IN-PLANT BIOLOGICAL EVALUATION OF THE RED BLUFF RESEARCH PUMPING PLANT ON THE SACRAMENTO RIVER IN NORTHERN CALIFORNIA:
1995 and 1996

A Summary Report
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IN-PLANT BIOLOGICAL EVALUATION OF THE RED BLUFF RESEARCH PUMPING PLANT ON THE SACRAMENTO RIVER IN NORTHERN CALIFORNIA: 1995 and 1996

Summary Report

C.D. McNabb, C.R. Liston and S.M. Borthwick

U.S. Bureau of Reclamation
Ecological Research and Investigations
Denver Technical Services Center
P.O. Box 25007
Denver, CO 80225-0007

Abstract. A research pumping plant was constructed on the Sacramento River in northern California as part of the commitment of the U.S. Bureau of Reclamation to improve fish passage at Red Bluff Diversion Dam; particularly the passage of adult and juvenile chinook salmon (*Oncorynchus tshawytscha*). Major portions of construction were completed in May of 1995 with installation of two Archimedes pumps and one internal helical pump. During the remainder of 1995 and in 1996, a variety of engineering modifications were made to pumps, screening facilities and fish bypass systems in the plant. The pumps ran sporadically during this interval. Fish passage work was conducted on an opportunistic schedule. Various procedures were tested for handling fish and evaluating mortality and injury cause by pump passage. Standardized procedures for conducting fish passage studies emerged from this preliminary work. These procedures, to be used for studies in 1997 and 1998, are described in this report. The Archimedes and internal helical pumps never ran simultaneously during 1995 and 1996. As a result, no observations were made to directly compare pump-types in regard to mortality and injury associated with passage. Observations on mortality and injury that were made with the Archimedes and internal helical pump were not sufficiently accurate to suggest that differences between these types of pumps exists. Because conditions in the pumping plant and procedures for handling fish were in transition during the period of observation, the information presented here on mortality and injury is preliminary in nature. It does provides an expectation for the range of results that may merge from standardized studies that will be conducted in 1997 and 1998.

For all pumps combined, a total of twenty-nine trials were conducted in which fish entrained from the Sacramento River were collected in holding tanks in the plant. Each trial had a 24-h duration, and separate samples were taken at the end of diurnal and nocturnal periods. In all, 20 different species of fish were entrained. Forty-eight percent of 2332 total fish were juvenile chinook salmon. Seventy-four percent of all species, and 75% of chinook salmon, were taken at night. Ninety-six percent of all entrained fish, and 97% of entrained chinook salmon, were alive when collected in the plant. Between 0.6% and 1.2% of live juvenile chinook entrained by any of the three pumps had external injuries.

In a second type of passage study, hatchery-reared juvenile chinook salmon were used as surrogates for riverine juveniles. In 65 separate trials, a total of 2080 juveniles were inserted in pump intakes and collected in downstream tanks. A total of 1725 juveniles were also passed from pump outfalls to holding tanks in 54 trials that were co-conducted with pump insertion trials. For all pumps combined, the calculated *pump-effect* on direct mortalities was <1%. The *pump-effect* on delayed mortality over 96-h post-passage observation was about 1%. The *pump-effect* on injuries during passage, estimated from examination of between 108 and 125 juveniles randomly selected before and after insertion in the pumps' flowstreams (a relatively small number of fish sampled), was zero. Hatchery-reared juvenile chinook used in these studies were relatively large; almost exclusively >46 mm fork length. Studies in 1997 and 1998 will emphasize the use of two size classes of juveniles; small fish with fork length from 30-45 mm, and larger ones from 46-70 mm fork length.

Four additional topics were addressed during 1995 and 1996. Hatchery-reared juveniles (1725) released at outfalls of the three pumps and collected in downstream tanks experienced ≤1% direct mortality. Less than 0.1% experienced delayed mortality (96 h), and about 1% of these fish received injuries. These observations suggest that the flowstreams from pump outfalls through screening facilities and bypass channels to collecting tanks in the plant are fish-friendly. A preliminary estimate (≥95%) was obtained for the efficiency with which chinook salmon entrained from the Sacramento River were captured in tanks in the plant. Exploratory studies conducted on passage of juvenile chinook through terminal (underground) portions of the plant's bypass system showed that residence times were long. A protocol was developed for safely flushing fish from the distal portion of the bypass should later studies show that such a strategy has advantages. In other work, sampling was conducted to relate the abundance of juvenile chinook passing the intake structure of the pumping plant and the abundance of juveniles entrained by the pumps. Passing juveniles were taken by a rotary screw trap, while entrained juveniles were collected in tanks in the plant. Sampling was done over 24-h periods on nine occasions to examine the variability in a *pump-take:trap-take* ratio. A ratio of about 0.50 was obtained except when juveniles passing the plant were uncommon. This work will continue in conjunction with expansive rotary screw trap sampling of downstream migrants in the river (Johnson and Martin 1997) in order to evaluate the reliability of using this *pump-take:trap-take* ratio to extrapolate to percentages of total out-migrating juvenile chinook that the pumping plant entrains.

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INTRODUCTION

The Red Bluff Research Pumping Plant is a U.S. Bureau of Reclamation facility located at the Tehama-Colusa Canal Operations and Maintenance Complex in Red Bluff, California. The plant is on the southwest shore of the Sacramento River immediately downstream from Red Bluff Diversion Dam. The dam and associated water conveyance systems were completed in 1964. The purpose of the dam is to impound water in the Sacramento River and divert it into a stilling basin. Water from the stilling basin runs by gravity southward in the Tehama-Colusa Canal for a distance of 182 km (113 mi). Pumps at the head works of the Corning Canal are also located on the stilling basin. Together these canals deliver water to irrigate farms and wildlife refuges in the northwest portion of the Central Valley of California.

The impoundment upstream of Red Bluff Diversion Dam is known as Lake Red Bluff. Commercial centers and homes of the City of Red Bluff occupy its shores. Historically, the dam has been operated to maintain the surface of the lake at an elevation of 77 ± 0.06 m (252.5 ± 0.2 ft) above mean sea level. This mode of operation provides a consistent hydraulic head on the Tehama-Colusa Canal, and gives the lake a surface area of 215 hectares (530 acres) and a mean depth of 2.3 m (7.4 ft). Minimum discharge from the lake has been set by law at 92 m^3/s (3250 cfs). Hydrographs for the Red Bluff reach of the river show that releases from the dam have always been higher than this minimum except on rare occasions during the middle and late years of prolonged droughts (Robert Bagshaw, U.S. Bureau of Reclamation, Red Bluff, California, personal communication).

Fisheries resources in the Sacramento River have been affected in a variety of ways since operations at Red Bluff Diversion Dam began (Hallock et al. 1982, Hallock 1983, Vondracek and Moyle 1983, Hallock and Fisher 1985, U.S. Fish and Wildlife Service 1987, Vogel et al. 1988). Impediments for populations of anadromous salmon and steelhead have captured the majority of attention. For example, the dam has delayed timely passage for adult salmonids on migration runs to upstream spawning grounds (Hallock et al. 1982, Vogel et al. 1988). This has been due in part to relatively low attraction flows from fish ladders that were put in place when the dam was constructed; that is, attraction flows that are low relative to flows through nearby gates of the dam that provide for a constant elevation on the surface of Lake Red Bluff. In addition, predators have tended to congregate in the dam's tailwaters. There they have fed on disoriented juvenile salmonids as they exited Lake Red Bluff in turbulent flows that passed under gates of the dam (Vogel et al. 1988, Garcia 1989).

Four runs of chinook salmon occur in the Sacramento River (Vogel and Marine 1991). Runs of fall, late-fall and spring chinook are present in very low abundance relative to earlier years (Johnson et al. 1992). Abundance of winter run chinook was so low that they were placed on the *List of Endangered and Threatened Wildlife* in November 1990 (U.S. Fish and Wildlife Service 1992a). In February of 1994, winter-run chinook salmon were listed as protected under the *Endangered Species Act of 1973* (National Marine Fisheries Service; 59 FR 440). Losses of chinook associated with upstream and downstream passage at Red Bluff Diversion Dam led federal and state agencies to consider returning the Sacramento River at Red Bluff to run-of-the-river conditions. As a result of interactions among the agencies, the gates at Red Bluff Diversion Dam were raised on various schedules during spring and summer of years between 1986 and 1994.

In 1993, the National Marine Fisheries Service (1993a, 1993b) directed the Bureau of Reclamation to raise gates on the Red Bluff Diversion Dam on September 15 and to leave them out of the water until the following May 15 beginning in September of 1994 and May of 1995 respectively. This mode of operation allowed for water deliveries via diversion from Lake Red Bluff during high demand in summer, allowed protected winter run adult chinook salmon unimpeded passage to upstream spawning grounds, and provided open passage for the majority of winter run juveniles during their annual out-migration from spawning grounds. This *reasonable and prudent alternative* was issued by the National Marine Fisheries Service (NMFS) with the understanding, based on Bureau of Reclamation commitments, that the Bureau would complete construction of a research pumping plant at the Red Bluff Diversion Dam in 1994. Additionally, it was understood by NMFS that this pumping plant, in combination with other pumping alternatives available at Red Bluff, would meet water delivery requirements for the Tehama-Colusa and Corning Canals during the dam-gates-out period from September to May when demands for irrigation water are relatively low.

Working with fisheries biologists and engineers from state and federal agencies, Liston and Johnson (1992a, 1992b) developed a detailed plan for bioengineering evaluation of the research pumping plant that Reclamation would build at Red Bluff. They identified specific objectives for biological and engineering evaluations of pumps, screening facilities and fish bypasses in the plant. Biological evaluations concerned potential impacts on fish populations in the Sacramento River caused by operation of the plant. In-river biological evaluations included assessments of movements of adult and juvenile salmonids in the vicinity of the plant, as well as movements of those fish species that prey on salmonid juveniles. In-plant biological evaluations included, for example, injury due to entrainment through pumps and passage through the plant's bypass system which was designed to return entrained fish to the river (Figure 1). Engineering evaluations concerned the performance characteristics of trash racks at pump intakes, two types of purportedly fish-friendly pumps, and vertical wedgewire screens that direct entrained fish and debris to bypasses during deliveries of irrigation water.

The Red Bluff Research Pumping Plant was constructed by the Bureau of Reclamation during 1993 and 1994. One internal helical pump and two Archimedes pumps were installed in the plant. The evaluation plan developed by Liston and Johnson (1992b) included an initial period during which facilities could be developed to handle fish required for biological evaluation, engineering modifications could be made to as-built conditions in the plant, and preliminary procedures for biological and engineering evaluations could be fine-tuned to fit the plant's actual operating modes. Facilities for handling experimental fish were completed at Red Bluff Diversion Dam in May of 1995. At that time, the contracting firm for construction also finished major aspects of its work on the site. The internal helical and Archimedes pumps were then put through operational tests, and engineering modifications to the plant's as-built conditions were begun. The internal helical pump became available for bioengineering evaluations in June 1995. Exploratory evaluations were conducted with this pump from June to September 1995 (U.S. Bureau of Reclamation 1995a, 1995b). The drive shaft of the internal helical pump failed in mid-September 1995. The pump was rebuilt, and it was returned to service in February of 1997. Seals at the junctions of stationary inlet pipes and rotating barrels of Archimedes pumps failed during initial operational tests in May of 1995. The seals were redesigned, new ones were installed, and the pumps became available for bioengineering evaluation in March of 1996. In May of 1996, the Archimedes pumps were shut down for realignment and repairs. They were returned to service in mid-September of 1996. Bioengineering evaluations were then conducted until the end of October. From November of 1996 until February of 1997, the Archimedes pumps were out of service while engineering modifications were made to them.

Purposes of this report are to review goals and objectives established for biological evaluation of the research pumping plant, and to summarize the information that was obtained during 1995 and 1996 that relates particularly to goals of work on in-plant biological evaluation. Considerable attention is given to the operation of fisheries facilities that were developed at Red Bluff for the biological evaluation program, and to standardized methods that were developed during 1995 and 1996 to use in studies of chinook salmon passage through pumps and fish bypasses in the plant. The purpose of this attention was to establish this report as a basic reference that could be used to cite details regarding facilities and methods in future reports on the biological evaluation program for the pumping plant.

As they peruse the summary of information presented here, readers should be aware that data presented here are preliminary; at best, they provide an indication of the range of results that may emerge from standardized biological evaluation studies that are planned for 1997 and 1998. In particular, readers should not make comparisons between mortalities and injuries associated with passage of fish through Archimedes and internal helical pumps. In work reported here, the pumps were available for evaluation in different years and in different seasons of those years. Environmental conditions (e.g., water temperature, turbidity, light), and health and condition of fish involved in this work varied between these years and seasons in these years. In addition, the impeller of the internal helical pump with which work was conducted failed in 1995, and it was redesigned and replaced. Thus, characteristics of the flow-path along which fish move through the pump may have been changed since the data presented here were obtained.

Also during the course of work in 1995 and 1996, a variety of changes were made along flow-streams of each of the pumps to improve operations in the plant and to facilitate safe fish passage. The orientation of plant's trash racks was changed to alter currents associated with undesirable accumulation and distribution of gravel and fine sediments around pump intakes. Characteristics of flow-fields through which fish moved from the river into pump intakes were changed by this action. Baffles were installed to control sweeping and approach velocities on wedgewire screens in the plant in order to prevent injury to passing fish. Drives for brushes on the screens were replaced to make removal of debris a continuous and reliable process. Splash guards were installed around pump outfalls to close escape routes and prevent loss of fish entrained from the Sacramento River. Weirs were installed to move entrained fish more promptly through entrances to the bypass channels by which they return to the river. Outfalls of fish holding tanks on pump bypasses were modified to distribute and moderate current velocities within the holding tanks. Finally, steady improvement was made during 1995 and 1996 with techniques for handling and sampling fish that passed through the plant, thus reducing the incidence of mortalities and injuries. In all, 1995 and 1996 were years of transition for development of improved pumping plant operations and standardized procedures for biological evaluation.

GOALS AND OBJECTIVES FOR BIOLOGICAL EVALUATION

Goals and objectives for biological evaluation of the pumping plant are listed in Table 1. Some objectives in column two of Table 1 are marked for a footnote. These objectives deal with studies of movements and behavior of anadromous salmonids in the Sacramento River in the vicinity of the pumping plant, and with other species of fish that prey on their young. These in-river studies are conducted by the U.S. Fish and Wildlife Service, Northern Central Valley Fishery Resource Office, Red Bluff, California. Objectives not marked for a footnote deal with studies of fish passage through the pumping plant, and development of a record of environmental and engineering data that are needed to interpret information from the fisheries studies. Work on these unmarked objectives is conducted by U.S. Bureau of Reclamation personnel from the Technical Service Center, Denver, Colorado and the Northern California Area Office, Shasta Lake, California.

The objectives in Table 1 that fall under the purview of Reclamation can be grouped into four subject classes;

(1) objectives B, C, D, E and G are concerned with passing hatchery-reared juvenile chinook salmon (surrogates for run-of-the-river chinook) through the pumping plant and assessing capture efficiency in the plant's holding tanks, and mortality, injury, and disorientation caused by passage,

(2) objectives I and N deal with entrainment of fish from the Sacramento River during pumping, and the mortalities and injuries they sustain,

(3) objectives F and L involve behavior of juvenile chinook and their predators around the intakes of pumps in the plant, and

(4) objectives O and P deal with monitoring the environment in which studies on other objectives are conducted.

This report deals with work on subject classes *1* and *2*. Preliminary information relating to objectives B, C, D and E is summarized. Procedures for dealing with objective G are in development at this time. Regarding subject class *2*, information is presented on entrainment of adult and juvenile fishes from the Sacramento River (objective I). Observations were made on an intermittent basis when pumps in the plant were operating. A study plan for objective N has been developed (U.S. Bureau of Reclamation 1997) and peer-reviewed. Work on objective N will begin in the spring of 1997. Work on subject class *3* has not yet begun. Study plans for objectives in subject class *3* are under development and will be available for review at a later date. Monitoring for subject class *4* is on-going. Data loggers in the project's on-site weather station provide continuous records of precipitation, air temperature, irradiance in the visible portion of the solar spectrum, wind direction, wind speed and barometric pressure. HydroLab® instruments provide continuous records of temperature, dissolved oxygen, Ph, and specific conductance in the Sacramento River at the diversion dam. These instruments have been in operation since late in 1994.

FEATURES OF THE STUDY SITE

Location and Riverine Environment

Red Bluff Diversion Dam is located at km 391 (river mile 243) above San Francisco Bay. The research pumping plant is located on the southwest shore of the river, just below the diversion dam. Its coordinates are 40.15° north latitude, 122.20° west longitude. The Sacramento River arises as a first order stream (Hynes 1970) in the mountains north of Red Bluff where undulations of the Coastal Range and the Cascade Range come together to form a horseshoe at the northern end of the Central Valley of California. After its confluence in the foothills with major tributaries, the river becomes a sixth order stream and is impounded at an elevation of about 165 m (540 ft) above mean sea level by Shasta Dam (Figure 2). Shasta is a high dam 184 m (602 ft). It was constructed between 1938 and 1944. At 14.5 km (9 mi) downstream from Shasta Dam, the river is impounded by Keswick Dam. Keswick Dam was constructed during the interval 1941-1950. Its impoundment forms an afterbay for Shasta Dam and the Trinity River Diversion. The Trinity River Diversion brings water from the western slopes of the Coastal Range eastward through the mountains into the Sacramento River drainage basin (U.S. Department of

Interior 1981). For the past five to six decades, Shasta Dam and Keswick Dam have blocked runs of anadromous salmonids that historically spawned in low-order streams at higher elevations where a montane climate occurs (Moyle et al. 1989). Loss of spawning grounds above the dams has been partially mitigated by production of salmonids at Coleman National Fish Hatchery at Anderson, California. The hatchery was established in 1942. It is situated on Battle Creek, a tributary that enters the Sacramento River between Keswick Dam and Red Bluff.

Presently, the reach of the Sacramento River between Keswick Dam and Red Bluff Diversion Dam has the best natural spawning grounds that remain in the mainstem of the river for salmonids (Frank Fisher, California Department of Fish and Game, Red Bluff, California, personal communication). This reach of the river is 95 km (59 mi) long. A mediterranean climate predominates in the Keswick-Red Bluff reach. Average annual precipitation varies between about 50 cm (20 in) and 70 cm (28 in). A rainy season extends from December through April. During that time, air temperatures are relatively mild, ice is absent on the river and backwaters, and snowfall is rare and short-lived. A dry season extends from May into November. Very little precipitation occurs during these months, and relative humidities are low. Unlike the wet season, skies are typically clear during the dry season and days are sunny and very hot. Vogel and Marine (1991) report that average weekly water temperatures at the downstream end of the reach (Red Bluff) prior to construction of Shasta Dam and Keswick Dam varied between a low of about 4.4° C (40° F) in January and February and a high of 16.7° C (62° F) in August and September. They also point out that mortality occurs in incubating eggs of chinook salmon as water temperatures are elevated above 13.3° C (56° F).

Since there are no large tributaries entering the Sacramento River between Keswick Dam and Red Bluff, the river is a sixth order stream through that reach. Prior to construction of dams upstream, flows of the river fluctuated from highs in the wet season lows in the dry season. On the average, the bed of the river drops 0.9 m/km (4.6 ft/mi) between Keswick and Red Bluff (U.S. Department of Interior, 1957), and current velocities in many portions of the gradient are adequate to oxygenate spawning gravels and clear them of silt. Presently, regulated discharges from Shasta and Keswick Dams dominate flows year-around, and are particularly important for supplying sufficient water to cover salmonid spawning beds and rearing areas during the dry season. In recent years, selective withdrawals and releases of cold water have been made from Shasta reservoir and the Trinity River Diversion in order to bring dry-season temperatures in the Keswick-Red Bluff reach closer to montane conditions to which chinook are historically adapted. The average daily water temperature at Red Bluff has been held near a management target value of ≤13.3° C (≤56° F) during the hot summer period to protect incubating eggs of the endangered winter run chinook (Johnson et al. 1991, Hovekamp and Sarsfield 1995). Successful spawning upstream of Red Bluff Diversion Dam has also been promoted by the addition of suitably sized gravels at locations below Keswick Reservoir (U.S. Fish and Wildlife Service 1992b, 1993). These additions compensate for gravel trapped upstream of the reach by dams. They also replace gravels that move annually out of the reach in the river's bed-load during high flows in the wet season. Because of natural spawning and rearing by chinook salmon in the Keswick-Red Bluff reach of the river, out-migrating juvenile chinook move downstream and past the Red Bluff Research Pumping Plant year-around. On occasion, releases of fall run and late-fall run juveniles from Coleman National Fish Hatchery are made in the Keswick-Red Bluff reach. These chinook also pass the pumping plant during their out-migration to the Sacramento-San Joaquin estuary.

Red Bluff Research Pumping Plant

Major features of the research pumping plant are shown in Figure 3. The plant has four pump bays. Bay-1 and bay-2 contain Archimedes pumps. Bay-3 contains an internal helical pump. An empty fourth bay is available for future expansion of pumping capability. Water drawn from the river during pumping passes through trash racks. Large fish, for example adult salmon, are excluded from the plant by close-interval spacing (5.1 cm, 2 in) of the trash rack bars. Intake pipes for each bay open behind the trash racks. These pipes are 1.22 m (48 in) in diameter, and are horizontally aligned. Intake pipes for bay-1 and bay-2 open directly into rotating barrels of Archimedes pumps. These pumps are 3.05 m (10 ft) in diameter and 11.58 m (38 ft) long. Each has an internal three-flight lift chamber. The Archimedes pump in bay-1 has a fixed-speed motor and operates at 26.5 rpm while delivering water at a rate of 2.7 m^3/s (94 cfs). The Archimedes pump in bay-2 is wired for variable rotational speeds from 1 to 26.5 rpm. This gives it the potential to deliver from 0.004 to 2.7 m^3/s (1.3 to 94 cfs). The internal helical pump also has variable speed control (250-370 rpm). It has a capacity to deliver between 0.6 and 2.8 m^3/s (22 and 100 cfs). Only one of the two variable speed pumps in the plant may be operated at less than maximum speed at any one time.

Water is discharged from the Archimedes and internal helical pumps into uncovered concrete sluice ways (Figure 4). The sluiceways are 3.7 m (12 ft) wide at pump outfalls and taper to 2.1 m (7 ft) width through a downstream distance of 5.2 m (17 ft). Sluiceways run an additional 5.2 m (17 ft) at 2.1 m (7 ft) wide and 1.6 m (5.3 ft) deep to the inlet of the screening facility. There, a pair of vertical wedgewire screens, each approximately 9.1 m (30 ft) in length, separate fish and other objects from water delivered to the forebay of the Tehama-Colusa Canal. In normal operating mode, the screens (2.4 mm, 0.09 in gap) pass 90% of pumped water to the forebay and 10% to open channels in the bypass system. Fish evaluation facilities, on bypasses downstream from the screens, have tanks that can be used to capture and hold fish that are entrained from the river, or hatchery-reared juvenile chinook that are inserted into the pumps' intakes during evaluation studies. When these tanks are in operation, ramps of wedgewire screening (2.4 mm, 0.09 in gap, dewatering ramps in Figure 1) are dropped in place to block the bypasses. A weir beneath each ramp can be adjusted to shunt a portion of flow from a bypass along the top of the ramp and into one of two holding tanks. The holding tanks operate in a flow-through mode; they discharge water back into the bypass from which it came. The water in a bypass that isn't shunted to holding tanks drops through the wedgewire screen on a ramp and continues to flow along the bypass. When holding tanks are not operated for collecting fish, dewatering ramps are raised above the water level in a bypass. In that case, water in a bypass goes under a ramp and drops into a plunge pool located just downstream.

