Georgiana Slough Acoustic Barrier Applied Research Project: Results of 1994 Phase II Field Tests

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Summary

Juvenile chinook salmon emigrating from spawning and rearing areas in the upper Sacramento River and its tributaries are susceptible to diversion into the central Delta from the Sacramento River at the Delta Cross Channel, Georgiana Slough, and Threemile Slough. Diversion of winter-run and other races of chinook salmon smolts from the Sacramento River into the interior Delta can be reduced by closing the Delta Cross Channel gates during smolt emigration. However, winter-run and other races of chinook salmon continue to be susceptible to movement from the Sacramento River into the central Delta through Georgiana Slough, where there are no provisions for fish protection. A behavioral barrier designed to make use of the avoidance response of juvenile salmon might reduce salmon migration into Georgiana Slough without adversely affecting hydrology, water quality, or navigation.

A preliminary field demonstration project was conducted during 1993 to evaluate the feasibility and effectiveness of an acoustic barrier in deterring juvenile chinook salmon from entering Georgiana Slough. Results of the Phase I field test showed that diversion efficiency of the acoustic barrier was promising. Based on these encouraging results, a more detailed and thorough evaluation of the effectiveness of an acoustic barrier at the confluence between the Sacramento River and Georgiana Slough was performed in 1994. In the 1994 applied research program, a temporary facility in operation from April through June was used to evaluate guidance efficiency for juvenile chinook salmon and other issues. Additional testing of the behavioral response of upstream-migrating adult fall-run chinook salmon (potential blockage or delays in migration) was conducted from October through mid-November 1994. Future phases of the project include guidance evaluations in different water year types and additional studies on delta smelt and adult salmon migrations.

Primary objectives of the 1994 applied research program were to gather data about:

- The effects of the acoustic barrier on guidance efficiency for fall-run chinook salmon smolts (used as a surrogate for winter-run salmon smolts).
- Potential blockage or delays in upstream migration for adult chinook salmon.
- Delayed effects of exposure (increased susceptibility to predation, mortality, loss of equilibrium, *etc*) of chinook salmon smolts and other fish to the underwater acoustic (sound) signal produced using two alternative acoustic technologies, EESCO and Sonalysts.

The acoustic barrier tested as part of the 1994 research program was in the Sacramento River immediately upstream of the confluence with Georgiana Slough. The acoustic technology and signal developed by Energy Engineering Services Company (EESCO) was the only system tested for juvenile chinook salmon guidance efficiency and effects of acoustic signals on the migration of adult chinook salmon. Exposure testing and underwater sound pressure measurements were performed, separately, for acoustic technologies developed by both EESCO and Sonalysts, Inc. Sonalysts testing focused principally on determining immediate and delayed effects of exposure of test species to the low-frequency signals generated by its transducers.

Conditions During Testing

Background sound pressure level measurements consistently showed sound pressure levels of about 88-97 dB. The maximum sound pressure level for the EESCO system was 160 dB (300 Hz). The majority of sound pressure levels measured in the immediate vicinity of the acoustic array were 130-150 dB. A biological perspective of sound pressure levels (dB) can be seen in lethal thresholds for fish produced by explosives at 229-234 dB 1 m Pa (Norris and Mohl 1982, cited in Bennett *et al* 1994). A difference of 80 dB (*ie*, 230-150 dB) is equivalent to a 10,000-fold decrease in underwater sound pressure. Sound pressure levels diminished rapidly with distance away from the acoustic array, but levels above background were detected about 1/4 mile upstream and downstream of the acoustic array.

Sound pressure measurements associated with the EESCO acoustic array measured during the fall were similar in frequency and magnitude characteristics to measurements during the spring. Sound pressure levels, above background, were measured during the fall studies (EESCO technology) across both the Sacramento River and Georgiana Slough. Results demonstrate that adult chinook salmon, striped bass, and other fish species migrating upstream in the Sacramento River or Georgiana Slough would be exposed to elevated underwater sound pressure levels throughout the cross section of the channel, although sound pressure levels measured at these sites were substantially lower (up to 99%) than those immediately adjacent to the acoustic array.

Guidance efficiency associated with operation of the acoustic barrier has been hypothesized to be closely related to water velocity in the Sacramento River and Georgiana Slough. Reactive distance to the acoustic signal is related to channel velocity and juvenile chinook salmon swimming performance capability. Water velocities during the flood tide were generally lower than those at the same stage during the ebb tide. Water in the Sacramento River downstream of the confluence with Georgiana Slough reverses direction, flowing upstream during the flood tide under flow conditions occurring during these studies. Such reverse flow was observed consistently throughout the spring during the juvenile salmon guidance evaluations. Direction of flow in Georgiana Slough was generally downstream. Results of velocity measurements demonstrate the complex hydraulics in the Sacramento River at the confluence with Georgiana Slough and the importance of tidal stage and flow in determining the direction and velocity of water movement.

Flow in the Sacramento River approaching the acoustic barrier, although varying substantially in response to tidal conditions, typically ranged between 4,000 and 6,000 cubic feet per second (daily average). Maximum instantaneous flows ranged as high as 12,000 cfs during ebb tide and as low as -6,000 cfs (flow in upstream direction) during flood tide. Daily flows entering Georgiana Slough from April 1 through May 27 typically averaged between 1,300 and 2,500 cfs. Instantaneous flows varied substantially in response to tidal conditions, with maximum flows above 4,000 cfs during ebb tides and minimum flows of about -1,000 cfs during flood tides. The Delta Cross Channel, located on the Sacramento River upstream of the acoustic barrier, remained closed throughout most of the spring testing period (gates were opened May 28).

Average daily Sacramento River flows downstream of the confluence with Georgiana Slough during the fall studies were relatively stable, at about 2,000 cubic feet per second, increasing during the latter part of the study. Instantaneous flows in a day varied substantially in response to tidal conditions. Maximum instantaneous flows exceeded 9,000 cubic feet per second, and minimum instantaneous flows approached -8,000 cfs. Results of these hydraulic measurements are consistent with data collected during the spring surveys in showing high downstream flows during ebb tides and substantial reverse flow in response to flood tides.

