to thank Scott Foote and Kim True of the U.S. Fish and Wildlife Service, California-Nevada Fish Health Center for volunteering to serve as our consultants on fish diseases. The administrative and technical support of Diana Weigmann, Group Manager, USBR Fisheries Applications Research Group, Denver Technical Service Center was greatly appreciated. A major portion of the funding for this work was provided by Reclamation's Mid-Pacific Region, supplemented by Reclamation's Research and Technology Development Program, Study Number AECO-98.016 (WATR) and from appropriations received under the CVPIA, Public Law 102-575, Title 34.

LITERATURE CITED

Bagenal, T.B. and F.W. Tesch. 1978. Age and growth. *In*, T.B. Bagenal, ed., pp. 101-136. Methods for Assessment of Fish Production in Freshwater. Blackwell Scientific Publications, Oxford.

Baldwin, W.J. 1973. Results of tests to investigate the suitability of fish pumps for moving live baitfishes. The Progressive Fish Culturist 35:39-43.

Borthwick, S.M., R.R.Corwin and C.R. Liston. 1999. Investigations of fish entrainment by Archimedes and internal helical pumps at Red Bluff Research Pumping Plant, Sacramento River, California: February 1997-June 1998. Red Bluff Research Pumping Plant Report Series, Volume 7. U.S. Bureau of Reclamation, Denver, CO.

Cone, R.S. 1989. The need to reconsider the use of condition indices in fishery science. Transactions of the American Fisheries Society 118:510-514.

Frizell, K.W. and S.P. Atkinson. 1999. Engineering evaluation of the Red Bluff Research Pumping Plant on the Sacramento River in Northern California: 1995-1998. Red Bluff Research Pumping Plant Report Series, Volume 5. Bureau of Reclamation, Denver, Colorado.

Kostecki,P.T., P. Clifford, S.P. Gloss and J.C. Carlisle. 1987. Scale loss and survival in smolts of Atlantic salmon (*Solmo salar*) after turbine passage. Canadian Journal of Fisheries and Aquatic Sciences 40:210-214.

Liston, C.R. and P.L. Johnson. 1992a. Design criteria and environmental setting for a pilot pumping plant installation at Red Bluff Diversion Dam on the Sacramento River, California. Bureau of Reclamation, Research and Laboratory Services Division, Denver, Colorado.

Liston, C.R. and P.L. Johnson. 1992b. Biological and engineering research evaluation plan for a pilot pumping plant on the Sacramento River, California. Bureau of Reclamation, Research and Laboratory Services Division, Denver, Colorado.

McNabb, C.D., C.R. Liston and S.M. Borthwick. 1998. In-plant biological evaluation of the Red Bluff Research Pumping Plant on the Sacramento River in Northern California: 1995 and 1996. Red Bluff Research Pumping Plant Report Series, Volume 3. U.S. Bureau of Reclamation, Denver, Colorado.

Mielke, P.W., K.J. Berry and G.W. Brier. 1981. Application of multi-response permutation procedures for examining seasonal changes in monthly mean sea-level pressure patterns. Monthly Weather Review 109:120-126.

Mielke, P.W. 1984. Meteorological applications of permutation techniques based on distance functions. *In*, P.R.Krishnaiah and P.K. Sen, eds., pp 813-830. Handbook of Statistics, Volume 4: Nonparametric Methods. North-Holland, Amsterdam.

Mielke, P.W. 1985. Design and evaluation of weather modification experiments. *In*, A.H. Murphy and R.W. Katz, eds.,pp. 439-459. Probability, Statistics, and Decision Making in the Atmospheric Sciences. Westview Press, Boulder, Colorado.

Moyle, P.B. and J.J. Cech Jr. 1988. Fishes: An Introduction to Ichthyology. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Mundie, J.H. and R.E.Taber. 1983. Movement of coho salmon *Oncorhynchus kisutch* fingerlings in a stream following marking with a vital stain. Canadian Journal of Fisheries and Aquatic Sciences 40:1318-1319.

Nikinmaa, M., A. Soivio, T. Nakari and S. Lindgren. 1983. Hauling stress in brown trout (*Salmo trutta*): physiological responses to transport in fresh water or salt water, and recovery in natural brackish water. Aquaculture 34:93-99.

Patrick, P.H. and B. Sim. 1985. Effectiveness of a Hidrostal pump in live transfer of American eels. Hydrobiologia 128:57-60.

Patrick, P.H. and R.S. McKinley. 1987. Field evaluation of a Hidrostal pump for live transfer of American eels at a hydroelectric facility. North American Journal of Fisheries Management 7:303-305.

Petrusso, P.A. 1998. Feeding habits and condition of juvenile chinook salmon in the upper Sacramento River, California. MS Thesis, Michigan State University, East Lansing, Michigan.

Rodgers, D.W. and P.H. Patrick. 1985. Evaluation of a Hidrostal pump fish return system. North American Journal of Fisheries Management 5:393-399.

Stahle, M. and D. Jackson. 1982. The development of a screw centrifugal pump for handling delicate solids. World Pumps 185:53-55.

Summerfelt, R.C. and L.S. Smith. 1990. Anesthesia, surgery and related techniques. *In*, C.B. Schreck and P.B. Moyle, eds., pp. 213-334. Methods for Fish Biology. American Fisheries Society, Bethesda, Maryland.

Vogel, D.A. and K.R. Marine. 1991. Guide to the Upper Sacramento River chinook salmon life history. CH2M Hill, Redding California.

Vogel, D.A. and K. Marine. 1995. Technical memorandum: 1996 predation evaluation near CGID Sacramento River pumping station. Natural Resource Scientists, Red Bluff, California.

Week, L.E., V.C. Bird and R.E. Geary. 1993. Effects of passing juvenile steelhead, chinook salmon, and coho salmon through an Archimedes screw pump. In-house report, California Department of Fish and Game and Pacific Gas and Electric Company, Yountville, California.

Wedemeyer, G. 1992. Transporting and handling smolts. World Aquaculture 23:47-50.

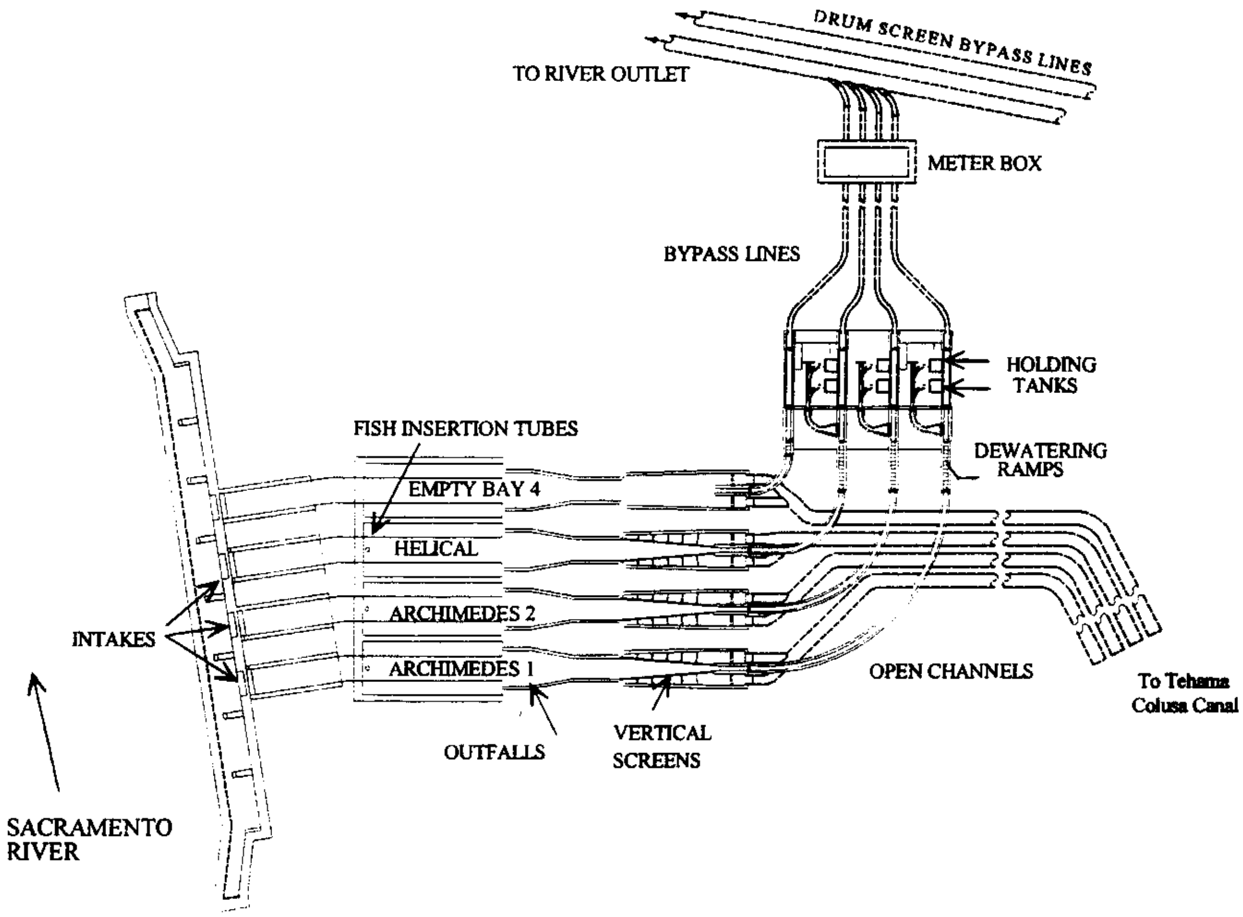

Figure 1. Pathways for the movement of experimental fish from Archimedes lifts and the internal helical pump to holding tanks in the Red Bluff Research Pumping Plant.