Water in each of four plunge pools in the plant (Figure 1) flows into a 46 cm (18 in) diameter pipe that runs beneath the plant's yard into a metering box. Sensors in the metering box relay information on discharge (cfs) to a display-board located in the yard. Beyond the metering box, the bypass of each pump in the plant is connected to a 152 cm (60 in) diameter pipe. This pipe is one of two lines that collect water and fish from a drum screen structure that lies across the forebay of the adjacent Tehama-Colusa Canal (Figure 3). Both of these lines from the drum screen terminate at an outfall located in the Sacramento River.

Because of localized weak currents, fish that pass through pumps can hold-up in the flowstreams along pump bypasses (U.S. Bureau of Reclamation 1995a, 1995b). Fish may delay their passage to the Sacramento River in refugia near pump outfalls, and in screening facilities, open bypass channels and plunge pools. However, entrained fish are unlikely to encounter refugia in the underground pipes that lead from plunge pools to the drum screen bypass (Figure 1). When pumps in the plant are operated to discharge water at rates normally used for irrigation deliveries, currents in this portion of the bypass move downstream at calculated rates of about 3.0 to 3.7 m/s (10-12 ft/s). These rates are well in excess of the maximum current velocity (0.6 m/s, 2.0 ft/s) in which juvenile salmonids can hold their position (Fields et al. 1954 cited by U.S. Army Corps of Engineers 1990). The nominal travel-time for water in pipes between plunge pools and junctions with the drum screen bypass is about 14.5 s.

Downstream of junctions of the pumping plant's bypasses and the drum screen bypass, the availability of refugia is dramatically different during different times of the year. During periods when gates of Red Bluff Diversion Dam are in the water (e.g., May 15 to September 15), drum screens on the Tehama-Colusa Canal are in operation. Upstream gates on the drum screen bypass are open, providing the hydraulic head that ordinarily moves about 3.40 m^3/s (120 cfs) of water at a calculated velocity of 1.9 m/s (6.2 ft/s). Refugia are likely not common in the drum screen bypass when these conditions prevail. In contrast, when the pumping plant is operated during a gates-out period (e.g. September 15 to May 15), upstream gates on the drum screen bypass are closed. Significant water movements in the drum screen bypass are generated by the pumping plant's discharge only. This discharge ranges from 0.25 m^3/s to about 0.80 m^3/s (9-28 cfs) when one, two or three pumps in the plant are operated in the mode normally used for irrigation deliveries. Current velocities that develop in the drum screen bypass with these discharges are low. Approximated by calculation, they range from 0.1 to 0.4 m/s (0.3 to 1.3 ft/s). Under these conditions, refugia for juvenile salmonids likely exist in the drum screen bypass both upstream and downstream of its junction with the plant's underground bypass pipes. The stress-related condition of entrained fish that emerge at the plant's outfall in the Sacramento River is unknown at this time. The possibility exists that use of refugia to delayed time-in-travel through the plant may provide entrained fish with an opportunity to recover from stress caused by pump passage. Work will begin in 1997 to examine the question of stress caused by pump passage and the time required to recover from stress (objective G).

Fish Holding Facilities

During 1995, two separate buildings were equipped for holding species of fish for use during biological evaluation of the research pumping plant. One building is designed to hold several thousand juvenile chinook salmon, depending on their size. These chinook are obtained periodically from Coleman National Fish Hatchery, located at a distance of 39 km (24.5 mi) by road from the site of the pumping plant. Goals of work in this holding facility are to provide healthy and robust chinook fingerlings for pumping plant passage experiments, and to hold these animals under reasonably consistent conditions throughout the year in order to exclude the holding experience as a major cause of variance in data from experiments. Surface water sources on the site at Red Bluff are not suitable to meet these goals. They contain disease micro-organisms to which salmonids held in captivity are particularly sensitive. In addition, the quality of surface water sources on the pumping plant site at Red Bluff (Sacramento River, Tehama Canal forebay) fluctuates diurnally and seasonally. The occurrence of these fluctuations introduces unpredictable variation in the holding conditions for individual groups of chinook used in experiments. Because of this, the holding facility is plumbed with wellwater. The wellwater is relatively free of disease organisms and has consistent water quality characteristics that are desirable for holding juvenile chinook salmon.

There are six circular plexiglass fish tanks in the wellwater facility. They are made by Frigid Units® Incorporated of Toledo, Ohio. Each tank is 1.2 m (4 ft) in diameter, and has an operating volume of 780 L (206 gal). In the normal operating mode, faucets on pressurized wellwater lines are adjusted to deliver approximately 26.5 L per min (7 gal per min). Wellwater enters tanks through three slot-outlets cut below water-level in a vertical plastic pipe (2 in, 5 cm diameter). Cross sections of the slots are sized to pressure in the line and the water delivery rate to generate clockwise currents with approximate velocities of two to three fish-body-lengths per second. Current velocities in this range are reported to be optimal for exercising juvenile chinook that are held in culture systems (Youngs and Timmons 1991, cited in Westers 1994a). Water carrying wastes of fish metabolism exits each tank through a centrally located standpipe. The flow-through mode of operation used in fish tanks results in a calculated water replacement rate of about one tank volume per 30 minute. The work of Tvinnereim and Skybakmoen (1989), using dyes as tracers and tanks with water inlets and outlets similar to those at Red Bluff, showed that, because of mixing that occurs, the actual time required to completely renew the water in a tank is likely in the range of 45-48 min.

Temperature of water in fish tanks in the wellwater facility varies annually between a low of 15.8° C (60.4 °F) in winter to a high of 16.4 ° C (61.5° F) in summer. These wellwater temperatures are in the upper portion of the optimum range for metabolism of juvenile chinook salmon (Vogel and Marine 1991, Westers 1994b). Data obtained from water samples submitted to CH2M HILL Analytical Laboratory, Redding, California show that the mix of dissolved ions in the wellwater is excellent for holding salmonids. The pH ranges from 7.3 to 7.4 and the water is well buffered with a total alkalinity of 120-125 mg/L $CaCO_3$. Total iron and suspended solids are very low. Turbidity of the water is consistently near 0.10 nephelometric turbidity units (NTU).

Wellwater is commonly low in dissolved oxygen and supersaturated with dissolved nitrogen (Stickney and Kohler 1990), and such is the case at the project's wellwater facility. Water enters fish tanks at 25-27% O_2 saturation, and 118-120% N_2 saturation. The former is too low to meet sustained respiratory requirements of salmonids and other fish species, while the latter may contribute to induction of gas bubble disease (Weitkamp and Katz 1980). To alleviate these problems, the wellwater facility has two AS-12 oxygen generators made by AirSep® Corporation, Buffalo, New York. These units take in ambient air at about 21% oxygen, 78% nitrogen and 1% argon plus other trace gasses. Nitrogen in air passing into the units is captured on columns using a synthetic zeolite absorbent. Under normal operating conditions used in the wellwater facility, these units deliver a gas mixture that contains 75-90% oxygen and about 10-25% nitrogen. The gas mixture enters water in each fish tank through a glass-bonded diffuser placed in the bottom of the tank. Gas flow through the diffuser forms a bubble curtain in a fish tank. Gas exchange occurs across surfaces of the bubbles in the curtain. Oxygen moves from the over-saturated bubbles to the under-saturated water, and nitrogen moves from the over-saturated water into the under-saturated bubbles. Bubbles breaking at the water's surface release scavenged nitrogen into the air. The rate at which the oxygen rich gas mixture is delivered to the bubble curtain in a tank is regulated by a valve on an incoming line from the AirSep units. Valves are adjusted to hold dissolved oxygen in the water near 100% of O_2 saturation. Data collected from fish tanks in the wellwater facility show that bubble curtains that produce 100% O_2 saturation also reduce the concentration of N_2 to a level near 100% of saturation (Figure 5).

Each of the circular holding tanks in the wellwater facility at Red Bluff is equipped with a spring-loaded, automatic feeding tray (Zeigler®). While holding juvenile chinook, trays are set on five days per week to release rations of fish-feed at intervals over a period of 10-12 hours. Feed used is supplied to the biological evaluation program by Coleman National Fish Hatchery. It is produced by the Fish Feed Division of Bioproducts®, Inc. of Warrenton, Oregon. The approach of Westers (1994b) is used to determine the daily ration of feed for juvenile chinook held in the wellwater facility. With that approach, the daily ration is expressed as a decimal fraction or percentage of the biomass of fish being held. It requires estimates of the total fresh-weight of juveniles in each tank, and their mean length. Total fresh weight is estimated from the product of the number of fish in a holding tank and the mean weight of individuals. The latter is derived from a subsample of 30 or more fish. The same subsample is used to obtain an estimate of mean length. The amount of feed given daily is obtained using the following relationship:

$$\text{grams of feed per tank} = (2\ ^{\circ}\text{C}/\text{L} \times \text{fresh weight of fish per tank})/100 \qquad (1)$$

where °C is the water temperature at which the fish are held in degrees celsius, L is mean fork-length in centimeters, and the fresh weight of fish is in grams. This approach is based on empirical information obtained while rearing juvenile salmonids in hatchery production systems. Westers (1987) observed that daily rations obtained by equation-1 produced robust juveniles in hatcheries, if the rearing environment was otherwise appropriate (Westers 1987). Juveniles fed using equation-1 were found to have condition factors (k) of about 1.0 where:

$$k = W/L^3 \times 100 \qquad (2)$$

and W is mean weight of individual fish in grams, and L is their mean fork-length in centimeters (Moyle and Cech 1988).

For groups of juvenile chinook salmon obtained from Coleman National Fish Hatchery in 1995 and 1996, k varied around 1.0; for example, from 0.8 with 44 mm juveniles, to 1.1 with 56 mm juveniles and 1.3 with 94 mm fish. Experience showed that juveniles of these and other sizes were over-fed in tanks at Red Bluff using daily rations given by equation-1; unused feed accumulated at the bottom of tanks. The same result was obtained at Red Bluff when daily rations were calculated by methods routinely applied at Coleman National Fish Hatchery (Roger Shudes, U.S. Fish and Wildlife Service, Anderson, California, personal communication). Because of this, feeding rates in the wellwater facility were progressively cut back, until records showed that daily half-rations determined by either the approach of Westers or that of Coleman National Fish Hatchery were fully consumed. Subsequent records showed that juvenile chinook held on half-rations had growth rates and condition factors comparable to healthy juveniles that were reared at Coleman hatchery. Records also showed that juveniles of various sizes held on half-rations had condition factors similar to various sizes of chinook (35-100 mm fork length) collected from the upper Sacramento River (Petrusso, in preparation). As a result, the standard feeding procedure used in the wellwater facility is based on one-half the ration obtained by equation-1.

In addition to circular holding tanks, the wellwater facility at Red Bluff has two rectangular plexiglass tanks, each with a capacity of 1840 L (486 gal). They are equipped with model D1-100 chillers made by Frigid Units® Inc. Water in these tanks can be held at selected temperatures between 5-21° C (35-70° F). The building is plumbed so that water from chiller tanks and the well can be mixed on entry to fish holding tanks. Chiller tanks are used on occasions when fish are moved into or out of the building and temperature acclimation is needed; for example, in winter when acclimating fish from cold water in raceways at the Coleman National Fish Hatchery to ambient wellwater temperature in holding tanks at Red Bluff. The wellwater facility is on-line with a backup generator to protect against shut-down of oxygen generators and the pump in the well during local power failures. Gas lines from the AirSep® units and water lines to fish tanks are also wired to provide a telephone alert in the event that deliveries go down. Pressurized oxygen cylinders are plumbed into the gas lines from AirSep® units to provide temporary backup so that dysfunctional oxygen generators can be replaced by standby units.

A second fish facility was developed at Red Bluff in 1995 immediately adjacent to the research pumping plant. Its water supply system is plumbed to the Sacramento River. The intake is located on the face of the intake structure of the plant. This riverwater facility has 10 circular plexiglass fish tanks (Frigid Units® Inc.), each at 1.2 m diameter (4 ft) with a capacity of 780 L (206 gal). Riverwater can be delivered to each of these tanks simultaneously at a rate of 53 L/min (14 gal/min). Riverwater quality varies with seasons of the year, particularly in regard to temperature, suspended solids and turbidity. The concentration of dissolved oxygen in water delivered to tanks tends to be consistently high; O_2 ranges from 96% to 103% of saturation. Each tank in the facility is tied into a pressurized line of ambient air to provide for emergency situations. Like the wellwater facility, the riverwater facility at Red Bluff is on-line with a backup generator to protect against power failures.

Development of the riverwater facility at Red Bluff was important for achieving Reclamation's goals and objectives for biological evaluation of the research pumping plant. In experiments related to program objectives B, C, D, and E (Table 1), groups of juvenile chinook are moved from the wellwater facility into riverwater tanks for essential pre-trial acclimation to ambient conditions they will encounter when inserted in flowstreams of pumps in the plant. Following insertion, juveniles are collected at downstream points and returned to the riverwater facility for post-trial detection of delayed mortalities. The facility also provides for short-term or long-term observation of chinook salmon and other fish that are entrained from the Sacramento River and pass through pumps in the plant (objectives I and N). Studies of interactions between predators and juvenile chinook that have passed through pumps (objective G) also require ambient riverwater conditions afforded by the facility in order to obtain useful results.

METHODS

Entrainment Trials for Objective I

Objective I in the biological evaluation program (Table 1) deals with estimating seasonal numbers, annual numbers, condition, and viability of juvenile chinook salmon and other fish that are entrained from the Sacramento River and pass through pumps in the plant. Studies conducted in 1995 and 1996 consisted of individual trials made opportunistically during periods when the Archimedes or internal helical pumps were running. Entrained fish were collected in holding tanks on the plant's bypass system (Figure 3). Each entrainment trial started at sunrise or sunset and continued for 24 hours. Times for sunrise and sunset were obtained from the web-site of the U.S. Naval Observatory in Bethedsa, Maryland using the coordinates of latitude and longitude for the pumping plant. Fish were removed from holding tanks twice during each 24-hour period; at sunset and at the following sunrise for trials that started at sunrise, and at sunrise and the following sunset for trials that started at sunset.

Thirteen trials were conducted with the internal helical pump during the summer period from June to September, 1995. The pump was run at its maximum water delivery rate. It ran at 378 revolutions per minute (rpm) yielding 3.0-3.2 m^3/s (106-113 cfs). Sixteen trials with the Archimedes pumps were conducted during the spring period from March to April in 1996, and again in the fall from September to October, 1996. During each of these trials, the two Archimedes pumps in the plant were run simultaneously. The Archimedes pumps were also run at their maximum rates. They each delivered 2.5-2.6 m^3/s (87-93 cfs) while making 26.5 rpm. Six trials were conducted in the March-April interval and ten trials during the September-October period.

Fish that were collected in holding tanks during trials were identified to species, measured (fork length), inspected for injuries and returned to the Sacramento River. Table 2 lists the types of injuries that were recorded. Run membership for chinook salmon (fall, late-fall, winter or spring) was determined from a daily fork-length table generated by Green (1992). On occasion, small larval fish in a size-class <30 mm length were observed in holding tanks. These fish were not efficiently captured because of the relatively large mesh-size (4.8 mm, 3/16 in) of nets used to trap fish in the tanks. Data regarding small larval fish are not reported here. Their abundances in pump entrainment streams will be accurately assessed in work of objective N of this program (Table 1). Work on objective N will begin during 1997 (U.S. Bureau of Reclamation 1997).

In addition to assessing the kinds and numbers of fish entrained by the pumping plant and their condition after passing through pumps, objective I of the biological evaluation program also deals with estimating seasonal and annual percentages of out-migrating chinook juveniles that the pumping plant entrains. In the spring of 1996, nine 24-hour entrainment trials in the pumping plant were synchronized with 24-hour collections of fish from the Sacramento River. Collections from the river were made by personnel from the U.S. Fish and Wildlife Service (USFWS) who were working on objective H of the biological evaluation program (Table 1). The Service ordinarily fished four rotary screw-traps spaced along a transect perpendicular to the river's flow and just upstream of the pumping plant (Johnson and Martin 1997). One purpose of their work was to obtain indices of abundance for out-migrating chinook juveniles that passed the pumping plant. The purpose of synchronizing entrainment trials and screw-trap work was to obtain preliminary data for estimating percentages of out-migrating chinook that the plant entrains.

Results presented in this report utilize data from a single screw-trap that the USFWS fished near the southwest shore of the Sacramento River just upstream (50-75 m, 165-245 ft) of the research pumping plant. The trap was located in the line-of-flow to the intake structure of the plant. Volumes of water passing through the trap per 24-hours were estimated from the product of the cross-section of the river that the trap fished (m^2), the mean velocity of water passing through the cross-section (m/s), and s/24 h. Volumes of water passing through pumps in the plant were continuously metered. Means of water delivery rates (m^3/s) taken at intervals over 24 hours were multiplied by s/24 h to obtain volumes taken by pumps. The number of juvenile chinook taken by either the trap or pumps was then used with the volume of water taken to estimate the numbers of juveniles that were captured by each of these devices per meter hectare (acre foot). Resulting data were used to examine variation in the ratio *pump-take:trap-take*. This type of work will continue during 1997. USFWS will also continue investigations to develop weekly estimates or indices of absolute abundance of juvenile chinook salmon passing their transect at the pumping plant (Johnson and Martin 1997). The possibility of using *pump-take:trap-take* ratios like those obtained here to extrapolate to the percentage of weekly out-migrating chinook taken by pumping will be examined.

Plant Passage by Hatchery Surrogates

Standardized Methods for Objectives B, C, D and E

Standard methods were developed during 1995 and 1996 for experiments to address objectives B, C, D and E of the biological evaluation program. These objectives deal with assessment of mortality and injury to juvenile chinook salmon that pass through the research pumping plant (Table 1). Consideration is given specifically to passage through Archimedes and internal helical pumps, screening facilities in the plant, and bypass channels by which entrained fish return to the Sacramento River. Hatchery-reared juvenile chinook salmon are used in this work as surrogates for run-of-the-river juveniles that are entrained while making irrigation deliveries. These surrogates are obtained from Coleman National Fish Hatchery.

The size, and size-related swimming ability of entrained juveniles, are thought to be important factors influencing the probability for safe passage. Because of this, experiments are designed to utilize at least two size-classes of chinook. Fisher in Vogel and Marine (1991) and Johnson et al. (1992) present information on size-classes of juvenile chinook that pass Red Bluff during the annual out-migrations of runs. The two most abundant size-classes are of particular interest for biological evaluation of the pumping plant; small individuals with fork lengths of 30-45 mm and larger fish with fork-lengths up to 70 mm. The 30-45 mm size-class includes relatively fragile individuals that have recently emerged from upstream redds. Fisher (1992) notes that the mean size of chinook leaving redds in the upper Sacramento River is about 34 mm fork-length. The 46-70 mm size-class passing Red Bluff includes river-spawned juveniles that have reared in the river or its tributaries for one to three months, or juveniles reared at Coleman hatchery and released in the Sacramento River above Red Bluff. These juveniles are more robust and stronger swimmers than individuals in the 30-45 mm size-class. Juveniles larger than 70 mm are also of interest, particularly those reared at Coleman National Fish Hatchery and released upstream of Red Bluff.

Pre-Trial Handling

The following are standard methods applied to work on objectives B, C, D and E of the in-plant biological evaluation program. Juvenile chinook are obtained from Coleman National Fish Hatchery in lots ranging from 1,000 to 7,000 individuals. They are trucked to Red Bluff in an insulated stainless steel tank. The tank is filled with water at Red Bluff to avoid disease organisms that are common from time-to-time in Coleman hatchery's raceways. Approximately 900 L (240 gal) of water are placed in the tank. The water is brought to a temperature near (±1.0° C) the ambient temperature of Coleman's raceways. Salt and Kordon's PolyAqua® (Novalek, Hayward, California) are added to water in the tank to reduce stress on fish during transport (Moyle and Cech 1988, Summerfelt and Smith 1990, Wedemeyer 1992); salt at 5-7 g/L and PolyAqua at 0.13 ml/L (Vogel and Marine 1995). Cylinders of commercial-grade compressed oxygen are connected to diffusers in the tank to supply oxygen to the water during transport. Concentrations of dissolved oxygen are held near 100% of saturation during travel.

Each lot of juvenile chinook obtained from Coleman National Fish Hatchery is transferred from the hauling tank to one or more circular plexiglass tanks in the wellwater facility. Prior to receiving fish, water in receiving tanks is brought to the temperature of the hauling tank. Salt and PolyAqua are added at concentrations used in the hauling tank. Transfer of fish is accomplished by joining fittings on the hauling tank to those on a 6.4 cm (4 in) diameter plastic tube and emptying the hauling tank into holding tanks by gravity flow. If necessary, water temperature in holding tanks is then slowly brought to the temperature of wellwater (16° C, 61° F) in which the fish are held until used in passage trials.

Sub-samples from each lot of chinook received from Coleman National Fish Hatchery are periodically removed from wellwater tanks and used in plant passage trials. Ordinarily, trials are scheduled so that fish in a lot are utilized within one to five weeks of the time they are delivered from Coleman. Guidelines related to fish health and condition were developed in order to maintain quality control on subsamples of chinook used in trials. The guidelines are given in Table 3. They include the history of disease and mortality in the lot of juveniles from which a sub-sample is taken, and the occurrence of external damage to head, fins and integument, and condition factor (*k*) at the time the sub-sample is selected for a trial. Incidences of disease and mortality are taken from a daily log that is maintained for each lot held in the wellwater facility. External physical abnormalities and descaling are assessed by examination of 30 randomly selected individuals from each sub-sample. Guidelines for recording external physical abnormalities are the same as those used for entrainment trials (see Table 2).

Descaling assessments are made on juveniles used in trials by examining both the left and right sides of the fish. Three zones on each side are visually delineated. A caudal zone includes the surface area above and below the lateral line and posterior to the posterior insertion of the dorsal fin. A dorsal zone includes the area anterior of the caudal zone and above the lateral line, while an abdominal zone includes the area anterior of the caudal zone and below the lateral line. These zones are the same as those used for descaling assessment by Kostecki et al. (1987). On the average, the caudal zone covers approximately 33% of the total scaled area on juveniles, while the dorsal zone covers 25% and the abdominal zone the remaining 42%. Scales on juvenile chinook <55 mm fork-length are poorly developed and are not easily detected. Juveniles in this size-class are examined microscopically, and the percentage of the area within each zone that is occupied by bruises to the outer integument is recorded. For larger juveniles, the percentage of descaled area in each zone is estimated microscopically and recorded. The percentage of bruised or descaled area per zone is then multiplied by the percentage of total scaled surface that is covered by that zone. The resulting products for six zones are summed to obtain the fraction of the fish's scaled integument that is bruised or descaled. Lengths and weights of the 30 individuals used in an assessment are also measured, and condition factors (*k*) are calculated from equation-2 above. Fisher (1992) and Petrusso (in preparation) show that smaller chinook juveniles in the upper Sacramento River are less robust than larger juveniles. Condition factors calculated for groups of juveniles obtained from Coleman National Fish Hatchery during this project show the same result. Because of this, smaller condition factors are allowed in Table 3 for small fish then for larger ones. Groups of fish that exceeded the limit for any one of the elements listed in Table 3 are excluded from experiments.

Table 4 shows the schedule established for handling juvenile chinook during experimental passage sessions. Pre-trial work begins with marking fish. A dye, Bismarck brown-Y, is used (Mundie and Taber 1983). The dye colors body surfaces and fins of young chinook with a golden sheen. This allows for distinction between project juveniles and run-of-the-river chinook that are entrained by pumps and pass through the plant while passage trials are underway. Marking is begun by moving a selected number of fish from tanks in the wellwater facility to a dye tank in the same building. The number of fish selected is determined by the number needed for plant passage trials to be undertaken in the schedule (Table 4). Wellwater delivery to the dye tank is turned off, and water in the tank is drawn down to one-half of normal operating volume. Oxygen delivery to the dye tank is maintained at a rate that results in ≥100% O_2 saturation during the dying process. Eight grams of Bismarck brown-Y powder are mixed into the water (379 L, 100 gal) in the dye tank. Fish are held in the resulting concentration for a period of 40 min. After that time, wellwater delivery to the tank is returned to the normal operating rate, and Bismarck brown-Y is slowly purged over the next few hours. The dye mark holds on juvenile chinook for 4-10 days before fading away.

