Arnold Schwarzenegger
Governor

EXPERIMENTAL AND FIELD STUDIES TO ASSESS PULSED, WATER FLOW IMPACTS ON THE BEHAVIOR AND DISTRIBUTION OF FISHES IN THE SOUTH FORK OF THE AMERICAN RIVER

PIER CONSULTANT REPORT

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Prepared By:
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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission) conducts public interest research, development, and demonstration (RD&D) projects to benefit the electricity and natural gas ratepayers of California. The Energy Commission awards up to $62 million annually in electricity-related RD&D, and up to $12 million annually for natural gas RD&D.

The PIER program strives to conduct the most promising public interest energy research by partnering with RD&D organizations, including individuals, business, utilities, and public or private research institutions.

PIER finding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Environmentally Preferred Advanced Generation
- Energy-Related Environmental Research
- Energy Systems Integration

Experimental and Field Studies to Assess Pulsed, Water Flow Impacts on the Behavior and Distribution of Fishes in the South Fork of the American River is the year one report for Contract 500-01-044, conducted by the University of California, Davis. The information from this project contributes to PIER's Energy Systems Integration program area.

For more information on the PIER Program, please visit the Energy Commission's website at: www.energy.ca.gov/pier or contact the Energy Commission at 916-654-5164.

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Abstract

Increased water flow (pulses) for hydroelectric generation and whitewater rafting may impact the distribution of native stream species because they represent significant deviations from the natural hydrograph. The research team conducted both experimental and field studies to assess the effect of these flows on four species of fishes that inhabit Californian rivers. Radio-tagged rainbow and brown trout were tracked during a single pulsed flow. No significant differences were found between the distances moved before, during, and after the release. Fish numbers were recorded in pools along this reach during snorkel surveys before and after the pulsed flow. The total fish density in each pool did not appear to differ before and after the pulse. The research team recorded the responses of juvenile rainbow trout, hardhead, and Sacramento suckers to artificially pulsed flows within a longitudinal flume. Although fish moved either upstream or downstream, the most common (or mean) position of the individuals was close to the center of the flume during pulsed flows. The distribution of individuals was also determined in a lateral displacement flume, consisting of a rectangular tank separated into a main channel that never drained and a sloped bank that alternately flooded and became exposed. Only three (7.8 percent) of the 38 fish placed within the apparatus became stranded. The field and laboratory studies described in the report provide an evaluation of the impacts of pulsed flows for recreational and commercial purposes on the behavior and movements of juveniles and adults of these species of fishes.

Keywords: Pulsed flows, Lateral displacement, Longitudindal displacement, American River, Hardhead, Rainbow trout, Brown trout, Sacramento suckers, artificial stream and radio telemetry.

Executive Summary

Introduction

Human-manufactured increases in water flow (pulses) are common within rivers. There are many reasons for human-made water discharges: generating electricity, providing irrigation water, releases for flood control within reservoirs, flushing streambeds, and facilitating human recreation such as river rafting. California native stream species evolved with seasonal fluctuations, but their increased frequency and late, warm-season timing represent significant deviations from the natural hydrograph.

Purpose

Although water releases provide benefits to humans, the effects of these three types of flow pulses on the community of species present within streams are relatively unknown. For that reason, both experimental and field studies were conducted to assess the impact of pulse flows on fish species that inhabit Californian rivers.

Strong pulsed flows may have possible negative effects on fishes such as longitudinal displacement (forcing downstream of normal habitat) and lateral displacement (stranding along changing channel margins).

Project Objectives

The overall objective of this research was to identify the effects of pulsed flows on fishes. Experimental and field investigations were conducted on four species: rainbow trout (*Oncorhynchus mykiss*), hardhead minnow (*Mylopharodon conocephalus*), brown trout (*Salmo trutta*), and Sacramento sucker (*Catostomus occidentalis*).

There were three phases to Year 1 of this study:

- Tracking the movement of juveniles and adults (> 15 centimeters total length, cm TL), tagged with radio transmitters, in a river to ascertain whether individuals are displaced longitudinally in response to pulsed flows.
- Quantifying the distribution of juveniles (< 15 cm) in a river from visual censuses of unmarked individuals and those marked with visible implant elastomer (VIE) before, during, and after releases.
- Determining the degree of longitudinal and latitudinal displacement, as well as substrate preference of juvenile fishes in varying flows in laboratory experiments.

Project Outcomes

Radio Tracking

The research team captured three rainbow trout by hook and line, implanted radio tags into their peritoneal cavities, and released them into the Chili Bar Reach of the American River during the period from July 23 to August 5, 2004. These fish were exposed to one and occasionally two pulsed flows per day. The research team searched for these fish during seven days, from August 3 through 12, 2004. Rainbow trout (RT) 1 was captured and tagged on July 29 and the tag was relocated 925 meters (m) upstream seven days later; 111 m further upstream on the following day. It exhibited no movement when located twice, three and four days later; and was determined to no longer be in the river. RT 2 was captured and tagged and subsequently never relocated by the research team. RT 3 was captured and tagged August 5 and was located four times later within a 100-m radius of its original release location.

One rainbow trout and six brown trout were tagged with radio tags and tracked during a single pulsed flow on September 15, 2004 in Silver Creek, a tributary of the American River. These individuals were located on the river after capture, later before the pulsed release, during the release, and after the release. No significant differences were found between the distances moved, normalized for their daily movement, between these three periods.

Snorkel Survey and VIE Marking

Young-of-the-year (less than one year old) and juvenile brown trout and rainbow trout were captured using minnow traps and angling, and marked by injecting Visible Implant Elastomer (VIE) prior to the pulsed release of water into Silver Creek. VIE is a silicone based material that is used to track fish. VIE tags are injected as a liquid beneath transparent or translucent tissue and then soon turns into a solid that remains externally visible and does not harm the fish. Individuals were marked with different colors in three reaches of the river, each 100 m in length, in order to detect movement between the reaches during the pulsed flow. The VIE marks were not observed on individuals of either species during visual snorkel surveys before and after the survey, but this could be because a relatively small proportion of the total fish populations were marked, and individuals could be observed only from several meters away.

Fish numbers were recorded in 15 pools along a 300 m reach of the river during snorkel surveys before and after the pulsed flow. Fish were identified to species where possible and age was estimated either as young-of-the-year, juveniles, or adults. The total fish density in each pool did not appear to differ markedly before and after the pulse. Some pools contained fewer fish after the pulse, but others contained more fish after the pulse, and there did not appear to be a pattern along the length of the study reach. Numbers of young-of-the year per pool tended to be lower after the pulse, although some pools contained more fish after the pulse. Numbers of juveniles were generally comparable pre- and post-pulse. Likewise, adult fish numbers did not appear to differ substantially between snorkel surveys. When the counts were examined, and normalized to take into account the different pool sizes, there were still no clear trends in fish distribution.

Longitudinal and Lateral Displacement Experiments

The research team determined the responses of juvenile hatchery-reared rainbow trout, hardhead minnows, and Sacramento suckers to simulated pulsed flows within a 16.5-m long longitudinal flume, in which rocks were placed to simulate the substrate of the main stem of the American River. Although fish moved either upstream or downstream, the mean position of each sample of individuals was close to the center of the flume for each of the five periods of increasing and decreasing flows. This indicated that the fish did not swim or were not transported downstream or moved upstream when in the flume, and this may be due to the presence of a substrate, which created a refuge with slower flows for a fish to avoid having to expend the energy to maintain its position in the presence of higher water velocities. Hardhead minnows and the hatchery-reared rainbow trout swam mainly over substrate; Sacramento suckers swam less often over the substrate.

The movements of individuals of these species were also determined in a 2 x 1 m lateral displacement flume, consisting of a rectangular tank separated into a main channel that never drained and a raised wide channel that alternately flooded and became exposed. Water circulated through the apparatus, flowing downward over a 10 degree slope into a series of channels and potential holding areas for this fish. Four pools existed on the raised wide channel with different shapes, holding, and draining capacities. Fish could become stranded in one of these pools as the water level subsided within the apparatus. Three (7.8 percent) of the 38 fish placed within the apparatus became stranded within one of the artificial pools. One Sacramento sucker and two hardhead minnows were stranded in the margin substrate and pools. The three fish were stranded after remaining within the apparatus during a short acclimation period; no individuals stranded after having a long period of acclimation. Rainbow trout did not strand during any experiments. The fish became stranded only in the largest pool.

Conclusions and Recommendations

Radio-telemetry in South Fork of the American River

Conclusions. This pilot study demonstrated that it was possible to tag and track fish on the South Fork. The paucity of individuals tagged and tracked precludes us from making any conclusions as to the effect of the pulsed flows on rainbow trout in the American River. However, the low densities of trout in comparison with other sierra streams would suggest that there are some factors limiting the trout population, which may be correlated to pulsed flows.

Recommendations. More rainbow trout need to be tracked both in the presence and absence of pulsed flows within the Chili Bar Reach of the American River. The research team angled for rainbow trout for a total of nine days during Year 1, for a total of about 23 person-days. With this amount of effort, only three rainbow trout were of suitable size and condition for tagging. For this reason, the research team concludes that it is infeasible to track wild rainbow trout in the main stem of the South Fork of American River. Alternatively, the team will tag and release rainbow trout raised at the local trout hatchery into the American River during Year 2. Hatchery trout may not respond to pulsed flows as wild fish might, but describing their response to these flows is important, because they represent the majority of trout presently inhabiting Californian rivers.

Radio-telemetry in Silver Creek

Conclusions. One rainbow trout and six brown trout were tagged with radio tags and tracked during a single pulsed flow in Silver Creek, a tributary of the American River. These individuals were located on the river after capture, later before the pulsed release, during the release, and after the release. The results indicate that the single pulsed flow did not alter the distribution of fish within the Silver Creek study reach.

Recommendations. This field study indicates that a single, small release of water into a stream does not significantly alter the distribution of subadult trout. More frequent stream channel maintenance (to promote scouring) releases may be of greater magnitude and frequency and could affect the distribution of fishes. Thus, it is necessary to identify the effect of different types of flow releases on fishes in Californian rivers. This is a first-step toward identifying the effect of water releases produced for recreational rafting or hydroelectric power on the local fish.

Snorkel Survey and VIE Marking in Silver Creek

Conclusions. Trout did not appear to experience large downstream displacements due to the one-day pulse in Silver Creek, or if they were displaced, they had moved back upstream by the time of the post-pulse survey. Additional statistical analyses may clarify the response of the local trout population to the pulse, particularly regarding young-of-the-year distribution. Preliminary analyses indicate that a one-day pulse may not be harmful to trout, at least not in a stream with a large number of velocity refugia (for example, crevices, boulders, deep pools), and a bedrock bottom. However, pulses may negatively affect the ability of trout (and other fish) to feed, due to very high flow velocities, and/or increased turbidity (decreased effective search distance). More frequent pulses may eventually result in decreased growth rates, increased vulnerability to predation (smaller fish are more vulnerable), and decreased survival rates.

Recommendations. The short time frame available for trapping and marking fish precluded doing multiple pre-pulse snorkel surveys, in order to determine the variability of fish density per pool in the absence of a pulse.

The pulse flow release occurred in September, when young-of-the-year trout were well developed and likely able to locate and move to low velocity areas to avoid the higher flows. It would be informative to test pulses of similar magnitude at other times of the year, such as early summer, when fry may be newly emerged, and less able to locate and use flow refugia.

The habitat in Silver Creek is relatively complex and heterogeneous, which likely provided a wide variety of flow refugia for fish. It would be useful to test the impacts of a similar pulse in a stream with less complex habitat to see whether fish are more likely to be displaced as habitat complexity declines.

Longitudinal Flume

Conclusions. Using the longitudinal-displacement experimental flume; featuring a long (15+ m) test section, clear panels for behavioral observations, a variable-speed drive to simulate pulsed flows, and rocks to simulate American River habitat characteristics; the research team found that juvenile rainbow trout, hardhead, and Sacramento suckers trended to remain in the section to which they were introduced throughout the pulsed flow period. Thus, despite open-channel water velocities up to 0.463 m s^{-1}, these three species were neither displaced downstream nor stimulated to swim upstream during or after the flow pulse. It is possible, of course, that these flow-pulse-associated behaviors would change at water velocities higher than those that were tested.

Recommendations. The research team will conduct temperature preference tests on adult rainbow trout and hardhead minnows under different flow regimes. These resulting data would complement field-derived temperature measurements of fishes' selected habitats (for example, before and after pulsed flows associated with hydroelectric or white-water rafting activities). Managers will be able to model adult fish distributions based on this study's resulting thermal (as well as hydraulic) maps of stream reaches. The value of the laboratory-derived data would be their accuracy (especially if derived from fish with different temperature acclimation histories), speed (many species measured within a few months, after set up), and low cost (especially after initial investment in equipment).

Lateral Displacement Flume

Conclusions. Using the lateral-displacement flume; featuring a main-channel and a pulse-flooded, gravel river-bank section with draining and non-draining pools and a 10º slope; juvenile rainbow trout appeared to resist stranding as pulse-flow waters receded down the slope bank. In contrast, with a short acclimation period (simulating the shorter inter-pulsed periods that may characterize days with both morning and evening high-hydroelectric-demand periods), Sacramento suckers, and especially hardhead, may be stranded via pulse-flow-associated lateral displacement. All of the stranded fish would be vulnerable to predation in their non-draining pools.

Recommendations. It is necessary to use both laboratory and field methods to determine the energetic costs when exposed to various pulsed flows. After determining the relationships among swimming velocity, tail beat frequency, and oxygen consumption (metabolic) rate in a Brett-type swimming respirometer, it will be possible to estimate the costs (energy, food, or oxygen-based) associated with a flow pulse by measuring tail beats, using special radio tags, over the flow pulse in the field. The field-based tail beat counts will give accurate estimates of stream-habitat energetic costs because the fish's behavior in a real stream (including the potential uses of hydraulic cover structures) is incorporated into the measurements.

Benefits to California

The field and laboratory studies described in this report provide an evaluation of the effects of pulsed releases of water for recreational and commercial purposes on the behavior and movements of subadults and adults of these species of fishes. The results of these studies may help agencies manage pulsed flows with minimal impacts to the local fish.

1.0 Introduction

Human-controlled flows (pulses) are common within rivers. There are many reasons for anthropogenic water discharges: (1) generating electricity, (2) flushing streambeds, (3) facilitating human recreation, (4) providing additional water for downstream diversion for the purpose of irrigation, and (5) preventing reservoirs from flooding. The most common rationale for controlling the flows of rivers is the production of electrical energy. Hydroelectricity makes up 25% of California's electrical capacity, and is thus a critical component of the state's electrical grid. Water from the Sierra snowmelt, which collects in reservoirs, is passed into large conduits that run laterally along ridges and then downward into secondary reservoirs within valleys, forcing the water to flow downward and to rotate a turbine attached to a generator and producing electrical power. Water is usually not released directly into the riverbed, but can be passed through the river bed instead of large conduits to a turbine. These controlled flows provide additional electrical energy during hot summer days when electrical loads from air conditioners are highest (Hunter 1992). Flushing flows are brief and infrequent, but are sufficiently large that they move silt and sand downstream from the stream bed where they have settled due to slow water flow (Milhous 1994; Reiser et al. 1989). Recreational flows are water releases made to accommodate activities such as rafting and kayaking.

Although water releases provide obvious benefits to humans, the effects of these flow pulses on the aquatic community are relatively unknown. Native Californian fish species have evolved with seasonal fluctuations, but their increased frequency (e.g., for electricity generation) and late-warm-season timing (for recreational purposes) represent significant deviations from the natural hydrograph. Thus, it is imperative that studies be conducted to determine the impact of pulse flows on the fish species that inhabit California's rivers.

1.1. Background

Strong pulsed flows may have possible negative effects on fishes such as longitudinal displacement (forcing downstream of normal habitat) and lateral displacement (stranding along changing channel margins). The former can result in slower growth, decreased reproduction, or mortality because of a reduction in the availability of natural prey (e.g., macroinvertebrates) or habitat (e.g., cobble for juvenile protection, gravel for adult spawning); the latter can result in mortality due to high water temperatures and enhanced vulnerability to predation in shallow pools.

1.1.1. Longitudinal Displacement

Strong pulsed flows force juvenile salmonids downstream (McCrimmon 1954; Erman and Leidy 1975; Ottaway and Clarke 1981; Ottaway and Forrest 1983; Heggenes and Traaen 1988; Crisp 1991; Crisp and Hurley 1991; Pearsons et al. 1992). Longitudinal displacement of juvenile coho salmon has been observed in streams during winter periods when floods are common (Bell et al. 2001; Shirvell 1994; Giannico and Healy 1998). Passive integrated transponder (PIT)-tagged juvenile coho salmon moved mostly in the downstream direction between 10 and 1,992 m (mean: 517 m) after a five-year recurrence flood in Prairie Creek, California (Bell et al. 2001). The higher recapture rates of the young coho in more hydraulically protected habitat types (alcoves and backwaters), compared with those in main-channel pools, probably reflects the value of these off-channel habitats in minimizing the washout/dispersal of fishes downstream (Bell et al.

2001). Furthermore, there may be an interaction between the seasonal timing of pulsed flow releases, the life history stage of fish present, and the relative magnitude of pulses compared with normal flows for that time of year.

In contrast, the longitudinal displacement of larger fish seems less likely, due to their increased swimming performance compared with smaller fishes (Webb et al. 1999). Seventeen adult rainbow trout, equipped with radio transmitters, were tracked in the San Juan River, below Navajo Reservoir, during an elevated, spring reservoir-discharge event (Gido et al. 2000). Twelve of the trout moved laterally into shoreline and side-channel habitats, and five were lost. Because many river species (e.g., members of the family Cyprinidae, the minnows and carps) may have less (aerobic) red muscle than trout (Bainbridge 1960; Bainbridge 1962), downstream displacement of larger minnows and suckers might be anticipated with a pulsed flow. Indeed, Sacramento suckers (*Catostomus occidentalis*), fitted with radio transmitters, were displaced a mean of two kilometers (km) downstream, after a flow pulse in the Mokelumne River during 2003 (C. Jeffres, pers. comm.).

Salamunovich (2003) studied fish distribution in the Rock Creek and Cresta reaches of the North Fork Feather River in response to recreational flow releases. Visual counts were made by two divers at eleven sites 24 hours before and after five separate monthly recreational flows. The study found little change in the observed species, number and sizes of fish before and after flow pulses. However, because fish were not marked prior to the surveys, it was not possible to determine whether the fish seen before and after the pulses were in fact the same fish. If fish were displaced along the river consistently throughout the reach, the only change in density would be observed at the very top (lower density) and bottom (higher density) of Cresta Reach. If this were not observed, fish throughout the reach may have been displaced downstream.

1.1.2. Lateral Displacement

In rivers regulated for electrical power generation, sediment removal, or for recreational rafting, the flow of water may be increased for several hours. During this period, the water level rises and may form side channels. The cessation of water release can result in a rapid lowering of the water level as the river returns to its normal river channel (Cushman 1985; Hunter 1992). Stranding in shallow side channels has been observed in field studies (Maciolek and Needham 1952; Hamilton and Buell 1976; Bauersfeld 1977, 1978; Wooden 1984; Hvidsten 1985; Olson 1986; Olson and Mezgar 1987; Higgins and Bradford 1996) and laboratory investigations (Bradford 1997; Bradford et al. 1995; Monk 1989).

Laboratory investigations have provided insight to the impact of pulsed flows because potentially critical factors were varied individually to assess effects on fish behavior and identify problematic factors. For example, Bradford et al. (1995) identified stranding of juvenile coho salmon (*Oncorhynchus kisutch)* and rainbow trout (*O. mykiss*) on river bars caused by rapid decreases in river flow in an artificial stream channel under winter conditions. Many fish became stranded because they concealed themselves in the interstitial areas in the gravel substrate and were reluctant to leave when water levels receded. Coho salmon were more likely to be stranded than rainbow trout. Also, juveniles of other species of salmonids responded to manufactured flows in the Sultan River, Washington, with differing susceptibility to stranding at different times of day or night (Olson and Metzgar 1987).

1.2. Project Objectives

The overall aim of this research was to identify the effects of pulsed flows on fishes. The research team conducted field and experimental investigations on three species: rainbow trout, hardhead minnow (*Mylopharodon conocephalus*), and Sacramento sucker. There were four objectives to the study during 2004–2005:

1. Characterize the flow velocities in rivers associated with manufactured releases of water for the purpose of electricity generation and recreation use with regard to normal flows
2. Track the movements of subadults and adult trout (> 15 cm TL), carrying radio transmitters, in the river during pulsed releases to determine whether they were displaced longitudinally
3. Quantify the effect of the flows on marked and unmarked juvenile trout (< 15 cm TL) from visual censuses made in the river before, during, and after releases
4. Determine the displacement of juvenile suckers, hardhead minnows, and hatchery-trout laterally or longitudinally, in two experimental apparatuses in the presence of increasing flows of water, simulating the pulsed releases into rivers

1.3. Report Organization

Section 2 describes the methods used in the study. Section 3 presents the results of Year 1 of the study. Finally, Section 4 discusses the results in the context of the results of prior studies, offering conclusions and recommendations. Throughout the report, field studies will be described first and the laboratory studies second.

2.0 Project Approach

2.1. Field Studies

2.1.1. Study Sites

This project's field studies of the effect of pulsed flows on trout were carried out in the South Fork of the American River (Figures 1 and 2). First, the research team tracked rainbow trout during daily pulsed flows in the reach between Chili Bar Dam and Folsom Reservoir. Second, the team tracked rainbow and brown trout (*Salmo trutta*) farther upstream in Silver Creek during a single pulsed flow released from Camino Dam.

2.1.1.1. South Fork

The research team tagged and released three rainbow trout and tracked them between Camp Lotus and Gorilla Rock, upstream of Fowler's Rock and downstream of Chili Bar Dam (see Figure 2). This 11.2 km reach of the river is characterized by strong pulsed flows and is a popular destination for whitewater rafting (see Figure 2). Water is released from the Chili Bar Dam into the Chili Bar reach of the South Fork. Pacific Gas and Electric Company (PG&E) operates this dam. Based on an agreement with the whitewater rafting community, PG&E releases daily pulses of water into this reach of the river from May–September of each year. The ambient rate of water discharge from Chili Bar dam is 5.0 cubic meters per second (m^3s). This rate is increased periodically during daytime to 35.0 m^3s on Tuesday through Friday; the rate of discharge is increased even further on Saturday and Sunday, often exceeding 40.0 m^3s. There is no agreement regarding the release of water on Monday, and PG&E releases an amount of water into the river that meets the current hydropower demand. The maximum discharge rates during the pulses ranged from 40.0 to 90.0 m^3s during the two-week period that the rainbow trout were tracked in the South Fork (Figure 3). For example, the discharge rate on 9 August 2004 increased from 5.0 to 50.0 m^3s from 0600 to 0900 hours (hrs), and decreased from 40.0 to 5.0 m^3s from 1600 to 1900 hrs (Figure 4).

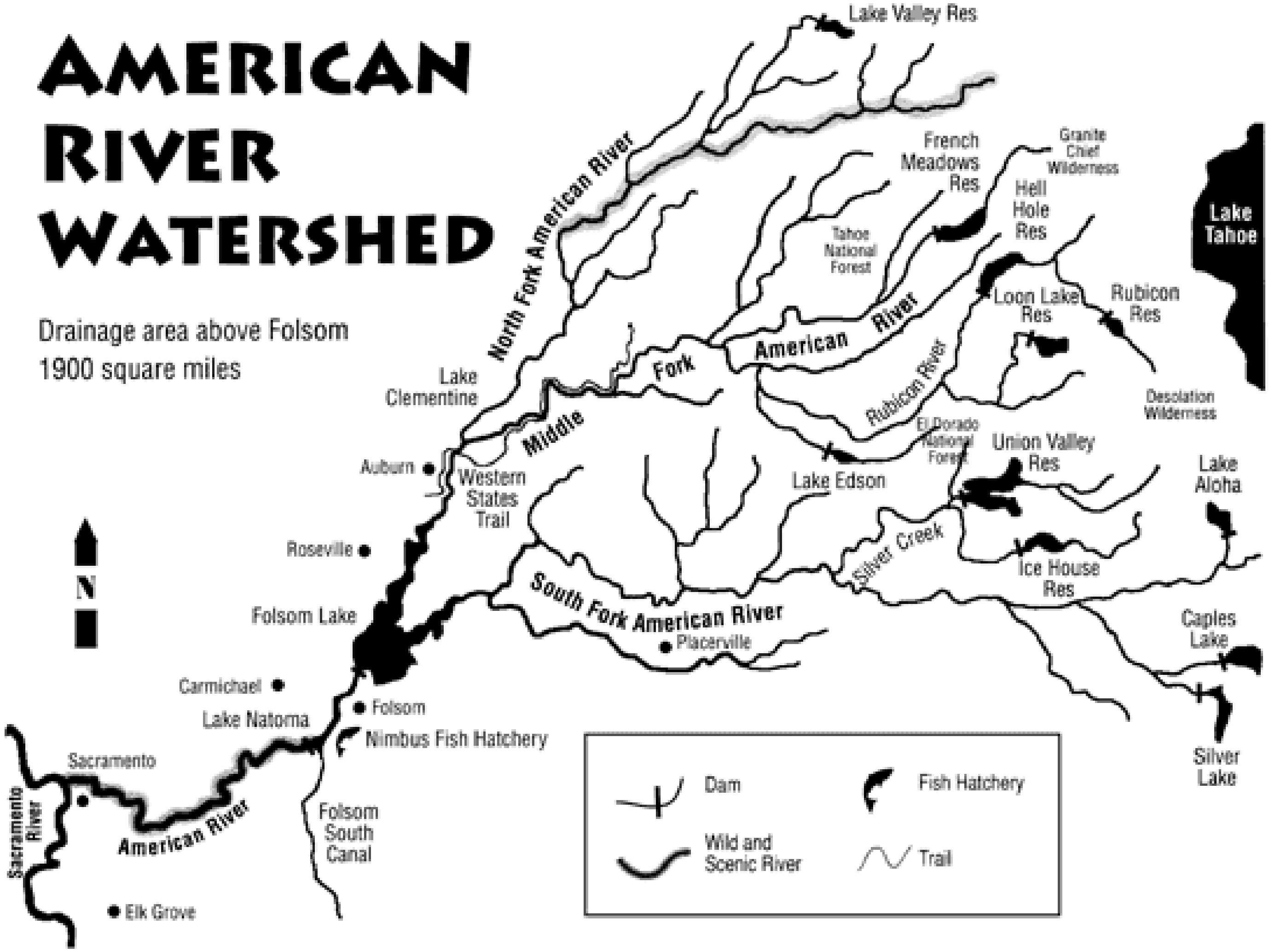


Figure 1. Map showing the American River Watershed, consisting of the North, Middle, and South Forks. Rainbow trout were tracked in the wide, lower reach of the South Fork between Folsom Reservoir and Chili Bar Dam; rainbow and brown trout were radio tracked and VIE marked upstream in an upstream tributary, Silver Creek, downstream of the Camino Dam.