Both instantaneous flow and tidal condition were included in the analysis of guidance efficiency for juvenile chinook salmon during the spring studies and the direction and rate of adult movement monitored during periods when the acoustic barrier was on and off as part of the fall investigations.

Acoustic Barrier Guidance Efficiency

One of the primary objectives of the 1994 field investigation was to quantitatively evaluate and document the effectiveness of the acoustic barrier in reducing the number of juvenile fall-run chinook salmon smolts entering Georgiana Slough. The experimental design involved a series of 2-day periods with the barrier on, followed by 2 days with the barrier off each week. Evaluation of the effectiveness of the acoustic behavioral barrier in reducing juvenile chinook salmon migration into Georgiana Slough involved a series of replicated fish collections using Kodiak trawls in the Sacramento River and Georgiana Slough. Kodiak trawls were complemented by use of both juvenile chinook salmon mark/recapture studies and hydroacoustic fish monitoring.

Juvenile Chinook Salmon Guidance Efficiency — Kodiak Trawl Collections

Guidance efficiency of the EESCO acoustic barrier was calculated from results of Kodiak trawls in both Georgiana Slough and the Sacramento River for juvenile chinook salmon. Experimental design and statistical analyses used in evaluating guidance efficiency were developed in cooperation with various state and federal agencies, most notably the California Department of Fish and Game Biometrics Unit. Results of these studies have demonstrated:

- Overall acoustic barrier guidance efficiency averaged 57.2% (95% confidence intervals, 47.4 to 65.0; $p < 0.001$) and was statistically significant. These results, although including all of the valid samples collected during the 1994 acoustic barrier guidance efficiency tests, predominantly reflect guidance efficiency during daytime hours, when the majority of juvenile chinook salmon were collected. Although guidance efficiency was typically lower during nighttime hours, results of these collections were given less weight in the statistical analysis because of the lower number of fish collected. The overall estimate of guidance efficiency also includes the influence of ebb and flood tidal hydraulic conditions, which were found to be a significant factor influencing guidance efficiency. Although results of the 1994 tests demonstrated statistically significant guidance efficiency, these tests represent a limited range of environmental conditions (for example, Sacramento River flows). Additional field studies have been planned to further evaluate acoustic barrier guidance efficiency at the Georgiana Slough site to encompass a broader range of environmental conditions and, collectively with the 1994 studies, provide a technical basis for determining the overall performance, constraints, and biological benefits of the acoustic barrier technology in protecting downstream-migrating juvenile chinook salmon.

- Acoustic barrier guidance efficiency varied among weekly tests.

- Guidance efficiency was typically greater during ebb tide (average efficiency 62.4%) than during flood tide (average 50.9%), although there was substantial variability in results of individual weekly testing when stratified to account for tidal effects.

- Guidance efficiency was generally greater during the daytime than at night. However, these analyses were confounded by observations showing a statistically significant decrease in juvenile chinook salmon collections using Kodiak trawls at night when compared with daytime collections.

- The observed (and sometimes significantly negative) reduction in acoustic barrier guidance efficiency during flood tides is consistent with observations of flow and velocity. Juvenile chinook salmon that had successfully moved downstream when the acoustic barrier was operating may be forced by tidally-driven hydraulic conditions to change directions and move upstream and into Georgiana Slough. Some of the data suggest that the arrangement and operation of the array may exacerbate this situation. Further studies may be warranted to determine if barrier operations or alignments should be modified. These conditions can occur during flood tides when there are reverse flows in the Sacramento River downstream of the barrier.

Chinook Salmon Mark/Recapture Tests

A series of mark/recapture studies were performed using juvenile fall-run chinook salmon smolts released into the Sacramento River about 3.2 miles upstream of the acoustic barrier with recapture downstream in the Sacramento River and Georgiana Slough. Mark/recapture studies provide independent data on acoustic barrier guidance efficiency and the influence of the tide on movement patterns of juvenile chinook salmon and thereby affecting acoustic barrier guidance efficiency. Results of mark/recapture studies are consistent with guidance efficiency estimates derived from Kodiak trawling in showing:

- Operation of the acoustic array contributed to positive guidance efficiency for juvenile chinook salmon smolts successfully migrating downstream in the Sacramento River past Georgiana Slough.
- Juvenile salmon released downstream of the acoustic array under ebb tide conditions were collected downstream in the Sacramento River; while juvenile salmon released under flood tide conditions moved upstream, passing into Georgiana Slough whether the acoustic barrier was on or off.
- Movement patterns of juvenile salmon were consistent with the tidally influenced hydraulic conditions at the confluence of the Sacramento River and Georgiana Slough.
- Tidally influenced movement patterns are consistent with the observed reduction in acoustic barrier guidance efficiency under flood tide conditions when compared with ebb tide conditions. These observations support the hypothesis that, during the 1994 test period, juvenile chinook salmon moved upstream in response to flood tides, reducing barrier guidance efficiency during flood tide.

Hydroacoustic Monitoring

Hydroacoustic monitoring was included as part of the 1994 investigations to examine movement patterns of juvenile chinook salmon during the spring using transducers mounted to the gunwale of the boat at a depth of 1.5 feet. Results of hydroacoustic monitoring for juvenile chinook salmon during May 9-18 failed to show a significant shift in estimated abundance of juvenile fish (assumed to be predominately chinook salmon, based on results of Kodiak trawls) in Georgiana Slough and the Sacramento River during periods when the acoustic barrier was on and off.

Results of these analyses were not consistent with findings from either Kodiak trawling or mark/recapture studies, which showed positive acoustic barrier guidance efficiency. Reasons for the discrepancy are unknown but may relate to variability in the short period when hydroacoustic monitoring was done (4 days with the barrier on and 6 days with it off), interaction between tidal and diel effects, or inherent variability in assessing fish abundance and distribution in the Sacramento River and Georgiana Slough. In addition, mobile survey methods may not have provided the resolution required to assess a response to the acoustic barrier given the limited sampling period. Fixed-aspect hydroacoustics may be more appropriate for this application.