Table 4 shows that chinook are marked on day-1 of the schedule and moved from the project's wellwater facility to the riverwater facility. They are moved by truck in the project's hauling tank. Throughout a period of trials, precautions are used to protect juveniles from damage or stress when they are moved. They are seldom taken out of water, and when they are, exposure to air is always <10 s. Juveniles are also pre-conditioned to moves by immersing them in a salt and PolyAqua® solution (5-7 g/L and 0.13 ml/L respectively). Once in the riverwater facility, juveniles are acclimated to ambient conditions of the Sacramento River for the next 48-60 hours (Table 4). During pre-trial holding periods, juveniles in the riverwater facility are not fed with formulated feed. They do however have access to planktonic organisms that are pumped to tanks in the facility from the Sacramento River.

Work scheduled for day-4 in Table 4 involves separating chinook in the batch that was dyed into individual samples of 34 fish each. The fish for a sample are counted into a live-cage. Live-cages are made from PVC cylinders that are 25.4 cm (10 in) in diameter and 40.6 cm (16 in) long. Each has a volume of 20.6 L (5.4 gal). One end of the cylinder is covered with a perforated plastic plate that is fixed in place. A perforated plate on the other end slides in a grooved frame so that the live-cage can be opened and closed. Perforations in the plates are 3.2 mm (0.13 in) in diameter. Live cages are numbered so that individual samples of juvenile chinook can be tracked during plant passage trials. After preparing samples, live-cages are distributed among circular tanks in the riverwater facility. Each of eight circular tanks in the facility holds a maximum of eight live-cages. Riverwater is delivered to tanks through underwater ports in vertical PVC inlet pipes. Flow-rates are adjusted to provide a minimum of one tank volume every 30 minutes. Ports in inlet pipes are arranged to direct jets of water through the live-cages to provide good circulation. Water leaves the tanks through a centrally located standpipe.

Conducting Passage Trials

Plant passage trials are started on day-4 of the handling schedule. One tank in the facility is filled to one-half volume (379 L, 100 gal) with riverwater, and salt and PolyAqua are added to it at standard dose rates (5-7 g/L, 0.13 ml/L respectively). Portions of this solution are taken to use for transporting individual samples of juvenile chinook to the pumping plant. Juveniles are carried to the plant in a device that was fabricated to insert them into the flowstreams of pumps. These inserters are made by removing the bottom of a 19 L (5 gal) plastic carboy. The carboy is then inverted. A flexible rubber plug is used to cover the interior portion of the carboy at its mouth. A sling fits around the exterior of the carboy. A snap-clamp attached to the sling holds a line that is used to lower the carboy to the water. A second line is attached to the plug so that it can be removed to release juvenile chinook at the waterline. In preparation to receive a sample of fish, an inserter with plug in place is filled to one-half capacity with salt and PolyAqua solution. The inserter is then held at the level of the rim of an acclimation tank. A live-cage (sample) is selected at random from among those containing juveniles that have been acclimated to riverwater. The lid on the live-cage is removed and the sample of fish is poured gently into an inserter. The inserter is placed in a 19 L (5 gal) plastic bucket for transport from the riverwater facility to the pumping plant.

During plant passage trials, juveniles are released in the flowstreams of pumps and recovered at points downstream. As standard procedure in all trials, two juveniles are netted at random and removed from among the 34 juveniles in each sample just prior to release. These fish are euthanized in a 200 mg/L solution of Finquel® that is buffered with an equal weight of sodium bicarbonate. They are transferred to a plastic bag containing water and stored in a refrigerator. They are used to make an estimate of the frequency of individuals used in trials that have pre-passage injuries. They are also used to estimate the percentage of the scaled surfaces that are descaled (fish ≥56 mm) or bruised (<56 mm fish) on pre-passage individuals. The remaining 32 juvenile chinook in each sample are released in flowstreams.

Releases of juvenile chinook into pump intakes utilize vertical standpipes that are located on intake pipes of pumps in the plant (Figure 3). These standpipes are 30 cm (12 inches) in diameter and extend from the top of the plant's intake structure downward a distance of 11.9 m (38 ft) to connect with intake pipes. They join pump intake pipes at distances of between 12.2 and 13.7 m (40-45 ft) from where the pipes open along the bottom of the Sacramento River. The standpipes open into intake pipes about 2 m (6.6 ft) upstream from where intake pipes connect to pump chambers. Calculations show that flow velocities in intake pipes are about 2.4 m/s (8 ft/s) with pumps running at 2.83 m^3/s (100 cfs) output. The elevation of the surface of water in the standpipes fluctuates with the elevation of water in the nearby Sacramento River. When making a release, juvenile chinook are lowered in an inserter to the water surface in a standpipe. The plug in the mouth of the inserter is retrieved with an attached line, and the juveniles are freed as the inserter is lifted from the standpipe. A crowder is then lowered in the standpipe to the point of junction between it and the pump's intake line. Crowders are made from sections of PCV pipe that are 41-46 cm (16-18 in) long and 25 cm (10 in) in diameter. The lower end of a crowder is covered with a perforated plastic plate. Perforations are 3.2 mm (0.13 in) in diameter. The crowders are weighted to promote their downward movement through the water standing in the pipes. Neoprene rings are attached to upper and lower rims of crowders to make them fit snugly within the standpipes to help insure that juvenile chinook move into the intakes of pumps. During work on objectives B, D and E, juvenile chinook are also released at locations downstream of the pumps; for example, in pump outfalls or at points along bypass channels. In these cases, they are lowered to the waterline in an inserter, and are freed by retrieving the plug in the inserter's mouth.

For work on objectives B, C and D, juvenile chinook are inserted in pump intakes or at pump outfalls. They pass downstream through screening facilities in the plant and into bypass channels. They are shunted from bypass channels and are recovered in holding tanks in the plant's fish facilities (Figure 3). Holding tanks are operated in a flow-through mode and are fitted with delta weight, knotless nylon netting with 3.2 mm (0.13 in) or 4.7 mm (0.19 in) mesh to retain juveniles. For work on objective E, juvenile chinook are inserted in pump intakes or at various downstream locations in the plant's bypass system (Table 5). In that case, they are recovered in the live-box on a net attached to the outfall structure of the plant's fish bypass in the Sacramento River. During trials, holding tanks or the outfall live-box are tended for the length of time ordinarily required to recover the 32 juveniles in a sample that was released upstream. In the recovery process, chinook are removed from holding tanks or live-box using small meshed hand-nets. Marked individuals are separated from unmarked juveniles that are entrained from the river during the travel-time of a sample. Juveniles in the sample that was released are placed in the numbered live-cage in which the sample resided prior to release. The live-cage is held in a companion 19 L (5 gal) bucket that is filled to one-half capacity with riverwater. Mortalities are recorded. Two juveniles are selected at random, euthanized in a buffered solution of Finquel, placed in water in a plastic bag and refrigerated. These fish are used to make an estimate of the frequency of individuals used in the trials that had post-passage injuries. They are also used to estimate the percentage of scaled surfaces that were descaled or bruised on post-passage fish. The live-cage is then returned in its bucket to the project's riverwater facility. There, the live-cage is separated from its bucket underwater in a holding tank. The work of day-4 in the handling schedule (Table 4) is completed by conducting several trials, each using the procedures that have been described here.

Injury and descaling assessments are made within 24 hours on pre-passage and post-passage juveniles that are euthanized for this purpose during trials. This activity is noted for day-5 on Table 4. Injuries are recorded using the guidelines in Table 2, and descaling follows the approach described earlier in this section. Timely attention to these fish avoids the risk of observing high incidences of deciduous scale loss that accompanies storage that is extended beyond 24 hours. On day-5, day-6, day-7 and day-8 of the handling schedule, post-trial samples of fish in live-cages in the riverwater facility are observed for delayed mortalities. The purpose of this work is to record losses due to internal or external injuries that were not detected at the time juveniles were recovered in holding tanks. The chinook are not fed a formulated feed during this post-trial observation period. After 96 hr, surviving post-trial fish are ordinarily released in the Sacramento River (day-8 in Table 4). On occasion, their stay in the riverwater facility is extended because their release would harm populations of endangered salmonids in the Sacramento River, or interfere with on-going studies of salmonids at downstream locations in the river and the delta estuary. When these occasions arise, post-trial fish are put on rations after 96 hr and are fed until they are released.

Statistical Design

The following protocol has been established for conducting experimental work related to objectives B, C, D and E. The purpose of the protocol is to minimize variability in data that is caused by procedures. Juvenile chinook salmon are passed through the pumping plant during *sessions* that last for 2-3 days. Juvenile chinook used in a session have the same history of rearing at Coleman National Fish Hatchery, and the same history of handling and holding in tanks in the wellwater facility at Red Bluff. Sessions are spread over wet and dry seasons of the year in an attempt to cover the range of values for water quality variables that are typical of these seasons (e.g., water temperature, turbidity). Each session consists of one or more *runs*. Juvenile chinook used in a run share a common history of pre-trial and post-trial handling at Red Bluff; that is, they proceed as a group through the handling schedule in Table 4. Since runs are conducted in a period of 4-6 hours, juveniles used in a run pass through the pumping plant under nearly identical conditions of water quality. Each run that is conducted has one or more *trials*. In each trial, *treatment* and *control* samples of juvenile chinook salmon are passed through the pumping plant. Objective B, for example, calls for assessment of mortality and injury to juveniles subjected to passage through the Archimedes and internal helical pumps. To obtain pump effects, treatment samples are placed in pump intakes and control samples in pump outfalls. Both types of samples are collected in holding tanks on pump bypasses for tally of mortalities and injuries. To obtain data to compare mortality and injury associated with passage through Archimedes and internal helical pumps, the two types of pumps are run simultaneously, and each trial has treatment and control samples for each type of pump. The response variable to be tested in these experiments is the difference in mortality and injury between groups of juvenile chinook passed through the plant as treatments and controls.

Null hypotheses will be tested during work related to objectives B, C, D and E. Null hypotheses for objective B, for example, are as follows:

(1) there is no difference in the proportion of juvenile chinook salmon killed by passage through the Archimedes and internal helical pumps,

(2) there is no difference in the proportion of scaled body surface that is descaled on juvenile chinook salmon passed through the Archimedes and internal helical pumps and

(3) there is no difference in the proportion of juvenile chinook salmon injured by passage through the Archimedes and internal helical pumps,

where treatment and control samples pass from pump intakes and pump outfalls respectively to holding tanks on each pump's fish bypass system.

Multi-response permutation procedures are used to detect significant differences ($p<0.05$) in mortality and injury between treatment and control groups of experimental fish. Multi-response permutation procedures, in contrast to parametric statistical techniques, use normed distances between measurements as the unit of analysis (Mielke et al. 1980, Mielke et al. 1981, Edgington 1986, Manley 1997). These permutation procedures yield inferential results solely dependent on randomization and permutations of the measured data sets. The experimental data are permuted (rearranged) repeatedly according to random assignments. The procedures avoid decisions about goodness of fit of univariate or multi-variate distributions. Multi-response permutation procedures are especially appropriate for experiments conducted here because of the exceptionally low incidence of mortalities and injuries expected from observations made in preliminary studies (see *Abstract*), and the consequent non-normal distribution of mortality and injury data that will be obtained. The permutation analyses also avoid the standard assumptions of ANOVA, such as normality and heterogeneity of variances.

Exploratory Trials for Objectives B

Exploratory plant passage trials with hatchery-reared juvenile chinook salmon were conducted opportunistically in 1995 and 1996 when pumps in the plant were running. One purpose of this work was to obtain hands-on experience with operation of the pumping plant so that standard methods could be developed for experiments using surrogates. Another was to obtain preliminary estimates of the variability to expect in data on mortality and injury associated with passage of juvenile chinook salmon through pumps (objective B). Windows of opportunity existed during the annual production cycle at Coleman National Fish Hatchery to obtain the size-classes of chinook that were sought for experiments.

Juveniles at 30-45 mm fork length were available in January and February (fall run) or in April and May (late-fall run), while 46-70 mm juveniles were available in March and April (fall run) and again in June and July (late-fall run). Juveniles at the hatchery were generally larger than 70 mm from July through December. Pumping schedules were restricted at Red Bluff during 1995 and 1996 by the need to make engineering modifications to the Archimedes and internal helical pumps. Because of this, pumps were not ordinarily available for work on biological evaluation at a time when juvenile chinook in the 30-45 mm size-class were available from the hatchery. Figure 6 and Figure 7 show the size-frequency distribution of chinook used with the internal helical and Archimedes pumps respectively. It can be noted from the figures that the majority of juveniles used with the internal helical pump could be put into two size-classes; those from 46-70 mm fork length, and those from 71-110 mm fork length. The majority of juveniles used with the Archimedes pumps were in a size-class from 46-70 mm.

Exploratory trials were conducted with the internal helical pump between June and September of 1995. The Archimedes pumps were used for trials from March to May of 1996. Juveniles of fall run and late-fall run chinook salmon were obtained from Coleman National Fish Hatchery. In a general sense, the methods used to handle these fish during this work were those described in the section above entitled *Standardized Methods for Objectives B, C, D and E*. Subtle differences did occur however, since fine tuning of methods was underway over the course of these trials. Development of a suitable method to assess descaling caused by passage was not completed until the end of these trials. Because of this, information on descaling is not included in this section of the report on exploratory trials.

All juvenile chinook used in these exploratory trials were dye-marked and acclimated to ambient riverwater conditions in the project's riverwater facility prior to plant passage. They were moved to the pumping plant in cylindrical live-cages. Two locations were used to insert samples of fish into the flowstreams of pumps; either pump intakes or just downstream of pump outfalls. Samples were inserted in the intake of the internal helical pump on 29 occasions. They were inserted in the intake of Archimedes-1 on 22 occasions, and the intake of Archimedes-2 on 14 occasions. In general, pump outfalls were used for release of samples on the same days that samples were released in pump intakes. Overall, samples were released on 18, occasions at the outfall of the internal helical pump, and on 22 and 14 occasions at the outfalls of Archimedes-1 and Archimedes-2 respectively. The number of fish per sample released varied from 27 to 32 individuals.

During the exploratory trials, dewatering ramps on pump bypasses were used to shunt released chinook into holding tanks in the plant's fish facility. Trials of plant passage conducted early in this work were conducted during daylight hours. It was found that the juvenile chinook tended to hold-up in the plant's screening facilities or bypass channels upstream of holding tanks during daylight hours. On occasion it took >120 minutes for all members of a released sample to enter the tanks. This severely limited the number of trials that could be conducted in a day with any one pump without juveniles belonging to sequential releases finding their way to holding tanks at the same time. When this happened, sample-membership for individual fish could not be resolved. To overcome this problem, laboratory studies were conducted with a variety of dyes in addition to Bismarck brown-Y. The purpose was to obtain several marks for juveniles so that membership of individuals in sequentially released samples could be discerned. These studies led to no satisfactory result. Fin-clips were considered as marks to distinguish between members of different samples. However, fin-clips were avoided at this juncture in the work in order not to jeopardize the ability of juvenile chinook to traverse flowstreams in the plant. Early in the project, work on entrainment of chinook from the Sacramento River showed that the majority of juveniles entered the pumping plant at night. It was also observed that hatchery-reared surrogates released at night tended not to hold-up in flowstreams in the plant. As a consequence of these observations, all passage trials conducted after August 1995 were conducted at night in order to retrieve chinook that belonged to individual samples in a timely manner.

As standard practice for exploratory trials, two juvenile chinook were selected at random from each group of fish in a sample prior to insertion of that sample into the flowstream of a pump. These fish were euthanized in a buffered solution of Finquel. They were later examined for injuries that they obtained during hatchery rearing or during pre-trial handling at Red Bluff. The remaining fish in each sample were inserted in the flowstream of the pump in use at the time, and they moved downstream to holding tanks on that pump's bypass. Tanks were tended until all juveniles released were recaptured, or until the rate of return of released juveniles to tanks was less than 1-2 individuals per 30 minutes. Marked juveniles collected in tanks during a trial were counted and mortalities were tallied. Two individuals were taken at random, euthanized, and later examined for injuries. The kinds of injuries in pre-trial and post-trial juveniles were recorded using the approach shown in Table 2. The number of fish injured by passage during all trials with each pump was estimated by subtracting the number of pre-trial fish with injuries from the number of fish with post-trial injuries. Dye-marked juvenile chinook that were alive when collected in tanks at the end of each trial were held for 96 hours in the project's riverwater facility. They were observed at intervals over that period of time to detect delayed mortalities.

Standardized Trials for Objective B

By mid-April of 1996, exploratory trials on plant passage with hatchery-reared juvenile chinook were finished and standard methods were established for conducting experiments related to objectives B, C, D and E of the biological evaluation program. Two pumps in the plant were out of service at that time; the internal helical pump and Archimedes-2. Between April 24 and May 14, trials were conducted with Archimedes-1 to examine the range of variation in mortality and injury data obtained with application of the standard methods. The work terminated on May 15 when Archimedes-1 went down for repairs. It was not until February of 1997 that pumps were again available and juvenile chinook were available at Coleman National Fish Hatchery so that experiments on surrogate plant passage could resume.

Plant passage work in the spring of 1996 was designed to assess mortality and injury to juvenile chinook salmon from pump passage (objective B). Methods used were those described in the section above entitled *Standardized Methods for Objectives B, C, D and E*. All juveniles used were from the same lot of fish; a fall run lot that was obtained from Coleman hatchery on April 15. They were held in the project's wellwater facility while awaiting use in trials. The schedule shown in Table 4 was used for handling juveniles. Four sessions were conducted; three with one run, and one with two runs. Two trials were conducted per run. A quality control assessment (Table 3) was conducted on each group of fish used to make up samples for a session. Fish in this lot from Coleman National Fish Hatchery had an excellent history of health throughout the sessions. There was no incidence of disease in holding tanks at Red Bluff and cumulative mortality over holding times for fish used in sessions was very low (<0.5%). Overall, only two of 90 fish taken randomly from holding tanks for quality control assessments during these sessions had injuries obtained during rearing at Coleman or holding in tanks at Red Bluff. Mean fork lengths for juveniles used in this work ranged from 65 mm in early sessions to 72 mm in later sessions. The juveniles were robust. Condition factors for fish used in the sessions ranged from 1.1 to 1.2; well above the 0.85 limit used to exclude juveniles of these sizes from use in experiments (Table 3). Scales on these fish tended to be deciduous. As noted in Table 3, this condition was typical for juveniles of these sizes that were obtained from Coleman hatchery.

At the beginning of each run, Archimedes-1 was shut down and the flowpath was examined from the pump's outfall to holding tanks on its bypass for open crevices through which released fish could move to escape recovery in tanks. Crevices noted were plugged with pieces of cloth or a synthetic spray-foam. Archimedes-1 was then turned on and operated in the normal mode for delivery of irrigation water; at 26.5 rpm and a discharge of 2.5-2.6 m^3/s (87-93 cfs). Each trial conducted had one *treatment* sample of 34 juvenile chinook marked with Bismarck brown-Y. Two fish were removed from the sample for pre-trial assessment of injuries and descaling. The remaining 32 fish in each treatment sample were released in the pump's intake. Each trial also had one *control* sample of 34 juvenile chinook marked with Bismarck brown-Y. Two fish were removed from each control sample for examination for pre-trial injuries and descaling. The remaining 32 juveniles in each control sample were released just downstream of the pump's outfall.

In all, 10 trials were conducted during this work. Each trial was done in the 3-4 hours after sunset in an attempt to obtain prompt retrieval of released juveniles. Holding tanks on the bypass of Archimedes-1 were tended for 30 minutes following a treatment or control release. Thirty minutes after a release, the metal diversion channels leading from the bypass to holding tanks were swept lightly with a broom to move chinook that were lingering in the channels into the tanks. Chinook marked with Bismarck brown-Y were removed from holding tanks with hand-nets and placed in live-cages that were marked with their sample-number. The number of juveniles collected from holding tanks during each trial was recorded, as were the number of mortalities that occurred among them. Two fish were taken from each sample to examine for post-trial injuries and descaling. After juveniles from a treatment or control sample were collected, the alternate sample (treatment or control) was released in the pump's flowstream and recovered in the holding tanks. Each sample recovered from holding tanks was taken promptly to the project's riverwater facility. There the juveniles were observed over 96 hours to detect delayed mortalities. During this work, chinook in *treatment* and *control* samples underwent the same pre-trial and post-trial handling. The flowpaths they travelled in the plant differed. Because of this, differences in mortalities, injuries and descaling between treatment and control samples, if they occurred, could be assigned to passage through Archimedes-1 and its outfall.

Exploratory Trials for Objective E

Exploratory trials were conducted in 1996 in preparation for development of a study plan for objective E in the biological evaluation program for the pumping plant. Objective E deals with residence time and mortality and injury that juvenile chinook salmon experience in terminal portions of the plant's fish bypass system. It deals specifically with those portions of each pump's bypass that are located downstream of dewatering ramps and channels that are used to shunt water and fish to holding tanks (Figure 3).

When the pumping plant is operating to make water deliveries, and a dewatering ramp is not in use to collect fish, the ramp is stored in a raised position above the concrete channel that carries water downstream from each pump's screening facility. When a dewatering ramp is up, fish entrained by pumps pass beneath it. Just downstream of each ramp, water and fish drop into a plunge pool. Water ordinarily occupies the plunge pool to a depth of about 0.31 m (12 in). It can be held at greater depths by placing stop-logs at the downstream end of the pool. Water and fish leave each pump's plunge pool through an underground pipe that is 46 cm (18 in) in diameter. Downstream, this pipe opens into a 1.52 m (5 ft) diameter pipe that is part of the fish bypass system for drum screens in the forebay of the Tehama-Colusa Canal (Figure 3). Water and fish leaving the pumping plant pass along the 1.52 m (5 ft) diameter drum screen pipe and enter the Sacramento River at a mid-channel, concrete structure.

Mortality and injury that entrained fish experience in portions of the plant's bypass system downstream of dewatering ramps will depend in part on the stress, and perhaps injury, that they experience in pumps and screening facilities before they pass downstream of dewatering ramps. Hence, early drafts of the study plan for work on objective E (U.S. Bureau of Reclamation, in preparation) call for releasing *treatment* samples of hatchery-reared chinook in pump intakes, and recovering them in a live-box attached to a net at the plant's outfall in the river. *Control* samples will be released at various points downstream of the pumps. They will also be recovered from the live-box at the outfall. A preview of the design for this work is given in Table 5. By using treatment and control samples identified in Table 5, mortality and injury that occurs during passage can be assigned to specific segments of the plant's bypass system, including those segments downstream of dewatering ramps. Residence time in terminal portions of the bypass system can also be obtained while handling treatment and control samples. Two size-classes of chinook will be used for this work; small fish (30-45 mm) and larger ones (46-70 mm).

Exploratory trials of chinook passage through the plant's bypass system were conducted in May and again in September of 1996. One purpose of the work was to develop procedures for sampling fish at the plant's outfall in the Sacramento River. The goal was to minimize or eliminate injuries to fish caused by the sampling process itself. Another purpose was to obtain preliminary estimates for residence time and mortality and injury for juvenile chinook salmon passing through portions of the plant's fish bypass system downstream of dewatering ramps. The trials were conducted during periods of the year when gates of the Red Bluff Diversion Dam were raised out of the water. Gates were raised in accord with the *biological opinion* under which the dam is currently operated (National Marine Fisheries Service (1993a). The work was done when dam gates were out of the water because it is only under that scenario that the research pumping plant is expected to operate on a fulltime basis to meet water delivery needs of the Tehama-Colusa Canal in years ahead.