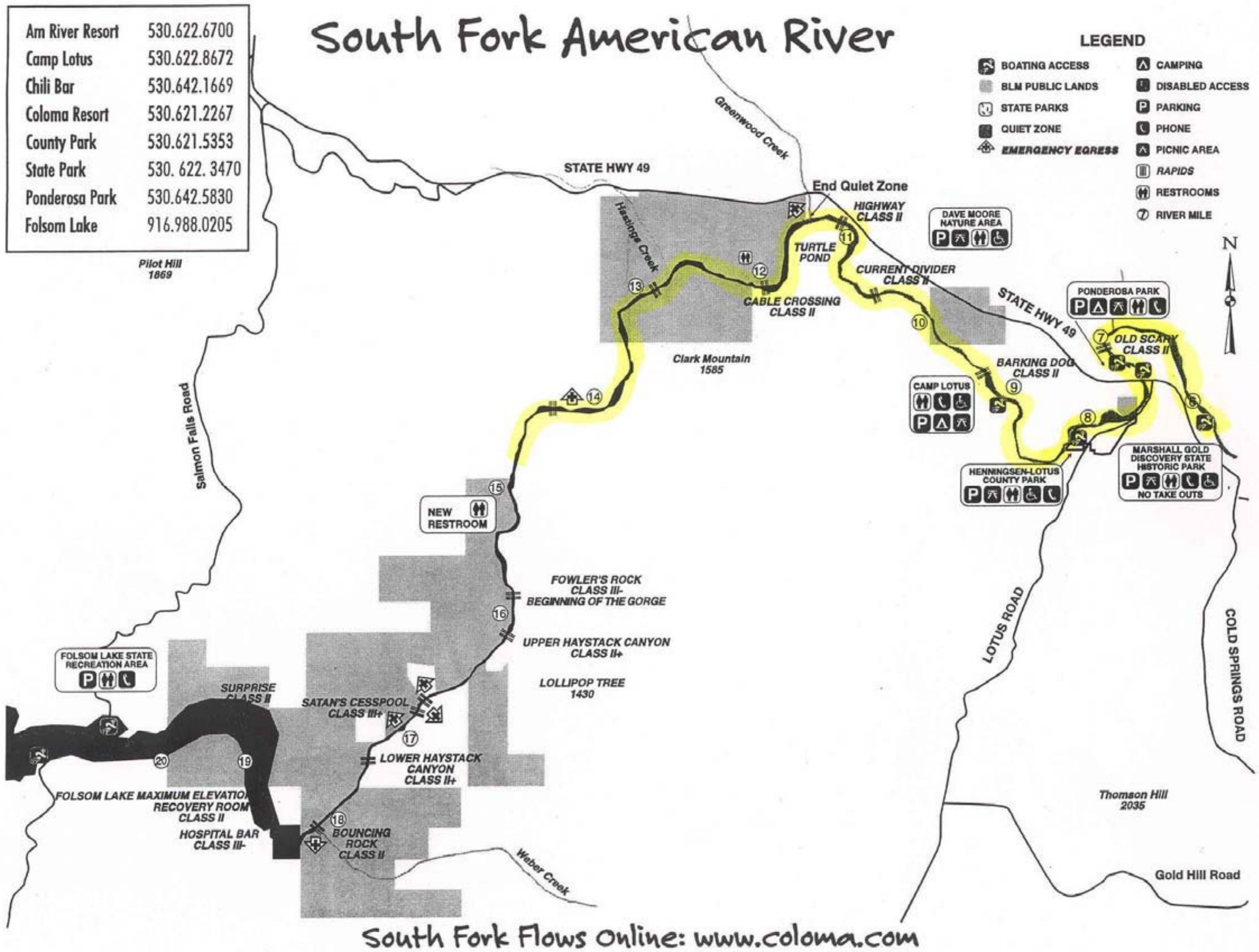


Figure 2. Shown is the 14.5-km long reach of the South Fork American River (see yellow) starting 9.6-km below Chili Bar dam, where rainbow trout movement during daily pulse flows were evaluated using radio-telemetry

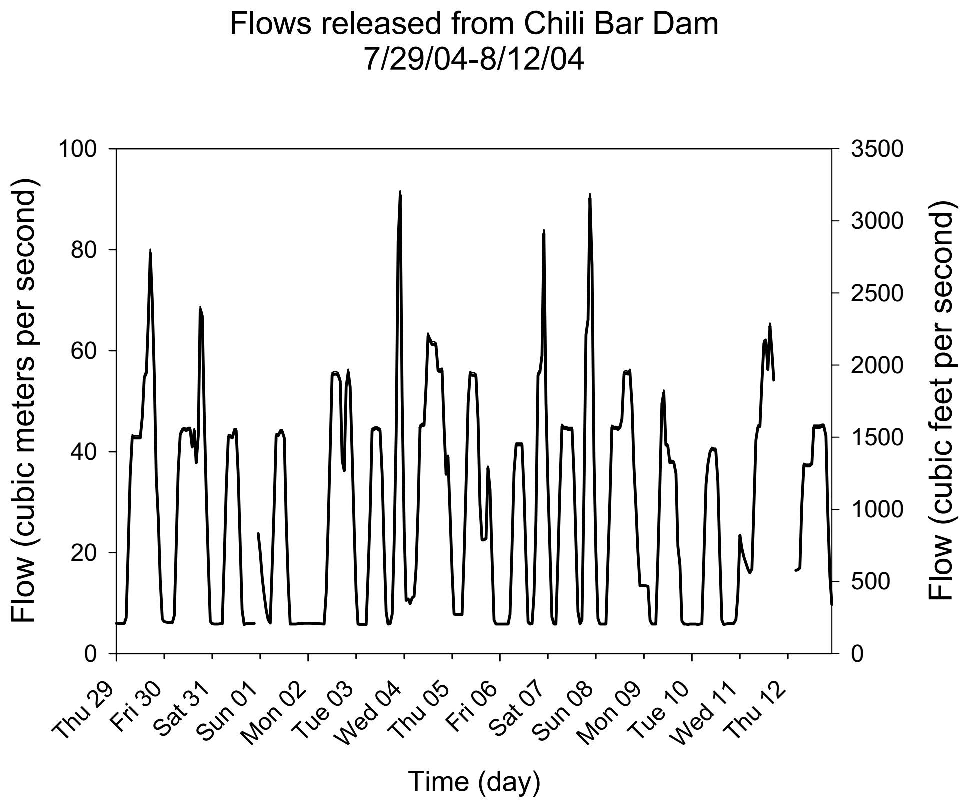


Figure 3. The rate of water discharged from Chili Bar Dam into the South Fork by PG&E during the 15-day rainbow trout radio tracking survey

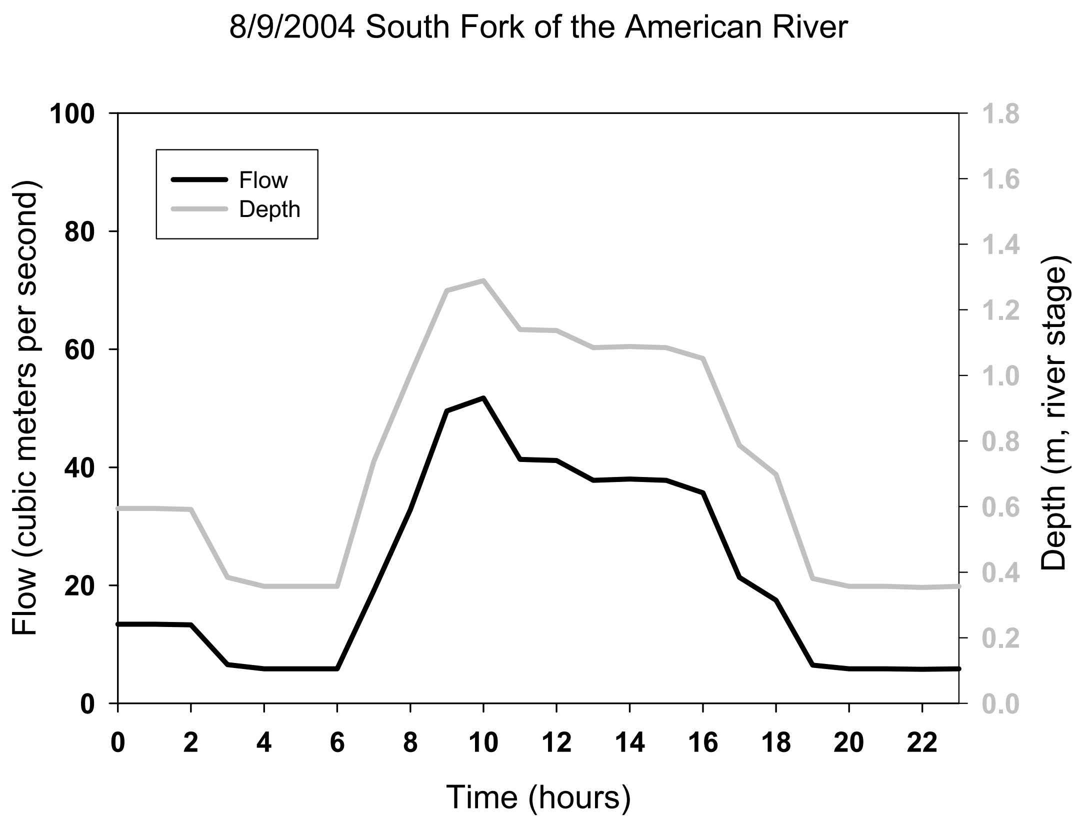


Figure 4. Discharge and stage data for South Fork of American River below Chili Bar Dam during a 24-hour period on 9 August 2004 (one of the days during the rainbow trout radio tracking survey)

Water height rose from 0.4 to 1.3 m at a reference point at Chili Bar Dam. Vast areas of cobble along the riverbed, exposed between flows, were submerged by rapidly flowing water during these temporary water discharges from Chili Bar Dam (Figure 5).

2.1.1.2. Silver Creek

The research team studied the movements of seven trout in a 600 m reach of Silver Creek (Figure 6), before, during, and after a pulsed discharge of water from the Camino Dam (Figure 7) on 15 September 2004. Water flows into this reservoir from the upper part of Silver Creek, and via the Jaybird Tunnel from Union Valley and Junction Reservoirs.

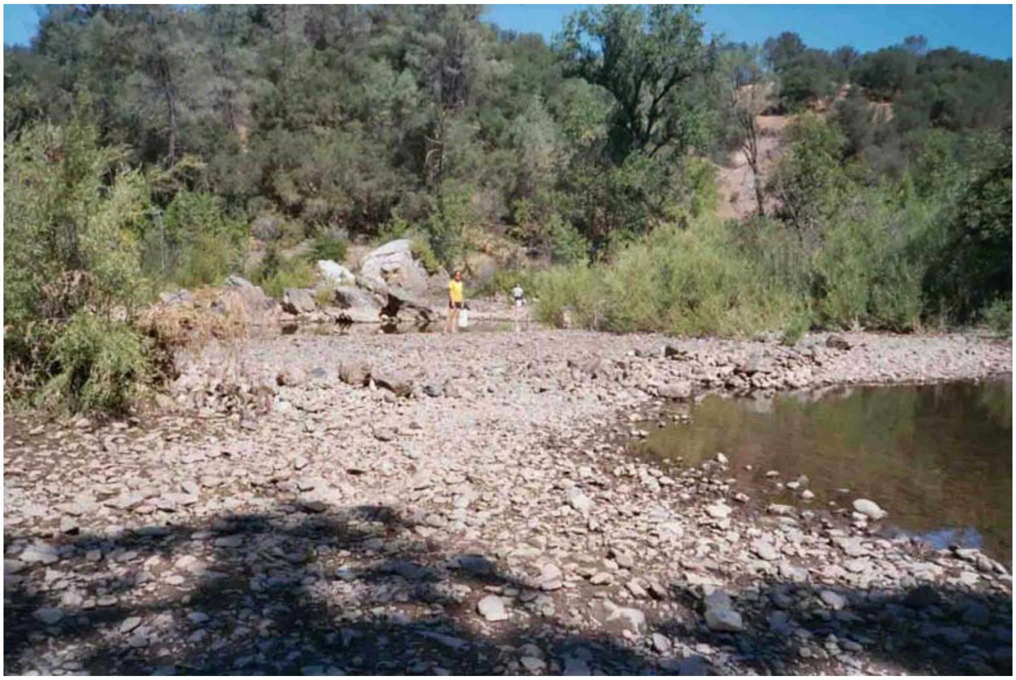


Figure 5. Two different reaches of South Fork: one, in the absence (above) and two, in the presence of a pulsed flow (below). Note how much of the riverbed is exposed between the pulsed discharges of water from Chili Bar Dam.

Figure 6. The distribution of radio-tagged, VIE marked, and observed fish were determined before, during, and after the pulsed flow within a 600 m reach of Silver Creek below Camino Dam (upstream view from the center of the study reach with dam in background).

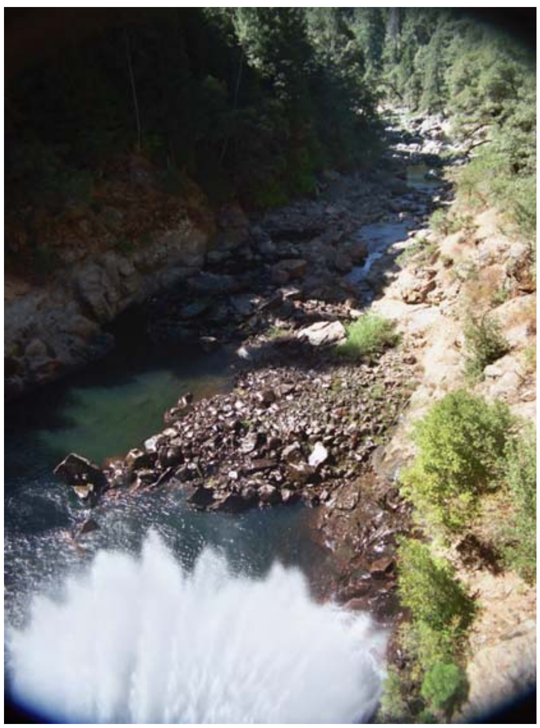


Figure 7. Water is shown being discharged from a pipe through Camino Dam into Silver Creek on a typical discharge day. On 15 September 2004, the rate of discharge was increased from 0.5 to 18.5 m^3/s before it was decreased to 0.5 m^3/s later the same day.

Water is stored in Camino Reservoir, and most of it is diverted through a series of pipes along a ridge and then downward to the Camino Powerhouse, from which it flows into the South Fork American River just upstream of Slab Creek Reservoir. Typically, during September water is discharged at a rate of 0.5 m^3s by the Sacramento Municipal Utility District (SMUD) into Silver Creek below Camino Dam.

Mr. David Hanson of SMUD informed the research team during early summer of 2004 that it could study the effect of a one-day pulsed release of water on trout in Silver Creek. This one-time discharge was designed to test the potential of the reach for Class IV to V whitewater kayaking. Water discharges from Camino Dam into Silver Creek varied from 0.3–2.1 m^3s from 1 October 2003 to 30 September 2004, with the exception of 15 September 2004 (Figure 8).

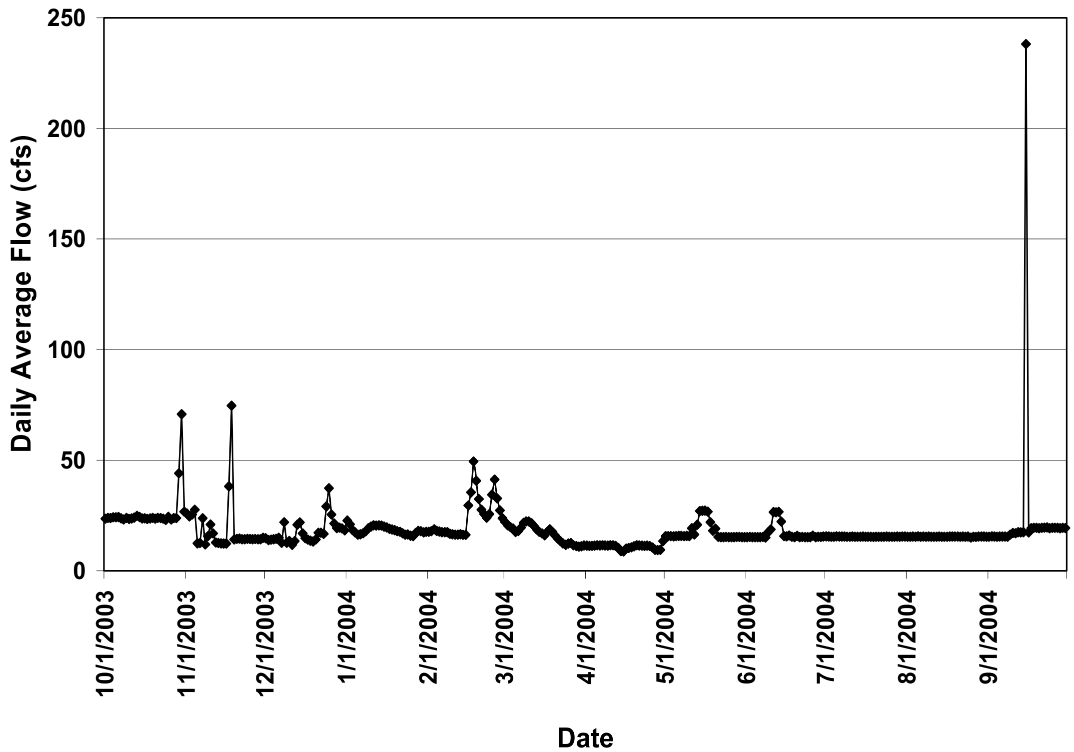


Figure 8. Daily mean rate of discharge from Camino Dam into Silver Creek from 1 October 2003 to 30 September 2004. Water discharge varied from 0.26 to 2.12 m^3/s (9 to 75 cubic feet per second, or cfs) over this period, with the exception of 15 September 2004. Data are courtesy of Mr. Randy Jensen, SMUD.

The rate of discharge on this day rose from 0.5 m^3s at 0600 hours (hrs) to 18.5 m^3s at 0945 hrs, stayed constant until 1445 hrs, and then dropped to 1.8 m^3s by 1730 hrs and 0.5 m^3s by 2015 hrs (Figure 9). There was a large change (i.e., 3.2 feet) in the level of water, illustrated by a river height gauge located halfway along the length of the 600-m long experimental reach (Figure 10).

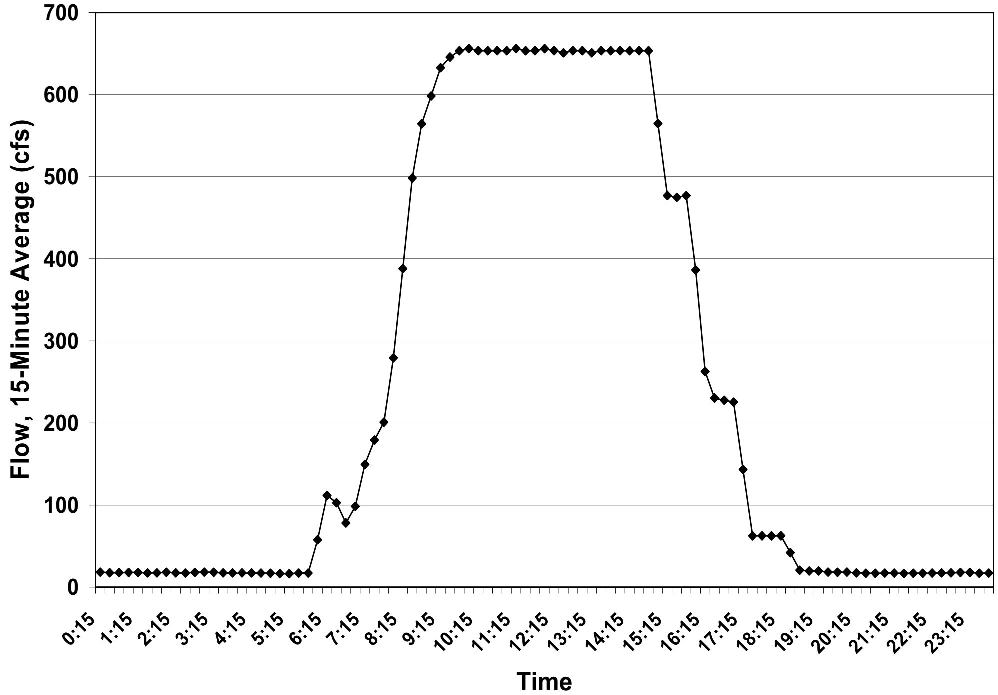


Figure 9. Rate of water release from Camino Dam to Silver Creek peaked at 18.5 m^3/s (653 cfs) during the pulsed flow on 15 September 2004

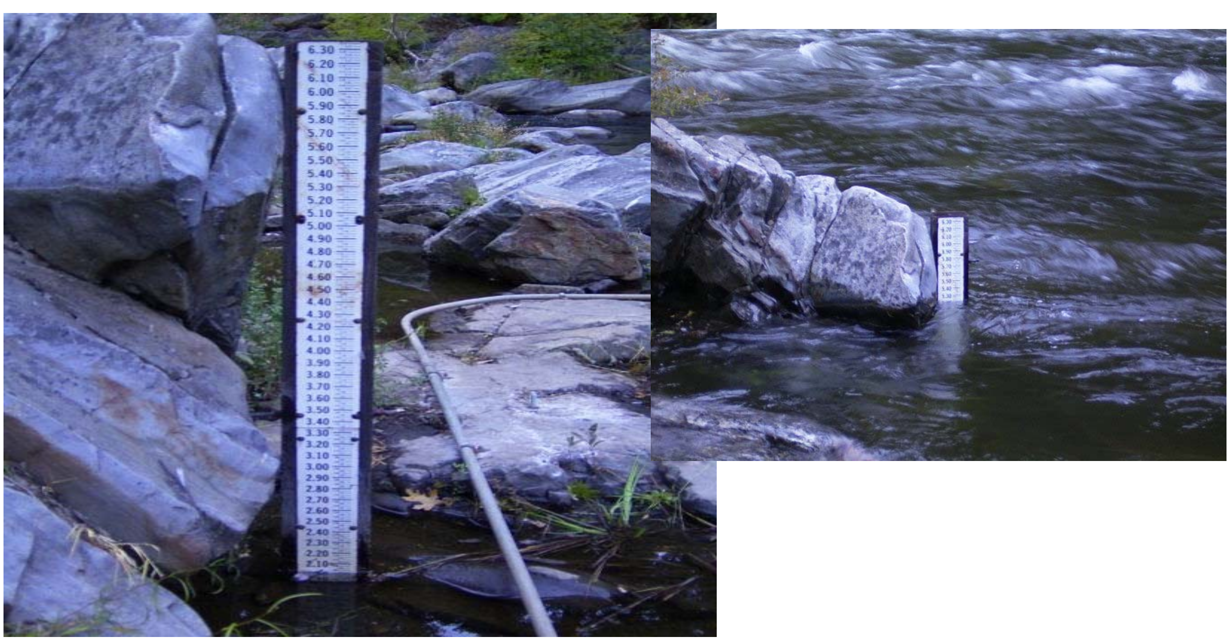


Figure. 10. Stage gauge for Silver Creek below Camino Dam before(left) and during (right) pulsed flow of 18.5 m^3/s on 15 September 2004

2.1.2. Fish Collection

Adult trout were captured by hook and line for radio tracking and juveniles were caught by hook and line and minnow traps for visible implant elastomer (VIE) marking on the South Fork (Figure 11) and Silver Creek (Figure 12) .

Figure 11. Fishing for adult rainbow trout for the radio telemetry study near Gorilla Rock on the South Fork of the American River (above). Retrieving minnow traps set to capture juvenile fish for the VIE marking study at the same site (below).

Figure 12. Fishing for adult rainbow and brown trout to radio tag (above) and trapping juvenile trout for VIE marking (below) at Silver Creek

The adult fish were captured using artificial lures and insects. They were captured quickly, to minimize and reduce stress. If a trout was hooked in any area other than the lip or swallowed the lure, it was released because of the increased chance of mortality. The research team recorded the size of each captured individual, its GPS coordinates (if available), and location along the river. The fish were allowed to recover in a mesh live trap placed in the river, and permitted to regain their equilibrium before undergoing surgery.

The juvenile trout were collected mainly using minnow traps. The traps had 2.5–3.2 cm openings on both ends enabling small trout to enter on either side. The research team employed salmon roe, dog food, cat food, beef liver, and Dove soap as bait in the South Fork. The traps were usually deployed at depths of 0.6–1.2 m, although this varied depending on whether water was being pulsed when they were set and retrieved. Traps were set in high, medium, and low flow areas and usually left overnight. Juvenile trout in Silver Creek were caught using salmon roe or dog food. The traps were left for periods of 3–6 hours during the afternoon before being examined for captive fish. Traps were set at depths ranging from 0.9–2.4 m. The research team recorded the date, location, depth, times set/retrieved, bait type, and GPS coordinates of each trap. The fish within the trap were identified and counted and their approximate lengths recorded when checking a trap.

2.1.3. Radio Tracking

2.1.3.1. Radio Tag Description

The radio tags utilized to track trout in the field were the smallest digitally encoded transmitters available for aquatic environments. A manual-tracking receiver (Lotek Wireless Inc., SRX400) recognized beacons transmitting pulses of the same frequency by their unique digital codes. The use of a single frequency decreased the chance of passing out of the range of a fish carrying a beacon of a particular frequency while scanning through frequencies other than that frequency.

Two sizes of beacons were available for implantation in sub-adult and adult trout:

1. 1. NTC-4-2L, 2.1 grams in air, 8.3 millimeters (mm) diameter by 18.3 mm long, with a life span of 93 days and a pulse burst every five seconds.
2. 2. NTC-6-2, 4.5 grams in air, 9.1 mm diameter by 30.1 mm long, with a life span of 126 days and a pulse burst every 2.5 seconds.

The research team chose one of the two tag sizes using the 2% rule of body mass as a guideline (Jepsen et al. 2002). The smaller tags were placed in the peritoneum of fish with a body mass between 105–225 grams and larger tags placed in fish with a body mass of > 225 grams.

2.1.3.2. Surgery

The trout were placed in live traps after capture while preparing the anesthesia solution and assembling the surgical gear. The research team implanted the tags using a surgery table attached to the raft at the site where the fish was captured on the South Fork American River. The surgical technique did not vary between field sites with a few exceptions: at Silver Creek, adult rainbow and brown trout were carried to a fixed surgery location in 18.9-liter buckets with lids and then returned to their capture sites after recovery from surgery. Individuals were transported a maximum distance of 250 m one way. When necessary, fish were kept in live traps immersed in the stream over night to insure full recovery before being transported to their capture site.

The anesthetic solution was prepared in a 18.9-liter, plastic bucket with 10 liters of river water, 27 grams of sodium bicarbonate, and 10 milliliters (ml) of glacial acetic acid to buffer the pH as outlined in (Peake 1998). The pH of the anesthetic solution was neutral (7.0). Each fish was placed into the bucket and anesthetized to Stage 4 anesthesia; characterized by loss of orientation and slowing of gill movement. The fish was then removed from the solution of anesthetic and placed on the surgical table, ventral side up (Figure 13). The anesthetic solution was continuously passed over the gills with tubing connected to a recirculating, battery-operated bilge pump.