Hydroacoustic monitoring, similarly, did not detect any substantial difference in densities of juvenile fish in the Sacramento River in the area of the Sonalysts acoustic signal before operation, during operation of the low-frequency sound pressures, or after completion of the Sonalysts operational cycle. The Sonalysts transducers were not configured nor installed to modify fish behavior (that is, they were not optimized as an array). Hence, results of these limited tests are not representative of the potential effectiveness of the system. In addition, results of the Sonalysts monitoring may be confounded, in part, by the relatively large area in the Sacramento River sampled using the hydroacoustic system relative to the operation of only two transducers. In addition, the lack of definitive information on the effectiveness of the Sonalysts signal may be due to the limited hydroacoustic sampling period (less than 1 day).

Data from hydroacoustic surveys associated with operation of both the EESCO and Sonalysts transducers are available and could be analyzed further to address these and other issues related to spatial and temporal distribution patterns for juvenile chinook salmon in the Sacramento River and Georgiana Slough.

Kodiak Trawl Capture Efficiency Evaluation

Gear efficiency studies (mark/recapture tests) were performed to evaluate collection efficiency of the Kodiak trawl in the Sacramento River and Georgiana Slough. Results of Kodiak trawl capture efficiency tests have shown:

- Spray-dye marking was performed with minimal (0.5%) mortality.
- Capture efficiency of the Kodiak trawl during ebb tides was greater in Georgiana Slough (5.33% recapture efficiency) than in the Sacramento River (2.77% recapture efficiency).

- The Kodiak trawl captured and retained 84% of fish 25-35 mm in length. Capture and retention efficiency was 100% for larger chinook salmon smolts (75-95 mm).

Exposure Tests: Acute and Delayed Mortality and Increased Susceptibility to Predation

Concern has been expressed that the effects on various life stages of fish of exposure to underwater sound pressure levels characteristic of those used in these tests are unknown. Exposure to underwater sound pressure levels could result in physiological damage, resulting in either acute or delayed mortality. There is also concern that sublethal damage may occur, resulting in increased susceptibility of fish to predation. The experimental design of the 1994 Georgiana Slough acoustic barrier research program included study elements designed to provide information on the effects of underwater sound pressure levels on acute and delayed mortality and on differential susceptibility of prey species (*eg*, chinook salmon smolts) to predation.

Results of exposure and predation tests using both the EESCO and Sonalysts transducers have shown:

- Acute and delayed mortality for a variety of fish species (including juvenile chinook salmon, striped bass, sturgeon, catfish, golden shiner, and inland silversides) did not show evidence of increased mortality following a 60-minute exposure to underwater sound pressure levels 9 feet from the sound source.

- Delta smelt exposed to the EESCO signal (60-minute exposure at a distance of 6 feet) did not show increased mortality between treatments (91% survival) and controls (86% survival).

- The rate of mortality for larval striped bass exposed to the EESCO acoustic signal was similar between treatments (90% survival) and controls (90% survival).

- Pacific herring eggs exposed to the EESCO acoustic signal for durations ranging from 24 to 312 hours during incubation did not show evidence of reduced hatching success or increased embryonic abnormalities when compared with controls.

- Results of predation studies provided no evidence of a statistically significant increase in juvenile striped bass (prey) predation following exposure to the EESCO sound signal at a distance of 9 feet for a period of 60 minutes.

Insufficient data were collected to evaluate predation susceptibility for juvenile striped bass exposed to the Sonalysts signal or for juvenile chinook salmon exposed to either the EESCO or Sonalysts transducers.

Blockage/Delay in Migration of Adult Striped Bass and Fall-Run Chinook Salmon

Adult striped bass and chinook salmon migrate upstream in the Sacramento River to spawn. Operation of the acoustic barrier has the potential to block or delay the movement of these fish in both Georgiana Slough and the Sacramento River. Particular concern exists regarding blockage or delays in the upstream migration of adult winter-run chinook salmon. To investigate the behavioral response of adult chinook salmon and striped bass, a series of ultrasonic tagging and hydroacoustic studies was performed.

Results of ultrasonic tagging and hydroacoustic monitoring performed during the fall have shown:

- Upstream migration of adult chinook salmon is not blocked by operation of the acoustic barrier.
- Results of these tests provide no evidence that acoustic barrier operations contribute to a delay in adult salmon migration in either Georgiana Slough or the Sacramento River.
- Adult chinook salmon (monitored using ultrasonic tagging) and potentially other adult fish (monitored with hydroacoustics) were observed moving both upstream and downstream in the Sacramento River whether the acoustic barrier was on or off. The direction of movement was not statistically associated with barrier operations.
- The rate and direction of adult chinook salmon passage was statistically related to environmental factors, principally the magnitude and direction of Sacramento River flow as influenced by the tides, in addition to acoustic barrier operations (significantly faster passage when the acoustic barrier was on).
- Results of hydroacoustic monitoring are consistent in showing the influence of Sacramento River flow and tidal conditions on the direction and movement of fish.

Effects of Acoustic Barrier Operations on Resident Fish and Crayfish Populations

Acoustic barrier operations in the Sacramento River near the confluence with Georgiana Slough may adversely affect habitat suitability of the area for resident fish and crayfish. A variety of fish species inhabit the area on a permanent or seasonal basis, including but not limited to catfish, tule perch, squawfish, splittail, chinook salmon, and striped bass. Operation of the acoustic barrier could contribute to behavioral avoidance of the area, resulting in reduced habitat suitability and utilization by resident fish and crayfish populations. To investigate this potential, the 1994 investigations included periodic fish surveys (beach seining, angler surveys, crayfish trapping).