TABLES OF THE TEXT

Table 1. Guidelines for making pre-trial quality control assessments on shipments of chinook salmon obtained from Coleman National Fish Hatchery. Limits listed in the table were used to eliminate sub-standard groups of fish from use in experiments. Sizes for chinook salmon that are given in the table are for fork-length (mm).

ELEMENTS	RECORDED INFORMATION	LIMITS FOR ELIMINATION	NOTES
Disease	**Outbreaks of Disease**	**>0**	**For outbreaks of disease in holding tanks in the project's wellwater facility (not outbreaks at Coleman). An outbreak was defined as a condition in holding tank(s) that required therapeutic treatment.**
Mortality	**Cumulative Mortality**	**>2%**	**Cumulative mortality in each group of fish obtained from Coleman Fish 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 on >5% of the fish**	**Confinement to raceways at Coleman Hatchery or tanks in the wellwater 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 opercula was allowed.**
Descaling	**% of Scaled Body Surface That Was Abraded on Individual Fish.**	**>5% abrasions on >7% of fish**	**Pre-trial juvenile chinook held at Red Bluff commonly had individual scales missing from small patches on their scaled surfaces (1-5%). These losses of individual scales were taken as a normal background condition, and were discounted in descaling assessments. Descaling assessments were based on the loss of scales associated with superficial abrasions (scrapes) that occurred on scaled surfaces as a result of pre-trial handling.**
Condition Factor	**Weight and Fork-Length for Individual Fish.**	**≤45 mm juveniles: mean <0.70**	**Condition Factor (*k*) was calculated from:** $k = W/L^3 \times 100$
		≥46 mm juveniles: mean <0.85	**where W was weight in grams and L was fork length in centimeters.**

Table 2. Time-in-travel for chinook salmon (43 mm fork-length) released in pump intakes and collected from holding tanks during night and day.

TIME	NO. OF JUVENILES[1] RELEASED	% OF JUVENILES RECOVERED IN TANKS		% OF JUVENILES	
		10 MIN	30 MIN + SWEEP	LATE	HOLDOUT
Night	128	84	88	8	4
Day	127	54	60	22	18

1 Four individual samples of approximately 32 fish each were used for night time-in-travel and for day time-in-travel. Two of the four samples were passed through an Archimedes lift, and the other two samples through the internal helical pump while pumps were run concurrently. Holding tanks were tended intermittently for 24-h post-release to collect late individuals.

Table 3. Total number of chinook salmon released, and percentages of fish not recaptured (holdouts) during trials for the Arch-Arch experiment. Thirteen trials were conducted in 1997 and 14 trials were conducted in 1998.

YEAR	ITEM	ARCHIMEDES-1		ARCHIMEDES-2	
		TREATMENT	CONTROL	TREATMENT	CONTROL
1997	No. Released	410	416	412	416
	% Holdout	1	6	2	1
1998	No. Released	419	432	432	431
	% Holdout	8	8	7	2

Table 4. Total number of chinook salmon released, and percentages of fish not recaptured (holdouts) during trials for the Arch-helical experiment. Twenty-five trials were conducted in 1997 and 15 trials were conducted in 1999.

YEAR	ITEM	ARCHIMEDES		INTERNAL HELICAL	
		TREATMENT	CONTROL	TREATMENT	CONTROL
1997	No. Released	797	781	773	798
	% Holdout	3	2	1	3
1999	No. Released	476	476	473	477
	% Holdout	7	3	8	3

Table 5. Total 96-h mortality associated with passage of chinook salmon through Archimedes-1 and Archimedes-2 during 27 trials.

LIFT	TYPE OF SAMPLE	MEAN TOTAL 96-H MORTALITY		PUMP-PASSAGE[2] EFFECT (% MORTALITY)
		% OF FISH PER TRIAL	P^1	
Archimedes-1	Treatment	1.3	0.71	none
	Control	1.8		
Archimedes-2	Treatment	1.2	0.82	none
	Control	1.0		

1 Probability ≤0.05 was taken to indicate statistically significant difference between treatment and control samples.

2 No statistically significant differences were observed between treatment and control samples used with either of the two lifts. There were also no significant differences between treatment samples used with Archimedes-1 and Archimedes-2 ($P=0.80$), nor between control samples used with Archimedes-1 and Archimedes-2 ($P=0.72$).

Table 6. Total 96-h mortality associated with passage of chinook salmon through Archimedes lifts and the internal helical pump during 40 trials.

PUMP	TYPE OF SAMPLE	MEAN TOTAL 96-H MORTALITY		PUMP-PASSAGE[1] EFFECT (% MORTALITY)
		% OF FISH PER TRIAL	P	
Archimedes	Treatment	1.5[2]	0.13	none
	Control	0.5		
Internal Helical	Treatment	3.6	<0.01	2.5
	Control	1.1		

1 No statistically significant difference was observed between treatment and control samples used with Archimedes lifts; there was no pump-passage effect. There was a highly significant difference between treatment and control samples used with the internal helical pump (0.001). Pump-passage effect for the internal helical pump was estimated from the difference in %-mortality between means for treatment and control samples.

2 There was a highly significant difference between treatment samples used with Archimedes lift and internal helical pump ($P=0.003$). There was no significant difference between control samples used with Archimedes lifts and internal helical pump ($P=0.22$).

Table 7. Total 96-h mortality among chinook salmon in size-classes used during the Arch-helical experiment. There were 12 trials in size-class 34-42 mm fork-length, 14 trials in size-class 43-56 mm, and 14 trials in size-class 58-74 mm.

PUMP	TYPE OF SAMPLE	MEAN %-MORTALITY BY SIZE-CLASS					
		34-42 mm		43-56 mm		58-74 mm	
Archimedes	Treatment	2.0	$P=0.39$	3.1	$P=0.23$	0.0	$P=1.00$
	Control	0.6		0.9		0.0	
Internal Helical	Treatment	5.5	$P=0.15$	2.2	$P=0.18$	3.2	$P=<0.01$
	Control	2.3		0.7		0.2	

Table 8. Total 96-h mortality among chinook salmon in size-classes used during the Arch-Arch experiment. There were 14 trials in size-class 37-41 mm fork-length, 10 trials in size-class 44-52 mm, and 3 trials in size-class 55-65 mm.

LIFT	TYPE OF SAMPLE	MEAN %-MORTALITY BY SIZE-CLASS				
		37-41 mm		44-52 mm		55-65 mm[1]
Archimedes-1	Treatment	1.8	$P=0.50$	1.0	$P=0.21$	0.0
	Control	1.1		3.3		0.0
Archimedes-2	Treatment	1.7	$P=0.68$	1.0	$P=0.55$	0.0
	Control	1.1		1.1		0.1

1 The number of trials available for this size-class (3 trials) was inadequate for statistical evaluation of differences between treatment and control samples.

Table 9. Descaling on chinook salmon in sub-samples taken post-passage from treatment and control samples used with Archimedes-1 and Archimedes-2 during 27 trials. Extent of descaling on descaled fish is reported in Table A-5.

LIFT	TYPE OF SAMPLE	%-FISH DESCALED PER TRIAL		PUMP PASSAGE[2] EFFECT (%-FISH DESCALED)
		MEAN	P^1	
Archimedes-1	**Treatment**	**17**	**0.29**	**none**
	Control	**7**		
Archimedes-2	**Treatment**	**11**	**0.08**	**none**
	Control	**2**		

1 No statistically significant differences were observed between treatment and control samples used with either of the two lifts. There were also no significant differences between treatment samples used with Archimedes-1 and Archimedes-2 ($P=0.61$), nor between control samples used with Archimedes-1 and Archimedes-2 ($P=0.18$).

Table 10. Descaling on chinook salmon in sub-samples taken post-passage from treatment and control samples used with the Archimedes lifts and the internal helical pump during 40 trials. Extent of descaling on descaled fish is reported in Table A-10.

PUMP	TYPES OF SAMPLES	%-FISH DESCALED PER TRIAL		PUMP-PASSAGE[2] EFFECT (%-FISH DESCALED)
		MEAN	P^1	
Archimedes	**Treatment**	**5**	**0.38**	**none**
	Control	**1**		
Internal Helical	**Treatment**	**8**	**0.53**	**none**
	Control	**5**		

1 No statistically significant differences were observed between treatment and control samples used with either type of pump. There were also no significant differences between treatment samples ($P=0.31$), or between control samples ($P= 0.18$), used with the two types of pumps.

Table 11. Frequency of injured chinook salmon in sub-samples taken post-passage from treatment and control samples used in the Arch-Arch experiment during 27 trials. Specific injuries to the head, eye, body, and fins of each injured fish are reported in Table A-7.

LIFT	TYPES OF SAMPLES	%-FISH INJURED PER TRIAL		PUMP-PASSAGE[2] EFFECT (%-FISH INJURED)
		MEAN	P[1]	
Archimedes-1	**Treatment**	**6**	**0.68**	**none**
	Control	**4**		
Archimedes-2	**Treatment**	**4**	**0.48**	**none**
	Control	**9**		

1 No statistically significant differences were observed between treatment and control samples used with either lift. There were also no significant differences between treatment samples ($P=0.64$), or between control samples ($P=0.37$), used with the two lifts.

Table 12. Frequency of injured chinook salmon in sub-samples taken post-passage from treatment and control samples used in the Arch-helical experiment during 40 trials. Specific injuries to the head, eye, body, and fins of each injured fish are reported in Table A-12.