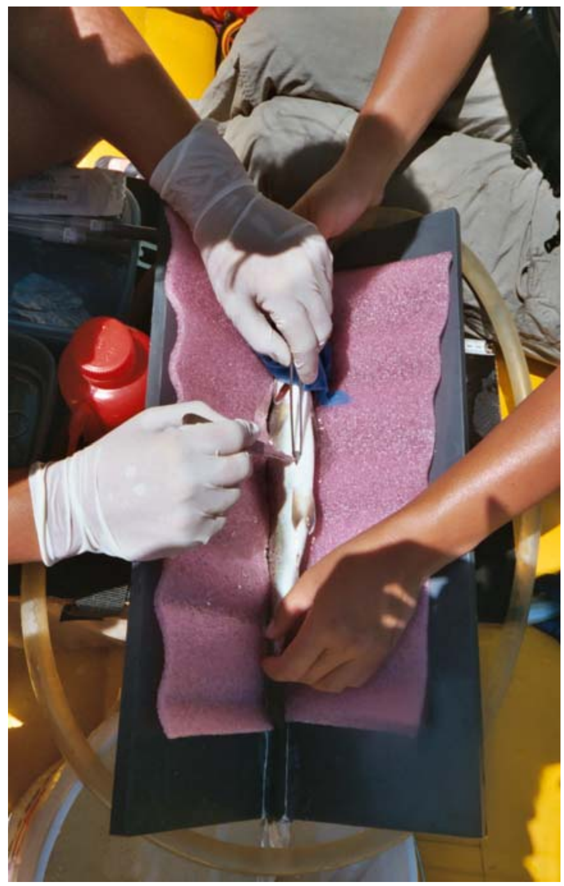


Figure 13. Rainbow trout positioned on surgical table with anesthetic solution circulating through the mouth and across the gills (left); an incision being made for tag implantation (right).

An incision, 1–2 cm long, was made below the rib cage and above the pelvic girdle, off the fish's midline. To avoid damaging internal organs, a sheathed plastic 16 gauge (Ga.) catheter was used to puncture the body wall, creating an exit point for the whip antenna. The whip antenna was threaded through the plastic catheter sheath and fish's body wall until reaching the site where the antenna attaches to the cylindrical tag. The tag was then gently pushed through the incision into fish's body cavity. A solution of 0.005 ml per 100 grams of fish of an antibiotic (Liquamycin® LA-200®) was injected into the incision site with the 1-cc syringe. Three to four sutures were made along the incision site with synthetic, absorbable suture material (Vicryl™). Each suture was dotted with liquid topical tissue adhesive (Nexaband) to secure the knots. The fish was gently placed into a live trap after surgery and monitored for gill rate, tail beat, orientation, and swimming ability. The fish was released when it began to swim normally (Figure 14), with typical recovery times of 15–30 minutes.

Figure 14. Rainbow trout (RT 3) released after tag-implant surgery.

2.1.3.3. Tracking

a. South Fork American River

A cooler with foam fitting snuggly around the equipment was secured into the back of the raft with cam straps. The research team programmed the receiver to continuously scan between the two frequencies at 5.5-second intervals and display the identification code of the tag if within range. The team floated downstream in the river, searching for the tagged fish by moving the antenna back and forth between banks of the river (Figure 15). Once a fish was detected by the receiver, the raft was rowed into an eddy or beached in order to determine location of the tagged fish more accurately from land.

A GPS location was recorded where the transmitter's signal was first detected. Bearings were taken to the fish from points on the riverbank. At least two sets of bearings were collected for each tagged fish. The research team tried to locate fish from the same triangulation points every day. Also, an attempt was made to locate the fish from opposite sides of the river when possible. It was difficult to accurately distinguish the direction where the strength of the signal was greatest. For that reason, the tracker stood in the same spot and rotated the vertically oriented antenna back and forth, noting each direction where the signal strength began to attenuate, and then selected the mid point between these divergent bearings. Fish location was estimated by triangulation of lines of position based on bearings taken to specific landmarks.

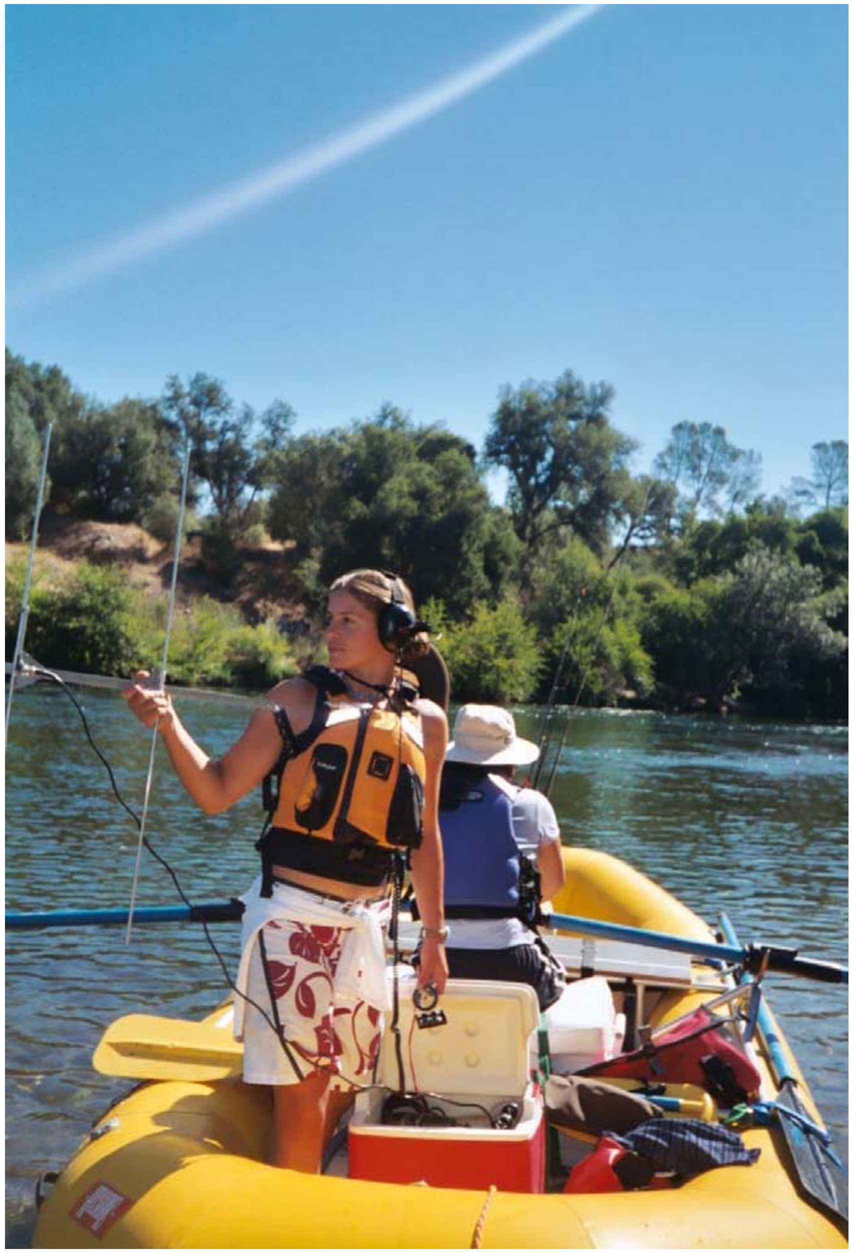


Figure 15. Searching for radio tag signals with directional antenna and receiver, enclosed in cooler, on South Fork

b. Silver Creek

Similar methodology was employed between the two field sites; however, with slight technical alterations due to the different nature of the sites. Silver Creek is a small creek, which is not passable by raft. Therefore, the research team climbed over rocks within the dry streambed along the length of the narrow creek, bordered by the steep sides of the small canyon. The creek consisted of rocky ledges, over which the water spilled into pools, in which there were turbulent eddies below the ledge, slower moving water in the deep center of the pool, and accelerating water in the riffles near the tail of the pool.

The positions of the radio-tagged fish were determined in Silver Creek (1) at the time of their release, (2) on the day before the pulse, (3) during the pulse flow release (15 September 2004), and (4) a week after the pulse. The same methodology was used to determine the position of a tagged fish prior to the pulse and after the pulse; a slightly different technique was used to position the fish during the pulsed flow. The team marked the location where each fish was caught and released. The experimental reach was 600 m long and was marked with flagging at 50 m intervals. The reach began approximately 200 m downstream of Camino Dam. The access point was 300 m downstream from the beginning of the reach. The research team began searching for fish at a distance of 350 m along the experimental reach, where the fish farthest downstream was tagged and released. Researchers pointed the antenna, its elements held vertical, oriented toward the river, and searched for the radio signal. The tracking crew moved upstream until it recorded the maximum signal strength and the strength of the signal began to diminish. The antenna was then rotated, so the elements were parallel to the ground, to increase the directionality of the antenna. Researchers moved the antenna back and forth to either side of the pool to distinguish where the signal was highest, and then recorded river meter, signal power, and gain for that fish and drew a map of the area where each fish was found.

The method used to detect fish during the pulse was slightly different to ensure that the research team would be able to operate safely while track during the pulse. The tracker recorded at every 50 m distance along the length of the creek the codes of the tags detected and their respective signal powers. The fish was first detected with the elements of the Yagi antenna held vertically and then switched to a horizontal orientation. The tracker recorded the fish's location where the signal strength was the most powerful.

2.1.3.4. Graphical Display

The research team employed a software program (Locate 2) to triangulate positions and convert them into their geographical coordinates of latitude and longitude. A macro (Excel, geofunc.xla) was used to calculate the distance between two positions, each with a latitudinal and longitudinal coordinate. Geographical information system software (ESRI, Arcview 8.3) was used to superimpose the calculated latitudes and longitudes of tagged fish on a map of the study area. The map used was downloaded from www.klofas.com, a source of digital USGS topographic maps, referenced to the Datum NAD83. Arcview 8.3 was further used to verify the accuracy of the calculated latitudes and longitudes.

2.1.3.5. Error Determination

A GPS position was recorded for the radio-tag on RT 1, and also positioned using the method of triangulation. The distance between both sets of geographic coordinates was calculated, and used as an estimate of the error associated with the radio-determined positions. The distance between the two locations was 45.1 m. The accuracy of the GPS was displayed on the device for this particular location, giving a mean = 9.8 m. The telemetry- and GPS-derived errors were added to provide a cumulative error of 55 m for the radio position determinations.

2.1.4. Snorkel Survey and VIE Marking

The objective of this phase of the study was to determine the response of juvenile fish to the one-day flow pulse (see Figures 10 and 11) on Silver Creek. The aim was to identify whether young-of-the-year and juveniles of the fish species present in the river were displaced downstream during a pulsed flow. The research team also wanted to check whether individual fish were stranded after the pulse, although stranding was considered unlikely due to the gradual ramping rate of the release.

2.1.4.1. Study Reach

A reach of the river was chosen for the study that began at the access point from the trail to Silver Creek, 500 m downstream of Camino Dam. This reach included the downstream half of the 600 m reach used in the radio tracking study and it contained 15 survey pools. A preliminary snorkel survey performed on 24 August 2004 of all the pools between the dam and the access point indicated that there were very few young-of-the-year or juvenile fish upstream of the access point. No fish < 14 cm TL were observed upstream of this point. The study reach was subdivided into three 100 m sections to allow for comparison of fish densities between sections. Each section contained between three and seven pools (Table 1).

2.1.4.2. Water Quality and Stream Geomorphology

Measurements of surface water temperature and dissolved oxygen concentration were made at the trail access point using a handheld meter (YSI, Model 550A) prior to, during, and after the 15 September 2005 pulsed flow. Triplicate water samples (250 ml each) were collected near the trail access point, prior to, during, and after the pulse flow on 15 September 2004. Samples were analyzed for total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N), soluble phosphorus, and total phosphorus. Water quality analyses were performed by the University of California Division of Agriculture and Natural Resources Analytical Laboratory, on the University of California (UC) Davis campus.

Table 1. Section and pool characteristics for the Silver Creek snorkel survey. Pool Area was calculated by assuming the pool was round, and averaging the pool length and maximum width to calculate the approximate pool diameter. Section Area is the sum of the areas of all the pools in a particular section of the study reach.

	Section Length (m)	VIE Color	Pool #	Maximum Depth (m)	Length (m)	Maximum Width (m)	Pool Area (m^2)	Section Area (m^2)
1	0–100	Red	1	1.37	37.2	12.8	490	1211
			2	1.32	15.8	11.3	144	
			3	1.3	15.2	10.1	126	
			4	1.28	7.9	9.1	57	
			5	3.3	18.0	26.8	394	
2	100–200	Green	6	2	22.9	12.2	241	505
			7	1.35	5.5	7.6	34	
			8	1.15	9.1	7.9	57	
			9	1.1	10.7	6.4	57	
			10	0.71	7.0	4.0	24	
			11	1.1	5.8	3.0	15	
			12	1.73	9.8	10.1	77	
3	200–300	Orange	13	2.08	34.1	13.4	444	906
			14	1.7	25.3	7.6	213	
			15	2.33	22.9	12.8	250	

Pool length and maximum pool width were recorded with a tape measure to allow an approximate calculation of pool area and fish densities. Maximum pool depth was measured using a stadia rod. Measurements were made after the pulse flow release on 16 September 2004, when the flow was about 17 cfs.

2.1.4.3. Trout Capture and Marking

The research team captured trout for Visible Implant Elastomer (VIE, Northwest Marine Technology) marking on 9, 10, 13, and 14 September. Young-of-the-year and juvenile fish were captured using minnow traps baited with roe, dog food, or cat food. Juvenile trout were also captured by angling, as part of the effort to capture adult fish for radio tagging. The fish were held in buckets filled with stream water. Holding and recovery containers were treated with 10 grams (g) rock salt/L to minimize fish stress by decreasing the osmotic gradient across the gills. Temperature and dissolved oxygen were monitored with a handheld meter. If water temperature increased, then more stream water was added. Oxygen levels were maintained at ambient stream concentration using small battery operated air pumps.

Trout were sedated using the same method used in radio-tag implantation. When an individual reached Stage 4 anesthesia (total loss of swimming motion with weak opercular movement), it was removed from the bucket and placed on a measuring board to have its length measured. Next the fish was marked by injecting VIE. These marks were injected at the base of the dorsal, adipose, or caudal fin to maximize their detection during subsequent snorkel surveys (Manning and Thompson 2003). The adipose fin mark proved to be the most effective and was used on all fish. The VIE injection generally took less than one minute. The fish was then placed in a recovery bucket filled with river water, with a battery operated pump and air stone, for approximately 30 minutes. Once the fish had fully recovered from anesthesia it was released back to the river, to the same pool, from which it was captured. Three colors of VIE were used in the 300 m study reach, depending on the section from which the fish was captured. Red was used for Section 1, Green for Section 2, and Orange for Section 3. Juvenile and adult fish captured from the creek upstream of the study reach (during angling for adult fish for radio-tagging) were marked with yellow VIE.

2.1.4.4. Survey Design

The research team recorded trout counts in the 15 study pools, using established snorkel survey procedures (Dolloff et al. 1996). On 14 September, the juveniles were counted by two snorkelers and a land-based support person, who performed a visual snorkel survey of each pool in each section, moving upstream along the banks, with one snorkeler on each side of the creek. The pools were sampled by moving upstream through the study reach. Fish were identified to species where possible, or listed as "unknown." Fish length was estimated by eye in order to classify fish into age/size categories. Young-of-the-year trout were defined as those with a TL of < 10 cm. Juvenile fish were defined as those with a TL of 10–18 cm. Adult fish were defined as those with TL of > 18 cm. On 16 September the pools were again surveyed by snorkeling to determine post-pulse locations and densities of fish.

2.1.5. Laboratory Studies

2.1.5.1. Fish Collection

The laboratory studies utilized hardhead, hatchery-reared rainbow trout, and Sacramento suckers. The fish were collected from two different sites: Slab Creek (Figure 16) and Putah Creek. Sacramento suckers were caught by electrofishing in Putah Creek. Hardhead minnows were collected at the Slab Creek location with a 6.1-m beach seine and minnow traps. The small size, shallow depth, and presence of natural barriers of the sampling site allowed us to herd the fish into the seines. Fish were placed in a bucket, identified, and sorted.

Electrofishing was used to capture Sacramento suckers in Putah Creek on the UC Davis campus because of the difficulty in capturing individuals in the South Fork of the American River. Sampling was conducted with two teams, each consisting of three to four trained staff members. Each team was led by one person equipped with a backpack electrofisher (Smith-Root, Inc., Model 12), who would extend the transducer under the overhanging bank to shock fish. The remaining staff netted fish as they drifted downstream. The teams moved simultaneously along the upstream margins during the capture process and covered three 50-m reaches on each side of the creek. Captured fish were sorted at the conclusion of the collection and Sacramento suckers were retained for laboratory studies. The rainbow trout used in the laboratory studies were obtained from the California Department of Fish and Game's American River Trout Hatchery at Rancho Cordova because of the difficulty of capturing individuals in the American River.

2.1.5.2. Fish Transport and Housing

The hardhead minnow, captured at Slab Creek, were placed into coolers containing four clear bags with river water. A water conditioner (NovAqua) was added to reduce handling and transport stress. The water was aerated while fish were counted and placed into the bags (with a maximum of 40 fish per bag) in the cooler. Once the bags were filled, a pocket of air was left at the top and the opening was securely fastened using zip ties. Ice was placed around the bags and the cooler was moved into the transport vehicle. The hardhead were immediately driven to the Center for Aquatic Biology and Aquaculture (CABA) at UC Davis, two hours away.

Once the juvenile Sacramento suckers from Putah Creek were sorted, fresh water was added to the collection bucket and the fish were hauled uphill to the transport vehicle. The fish were transported in the front seat of the truck (while under the observation of the van passenger) to CABA, a trip that took five minutes.

These Nimbus Hatchery rainbow trout were captured by net and placed in a cooler filled with aerated hatchery water and 30-ml solution of NovAqua. Two plastic bags filled with ice were placed in the cooler to ensure the water temperature was cool during transport. The cooler was secured to the bench seat of the vehicle during the 45-minute period of transport to CABA.

Figure 16. Slab Creek Reach of the south fork of the American River

All fish were housed at CABA in 250-L flow-through circular tanks filled with air-equilibrated well water and were held under conditions of natural photoperiod. A ten-day disease prevention treatment consisting of malachite formalin and nitrofurazone was administered immediately after fish arrived at the facility. Tanks were cleaned and fish were fed Semi-moist feed (Rangen, Inc., Buhl, Idaho) on a daily basis. Water temperature was maintained at 14°C.

2.1.5.3. Longitudinal Flume

Longitudinal displacement of hardhead minnow, Sacramento suckers, and hatchery-reared rainbow trout was studied using a 16.5 x 0.6 m flume located at the J. Amorocho Hydraulics Laboratory on the UC Davis campus. The experiments were carried out between July and September 2004.

a. Apparatus Design

The experimental apparatus was a 4,542-L, self-contained flume that utilized a variable-speed motor to move water through the system. Water was pumped to one end of the apparatus by the motor, allowed to flow through the open-topped, glass experimental chamber, and drained at the opposite end into a pipe connected to the pump (Figure 17).

An additional connection to an underground sump was constructed using PVC pipes so that temperature could be regulated during the experiment via the delivery and removal of a small amount of water to and from the apparatus (Figure 18).

A small, ¾-horsepower pump, connected to the pipes and located in the sump, filled and supplied water to the apparatus before and during experiments. The experimental area, measuring 15.24 x 0.6 m, was blocked off by fish screens on each end. A false Plexiglas bottom was affixed to the bottom of the flume so small river rocks could be fastened without damaging the apparatus. The simulated rock bed (Figures 19 and 20) was designed after observations and measurements taken of the streambed along the original study area (see Figure 5) in the South Fork of the American River.

The study was limited to rocks ranging from 3.2–25.6 cm. Small rocks and sand were not used because they could come loose and endanger the flume's motor; large rocks weighed too much to be transported easily. The substrate in the flume was composed of very course gravel (37% of total substrate), as well as small (45%) and large (18%) cobble, according a bed and bank material characterization chart (Harrelson et al. 1994). The final flume interior (Figure 21) consisted of areas without rock, or with small rocks, large rocks, or a mix of rock types.

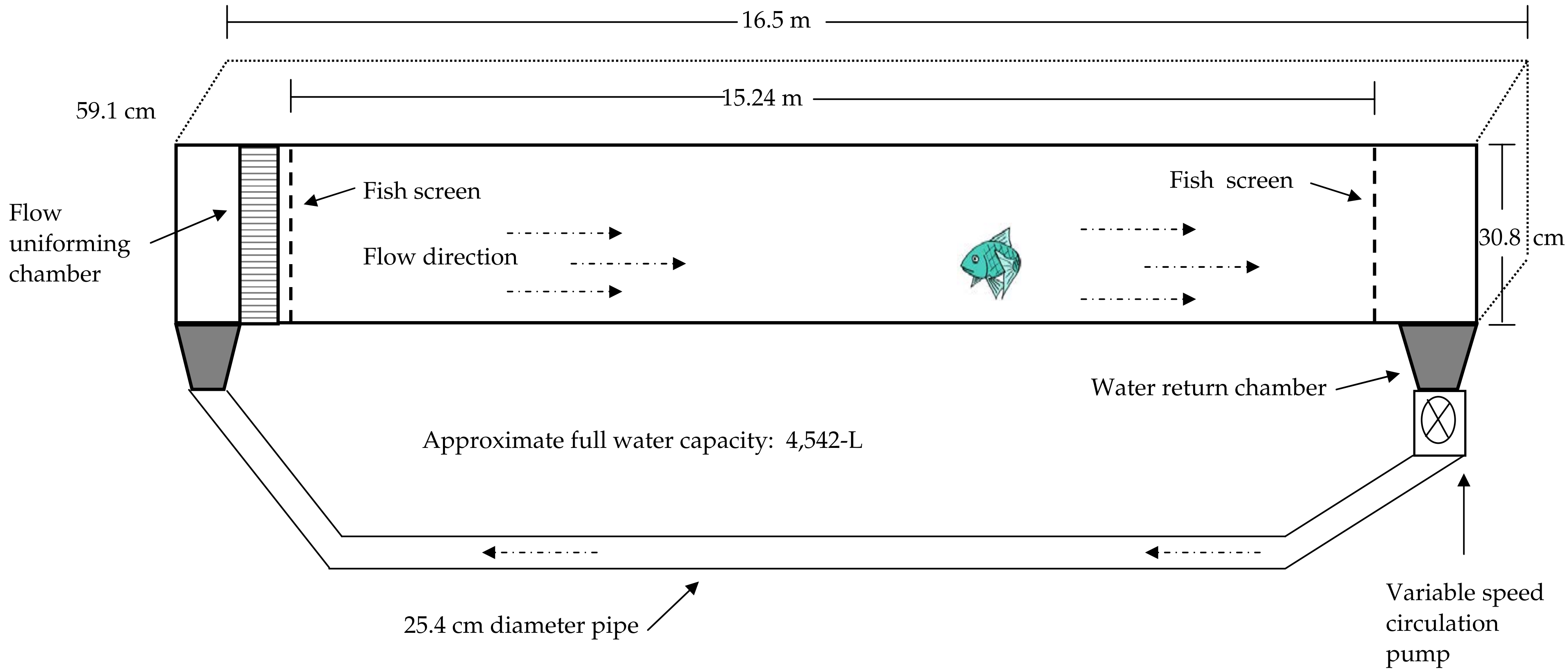


Figure 17. Schematic of longitudinal displacement flume, showing flow direction and flume dimensions. The variable speed circulation pump at the end propels water under the chamber and through-flow straighteners before entering the experimental area located between the fish screens.

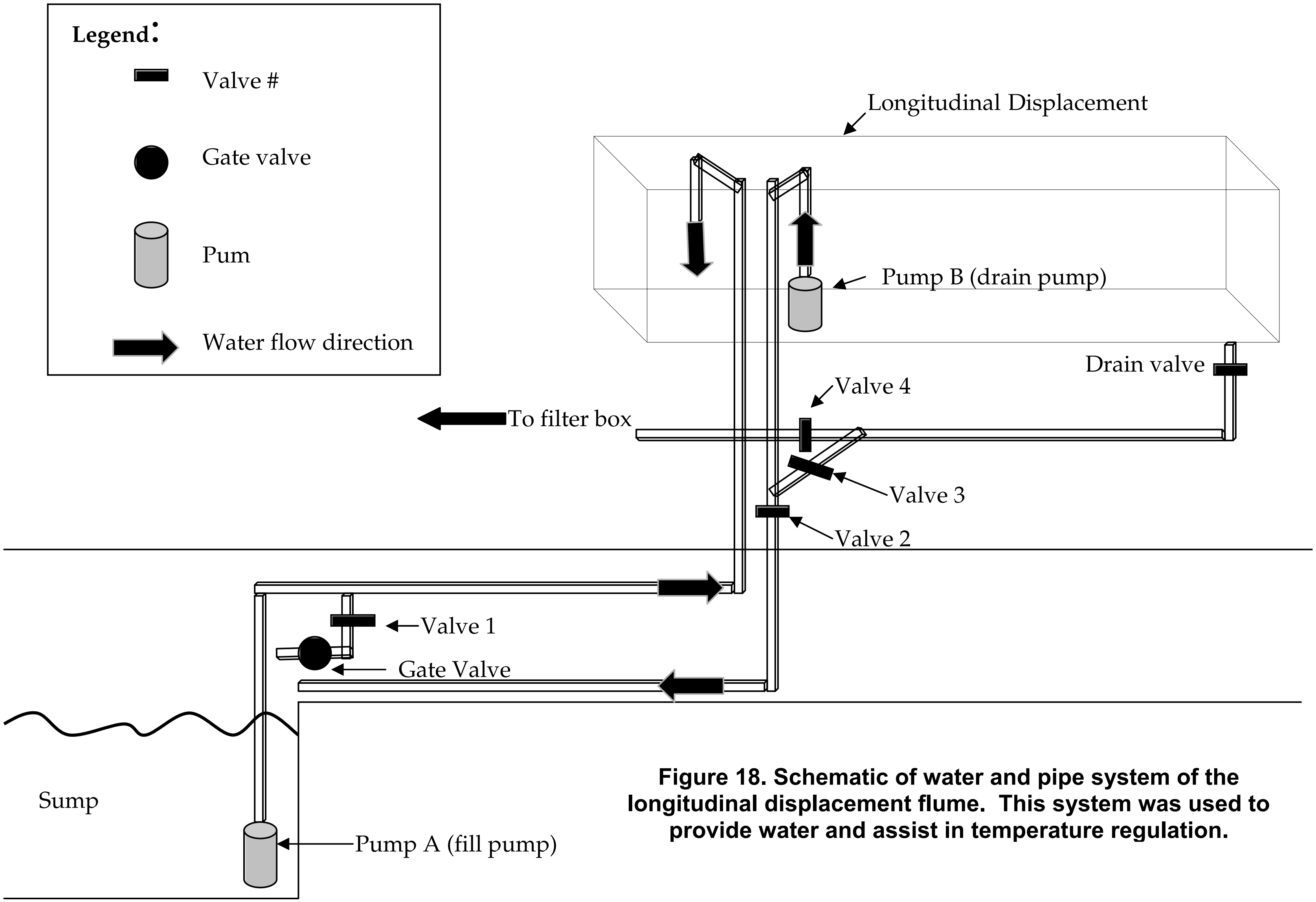


Figure 18. Schematic of water and pipe system of the longitudinal displacement flume. This system was used to provide water and assist in temperature regulation.