Results of resident species investigations near the acoustic barrier have shown:

- A diverse group of juvenile fish are abundant in the Sacramento River and Georgiana Slough, including chinook salmon, splittail, silversides, large- and smallmouth bass, gobies, squawfish, striped bass, and others.
- A variety of juvenile fish species were collected in beach seine surveys in the immediate vicinity of the acoustic array when the acoustic barrier was on and when it was off. No pattern was apparent in either abundance or numbers of species collected associated with periods when the acoustic barrier was in operation.
- Crayfish were found to be abundant and widely distributed in the area during both spring and fall surveys.
- Crayfish moved throughout the area, as evidenced by results of mark/recapture studies. However, movement into and out of the area immediately adjacent to the acoustic array was not correlated with barrier operations.
- Crayfish catch per unit effort during the spring studies was lower at the three trapping sites closest to the acoustic barrier during periods when the acoustic barrier was on when compared with periods when it was off. No difference was detected in catch per unit effort at these stations in a limited series of collections during the fall.
- The area where reduced crayfish catch per unit effort was observed during the spring studies appears to extend about 300 feet upstream and downstream of the acoustic array.
- Results of angling surveys showed that striped bass were the most abundant species caught when the acoustic barrier was on (96% of the fish collected) and when the acoustic barrier was off (99% of the fish collected).
- Catch per unit effort in the recreational angler surveys immediately adjacent to the barrier (50-100 feet) was lower when the acoustic barrier was on (0.83 fish/rod-hour) than when it was off (1.8 fish/rod-hour). Factors contributing to the reduction when the barrier was on are unknown.

Acknowledgment

The Department of Water Resources, U.S. Bureau of Reclamation, San Luis & Delta-Mendota Water Authority, and State Water Contractors provided financial and technical support for the 1994 acoustic barrier investigations. Dan Nelson, Frances Mizuno, and Lance Johnson were instrumental in project permitting, administrative, technical and logistic support. Darryl Hayes (DWR) was particularly helpful in providing data and other assistance throughout the 1994 program. Interagency Program and resource agency staffs, including Pat Coulston, Dan Odenweller, Ted Frink, Randy Brown, Gary Stern, Marty Kjelson, Bob Pine, and Ron Brockman reviewed the study plan and experimental design and assisted in various aspects of program implementation. Gary He (DFG Biometrics Unit) provided valuable contributions to the statistical design used in evaluating juvenile chinook salmon guidance data and Phillip Law in providing detailed reviews and comments of preliminary statistical analyses. The staffs of both EESCO and Sonalysts designed, installed, and assisted with various aspects of the operation and testing of the acoustic technologies. Jim Pickens performed underwater acoustic measurements. Patrick Nealson and Kevin Kumagai (HTI), and Eddie Kudera (BioSonics) performed hydroacoustic monitoring. The USGS staff provided data on Sacramento River and Georgiana Slough flows and performed velocity measurements. The Boathouse Marina in Locke provided moorage facilities and logistic support for the field fisheries investigations. Fish were collected by Bill Harrell, Kim Laur, Frank Bauman, Keith Whitener, Charles Pratt, Andy Milam, Tom Copper, Blake Price, Jackie Hagen, Doug Brooks, Kris Kuhn, Vergil Chaddock, Barbara Gardener, and Dennis Hood. Jeff Hagar provided technical assistance in the early phases of the project and was instrumental in the design of much of the equipment used. Charles White performed statistical analyses and assisted with various aspects of data interpretation. Tom Boardman and Christine Zupan provided assistance in data management and preparation of graphics. Sandi Hanson assisted in all aspects of the project, including preparation of data summaries and the 1994 documentation report.

Scientists from state and federal resource agencies have provided valuable and constructive comments, which substantially improved the 1994 research program. We express our thanks and appreciation to all who have contributed to this project.

Chapter 1

Introduction

Juvenile chinook salmon emigrating from spawning and rearing areas in the upper Sacramento River and its tributaries are susceptible to diversion into the central Delta from the Sacramento River at the Delta Cross Channel, Georgiana Slough, and Threemile Slough. Studies using fall-run salmon smolts have demonstrated substantially higher mortality rates for those fish passing into the interior Delta (Kjelson *et al* 1990; USFWS 1992). The increased mortality rates reflect, in part, increased susceptibility to predation, delays in migration, exposure to elevated temperatures, and increased exposure to entrainment at the State Water Project, Central Valley Project, and other Delta water diversions. Juvenile winter-run chinook salmon losses as a result of entrainment at the SWP and CVP diversions are regulated by incidental take provisions of the Endangered Species Act.

The diversion of winter-run and other races of chinook salmon smolts from the Sacramento River into the interior Delta can be reduced if the Delta Cross Channel gates are closed coincident with the period of emigration. However, winter-run and other races of chinook salmon continue to be susceptible to movement from the Sacramento River into the central Delta through Georgiana Slough (Figure 1), where no provisions for fish protection currently exist. Proposals have been considered to physically block the passage of juvenile salmon into Georgiana Slough through installation of a rock barrier or other structures. Concern has been expressed, however, that the use of such a barrier may adversely affect water quality within the slough and Delta, alter the natural flow of water from the Sacramento River through interior Delta channels, impede upstream migration of adult fish, and obstruct recreational boating.

An alternative approach would be a behavioral barrier designed to use the avoidance response of juvenile salmon to reduce diversion into Georgiana Slough without adversely affecting hydrology, water quality, or navigation. In light of provisions of the Endangered Species Act that limit the incidental take of protected species, the application of behavioral barriers represents a potentially significant benefit contributing to an overall reduction in incidental take from water diversion operations.

A preliminary field demonstration project (Phase I) was conducted during May and June, 1993, to evaluate the feasibility and effectiveness of an acoustic barrier in deterring juvenile chinook salmon from entering Georgiana Slough (Hanson 1993). Results of the Phase I field test showed that diversion efficiency of the acoustic barrier was promising (Hanson 1993). Based on the encouraging results, a more detailed and thorough evaluation of the effectiveness of an acoustic barrier at the confluence of the Sacramento River and Georgiana Slough was proposed (Phase II; Hanson and Johnson 1994). The Phase II applied research program was conducted using a temporary facility in operation from April through June 1994 to evaluate guidance efficiency for juvenile chinook salmon and other issues. Additional testing of the behavioral response of upstream-migrating adult fall-run chinook salmon (potential blockage or delays in migration) was conducted from October through mid-November 1994. Prior to initiating fall testing of the behavioral response of adult chinook salmon to the acoustic barrier, results of all spring monitoring and experimental investigations were compiled and presented to State and Federal resource agencies.

This report documents objectives, methods, and results of the spring and fall 1994 Phase II acoustic barrier investigations. Future phases of the project include guidance evaluations in different water year types and additional studies on delta smelt and adult salmon migrations.