When gates on the dam at Red Bluff are in the water, the hydraulic head on the Tehama-Colusa Canal is maintained by gravity feed from Lake Red Bluff to the canal's forebay. When gates are out of the water, pumps are needed to lift water from the Sacramento River into the forebay of the canal. Pumped deliveries of water to the forebay are screened to prevent removal of fish from the Sacramento River. Drum screens on the forebay of Tehama-Colusa canal are not needed during gates-out periods. They are shut down and gates at located at upstream positions on the drum screens' fish bypasses are closed to prevent loss of hydraulic head in the canal's forebay. Standing water occupies the 1.52 m (5 ft) diameter pipe, the distal portion of which, also serves as the distal portion of the pumping plant's fish bypass system (Figure 3). These gates-out conditions prevailed during the trials that are reported here.

Each exploratory trial made in 1996 used every pump in the plant that was up and running at the time. Archimedes-1 was used for trials in May. Archimedes-1 and Archimedes-2 were run simultaneously in September. In each case, pumps were run at normal operating water delivery rates. That produced discharges of water through each fish bypass of 0.32 to 0.34 m^3/s (11.3-12 cfs). Juvenile chinook available from Coleman National Fish Hatchery at times of these trials were relatively large.

Their fork length in May ranged from 60-72 mm, while in September it ranged from 100-110 mm. Fifty juvenile chinook were used in each trial. In May, they were released at the entrance to the underground bypass pipe at the downstream end of the plunge pool on the bypass of Archimedes-1. In September, juveniles were released at a point upstream of the plunge pool and directly below the proximal end of the raised dewatering ramp on the bypass of Archimedes-1 (Figure 3).

A fyke net with live-box was fit to the outfall of the pumping plant in the Sacramento River to recover chinook juveniles. The net was fit in a frame on the concrete outfall structure so that it captured the entire discharge from the bypass. The net was 12.2 m (40 ft) in length. It had 0.64 cm (0.25 in) delta-style mesh for the first 3.05 m (10 ft) from the throat, and 0.32 cm (0.13 in) delta mesh from there to the live box. The live-box had a capacity of 280 L (74 gal). A workboat was tethered to the outfall structure. Its motor was used in conjunction with the tether and the river's current to hold in position adjacent to the live-box. At times for sampling fish, the live-box and rear portions of the net were lifted aboard the boat with a hand-operated wench.

During trials in May, juvenile chinook that were released in the plant tended to hold in the bypass, rather than move to the outfall. By calculation, the discharge from Archimedes-1 during these trials produced very weak currents in the 1.52 m (5 ft) diameter drum screen pipe downstream; that is, currents of about 0.18 m/s (0.6 ft/s). It was possible to pulse the drum screen portion of the plant's bypass by opening an upstream gate and releasing water from the forebay of the Tehama-Colusa Canal. An electrical switch was thrown to lift the gate open or drop it closed. Various gate openings were used to examined effects of pulses of high discharge on sampling at plant's outfall. Openings greater than 0.6 m (2 ft) on the vertical diameter of the drum screen pipe were found to excessively bellow the sampling net and created an undesirable, high degree of turbulence in the live-box. Gate openings of 0.3 m (1 ft) or 0.6 m (2 ft) were chosen for use during trials. Adequate information was not available on the hydraulic head on the open gate to calculate discharges obtained by openings that were used (Max Stodolski, U.S. Bureau of Reclamation, Red Bluff, California, personal communication).

Three chinook passage trials were conducted in May of 1996. Juveniles were released in mid-morning. In the first trial, the live-box at the outfall was tended at 0.5 h intervals post-release over a period of five hours, at which time fish collections were terminated. In the second and third trials, the live-box was tended at 0.5 h intervals for three hours. Pulses of water were then applied to the bypass at intervals for an additional 1-2 hours. Openings of 0.3 m (1 ft) or 0.6 m (2 ft) were used. Pulses that were developed with the gate open either 0.3 m or 0.6 m lasted either two or four minutes.

One chinook passage trial was conducted in September of 1996. Juveniles were released in mid-morning. Archimedes-1 and Archimedes-2 were both running during this trial. Water currents developed in the drum screen bypass pipe by discharges of the two pumps were higher than in May trials; calculated at about 0.36 m/s (1.2 ft/s). The drum screen bypass was pulsed five minutes post-release and about every 40 minutes thereafter for a period of 3.5 hours. In all, five pulses were used. The drum screen gate was opened to 0.3 m (1 ft) for four minutes to develop the first two pulses, 0.6 m (2 ft) for four minutes for pulses three and four, and 0.6 m for ten minutes for the fifth and final pulse.

While making pulses during these trials, it took two minutes to open the gate on the drum screen bypass to a height of 0.3 m (1 ft), and two minutes to close it. To obtain a 0.6-meter (2-foot) pulse, it took four minutes to open and four minutes to close the gate. When pulses were used, the live-box at the pumping plant's outfall was tended 15 minutes after the gate began to open. Pulses were clearly visible at the net on the plant's outfall. For all trials taken together, water in pulses passed through the net and live-box between 5-9 minutes before the live-box was tended. Juvenile chinook that were released in the pumping plant and recovered in the live-box were examined for injuries or mortalities, and counted. Fish species that were entrained from the Sacramento River and passed through the plant during the studies were identified, counted, measured and examined for injuries. Notations were made during the trials on debris that accumulated in the live-box.

RESULTS

Entrainment Trials for Objective I

During 1995 and 1996, the Archimedes and internal helical pumps in the Red Bluff Research Pumping Plant were used opportunistically for entrainment studies while engineering modifications were made to the pumping plant. Trials were conducted over 24-hour periods. Fish entrained from the Sacramento River passed through pumps and screening facilities and were captured in the plant's holding tanks. Information was obtained from 13 trials with the internal helical pump, and 16 trials during which the two Archimedes pumps were run simultaneously. Trials with the internal helical pump were conducted in the summer of 1995. Trials with the Archimedes pumps were conducted in the spring and fall of 1996. Purposes of this work were to establish a list of those fish species that are most likely to be entrained during pumping, and to observe mortalities and injuries that they incur while passing through pumps to holding tanks on the plant's fish bypass system. Nine additional 24-hour entrainment trials were made in the pumping plant and synchronized with nine 24-hour collections of fish from the Sacramento River. From this work, preliminary information was obtained regarding the fraction of out-migrating juvenile chinook that might be entrained by pumping as they pass the plant.

Table 6 lists the species of fish that were entrained during trials, and their numbers. In all, 20 species were taken from the Sacramento River. Eight species at the top of Table 6 comprised 99% of the individuals captured in holding tanks. Juvenile chinook salmon (*Oncorynchus tshawytscha*) were the fish most commonly taken. Prickly sculpin (*Cottus asper*), Sacramento sucker (*Catastomus* ccidentalis*), lamprey (*Lampetra* spp.), bluegill (*Lepomis macrochirus*), white catfish (*Ictalurus catus*), acramento squawfish (*Ptychocheilus grandis*) and threespine stickleback (*Gasterosteus aculeatus*) ollowed chinook in order of abundance. Of the 153 lamprey entrained, 28 (19%) were adult Pacific amprey (*Lampetra tridentata*), and 2 (1%) appeared to be adults of either river lamprey (*L. ayresi*) or acific brook lamprey (*L. pacifica*). One hundred twenty-three (80%) of the lamprey taken were mmocetes. Adult Pacific lamprey were most common in summer, while ammocetes were most ommon from mid-March through early April. Bluegill were included among the commonly entrained pecies primarily because of a single pulse of juveniles that was taken in mid-September of 1996 when ates of the Red Bluff Diversion Dam were lifted from the water to comply with operating regulations. hese fish had apparently been rearing in Lake Red Bluff prior to the time the gates were lifted.

Figure 8 shows the frequency distribution for lengths of the four species most commonly ntrained by pumps. These four species made up 87% of all fish entrained during trials. The high ercent-frequency for chinook salmon in the 30-39 mm size class was due primarily to entrainment of vinter-run juveniles in September of 1995. High relative frequency in the 60-79 mm size-class of chinook oincided with the period in which Coleman National Fish Hatchery released over 12 million fall-run veniles upstream of Red Bluff in the spring of 1996. The frequency distribution for length of lampreys hown in Figure 8 is split between ammocetes in a range of lengths from about 60 mm to 139 mm, and dult Pacific lamprey in the size-class >400 mm.

While conducting entrainment trials, fish were trapped in the plant's holding tanks during diurnal nd nocturnal portions of each 24-hour period used for sampling. Information obtained with this pproach is shown in Table 7 for the eight most commonly entrained species. These species, except for luegill and threespine stickleback, showed a strong propensity for entrainment from the river at night. he ordinary diel pattern for bluegill was likely masked in these data by downstream movements that ey made in association with water that was draining from Lake Red Bluff in September of 1996. A ixed pattern for diel entrainment was observed among the runs of chinook salmon. In trials reported ere, a large majority of winter run and fall run juveniles were entrained at night. Juveniles placed in the pring run and late-fall run were more evenly entrained day and night.

Table 8 summarizes *information* obtained on the survival of fish that were entrained from the acramento River. Data in the table on run membership for chinook salmon entrained by the rchimedes pumps was strongly influenced by the capture of juveniles reared at Coleman National Fish latchery. As noted earlier in the text, the hatchery released over 12 million fall run chinook upstream of ed Bluff during the spring of 1996 when entrainment trials were conducted with the Archimedes pumps. ome of those released had fork lengths in the range for spring-run juveniles (Greene 1992). Because ess than 10% of the fall run fish from the hatchery were marked with adipose fin clips, it was not ossible in most instances to distinguish between fall run hatchery fish of spring run size and wild fish of the river and discharge through the mouth of the trap. The index of abundance for out-migrating chinook juveniles that were moving past the intake structure of the plant, as measured by the screw trap, declined during the period of this work. That decline is shown in column four of Table 11. The ratio between take of chinook by pumps in the plant and take by the screw trap fluctuated around 0.50 until the index of abundance for chinook passing the plant diminished to a very small number on May 2. The index of abundance remained very low through May 13. During the May 2 to May 13 interval, the screw trap take ranged from 0.06-0.11 chinook per acre foot and the *pump-take:trap-take* ratio was highly variable (0.09-0.83).

Plant Passage by Hatchery Surrogates

Exploratory Trials for Objective B

Information was obtained from work in 1995 and 1996 on mortality and injury to hatchery-reared juvenile chinook salmon that were inserted into flowstreams of pumps in the plant at their intakes or at their outfalls. Fish inserted in intakes passed through pumps and were discharged into outfall channels. They travelled downstream through screening facilities and bypass channels and were collected in holding tanks. Fish inserted in pump outfalls passed downstream through screening facilities and bypass channels and were also collected in holding tanks.

Table 12 summarizes information on percentages of released chinook that were not recovered in holding tanks during the trials. Data in the table show that, overall, 2% to 7% of juveniles released in pump intakes were not recovered, and from 0% to 3% of those released at pump outfalls were not recovered. Various routes were observed during these trials by which fish could escape capture in holding tanks. These included overflow splash that occurred around pump outfalls and small crevices along edges of dewatering ramps and diversion channels and gates that shunted fish into holding tanks. On occasion, fish were observed to slide over the top of debris separators and drop into bypasses before reaching holding tanks. Table 12 shows that losses of released chinook were somewhat higher during work with the internal helical pump than with the Archimedes pumps. This difference may be explained by the fact that escape routes were identified and progressively plugged between June of 1995 when work with the internal helical pump was begun and March to May of 1996 when work was conducted with the Archimedes pumps.

The column at the right side of Table 12 shows percentages of juvenile chinook that were alive when collected from holding tanks. There was little difference in percentages of mortality observed among fish inserted in intakes of the three pumps in the plant, or in percentages of mortality among fish inserted in outfalls of the pumps. For all pumps combined, a mortality of 1% was observed among chinook inserted in pump intakes, and <1% for those inserted in pump outfalls. The highest percent mortality (2%) was found among juveniles released in the intake of the internal helical pump. However, techniques for insertion of juveniles into pump intakes, and procedures for collecting juveniles from holding tanks were under improvement during the course of these trials. Handling procedures, later refined, were known to cause some fraction of the mortalities recorded during early phases of the program when the internal helical pump was used. Because of this, the mortality data in Table 12 are not sufficient to infer differences regarding the effects of passage through the internal helical and Archimedes pumps.

During 1995 and 1996, information was also obtained on the frequency of injured juveniles in samples of chinook that were used for plant passage trials. A subsample was taken of fish used in each trial just prior to insertion of a group of juveniles into a pump's flowstream. Another subsample was taken when individuals of the same group were collected in holding tanks. Injuries observed in pre-passage fish were due to pre-trial handling. Injuries observed in post-passage fish were due to pre-trial handling, to passage, or to a combination of the two. Data obtained over the intervals of work with each pump were combined for groups of fish that were inserted in pump intakes and those that were inserted in pump outfalls. Results of this work are shown in Table 13. The net injury-effect due to passage, shown in Table 13 under the heading *No. of Fish Injured by Passage*, was obtained for pump-intake and pump-outfall trials by subtracting the number of pre-passage fish with injuries from the number of post-passage fish with injuries. Where this yielded a negative value, injuries caused by passage were considered nil. Table 13 shows, that while relatively few fish were used in the analyses, indications are that the frequency of injury to juvenile chinook that could be assigned to plant passage was very low; for all pumps, and juveniles released in intakes or at pump outfalls, about 1%. During this work, all chinook that were alive at the time they were recovered in holding tanks were held in the project's riverwater facility for 96 hours to record mortalities that may have been caused by internal or external injuries that were not detected at the time of recovery. Table 13 shows that, combining data for all pumps, delayed mortality was about 2% for chinook inserted in pump intakes and <1% for juveniles inserted in pump outfalls.

Standardized Trials for Objective B.

Trials were conducted in the spring of 1996 to examine the range of variation in mortality and injury data obtained with application of standardized procedures for conducting experiments on pump passage with hatchery-reared juvenile chinook salmon. A single pump (Archimedes-1) and one size-class of fish (65-72 mm fork length) were available for work at that time. The trials were designed to isolate the effects of pump passage (objective B). Samples of *treatment* fish were released in the pump's intake and recovered in holding tanks on the pump's bypass. Samples of *control* fish were released just downstream of the pump's outfall and recovered in holding tanks. Differences in the frequencies of mortalities and injuries between control and treatment samples were assigned to passage through the pump and its outfall.

Data resulting from this work are shown in Table 14. Data in Table 14 show that all of the juveniles released in treatment and control samples were recovered in holding tanks. Escape routes that were used by juveniles in earlier studies had been plugged along the flowstream of the pump prior to trials and were apparently unavailable, at least for the large sized juvenile used (65-72 mm fork length). In the course of 10 trials, no mortalities were observed. Standard procedures were used in this work for assessing the percent frequency for individual chinook that were injured by passage. Resulting data are not tabled since no injuries were observed in either treatment or control samples. A total of 300 treatment and 300 control fish were observed over 96 hours in the project's riverwater facility to record delayed mortalities. No delayed mortalities occurred.

Table 15 shows data on the descaling effects of passage that were obtained during these trials. Results are shown in the table for pre-trial quality control assessments (QA) of descaling that were made on juvenile chinook used in each session. These quality control assessments showed that mean percent descaled per fish increased from 2% to 26% between the first session of work on April 24 and the last session of work on May 15. The percent of scaled surface that was descaled on pre-trial treatment and control fish increased in a similar manner during successive sessions. Over the period of work, the mean fork length of juveniles increased from 65 mm to 72 mm. Results just cited suggest that scales on these smolt-sized chinook became progressively more deciduous over the period of time in which sessions were conducted. These observations also demonstrate that descaling due to pre-trial handling of juveniles (marking, moving for acclimation, etc.) had little or no descaling effect.

Percent-descaling due to passage shown in Table 15 was obtained for treatment and control samples by subtracting the mean percent-descaled per fish in pre-passage samples from the mean percent-descaled per fish in post-passage samples. The percent-descaling due to pump passage was obtained by subtracting percent-descaling due to passage in treatment samples from percent-descaling due to passage in control samples. Information in column 10 of Table 15 on percent-descaling due to pump passage suggests that, if descaling occurred at all during pump passage, the surface descaled was a small percentage of the total scaled surface (3-7%) of the juveniles used in this work.

Exploratory Trials for Objective E

During 1996, hatchery-reared juvenile chinook salmon were passed through portions of the pumping plant's bypass system that are located downstream from dewatering ramps and fish holding tanks that were used to obtain results discussed thus far in the text. The work was done during spring and fall months when drum screens in the forebay of the Tehama-Colusa Canal were shut down, and gates on fish bypasses associated with the drum screens were closed. Given these conditions, standing water filled the 1.52 m (5 ft) diameter pipe on the drum screen that served as the terminal portion of the plant's fish bypass system (Figure 3). When the pumping plant was in operation, currents generated by water from the pumps moved toward the river in the distal portion of the drum screen bypass; that is, the portion of the drum screen bypass downstream from the point of its connection with bypass pipes from the pumping plant (Figure 1). Velocities of these currents, estimated by calculation, were low; about 0.2 m/s (0.6 ft/s) for trials conducted in the spring and 0.4 m/s (1.2 ft/s) for a trial conducted in the fall. Because of these conditions, the possibility existed that juvenile chinook and other fish that passed through the plant might delay passage to the river by holding in refugia available in the drum screen bypass.

Four exploratory trials were conducted to examine residence time for juvenile chinook in portions of the plant's fish bypass system downstream of dewatering ramps. The first three of these trials were conducted in May of 1996. Archimedes-1 was the only pump in the plant that was available for this work at the time of these trials. It was operated to deliver between 0.32 and 0.34 m^3/s (11.3-12.0 cfs) to its fish bypass system. In each trial, hatchery-reared, fall-run chinook (60-72 mm fork length) were released in high-velocity currents (3.0-3.7 m/s, 10-12 ft/s) at the entrance of the pump's underground bypass pipe. The entrance to that pipe is located at the downstream end of the plunge pool that exists on the pump's fish bypass system (Figure 3). Released fish were recovered at the bypass outfall in the Sacramento River.

Results of the first trial showed that, under conditions of discharge that prevailed in the bypass during the trial, about 90% of juvenile chinook that were released held-up in the bypass pipes for more than 5 hours. It also showed that pulsing the discharge in the drum screen bypass by introducing water from the forebay of the Tehama-Colusa Canal would hasten the recovery of released juveniles at the bypass outfall in the river. During the second and third exploratory trials, such pulses were used. Results obtained during these two trials were essentially the same. For illustration, information obtained from one of the trials is shown in Figure 9. Results from trials two and three showed 94% to 96% of the released juveniles held in the system for three hours, after which a high-discharge pulse was applied to the plant's terminal bypass line by opening a gate on the drum-screen bypass. Three additional pulses were applied over the following two hours. As demonstrated in Figure 9, pulsing resulted in relatively rapid recovery of the juvenile chinook that were released. Over-all, 98% of those released in trial-2, and 100% of those released in trial-3, were recovered. In both of these trials, no mortalities were observed among the juveniles used. Injuries were observed in 1% of those juveniles that were recovered.

In September of 1996, Archimedes-1 and Archimedes-2 were used for a short time to make water deliveries to the Tehama-Colusa Canal. A window of opportunity existed to conduct a single trial of passage through terminal portions of the plant's fish bypass system. The pumps were run simultaneously, each discharging approximately 0.33 m^3/s (11.5 cfs) to its fish bypass. The dewatering ramp on the fish bypass for Archimedes-1 was in a raised position for this work. Late-fall chinook (100-110 mm fork length) were released in the open, concrete bypass channel of Archimedes-1 at a point located below the upstream end of the dewatering ramp. The juveniles moved downstream into the plunge pool that exists at the head of the underground pipes through which the plant's fish bypass system discharges to the Sacramento River (Figure 3). The possibility existed that this plunge pool, as well as the drum screen bypass located downstream, provided refugia in which juveniles could delay passage to the river. In this trial, the drum screen bypass was pulsed five minutes after fish were released, and on four additional occasions spaced over the following three hours. Figure 10 shows that the recovery of juveniles at the plant's outfall was more gradual than recovery obtained following pulses used in May of 1996 (Figure 9). In this trial, approximately 50% of the juveniles held-up in the bypass through two pulses that occurred in the first hour. Twenty-five percent held-up through three pulses that occurred over the first two hours, and 15% held-up for three hours or more during which a total of five pulses were used. One juvenile, from among 50 that were released, was dead at the time of recovery. No injuries were observed among the juveniles that were recovered alive.

DISCUSSION

Objectives for biological evaluation of the Red Bluff Research Pumping Plant were established in 1992 by cooperative efforts of personnel from the Bureau of Reclamation, California Department of Fish and Game, California Department of Water Resources, U.S. Fish and Wildlife Service and the National Marine Fisheries Service (Liston and Johnson 1992b). Construction of the pumping plant began early in 1994. Major components of construction were finished in May of 1995. Initial engineering tests on pumps, screening facilities and fish bypasses began at that time. Through the remainder of 1995 and throughout 1996, mechanical modifications were underway to improve their performance (Liston et al., in press). Concurrently, fish facilities required for the evaluation program were developed on-site, and hands-on experience was obtained with fish passage through the plant. The internal helical and Archimedes pumps in the plant ran intermittently during 1995 and 1996. The internal helical pump was in operation from June to September of 1995. The Archimedes pumps were in operation from March to May of 1996, and again in September and October of that year. Summaries of the information that was collected on fish passage during those intervals are presented in this report. These summaries relate to objectives B, C, D, E and I of the biological evaluation program. Because operation of the pumping plant and procedures for conducting fish passage work were in transition during years covered by this report, data presented here were not collected in a standardized manner, and they provide only preliminary estimates of ranges of variation to be expected in results of standardized studies on these topics that are planned for 1997 and 1998.

Entrainment Trials for Objective I

Objective I in the biological evaluation program for the Red Bluff Research Pumping Plant is concerned with estimating the numbers of juvenile chinook salmon and other fish that are entrained from the Sacramento River in different seasons of the year, and injuries and mortalities they sustain while passing through pumps. Information on this topic was obtained during 1995 and 1996 by conducting 29 entrainment trials. During trials, pumps were run at the rates normally used for water deliveries to the Tehema-Colusa Canal. As a result of normal operations, about 10% of the water pumped was diverted to fish bypasses. Fish entrained by pumps were captured in holding tanks in the plant's fish facility. Tanks were tended so that each trial covered an interval of 24 continuous hours. Forty-five percent of the trials were conducted with the internal helical pump only. The remaining 55% of trials were conducted with Archimedes-1 and Archimedes-2 running simultaneously. Trials were spread over the summer and early fall of 1995, and spring and early fall of 1996. During these times, the numbers of out-migrating juvenile chinook salmon passing Red Bluff were low relative to peak out-migrations of juveniles that occur annually (Vogel et al. 1988, Vogel and Marine 1991, Craig Martin, U.S. Fish and Wildlife Service, Red Bluff, California, personal communication). As a consequence, the numbers of juvenile chinook entrained during these trials was also relatively low.

A total of 2332 fish were entrained from the Sacramento River during these trials. The volume of water pumped through the plant during trials was about 8548 acre ft (1051 hectare m). On average, the pumps took 0.3 fish per acre ft (2.3 fish per hectare m). Fish taken were distributed among 20 different species. They represents about one-third of the 62 species of Sacramento River fish cited by Liston and Johnson (1992b) as potentially present in the river at Red Bluff. Johnson and Martin (1997) report the capture of 28 species in U.S. Fish and Wildlife Service screw trap collections made in the Sacramento River for objective H of the program from July 1994 to June 1995. All of the species entrained by the pumping plant were also taken in their collections. Ninety-five percent of all fish taken by the pumping plant, and 98% of all fish taken by screw traps, belonged to the same six species. Chinook salmon (*Oncorynchus tshawytscha*) dominated both catches. The other most common species in both catches were Sacramento sucker (*Catastomus occidentalis*), prickly sculpin (*Cottus asper*), lamprey (*Lampetra* spp.), Sacramento squawfish (*Ptychocheilus grandis*) and bluegill (*Lepomis macrochirus*).