Figure 19. The longitudinal displacement flume outfitted with rocks from the South Fork of the American River

Figure 20. Water velocities being measured within longitudinal displacement flume

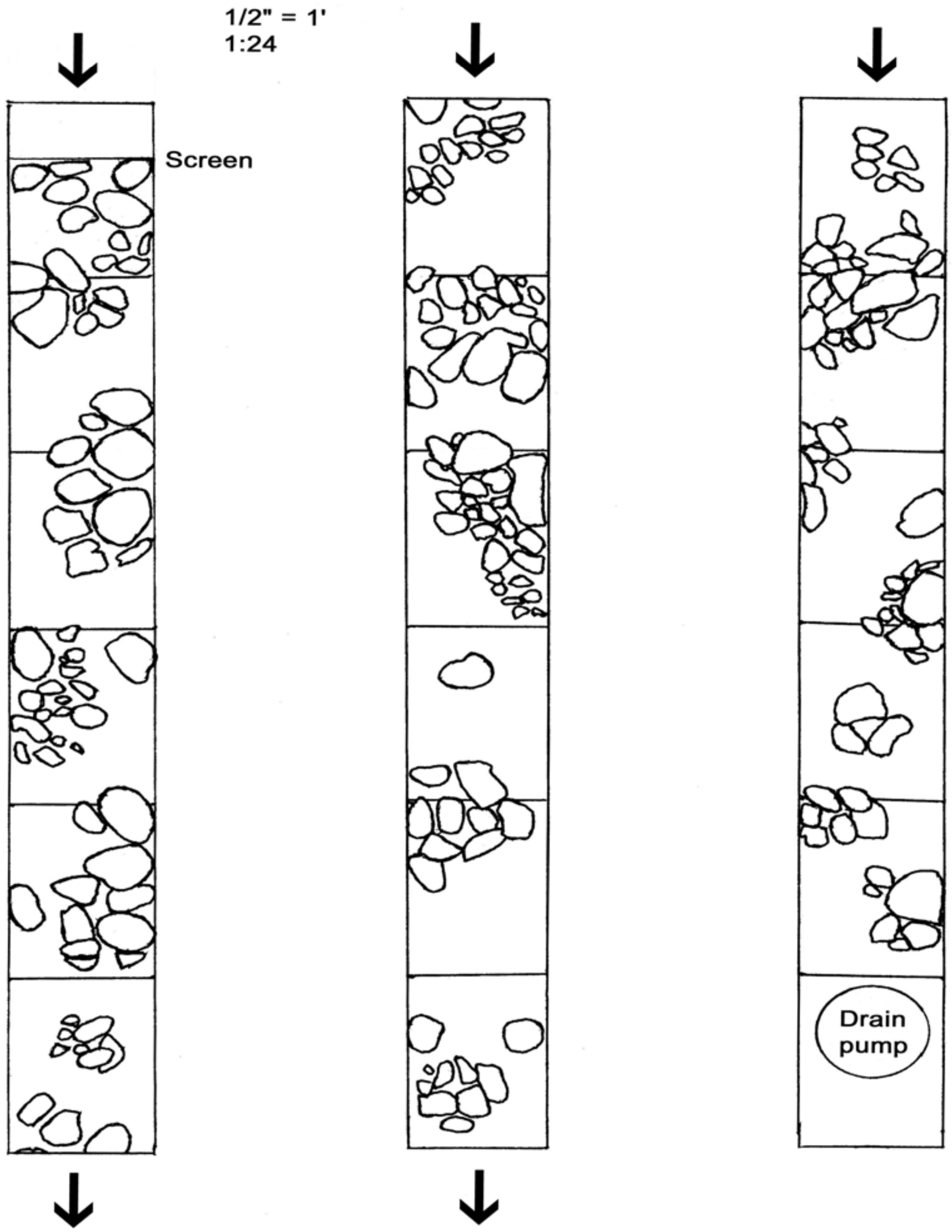


Figure 21. Arrangement of artificial substrate in longitudinal displacement flume. The interior is shown in three sections due to its length. The upstream area is shown in the top left corner while the downstream area is located above the drain pump in the lower right corner. Rock locations are outlined along 0.9 m flume sections.

b. Calibration and Measurement

Water velocities were measured with a flow meter (Marsh-McBirney Inc., Flo-Mate 2000) at different locations in the flume to generate this study's experimental velocity intervals (slow, mean=0.10 meters per second (m/s) (±0.003 standard error (SE)); medium, mean=0.31 m/s (±0.009 SE); and fast, mean=0.46 m/s (±0.018 SE) [Figure 20]. These velocity intervals were used in a pattern consisting of slow, medium, fast, medium, and slow water velocities (Table 2).

Table 2. Description of the experimental conditions in the longitudinal displacement flume. Given are the mean flume water velocities and time spent by hardhead, rainbow trout, and Sacramento suckers in the flume during acclimation and the five periods of velocity intervals.

Velocity Interval	Water Velocity (m/s)	Time Interval (min)
Acclimation	0.0	30
Slow	0.10 (± 0 SE)	20
Medium	0.31 (± 0 SE)	20
Fast	0.46 (± 0 SE)	20
Medium	0.31 (± 0 SE)	20
Slow	0.10 (± 0 SE)	20

This flow regime was set to simulate a hypothetical sequence of velocity conditions (gradually increasing to a maximum and decreasing to the baseline level) associated with daily river pulses in the South Fork of the American River. Fish were subjected to this five-stage velocity sequence in continuous 20-minute intervals.

c. Experimental Design

To begin an experiment, the flume was filled with 14°C (± 1°C) water until the level in the glass portion achieved a height of 17.8 cm. Two "crowders," PVC panels that temporarily forced fish toward the center, were placed in the middle of the apparatus at 6.7 and 8.5 m, respectively. An individual fish (4–7 cm TL) was collected and transported in a bucket filled with water, released between the crowders in the flume, and allowed to acclimate for 30 minutes. Tracking difficulties did not allow us to test more than one fish per experiment. Pretest temperature and release time were noted and recorded.

After the acclimation period, the water velocity was gradually increased from zero velocity to the slow velocity. Observations of the location of the fish, its substrate use, swimming type, and overall behavior were recorded over five-minute periods. The fish's position was recorded relative to the length of the flume, distance from a reference wall, and the elevation above the bottom (Figure 22). After 20 minutes, the water velocity was changed to the next speed (medium), and data were recorded again. This pattern was continued until 100 minutes had passed and the fish had been exposed to the increasing and decreasing sequence of the three flow speeds. The research team recorded a final water temperature and measured the fish (standard, fork, and total length) at the conclusion of the experiment. Eleven to twelve replicate experiments were conducted for each species to maximize statistical rigor. Water velocity and directional measurements at each observed fish location as well as at four to six additional adjacent points (representing other available flow options) were recorded after the completion of the experiments.

Figure 22. A rainbow trout swimming upstream during an experiment in the longitudinal flume

2.1.5.4. Lateral Displacement Flume

a. Apparatus Design

The lateral displacement flume was designed to assess the potential for lateral stranding in response to a pulsed water release into the South Fork of the American River from Chili Bar Dam. Experiments were conducted from September through November within an artificial stream channel, located at CABA at UC Davis.

Plywood, coated with a primer base and marine topside polyurethane topcoat, was utilized in constructing the base, walls, and raised-bank habitat of the flume (Figure 23). The testing chamber consisted of a 200-cm long x 118.1-cm wide x 59.1-cm high testing area separated into a 15.9-cm wide main channel (gutter) that never drained during an experiment and a 12.1-cm raised 102.2-cm wide bank that flooded and dewatered with water level changes. Water circulated through the apparatus in a series of channels and holding areas, starting from the head tank and moving through the main channel of the testing area to the tail tank before being recycled under the substrate through a tunnel. Head and tail tanks were separated from the main channel by plastic mesh screens to ensure that the fish remained only within the test area. Partial walls, separating the

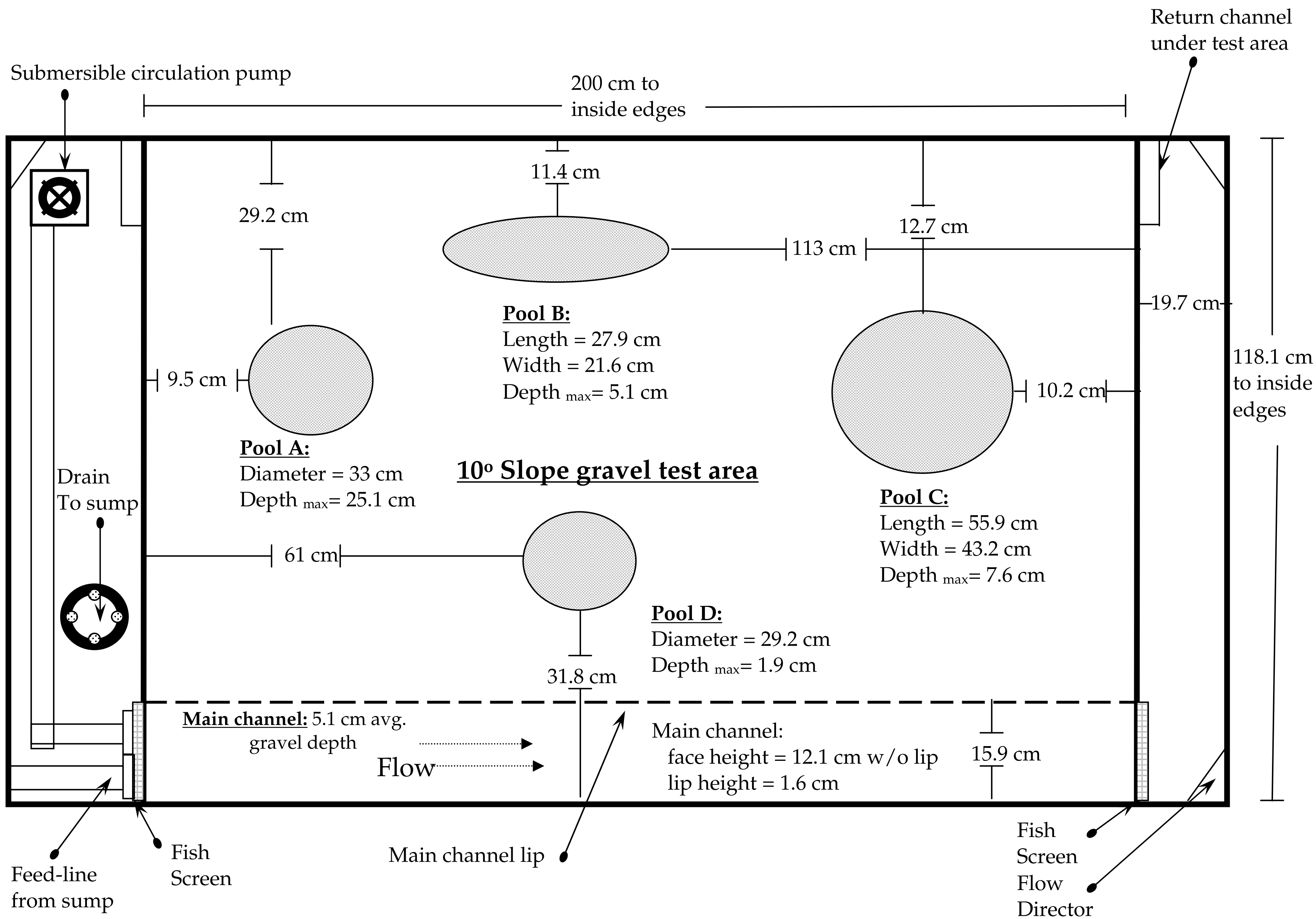


Figure 23. Schematic of lateral displacement flume. Top view.

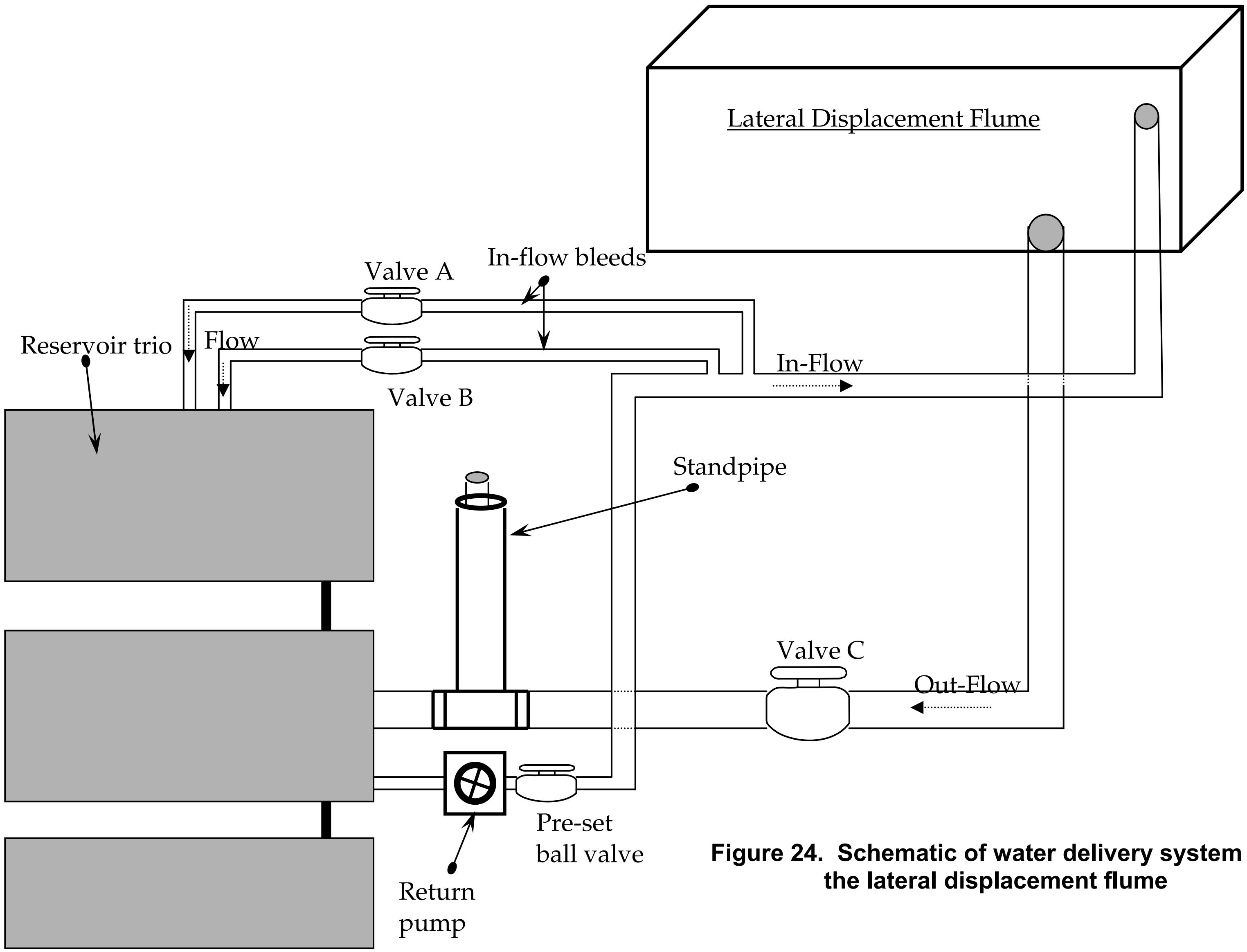


Figure 24. Schematic of water delivery system for the lateral displacement flume

testing area from the head and tail tanks, created an eddy in the raised substrate. This setup mimics the flow dynamics observed at the South Fork of the American River, which has a main channel with continuous directional flow and bank habitats with irregular flows and eddies.

A 0.75-horsepower (hp) pump filled and drained the apparatus, changing the water level by 30 cm during one experiment. Water level was controlled by utilizing a 12.7-cm diameter standpipe along with a series of bleed valves (Figure 24). Three connected sumps were used to keep an adequate amount of water available for experiments. Reservoir temperatures were maintained using three flow-through chillers. The water in the flume was constantly aerated and replaced weekly. Water circulation was maintained using a pump in the head tank to maintain a base flow. The water velocity and depth was then increased or decreased via bleed valves in specific sequences. The main channel floor was covered with a 5-cm layer of pebbles (2.2–4.5 cm size range) and the side margin was arranged with a 10-degree slope to simulate the bank habitat on the South Fork of the American River (Figure 25). The substrate was composed of rock from American River donated by Dennis Redfern of the American River Trout Hatchery, combined with a 50-50 mix of gravel and pebbles obtained from a local hardware store. The substrate was divided into pool habitats, rock piles with cover, and open areas. The bottom in the apparatus increased in elevation from 1.0–17.7 cm with a slope of 10 degrees from the edge of the main channel to the wall of the flume.

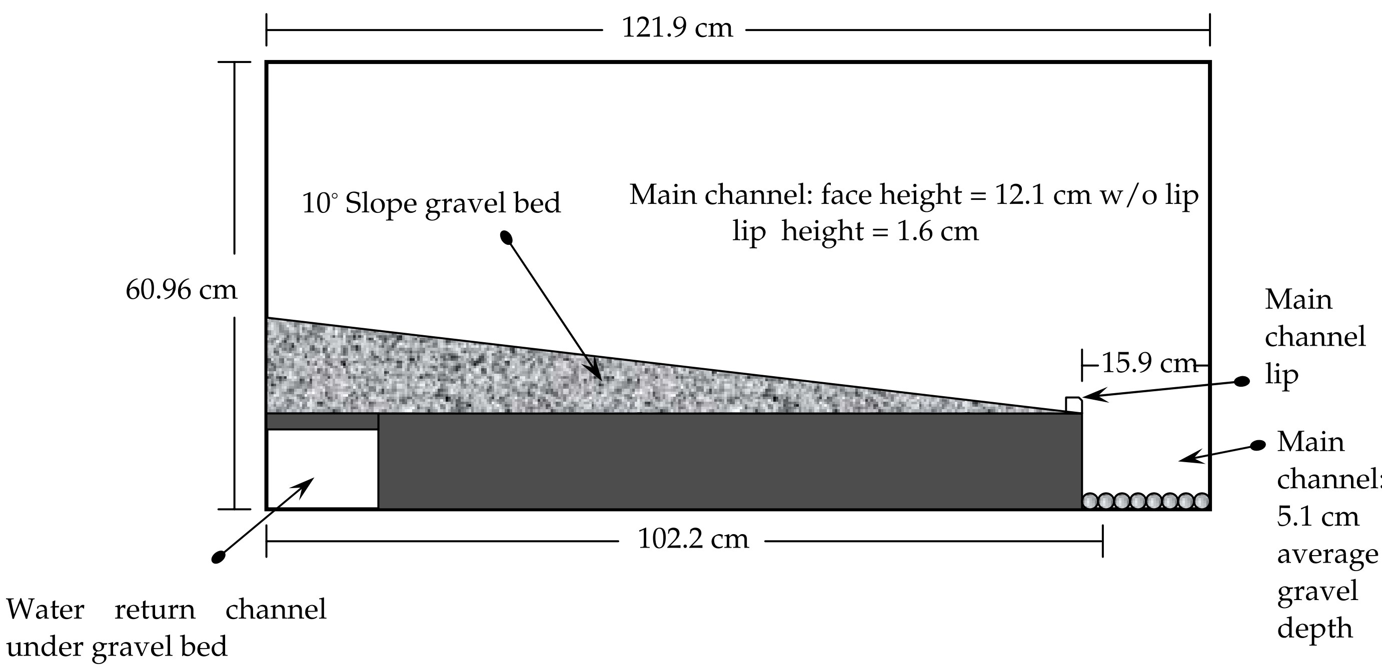


Figure 25. Schematic of the lateral displacement flume (lateral view)

The 10-degree slope represents one of the lower gradient slopes measured during preliminary site surveys along the South Fork of the American River. The research team started with a minimum slope based on the observation that juvenile coho salmon stranded less frequently on steeper slopes (Bradford et al. 1995). Based on this information, the team chose to test the lowest mean site slope because it potentially had the highest potential for stranding. The flume was designed with the option to increase the slope of the bank by adding more substrate (e.g., for future experiments).

Four distinct pools (A, B, C, and D) with different draining and water holding capacities were created in the sloping substrate habitat.

1. Pool A had a slow dewatering rate and retained much of its water during flume dewatering. Cobble of 7–13 cm diameter was placed within the pool to simulate cover.
2. Pool B had larger cobble (9–25 cm diameter) bordering and over hanging the pool for cover with the substrate dugout underneath. This design allowed water level in the pool to drop as the flume's water level decreased.
3. Pool C had a wire mesh buried in the gravel substrate with larger cobble (8–16.5 cm diameter) placed for cover. The water in this pool emptied, as did the water in pool B.
4. Pool D had a slow dewatering rate similar to pool A. This pool never entirely lost its water during the experiments, with a narrow passage to the main channel kept open for fish to use.

b. Experimental Design

Acclimation began when a randomly selected fish was removed from the nearby holding tank and placed into the main channel of the lateral displacement flume. For each experiment, fish were subjected to one of two different acclimation periods: long or short. A minimum of six fish per each species was used for each acclimation type, making at least twelve fish of each species tested within the lateral displacement flume. Fish acclimating for the long period were placed into the flume at the end of the day and experiments begun at the beginning of the following day. This enabled the fish to acclimate overnight for a period of 16–17 hours. The shorter, 2-hour acclimation period could be completed during the same day. The fish were kept under a natural light cycle during the acclimation and testing periods. Water depths during acclimation were 19–21 cm, measured from the base of the main channel. The initial (or pre-pulse) water level allowed fish to become accustomed with the main channel without access to the rest of the substrate and pools.

To begin an experiment, the water level was raised to a depth of 50–54 cm over a 20 minute period (Figure 26), using water from the reservoirs, and then kept at that depth for 90 minutes until the level was decreased to the pre-pulse depth (Table 3). During the 90-minute, deep-water pulse the fish had access to the entire bank and pool area (Figure 27). Dewatering lasted for 30 minutes, by which time the water had returned to the acclimation level. In this way, the experiment simulated the daily rising and falling water level (but not the velocity gradients) experienced by fish in the South Fork of the American River during a pulsed release of water. Observations were made from behind a semi-opaque screen in order not to disturb the fish (Figure 28).

Table 3. Description of the experimental conditions in the lateral displacement flume. Shown are water heights, measured from the bottom of the main channel, and time spent during acclimation, rising water, constant high level, and receding water level.

Experiment	Time Interval (min., unless noted)	Water Height (cm)
Acclimation – Short	2 hrs	20 ± 1
Acclimation – Long	16–17 hrs	20 ± 1
Increasing	20	20 ± 1 to 52 ± 2
Flooded – High water	90	52 ± 2
Decreasing	30	52 ± 2 to 20 ± 1

Figure 26. The lateral displacement flume during an experiment. Note the main channel in front of the simulated bank habitat.

Figure 27. A rainbow trout swimming between bank habitat and main channel

Figure 28. View from above the bank, pools and substrate during high water. Fish behavior and stranding were observed from opaque screens.

c. Statistical Design

Laboratory longitudinal flume data were entered and analyzed using Microsoft Excel, SPSS Sigma Stat, and Sigma Plot software. Non-parametric statistics were used because the data failed Kolmogorov-Smirnov normality tests, violating t-test and one-way analysis of variance (ANOVA) assumptions. Instead, Mann-Whitney rank sum tests were used to determine statistical significance (Neter et al. 1996).

3.0 Project Outcomes

3.1. Field Studies

3.1.1. Radio Tracking Results

3.1.1.1. a. South Fork of American River

The research team tracked three rainbow trout subjected to one (rarely two) pulse flows per day in the South Fork of the American River during August 2004. The trout ranged from 29.0–29.6 cm standard length (SL). The tagged fish were caught and released between river kilometer (rk) 12 and 26 in the reach below Chili Bar Dam. The team attempted to locate fish that were radio-tagged during seven days over a period from 3–12 August 2004.

Rainbow Trout (RT) 1 was first detected 925 meters upstream of its release site on 5 August 2004, seven days after being radio-tagged (Table 4). After being located, RT 1 stayed in the same area for the remainder of the period of tracking (Figure 29). The strongest signal was in the direction of a small sand bar near a backwater eddy on 9 August 2004. Based upon this observation and confirmation made two days later, the research team determined that the radio-tag was at the base of an overhanging stump on the same sand bar. Because the estimated tag position and its associated error (indicated by a circle with a diameter of 55 m) did not overlap the river (Figure 30), the team concluded that the fish's radio-tag was on land and not in the river. Bill Center, owner of Camp Lotus, told us that river otters have been observed in this area. One explanation for the fate of the RT 1 is that an otter consumed the trout (and beacon), depositing the tag where it later defecated on land. Another possible explanation is that the RT 1 swam upstream and died at that location. However, failure to detect RT 1 in the river when tracking on 3 August 2004 would support the first explanation.

Table 4. Summary of RT1's movements on the South Fork American River

ID	Frequency (MHz)	SL (cm)	Dates	Distance (m)	Days Between	Mean Distance (m/day)
1	151.400	29.3	29 Jul	-	-	-
			5 Aug	925	7	132.1
			6 Aug	111	1	111.0
			9 Aug	0	3	0
			11 Aug	0	2	0
			12 Aug	45	1	45.0

Rainbow Trout 2 was caught and released downstream of RT 1 on 29 July 2004. This trout (RT2) was 29.6 cm SL. It was never relocated by the research team after its release into the river despite the following extra efforts to locate it above and below the tracking reach. The research team searched for the trout on the upper section of the study reach from Marshall Gold (rk 9.7) to Camp Lotus (rk 14.5) on 5 August. The researchers also walked downstream 500 m from Gorilla Rock along the riverbank, searching for RT 2 without detecting its signal on 11 August 2004. It is likely that the RT 2 moved downstream of Gorilla Rock, the downstream terminus of the study reach, 896 m from the capture site. Alternatively, a predator such as an otter or human may have caught the fish.