The Phase II applied research project was developed based on findings of the 1993 Phase I cooperative research program conducted under the auspices of the Interagency Ecological Program. The Phase II program included a series of field and laboratory investigations (Table 1) designed specifically to provide scientific data to address agency concerns regarding the effectiveness and potential adverse effects associated with operation of the acoustic barrier. Specific issues to be addressed were identified in cooperation with the National Marine Fisheries Service, U.S. Fish and Wildlife Service, California Department of Fish and Game, California Department of Water Resources, and U.S. Bureau of Reclamation.

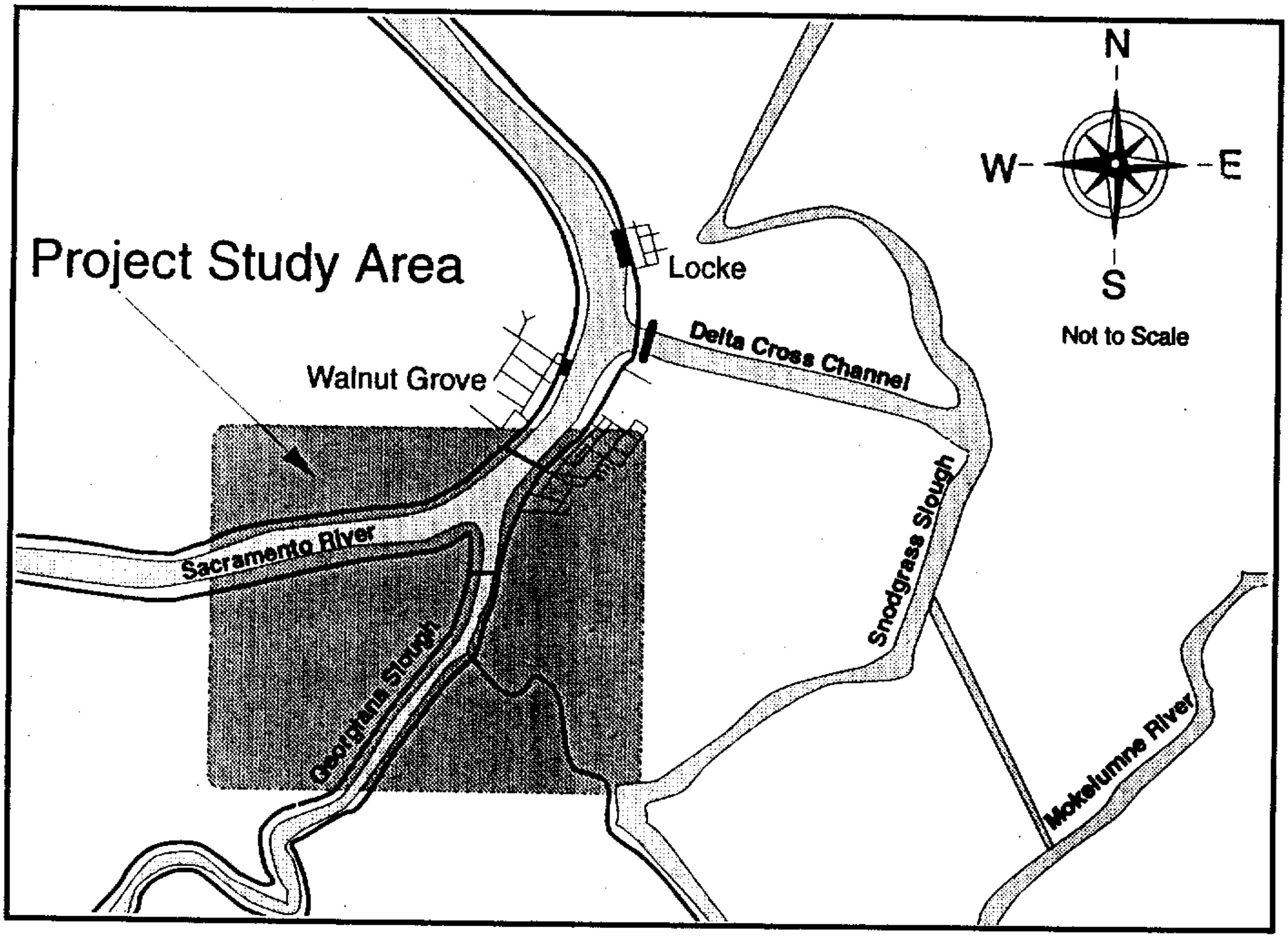

Figure 1
PROJECT STUDY AREA, INCLUDING THE SACRAMENTO RIVER AND GEORGIANA SLOUGH

Table 1
SUMMARY OF ISSUES AND STUDY ELEMENTS
1994 Acoustic Barrier Investigations

Issue	Comment
Anchoring	Engineering review; weekly aerial photos of barrier location
Impacts to boaters/navigation	Field observations; interviews; complaints
Predictive design criteria	Velocity measurement; flow measurements; acoustic mapping
Impact to delta smelt spawning	Acoustic mapping- area of potential influence; laboratory tests
Guidance efficiency over a range of flows	Kodiak trawl surveys over a range of flows; hydroacoustic surveys
Horizontal and vertical distribution of juvenile chinook salmon	Three trawls across river up and downstream; paired Otter/Kodiak trawls; hydroacoustic surveys
Lack of replication/statistical power	Replication of barrier configuration and guidance evaluation in 1994
Calculation of guidance efficiency	IEP study plan review; CDFandG statistical review; CWT survival test
Impacts on recreational fishery	Creel survey (CPUE); interviews
Impact to delta smelt egg development/hatching success	Laboratory exposure experiment
Increased susceptibility to predation	CWT survival test; experimental predation tests
Attraction of predatory fish	Creel survey; hydroacoustic surveys

Objectives of the Phase II Investigations

Primary objectives of the Phase II applied research program were to gather data about:

- The effects of the acoustic barrier on guidance efficiency for fall-run chinook salmon smolts (used as a surrogate for winter-run smolts);
- Potential blockage or delays in upstream migration for adult chinook salmon;
- Delayed effects of exposure (*eg*, increased susceptibility to predation, mortality, loss of equilibrium, etc) of chinook salmon smolts and other fish to the underwater acoustic (sound) signal produced using two alternative acoustic technologies (EESCO and Sonalysts).