The vast majority of all fish entrained from the Sacramento River by pumps were small; <100 mm in length. Juvenile chinook salmon, uncommon during sampling relative to periods of major out-migrations, comprised 48% of the take of all species. Fork lengths of 98% of the chinook salmon were <80 mm. Thirty percent of the chinook salmon were post-emergent individuals with fork lengths in a range of 30-39 mm. Sampling that was conducted during trials from sunrise to sunset, and sunset to sunrise, showed that about 75% of chinook salmon were entrained from the river at night. Between 2% and 3% of chinook entrained by Archimedes pumps were dead at times when they were collected from holding tanks. Mortalities with chinook entrained by the internal helical pump were higher; at 7%. Scrutiny of the relatively limited data that were available from these trials did not reveal tendencies for mortalities with either kind of pump to be higher in one size-class of chinook than in another; for example, among juveniles <40 mm fork length as compared to larger juveniles. Some portion of the mortality difference between the two kinds of pumps was known to be due to fish-friendly improvements that were made between 1995 trials with the internal helical pump and 1996 trials with Archimedes pumps. Flow-paths from pumps to holding tanks and procedures for handling fish captured in tanks were both improved. For chinook that survived passage and holding tank conditions until they were collected, the incidence of injury was low. It varied between 0.6% and 1.2% for all pumps combined. The most common injuries were observed to the integument covering the body surface. Damage to head, eyes and fins were less common.

In general, species-specific variations from the trends just described for chinook salmon were absent in collections of the seven other species of fish that were most commonly entrained during trials. High nocturnal entrainment tended to be the rule for all species except threespine stickleback. Twenty-six percent of all fish were entrained during daylight, and 74% at night. Low percentages of mortality and injury also tended to be the rule among non-salmonid species of fish entrained during trials. However, mortalities were somewhat higher among Sacramento suckers and Sacramento squawfish than among other commonly entrained species. Taken together, mortalities for these two species ranged from 18-24% in trials with the internal helical pump, and 5-6% in trials using Archimedes-2. Reasons for higher than average mortalities among fish in these species is not clear at this juncture in the work.

In addition to topics discussed above, objective I of the biological evaluation program also deals with estimating seasonal and annual percentages of out-migrating chinook juveniles that the pumping plant entrains. Work regarding this was begun in March of 1996, and it extended into the following May. There were no upstream releases of chinook from Coleman National Fish Hatchery during the interval of this work. Juveniles that were entrained during trials were in the waning tail of the annual out-migration curve for river-spawned fall run chinook salmon (Craig Martin, U.S. Fish and Wildlife Service, Red Bluff, California, personal communication).

During this work, an index of the abundance of juvenile chinook passing the intake structure of the pumping plant per day (24 h) was obtained from the catch in a screw trap located in the Sacramento River just upstream of the pumping plant's intake structure. The number of juveniles entrained by the pumping plant during the same 24 hours was obtained by sampling holding tanks in the plant. In both cases, the catch was expressed as number per acre foot (hectare meter) of water sampled. The ratio *pump-take:trap-take* was calculated from catch data for nine sampling dates spread over the interval of March to May.

The number of juvenile chinook salmon taken by the screw trap per acre foot gradually declined during the interval of this study; from a high of 1.86 in mid-March to a low of 0.06 in early May. The number taken per acre foot of water pumped by the plant declined as well. The *pump-take:trap-take* ratio was relatively stable and varied around 0.50 for the first six days of sampling (3 March to 30 April). It had a range from 0.43 to 0.59. However, during the last three sampling dates (2 May to 13 May), the pump take and the screw trap take both declined to very low values. For those dates, the *pump-take:trap-take* ratio was highly variable. It ranged from 0.09 to 0.83. These results suggest that a mean *pump-take:trap-take* ratio, with relatively small variation around it, can be obtained with techniques used here if juvenile chinook salmon are relatively abundant in the river. Synchronized sampling of passing juveniles and the plant's take will continue during 1997 to further assess the range of variation in the *pump-take:trap-take* ratio.

As part of the biological evaluation program for the pumping plant, personnel of the U.S. Fish and Wildlife Service fish the near-plant rotary screw trap used in this work, and three other traps all located on a transect that extends the width of the Sacramento River just upstream of the pumping plant. An objective of their work is to develop a predictive model to estimate the numbers of juvenile chinook salmon that out-migrate pass Red Bluff during different seasons (Johnson and Martin 1997). If that can be done, the catch of juvenile chinook in the near-plant trap can be related to catches in the other three traps on the transect, and used with *pump-take:trap-take* ratios to make extrapolations to estimate percentages of out-migrating chinook that the pumping plant entrains.

Plant Passage by Hatchery Surrogates

Exploratory Trials for Objectives B

Objective B of the biological evaluation program is concerned with mortality and injury incurred by juvenile chinook salmon due to passage through pumps in the plant at Red Bluff. The goal is to compare the internal helical and Archimedes pumps in this regard. Hatchery-reared juvenile chinook salmon are used as surrogates for run-of-the-river chinook.

Precise information on the goal of objective B was not obtained from trials conducted in 1995 and 1996. There was no time in this interval when the internal helical pump and Archimedes pumps were running simultaneously. As a result, and because procedures for handling juveniles during trials were in transition, surrogates used in trials with the two kinds of pumps, importantly, did not share a common history of rearing, health or handling. Substantial modifications were also made to the flowpaths that surrogates traveled between the time trials were conducted with the internal helical pump (1995) and the Archimedes pumps (1996). Examples of the latter include placement of baffles on vertical wedgewire screens in the plant, and inverted weirs at entrances to bypass channels just beyond the screens. Damage from turbulence in holding tanks where surrogates were collected was reduced by modifying the outlets to holding tanks. In addition, the trials conducted in 1995 and 1996 on passage of juvenile chinook through the two kinds of pumps were not conducted under the same set of season-related environmental conditions (e.g., debris load, water temperature and turbidity).

The possibility that the situation just described would occur in early stages of operation of the research pumping plant did not escape the interagency planners who developed objectives for biological evaluation of the pumping plant. They allowed in their plan for a liberal time-period to shakedown pre-experiment engineering and biological aspects of the program (Liston and Johnson 1992b). And as they anticipated, the shakedown period was used to obtain important background information on fish passage through pumps. For example, data from exploratory trials on objective B were analyzed to estimate an adequate sample size (32 fish per sample) and a sufficient number of standard trials (20) needed to detect significant differences between pump types for mortality and injury due to pump passage under environmental conditions that occur in either the wet or dry season at Red Bluff (Jon Medina, U.S. Bureau of Reclamation, Denver, Colorado, personal communication). Preliminary estimates of *pump-effects* for chinook passing through the pumps at Red Bluff were also obtained. These can be gleaned from the combined data for all pumps presented in Tables 12 and 13 of this report.

Data in Table 12 show that mortality for juveniles that passed through pumps to holding tanks was about 1% for all pumps combined. Data in Table 13 show that <1% of chinook released in pump intakes were injured during passage through pumps to holding tanks, and about 2% experienced delayed mortality. The mortality or injury effects due to passage through pumps can be estimated by subtracting %-mortality or %-injury observed from passage through pumps to holding tanks from %-mortality or %-injury observed from passage from pump outfalls to holding tanks. Using this procedure, for all pumps combined, the *pump-effect* on mortality during passage from intakes to holding tanks was <1%. The *pump-effect* on delayed mortalities was about 1%, while the *pump-effect* on injuries during passage from intakes to holding tanks was zero. With this approach, one cannot discern whether mortalities and injuries to juveniles that passed through pumps occurred during passage through the pumps themselves, or during passage from pump outfalls to holding tanks. If the last case were true, mortalities and injuries may have resulted from pump-induced difficulties that juveniles encountered while traversing the outfall-to-holding-tank flowpath. Because the incidence of mortality and injury was small, this lack of ability to discern is not an impediment to concluding that 1995 and 1996 information suggests that pumps in the plant, as well as screening facilities and downstream channels to holding tanks, were fish-friendly; at least for juvenile chinook salmon with fork length >46 mm.

Studies which will yield precise information on the goal of objective B are planned for 1997 and 1998. These studies call for the internal helical pump and the Archimedes pumps to run at the same time. Standardized methods described earlier in this report will be used to conduct trials. Juvenile chinook salmon will be passed through the two types of pumps simultaneously. These juveniles will have the same history of rearing, health and handling. Emphasis will be put on obtaining data for chinook in both of the 30-45 mm and 46-70 mm size-classes.

Standardized Trials for Objectives B

Fisheries facilities and standard methods to evaluate mortality and injury that juvenile chinook salmon incur as a result of pump passage were fully in place at Red Bluff by mid-April of 1996. However, the internal helical pump and Archimedes-2 were down at that time for engineering modifications. This situation precluded making studies related to the goal of objective B; namely, to compare passage effect with the two types of pumps in the plant running simultaneously. An opportunity did exist to use standard methods to examine the range of variability in mortality and injury that resulted from passage through Archimedes-1. Ten pump passage trials were conducted with Archimedes-1 between April 24 and May 15, 1996. For the first time in the biological evaluation program standard methods were fully applied. The first complete set of data was obtained on passage-related descaling of juvenile chinook. The work was abruptly terminated in mid-May when Archimedes-1 went down for engineering evaluations.

Data resulting from pump passage sessions with Archimedes-1 have been presented earlier in the text and in Table 14 and Table 15. Relative to expectations from earlier preliminary trials conducted on pump passage, results of this work were in many ways spectacular; spectacular perhaps by chance. All of 320 juvenile chinook released in the pump intake, and all of 320 juveniles released at the pump outfall, were retrieved in holding tanks on the pump's bypass. No direct mortalities occurred, and no injuries were observed among these 640 salmon. All of the fish used in trials were held for 96 hours and observed at intervals for delayed mortalities. No delayed mortalities occurred. A quality control assessment was conducted on each group of fish that were used in sessions. It showed that the chinook had an excellent history of health throughout the sessions. There was no incidence of disease in holding tanks at Red Bluff and cumulative mortality over holding times for fish used in sessions was

<0.5%. Overall, only two of 90 fish taken randomly from holding tanks for quality control assessments had an injury of any kind. Mean fork lengths for juveniles used in this work ranged from 65 mm in early sessions to 72 mm in later sessions. The juveniles were robust with condition factors ranging from 1.1 to 1.2. However, scales on these fish tended to be deciduous; a condition typical at Red Bluff for juvenile chinook salmon in this size-class. In spite of this, estimates showed that descaling due to pump passage was nil during three of five sessions, and very small during the others (3-7% per fish).

Work of the type presented here will continue in 1997 and 1998 in order to achieve the goals of objective B. Trials will be conducted with the internal helical and Archimedes pumps running simultaneously. Pump passage effects on mortality and injury will be obtained for small (30-45 mm fork length) as well as larger juveniles (46-70 mm). Sessions with each of these size-classes will be conducted over intervals of time sufficient to cover the range of environmental conditions (debris loading, water temperature, turbidity) that occur at Red Bluff during wet and dry seasons of the year.

Progress on Objectives C and D

Objective C of the biological evaluation program deals with the percent-efficiency with which holding tanks on pump bypasses capture chinook salmon that are entrained from the Sacramento River during pumping. This topic is important to the program for several reasons. The efficiency of the tanks as sampling devices needs to be known to accurately estimate the percentage of out-migrating chinook moving past Red Bluff that are taken by the plant while pumping to meet water deliveries (objective I). The efficiency also needs to be known to accurately estimate the take of juveniles chinook salmon belonging to the endangered winter run. That estimate is required by the National Marine Fisheries Service when the plant is operated between 1 July and the following 31 March of each year; the interval during which juvenile winter run are in the Sacramento River at Red Bluff.

It is clear from results presented in the section of this report entitled *Standardized Trials for Objective B* that 100% of chinook that pass through pumps in the plant can be captured in holding tanks. Table 14 shows that in 10 separate trials in which a total of 320 hatchery-reared juvenile chinook were inserted in the intake of Archimedes-1, all released fish were captured in the holding tank on the pump's bypass. In the case of these trials, the pump was shut down and special attention was given to closing all open escape routes in the flowstream of the pump prior to insertion of juveniles. Also in the case of these trials, only 1% of the chinook that were released held-up in the pump's flowstream upstream to the holding tanks for longer than a period of 30 minutes. These trials were conducted at night, and the prompt downstream movement to holding tanks was rather typical for juveniles in the size-class used (65-72 mm fork length) when they were released in trials conducted at night. In comparison, information presented in the section of this report entitled *Exploratory Trials for Objective B* showed that, for all trials of surrogate passage through pumps to holding tanks conducted in 1995 and 1996, the capture efficiency of holding tanks was <100%. Data regarding this are shown in Table 12. Capture efficiencies varied between 93% and 98% for 929, 705 and 446 juveniles inserted in intakes of the internal helical pump, Archimedes-1 and Archimedes-2 respectively. For all pumps and all juveniles released, capture efficiency was 95%. Juvenile chinook used for these releases shown in Table 12 were relatively large; almost exclusively >46 mm fork length. In some ways, these capture efficiencies appear to represent a worst-case, at least for larger-sized juveniles. Unplugged escape routes were known to exist along flowpaths from pumps to holding tanks, particularly in early phases of this work. Also, some trials included in this work were conducted during bright daylight hours when released juveniles tended to hold-up in flowstreams upstream of holding tanks. During these daylight trials, sampling of holding tanks was occasionally terminated after several hours, thus preventing full recovery of individuals that delayed their passage in refugia. Overall, work conducted in 1995 and 1996 suggests that mean efficiencies of tanks as sampling devices for entrained chinook >46 mm fork length are high; that is, ≥ 95%.

Objective D of the biological evaluation program deals with an assessment of mortality and injury to juvenile chinook during passage from pump outfalls through screening facilities, bypass channels, dewatering ramps, debris separator boxes and diversion channels leading to holding tanks. Work on exploratory trials for objective B, summarized in Table 12, showed that ≤1% of hatchery-reared chinook released at pump outfalls and collected in holding tanks experienced mortality during passage. Table 13 shows that <1% of chinook that were released were injured in passage from pump outfalls to holding tanks, and <0.1% experienced delayed mortality while being held for 96-hour post-passage observation. These results suggest that the flowpaths between outfalls and holding tanks of both kinds of pumps in the plant were fish-friendly; at least for large-sized juvenile chinook (>46 mm fork length) that had not passed through the internal helical or Archimedes pumps. As noted in the paragraph directly above, calculated *pump-effects* on direct mortality, injury, and delayed mortality during exploratory studies of passage from pump intakes to holding tanks were all ≤1%. Taken together, these results on passage from pumps-to-holding tanks, and pump outfalls-to-holding tanks, demonstrate that not only were pumps in the plant fish-friendly, but screening facilities, bypass channels, dewatering ramps, debris separator boxes and diversion channels leading to holding tanks were fish-friendly as well, even for juveniles that did pass through pumps.

Objective D of the biological evaluation program also deals with mortalities and injuries incurred by juvenile chinook during the time they reside in holding tanks. Information on this topic is important for interpreting mortality and injury data collected when holding tanks are used to sample chinook salmon that are entrained by the plant from the Sacramento River (objective I). Observations made while sampling entrained chinook during 1995 and 1996 indicated that refugia were available in holding tanks for juveniles captured in tanks, and the incidence of tank-related mortality or injury was very low if the intervals between collections of juveniles from tanks were 12-14 hours or less. Exceptions to this expectation may occur, however, during periods of the year (spring and fall) when leaves, small sticks, filamentous algae and other bits of debris are entrained from the river and enter holding tanks along with juveniles. If during debris-ladened periods, intervals between collections from holding tanks are long (>4-6 h), the incidence of mortality and injury among chinook may be elevated.

Observations made during 1995 and 1996 also indicated that early life stages of fish species other than chinook salmon may indeed be susceptible to mortality and injury while residing in tanks for long periods of time. In particular, high (>95%) incidence of mortality was observed among post-larval sacramento suckers (<40 mm length) while conducting diel entrainment trials for objective I. During these trials, holding tanks were tended at sunrise to collect fish entrained during the previous night, and another collection was made at the following sunset. If tanks were tended and suckers removed at shorter intervals of 5-7 hours, the incidence of mortality was about 35%. If tanks were tended and suckers removed at intervals ≤1 hour, mortality in collections was reduced to <5%.

The topics of tank-related mortality and injury will be targeted during 1997 and 1998 in studies that are designed specifically to evaluate mortality and injury that chinook and other species experience while contained in the pumping plant's holding tanks. Standardized trials of pump-to-holding tank passage, and pump outfall-to-holding tank passage will also be conducted to expand the database related to the goals of objective B, as well as the goals discussed here for objectives C and D.

Exploratory Trials for Objective E

Exploratory trials were conducted in 1996 in preparation for development of a study plan for objective E of the biological evaluation program for the Red Bluff Research Pumping Plant. This work was done under the gates-out operating mode that is used at Red Bluff Diversion Dam for making water deliveries to the forebay of the Tehama-Colusa Canal. It is in this mode that pumps, rather than gravity flow from Lake Red Bluff, are used to maintain the hydraulic head on the canal. Trials were conducted on an opportunistic basis during a period when pumps in the plant were periodically in and out of service due to engineering modifications. Because all pumps in the plant were not available simultaneously, work was done at less than full water delivery capacity. Discharges to fish bypasses and velocities of currents, particularly those in distal portions of the bypass system under study, were lower than is expected with full capacity operation. Fall run and late-fall run, hatchery-reared juvenile chinook salmon were used in these trials as surrogates for run-of-the-river juveniles that are entrained from the Sacramento River during pumping. The opportunistic nature of the work required using hatchery fish from size-classes (60-72 and 100-110 mm fork length) that represented the largest size-classes that pumps at Red Bluff entrain from the river. Chinook in smaller size-classes (30-45 mm and 46-70 mm) will be used for this work during 1997 and 1998.

Results from exploratory trials showed that refugia exist in terminal portions of the plant's bypass system where entrained fish can hold and delay their exit to the Sacramento River for relatively long periods of time. Work conducted in May 1996 provided insights regarding this. Hatchery-reared juvenile chinook were released at the entrance to the 46 cm (18 in) diameter underground pipe that connects the plunge pool on each pump's bypass to the drum screen bypass (Figure 3). Currents in the pipe move downstream at a calculated rate of 3.0 to 3.7 m/s (10-12 ft/s). Juvenile chinook are unable to hold in currents of these velocities (U.S. Army Corps of Engineers 1990). Data showed that released fish accumulated in the drum screen bypass and tended to hold there until the drum screen bypass was pulsed (Figure 9). Some of these fish may have lingered in standing water that was available in the drum screen bypass upstream of its connections to the pumping plant's 46 cm (18 in) diameter pipe. The time-course of pulsing and recovery of chinook at the plant's outfall during work conducted in September 1996 (Figure 10) suggested that juveniles released in a bypass channel upstream of a plunge pool used refugia in the plunge pool to delay passage. The data indicate that they gradually moved from the plunge pool into the drum screen bypass where pulses of water promoted their downstream movement to the plant's outfall.

Pulses of various strength were used in the drum screen bypass during 1996 in order to examine their effects on moving juvenile chinook to the plant's outfall, and to assess the magnitude of water currents and turbulence that pulses cause in the fyke net and live-box used to collect fish at the outfall. Pulses created by opening the gate leading to the 1.52 m (5 ft) diameter drum screen bypass to 0.3 or 0.6 m (1 or 2 ft) on its vertical axis for a period of 2-4 minutes were found to be optimal. Under their influence, juvenile chinook left the pumping plant's bypass outfall and were retained by the fyke net and its live-box without injury. Pulses produced by greater openings developed currents and turbulence in the net and live-box that impinged juvenile chinook and other small fish on webbing. Pulses in the optimal range will be incorporated in the study plan for objective E of the biological evaluation program.

During the trials, it became clear that leaves, twigs, sticks, filamentous algae and gravel accumulated along with fish in the live-box used for sampling at the outfall of the plant's bypass. The debris, along with turbulence in water in the box, posed a threat to small fish. Unless the live-box was emptied at short intervals (e.g., <1 h), the debris tended to cause mortalities and injuries. At the end of trials, plans were made to fabricate a pontoon platform that would hold a larger live-box and provide a stable base for working with a large box. The pontoon platform with live-box, fittings to couple the box to the fyke net used in 1996 trials, and fittings to secure the platform to the plant's outfall were assembled and ready to use for work on objective E in early 1997.

SUMMARY

A research pumping plant was constructed on the Sacramento River in northern California as part of the commitment of the U.S. Bureau of Reclamation to improve fish passage at Red Bluff Diversion Dam; particularly the passage of adult and juvenile chinook salmon (*Oncorynchus tshawytscha*). Major portions of construction were completed in May of 1995 with installation of two Archimedes pumps and one internal helical pump. Through the remainder of 1995 and throughout 1996, modifications were underway to improve the performance of the pumps, screens and fish bypasses. Concurrently, facilities were developed on-site for holding experimental fish, and experimental procedures were developed to properly address objectives that had been established for biological evaluation of the plant (Liston and Johnson 1992b).

A long-term goal of work reported here is to determine if the pumping plant can make water deliveries to the adjacent Tehama-Colusa Canal without serious harm to downstream migrating chinook salmon young. These young, belonging to fall, late-fall, winter and spring runs, pass Red Bluff year-around. During pumping and entrainment, they and other small fishes pass through the plant's trash racks to pump intakes, through pumps to screening facilities, and then to bypass lines that open in the Sacramento River. They can be diverted to holding tanks on the bypass lines for purposes of sampling. Preliminary information on fish passage through the plant is summarized in this report. It was obtained opportunistically during 1995 and 1996 when pumps in the plant were running. The internal helical pump ran from June to September of 1995, and the Archimedes pumps from March to May of 1996 and again in September and October of that year.

Two types studies were undertaken during which fish passed through pumps in the plant and were collected in holding tanks. Assessments of mortality and injury were made. Twenty-nine entrainment trials of 24 hours each were conducted with separate samples taken at the end of diurnal and nocturnal periods (objective I). Thirteen of these trials were conducted with the internal helical pump between June and September of 1995. Sixteen trials were conducted with the two Archimedes pumps running simultaneously between March and April, and again in September and October 1996. For all trials combined, 20 different species of fish were entrained from the river. Forty-eight percent of 2332 total fish were juvenile chinook salmon. Seventy-four percent of all species, and 75% of chinook salmon, were taken at night. Ninety-six percent of all entrained fish, and 97% of entrained chinook salmon, were alive when collected from holding tanks. Between 0.6% and 1.2% of juvenile chinook entrained by the three pumps had external injuries.

In a second type of passage study, hatchery-reared juvenile chinook salmon were used as

surrogates for riverine juveniles (objective B). A total of 2080 juveniles were inserted in pump intakes and collected in holding tanks during 65 separate trials. A total of 1725 juveniles were passed from pump outfalls to holding tanks in 54 trials that were co-conducted with pump insertion trials. Pump insertion trials and outfall insertion were both somewhat evenly distributed among the three pumps in the plant. There were no indications in resulting data that mortality and injury effects from passage through the internal helical and Archimedes pumps were different. For all three pumps combined, the calculated *pump-effect* on mortalities observed in holding tanks was <1%. The *pump-effect* on delayed mortality over 96-h post-passage observation was about 1%. The *pump-effect* on injuries during passage, estimated from examination of 108-125 juveniles randomly selected pre-trial and post-trial during each trial conducted (a relatively small number of fish samples), was zero. Lower %-mortality was observed among surrogates in trials from pump intakes to holding tanks than among riverine chinook in entrainment trials. This may have been due to prompt retrieval of surrogates from holding tanks relative to retrieval time for riverine chinook, thereby reducing the damage to surrogates caused by turbulence and debris in tanks; or by differences in damage susceptibility between predominantly small chinook (30-39 mm fork length) taken in entrainment trials and larger hatchery-reared juveniles (46-130 mm) used as surrogates.