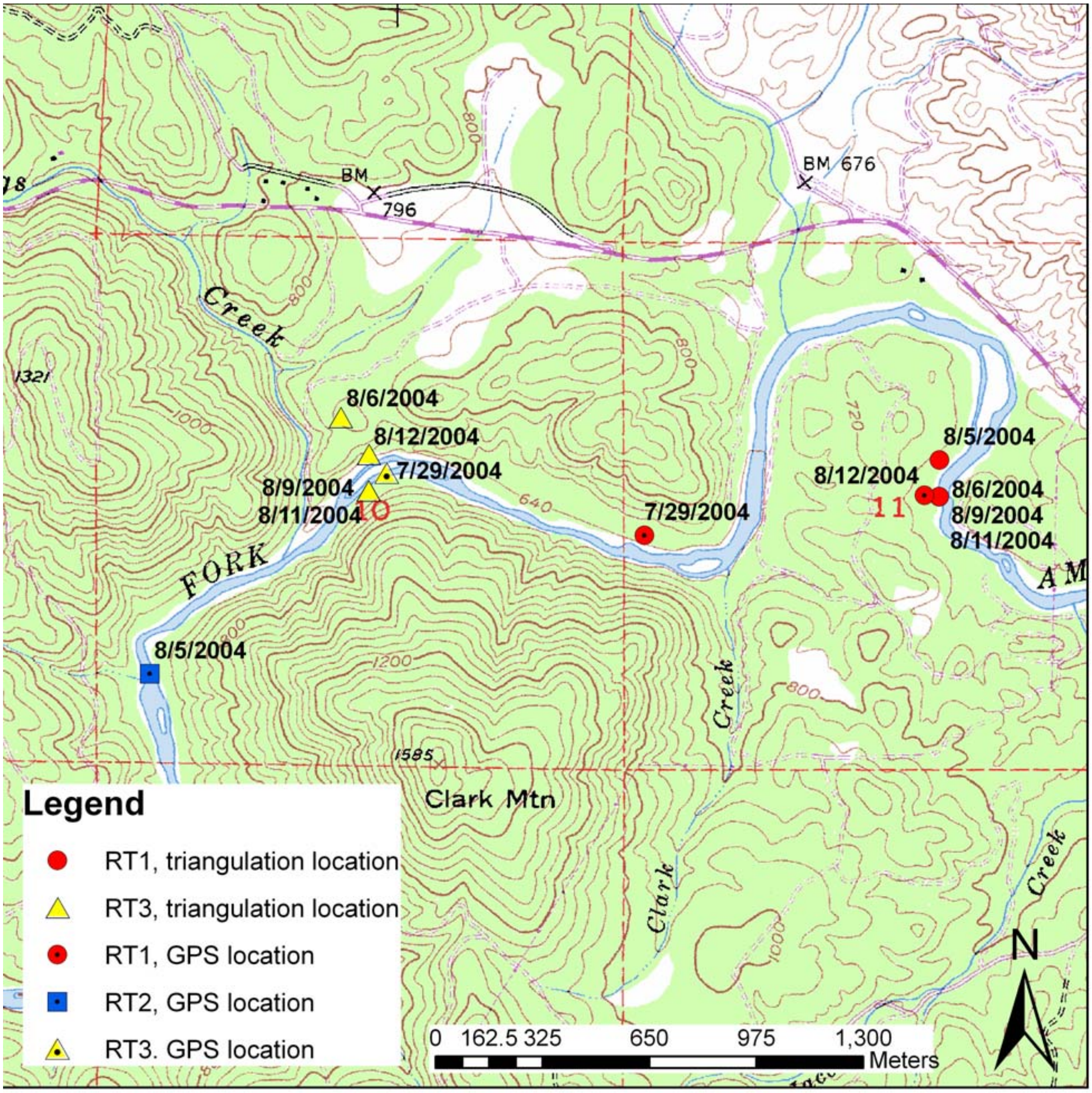


Figure 29. Map with fish latitude and longitude locations on the South Fork American River. Colored points with black dots in the center denote positions determined using a handheld GPS unit. The GPS was used for release sites. Colored points without the black dots indicate locations determined using radio-telemetry. A dot's radius is about 20 m.

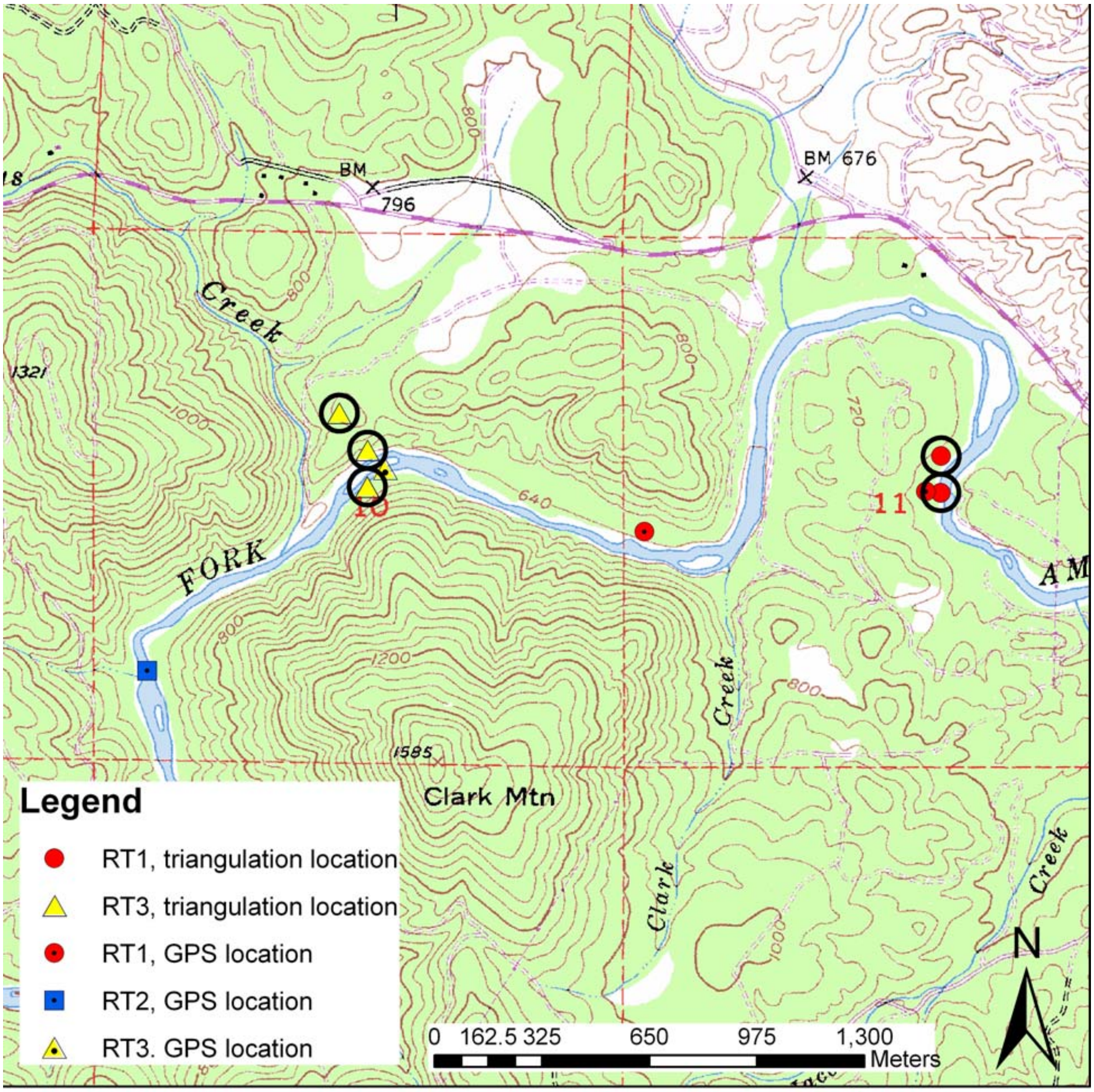


Figure 30. Same map with trout positions, however, circles indicate spatial error around the points determined by radio telemetry. Error calculations estimate the maximum radio telemetry error is 55 m. However, one of RT 3's points is on land more than 55 m from riverbed.

Rainbow Trout 3 (RT3) was caught and radio-tagged on 5 August 2004. The field crew was able to relocate RT 3 in the same general location on four occasions over the next eight days. The position determined on 6 August 2004 is erroneous because RT 3 was on land and 216 m distant from the capture site, while it was found within the river on the following days near the capture site. The maximum distance moved by RT 3 during the study was 111 m (Table 5).

Table 5. Movement summary for RT3 on the South Fork American River

ID	Frequency (MHz)	SL (cm)	Dates	Distance (m)	Days Between	Mean Distance (m/day)
3	151.320	29.0	5 Aug	-	-	-
			9 Aug*	74	4	18.5
			11 Aug	0	2	0.0
			12 Aug	111	1	111.0

*Distance from 5–6 August 2004 was not included, because the location on August 6 is inaccurate.

In summary, RT 1 and RT 2 were removed from the river or traveled downstream out of detection range, whereas RT 3 stayed within 100 m of the release site. Potential graphical analysis for year two is shown for RT 3 in Figure 31, which relates river discharge to fish location.

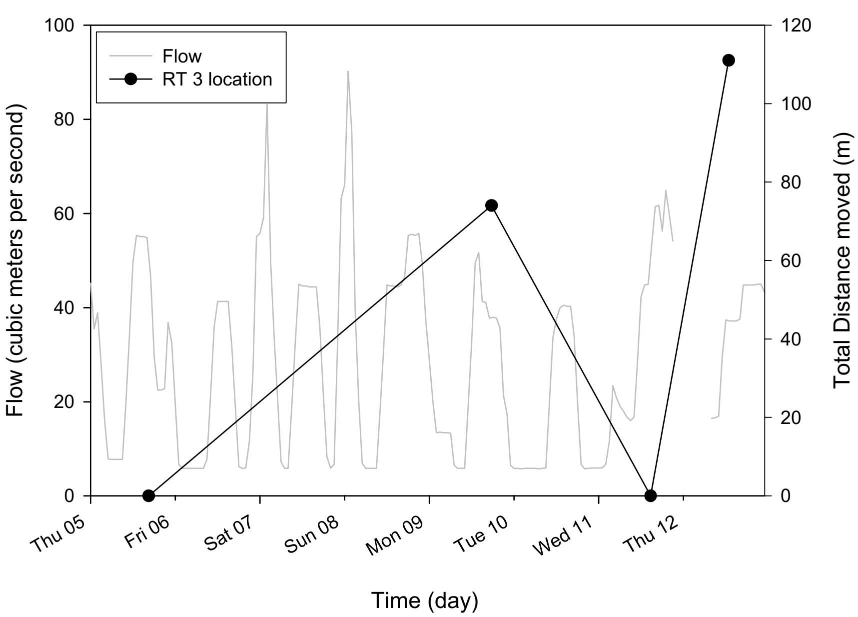


Figure 31. Example of potential data analysis for next year in order to correlate discharge and fish movement. This graph overlays the total distance RT 3 moved between tracking events onto a graph showing time lagged discharge from Chili Bar Dam. The delay was four hours to account for traveling 14 miles downstream of the dam. The total distance RT 3 moved does not have directionality associated with it (i.e., upstream, downstream or cross-channel).

3.1.1.2. Silver Creek

Seven trout (one rainbow trout and six brown trout) were radio-tagged and tracked before, during, after the pulsed flow in Silver Creek. The standard lengths and masses of the fish radio tagged are summarized in Table 6.

Table 6. Fish identity, species, standard length, weight, and date of release for one rainbow and six brown trout tracked at Silver Creek

Fish ID	Species	SL (cm)	Mass (g)	Date Tagged
1	Rainbow trout	24.0	172	10 Sep
2	Brown trout	21.2	138	10 Sep
3	Brown trout	27.3	270	10 Sep
4	Brown trout	20.5	118	10 Sep
5	Brown trout	28.2	360	10 Sep
6	Brown trout	24.5	232	13 Sep
7	Brown trout	22.8	183	13 Sep

The research team searched for the tagged fish within the stream's pools using the antenna and radio receiver. Once the fish was found, the team recorded the distances, at which the seven trout were located along the 600 m long experimental reach, using the flags placed every 50 m along the bank of the creek. In Figure 32, locations of the one rainbow (Trout T1) and six brown trout (T 2-6) are shown on the study reach during release, pre-pulse, pulse, and post-pulse. The minimum distance moved between tracking events was 0 m; maximum distance was 120 m. T 4 was not detected after being tagged and released. Little movement was detected either up or down stream between the pre-pulse and pulse (i.e., in response to the pulsed discharge of water) compared with the movements between the release after tagging and the pre-pulse and between the pulse and post-pulse for the one rainbow trout (T 1) and two brown trout (T2 and T3). Two brown trout (T5 and T6) appeared to move downstream during the pulse; and one brown trout (T7) appeared to move upstream. However, these apparent movements may, in reality be due to the error associated with different method of detection during the pulsed flow (see error bars, Figure 33). The estimated movement (with errors) for the six tagged fish detected after release were: T1 0±50 m; T2 10±50 m; T3 +25±50 m; T5 -85±50 m; T6 -50±50 m; T7 +35±50 m.

Table 7 gives the distances moved upstream (denoted by ”+”) and downstream (indicated by “-“) by the six trout.

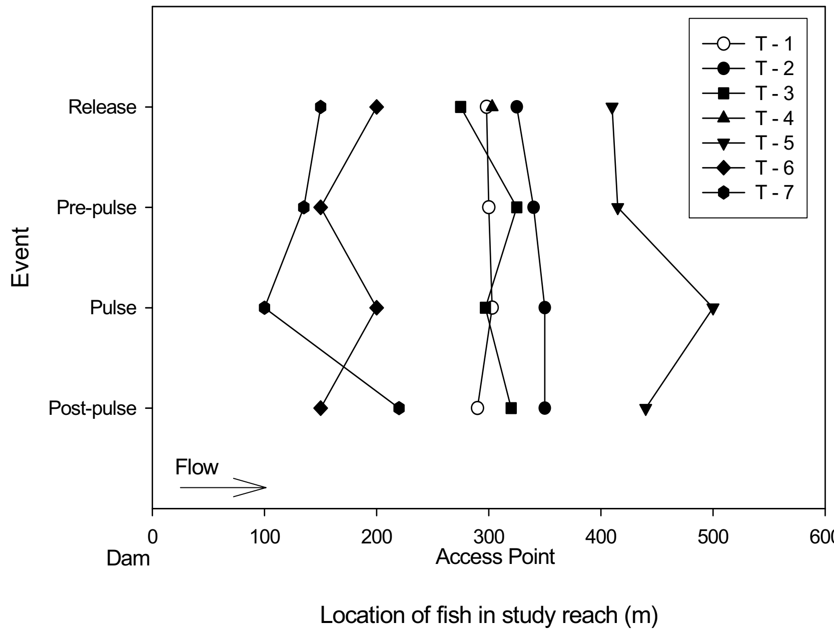


Figure 32. The locations of fish in the study reach during the four conditions during the radio telemetry study at Silver Creek

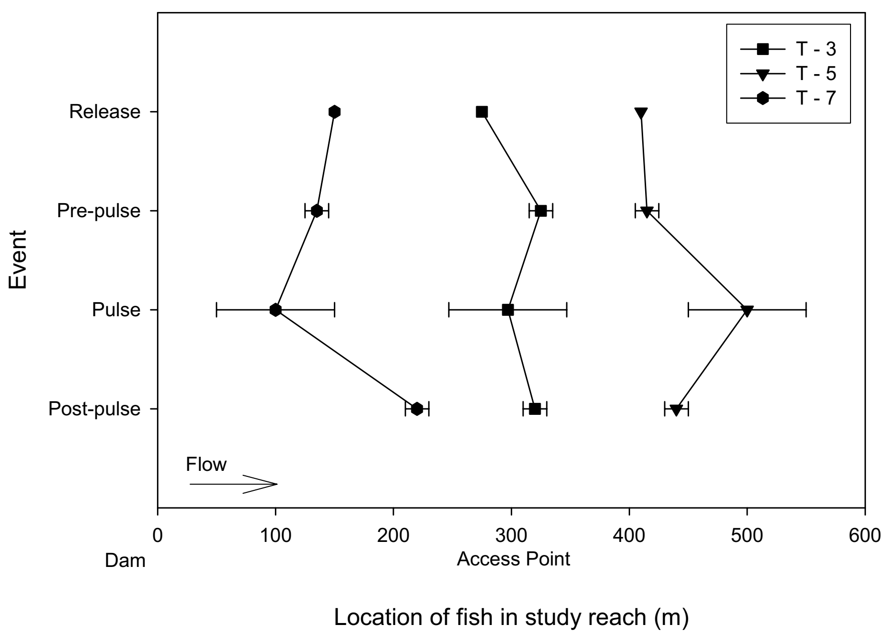


Figure 33. The errors for positions determined during the tracking studies. These were estimated for each tracking event: pre-pulse error = ± 10 m, pulse error = ± 50 m, and post-pulse error = ± 10 m.

Table 7. A summary of the movements of trout between successive position determinations before, during, and after the pulsed flow at Silver Creek

Fish ID	Distance (m)		
	Release to Pre-pulse	Pre-pulse to Pulse	Pulse to Post-pulse
1	0	0	+10
2	- 15	- 10	0
3	- 50	+ 25	- 20
4	*	*	*
5	- 5	- 85	+ 60
6	+ 50	- 50	+ 50
7	+ 15	+ 35	- 120

Note: The ”–“ sign indicates movement downstream and the “+” sign indicates upstream movement, and zero indicates no movement.

* Indicates that fish was not detected during experiment.

The mean distances moved for the period between the release of the trout after tagging and the day before the pulse was 23 m ± 9 m SE, with a range from 0 m to 50 m. The mean distance moved the day before the pulse to the day of the pulse was 34 m ± 13 m SE, with distances ranging from 0 m to 85 m. The mean distance between the day of the pulse and the position of the trout a week after the pulse was 43 m ± 18 m SE with a range from 0 m to 120 m. Table 8 shows the proportions of trout moving upstream, downstream, or remaining in one location. Fish were equally likely to move upstream or downstream, independent of the stream flows, pulsed or not pulsed.

Table 8. Proportions of fish moving upstream, downstream, or remaining stationary between tracking events at Silver Creek

Event	Upstream (%)	Downstream (%)	No Movement (%)
Release to Pre-pulse	33	50	17
Pre-pulse to Pulse	33	50	17
Pulse to Post-pulse	50	33	17

There are a few details concerning the data that must be addressed before making any conclusions. Firstly, the research team pooled radio tracking data from five brown and one rainbow trout. Rank sum tests suggest that the medians for rainbow trout and brown trout daily movements were not significantly different (Mann-Whitney Test, $p = 0.333–0.667$). The data were then combined to increase the sample size for statistical comparisons.

Second, fish were tagged on different days, and hence had shorter or longer periods to recover from their surgery before the increase in flow in the creek (see Table 7). Trout tagged and released on 10 September (T1–T5) had three additional days to recover compared to the two brown trout (T6 and T7) tagged on the 13 September and released on 14 September before the pulsed flow from Camino Dam on 15 September 2004. These two late-tagged brown trout fish had been released only six hours before their positions were determined. Arguing against a n affect from differing release dates is that the release to pre-pulse and pre-pulse to pulse are normalized for the differing periods of time (Tables 9 and 10), which were not significantly different between release dates (Mann-Whitney Rank Sum, $p = 0.133$ and 0.533).

Table 9. Mean distances moved for trout between the day of their release and the day before the pulsed flow at Silver Creek

Fish ID	Days Between Tracking	Mean Distance per Day (m/day)
1	4	3.8
2	4	0
3	4	12.5
5	4	1.3
6	< 1	50.0
7	< 1	15.0

Table 10. Mean distances moved per day for fish between the day before and the day of the pulsed flow release at Silver Creek

Fish ID	Days Between Tracking	Mean Distance per Day (m/day)
1	1	0
2	1	10
3	1	25
5	1	85
6	1	50
7	1	35

Table 11. Mean distances moved per day for fish between the pulse and a week after pulsed flow at Silver Creek

Fish ID	Days Between Tracking	Mean Distance per Day (m/day)
1	7	1.4
2	7	0
3	7	2.9
5	7	8.6
6	7	7.1
7	7	17.1

Third, a different method of position determination was used during the pulsed flow versus before and after the pulse intervals (see Project Approach). The resulting location estimates have an error of approximately ± 50 m during the pulse flow period versus ± 10 m prior to and following the pulse release. The estimated error was determined by examining how many pools were in a 50 m and 100 m reach of the river. The research team was able to distinguish which pools the fish were located in, and in some cases verifying their identity based on observing the radio antenna leading from the fish when sampling pre-pulse and post-pulse. There were roughly 15 pools for the 300 m reach, and each pool was approximately 20 m, thus the error was ± 10 m. Much of the difference between the positions of the fish during the pulsed and other conditions can be explained by the ± 50 m error estimate for the pulse flow period (see Figure 32).

The distances between the three conditions can be normalized by dividing each distance, by the number of days between subsequent position determinations (Tables 9–11). When the distances are normalized per day, there are no significant differences apparent between the distances moved between: 1) release after tagging and the pre-pulse (Wilcoxon Test, $p = 0.125$), 2) the pre-pulse and pulse ($p = 0.063$), and 3) pulse to post-pulse ($p = 0.563$). The research team concluded that there were no differences between the movement of the trout, standardized for daily movement, during the pulsed flow and before and after the flow. The one day pulsed flow on Silver Creek did not appear to alter the daily movement patterns of the tagged trout.

3.1.2. Snorkel Survey and VIE Marking Results

3.1.2.1. Habitat Measurements

The discharge from Camino Dam into Silver Creek varied from 0.26 to 2.12 m^3s from 1 October 2003 to 30 September 2004, with the exception of the pulse flow release (see Figures 8 and 9). The rate of discharge on this day rose from 0.5 m^3s at 0600 hrs to 18.5 m^3s at 0945 hrs, stayed constant until 1445 hrs, and then dropped to 1.8 m^3s by 1730 hrs and 0.5 m^3s by 2015 hrs (see Figure 10). There was a 33 cm change in the level of water, measured at a river height gauge located halfway along the length of the 600-m long experimental reach (see Figure 11).

The pools in the study reach were at bedrock, but often contained some gravel, finer sediment, and fallen leaves. The habitat was relatively complex, with numerous boulders at the upper and lower boundaries of pools. Maximum depth of the pools ranged from 0.7 to 3.3 m (Table 1). Pool length ranged from 5.5 to 37.2 m, and maximum pool width ranged from 3.0 to 26.8 m. Approximate pool area ranged from 15 to 490 m^2. The total area of pools in Sections 1, 2, and 3 was 1212 m^2, 505 m^2, and 906 m^2, respectively. Section 1 contained five average sized pools, while Section 2 contained seven smaller pools, and Section 3 contained three large pools.

Water temperatures before and after the pulsed flow were 10.7°C (Table 12). Values observed on the day of the pulse ranged between 10.2°C and 10.9°C. Dissolved oxygen was approximately 11 mg/L during the pulse and 9.64 mg/L on the following day. Nutrient concentrations were generally low in samples taken near the Silver Creek, flow gage site both before and after the pulse flow release (Table 13). Total Kjeldahl nitrogen (TKN) was below the detection limit (< 0.1 mg/L) in about half of the samples taken. Ammonia-nitrogen (NH_4-N) and nitrate-nitrogen (NO_3-N) were below the detection limit (< 0.05 mg/L) in all samples. Soluble phosphorus (soluble P) was below the detection limit (< 0.05 mg/L) in all samples. Total phosphorus (total P) was below the detection limit (< 0.1 mg/L) in all samples.

Table 12. Water temperature and dissolved oxygen concentration in relation to water flow in Silver Creek. Values were measured at the stillwell downstream of Camino Dam using a YSI 550A handheld meter, in Pool 1. Flow values, measured in cubic meters per second at the outflow of Camino Dam, were provided by Mr. Randy Jensen, SMUD. Flow values for 14, 16, and 21 September are daily averages. Flow values for 15 September are the 15-minute averages for the time period closest to when temperature and dissolved oxygen were measured. Dissolved oxygen was not measured until 15 September at 1600 due to slow calibration of the meter.

Date	Time	Flow ($m\ s^{-1}$)	Water Temperature (°C)	Dissolved Oxygen (mg/L)
14-Sep-04	1804	0.5	10.7	N/A
15-Sep-04	1045	18.5	10.2	N/A
15-Sep-04	1339	18.5	10.6	N/A
15-Sep-04	1600	10.9	10.9	11.54
15-Sep-04	1655	6.4	10.9	11.09
16-Sep-04	1145	0.5	10.7	9.64
21-Sep-04	1255	1.6	10.7	10.67

3.1.2.2. Survey of Trout Distribution

Two species of fish were observed during the snorkel surveys: rainbow trout, and non-native brown trout. Young-of-the-year, juveniles, and adults were observed for both species. A total of 19 fish were captured for VIE marking (Table 14). Of these, 11 fish were caught in the main snorkel study area, relative to a total of 140 fish observed in the snorkel survey prior to the pulse flow release. Only two fish were captured in minnow traps. The low trap capture rate is likely due to the short time available for setting traps (one afternoon), due to the efforts spent on capturing and radio tagging. The remaining VIE marked fish were captured by angling as part of the radio telemetry study. Six adult brown trout were VIE marked; of these, four were caught and released upstream of the main snorkel survey area, one was released in Section 1, and one in Section 2. Four juvenile rainbow trout were caught and released upstream of the main snorkel survey area. Three juvenile and four adult rainbow trout were VIE marked in Section 1. One juvenile rainbow trout was marked in Section 2, and one young-of-the-year rainbow trout was marked in Section 3. VIE marks were not observed on any fish of either species during the pre- and post-pulse snorkel surveys. The relatively small proportion of marked fish combined with typical observation distances of several meters probably reduced the chances of mark detection during the snorkel counts.

Table 13. Water quality before, during, and after the pulse flow release in Silver Creek near the stillwell, at Pool 1. Values are shown for total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N), soluble phosphorus, and total phosphorus. All nutrients were measured in units of mg/L.

Date	Time	Replicate #	TKN	NH_4-N	NO_3-N	P (Soluble)	P (Total)
14-Sep-04	1000	1	0.1	< 0.05	< 0.05	< 0.05	< 0.1
		2	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1
		3	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1
15-Sep-04	1020	1	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1
		2	0.1	< 0.05	< 0.05	< 0.05	< 0.1
		3	0.1	< 0.05	< 0.05	< 0.05	< 0.1
15-Sep-04	1330	1	0.2	< 0.05	< 0.05	< 0.05	< 0.1
		2	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1
		3	0.1	< 0.05	< 0.05	< 0.05	< 0.1
15-Sep-04	1655	1	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1
		2	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1
		3	0.1	< 0.05	< 0.05	< 0.05	< 0.1
16-Sep-04	1020	1	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1
		2	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1
		3	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1
16-Sep-04	1650	1	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1
		2	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1
		3	< 0.1	< 0.05	< 0.05	< 0.05	< 0.1
21-Sep-04	1255	1	0.2	< 0.05	< 0.05	< 0.05	< 0.1
		2	0.2	< 0.05	< 0.05	< 0.05	< 0.1
		3	0.1	< 0.05	< 0.05	< 0.05	< 0.1

Table 14. Number of fish in Silver Creek that were captured and given a VIE mark, grouped by species, age class, and location of capture. Fish were released to the location from which they were captured. All fish were marked on both the adipose and caudal fins, with the exception of 2 fish that were given only adipose fin marks.

Section	Section Length (m)	VIE Color	Brown Trout			Rainbow Trout		
			YOY	Juvenile	Adult	YOY	Juvenile	Adult
Between Dam and Section 1	300	Yellow			4		4	
1	0–100	Red			1		3	4
2	100–200	Green			1		1	
3	200–300	Orange				1		

YOY = young-of-the-year

Total trout density in each pool did not appear to differ markedly before and after the pulse (Figure 34). Some pools contained fewer fish after the pulse, but some contained more, and there did not appear to be a pattern along the length of the study reach. Numbers of young-of-the-year per pool tended to be lower after the pulse (Figure 35), although some pools contained more trout after the pulse. Numbers of juveniles were generally comparable pre- and post-pulse (Figure 36). Likewise, adult trout numbers did not appear to differ substantially between snorkel surveys (Figure 37). The total number of brown trout per pool ranged from 0–18 fish pre-pulse, and 0–7 post-pulse, with the highest number of brown trout occurring in Pool 13 both pre- and post-pulse (Figure 38). Rainbow trout were more abundant than brown trout in the study reach (Figure 39). While the total number of rainbow trout per pool ranged from 1–20 fish pre-pulse, and 0–19 post-pulse, rainbow trout occurred in a higher proportion of pools than brown trout, both pre- and post-pulse. There was no clear pattern of longitudinal displacement for either species.