The Phase II studies addressed concerns related to:

- Evaluation and documentation of the acoustic barrier in successfully guiding juvenile chinook salmon away from the entrance to Georgiana Slough (evaluation of fish guidance/repulsion capability);
- Potential adverse effects on the behavior or survival of chinook salmon, delta smelt, striped bass, and other fish species as a direct result of exposure to the underwater acoustic signal.

Design of the Phase II Investigations

Although the 1994 studies addressed a wide range and number of program elements, the primary emphasis of the field sampling and controlled experimental studies was to provide statistically reliable, replicated data for use in evaluating:

- Guidance efficiency of the acoustic barrier for juvenile salmon;
- Acute mortality and delayed effects as a result of exposure to the acoustic signal.

The Phase II investigations involved cyclical barrier operation and intensive physical and biological data collection to address a number of issues related to barrier operations (Table 1). Unless modified for specific experiments, routine acoustic barrier operations followed a cyclical pattern of 2 days on and 5 days off each week (guidance efficiency studies based on Kodiak trawl collections were conducted 2 days with the barrier on and 2 days with the barrier off each week). Results of the 1994 field studies and controlled experimental (field and laboratory) tests provide additional data on the effectiveness of this technology, facilitate refinement of the acoustic system at Georgiana Slough, evaluate remaining questions as to potential impacts of system operation, and increase the understanding of the potential use of this technology at Georgiana Slough and elsewhere in the estuary as a means of protecting and enhancing native fish populations.

Development of the 1994 study plan and experimental design for the Georgiana Slough acoustic barrier tests benefited from consultations and review comments provided by representatives of the Department of Fish and Game, U.S. Fish and Wildlife Service, National Marine Fisheries Service, Department of Water Resources, and U.S. Bureau of Reclamation. Agency consultation and review of the 1994 Phase II Research Program has been coordinated through the Interagency Ecological Program Fish Facilities Committee. The National Marine Fisheries Service, U.S. Fish and Wildlife Service, and Department of Fish and Game provided consultations related to winter-run chinook salmon and delta smelt.

Chapter 2

Acoustic Barrier Operations and Environmental Conditions

The acoustic barrier tested as part of the 1994 research program was in the Sacramento River immediately upstream of the confluence with Georgiana Slough (Figure 1). The test site is adjacent to the town of Walnut Grove. The acoustic barrier was about 0.1 mile downstream of the Highway 160 bridge across the Sacramento River and about 0.5 mile downstream of the Delta Cross Channel.

To facilitate testing, an on-site facility was established on the downstream point of the confluence between Georgiana Slough and the Sacramento River. The on-site facility included diesel-powered electrical generators, amplifiers, and computer control systems for operating the EESCO acoustic system. The site also housed operating controls for the Sonalysts acoustic system. On-site storage and office facilities were provided by temporary structures, in addition to an on-site holding and experimental testing system composed of various fiberglass tanks and a once-through water supply system providing ambient river water to the holding facilities. The site was equipped with a floating dock for access to boats and fish holding and testing equipment.

The acoustic technology and acoustic signal developed by Energy Engineering Services Company (EESCO) was the only system tested for juvenile chinook salmon guidance efficiency and effects of acoustic signals on the migration of adult chinook salmon. Exposure testing and underwater sound pressure measurements were performed, separately, for acoustic technologies developed by both EESCO and Sonalysts, Inc. Sonalysts testing focused primarily on determining immediate and delayed effects of exposure of test species to signals generated by the Sonalysts transducers.

The site was instrumented to provide detailed information on environmental conditions during the testing period. Flow measurements were recorded at 15-minute intervals at acoustic velocity measurement (AVM) stations operated by USGS, which were located in the Sacramento River upstream (above the Delta Cross Channel) and downstream of the acoustic barrier. Sacramento River water temperature was monitored at 20-minute intervals throughout the testing period (Ryan Model RTM 2000). In addition, underwater sound pressure levels (during acoustic barrier operations and as background conditions) were measured periodically at various sites and water depths at the site. Water surface elevation, used to determine tidal stage, was provided at 15-minute intervals from a DWR monitoring gauge at the confluence of Georgiana Slough and the Sacramento River. Water velocities throughout the water column were measured by USGS at various transects in the Sacramento River and Georgiana Slough during ebb and flood tidal stages for use in characterizing generalized current patterns and velocity profiles at the site.

This chapter describes the acoustic technologies tested as part of the 1994 program and presents general information on environmental conditions during the spring and fall testing periods. Results of environmental monitoring (*eg*, Sacramento River flow rate, tide stage, underwater sound pressure levels) were used at discrete periods coinciding with data collected as part of the acoustic barrier guidance efficiency tests and exposure testing to provide detailed information on conditions occurring coincident with biological collections.

Energy Engineering Services Company (EESCO)

The Phase II project involved the reinstallation and operation of a low-frequency (300-400 Hz) underwater acoustic (sound) array. The acoustic array comprised 21 underwater transducers (Argotec Model 215) spaced at intervals of about 30 feet and temporarily anchored in a linear configuration in the Sacramento River (Figure 2). The site of each underwater transducer (suspended about 12 feet below the surface) was marked using a surface float about 30 inches in diameter. The acoustic signal was conveyed to the transducers through a series (bundle) of shielded coaxial cable anchored to the river bottom (Figure 3). The coaxial cable extended across the surface of the shoreline levee to an on-site facility housing the computerized signal generators, amplifiers, and other electronic equipment.