PUMP	TYPES OF SAMPLES	%-FISH INJURED PER TRIAL		PUMP-PASSAGE[2] EFFECT (%-FISH INJURED)
		MEAN	P[1]	
Archimedes	**Treatment**	**9**	**0.44**	**none**
	Control	**5**		
Internal Helical	**Treatment**	**10**	**0.68**	**none**
	Control	**8**		

1 No statistically significant differences were observed between treatment and control samples used with either type of pump. There were also no significant differences between treatment samples ($P=0.61$), or between control samples ($P=0.91$), used with the two types of pumps.

Table 13. Direct and delayed mortality associated with passage of chinook salmon through Archimedes-1 and Archimedes-2 during 27 trials for the Arch-Arch experiment (1997 and 1998).

LIFT	TYPE OF SAMPLE	MEAN DIRECT MORTALITY[1]		MEAN DELAYED MORTALITY[2]	
		% OF FISH PER TRIAL	P[3]	% OF FISH PER TRIAL	P[3]
Archimedes-1	Treatment	0.4	0.29	1.0	0.39
	Control	0.8		1.0	
Archimedes-2	Treatment	0.4	0.74	0.9	0.70
	Control	0.4		0.7	

1 From mortalities tallied at the time juveniles in each sample were collected from holding tanks.
2 From mortalities observed among juveniles in each sample that were held for 96-h post-trial observation.
3 $P \leq 0.05$ was taken to indicate a statistically significant difference between treatment and control samples.

Table 14. Direct and delayed mortality associated with passage of chinook salmon through the Archimedes lifts and the internal helical pump during 40 trials for the Arch-helical experiment (1997 and 1999).

PUMP	TYPE OF SAMPLE	MEAN DIRECT MORTALITY[1]		MEAN DELAYED MORTALITY[2]	
		% OF FISH PER TRIAL	P[3]	% OF FISH PER TRIAL	P[3]
Archimedes	Treatment	0.8[4]	0.02	0.7	0.60
	Control	0.1		0.4	
Internal Helical	Treatment	2.8[4]	<0.01	0.8	0.95
	Control	0.5		0.6	

1 From mortalities tallied at the time juveniles in each sample were collected from holding tanks.
2 From mortalities observed among juveniles in each sample that were held for 96-h post-trial observation.
3 $P \leq 0.05$ was taken to indicate a statistically significant difference between treatment and control samples.
4 The difference in %-direct mortality was highly significant for treatment samples used with the two types of pumps ($P=0.001$), but the difference between control samples used with the two types of pumps was not ($P=0.44$).

Table 15. Descaling and other injuries that occurred on chinook salmon that were dead on arrival in holding tanks (direct mortalities). Except as noted in footnote 1, each direct mortality that occurred during 27 trials for the Arch-Arch experiment, and 40 trials for the Arch-helical experiment, was inspected for injuries.

EXPERIMENT	PUMP	TYPE OF SAMPLE	NO. OF FISH INSPECTED	% WITH INJURIES	% OF SURFACE DESCALED		% OF FISH WITH OTHER INJURIES			
					MEAN	RANGE	HEAD	EYE	SKIN	FINS
Arch-Arch	Arch-1	Treatment	3	100	28	0-85	66	33	100	100
		Control	6	100	15	0-90	66	100	83	50
	Arch-2	Treatment	3	100	20	0-60	66	33	100	66
		Control	2[1]	100	45	0-90	100	100	100	50
Arch-Helical	Arch	Treatment	10	100	11	0-75	60	70	70	50
		Control	1	100	-	85	0	100	100	0
	Helical	Treatment	33	97	27	0-100	88	64	70	42
		Control	6	100	38	0-89	66	66	83	50

1 Three direct mortalities occurred in these control samples. One of the three fish was not examined for injuries.

TABLES OF THE APPENDIX

Table A-1. Between-year comparisons of time-in-travel for chinook salmon in treatment (T) and control (C) samples in the Arch-Arch experiment using cumulative percentages for fish retrieved from holding tanks at intervals of time following their release.

TIME (MIN)	ARCHIMEDES-1				ARCHIMEDES-2			
	1997		1998		1997		1998	
	T (410)	C (416)	T (419)	C (432)	T (412)	C (416)	T (432)	C (431)
10	93	91	40	82	91	93	48	88
20	97	92	62	85	95	97	68	92
30	98	93	72	89	97	97	74	94
Sweep[1]	98	93	76	89	97	98	78	94
Plus *Late*[1]	99	94	92	92	98	99	93	98

1. See text, METHODS, *Recovering Samples of Released Fish,* for descriptions of *sweep* and *late.*

Table A-2. Between-year comparisons of time-in-travel for chinook salmon in treatment (T) and control (C) samples in the Arch-helical experiment using cumulative percentages for fish retrieved from holding tanks at intervals of time following their release.

TIME (MIN)	ARCHIMEDES LIFTS				INTERNAL HELICAL PUMP			
	1997		1999		1997		1999	
	T (797)	C (781)	T (476)	C (476)	T (773)	C (798)	T (473)	C (477)
10	80	80	80	90	92	87	82	95
20	88	83	86	96	94	91	85	97
30	92	87	88	97	96	93	88	97
Sweep[1]	94	90	88	97	98	97	90	97
Plus *Late*[1]	97	98	93	97	99	97	92	97

1. See text, METHODS, *Recovering Samples of Released Fish,* for descriptions of *sweep* and *late.*

Table A-3. Mortalities in samples of juvenile chinook salmon that were used to compare the effects of passage through Archimedes-1 and Archimedes-2 (1997 and 1998).

TRIAL NO. & DATE		SALMON RUN & MEAN FORK LENGTH (SD)	NO. OF FISH RELEASED				NO. OF HOLDOUTS[1]				NO. OF DIRECT MORTALITIES[2]				NO. OF DELAYED MORTALITIES[3]			
			ARCH-1		ARCH-2		ARCH-1		ARCH-2		ARCH-1		ARCH-2		ARCH-1		ARCH-2	
			T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
3/11/97	1	Fall 44 mm (2.7)	31	32	32	32	0	5	1	0	0	0	0	0	0	0	1	0
3/13/97	2		30	32	32	32	0	3	0	0	0	0	0	0	1	0	0	1
	3		32	32	30	32	0	2	0	1	0	0	0	0	0	4	0	0
3/18/97	4	Fall 48 mm (3.0)	32	32	31	32	0	0	0	3	0	1	0	0	0	0	0	1
	5		31	32	32	32	0	0	0	0	0	0	0	0	0	0	0	1
3/25/97	6	Fall 52 mm (3.8)	32	32	32	32	0	3	1	0	0	0	0	0	0	0	0	0
	7		32	32	32	32	0	1	0	0	0	0	0	0	1	0	1	0
4/22/97	8	Late-Fall 37 mm (1.5)	30	32	32	32	2	2	3	1	0	0	1	0	0	0	0	0
	9		32	32	32	32	0	2	0	0	0	0	0	0	0	0	0	-
4/24/97	10		32	32	32	32	1	1	2	1	1	0	0	1	1	0	0	1
	11		32	32	32	32	0	4	0	0	0	0	1	1	1	2	0	0
4/29/97	12	Late-Fall 41 mm (1.9)	32	32	32	32	0	0	0	0	0	0	0	0	0	1	0	0
	13		32	32	31	32	0	2	0	0	1	0	0	0	0	0	0	0
3/17/98	14	Fall 48 mm (2.8)	32	31	32	32	1	10	4	5	1	0	0	0	0	0	0	0
	15		32	32	32	31						2	0	0	0	0	1	0
3/19/98	16		32	32	32	32	5	6	5	0	0	2	0	0	0	0	0	0
4/07/98	17	Fall 55 mm (3.1)	32	32	32	32	0	3	3	0	0	0	0	0	0	0	0	0
4/15/98	18	Fall 65 mm (5.1)	32	32	32	31	3	0	0	0	0	0	0	1	0	0	0	0
4/16/98	19		32	32	32	32	2	0	6	1	0	0	0	0	0	0	0	0
5/13/98	20	Late-Fall 37 mm (1.8)	20	25	25	25	1	5	0	3	0	1	0	0	0	0	0	1
	21		23	25	25	25	1	2	3	0	0	0	0	0	0	0	0	0
5/14/98	22		32	32	32	32	11	1	3	0	0	0	0	0	3	0	4	0
	23		29	32	32	32		6		0	0	0	1	0		0		0

Table A-3 Continued.