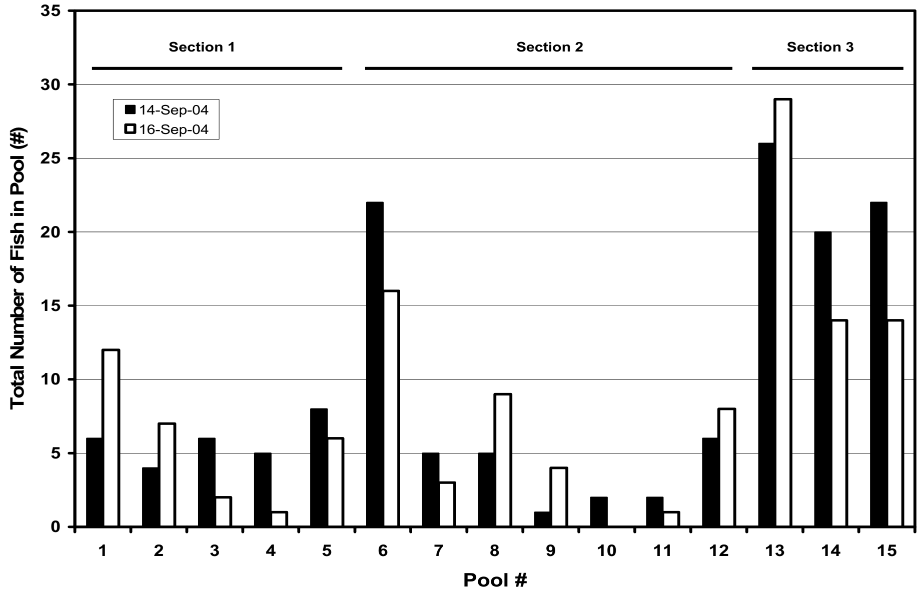


Figure 34. Total number of trout observed during snorkel counts of Silver Creek pools on 14 September 2005, and on 16 September 2005, before and after the 18.5 m^3/s kayaking pulse flow event on 15 September 2004. The experimental reach was divided into three 100 m sections containing a total of fifteen pools, with Pool 1 at the upstream end of the reach, and Pool 15 at the downstream end of the reach.

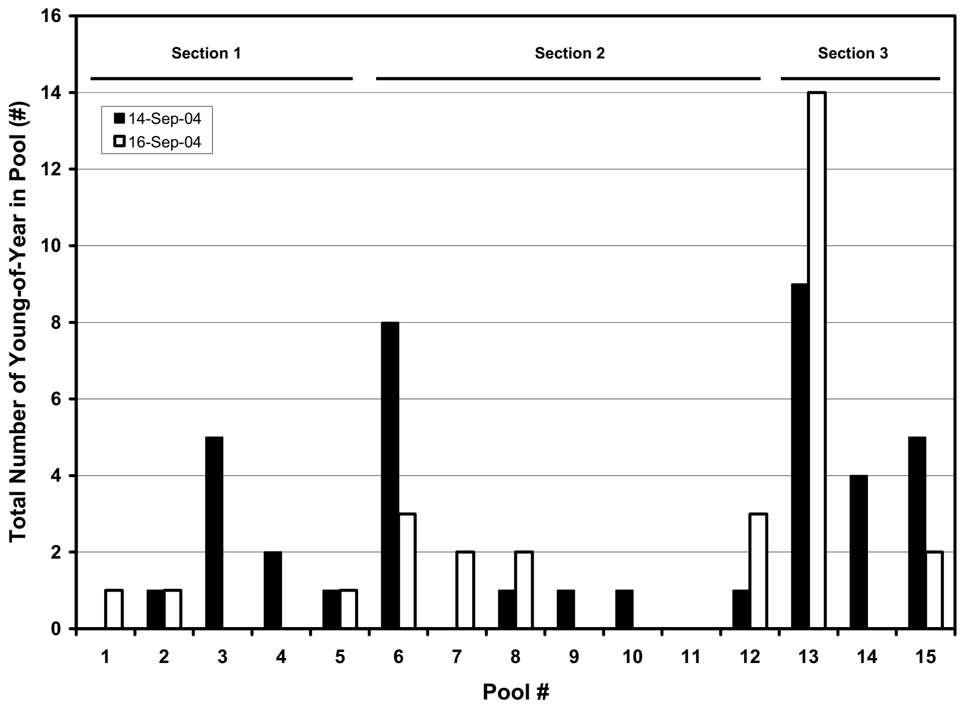


Figure 35. Total number of young-of-the-year trout (total length < 10 cm) observed during snorkel counts of Silver Creek pools on 14 September 2005, and on 16 September 2005, before and after the 18.5 m^3/s kayaking pulse flow event on 15 September 2004. Young-of-the-year were defined as those < 10 cm TL.

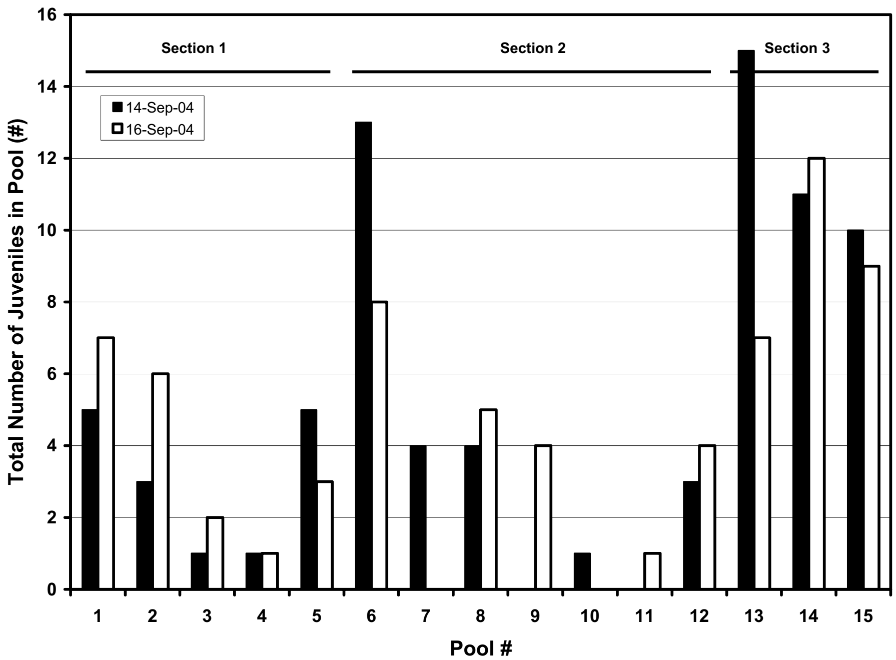


Figure 36. Total number of juvenile trout (total length 10–18 cm) observed during snorkel counts of Silver Creek pools on 14 September 2005, and on 16 September 2005, before and after the 18.5 m^3/s kayaking pulse flow event on 15 September 2004. Juveniles were defined as 10–18 cm TL.

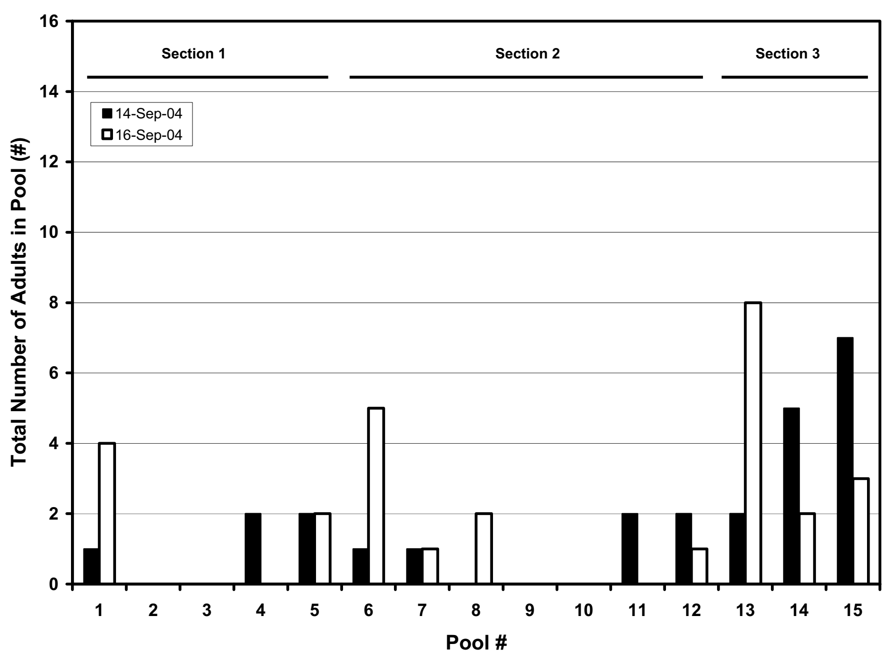


Figure 37. Total number of adult trout (total length > 18 cm) observed during snorkel counts of Silver Creek pools on 14 September 2005, and on 16 September 2005, before and after the 18.5 m^3/s kayaking pulse flow event on 15 September 2004. Adult trout were defined as > 18 cm TL.

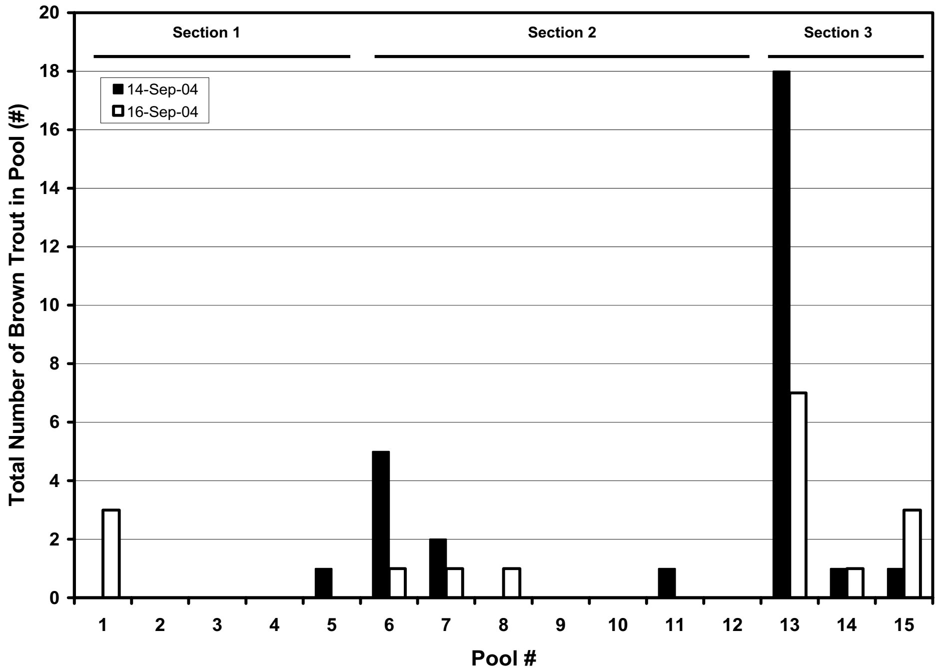


Figure 38. Total number of brown trout observed during snorkel counts of Silver Creek pools on 14 September 2005, and on 16 September 2005, before and after the 18.5 m^3/s kayaking pulse flow event on 15 September 2004

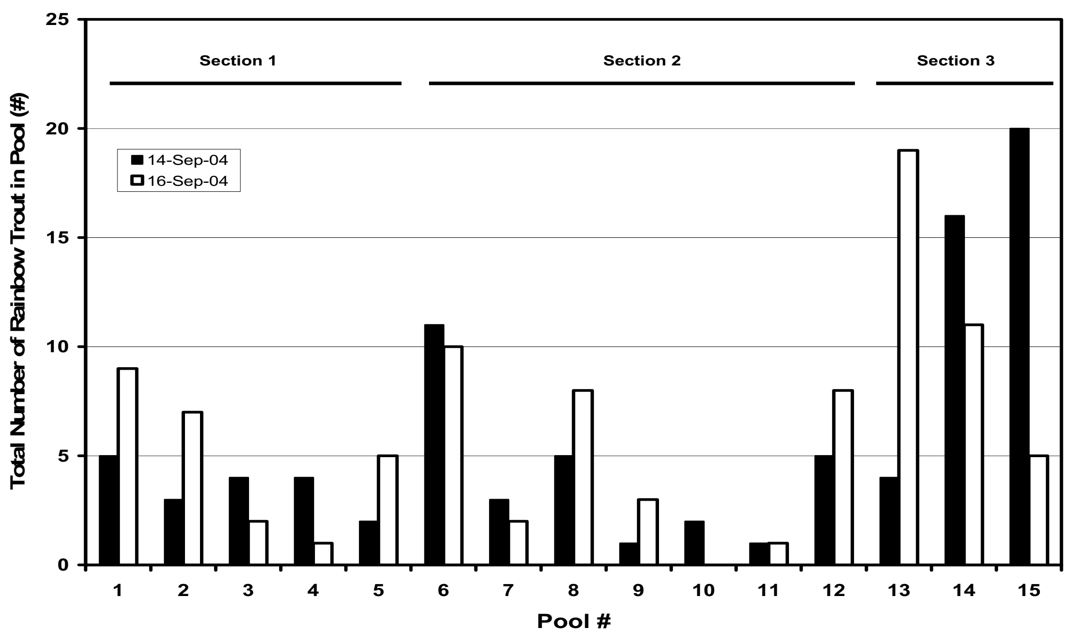


Figure 39. Total number of rainbow trout observed during snorkel counts of Silver Creek pools on 14 September 2005, and on 16 September 2005, before and after the 18.5 m^3/s kayaking pulse flow event on 15 September 2004

Examination of trout densities did not indicate any pulse flow impacts. It appeared that the density of young-of-the year might have declined in Section 1 post-pulse, with more trout appearing at the upper end of Section 2, and the upper end of Section 3 (Figure 40). Juvenile densities were similar in Section 1 pre-and post-pulse, and this was also observed for Section 3, but juveniles may have shifted downstream within Section 2 (Figure 41). The density of adults was below 0.04 fish/m² in all pools, with the exception of Pool 11, which had a pre-pulse density of 0.13 fish/m² (Figure 42). Five pools in Sections 1 and 2 had higher densities post-pulse, while three pools had lower post-pulse densities.

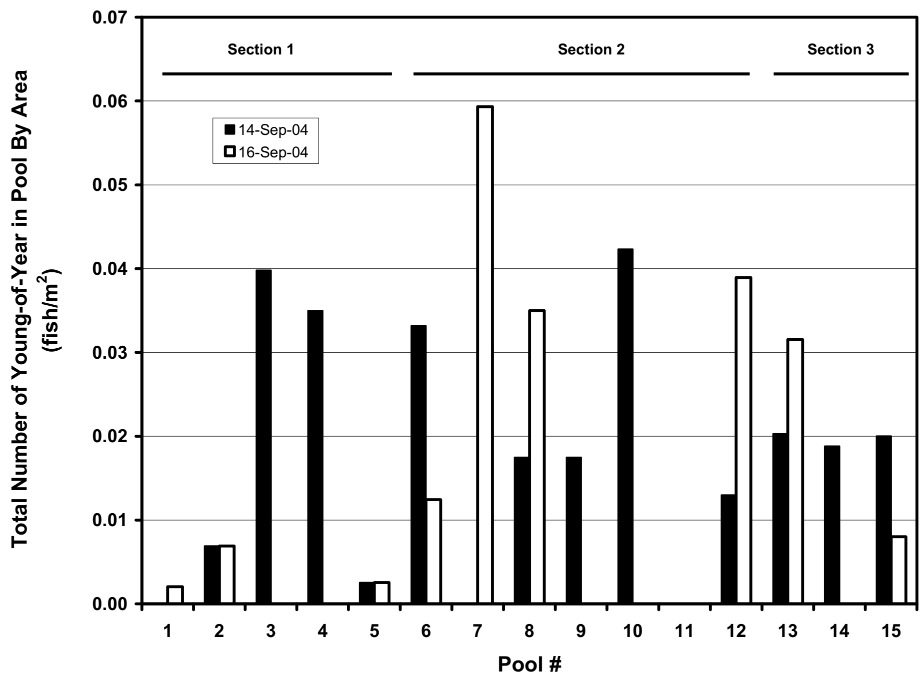


Figure 40. Density of young-of-the-year trout (total length < 10 cm) observed during snorkel counts of Silver Creek pools on 14 September 2005, and on 16 September 2005, before and after the 18.5 m3/s kayaking pulse flow event on 15 September 2004

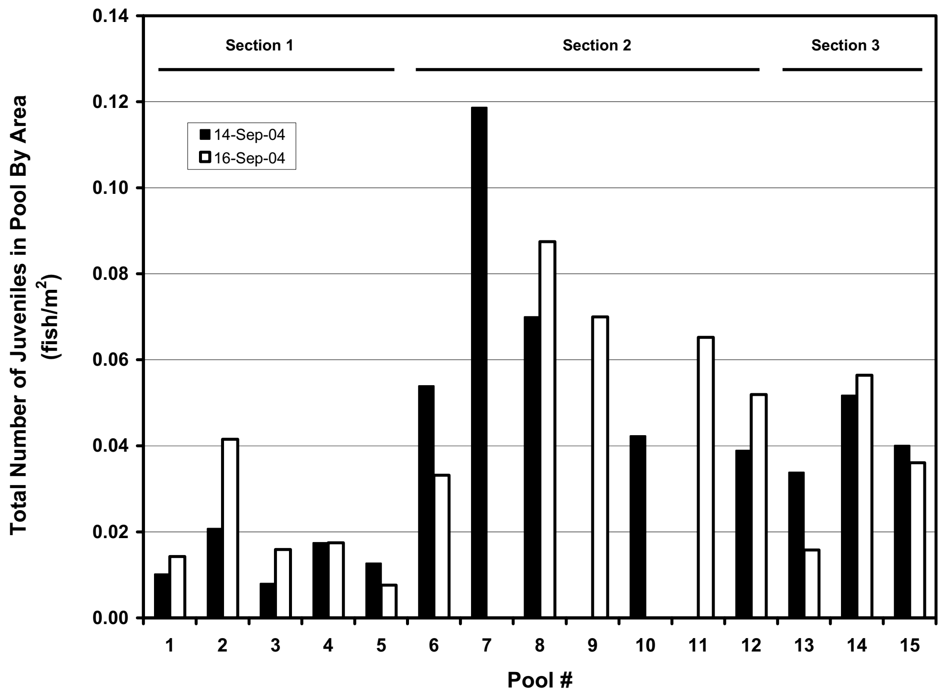


Figure 41. Density of juvenile trout (total length 10–18 cm) observed during snorkel counts of Silver Creek pools on 14 September 2005, and on 16 September 2005, before and after the 18.5 m^3/s kayaking pulse flow event on 15 September 2004

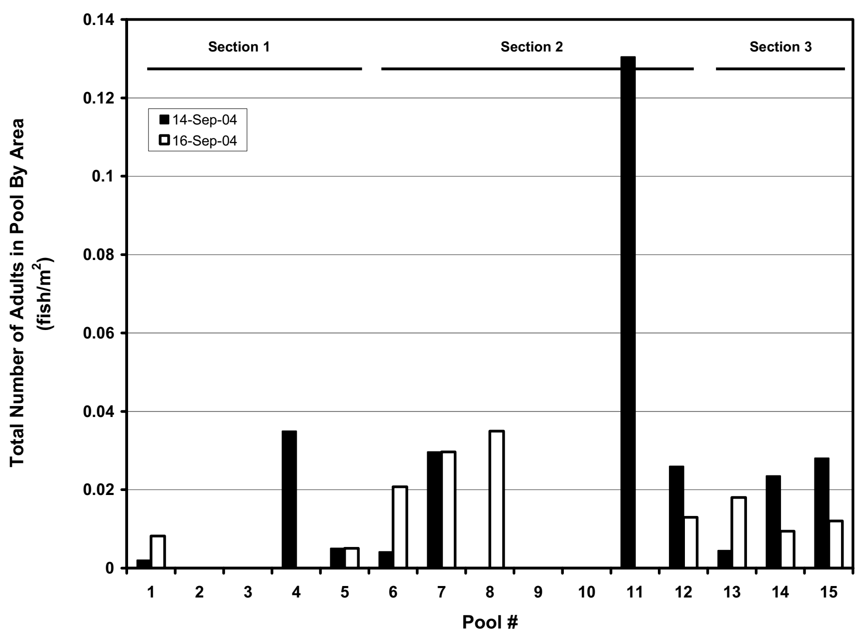


Fig 42. Density of adult trout (total length > 18 cm) observed during snorkel counts of Silver Creek pools on 14 September 2005, and on 16 September 2005, before and after the 18.5 m^3/s kayaking pulse flow event on 15 September 2004

3.2. Laboratory Studies

3.2.1. Experiments in Longitudinal Flume

The research team tested 12 hardhead minnows, 11 rainbow trout, and 12 Sacramento suckers in the longitudinal flume. All the fish tested were young-of-the-year fish (< 10 cm). Mean standard lengths (SL) for hardhead, rainbow trout, and Sacramento suckers were 6.2 (±0.2 SE), 5.0 (±0.2 SE), and 7.0 (±0.2 SE) cm respectively. Mean weights ranged between 2.6 and 6.7 g (Table 15).

Table 15. Standard lengths and weights of juvenile hardhead, rainbow trout, and Sacramento suckers from the longitudinal displacement study. The mean, standard error (SE), and range are shown for each species.

Species	n	SL (cm)			Weight (g)		
		Mean	SEM	Range	Mean	SEM	Range
Hardhead	12	6.2	0.2	4.7–7.4	5.5	0.5	2.7–8.3
Rainbow trout	11	5.0	0.2	4.1–6.5	2.6	0.4	1.0–6.2
Sacramento sucker	12	7.0	0.2	5.8–8.0	6.7	0.5	4.0–9.3

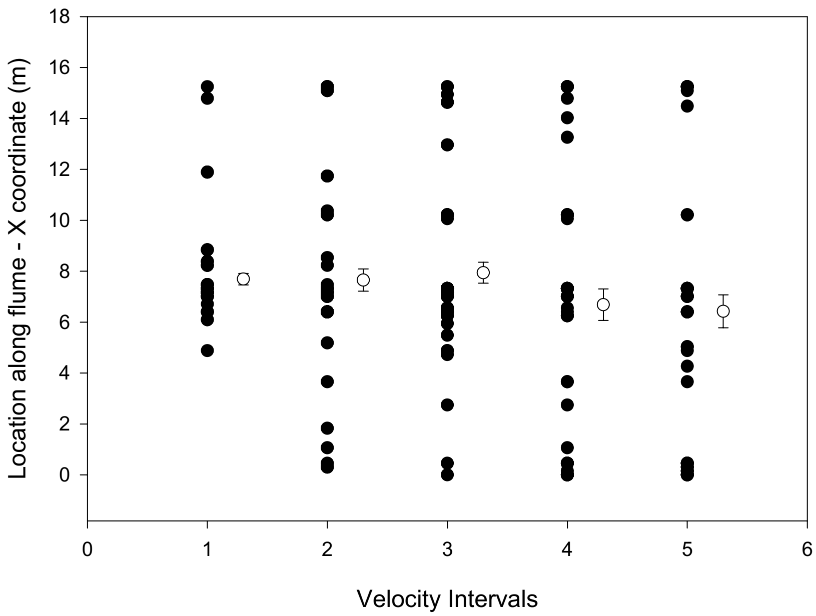
The research team measured water velocities at the observed test fish locations in the flume during the five successive flow rates. Adjacent velocities were also recorded at four to six points (3 cm upstream, downstream, to either side, and above and/or below) at each of the test flows. All measurements were taken in the absence of the subject, because making water velocity measurements during an experiment might alter fish behavior. Mean flume velocities were determined by measuring 50 random points along the entire length of the flume. During the slow, medium, and fast velocity tests, the mean velocities across the flume were 0.10 m/s (±0.00 SE), 0.31 m/s (±0.01 SE), 0.46 m/s (±0.02 SE), respectively. Water velocities were especially variable in certain flume locations, in part due to turbulence and eddies created by the substrate elements (see Figures 19–22). Because water velocities were difficult to measure at some test fish locations, twenty additional measurements were taken between rocks or in crevices to simulate velocities in those areas. Areas partially or fully surrounded by cobble elements were often characterized by eddies with reverse flows as rapid as –0.11 m/s.

The locations of fish were measured in three-dimensions: x (flume length), y (flume width), and z (flume depth). Within each species, there were fish that moved either up or downstream during the experiment. However, the mean overall location for all species was near the center of the flume during each time interval (Figures 43–45) suggesting that fish species tested did not favor particular upstream or downstream area when tested in the flume. There were no significant differences in location selection between the three species (Mann-Whitney Test, $p < 0.01$). These results are consistent with members of the species staying in the center of the flume at their original introduced location by hiding in the velocity refuges downstream of rocks where eddies and slower velocities existed.

The water velocities measured at observed fish locations during each five-minute test interval were compared to the mean velocity measured throughout the flume (Figures 46–48).

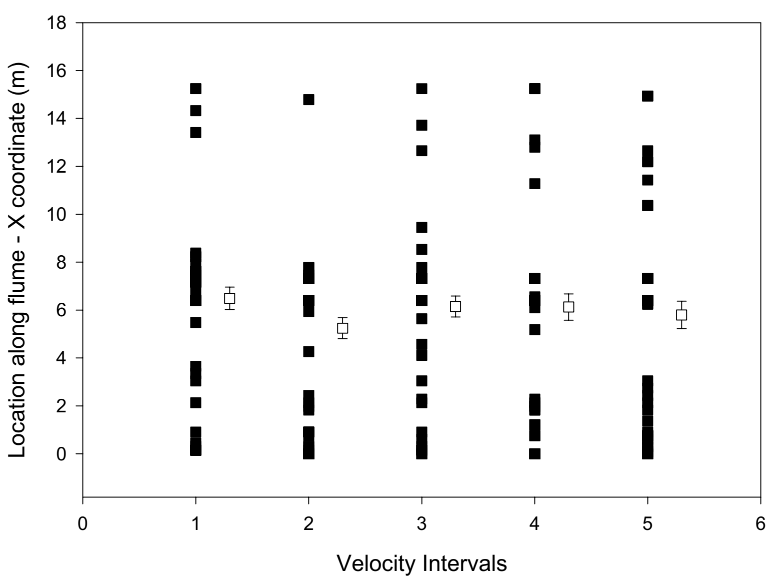
Hardhead and Sacramento suckers preferred locations in the flume characterized by slower velocities. The research team observed Hardhead and suckers at locations in the flume where velocities were significantly lower than the mean velocities recorded at points throughout the flume for all five velocity intervals (Mann-Whitney Test, $p < 0.01$). Hardhead minnows and Sacramento suckers chose significantly higher velocities during the two medium and high intervals than to the initial and final slow intervals (Mann-Whitney Test, $p < 0.01$). This may have resulted because no lower velocities were available at the medium and high velocity intervals. Although preferred velocities were higher during the higher velocity intervals, they remained 0.20–0.35 m/s below the mean flume velocity. The velocity preference of the hatchery rainbow trout remained elevated during the final slow velocity interval despite their displaying velocity preferences at lower than average flume velocities during the first four test intervals (Figure 48). The trout appear to prefer swimming in water of higher velocities than hardhead and Sacramento suckers during the slow water velocity periods. This tendency to choose higher velocity area may be a result of their swimming behavior (tendency to orient into flows [positive rheotaxis] in order to feed on drifting organisms (Moyle 2002). This is most apparent in a comparison of the water velocities chosen by hardhead, rainbow trout, and Sacramento suckers (Figure 49). The rainbow trout chose significantly higher velocities to swim than hardhead minnows and Sacramento suckers (Mann-Whitney Test, $p < 0.01$) in the first and last velocity intervals (Figure 49). These significant differences may be attributed to the preference of salmonids of orienting to higher flows and their foraging behavior.