Details of the signal development process used by EESCO are included in Loeffelman *et al* 1991a, b, and c. The theory behind the EESCO acoustic signal is that juvenile chinook salmon, and other fish species, will elicit a behavioral response (*eg*, avoidance reaction) to an audible sound signal. The acoustic signal used during the 1994 testing program was identical, in frequency and magnitude, to the acoustic signal used during the 1993 Phase I preliminary

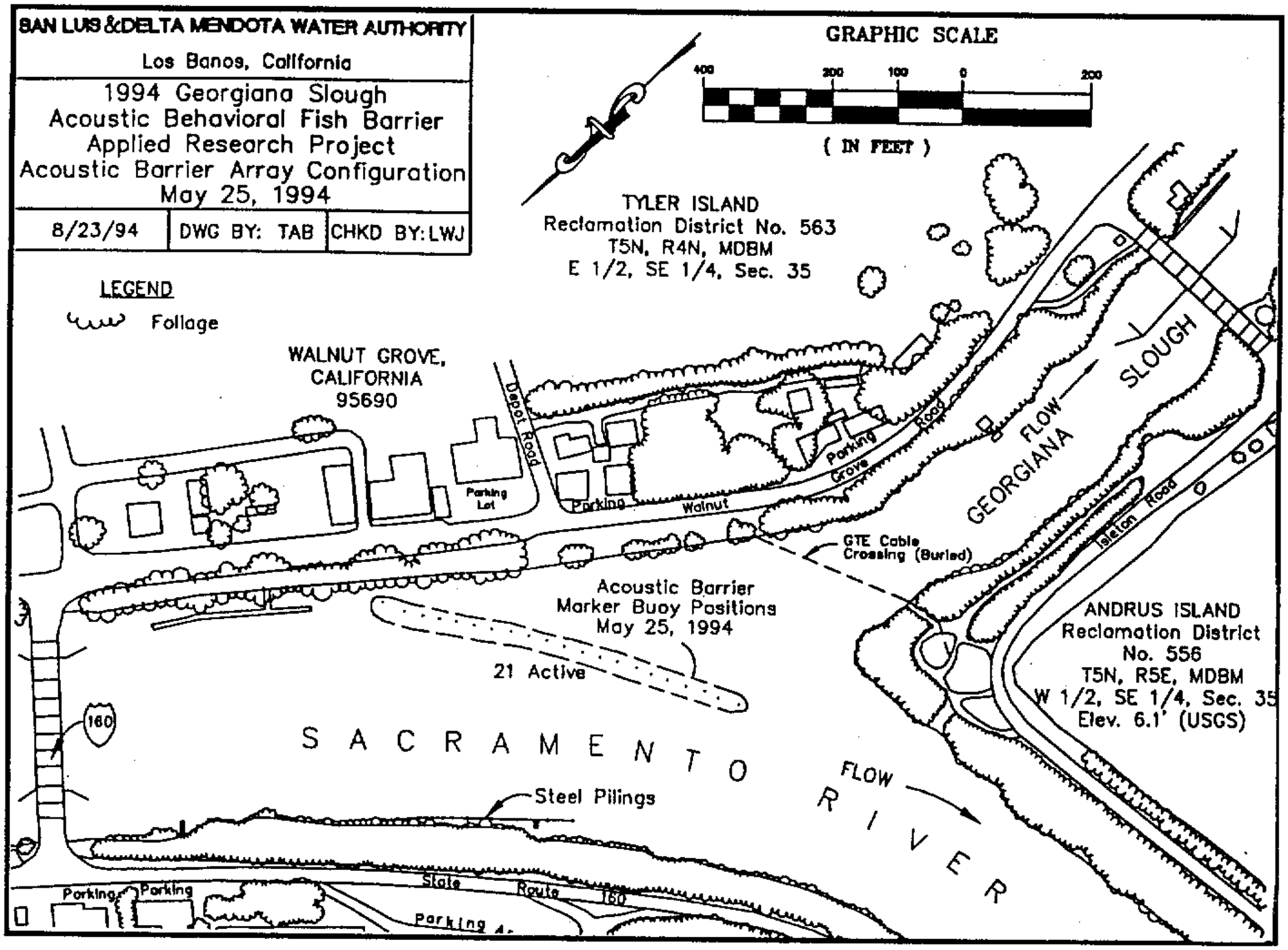

Figure 2
LOCATION OF THE EESCO ACOUSTIC ARRAY DURING SPRING AND FALL TESTING

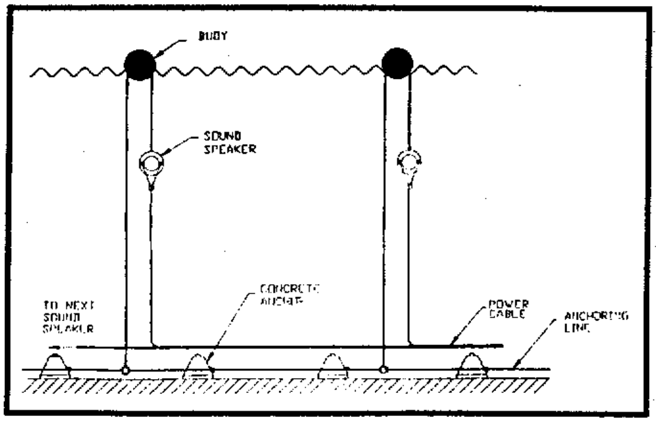

Figure 3
ANCHORING SYSTEM FOR THE
EESCO ACOUSTIC BARRIER

investigations. The original signal was developed after characterizing sounds produced by fall-run chinook salmon smolts. After technical analysis of the sound spectra recorded from juvenile smolts, an artificial acoustic signal was synthesized on a waveform generator. The signal was designed to be heard by salmon smolts to stimulate a behavioral response to the acoustic system created by the transducer array in the river. Two frequencies (300 and 400 Hz) were used in a pulsed, crescendo pattern verified by field acoustic mapping. Both the configuration of the acoustic array and the frequency and magnitude of the acoustic signal were maintained throughout the 1994 testing period to allow for development of statistical replication among weekly testing cycles for use in evaluating juvenile chinook salmon guidance efficiency during the spring and adult response during the fall testing.

Sonalysts, Inc.