TRIAL NO. & DATE	SALMON RUN & MEAN FORK LENGTH (SD)	NO. OF FISH RELEASED				NO. OF HOLDOUTS[1]				NO. OF DIRECT MORTALITIES[2]				NO. OF DELAYED MORTALITIES[3]			
		ARCH-1		ARCH-2		ARCH-1		ARCH-2		ARCH-1		ARCH-2		ARCH-1		ARCH-2	
		T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
5/19/98 24	Late-Fall	29	32	31	31	4	0		0	0	0	0	0	0	0	0	0
	39 mm (2.2)							5									
25		31	32	31	32	0	0		1	0	0	0	0	0	0	0	0
5/26/98 26	Late-Fall	32	32	32	32		0	3	0	0	0	0	0	0	0	0	0
	40 mm (2.4)					4											
27		31	31	32	32		0	0	0	0	0	0	0	0	0	0	0
GRAND TOTALS FOR COLUMNS TOTALS FOR 1997 (13 TRIALS) TOTALS FOR 1998 (14 TRIALS)		829 410 419	848 416 432	844 412 432	847 416 431	35 3 32	58 25 33	39 7 32	15 6 10	3 2 1	6 1 5	3 2 1	3 2 1	7 4 3	7 7 0	7 2 5	5 4 1
GRAND TOTAL NO. FISH EXAMINED TOTAL EXAMINED FOR 1997 TOTAL EXAMINED FOR 1998										794 407 387	790 391 399	805 405 400	832 411 421	737 379 358	730 364 366	748 377 371	744 352 392
OVERALL PERCENTAGE PER COLUMN PERCENTAGE FOR 1997 PERCENTAGE FOR 1998						4 1 8	7 6 8	5 2 7	2 1 2	0.4 0.5 0.3	0.8 0.3 1.3	0.4 0.5 0.3	0.5 0.5 0.2	0.9 1.1 0.8	1.0 1.9 0.0	0.9 0.5 1.3	0.6 1.1 0.3

1 These columns show the number of juvenile chinook that were released in trials but were not recovered in holding tanks. During some trials, for example trials 14 and 15, some juveniles that were released did not appear in holding tanks for a long period of time (12 hours to 4 days) after they were released. These *late* fish could not be assigned to a particular trial, but because of markings (Bismarck brown-Y and/or fin clips), they could be assigned to a specific pump and to treatment or control samples that were used on a particular date. The record of holdouts for trials in which this occurred is offset from rows of data in the table that show results of individual trials (e.g., trials 14 and 15).

2 These columns show the number of juvenile chinook in each sample that were dead at the time they were collected from holding tanks.

3 These columns show the number of mortalities that occurred during 96-h post-trial observations among those juveniles in each sample that were alive when taken from holding tanks (delayed mortalities). The dash (-) in the far right-hand column is for a sample of juveniles that accidentally escaped from their live-cage during the post-trial period.

Table A-4. Quality control assessments of descaling and potentially debilitating injuries that hatchery-reared juvenile chinook salmon had prior to preparation of samples that were used in trials to compare the effects of passage through Archimedes-1 and Archimedes-2 (1997 and 1998).

SESSION[1] AND (TRIAL NO.)	SALMON RUN & MEAN FORK LENGTH	NO. OF[2] JUVENILES OBSERVED	MISSING INDIVIDUAL SCALES[3]		NO. OF CHINOOK WITH BODY[4] ABNORMALITIES			NO. OF CHINOOK WITH FIN ABNORMALITIES[4]				
			NO. OF FISH	% OF SCALED SURFACE	HEAD	EYE	SKIN	PECTORAL	PELVIC	DORSAL	ANAL	CAUDAL
1 (1,2,3)	Fall 44 mm	30	-	-	0	1[4]	0	0	0	0	0	0
2 (4,5)	Fall 48 mm	30	-	-	0	0	1[5]	0	0	0	0	0
3 (6,7)	Fall 52 mm	30	-	-	0	0	0	0	0	0	0	0
4 (8,9,10,11)	Late-Fall 37 mm	30	-	-	0	0	1[6]	1[7]	1[7]	1[7]	1[7]	0
5 (12,13)	Late-Fall 41 mm	30	-	-	0	0	0	2[8]	0	0	0	0
6 (14,15,16)	Fall 48 mm	30	-	-	0	0	0	0	1[9]	0	0	1[10]
7 (17)	Fall 55 mm	30	12	Range 1-5 Mean 2	0	0	0	1[11]	0	0	0	0
8 (18,19)	Fall 65 mm	29	7	Range 1-10 Mean 3	0	0	0	0	0	0	0	0
9 (20,21,22,23)	Late-Fall 37 mm	29	-	-	0	0	2[12]	0	0	0	0	0
10 (24,25)	Late-Fall 39 mm	30	-	-	0	0	0	0	0	0	0	0
11 (26,27)	Late-Fall 40 mm	30	-	-	0	0	1[13]	0	0	0	0	0
Totals		328	-	-	0	1	5	4	2	1	1	1

Table A-4 Continued: Footnotes.

1 Numbers for trials, in parentheses in this column, are the numbers given to trials on the specific dates shown in Appendix Table A-3. *Sessions* were periods of short duration (1-3 days). The trials in each session were conducted with juvenile chinook salmon that had the same history of rearing at Coleman National Fish Hatchery, and the same history of transport to Red Bluff and holding in the wellwater facility. Juveniles used in trials of each session were also processed as one group during pre-trial preparations; that is during marking, moving from the wellwater facility to the riverwater facility, separation into live cages, and acclimation to riverwater.

2 At the start of each session, one group of several hundred juvenile chinook was randomly selected for use in trials from among all of the juveniles that were held at the wellwater facility. As standard practice, 30 individuals were then removed from this trial-group. These juveniles were examined for descaling, and for injuries on the body and fins. They were also weighed and measured for fork-length to obtain a condition factor. The purpose of this work was to give some assurance that fish used in trials were robust and not badly damaged.

3 Numbers reported in these columns resulted from microscopic detection of areas where individual scales were missing from scaled surfaces of experimental fish. Data are shown only for juveniles in trial-groups with mean fork-length ≥55 mm. Scales on these juveniles were well developed with distinct margins so that areas of missing scales were readily distinguishable. Dashes (-) in these columns are for samples of juveniles from trial-groups with mean fork-length <55 mm that had small, transparent scales which were poorly developed. Detection of missing scales on these fish was difficult, and estimates of the extent of descaling were unreliable with microscopic techniques that were used during this study.

Descalings due to superficial abrasions are listed in the adjacent column dealing with *Body Abnormalities - Skin* (see footnote 4).

4 Superscripts on numbers in these columns are used to identify the occurrence of specific abnormalities that are listed below.

4 Slightly bulging right eye.
5 Abrasion covering 5% of fish's scaled surface.
6 Abrasion covering 3% of fish's scaled surface.
7 Fin abnormalities shown in this row occurred on a single fish. It had hemorrhaging at the base of both pectoral fins and both pelvic fins, and hemorrhaging at the base of all rays of the dorsal and anal fins.
8 One of these fish had hemorrhaging at the base of the left pectoral fin, and the other fish had the tip of the right pectoral fin eroded to >30% of the total area of the fin.
9 Right pelvic fin slightly folded.
10 Caudal fin wrinkled.
11 Right pectoral fin >30% eroded.
12 Both fish hemorrhaging from anal fin forward long ventral side.
13 Bruise dorsal to the anal fin.

Table A-5. The frequency of juvenile chinook salmon with superficial abrasions, and sizes of the abrasions on individuals taken randomly from samples that were used to compare pump-passage effects of Archimedes-1 and Archimedes-2 (1997-1998).

DATE & TRIAL NO.		SALMON RUN & FORK LENGTH	PERCENTAGE OF SCALED SURFACE ABRADED ON EACH FISH EXAMINED[1]							
			PRE-TRIAL SAMPLES				POST-TRIAL SAMPLES			
			ARCHIMEDES-1		ARCHIMEDES-2		ARCHIMEDES-1		ARCHIMEDES-2	
			TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL
3/11/97	1	Fall 44 mm	0 & 0	0 & 0	0 & 0	0 & 0	0 & 0	0 & 0	0 & 0	0 & 0
3/13/97	2		0 0	0 0	0 0	0 0	30 75	0 0	5 0	0 0
	3		0 0	23 0	0 0	0 0	0 5	0 3	10 0	0 0
3/18/97	4	Fall 48 mm	0 0	0 0	0 0	0 0	30 0	13 0	0 8	0 0
	5		0 0	0 0	0 0	0 0	0 35	0 5	0 0	0 0
3/25/97	6	Fall 52 mm	0 0	0 0	3 0	0 0	0 5	0 0	3 5	0 0
	7		0 0	0 0	0 0	0 0	0 10	0 0	0 0	0 0
4/22/97	8	Late-Fall 37 mm	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	9		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
4/24/97	10		0 0	0 0	0 0	0 0	8 10	0 0	5 0	3 0
	11		0 0	0 0	0 0	0 0	0 0	0 15	0 0	0 0
4/29/97	12	Late-Fall 41 mm	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	13		0 0	0 0	0 0	0 3	0 0	0 0	0 0	0 0
3/17/98	14	Fall 48 mm	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	15		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
3/19/98	16		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
4/07/98	17	Fall 55 mm	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
4/15/98	18	Fall 65 mm	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
4/16/98	19		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0

Table A-5 Continued.

DATE & TRIAL NO.		SALMON RUN & FORK LENGTH	PERCENTAGE OF SCALED SURFACE ABRADED ON EACH FISH EXAMINED[1]							
			PRE-TRIAL SAMPLES				POST-TRIAL SAMPLES			
			ARCHIMEDES-1		ARCHIMEDES-2		ARCHIMEDES-1		ARCHIMEDES-2	
			TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL
5/13/98	20	Late-Fall 37 mm	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	21		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
5/14/98	22		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	23		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
5/19/98	24	Late-Fall 39 mm	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	25		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
5/26/98	26	Late-Fall 40 mm	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	27		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
NUMBER OF CHINOOK EXAMINED			54	54	54	54	54	54	54	54
NUMBER OF CHINOOK WITH ABRASIONS			0	1	1	1	9	4	6	1
% SCALED SURFACE ABRADED ON AFFECTED FISH			Range: - Mean: -	Range: 0-23 Mean: -	Range: 0-3 Mean: -	Range: 0-3 Mean: -	Range: 3-75 Mean: 22	Range: 3-13 Mean: 9	Range: 5-10 Mean: 7	Range: 0-3 Mean: -

1 Each entry in this table represents a single fish. These fish were selected as follows. Four separate samples of juvenile chinook salmon were used for each of the trials for which data are reported in this table. Archimedes-1 and Archimedes-2 were run simultaneously. During each trial, two of the samples used were released in the intake of either the Archimedes-1 or Archimedes-2 (treatment). Two additional samples, one for Archimedes-1 and one for Archimedes-2, were released just downstream of the fallouts of their discharges into channels leading to the pumping plant's fish-bypass system (control). Prior to release, two juvenile chinook were removed at random from each of the four samples used for each trial. These fish were examined to establish an estimate of the pre-passage condition of juveniles in samples. During each trial, two live juvenile chinook were also removed at random from each control and treatment sample after juveniles in samples were recovered in holding tanks. These fish were examined to establish an estimate of the post-passage condition of juveniles in samples.