Four additional topics in the program for biological evaluation were addressed during 1995 and 1996. A portion of the data from surrogate trials discussed above was used to assess mortality and injury to juvenile chinook during passage from pump outfalls through screening facilities to holding tanks (objective D). Hatchery-reared juveniles (1725) released at outfalls of the three pumps and collected in holding tanks experienced ≤1% mortality. Less than 1% of these fish received injuries, and <0.1% experienced delayed mortality (96 h). These results show that the flowstreams from pump outfalls through screening facilities to holding tanks were fish-friendly. Preliminary estimates were also obtained for the efficiency with which entrained chinook salmon were captured in holding tanks (objective C). Data from releases of 2080 hatchery-reared juveniles in pump intakes showed that 95% of these were recaptured in holding tanks during the exploratory passage trials discussed above. By mid-May 1996, standardized techniques and procedures were in place for conducting trials of surrogate passage. These procedures were used in 10 separate trials in which a total of 320 hatchery-reared chinook were inserted in the intake of an Archimedes pump. One hundred percent of these fish were recaptured. Using these data, a preliminary mean capture efficiency of holding tanks was estimated at ≥95%. Additional data of this type will be gathered during 1997 to improve the accuracy of this estimate.

Information on fish passage given in paragraphs above resulted from observations on chinook salmon and other fishes that moved through pumps in the plant to holding tanks on the plant's fish bypass system. Exploratory studies were conducted in 1996 on passage of juvenile chinook through terminal portions of the plant's bypass system downstream from holding tanks (objective E). Three releases of hatchery-reared juvenile chinook salmon were made downstream from holding tanks in May of 1996, and one release was made during the following September. A net with live-box was in place at the plant's outfall in the Sacramento River to retrieve juveniles. Results provided preliminary estimates for residence time for entrained chinook in these portions of the plant's bypass system. Estimated residence times were long. A protocol was developed for safely flushing fish from the bypass should later studies show that such a strategy has advantages. Procedures for sampling fish at the plant's outfall were developed that minimize the risk of causing mortalities and injuries during the sampling process.

In other work, synchronized sampling was conducted to relate the abundance of juvenile chinook passing the intake structure of the pumping plant and the abundance of juveniles entrained by the plant (objective I). Passing juveniles were taken by a rotary screw trap, while entrained juveniles were taken in holding tanks. Sampling was done over 24-h periods on nine occasions to examine the variability in a *pump-take:trap-take* ratio. A ratio of about 0.50 ± 0.08 was obtained except when juveniles passing the plant were uncommon. This work will continue in conjunction with expansive rotary screw trap sampling of downstream migrants in the river (Johnson and Martin 1997) in order to evaluate the reliability of using this *pump-take:trap-take* ratio to extrapolate to percentages of total out-migrating juvenile chinook that the pumping plant entrains.

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LITERATURE CITED

Bigelow, J.P. and R.R. Johnson. Estimates of survival and condition of juvenile salmonids passing through the downstream migrant fish protection facilities at Red Bluff Diversion Dam on the Sacramento River, spring and summer 1994. U.S. Fish and Wildlife Service Annual Report. Northern Central Valley Fish and Wildlife Office, Red Bluff, California.

Edgington, E.S. 1987. Randomization tests. Marcel Dekker, Inc. New York, New York.

Fisher, F.W. 1992. Chinook salmon, *Oncorhynchus tshawytscha*, growth and occurrence the Sacramento-San Joaquin river system. California Department of Fish and Game, Inland Fisheries Division Report, Red Bluff, California.

Garcia, A. 1989. Impacts of squawfish predation on juvenile chinook salmon at Red Bluff Diversion Dam and other locations on the Sacramento River. Report No. AFF/FAO-89-05. U.S. Fish and Wildlife Service, Northern Central Valley Fishery Resource Office, Red Bluff, California.

Green, S. 1992. Daily fork-length table from data by Frank Fisher, California Department of Fish and Game. California Department of Water Resources, Environmental Services Office, Sacramento.

Hallock, R. 1983. Effects of Red Bluff Diversion Dam on chinook salmon, *Oncorhyncus tshawytscha*, fingerlings. California Department of Fish and Game, Anadromous Fisheries Branch, Office Report.

Hallock, R. and F. Fisher. 1985. Status of winter-run chinook salmon, *Oncorhyncus tshawytscha*, in the Sacramento River. California Department of Fish and Game, Anadromous Fisheries Branch, Office Report.

Hallock, R., D. Vogel and R. Reisenbichler. 1982. The effect of Red Bluff Diversion Dam on migration of adult chinook salmon, *Oncorhyncus tshawytscha*, in the Sacramento River. California Department of Fish and Game, Anadromous Fisheries Branch, Office Report.

Hovekamp S. and C. Sarsfield. 1995. Shasta dam temperature control device ecological study design. U.S. Bureau of Reclamation, Northern California Area Office, Shasta Lake, California.

Hynes, H.B.N. 1970. The Ecology of Running Waters. Liverpool University Press, Liverpool.

Johnson, P., R. Lafond and D. Webber. 1991. Shasta temperature control device - hydraulic and mathematical model studies. U.S. Bureau of Reclamation, Technical Services Center, Denver, Colorado.

Johnson, R.R. and C.D. Martin. 1997. Abundance and seasonal, spatial and diel distribution patterns of juvenile salmonids passing the Red Bluff diversion dam, Sacramento River, July 1994-June 1995. U.S. Fish and Wildlife Service Annual Report. North Central Valley Fish and Wildlife Office, Red Bluff, California.

Johnson, R.R., D.C. Weigand and F.W. Fisher. 1992. Use of growth data to determine spatial and temporal distribution of four runs of juvenile chinook salmon in the Sacramento River, California. Report No. AFF1-FAO-92-15. U.S. Fish and Wildlife Service, Northern Central Valley Fishery Resource Office, Red Bluff, California.

Kostecki, P.T., P. Clifford, S.P. Gloss and J.C. Carlisle. 1987. Scale loss and survival in smolts of Atlantic salmon (*Salmo salar*) after turbine passage. Canadian Journal of Fisheries and Aquatic Science 44:210-214.

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.

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

Liston, C., C. McNabb, S. Borthwick, W. Frizell and S. Atkinson. (in press) Use of "fish-friendly" pumps for fish passage on the Upper Sacramento River: early experiments at Red Bluff Research Pumping Plant (USA). Proceedings of American Fisheries Society Symposium: Implementing and Advancing Fish Passage Technology, 127th Annual Meeting of American Fisheries Society, Monterey, California.

Manly, B.F. 1997. Randomization, bootstrap and Monte Carlo methods in biology. Chapman and Hall. New York, New York.

Mielke, P.W., K.J. Berry and G.W. Brier. 1980. Application of multi-response permutation procedures for examining seasonal changes in monthly mean sea-level pressure patterns. Monthly Weather Review 109:120-125.

Mielke, P.W., K.J. Berry and J.G. Medina. 1981. Climax I and II: Distortion resistant residual analyses. Journal of Applied Meteorology 21:788-792.

Mundie, J.H. and R.E. Taber. 1983. Movements 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.

National Marine Fisheries Service. 1993a. Biological opinion for the operation of the Federal Central Valley Project and the California State Water Project. National Marine Fisheries Service, Southwest Region, Long Beach, California (February 12).

National Marine Fisheries Service. 1993b. Endangered Species Act, Section 7 Consultation-Biological Opinion; a pilot pumping plant program at Red Bluff Diversion Dam. National Marine Fisheries Service, Southwest Region, Long Beach, California (February 2).

Moyle, P.B. and J.J. Cech Jr. 1988. Fishes: an introduction to ichthyology. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Moyle, P.B., J.E. Williams and E.D. Wikramanayaka. 1989. Fish species of special concern of California. Report to California Department of Fish and Game, Inland Fisheries, Rancho Cordova, California.

Petrusso, P.A. (in preparation) Food abundance, feeding, and condition of young-of-year chinook salmon in the Upper Sacramento River. Master's Thesis. Michigan State University, East Lansing, Michigan.

Stickney, R.R. and C.C. Kohler. 1990. Maintaining fishes for research and teaching. *In* C.B. Schreck and P.B. Moyle, eds., pp. 633-663. Methods for Fish Biology. American Fisheries Society, Bethesda, Maryland.

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.

Tvinnereim, K. and S. Skybakmoen. 1989. Water exchange and self cleaning in fish-rearing tanks. In K. DePauw, E. Jaspers, H. Ackefors, N. Wilkins Eds, Aquaculture-A Biotechnology in Progress, pp. 1041-1047. European Aquaculture Society, Bredene, Belgium.

U.S. Army Corps of Engineers. 1990. Fisheries handbook of engineering requirements and biological criteria. North Pacific Division, Portland, Oregon.

U.S. Bureau of Reclamation. 1995a. Preliminary studies of fish entrainment and hatchery fish passage with the centrifugal-screw pump at Red Bluff Research Pumping Plant; June 1995. Pumping Plant Evaluation Team, Red Bluff, California.

U.S. Bureau of Reclamation. 1995b. Fish entrainment and hatchery fish passage at Red Bluff Research Pumping Plant; summary report for FY 95. Pumping Plant Evaluation Team, Red Bluff, California.

U.S. Bureau of Reclamation. 1997. Investigations of entrainment of larval and post-larval stages of fish from the Sacramento River by Archimedes and internal helical pumps at the Red Bluff research pumping plant. Ecological Research and Investigations Group, Technical Services Center, Denver, Colorado.

U.S. Department of Interior. 1957. Topographic quadrangles; Redding and Red Bluff East, California, photo revised 1969. U.S. Geological Survey, Denver, Colorado.

U.S. Department of Interior. 1981. Project Data. Water and Power Resources Service, Washington, D.C. pp. 217-224.

U.S. Fish and Wildlife Service. 1987. Evaluation of the measure of raising the Red Bluff Diversion Dam gates in improving anadromous salmonid fish passage based on observations of radio-tagged fish. Report No. FR1/FAO-87-21. U.S. Fish and Wildlife Service, Northern Central Valley Fishery Resource Office, Red Bluff, California.

U.S. Fish and Wildlife Service. 1992a. Endangered and threatened wildlife and plants; 50 CFR 17.11 & 17.12. U.S. Fish and Wildlife Service, Washington, District of Columbia.

U.S. Fish and Wildlife Service. 1992b. Evaluation of the initial phase of the Sacramento River gravel restoration project. USFWS Report No. AFF1/FRO-92-06. U.S. Fish and Wildlife Service, Northern Central Valley Fishery Resource Office, Red bluff, California.

U.S. Fish and Wildlife Service. 1993. Evaluation of the Sacramento River spawning gravel restoration project and winter-run chinook salmon redd survey data, 1992. USFWS Report No. AFF1/FRO-93-07. U.S. Fish and Wildlife Service, Northern Central Valley Fishery Resource Office, Red bluff, California.

Vondracek, B. and P. Moyle. 1983. Squawfish predation at Red Bluff Diversion Dam. California Department of Water Resources, Contract Report, Sacramento, California.

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

Vogel, D. and K. Marine. 1995. Technical memorandum: 1995 predation evaluation near the GCID Sacramento River pump station. Natural Resource Scientists, Red Bluff, California.

Vogel, D.A., K.R. Marine and J.G. Smith. 1988. Fish passage action program for Red Bluff Diversion Dam. Report No. FR1/FAO-88-19. U.S. Fish and Wildlife Service, Northern Central Valley Fishery Resource Office, Red Bluff, California.

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

Weitkamp, D.E. and M. Katz. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society 109:659-702.

Westers, H. 1987. Feeding levels for fish fed formulated diets. Progressive Fish Culturist 49:87-92.

Westers, H. 1994a. Hatchery management for flow-through fish production systems. Aquaculture Bioengineering Corp., Rives Junction, Michigan.

Westers, H. 1994b. Recommendations for the Red Bluff Research Pumping Plant wet laboratory design for fish maintenance and studies. Aquaculture Bioengineering Corp., Rives Junction, Michigan.

Table 1. Goals and objectives for biological evaluation of the Red Bluff Research Pumping Plant (Liston and Johnson 1992b).

GOALS	RESEARCH OBJECTIVES	
Determine if the pumping plant can operate with minimal loss or harm to downstream migrating chinook salmon young.	A[1]	Assess mortality and injury to young chinook passing through the drum screen bypass at Red Bluff diversion dam (terminus for the pumping plant bypass) under conditions that reflect seasonal and flow rate changes.
	B	Assess mortality and injury to young chinook subjected to passage through Archimedes and internal helical pumps under environmental conditions typical of wet and dry seasons of the year.
	C	Obtain 100% recovery of juvenile chinook salmon entrained from the Sacramento River in holding tanks on fish bypasses in the pumping plant.
	D	Assess mortality and injury to young chinook subjected to passage through pump outfalls, screening facilities, above-ground bypass channels and holding tanks in the plant under environmental conditions typical of wet and dry seasons of the year.
	E	Obtain residence time and assess mortality and injury to young chinook subjected to passage through the below-ground bypass from the pumping plant to the Sacramento River using the low bypass discharge expected with normal operation of the pumping plant and using higher pulsed flows that may be required to move fish to the bypass outlet.
	F	Describe movements and behavior of young chinook salmon in the vicinity of the plant's trash racks and pump intake structures using underwater video cameras and hydroacoustics.
	G	Assess predator-prey interactions between young chinook and Sacramento squawfish following passage of young chinook through experimental pumps.
	H[1]	Develop an understanding of the seasonal and diel distribution and abundance of out-migrating juvenile chinook salmon in the Sacramento River near Red Bluff Diversion Dam.
	I	Estimate seasonal numbers, annual numbers, condition, and viability of juvenile chinook salmon and other fish that are entrained from the Sacramento River and pass through pumps in the plant. Estimate seasonal and annual percentages of out-migrating juveniles that the plant entrains.
Determine if the pumping plant can be constructed and operated in a manner that creates no new attraction for fish predators and, where possible, minimizes fish predation near structures of the plant.	J[1]	Assess seasonal adult squawfish movements and behavior near the pumping plant using radiotracking techniques.
	K[1]	Estimate seasonal abundance of fish predators near the trash racks, pump intakes and bypass outfall of the plant, and if predators increase over time, develop methods to scatter or remove them.

Table 1. Continued.

GOALS	RESEARCH OBJECTIVES	
	L	Assess predator colonization of the intake sump portion of the plant, and if predators reside in this area, develop methods to remove them.
Determine if the pumping plant can be operated with no deleterious effects on upstream spawning migrations of runs of chinook salmon and steelhead trout.	M[1]	Assess seasonal and diel movements of upstream migrating chinook salmon and steelhead trout near the plant while it's operating using radiotracking techniques, and if operations modify behavior in a negative way, recommend operational or structural changes for the plant.
Determine if the pumping plant can be operated with no harm to native Sacramento River fish populations from entrainment of their larvae.	N	Estimate levels of annual entrainment of larval and post-larval fishes by the pumping plant, and assess the impact of entrainment on their populations.
Provide a record of environmental and engineering data for researchers to use to interpret data obtained from fisheries studies.	O	Record water temperature, dissolved oxygen, pH, conductivity, turbidity, suspended solids, river stage and discharge, near the intake area of the plant through the duration of evaluation studies.
	P	Record air temperature, precipitation, barometric pressure, wind direction, wind velocity and solar irradiance at the pumping plant through the duration of evaluation studies.

1 Work on these objectives is conducted by personnel from the U.S. Fish and Wildlife Service, Northern Central Valley Fishery Resource Office, Red Bluff, California. Work on unmarked objectives is conducted by U.S. Bureau of Reclamation personnel from the Technical Service Center, Denver, Colorado and the Northern California Area Office, Shasta Lake, California.

Table 2. Guidelines for recording injuries on chinook salmon and other fishes that pass through the research pumping plant at Red Bluff, California.

EXTERNAL FEATURE	INJURIES	CODE RECORDED
Head	One operculum missing	1
	Both opercula missing	2
	Integument missing	3
	Decapitated	4
	Other (List)	5
Eyes	Bulging	1
	One missing	2
	Both missing	3
	Hemorrhaging	4
	Other (List)	5
Skin	Discolored, bruised areas or 1-25% deskinned	1
	25-50% of body deskinned	2
	>50% of body deskinned	3
	Split, abraded, or with open lesions	4
	Other (List)	5
Fins	Discolored, frayed, <30% erosion	1
	>30% erosion, but visible	2
	Eroded to base or hemorrhaging	3
	Other (List)	4

Table 3. Guidelines for making quality control assessments on different lots of hatchery-reared juvenile chinook salmon used in experiments at Red Bluff. Limits listed in the table are used to eliminate sub-standard groups of juveniles from use in experiments. Sizes for juveniles 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 is defined as a condition in holding tank(s) requiring therapeutic treatment.
Mortality	Cumulative Mortality	>2%	Cumulative mortality in each group of fish obtained from Coleman 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 or eroded on >5% of the fish	Confinement to raceways at Coleman Hatchery and tanks in the wellwater facility at Red Bluff tends to result in fraying at the edges of fishes' fins (splitting between fin rays) and erosion of the edges of opercula. Fin damage is 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 is >4% of fish, except that erosion along the edges of opercula is allowed.
Descaling	% of Scaled Body Surface That is Descaled or Abraded on Individual Fish.	<55 mm juveniles: >5% abrasions on >7% of fish 56-65 mm juveniles: >5% descaling on >7% of fish	Because of small size of scales and their transparency, descaling estimates cannot be reliably replicated during low-power microscopic examinations. Consequently, % of scaled surface abraded is used with juveniles <55 mm on the assumption that abraded areas are descaled.
		≥66 mm juveniles: no limit	Juveniles obtained from Coleman Hatchery at >65 mm are beginning to smolt and scales are deciduous.
Condition Factor	Weight and Fork Length for Individual Fish.	<45 mm juveniles: mean <0.70 ≥45 mm juveniles: mean <0.85	Condition Factor (k) is calculated from: $k = W/L^3 \times 100$ where W is weight in grams and L is fork length in centimeters.

Table 4. A standard schedule for handling hatchery-reared juvenile chinook salmon during plant passage trials related to objectives B, C, D and E of the biological evaluation program.

DAY	ACTIVITY	NOTES
1	Select fish for trials and isolate them in a dye-tank in the wellwater facility. Mark them with Bismarck brown-Y. Hold them for 5-6 h, then move them to a tank in the riverwater facility.	Day-1. Several thousand juvenile chinook are obtained periodically from Coleman National Fish Hatchery. These are held in the project's wellwater facility until they are used in trials. On day-1, the number of fish selected for marking is the number required to complete work in the schedule. See the text for methods to mark fish with Bismarck brown-Y.
2	Acclimate fish to riverwater.	Day-2 and 3. Water from the Sacramento River is pumped through tanks in the project's riverwater facility. Chinook are acclimated to riverwater conditions that they will encounter when they pass through pumps and bypass systems in the pumping plant.
3	Acclimate fish to riverwater.	Day-4. Each trial of plant passage for objectives B, C and D use samples of 34 juvenile chinook each. Each sample is held in a cylindrical live-cage. Live cages are held in tanks in the riverwater facility until used in a trial. Samples of fish are then released for plant passage, recaptured downstream, and returned to their live-cages for post-trial observation. Live cages are numbered so that the history of each sample of fish can be tracked. The number of juvenile chinook needed per sample for objective E will be determined from exploratory studies on objective E that are described in the text.
4	Separate fish into the number of live-cages required for work below. Begin a session by conducting a run consisting of 1 to several trials.	
5	Finish descaling assessments for each trials in the run. Record delayed mortalities for each trial in the run.	Experiments that are planned for pumping plant passage (1997, 1998) are conducted using multiple sessions of work. *Sessions* may consist of a single *run* where 1-3 *trials* are conducted on the same day, or a session may consist of two runs where trials are conducted on two closely spaced days. Fish used in a run have the same history of pre-trial and post-trial handling; that is, they proceed through the handling schedule together. During sessions, samples of chinook are passed through the pumping plant under the same conditions of plant operation, and within a relatively narrow range of environmental parameters (e.g., water temperature, turbidity).
6	Record delayed mortalities for each trial in the run.	
7	Record delayed mortalities for each trial in the run.	Day-5. Procedures for descaling assessment are found in the text. Delayed mortalities are recorded during 96 h post-passage for each sample of juveniles used in trials.
8	Record delayed mortalities for each trial in the run. Measure fork length and weight of 50 fish from the run. Release fish from the run to the Sacramento River.	Day-8. Ordinarily, juvenile chinook that survive trials are released in the Sacramento River after Reclamation notifies USFWS, Red Bluff of the intention to do so. Measurements of randomly selected fish from the group to be released are used to estimate mean length and its standard deviation as per request of USFWS. Length and weight are also used to estimate the *condition factor* for juvenile chinook used in the session.

Table 5. An overview of the design for work on objective E in the biological evaluation program[1].

TYPES OF[2] SESSIONS	PUMP EFFECT MEASURED	RELEASE LOCATION		RECOVERY LOCATION
		TREATMENT	CONTROL	
1	Pump to Outfall	Pump Intake	Pump Outfall	All Released Samples Recovered in the Live-Box at the Plant Outfall
2	Pump to Plunge Pool	Pump Intake	Entrance to the Plunge Pool	
3	Pump to Underground Bypass Pipe	Pump Intake	Entrance to Underground Bypass Pipe	
4	Pump to Outfall Net	Pump Intake	Mouth of the Plant Outfall Net	
5	Pump to Live-Box	Pump Intake	Live-Box	

1 Standardized procedures developed in 1995 and 1996 will be used for handling and processing hatchery-reared juvenile chinook salmon to assess mortality and injury caused to plant passage (see *METHODS, Standardized Methods for Objectives B, C, D and E*).

2 Null hypotheses to be tested by work on session type-1 are as follows:

(1) There is no difference in the proportion of juvenile chinook salmon killed by passage through the Archimedes and internal helical pumps to the outfall of the plant in the Sacramento River.

(2) There is no difference in the proportion of scaled body surface that is descaled on juvenile chinook salmon due to passage through the Archimedes and internal helical pumps to the outfall of the plant in the Sacramento River.

(3) There is no difference in the proportion of juvenile chinook salmon injured by passage through the Archimedes and internal helical pumps to the outfall of the plant in the Sacramento River.

Similar hypotheses will be tested for passage of juvenile chinook through the Archimedes and internal helical pumps to holding tanks in the plant (see *METHODS, Standardized Methods for Objectives B, C, D and E*). If data on mortalities and injuries from passage through pumps to the plant's outfall do not differ from data on mortalities and injuries through pumps to holding tanks, then portions of the plant's fish bypass system downstream of holding will not be studied further; that is session types-2, 3, 4 and 5 will be omitted.

Table 6. Species of fish taken from the Sacramento River during 29 entrainment trials conducted during 1995 and 1996 for objective I of the biological evaluation program. Each trial covered an interval of 24 consecutive hours.