The research team recorded whether the fish swam mainly over rocky substrate or the exposed Plexiglas bottom during the five-minute intervals. Hardhead and rainbow trout both preferred a rocky substrate, with the former spending roughly 80% of the time during the five flow intervals over a rocky bottom (Figure 50) and the trout roughly 65% over a rocky substrate (Figure 51). This suggests a common swimming behavior to cope with elevated water velocities associated with pulsed flows. Conversely, Sacramento suckers swam less often over rocky substrate 30%–40 % of the time during the high flows, but still favored rocky bottoms 75% and 45% during the initial and final slow flow intervals, respectively (Figure 52). In conclusion, hardhead more often sought out rocky substrate, while the Sacramento sucker favored this type of bottom the least (Figure 53). Other research suggests that suckers may not need to seek the slower velocities down current of rocky substrate due to their unique cranial morphology (i.e., flattened head) and behavior (Myrick and Cech 2000).



(1-Slow, 2-Medium, 3-Fast, 4-Medium, 5-Slow)

Figure 43. Locations of 12 hardhead minnows (solid circles), mean location (open circle), and standard error (bars with ticks) along the length of flume during each of the velocity intervals. Note the fish were acclimated in the center of the flume (between 6.7–8.5 m) at the beginning of the experiment.



(1-Slow, 2-Medium, 3-Fast, 4-Medium, 5-Slow)

Figure 44. Positions of 11 rainbow trout (solid squares), mean location (open square), and standard deviation (bars with ticks) along the length of flume during each of the velocity intervals

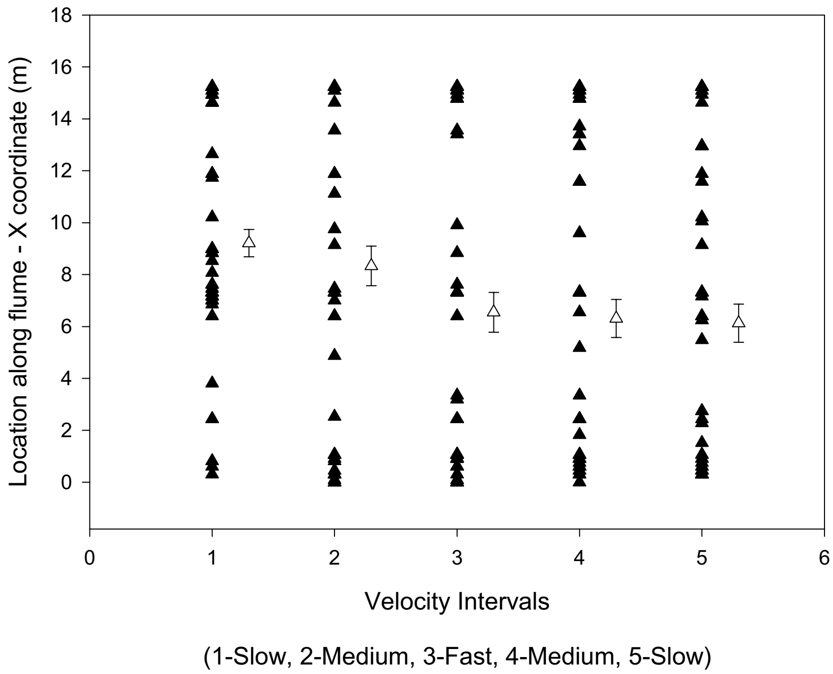


Figure 45. Locations of 12 Sacramento suckers (solid triangles), mean location (open triangles), and standard error (bars with ticks) along the length of flume during each of the velocity intervals. Note the fish were acclimated in the center of the flume (between 6.7 to 8.5 m).

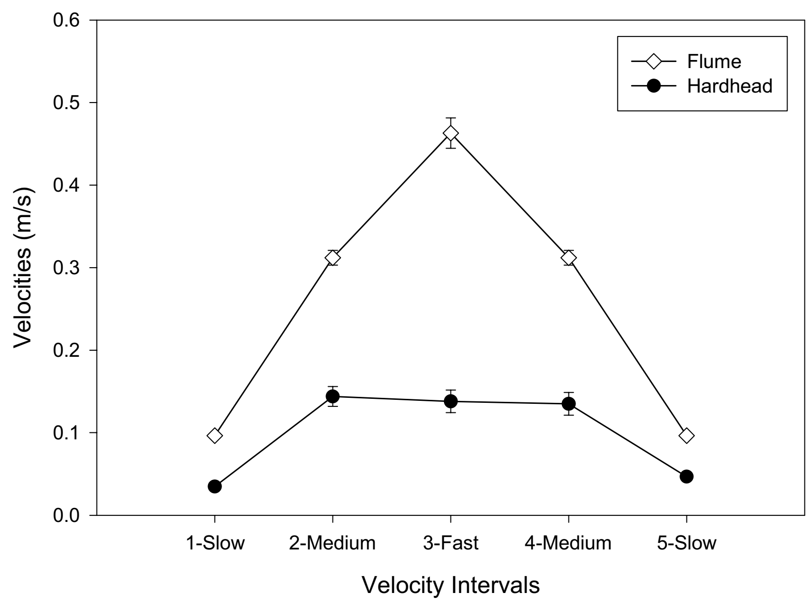


Figure 46. Comparison of the flume and fish measured velocities during the five experimental velocity intervals. Hardhead minnow results show that fish select lower velocities than those available in the flume.

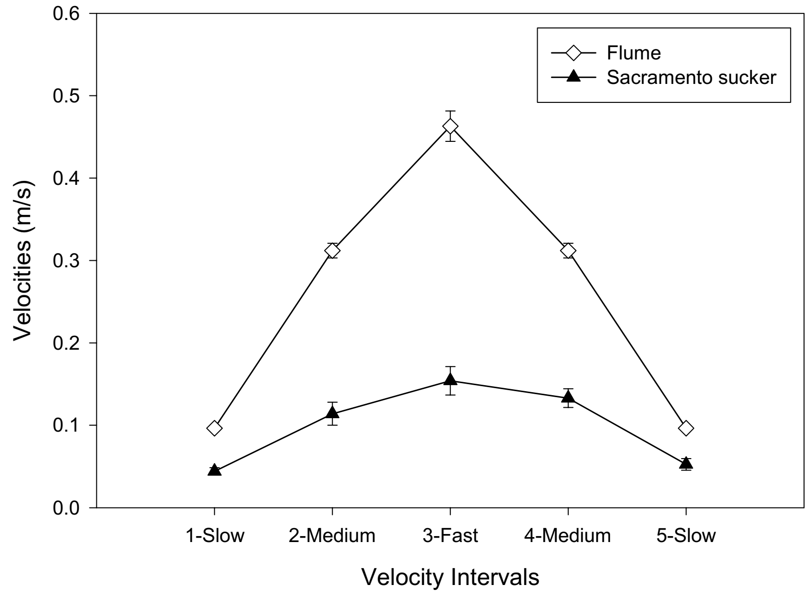


Figure 47. Comparison of the flume and fish measured velocities during the five experimental velocity intervals. Sacramento sucker results show that fish select lower velocities than those available in the flume.

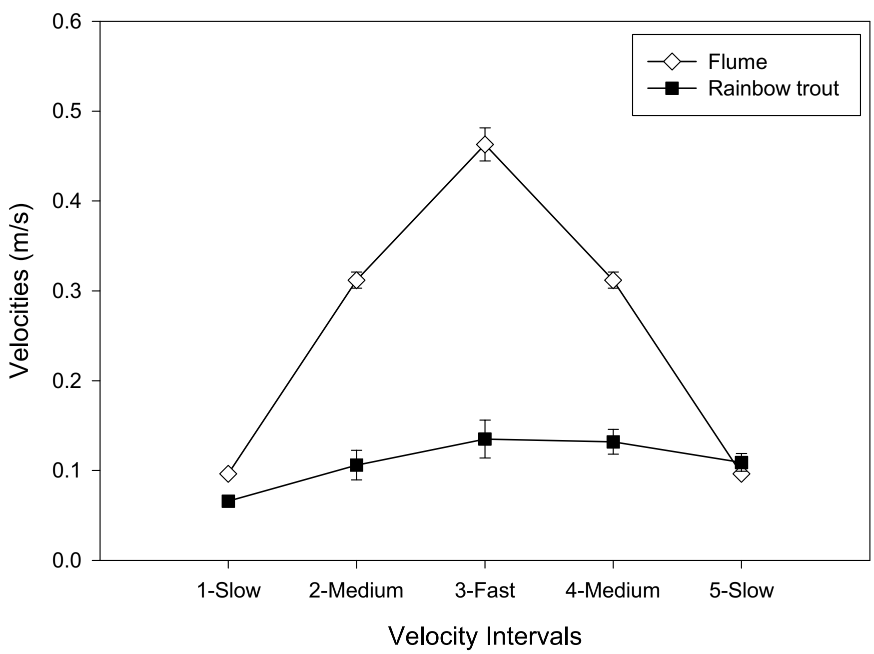


Figure 48. Comparison of the flume and fish measured velocities during the five experimental velocity intervals. Rainbow trout results show that fish select lower velocities than those available in the flume, except at the last slow interval.

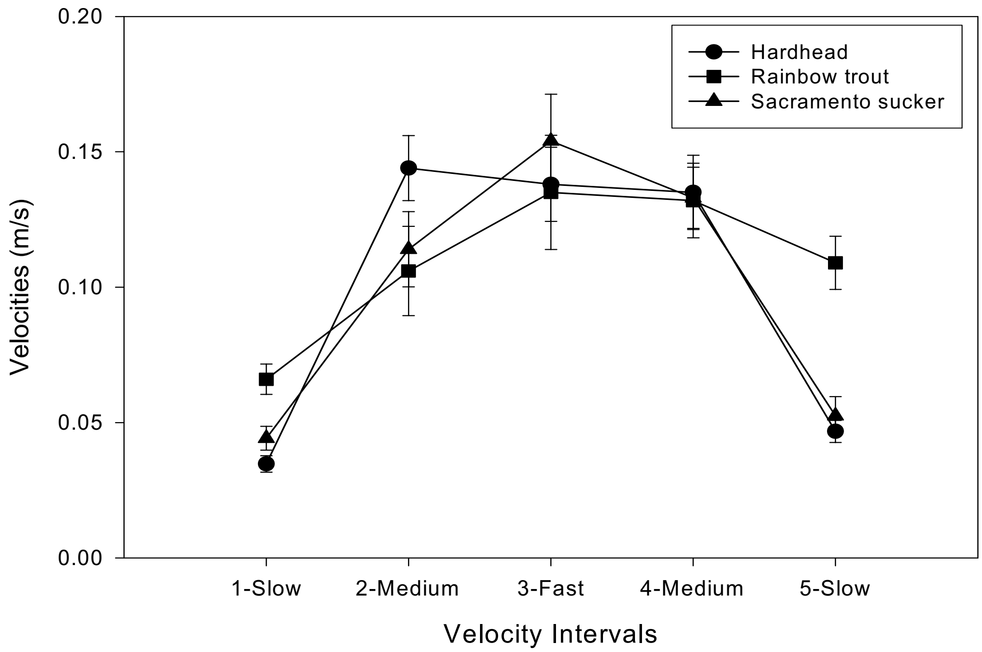


Figure 49. Comparison of the three species' velocity selection. Rainbow trout preferences differed significantly from hardhead and Sacramento suckers during both slow velocity intervals. In addition, there were significantly different velocity preferences between rainbow trout and hardhead during the first medium velocity interval.

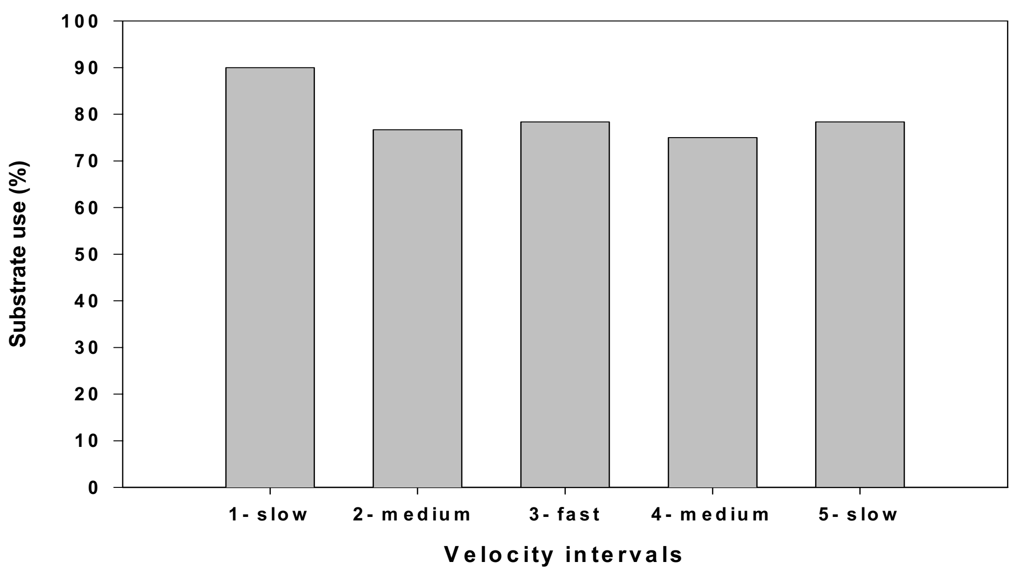


Figure 50. Percentage of 20-min. periods spent by hardhead minnows over rock substrate versus the Plexiglas bottom during the five velocity intervals. Hardhead swam over rocky substrate during most of time over the entire experiment.

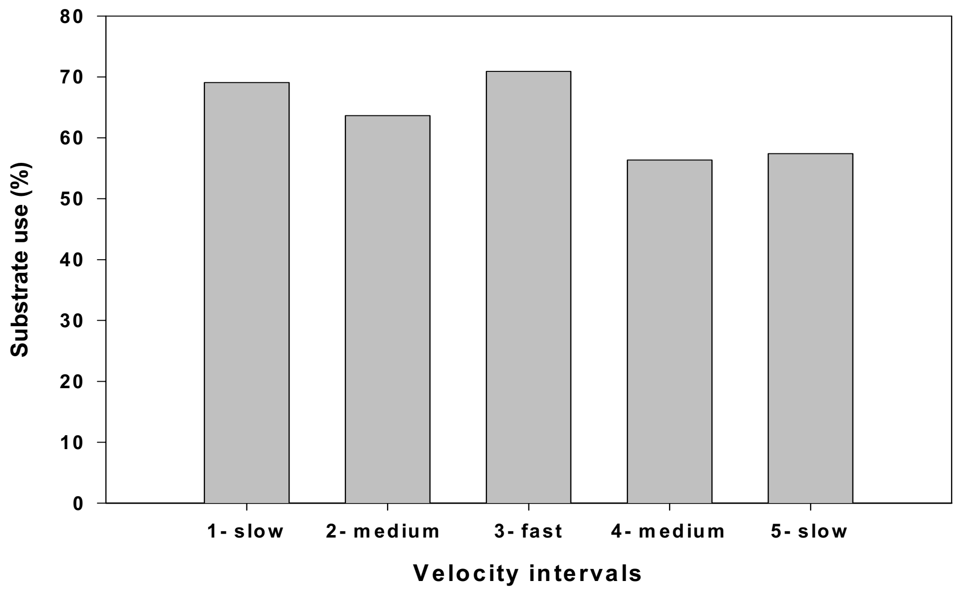


Figure 51. Percentage of 20-min. periods spent by rainbow trout over a rock substrate versus a Plexiglas bottom during the five velocity intervals. Rainbow trout consistently used substrate throughout the experiment.

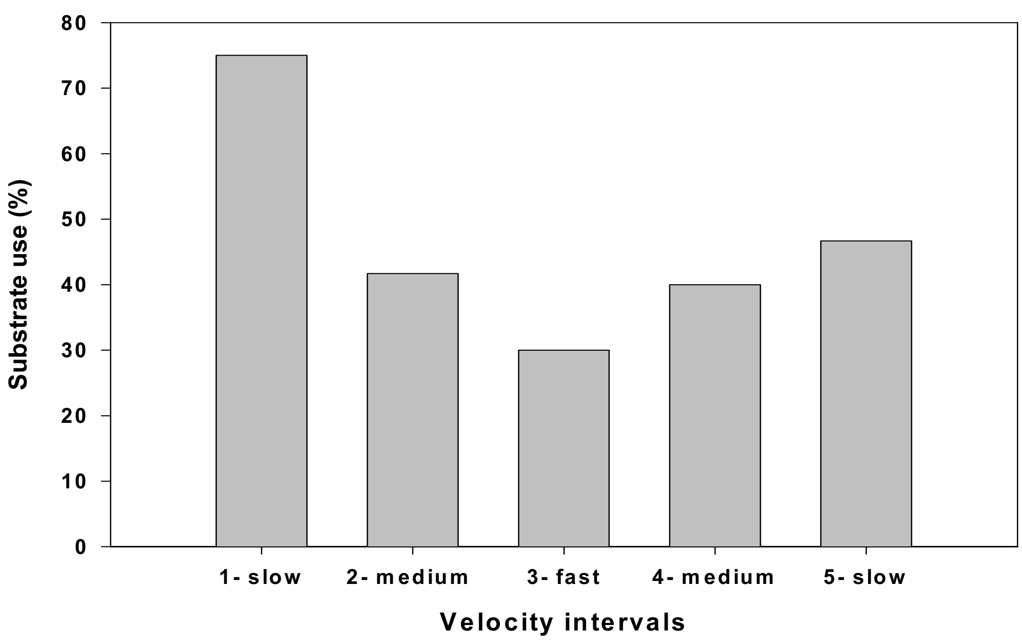


Figure 52. Percentage of 20-min. periods spent by Sacramento suckers over a rock substrate versus a Plexiglas bottom during the five velocity intervals. The suckers swam over the rocky substrate less often when the water flowed faster and more when the water flowed slower.

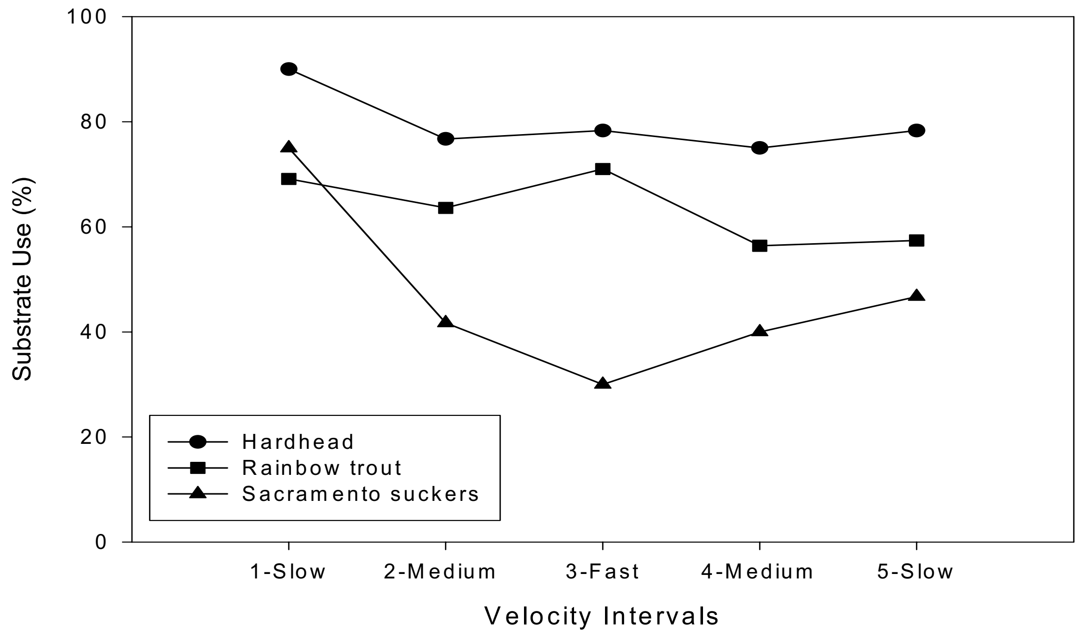


Figure 53. Percentages of time spent over rocky substrate shown all three species during the five velocity intervals. Hardhead minnow favored the rocky bottoms the most, while Sacramento suckers least preferred them.

The research team qualitatively measured swimming activity, using an index, which had four states: no swimming, holding or maintaining position in the flow, routine or slow movement forward, and a burst or acceleration of swimming. These rates of movements were based on the team's observations of the swimming activity of rainbow trout in a Brett–type swim tunnel. Members of all species tended to swim more (sustained, prolonged, and burst) during the faster flows than during slower flows. Hardhead and rainbow trout displayed similar percentages of swimming (sustained, prolonged, and burst combined) compared to non-swimming levels (Figure 54). However hardhead tended to rely on sustained swimming more than rainbow trout, which seemed to prefer routine swimming. Sacramento suckers swam the least.

In conclusion, the research team found no significant movement up or downstream by any of the three species tested. It is important to point out that the team was limited by the length and width of the flume (16.5 x 0.6 m). It is also possible that raceway-reared hatchery trout may have different swimming and feeding behavior from wild stream trout. The rainbow trout and other fish in the South Fork of the American River would not necessarily be restricted to such a confined space even at the lowest water levels. Although no significant differences in movement were seen, some individuals seemed to inhabit up or downstream areas. It is likely that some individual fish might move up or downstream in the river. The high usage of substrate by hardhead and rainbow trout suggests that the availability of velocity shelters (e.g., rocky substrate) is important to these species during pulsed flows. For these species, the presence and/or absence of refuge areas may determine whether they exhibit longitudinal displacement within the South Fork of the American River.

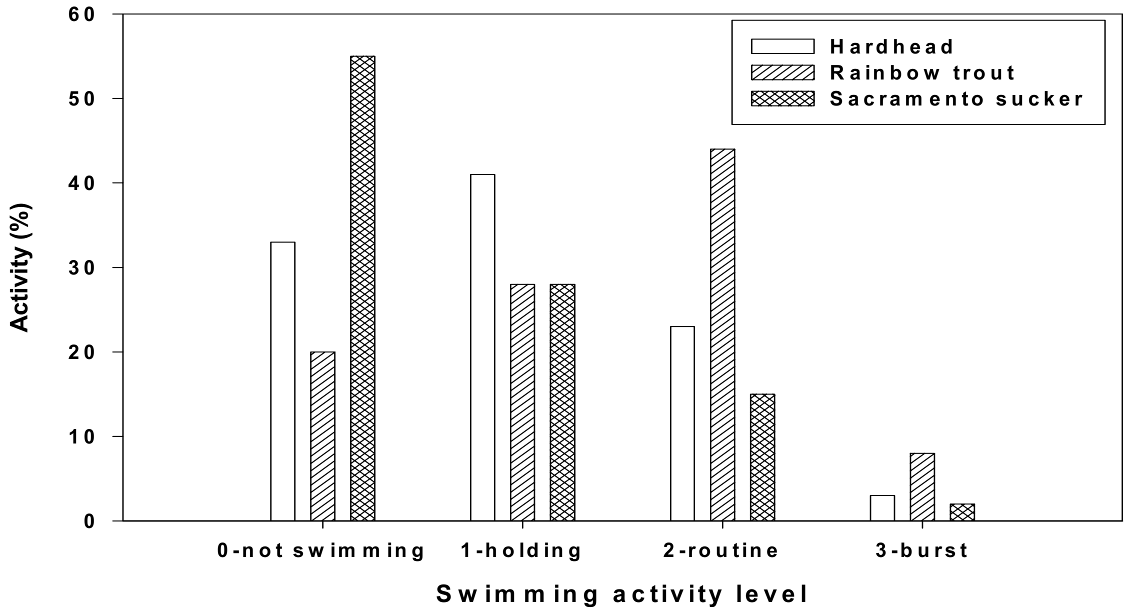


Figure 54. The percentage of time spent by members of three species in different forms of locomotion. Hardhead and rainbow trout spent the majority of their time holding position and swimming in a routine manner.

Temperature differences can also affect fish swimming performance. It would be informative to conduct further testing at different temperatures. Although all of the fish were acclimated to 14°C before testing, hardhead found in Slab Creek were caught in warmer water. In this study's experiments, the research team was limited to simulating water velocities ranging between 0.10 to 0.46 m/s. Actual velocities in a river during pulse flow release may exceed this range. This may indicate that other variables, such as substrate or fish swimming ability, could have a significant influence on the longitudinal displacement of rainbow trout, hardhead, and Sacramento suckers. In addition, the research team tested fish under a one-pulsed-flow regime; whereas fishes in the South Fork of the American River are subjected to one or more pulsed flows per day, during a time of year when the river flows would be expected to be low. These continuous water releases could have a cumulative effect on the longitudinal movement and displacement of these fishes; however this was not evaluated.

3.2.2. Experiments in Lateral Displacement Flume

The ranges in the size of the fish used to test stranding and bank habitat use in the lateral displacement flume are summarized in Table 16. Long and short acclimated runs were combined within each species for fish size, (Mann-Whitney Test, $p = 0.065–0.699$). The rainbow trout (mean = 9.8 cm SL ± 0.4 cm SE) were longer than the hardhead minnows (mean = 5.7 cm SL ± 0.2 cm SE) and Sacramento suckers (mean = 5.4 SL ± 0.3 cm SE). It should be noted that the mean length of rainbow trout used in the lateral displacement experiments was almost twice that of those used in the longitudinal displacement experiments. Although their lengths were still < 1/3 that of the mean pool length of the sloped gravel test area of the lateral displacement flume (Figure 23), it is possible that smaller fish may have stranded at a higher rate.

A fish was considered stranded during experiments when it became isolated in a pool or the substrate as the flume drained of water and was unable to return to the main channel. Three (8%) of the 38 test fish were stranded during the lateral displacement flume tests (Table 17): two hardhead and one sucker. None of the hatchery rainbow trout were stranded during the experiments. All three stranded fish were from the short acclimation (2 hour) category and all were isolated in pool A (see Figure 23), the deepest pool area, which retained water as water drained out of the apparatus. There were no significant differences in stranding incidences between species or acclimation times (Fisher's Exact Test, $p = 0.45–1.0$).