Table A-6. Areas of missing scales on scaled surfaces of juvenile chinook salmon (≥55 mm fork length) taken pre-passage and post-passage from samples that were used in the Arch-Arch experiment to assess the effects of pump-passage (1998).

DATE & TRIAL NO.	SALMON RUN & MEAN FORK LENGTH	PERCENTAGE OF BODY SURFACE WITHOUT SCALES ON EACH FISH EXAMINED[1]							
		PRE-PASSAGE SAMPLES[2]				POST-PASSAGE SAMPLES[2]			
		ARCH-1		ARCH-2		ARCH-1		ARCH-2	
		TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL
4/07/98 17	Fall 55 mm	2 & 0	0 & 0	0 & 0	0 & 0	4 & 0	0 & 0	0 & 3	0 & 1
4/15/98 18	Fall 62 mm	0 0	0 0	0 1	0 0	0 0	0 1	0 1	5 0
4/16/98 19		0 0	1 0	0 0	1 3	0 0	2 0	0 1	0 0
NUMBER OF CHINOOK EXAMINED		6	6	6	6	6	6	6	6
NUMBER OF CHINOOK WITH DESCALING		1	1	1	2	1	2	3	2
MEAN %-SCALED SURFACE DESCALED ON AFFECTED FISH		-	-	-	-	-	-	-	-
MEAN %-DESCALED PER CHINOOK EXAMINED		-	-	-	-	-	-	-	-

1 Each entry in this table represents a single fish. These fish were selected as follows. Four separate samples of juvenile chinook salmon were used for each of the trials for which data are reported in this table. The two Archimedes lifts were run simultaneously. During each trial, two of the samples used were released in the intake of either Archimedes-1 or Archimedes-2 (treatment). Two additional samples, one for each lift, were released just downstream of the fallouts of their discharges into channels leading to the pumping plant's fish-bypass system (control). Prior to release, two juvenile chinook were removed at random from each of the four samples used for each trial. These fish were examined to establish an estimate of the pre-passage condition of juveniles in samples. During each trial, two live juvenile chinook were also removed at random from each control and treatment sample after juveniles in samples were recovered in holding tanks. These fish were examined to establish an estimate of the post-passage condition of juveniles in samples.

2 Numbers reported in these columns resulted from microscopic detection of areas where individual scales were missing from scaled surfaces of experimental fish. Data are shown only for juveniles in trial-groups with mean fork-length ≥55 mm. Scales on these juveniles were well developed with distinct margins so that areas of missing scales were readily distinguishable. In contrast, juveniles from trial-groups with mean fork-length <55 mm had small, transparent scales that were poorly developed. Detection of missing scales on these fish was difficult and estimates of the extent of descaling were unreliable with microscopic techniques that were used during this study.

Table A-7. The number of juvenile chinook salmon that had sub-lethal injuries on the head, body and fins when taken from pre-passage and post-passage samples that were used to compare the effects of passage through Archimedes-1 and Archimedes-2.

DATE & TRIAL NO.		SALMON RUN & MEAN FORK LENGTH	THE NUMBER OF CHINOOK SALMON WITH INJURIES[1]							
			PRE-PASSAGE SAMPLES				POST-PASSAGE SAMPLES			
			ARCHIMEDES-1		ARCHIMEDES-2		ARCHIMEDES-1		ARCHIMEDES-2	
			TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL
3/11/97	1	Fall 44 mm	2[1,2]	0	0	0	0	0	0	0
3/13/97	2		0	0	0	0	0	0	0	0
	3		0	0	0	0	0	0	0	0
3/18/97	4	Fall 48 mm	0	0	0	0	0	0	0	0
	5		0	0	0	0	1[3]	1[4]	1[5]	0
3/25/97	6	Fall 52 mm	0	0	0	0	0	0	0	0
	7		0	0	0	0	0	0	0	0
4/22/97	8	Late-Fall 37 mm	0	0	0	1[6]	0	0	0	0
	9		0	0	0	0	0	0	0	0
4/24/97	10		0	0	0	1[7]	0	0	0	0
	11		0	0	0	2[8,9]	1[10]	0	0	2[11]
4/29/97	12	Late-Fall 41 mm	0	1[12]	0	0	0	0	0	0
	13		0	0	0	1[13]	0	1[14]	0	1[15]
3/17/98	14	Fall 48 mm	0	0	0	0	0	0	0	0
	15		0	0	0	0	0	0	0	2[16]
3/19/98	16		0	0	0	0	0	0	0	0
4/07/98	17	Fall 55 mm	0	0	0	0	0	0	0	0
4/15/98	18	Fall 65 mm	0	0	0	0	0	0	0	0
4/16/98	19		0	0	0	0	0	0	0	0

Table A-7 Continued.

DATE & TRIAL NO.		SALMON RUN & MEAN FORK LENGTH	THE NUMBER OF CHINOOK SALMON WITH INJURIES[1]							
			PRE-PASSAGE SAMPLES				POST-PASSAGE SAMPLES			
			ARCHIMEDES-1		ARCHIMEDES-2		ARCHIMEDES-1		ARCHIMEDES-2	
			TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL
5/13/98	20	Late-Fall 37 mm	0	0	0	0	0	0	0	0
	21		0	0	0	0	0	0	1[17]	0
5/14/98	22		0	0	0	0	1[18]	0	0	0
	23		0	0	0	0	0	0	0	0
5/19/98	24	Late-Fall 39 mm	0	0	0	0	0	0	0	0
	25		0	0	0	0	0	0	0	0
5/26/98	26	Late-Fall 40 mm	0	0	0	0	0	0	0	0
	27		0	0	1[19]	0	0	0	0	0
NUMBER OF CHINOOK EXAMINED			54	54	54	54	54	54	54	54
NUMBER OF CHINOOK WITH INJURIES			2	1	1	5	3	2	2	5

1 Each entry in this table resulted from examination of two fish. Zeros are shown in the table for samples in which fish had no injuries. For samples in which fish had injuries, the number of injured fish is shown.

Fish examined for injuries were selected as follows. Four separate samples of juvenile chinook salmon were used for each of the trials for which data are reported in this table. The two Archimedes lifts were run simultaneously. During each trial, two of the samples used were released in the intake of either Archimedes-1 or Archimedes-2 (treatment). Two additional samples, one for Archimedes-1 and one for Archimedes-2, were released just downstream of the fallouts of their discharges into channels leading to the pumping plant's fish-bypass system (control). Prior to release, two juvenile chinook were removed at random from each of the four samples used for each trial. These fish were examined to establish an estimate of the pre-passage condition of juveniles in samples. During each trial, two live juvenile chinook were also removed at random from each control and treatment sample after juveniles in samples were recovered in holding tanks. These fish were examined to establish an estimate of the post-passage condition of juveniles in samples.

Table A-7 Footnote Continued.

A superscript accompanies those samples in Table A-7 in which fish had injuries. Superscript numbers from the table are given below with the kind of injury each fish had. Where (2) is shown in the table below, both injured fish in the superscripted sample had the same injury. The following notations are used below to indicate the type of sample from which each injured fish was drawn; that is, Pre-Ps indicates an injured fish was drawn from a Pre-passage sample, A^1-T and A^1-C indicate that injured fish were drawn from treatment and control samples used with Archimedes-1, and A^2-T and A^2-C indicate that injured fish were drawn from treatment and control samples used with Archimedes-2.

Sub-lethal Injuries							
Head		Eye		Body		Fins	
No. & Sample Type	Injury	No.	Injury	No.	Injury	No.	Injury
1 Pre-Ps	abrasion left operculum	6 Pre-Ps	right eye bulging	3 A^1-T^+	pinhead puncture wound on lateral line	- -	none
2 Pre-Ps	abrasion right operculum	7 Pre-Ps*	left eye bulging; right eye sunken	4 A^1-C^+	vertical pinch mark posterior to head		
12 Pre-Ps	bruise left operculum	8 Pre-Ps	left eye bulging	15 A^2-C*	split skin posterior to adipose fin		
14 A^1-C	bruise right operculum	9 Pre-Ps	right eye bulging; left eye sunken	7 Pre-Ps*	bruise between pectoral fins		
13 Pre-Ps	wound right operculum; small lesion left operculum	11 A^2-C	right eye bulging (2)	5 A^2-T	compressed area right side between pelvic and caudal fins		
15 A^2-C*	abraded right operculum	19 Pre-Ps	left eye bulging	10 A^1-T	bruise right side posterior to right		
16 A^2-C	hemorrhage left eye socket (2)			17 A^2-T	dark bruise on left side		
18 A^1-T	hemorrhage lower jaw						

* Injuries on these fish are listed in more than one column.

\+ These fish also had abrasions.

Table A-8. Mortalities in samples of chinook salmon that were used to compare the effects of passage through the Archimedes lifts and the internal helical pump (1997 and 1999).