SPECIES	NUMBER ENTRAINED	PERCENT OF TOTAL
Chinook Salmon (*Oncorynchus tshawytscha*)	1092	48
Prickly Sculpin (*Cottus asper*)	569	25
Sacramento Sucker (*Catastomus occidentalis*)	152	7
Lamprey (*Lampetra* spp)[1]	153	7
Bluegill (*Lepomis macrochirus*)	104	5
White Catfish (*Ictalurus catus*)	63	3
Sacramento squawfish (*Ptychocheilus grandis*)	60	3
Threespine Stickleback (*Gasterosteus aculeatus*)	23	1
California Roach (*Hesperoleucus symmetricus*)	16	<1
Tule Perch (*Hysterocarpus traski*)	13	<1
Steelhead/Rainbow Trout (*Oncorynchus mykiss*)	9	<1
Hitch (*Lavinia exilicauda*)	7	<1
Riffle Sculpin (*Cottus gulosus*)	6	<1
Hardhead (*Mylopharodon conocephalus*)	4	<1
Sturgeon (*Acipenser* spp)	4	<1
Brown Bullhead (*Ictalus nebulosus*)	2	<1
Largemouth Bass (*Micropterus salmoides*)	2	<1
Smallmouth Bass (*Micropterus dolomieui*)	1	<1
Mosquitofish (*Gambusia affinis*)	1	<1
Total	2281	

1 Of the 153 lamprey entrained, 123 (80%) were ammocetes, 28 (19%) were adult Pacific Lamprey (*Lampetra tridentata*), and 2 (1%) appeared to be adults of River Lamprey (*L. ayresi*) or Pacific Brook Lamprey (*L. pacifica*).

Table 7. Diel capture of fish in species most commonly taken by the internal helical and Archimedes pumps during entrainment trials at Red Bluff Research Pumping Plant in 1995 and 1996. The number (N) of juveniles in each run of chinook salmon is shown.

SPECIES		PERCENT CAPTURED	
		DAY	NIGHT
Chinook Salmon	N		
Winter Run	194	1	99
Spring Run[1]	272	46	54
Fall Run	604	27	73
Late-Fall Run	22	42	58
All Chinook	1092	27	73
Prickly Sculpin		16	84
Sacramento Sucker		16	84
Lamprey		5	95
Bluegill		69	31
White Catfish		13	87
Sacramento Squawfish		5	95
Threespine Stickleback		74	26
All Fish		24 %	76 %

1 Most, if not all, of these fish were fall run juveniles released by Coleman National Fish Hatchery. They were classified as spring run because they fit spring run fork-lengths in the reference table generated by Greene (1992).

Table 8. Percent-survival of fish in species most frequently taken at the Red Bluff Research Pumping Plant during entrainment trials in 1995 and 1996. Parentheses show the numbers of fish that were collected in the plant's holding tanks.

SPECIES		PUMP		
		INTERNAL HELICAL	ARCHIMEDES-1	ARCHIMEDES-2
Chinook Salmon				
Winter Run[1]	(194)	94 %	100 %	94 %
Spring Run[2]	(272)	-	96	99
Fall Run	(604)	86	98	98
Late-Fall Run	(22)	75	100	92
All Chinook	(1092)	93 (194)	97 (398)	98 (500)
Prickly Sculpin		98	99	99
Sacramento Sucker		82	100	94
Lamprey		100	100	100
Bluegill		-[3]	100	100
White Catfish		-[3]	90	87
Sacramento Squawfish		76	100	95
All Fish		92% (675)	98% (733)	98% (873)

1 One hundred seventy (88%) of the 194 winter run chinook reported here were taken by the internal helical pump in the fall of 1995.

2 Most, if not all, of these fish were fall run juveniles released by Coleman National Fish Hatchery. They were classified as spring run because they fit spring run fork-lengths in the reference table generated by Greene (1992).

3 Percent-survival that could be reported here was very low. The numbers of bluegill and white catfish entrained by the internal helical pump were also very low. Overall, 63-65 fish of these species were taken by all pumps combined during 1995 and 1996 (Table 6), and only 2-4 of these were taken by the internal helical pump. Two of two bluegill taken were dead when collected from holding tanks on the bypass of the internal helical pump, as were two of four white catfish.

Table 9. Percentages of juvenile chinook salmon and other fish that were entrained by pumps at Red Bluff and exhibited injuries when collected from holding tanks during trials conducted in 1995 and 1996. Parentheses in the table show the numbers of fish that were examined in each category.

GROUPS OF FISH	HELICAL PUMP	ARCHIMEDES-1	ARCHIMEDES-2
All Chinook[1]	2.6% (194)	1.0% (398)	1.8% (500)
Surviving Chinook	0.6 (180)	0.8 (386)	1.2 (490)
All Fish[1]	3.1 (675)	1.2 (733)	1.9 (873)
All Surviving Fish	1.4% (621)	0.8% (716)	1.5% (851)

1 Includes all fish with injuries, whether individuals were alive or dead at the time of collection.

Table 10. The numbers of each type of abnormality observed on injured fish that were collected in holding tanks during entrainment trials in 1995 and 1996. Parentheses in the table show the total number of fish that were examined for injuries per pump.

TYPE OF ABNORMALITY	HELICAL PUMP (675)	ARCHIMEDES-1 (733)	ARCHIMEDES-2 (873)
Fins			
Eroded >30%	5	1	2
Eroded to Base	1	1	3
Skin			
Split, Abrasion, Open Wound	7	6	5
Bruise	3	3	3
Hemorrhage	2	0	3
Eyes			
Missing One	1	0	2
Missing Both	1	0	0
Bulging Eye(s)	1	1	0
Hemorrhaging Eye(s)	1	0	0
Head			
Decapitated	2	0	0

Table 11. Results from synchronized 24-h collections of juvenile chinook salmon taken with a rotary screw trap just upstream of pump intakes and in holding tanks on bypasses of Archimedes pumps in Red Bluff Research Pumping Plant during 1996. Two Archimedes pumps were available for this work on the first five dates in the table, and one Archimedes pump was available thereafter.

DATE	SAMPLING DEVICES	ACRE FEET[1] SAMPLED	CHINOOK TAKEN[1] PER ACRE FOOT	TAKE RATIO PUMP/TRAP
03/18	Arch-1 & 2	351	0.80	0.43
	Screw Trap	138	1.86	
03/19	Arch-1 & 2	350	0.62	0.59
	Screw Trap	132	1.05	
03/25	Arch-1 & 2	357	0.28	0.48
	Screw Trap	89	0.58	
03/27	Arch-1 & 2	357	0.20	0.50
	Screw Trap	91	0.40	
04/24	Arch-1 & 2	361	0.19	0.48
	Screw Trap	65	0.40	
04/30	Arch-1	179	0.09	0.53
	Screw Trap	99	0.17	
05/02	Arch-1	177	0.02	0.20
	Screw Trap	109	0.10	
05/07	Arch-1	174	0.05	0.83
	Screw Trap	91	0.06	
05/13	Arch-1	175	0.01	0.09
	Screw Trap	96	0.11	

1 To convert acre feet sampled to hectare meters sampled, or to convert chinook taken per acre foot to chinook taken per hectare m (10,000 m^3) multiply numbers in these columns by 0.123.

Table 12. Summary of mortalities that occurred during exploratory passage trials with hatchery-reared juvenile chinook salmon in 1995 and 1996. In each trial, a sample of juveniles was inserted in a pump intake or a pump outfall. Juveniles ranged in size from 42-128 mm fork length.

PUMP	INSERTION POINT	NO. TRIALS	TOTAL NO. FISH	%[1] UNKNOWN	% SURVIVAL AT CAPTURE
Helical	Pump Intake	29	929	7	98
	Pump Outfall	18	575	3	100
Archimedes-1	Pump Intake	22	705	2	99
	Pump Outfall	22	704	2	99
Archimedes-2	Pump Intake	14	446	4	99
	Pump Outfall	14	446	0	100
All Pumps	Pump Intake	65	2080	5	99
	Pump Outfall	54	1725	2	>99

1 Percentages of fish inserted in the pumps' flowstreams but not recovered in holding tanks.

Table 13. An assessment of injuries due to plant passage by hatchery-reared juvenile chinook salmon in trials conducted in 1995 and 1996. The number of fish injured by passage was obtained by comparing the number of injured juveniles observed in groups of chinook that were randomly selected for pre- and post-passage examination (see text).

PUMP	NO. OF FISH INJURED BY PASSAGE[1]		% DELAYED MORTALITY (96 H)	
	PUMP INTAKE INSERTION (N)	PUMP OUTFALL INSERTION (N)	PUMP INTAKE INSERTION (N)	PUMP OUTFALL INSERTION (N)
Helical	- (53)	1 (32)	3 (789)	1 (522)
Archimedes-1	- (44)	- (44)	0 (640)	0 (639)
Archimedes-2	1 (28)	0 (28)	1 (396)	0 (418)
All Pumps	1 (125)	1 (108)	2 (1825)	<1 (1579)

1 Parentheses show the number (N) of post-trial juveniles examined per category reported. An equal number of juveniles was examined for injury before passage (see text). A dash (-) denotes cases in which injuries due to passage were nil; that is, where the number of pre-trial fish with injuries was greater than the number of post-trial fish with injuries.

Table 14. The record of mortalities for hatchery-reared juvenile chinook salmon during standardized pump passage trials with Archimedes-1. The work was done with fall run juveniles with mean fork lengths of 65 to 72 mm.

SESSION & CHINOOK RUN	DATE OF EXPERIMENTAL RUN	NO. TRIALS	TOTAL[1] NO. OF FISH		NO.[2] UNKNOWN		NO. DEAD AT CAPTURE	
			T	C	T	C	T	C
A Fall	04/24	2	64	64	0	0	0	0
B Fall	04/30 05/02	2 2	64 64	64 64	0 0	0 0	0 0	0 0
C Fall	05/07	2	64	64	0	0	0	0
D Fall	05/14	2	64	64	0	0	0	0

1 For each trial, two samples of 32 juveniles each were passed through the plant; one treatment sample (T) that was released in the pump's intake and one control sample (C) that was released just downstream of the pump's outfall.

2 The number of juveniles that were inserted in the pump's flowstream but were not recovered in holding tanks.

Table 15. Trends in descaling data for hatchery-reared juvenile chinook salmon during standardized pump passage trials with Archimedes-1. Fall run juveniles with mean fork lengths of 65 to 72 mm were used.

SESSION	DATE	MEAN % DESCALED PER FISH					% DESCALED DUE[2] TO PASSAGE		
		QA[1]	TREATMENT		CONTROL				
			PRE	POST	PRE	POST	TREATMENT	CONTROL	PUMP
A	4/24	2	1	1	1	2	0	1	-
B	4/30	4	3	3	6	8	0	2	-
	5/02		6	9	7	4	3	-	3
C	5/07*	19	17	13	19	18	-	-	-
D	5/14*	26	18	25	19	18	7	-	7

1 QA is percent descaled observed in the stock of fish used for quality control assessments for each session. Except for dates marked with an asterisk, percent body surface descaled in QA fish is a mean for 30 individuals randomly selected from the stock at the time of each session. Asterisks indicate means obtained with 15 fish.

2 Percent descaled due to passage of treatment and control samples was estimated by subtracting mean % descaled per fish in pre-trial fish from mean % descaled per fish in post-trial fish. Percent descaled due to pump passage was estimated by subtracting % descaled due to passage in control fish from % descaled due to passage in treatment fish. A dash (-) denotes cases in which descaling due to passage was nil; for example, where the percent descaled in pre-trial treatment and in pre-trial control fish was greater than percent descaled in post-trial treatment and post-trial control fish.

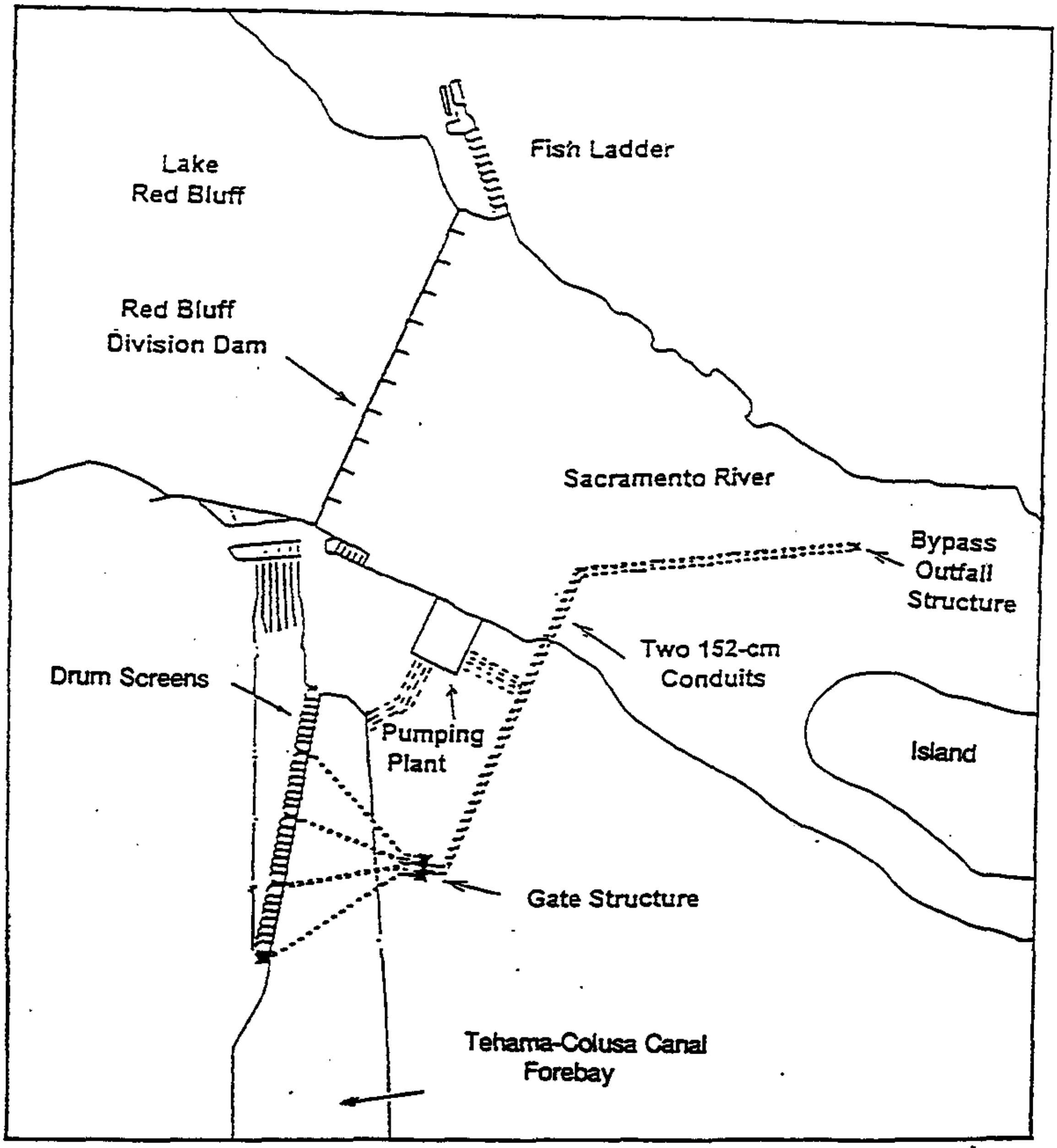

Figure 1. Location of the research pumping plant at the U.S. Bureau of Reclamation's Tehama-Colusa Canal Operations and Maintenance Complex in Red Bluff, California (from Bigelow, J.P. and R.R. Johnson 1996 with modifications).

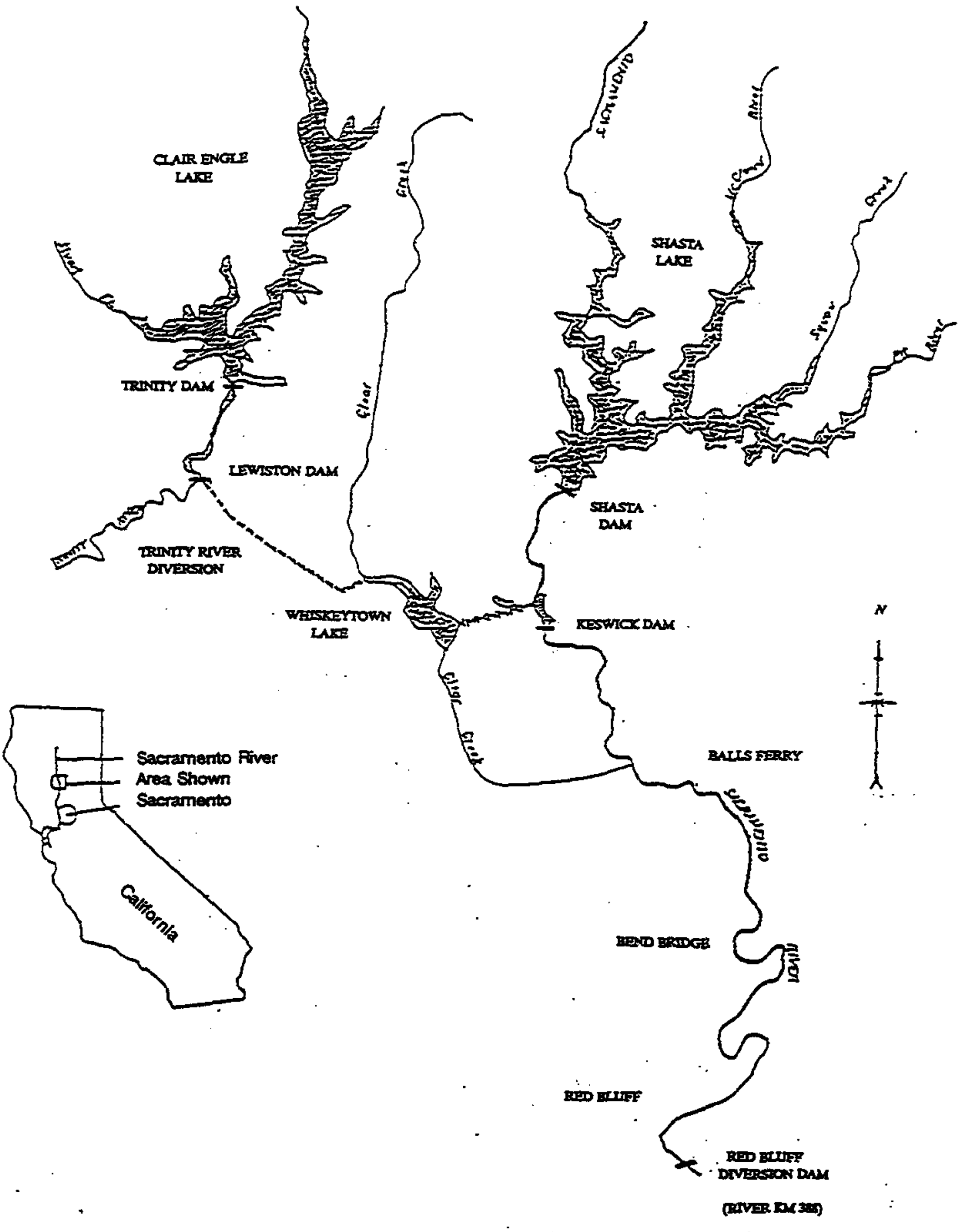

Figure 2. Some aspects of the Sacramento River drainage system above Red Bluff Diversion Dam.

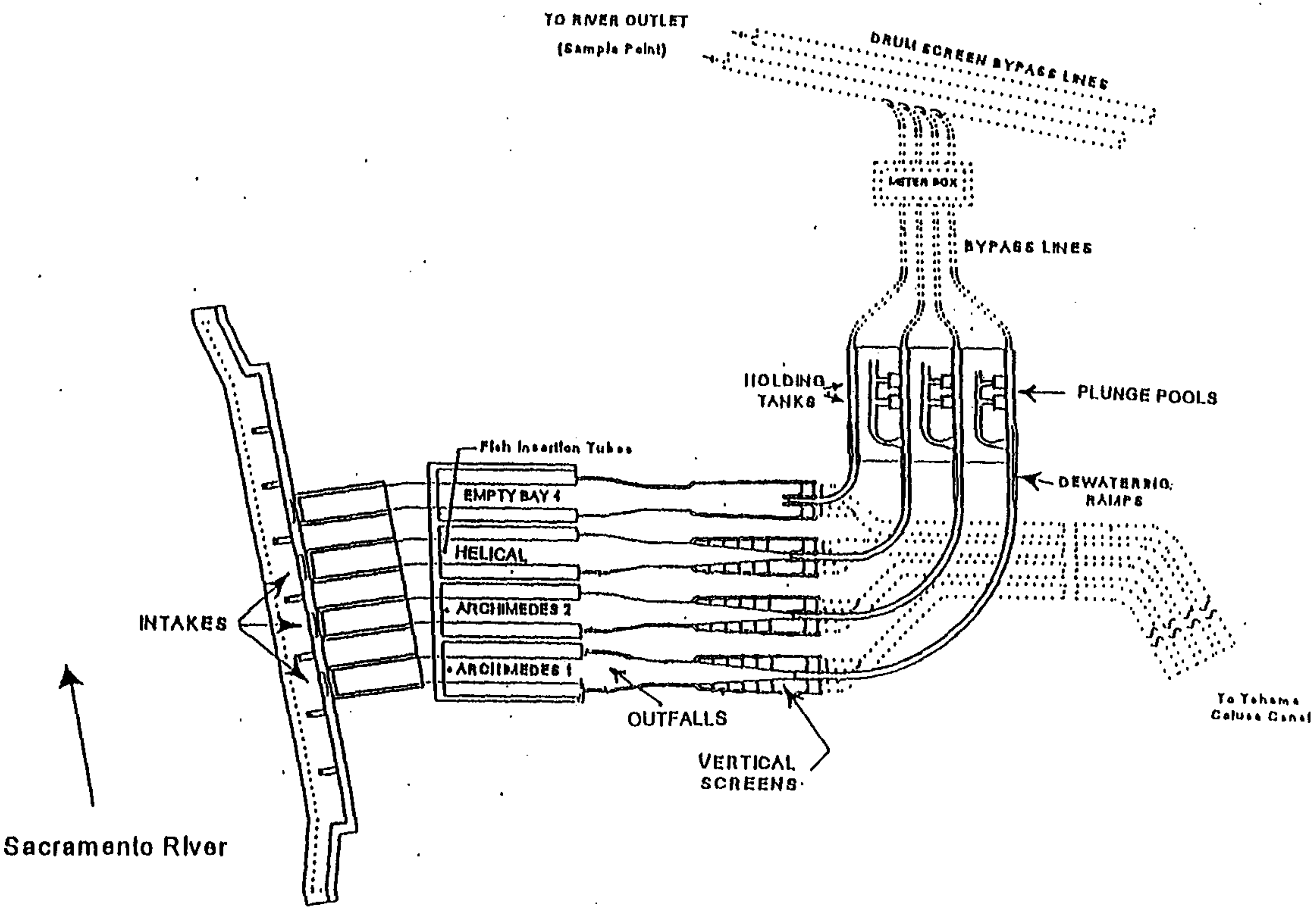

Figure 3. Pathways for the flow of water through the Red Bluff Research Pumping Plant. Holding tanks for collecting fish are shown as paired boxes on the bypass lines of each pump. Underground portions of the plant's fish bypass system are shown with dashed lines.