Table 16. Standard lengths and weights of juvenile hardhead, rainbow trout, and Sacramento suckers used for experiments in the lateral displacement flume. The means, standard error (SE) and range are shown for each species.

Species	n	SL (cm)			Weight (g)		
		Mean	SE	Range	Mean	SE	Range
Rainbow trout	12	9.8	± 0.4	8.0–13.0	17.6	± 2.3	8.5–38.1
Hardhead	14	5.7	± 0.2	5.0–8.0	4.6	± 0.5	2.4–10.5
Sacramento suckers	12	5.4	± 0.3	3.9–6.9	3.4	± 0.5	1.4–6.5

Table 17. Summary of the occurrences of stranding in the lateral displacement flume

Species	Acclimation	N	# Strand	# Not Strand	% Strand	% Not Strand
Hardhead	Short	7	2	5	29	71
	Long	7	0	7	0	100
Rainbow trout	Short	6	0	6	0	100
	Long	6	0	6	0	100
Sacramento sucker	Short	6	1	5	17	83
	Long	6	0	6	0	100

Test fish often entered the simulated river margin, although few of them stranded in this habitat during experiments. For example, a majority (9 fish of 12) of the rainbow trout entered the margin after both long and short acclimation periods (Table 18). Four of 12 Sacramento suckers entered the margin following both acclimation periods. Hardhead minnows did not leave the main channel after the long acclimation, but 43% of individuals entered the margin habitat after a short acclimation period. Rainbow trout utilized the substrate habitat more than the hardhead after long acclimation (Fisher's Exact Test, $p = 0.0046$).

Table 18. Summary of the frequencies (and percent totals) that hardhead minnows, rainbow trout, and Sacramento sucker, acclimated for both short and long periods, entered the bank habitat during pulsed flows.

Species	Acclimation	N	Enter Margin Habitat	Remain in Main Channel	% Enter Margin Habitat	% Remain in Main Channel
Hardhead	Short	7	3	4	43	57
	Long	7	0	7	0	100
Rainbow trout	Short	6	4	2	67	33
	Long	6	5	1	83	17
Sacramento sucker	Short	6	2	4	33	67
	Long	6	2	4	33	67

Although the fish entered the margin more frequently than they became stranded, they still spent the majority of time in the main channel during experiments. The flume locations were separated into three categories: main channel, bank substrate and bank pools. All species spent significantly (Mann-Whitney Test, $p < 0.05$) more time in the main channel than in either the bank substrate or pools under either the short (Figure 55) and long acclimation periods (Figure 56). There was no significant difference in the time spent in the bank pools compared to the bank substrate areas.

The research team tried to determine whether the fish were responding to increases and decreases in water level (pulsed flows) while in the main channel. Fish depth was recorded during the experiments, and researchers then plotted the depths of short and long acclimated fish during the rise in water level, its high water state, and when the water level fell for hardhead minnows (Figure 58), rainbow trout (Figure 59), and Sacramento sucker (Figure 60). This simulated a pulsed flow within the river. Only fish, swimming within in the main channel, were included in this analysis. The team did not observe a change in depth of the hardhead (see solid and clear diamonds, Figure 57) and Sacramento suckers (see solid and clear squares, Figure 59). The rainbow trout did move slightly upward in the water column during the high water period and downward when the level of water was lowered (see solid and clear triangles, Figure 58). Rainbow trout may be responding to high flows by increasing their depth in the water column.

Short Acclimation

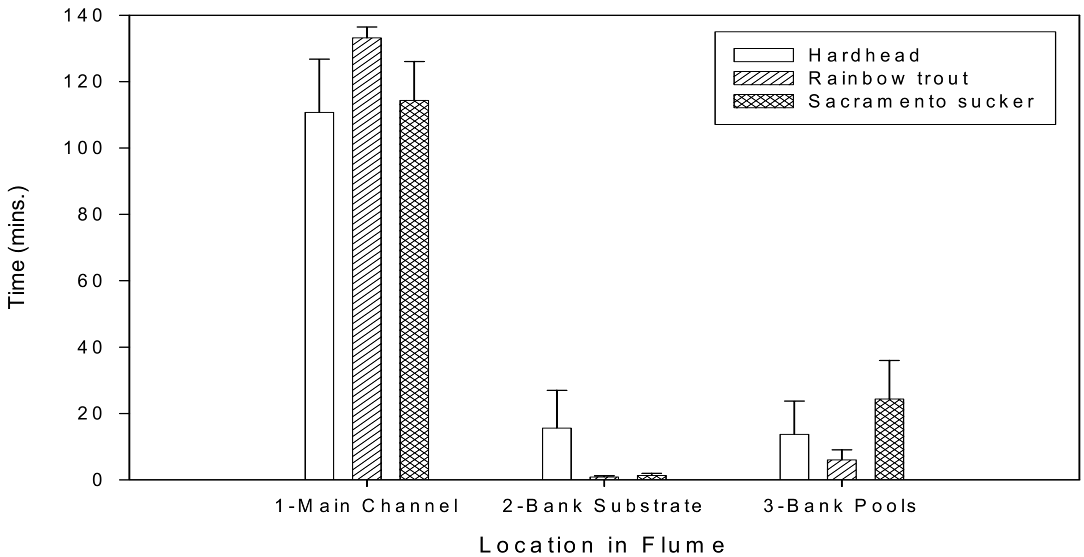


Figure 55. Time spent in different sections of lateral displacement flume after experiencing the short acclimation period. Mean (+ SE) time spent in different flume sections are indicated with standard error bars. All three species spent the majority of their time in the main channel rather than the bank habitat.

Long Acclimation

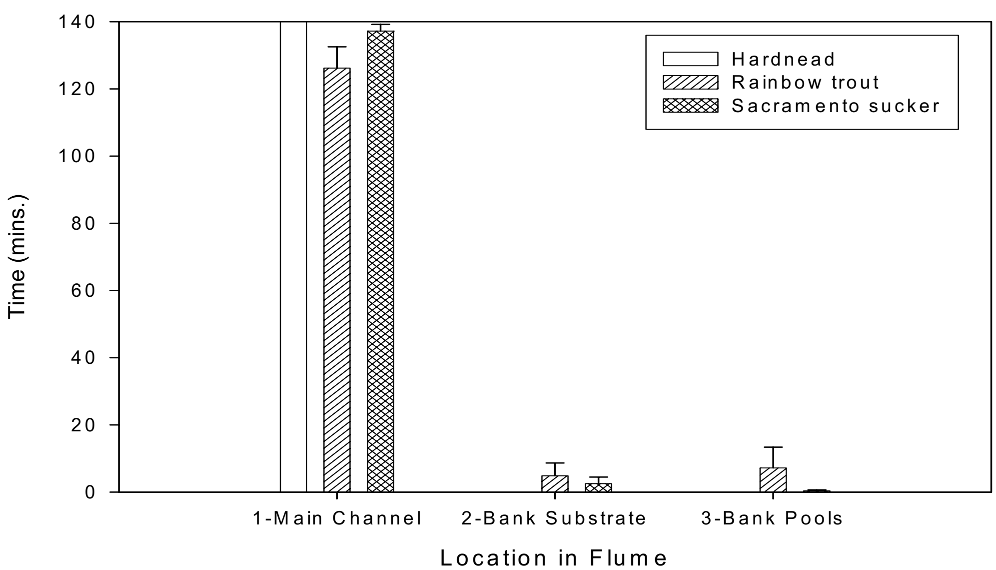


Figure 56. Mean (+ SE) time spent in different sections of lateral displacement flume after experiencing the long acclimation period. All three species spent the majority of their time in the main channel rather than the bank habitat.

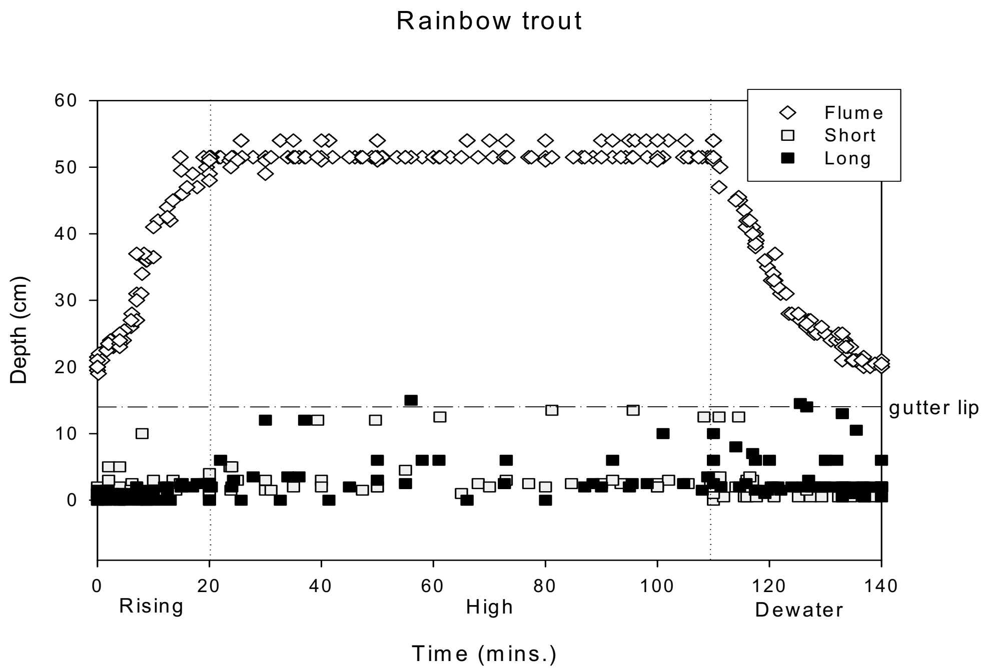


Figure 57. The height of short and long acclimated hardhead minnows in the water column during experiments in lateral displacement flume. The hardhead minnows stayed close to the bottom during the changes in water height.

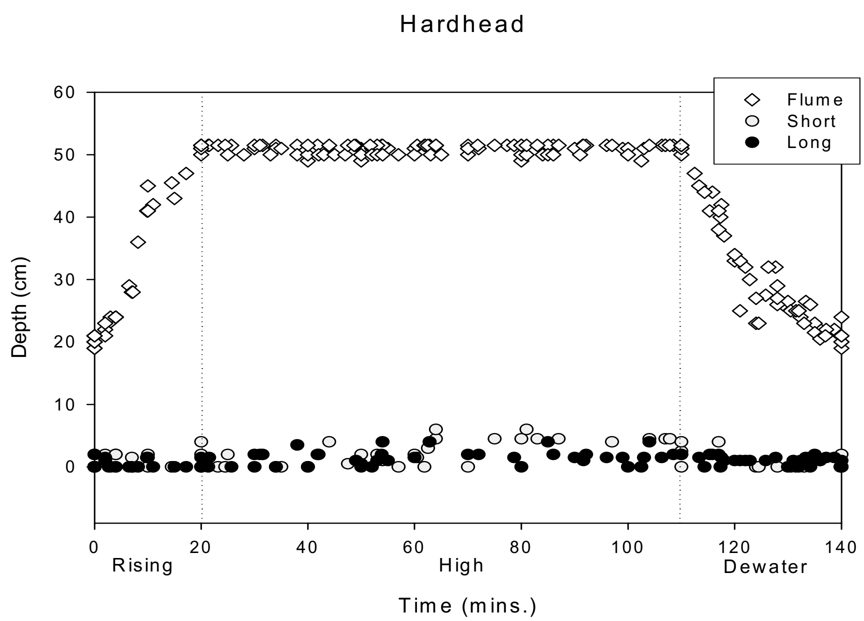


Figure 58. The positions of short and long acclimated rainbow trout in the water column during simulated pulse flow in lateral displacement flume. Some of the short acclimated rainbow trout changed their position in the water column in response to the change in water level. They swam higher in the water column (see solid and clear squares during high water period) during the pulsed flow. Only a small proportion actually swam higher than the main channel lip (see dash and dotted line).

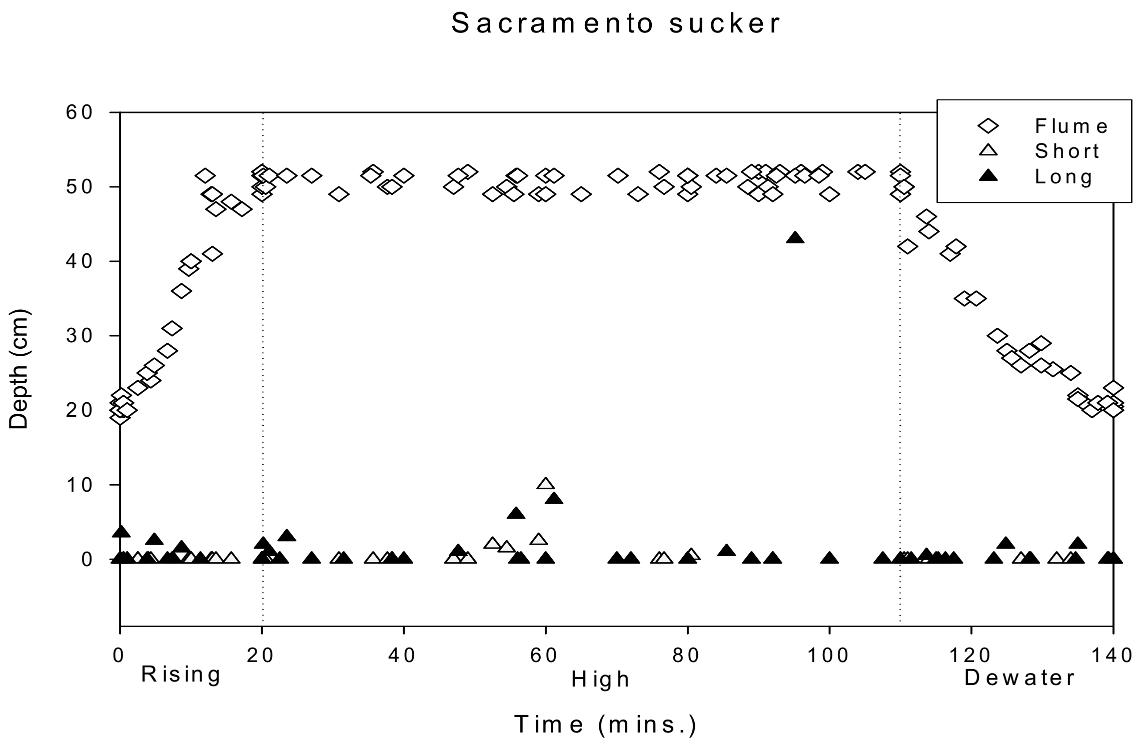


Figure 59. The depth of short and long acclimated Sacramento suckers in water column during simulated pulse flow in lateral displacement flume. They respond to rising and high water levels more than the hardhead minnows but still stay close to the bottom of the main channel.

In summary, very few fish explored and became stranded on the bank habitat. In addition those fish that explored the bank habitat, once it became available, still spent the majority of their time in the main channel. Long and short acclimated fish did not seem to vary behavior, hardhead and Sacramento suckers stayed near the bottom of the flume regardless of flume water depth. Rainbow trout seemed to respond to simulated pulsed flows by venturing higher in the water column. The infrequent stranding and using substrate margin may have resulted from the fish acclimating in the main channel with minimal substrate exposure. However, the acclimation was set to mimic pulses observed in the South Fork American River. The recreational pulses on the South Fork occur in the morning, increasing with the concomitant flooding of the riverbank before subsiding later in the day. The hatchery rainbow trout were the only species that did not strand during the experiments, yet they were larger than the hardhead and Sacramento suckers, which might explain why the former are less susceptible to stranding. At the same time, the rainbow trout entered the bank substrate with more frequency than the hardhead or Sacramento suckers. The trout were also observed nipping and biting at the substrate, indicative of a motivation to feed within the apparatus. Trout may search for food in the margin of the river when the banks flood, and return to the deep channel. This may explain why they return to the main channel in the flume when the waters recede in the flume, unlike the one sucker and two hardhead that stranded during the experiment. The low degree of stranding observed during the experiments might also be a function of the experimental apparatus which could not mimic the elevated velocities associated with high steam flows that might be expected to promote fish movement out of the high velocity areas along the expanding bank area where fish would then be more prone to stranding during receding flows. Thus, these experiments may underestimate stranding rates.

4.0 Conclusions and Recommendations

4.1. Field Studies

4.1.1. Radio-telemetry in South Fork of the American River

Conclusions. The research team captured three rainbow trout by hook and line, implanted radio tags into their peritoneal cavities, and released them into the Chili Bar Reach of the South Fork of the American River during the period from 23 July to 5 August 2004. These fish were exposed to one and rarely two pulsed flows per day. The team searched for these fish during seven days from 3–12 August. One fish was located a short distance upstream seven days latter, one moved slowly upstream on the following day before staying in the same reach three and four days later. Another was relocated a small distance upstream four days later, occupied the same location two days later, and moved a small distance upstream on the following day. The third fish was never relocated following tagging. This pilot study demonstrated that it was possible to tag and track fish on the South Fork. The paucity of individuals tagged and tracked precludes us from making any conclusions as to the affect of the pulsed flows on rainbow trout in the American River. However, the low densities of trout in comparison with other sierra streams would suggest that there are some factors limiting the trout population in the South Fork; which may be a result of or correlated to pulsed flows.

Recommendations. More rainbow trout need to be tracked both in the presence and absence of pulsed flows within the Chili Bar Reach of the American River. The research team angled for rainbow trout for a total of nine days during Year 1, repeatedly fishing in the area between the Marshall Gold Discovery Site (rk 9.6) and Gorilla Rock (rk 24.2). Researchers traveled by raft and kayak, fishing continuously from the boats (except during rapids), and also stopping at locations that the anglers thought looked particularly promising. On all days at least two people fished, and on some days three or four. Thus the team fished for a total of about 23 person-days. With this amount of effort, ten rainbow trout were caught. Of these, only three rainbow trout were of suitable size and condition for tagging. For this reason, the research team concludes that it is infeasible to track wild rainbow trout in the main stem of the American River.

Alternatively, the team will tag and release rainbow trout raised at the local trout hatchery into the American River during Year 2. Dennis Redfern, manager of the hatchery, has furnished 50 individuals that will be grown to a length of 28–36 cm FL in the Center for Aquatic Biology and Aquaculture (CABA) by summer, when they will be equipped with electromyogram (EMG)-recording tags, observed to ensure that the surgical wounds heal properly, and then released into the river where they can be tracked in the presence and absence of pulsed flows. He will also supply 25 subadults during summer, which will be equipped with smaller position-determining tags, observed similarly, and released into the river at the same time as the adults to assess the effect of pulsed flows on their distribution. Hatchery trout may not respond to pulsed flows as wild fish might, but describing their response to these flows is important, because they represent the majority of trout presently inhabiting Californian rivers.

First, the research team will tag 12 small rainbow trout (15–20 cm TL), obtained from the hatchery, with position-detecting tags. The team will also tag 12 large rainbow trout (21–30 cm TL), grown to adulthood in CABA, with larger beacons. These tagged individuals will be tracked to determine whether they are displaced into the river's side channels or downstream. It will be of considerable value to identify the effect of pulsed flows on hatchery-reared trout, because they are released in the American River annually, and constitute the largest component of the trout population within this and other rivers in California.

Second, the research team will insert 12 EMG-detecting tags with a similar longevity into the peritoneum of large, adult rainbow trout. These trout will first be monitored in the laboratory and later in the field. The individuals carrying these tags will be tested firstly in the flow chamber under varying flow speeds to determine the oxygen consumed at various tail beat rates. They will then be released into the American River to be tracked both in the presence and absence of pulsed flows. They will record tail beat frequency in the field during pulsed and non-pulsed flows, and enable us to calculate the energy expenditure during the two conditions.

4.1.2. Radio-telemetry in Silver Creek

Conclusions. One rainbow trout and six brown trout were tagged with radio tags and tracked during a single pulsed flow in Silver Creek, a tributary of the American River. These individuals were located on the river after capture, later prior to the pulsed release, during the release, and after the release. Little movement was recorded for tagged fish between release and later positioning prior to the pulse. No significant movement was detected fish between the pre-pulse and pulsed condition; although two fish moved upstream and two moved downstream between tracking events. Finally, no movement was detected for three fish after the pulsed flow, while two fish were located upstream from their previous location and one fish downstream. The results indicate that the single pulsed flow did not alter the distribution of fish within the Silver Creek study reach.

Recommendations. This field study indicates that a single, small release of water into a stream does not significantly alter the distribution of subadult trout. More frequent stream channel maintenance (to promote scouring) releases may be of greater magnitude and frequency, and could affect the distribution of fishes. Thus, it is necessary to identify the effect of different types of flow releases on fishes in Californian rivers. This is a first-step toward identifying the effect of water releases produced for recreational rafting or hydroelectric power on the local fish fauna.

4.1.3. Snorkel Survey and VIE Marking in Silver Creek

Conclusions. Trout did not appear to experience large downstream displacements due to the one-day pulse in Silver Creek, or if they were displaced, they had moved back upstream by the time of the post-pulse survey. Additional statistical analyses may clarify the response of the local trout population to the pulse, particularly with regard to young-of-the-year distribution. Preliminary analyses indicate that a one-day pulse may not be harmful to trout, at least not in a stream with a large number of velocity refugia (e.g., crevices, boulders, deep pools), and a bedrock bottom. The rainbow and brown trout may have been able to take shelter under or behind rocks in order to avoid excessive water velocities. However, pulses may negatively affect the ability of trout (and other fish) to feed, due to very high flow velocities, and/or increased turbidity (decreased effective search distance). More frequent pulses may eventually result in decreased growth rates, increased vulnerability to predation (smaller fish are more vulnerable), and decreased survival rates. Furthermore, more frequent pulses may disturb the habitat and cause indirect impacts on fish, e.g., changes to bank structure, riparian vegetation. For example, frequent pulses may prevent riparian plants from growing, resulting in reduced cover near the banks for juvenile fish. Reduced plant cover could also lead to increased turbidity due to instability of the banks, and resultant increased erosion. This may be particularly important in streams with soil banks, as is the case for sections of the South Fork American River between Chili Bar Dam and Lake Folsom, rather than bedrock channels like Silver Creek. Furthermore, decreased riparian cover would result in a lower density of terrestrial invertebrate prey for fish (fewer invertebrates in plants near stream, and greater distance between plants and flowing water during low flow periods).

Recommendations. The short time frame available for trapping and marking fish precluded doing multiple pre-pulse snorkel surveys, in order to determine the variability of fish density per pool in the absence of a pulse. In other words, the research team had no measurement of how much fish move between pools when flows are steady. Increasing the number of pre- and post-pulse surveys would improve the study design.

The pulse flow release occurred in September, when young-of-the-year trout were well developed and likely able to locate and move to low velocity areas to avoid the higher flows. It would be informative to test pulses of similar magnitude at other times of the year, such as early summer, when fry may be newly emerged, and less able to locate and use flow refugia.

The habitat in Silver Creek is relatively complex and heterogeneous, which likely provided a wide variety of flow refugia for fish. It would be useful to test the impacts of a similar pulse in a stream with less complex habitat to see whether fish are more likely to be displaced as habitat complexity declines. Furthermore, the fish community in Silver Creek is very simple, and is likely compromised mainly of the two trout species that were observed. A similar magnitude pulse might have more dramatic impacts in a stream with a greater number of species that prefer slower moving water than trout. This could be tested in conjunction with tests of the effect of seasonality and habitat complexity.

4.2. Laboratory Studies

4.2.1. Longitudinal Flume

Conclusions. Using the longitudinal-displacement experimental flume; featuring a long (15+ m) test section, clear panels for behavioral observations, a variable-speed drive to simulate pulsed flows, and rocks to simulate American River habitat characteristics; the research team found that juvenile rainbow trout, hardhead, and Sacramento suckers trended to remain in the section to which they were introduced, throughout the pulsed flow period. Thus, despite open-channel water velocities up to 0.463 m s^{-1}, these three species were neither displaced downstream nor stimulated to swim upstream during or after the flow pulse. While rainbow trout and hardhead sought refuge among the rocks during the highest flows, the Sacramento suckers occupied more open, smooth–substrate areas. Therefore, with higher velocities than could be achieved in this study's flume, but which may characterize pulsed flows associated with some hydroelectric power generation or white-water rafting water releases from California reservoirs, Sacramento suckers may be more susceptible to longitudinal displacements. It is possible, of course, that these flow-pulse-associated behaviors would change at water velocities higher than those that were tested.

Recommendations. The research team will conduct temperature preference tests on adult rainbow trout and hardhead minnows under different flow regimes. These resulting data would complement field-derived temperature measurements of fishes' selected habitats (e.g., before and after pulsed flows associated with hydroelectric or white-water rafting activities).

Managers will be able to model adult fish distributions based on this study's resulting thermal (as well as hydraulic) maps of stream reaches. The value of the laboratory-derived data would be their accuracy (especially if derived from fish with different temperature acclimation histories), speed (many species measured within a few months, after set up), and low cost (especially after initial investment in equipment).

4.2.2. Lateral Displacement Flume

Conclusions. Using the lateral-displacement flume; featuring a main-channel and a pulse-flooded, gravel river-bank section with draining and non-draining pools and a 10º slope; juvenile rainbow trout appeared to resist stranding as pulse-flow waters receded down the slope bank. In contrast, with a short acclimation period (simulating the shorter inter-pulsed periods that may characterize days with both morning and evening high-hydroelectric-demand periods), Sacramento suckers, and especially hardhead, may be stranded via pulse-flow-associated lateral displacement. All of the stranded fish would be vulnerable to predation in their non-draining pools.

Recommendations. It is necessary to use both laboratory and field methods to determine the energetic costs when exposed to various pulsed flows. After determining the relationships among swimming velocity, tail beat frequency, and oxygen consumption (metabolic) rate in a Brett-type swimming respirometer, it will be possible to estimate the costs (energy, food, or oxygen-based) associated with a flow pulse by measuring tail beats, using special radio tags, over the flow pulse in the field. The field-based tail beat counts will give accurate estimates of stream-habitat energetic costs, because the fish's behavior in a real stream (e.g., including the potential uses of hydraulic cover structures) is incorporated into the measurements.

4.3. Benefits to California

Human-manufactured water flow increases (pulses) are common within Californian rivers. Although the native stream species evolved with seasonal fluctuations, the increased frequency (e.g., for peaking hydroelectric operations) and late-summer timing (for recreational purposes) represent significant deviations from the natural hydrograph. The effects of flow pulses on the community of species present within the streams are relatively unknown. The field and laboratory studies described in this report provide a description of the impacts of pulsed releases of water for recreational and commercial purposes on a diversity of species of fishes. These include the brown trout, hardhead minnow, rainbow trout, and Sacramento sucker. The knowledge resulting from these studies help agencies manage their pulsed flows so that their effect on the local fish fauna is minimal.

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6.0 Glossary

ANOVA	analysis of variance
CABA	Center for Aquatic Biology and Aquaculture
EMG	electromyogram
GPS	global positioning system
PG&E	Pacific Gas & Electric
PIT	Passive integrated transponder
PVC	polyvinyl chloride
RT	radio tag
SE	standard error
SMUD	Sacramento Municipal Utility District
TKN	total Kjeldahl nitrogen
TL	total length
UC	University of California
USGS	United States Geological Survey
VIE	visible implant elastomer
YOY	young-of-the-year