DATE & TRIAL NO.		SALMON RUN & MEAN FORK LENGTH (SD)	PUMP[1] NO.	NO. OF FISH RELEASED				NO. OF HOLDOUTS[2]				NO. OF DIRECT MORTALITIES[3]				NO. OF DELAYED MORTALITIES[4]			
				ARCH		HELICAL		ARCH		HELICAL		ARCH		HELICAL		ARCH		HELICAL	
				T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
03/27/97	1	Fall 52 mm (3.8)	1 vs 3	32	32	29	32	3	1	2	2	0	0	0	0	0	0	0	0
	2			32	32	32	32	0	1	2	2	0	0	0	0	0	0	0	0
04/01/97	3	Fall 56 mm (3.4)	2 vs 3	32	32	32	32	0	0	0	4	2	0	0	0	0	1	0	0
	4			30	32	13	32	0	0	0	1	1	0	0	0	2	0	0	1
	5			32	13	31	32	0	1	0	0	3	0	2	0	0	0	0	0
04/08/97	6	Fall 58 mm (4.2)	1 vs 3	32	32	32	32	0	0	0	2	0	0	2	0	0	0	0	0
	7			32	32	31	32	0	1	0	0	0	0	0	0	0	0	0	0
04/10/97	8		1 vs 3	32	32	30	32	0	0	0	0	0	0	0	0	0	0	0	0
	9			32	32	32	32	0	1	0	2	0	0	0	0	0	0	0	0
04/17/97	10	Late-Fall 34 mm (0.9)	1 vs 3	32	32	32	32	5	2	0	0	0	0	0	0	0	0	0	0
	11			32	32	32	32	0	0	0	2	1	0	1	0	3	1	1	1
05/27/97	12	Late-Fall 56 mm (3.0)	1 vs 3	32	32	32	32	1	1	1	2	0	0	2	0	0	0	0	0
	13			32	32	32	32	0	1	0	1	0	0	0	0	0	0	0	0
05/29/97	14		2 vs 3	32	32	32	32	0	2	0	0	0	0	2	0	0	0	0	0
	15			32	32	32	32	0	0	0	0	0	0	0	0	0	0	0	2
06/10/97	16	Late-Fall 60 mm (4.7)	1 vs 3	32	32	32	32	0	1	1	0	0	0	2	0	0	0	0	0
	17			32	32	32	32	0	0	0	2	0	0	1	0	0	0	0	0
06/18/97	18	Late-Fall 61 mm (3.8)	1 vs 3	32	32	32	32	2	0	3	1	0	0	3	0	0	0	0	0
	19			31	32	31	32	3	1	0	0	0	0	0	1	0	0	0	0
06/30/97	20	Late-Fall 72 mm (6.5)	2 vs 3	32	32	32	32	0	0	0	0	0	0	2	0	0	0	0	0
	21			32	32	32	32	0	0	0	2	0	0	0	0	0	0	0	0
07/02/97	22		1 vs 3	32	32	32	32	3	3	0	1	0	0	2	0	0	0	0	0
	23			32	32	32	32	4	3	0	0	0	0	0	0	0	0	1	0
07/08/97	24	Late-Fall 74 mm (5.5)	2 vs 3	32	32	32	32	0	0	0	0	0	0	0	0	0	0	0	0
	25			32	32	32	30	0	0	0	0	0	0	0	0	0	0	1	0

Table A-8 Continued.

DATE & TRIAL NO.	SALMON RUN & MEAN FORK LENGTH (SD)	PUMP[1] NO.	NO. OF FISH RELEASED				NO. OF HOLDOUTS[2]				NO. OF DIRECT MORTALITIES[3]				NO. OF DELAYED MORTALITIES[4]			
			ARCH		HELICAL		ARCH		HELICAL		ARCH		HELICAL		ARCH		HELICAL	
			T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
01/26/99 26	Fall 36 mm (1.2)	1 vs 3	32	32	32	32	1	1	5	2	0	0	3	2	0	0	1	0
27			32	32	31	32	3	1	0	4	0	0	1	1	0	0	1	1
01/28/99 28		2 vs 3	32	32	32	32	10	4	3	4	0	0	0	0	0	0	0	0
29			32	31	29	31	2	1	4	1	1	0	1	1	0	1	0	0
02/03/99 30	Fall 38 mm (1.5)	1 vs 3	31	32	30	32	2	2	0	0	0	0	1	0	0	0	0	1
31			32	31	32	32	5	3	0	0	0	0	2	0	0	0	0	0
02/24/99 32	Fall 46 mm (3.1)	2 vs 3	32	32	32	32	1	0	8	0	0	0	2	0	0	0	0	0
33			32	32	32	32	1	0	0	0	0	0	0	0	0	0	0	0
02/25/99 34		1 vs 3	30	32	32	32	3	0	0	1	1	1	1	0	0	1	0	0
03/17/99 35	Fall 42 mm (1.7)	2 vs 3	32	32	32	32	0	1	0	0	0	0	1	0	0	0	0	0
36			32	32	32	32	1	1	0	0	0	0	0	0	1	0	1	-
03/18/99 37		2 vs 3	32	30	32	30	2	0	1	0	0	0	1	0	0	0	3	0
38			32	32	32	32	1	0	0	0	0	0	1	1	1	0	0	1
03/25/99 39	Fall 46 mm (2.3)	1 vs 3	32	32	32	32	3	0	5	3	0	0	0	0	0	1	0	0
40			31	32	31	32	0	2	14	0	1	0	0	0	1	0	0	0
GRAND TOTALS FOR COLUMNS			1273	1257	1246	1275	56	35	49	39	10	1	33	6	8	5	9	7
TOTALS FOR 1997 (25 TRIALS)			797	781	773	798	21	19	9	24	7	0	19	1	5	2	3	4
TOTALS FOR 1999 (15 TRIALS)			476	476	473	477	35	16	40	15	3	1	14	5	3	3	6	3
GRAND TOTAL NO. FISH EXAMINED											1217	1223	1197	1236	1125	1142	1085	1119
TOTAL EXAMINED FOR 1997											776	763	764	774	717	713	696	721
TOTAL EXAMINED FOR 1999											441	460	433	462	408	429	389	398
OVERALL PERCENTAGE PER COLUMN							4	3	4	3	0.8	0.1	2.8	0.5	0.7	0.4	0.8	0.6
PERCENTAGE FOR 1997							3	2	1	3	0.9	0.0	2.5	0.1	0.7	0.3	0.4	0.5
PERCENTAGE FOR 1999							7	3	8	3	0.7	0.2	3.2	1.1	0.7	0.7	1.5	0.8

Table A-8 Continued (Footnotes).

1 Pump numbers 1 and 2 were Archimedes lifts. Pump number 3 was the internal helical pump.

2 These columns show the number of juvenile chinook that were released in trials but were not recovered in holding tanks (holdouts).

3 These columns show the number of juvenile chinook in each sample that were dead at the time they were collected from holding tanks (direct mortalities).

4 These columns show the number of mortalities that occurred during 96-h post-trial observations among those juveniles in each sample that were alive when taken from holding tanks (delayed mortalities). The dash (-) in the far right-hand column is for a sample of juveniles that accidentally escaped from their live-cage during the post-trail period.

Table A-9. Quality control assessments of descaling and potentially debilitating injuries that hatchery-reared juvenile chinook salmon had prior to preparation of samples that were used in trials to compare the effects of passage through the Archimedes and internal helical pumps (1997 and 1999).

SESSION[1] AND (TRIAL NO.)	SALMON RUN & MEAN FORK LENGTH	NO. OF[2] JUVENILES OBSERVED	MISSING INDIVIDUAL SCALES[3]		NO. OF CHINOOK WITH BODY[4] ABNORMALITIES			NO. OF CHINOOK WITH FIN ABNORMALITIES[4]				
			NO. OF FISH	% OF SCALED SURFACE	HEAD	EYE	SKIN	PECTORAL	PELVIC	DORSAL	ANAL	CAUDAL
1 (1,2)	Fall 50 mm	30	-	-	0	0	0	0	0	0	0	0
2 (3,4,5)	Fall 54 mm	30	-	-	0	0	1[4]	0	0	0	0	0
3 (6,7,8,9)	Fall 59 mm	30	27	Range 1-8 Mean 3	0	0	0	0	0	0	0	0
4 (10,11)	Late-Fall 34 mm	30	-	-	0	0	0	0	0	0	0	0
5 (12,13,14,15)	Late-Fall 56 mm	30	22	Range 1-3 Mean 2	0	0	0	0	0	0	0	0
6 (16,17)	Late-Fall 60 mm	30	19	Range 1-3 Mean 2	0	0	0	0	0	0	0	0
7 (18,19)	Late-Fall 61 mm	30	27	Range 1-5 Mean 2	0	0	1[5]	0	0	0	0	0
8 (20,21,22,23)	Late-Fall 72 mm	30	14	Range 1-3 Mean 2	0	0	0	0	0	0	0	0
9 (24,25)	Late-Fall 74 mm	30	30	Range 1-6 Mean 2	0	0	0	0	0	0	0	0
10 (26,27,28,29)	Fall 37 mm	30	-	-	0	0	0	0	0	0	1[6]	0
11 (30,31)	Fall 39 mm	30	-	-	1[7]	0	3[8,9,10]	0	0	0	0	0
12 (33,33,34)	Fall 44 mm	30	-	-	0	0	0	0	0	0	0	0

Table 9 Continued.