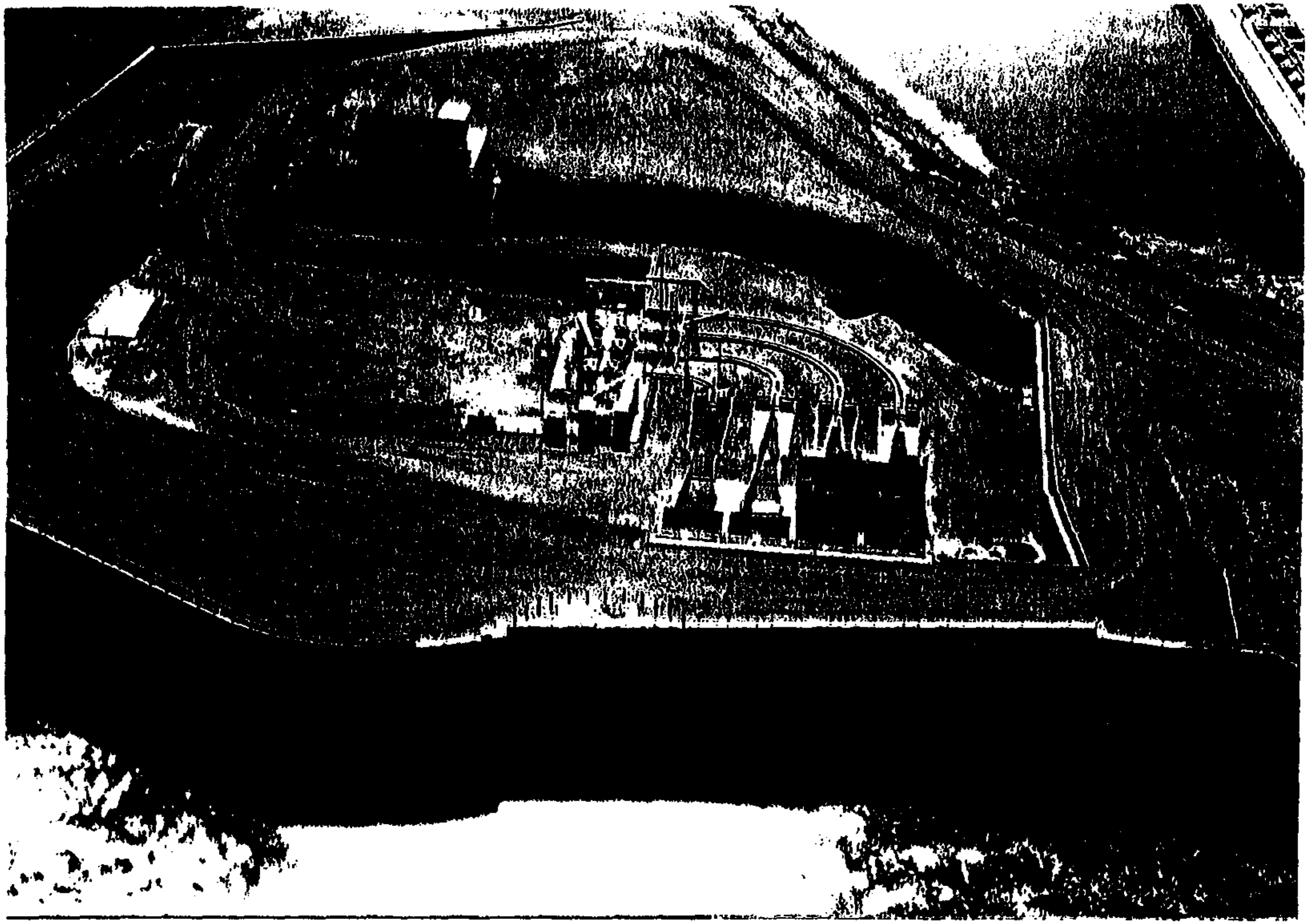

Figure 4. Red Bluff Research Pumping Plant with the Sacramento River and the plant's intake structure in the foreground. Semi-circular bypass channels can be seen leading away from screening facilities toward fish facilities in the center of the photograph. The forebay of the Tehama-Colusa Canal is at the upper right.

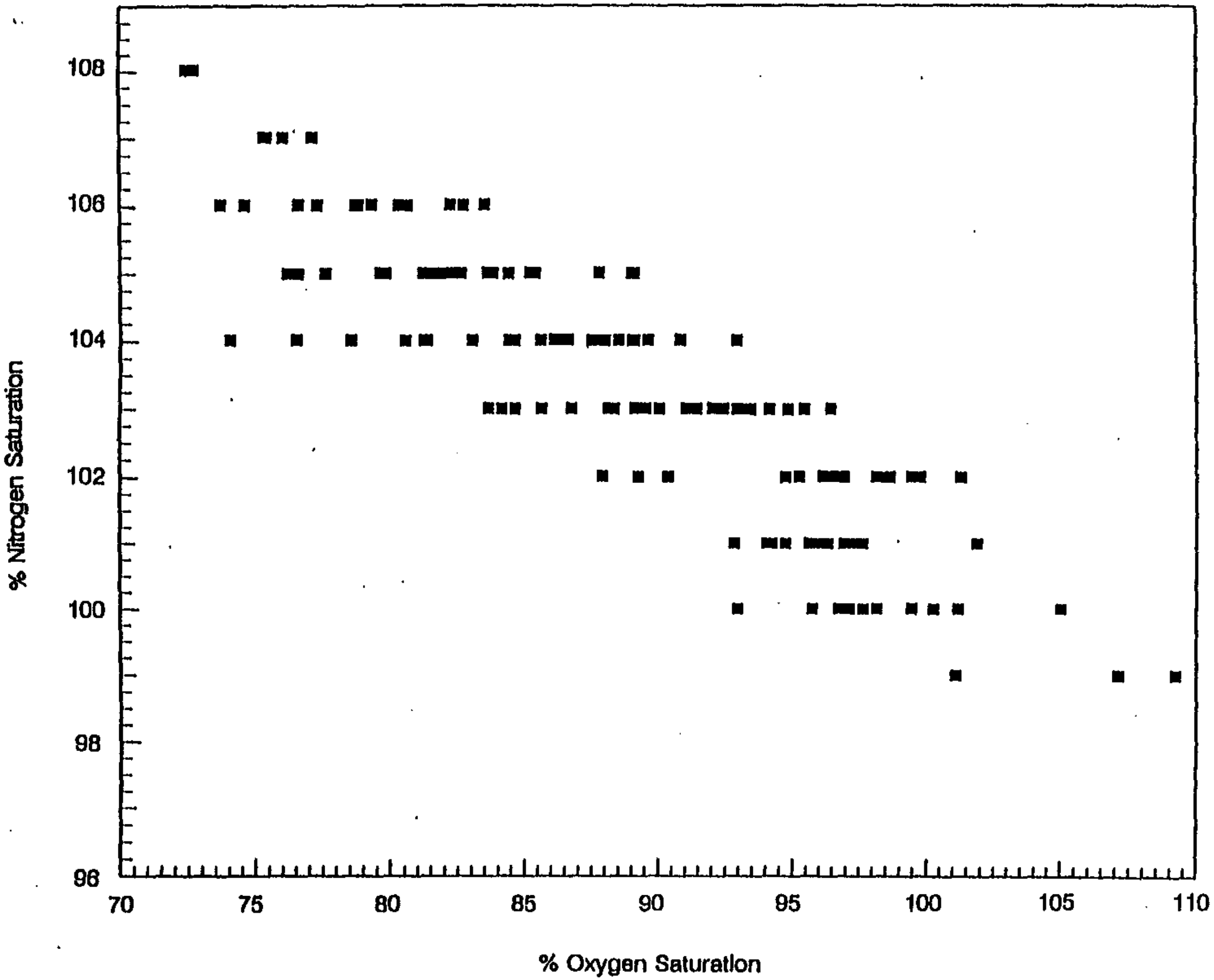

Figure 5. The relationship between nitrogen gas and dissolved oxygen in fish holding tanks in the Wellwater Facility at Red Bluff. Raw wellwater at Red Bluff is supersaturated with nitrogen gas; between 118 and 120 %-saturation. Wellwater and oxygen delivery rates to tanks are regulated to hold oxygen saturation near 100%. This strategy results in a nitrogen saturation near 100% (see text, page 10).

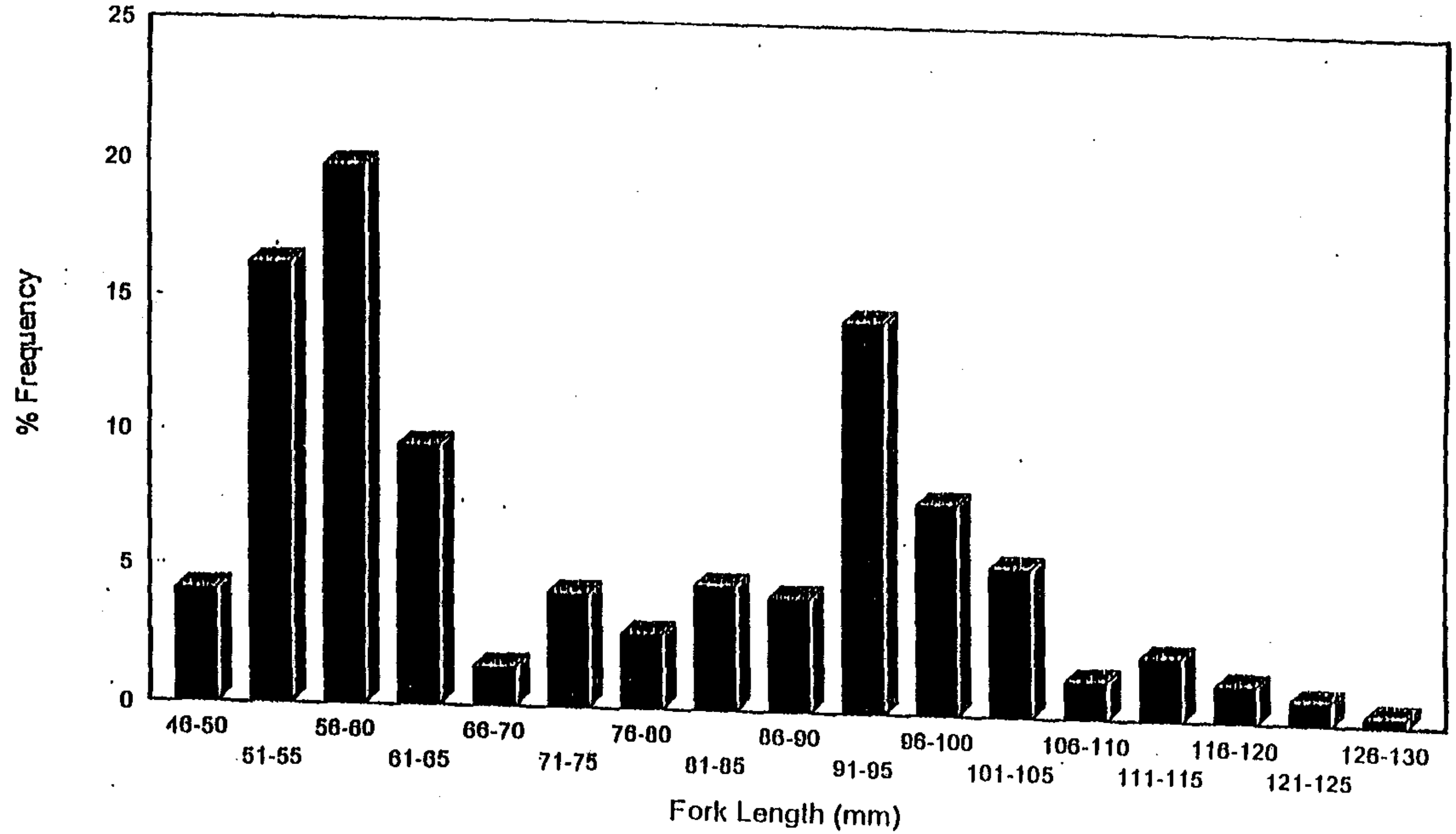

Figure 6. Size-frequency distribution of hatchery-reared chinook salmon that were used for exploratory pump passage trials (objective B) with the internal helical pump from June to September of 1995.

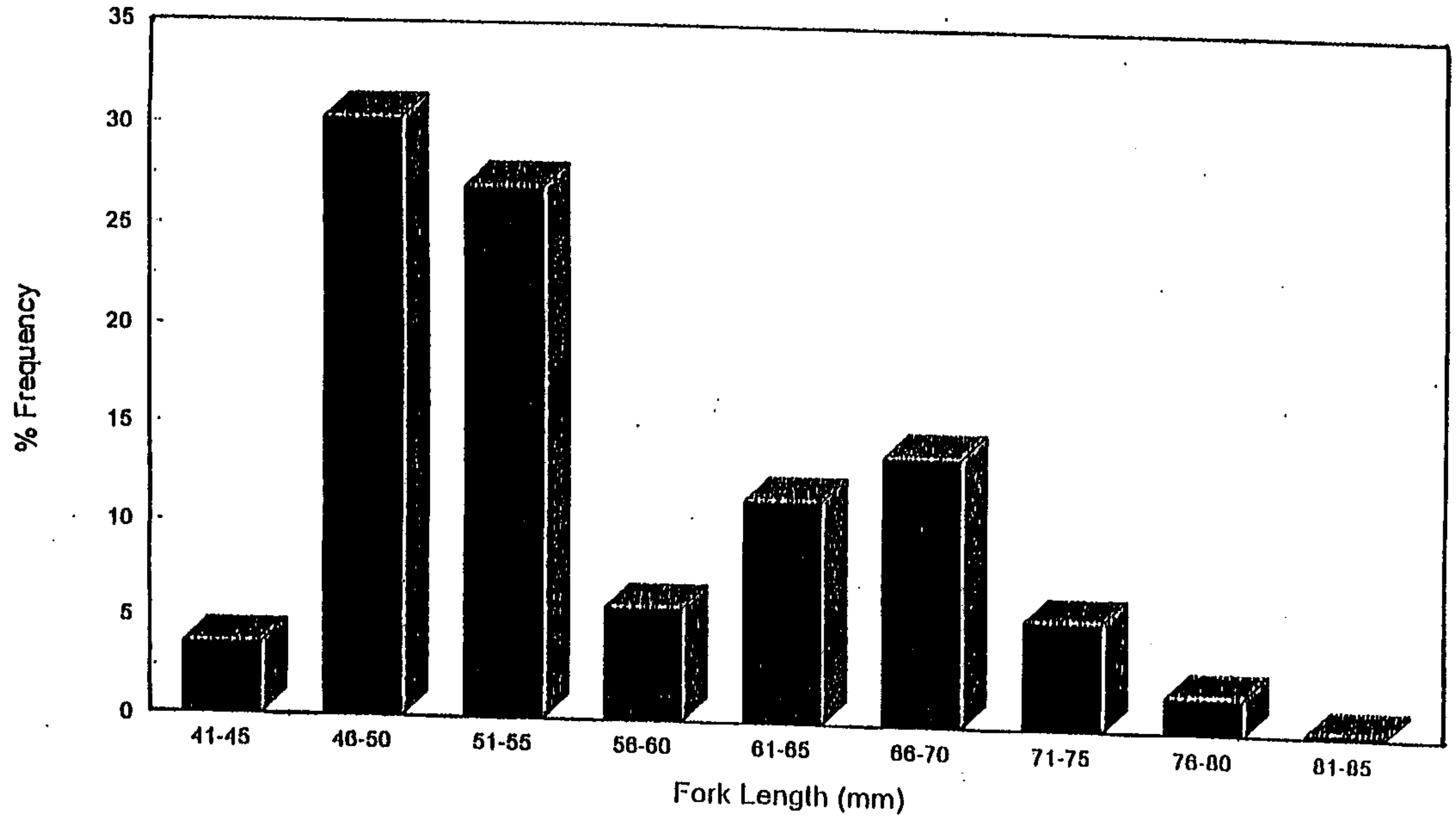

Figure 7. Size-frequency distribution of hatchery-reared chinook salmon that were used for exploratory pump passage trials (objective B) with the Archimedes pumps from March to May of 1996.

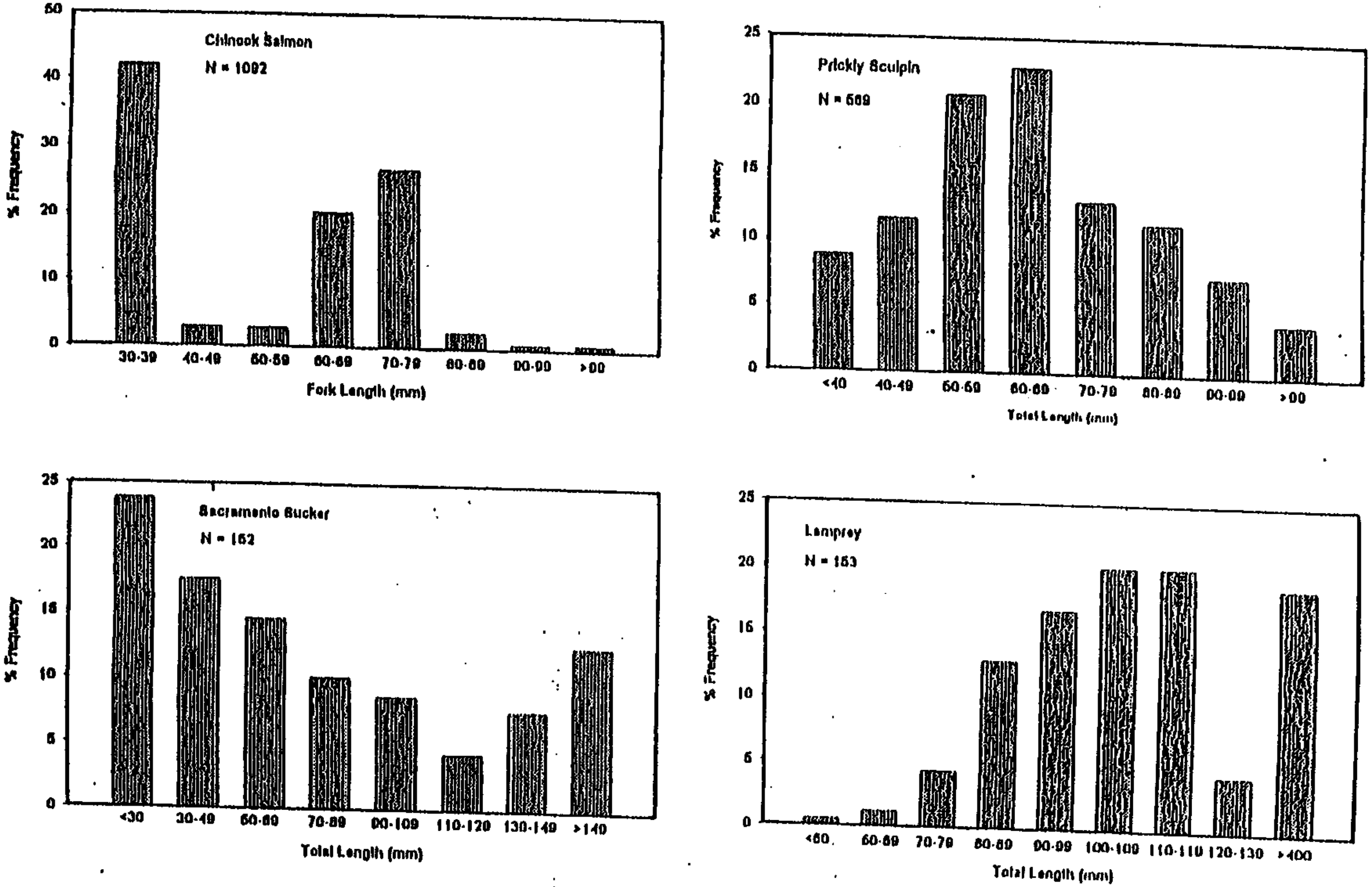

Figure 8. Size-frequency distribution of the four fish species that were most commonly entrained from the Sacramento River during entrainment trials (Objective I) conducted in 1995 and 1996. Individuals of these species made up 87% of the total number of fish entrained.

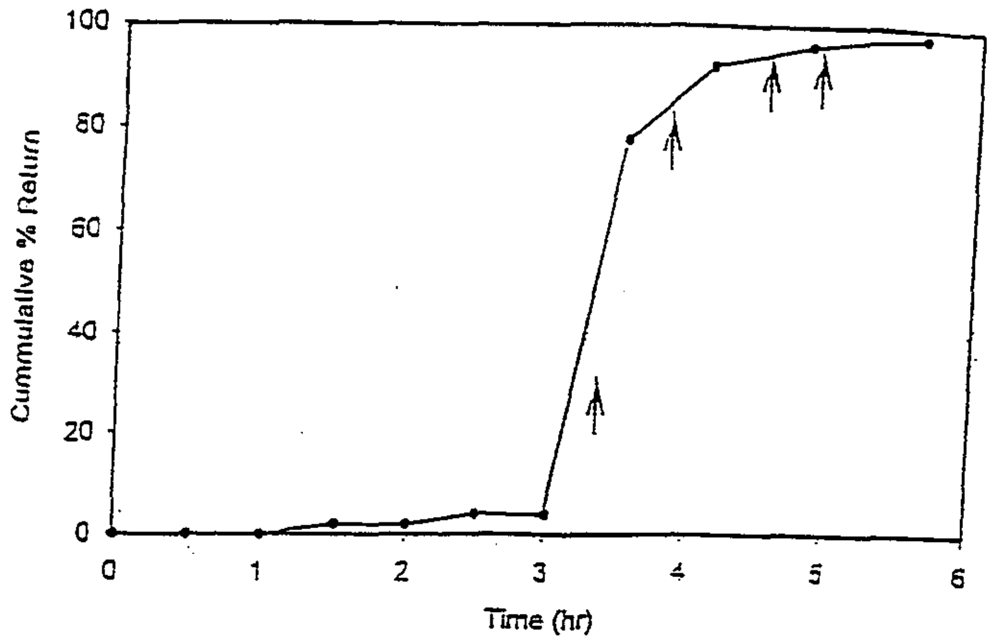

Figure 9. The time-course for recapture of juvenile chinook salmon that were released at the entrance to the underground bypass of Archimedes-1 and collected at the outfall of the plant's bypass system in the Sacramento River. Arrows indicate times at which the terminal portion of the plant's fish bypass (i.e., drum screen bypass) was pulsed.

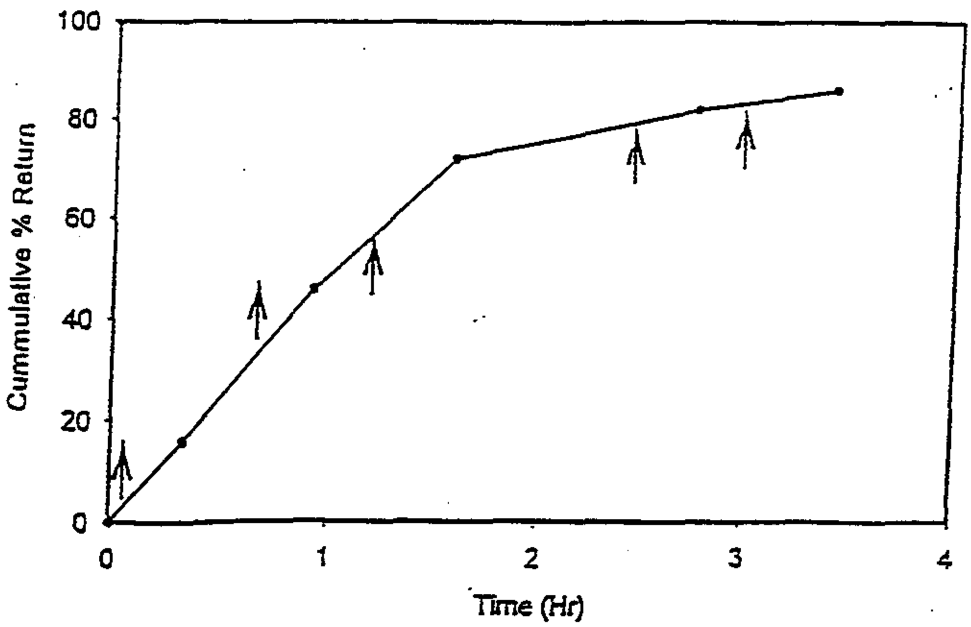

Figure 10. The time-course for recapture of juvenile chinook salmon that were released upstream of the plunge pool on the bypass of Archimedes-1 and collected at the outfall of the plant's bypass system in the Sacramento River. Arrows indicate times at which the terminal portion of the plant's fish bypass (i.e., drum screen bypass) was pulsed.