SESSION[1] AND (TRIAL NO.)	SALMON RUN & MEAN FORK LENGTH	NO. OF[2] JUVENILES OBSERVED	MISSING INDIVIDUAL SCALES[3]		NO. OF CHINOOK WITH BODY[4] ABNORMALITIES			NO. OF CHINOOK WITH FIN ABNORMALITIES[4]				
			NO. OF FISH	% OF SCALED SURFACE	HEAD	EYE	SKIN	PECTORAL	PELVIC	DORSAL	ANAL	CAUDAL
13 (35,36,37,38)	Fall 43 mm	30	-	-	0	0	0	0	0	0	0	0
14 (39,40)	Fall 46 mm	30	-	-	0	0	0	0	0	0	0	0
TOTALS		420	-	-	1	0	5	0	0	0	1	0

1 The numbers for trials, in parentheses in this column, are the numbers given to trials on the specific dates shown in Appendix Table A-8. *Sessions* were periods of short duration (1-3 days). Trials in each session were conducted with juvenile chinook salmon that had the same history of rearing at Coleman National Fish Hatchery, and the same history of transport to Red Bluff and holding in the wellwater facility. Juveniles used in trials of each session were also processed as one group during pre-trial preparations; i.e., during marking, moving from the wellwater facility to the riverwater facility, separation into live cages, and acclimation to riverwater.

2 At the start of each session, one group of several hundred juvenile chinook was randomly selected for use in trials from among all of the juveniles that were held at the wellwater facility. As standard practice, 30 individuals were then removed from this trial-group. These juveniles were examined for descaling, and for injuries on the body and fins. They were also weighed and measured for fork-length to obtain a condition factor. The purpose of this work was to give some assurance that fish used in trials were robust and not badly damaged.

3 Numbers reported in these columns resulted from microscopic detection of areas where individual scales were missing from scaled surfaces of experimental fish. Data are shown only for juveniles in trial-groups with mean fork-length ≥55 mm. Scales on these juveniles were well developed with distinct margins so that areas of missing scales were readily distinguishable. Dashes (-) in these columns are for samples of juveniles from trial-groups with mean fork-length <55 mm that had small, transparent scales which were poorly developed. Detection of missing scales on these fish was difficult, and estimates of the extent of descaling were unreliable with microscopic techniques that were used during this study.

Descalings due to superficial abrasions are listed in the adjacent column dealing with *Body Abnormalities - Skin* (see footnote 4).

Table A-9 Continued: Footnote

4 Superscripts on numbers in these columns are used to identify the occurrence of specific abnormalities that are listed below.

- 4 With an abrasion covering 40% of scaled area on left side only.
- 5 With an abrasion covering 20% of scaled area on left side only.
- 6 Small nodule on one ray.
- 7 Nodule on right operculum.
- 8 Skin split (healed) anterior to dorsal fin.
- 9 Abrasion covering 3% of total scaled surface.
- 10 Abrasion covering 2% of total scaled surface.

Table A-10. The frequency of juvenile chinook salmon with superficial abrasions, and sizes of the abrasions on individuals taken pre-passage and post-passage from samples that were used to compare effects of passage through Archimedes lifts and the internal helical pump.

DATE & TRIAL NO.		SALMON RUN & MEAN FORK LENGTH	PERCENTAGE OF SCALED SURFACE ABRADED ON EACH FISH EXAMINED[1]							
			PRE-PASSAGE SAMPLES				POST-PASSAGE SAMPLES			
			ARCHIMEDES		HELICAL		ARCHIMEDES		HELICAL	
			TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL
3/27/97	1	Fall 50 mm	0 & 0	0 & 5	0 & 0	0 & 0	0 & 0	3 & 0	0 & 0	0 & 0
	2		0 0	0 0	5 0	0 0	0 0	0 0	0 0	10 0
4/01/97	3	Fall 54 mm	0 0	0 0	0 0	0 0	0 0	0 0	10 0	0 0
	4		0 0	0 0	0 -	0 0	0 0	0 0	0 -	0 0
	5		0 0	0 -	0 0	0 0	5 0	0 -	0 0	0 0
4/08/97	6	Fall 56 mm	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	7		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
4/10/97	8		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	9		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
4/17/97	10	Late Fall 34 mm	0 0	0 0	0 0	0 0	3 0	0 0	0 0	0 20
	11		0 5	0 0	15 0	0 0	0 0	0 0	10 10	20 0
5/27/97	12	Late-Fall 56 mm	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	13		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
5/29/97	14		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	15		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
6/10/97	16	Late-Fall 60 mm	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	17		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0

Table A-10 Continued.

DATE & TRIAL NO.		SALMON RUN & MEAN FORK LENGTH	PERCENTAGE OF SCALED SURFACE ABRADED ON EACH FISH EXAMINED[1]															
			PRE-PASSAGE SAMPLES								POST-PASSAGE SAMPLES							
			ARCHIMEDES				HELICAL				ARCHIMEDES				HELICAL			
			TREATMENT		CONTROL		TREATMENT		CONTROL		TREATMENT		CONTROL		TREATMENT		CONTROL	
6/18/97	18	Late-Fall 61 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	19		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6/30/97	20	Late-Fall 72 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	21		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/02/97	22		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	23		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7/08/97	24	Late-Fall 73 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	25		0	8	3	0	0	0	0	0	0	0	0	0	0	0	0	0
01/26/99	26	Fall 37 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	27		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
01/28/99	28	Fall 37 mm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	29		0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0
02/03/99	30	Fall 39 mm	0	0	0	0	0	0	0	0	0	0	0	0	30	0	0	0
	31		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
02/24/99	32	Fall 45 mm	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0
	33		0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
02/25/99	34	Fall 44 mm	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0

Table A-10 Continued.

DATE & TRIAL NO.		SALMON RUN & MEAN FORK LENGTH	PERCENTAGE OF SCALED SURFACE ABRADED ON EACH FISH EXAMINED[1]							
			PRE-PASSAGE SAMPLES				POST-PASSAGE SAMPLES			
			ARCHIMEDES		HELICAL		ARCHIMEDES		HELICAL	
			TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL
03/17/99	35	Fall 42 mm	0 & 0	0 & 0	0 & 0	0 & 0	0 & 0	0 & 0	0 & 0	0 & 0
	36		0 0	0 0	0 0	0 0	1 0	0 0	0 0	0 0
03/18/99	37	Fall 43 mm	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	38		0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
03/25/99	39	Fall 46 mm	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0
	40		0 0	0 0	0 0	0 0	0 0	0 0	2 0	0 0
NUMBER OF CHINOOK EXAMINED			80	79	79	80	80	79	79	80
NUMBER OF CHINOOK WITH ABRASIONS			2	2	3	0	4	1	6	4
% SCALED SURFACE ABRADED ON AFFECTED FISH			Range: 5-8 Mean: 7	Range: 3-5 Mean: 4	Range: 2-15 Mean: 7	Range: - Mean: -	Range: 1-20 Mean: 7	Range: 0-3 Mean: -	Range: 2-30 Mean: 13	Range: 4-20 Mean: 14

1 Each entry in this table represents a single fish. These fish were selected as follows. Four separate samples of juvenile chinook salmon were used for each of the trials for which data are reported in this table. One of the Archimedes lifts and the internal helical pump were run simultaneously. During each trial, two of the samples used were released in the intake of either the Archimedes lift or the internal helical pump (treatment). Two additional samples, one for the lift and one for the pump, were released just downstream of the fallouts of their discharges into channels leading to the pumping plant's fish-bypass system (control). Prior to release, two juvenile chinook were removed at random from each of the four samples used for each trial. These fish were examined to establish an estimate of the pre-passage condition of juveniles in samples. During each trial, two live juvenile chinook were also removed at random from each control and treatment sample after juveniles in samples were recovered in holding tanks. These fish were examined to establish an estimate of the post-passage condition of juveniles in samples.

Table A-11. Areas of missing scales on scaled surfaces of juvenile chinook salmon (≥55 mm fork-length) taken pre-passage and post-passage from samples that were used in the Arch-helical experiment to assess the effects of pump-passage.

DATE & TRIAL NO.		SALMON RUN & MEAN FORK LENGTH	PERCENTAGE OF BODY SURFACE WITHOUT SCALES ON EACH FISH EXAMINED[1]							
			PRE-PASSAGE SAMPLES[2]				POST-PASSAGE SAMPLES[2]			
			ARCHIMEDES		HELICAL		ARCHIMEDES		HELICAL	
			TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL
4/08/97	6	Fall 56 mm	0 & 3	0 & 2	0 & 5	4 & 4	0 & 2	1 & 1	1 & 5	0 & 0
	7		0 1	2 5	0 1	0 2	0 1	2 4	0 1	0 0
4/10/97	8		1 2	1 1	2 2	1 1	0 1	0 2	0 0	1 1
	9		2 2	1 1	0 0	0 2	0 2	1 2	0 2	0 2
5/27/97	12	Late-Fall 56 mm	2 4	0 2	0 2	0 1	0 3	0 1	0 1	0 0
	13		1 2	0 0	0 1	1 2	0 1	0 1	0 11	1 2
5/29/97	14		1 2	0 1	1 1	0 2	1 1	0 2	0 1	0 1
	15		1 4	0 2	0 0	2 2	0 0	0 1	0 1	0 0
6/10/97	16	Late-Fall 60 mm	0 1	0 1	3 3	0 1	0 3	0 3	0 9	2 2
	17		3 4	0 4	0 0	0 3	4 6	1 4	1 3	0 2
6/18/97	18	Late-Fall 61 mm	2 2	1 2	0 0	0 1	0 3	2 3	0 2	0 2
	19		0 1	1 2	2 3	1 1	1 3	0 2	0 2	1 3
6/30/97	20	Late-Fall 72 mm	0 3	0 0	0 0	0 1	0 0	0 0	0 0	0 1
	21		0 2	0 2	1 4	0 1	0 1	0 1	1 1	0 0
7/02/97	22		2 2	0 1	1 2	0 1	0 2	0 1	0 3	0 1
	23		1 1	0 2	3 3	0 2	0 3	0 2	1 3	0 0
7/08/97	24	Late-Fall 73 mm	3 5	0 0	4 7	1 2	1 3	3 3	0 1	0 3
	25		2 5	0 5	5 2	0 2	2 4	1 3	0 0	0 1

Table A-11 Continued.

TABULATIONS PER COLUMN	PRE-PASSAGE SAMPLES[2]				POST-PASSAGE SAMPLES[2]			
	ARCHIMEDES		HELICAL		ARCHIMEDES		HELICAL	
	TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL
NUMBER OF CHINOOK EXAMINED	36	36	36	36	36	36	36	36
NUMBER OF CHINOOK WITH DESCALING	30	20	24	24	21	24	19	16
MEAN %-SCALED SURFACE DESCALED ON AFFECTED FISH	3	2	2	2	2	2	3	2
MEAN %-DESCALED PER CHINOOK EXAMINED	2	1	2	1	1	1	1	<1

1 Each entry in this table represents a single fish. These fish were selected as follows. Four separate samples of juvenile chinook salmon were used for each of the trials for which data are reported in this table. One of the Archimedes lifts and the internal helical pump were run simultaneously. During each trial, two of the samples used were released in the intake of either the Archimedes lift or the internal helical pump (treatment). Two additional samples, one for the lift and one for the pump, were released just downstream of the fallouts of their discharges into channels leading to the pumping plant's fish-bypass system (control). Prior to release, two juvenile chinook were removed at random from each of the four samples used for each trial. These fish were examined to establish an estimate of the pre-passage condition of juveniles in samples. During each trial, two live juvenile chinook were also removed at random from each control and treatment sample after juveniles in samples were recovered in holding tanks. These fish were examined to establish an estimate of the post-passage condition of juveniles in samples.

2 Numbers reported in these columns resulted from microscopic detection of areas where individual scales were missing from scaled surfaces of experimental fish. Data are shown only for juveniles in trial-groups with mean fork-length ≥55 mm. Scales on these juveniles were well developed with distinct margins so that areas of missing scales were readily distinguishable. In contrast, juveniles from trial-groups with mean fork-length <55 mm had small, transparent scales that were poorly developed. Detection of missing scales on these fish was difficult and estimates of the extent of descaling were unreliable with microscopic techniques that were used during this study.

Table A-12. The number of juvenile chinook salmon that had sub-lethal injuries on the head, body and fins when taken pre-passage and post-passage from samples that were used to compare the effects of passage through the Archimedes lifts and internal helical pump.

DATE &	TRIAL NO.	SALMON RUN & MEAN FORK LENGTH	THE NUMBER OF CHINOOK SALMON WITH INJURIES[1]							
			PRE-PASSAGE SAMPLES				POST-PASSAGE SAMPLES			
			ARCHIMEDES		HELICAL		ARCHIMEDES		HELICAL	
			TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL
3/27/97	1	Fall 52 mm	0	0	0	0	0	0	0	0
	2		0	0	0	0	0	0	0	0
4/01/97	3	Fall 56 mm	0	0	0	0	0	0	0	0
	4		0	0	0*	0	0	0	0*	0
	5		0	0*	0	0	0	1[6]*	0	0
4/08/97	6	Fall 58 mm	1[1]	0	0	0	0	0	0	0
	7		2[2]	0	0	0	0	0	0	0
4/10/97	8		0	0	0	0	0	0	0	0
	9		0	0	0	0	1[5]	1[7]	0	0
4/17/97	10	Late Fall 34 mm	0	0	0	0	0	0	0	1[8]
	11		0	0	0	0	0	0	0	0
5/27/97	12	Late-Fall 56 mm	0	0	0	0	0	0	0	0
	13		0	0	0	0	0	0	0	2[9, 10]
5/29/97	14		0	0	0	0	0	0	0	0
	15		1[3]	1[4]	0	0	0	0	0	0
6/10/97	16	Late-Fall 60 mm	0	0	0	0	0	0	0	0
	17		0	0	0	0	0	0	0	0

Table A-12 Continued.

DATE & TRIAL NO.		SALMON RUN & MEAN FORK LENGTH	THE NUMBER OF CHINOOK SALMON WITH INJURIES[1]							
			PRE-PASSAGE SAMPLES				POST-PASSAGE SAMPLES			
			ARCHIMEDES		HELICAL		ARCHIMEDES		HELICAL	
			TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL
6/18/97	18	Late-Fall 61 mm	0	0	0	0	0	0	0	0
	19		0	0	0	0	1[18]	0	0	0
6/30/97	20	Late-Fall 72 mm	0	0	0	0	0	1[22]	0	0
	21		0	1[13]	0	0	0	0	0	0
7/02/97	22		0	0	0	0	0	0	0	0
	23		1[11]	0	0	0	0	0	0	0
7/08/97	24	Late-Fall 74 mm	0	0	0	0	0	0	0	0
	25		0	0	0	0	0	0	0	0
01/26/99	26	Fall 36 mm	0	1[14]	0	0	2[19]	0	1[24]	0
	27		0	0	2[15]	0	1[20]	0	0	1[30]
01/28/99	28		0	0	1[16]	1[17]	2[21]	1[23]	1[25]	0
	29		1[12]	0	0	0	0	0	2[26]	2[31]
02/03/99	30	Fall 38 mm	0	0	0	0	0	0	1[27]	0
	31		0	0	0	0	0	0	0	0
02/24/99	32	Fall 46 mm	0	0	0	0	0	0	1[28]	0
	33		0	0	0	0	0	0	2[29]	0
02/25/99	34		0	0	0	0	0	0	0	0

Table A-12 Continued.

DATE & TRIAL NO.		SALMON RUN & MEAN FORK LENGTH	THE NUMBER OF CHINOOK SALMON WITH INJURIES[1]							
			PRE-PASSAGE SAMPLES				POST-PASSAGE SAMPLES			
			ARCHIMEDES		HELICAL		ARCHIMEDES		HELICAL	
			TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL	TREATMENT	CONTROL
03/17/99	35	Fall 42 mm	0	0	0	0	0	0	0	0
	36		0	0	0	0	0	0	0	0
03/18/99	37		0	0	0	0	0	0	0	0
	38		0	0	0	0	0	0	0	0
03/25/99	39	Fall 46 mm	0	0	0	0	0	0	0	0
	40		0	0	0	0	0	0	0	0
NUMBER OF CHINOOK EXAMINED			80	79	79	80	80	79	79	80
NUMBER OF CHINOOK WITH INJURIES			6	3	3	1	7	4	8	6

1 Each entry in this table resulted from examination of two fish, except in the case of entries marked with an asterisk. Only one fish was examined for entries marked with an asterisk.

Fish examined for injuries were selected as follows. Four separate samples of juvenile chinook salmon were used for each of the trials for which data are reported in this table. One of the Archimedes lifts and the internal helical pump were run simultaneously. During each trial, two of the samples used were released in the intake of either the Archimedes lift or the internal helical pump (treatment). Two additional samples, one for the lift and one for the pump, were released just downstream of the fallouts of their discharges into channels leading to the pumping plant's fish-bypass system (control). Prior to release, two juvenile chinook were removed at random from each of the four samples used for each trial. These fish were examined to establish an estimate of the pre-passage condition of juveniles in samples. During each trial, two live juvenile chinook were also removed at random from each control and treatment sample after juveniles in samples were recovered in holding tanks. These fish were examined to establish an estimate of the post-passage condition of juveniles in samples.

Table A-12 Continued (Footnote).

A superscript accompanies those samples in Table A-12 in which fish had injuries. Superscript numbers from Table A-12 are given below with the kind of injury that each injured fish had. Where (2) is shown in the table below, both injured fish in the superscripted sample had the same injury. The following notations are used below to indicate the type of sample from which each injured fish was drawn; that is, Pre-Ps indicates an injured fish was drawn from a pre-passage sample. Fish from post-passage samples are marked A-T and A-C to indicate that injured fish were drawn from treatment and control samples used with the Archimedes lifts, and H-T and H-C indicate that injured fish were drawn from treatment and control samples used with the internal helical pump.

Sub-lethal Injuries							
Head		Eye		Body		Fins	
No. & Sample Type	Injury	No.	Injury	No.	Injury	No.	Injury
3 Pre-Ps	dorsal lesion	4 Pre-Ps	left eye bulging	1 Pre-Ps	small wound at base of right pectoral fin	2 Pre-Ps (2)	one dislocated fin
12 Pre-Ps	minor hemorrhage ventral where opercula meet	7 A-C	right eye bulging	5 A-T	discolored bruise ventral of dorsal fin	6 A-C	>30% of area of dorsal fin eroded
14 Pre-Ps (2)	"	8 H-C	right eye bulging	10 H-C	dorsal-ventral pinch mark behind head		
15 Pre-Ps (2)	"	9 H-C	right eye bulging	13 Pre-Ps	dorsal-ventral pinch mark behind head		
16 Pre-Ps	"	11 Pre-Ps	left eye bulging	22 A-C	bruise anterior of dorsal fin		
17 Pre-Ps	"	27 H-C	eye bulging and with hemorrhage				
18 A-T	hemorrhage on gill filament	28 H-C	eye with hemorrhage				
19 A-T	minor hemorrhage ventral where opercula meet	29 H-C (2)	eye bulging and with hemorrhage				
20 A-T	"						
21 A-T (2)	"						
23 A-C	"						
24 H-T	"						
25 H-T	"						
26 H-T (2)	"						
30 H-C	"						
31 H-C (2)	"						