The 1994 studies were expanded to include a limited series of controlled field tests using equipment and the low-frequency (10 Hz) acoustic signal developed by Sonalysts, Inc. The theory behind the Sonalysts signal is that juvenile chinook salmon and other fish species are able to detect and behaviorally respond (*eg*, avoidance reaction) to particle acceleration exceeding a threshold of 0.01 m/sec/sec. Appendix A is report by Sonalysts (1994) discussing the installation and operations of the low-frequency (FishStartle) acoustic system. Sonalysts provided two low-frequency electro-mechanical transducers and all necessary power cables, system controls, and mooring for use in these tests. Each low-frequency transducer included an electric motor, a reduction gear box, and a two-throw crankshaft, each throw connected to a shaft driving a circular plate projector about 10 inches in diameter. The projector is operated in synchronization, making the transducer a dipole source. Each transducer was suspended from three polyform floats and anchored to the bottom. Each transducer was powered by a 7.5 horsepower, 460 volt, three-phase electric motor. Electrical power for the transducers was provided by a diesel generator.

Each transducer was oriented vertically in the water column, with the top of the transducer 4 feet below the surface. Water depth in the area was about 15 feet. The transducers were installed during the first week of May and removed from the site during the second week of July.

During the testing period, two equipment-related problems occurred. A mechanical problem with the gear box to crankshaft drive coupling prevented the motor from driving the crankshaft, thereby disabling the projectors. Underwater inspection confirmed that coupling setscrews had become loose. The problem was solved by applying an anaerobic locking thread compound (LOC TITE) to all fasteners susceptible to vibration loosening.

The second problem involved a failure of the anchoring system, which allowed the upstream transducer to drift downstream and become entangled with the downstream unit. Inspection showed that the stainless steel cable used in anchoring the upstream transducer had chafed and parted as a result of current and wave activity.

Studies using the Sonalysts signal included predation susceptibility tests and evaluation of acute and delayed mortality effects on selected juvenile fish species. Tests of the Sonalysts acoustic technology were performed using two sound generators temporarily anchored in the Sacramento River near the Georgiana Slough test site (Figure 4). Operation and testing of the Sonalysts technology was scheduled to avoid conflicts with the EESCO guidance tests. These studies were selected for inclusion in the 1994 program to provide comparative information regarding these two alternative acoustic technologies.

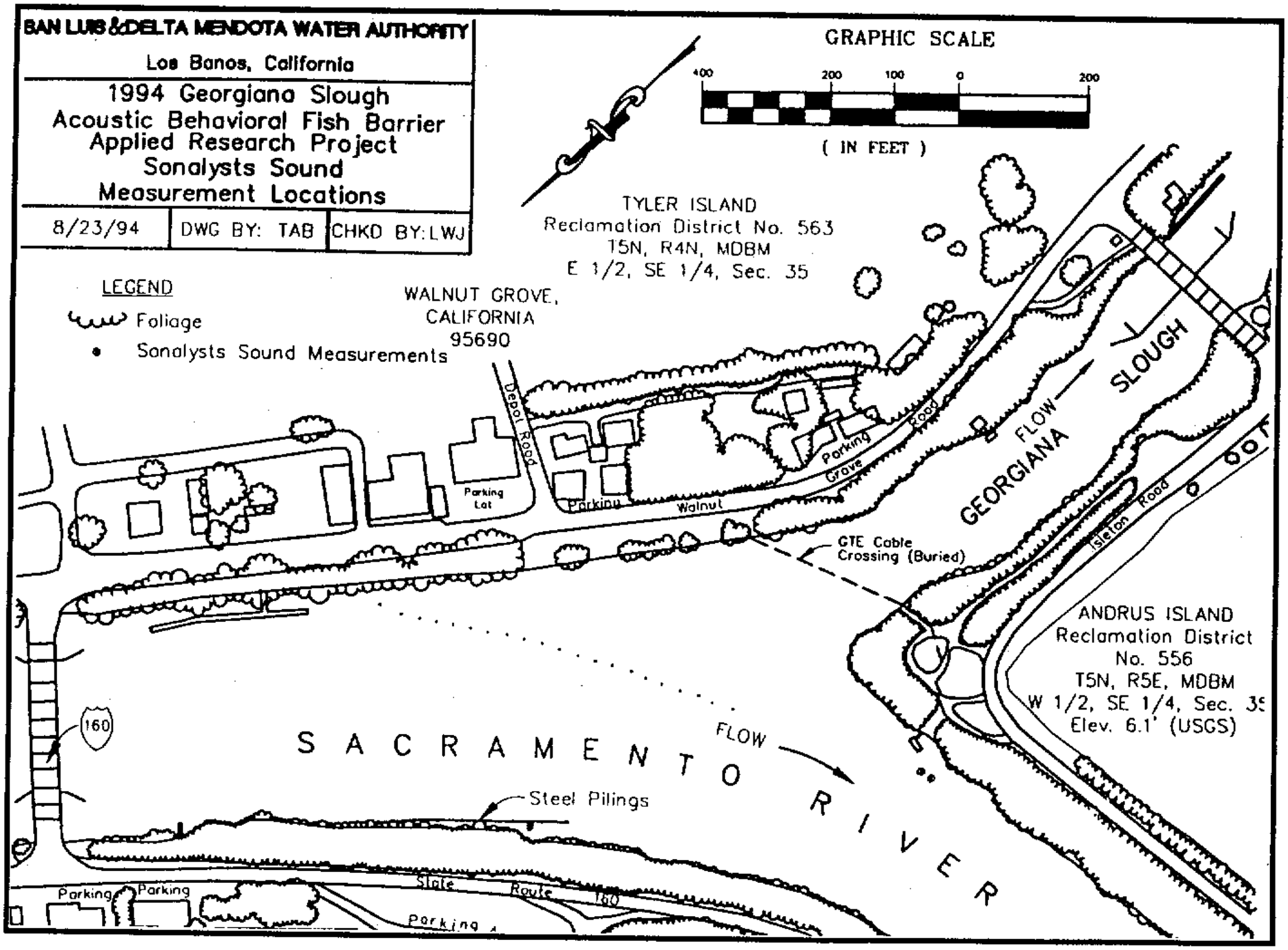

Figure 4
LOCATION OF THE SONALYSTS ACOUSTIC TRANSDUCERS

Acoustic Barrier Sites

To confirm the site of the EESCO acoustic array, vertical aerial photographs were taken weekly to document the site of each sound projector throughout the spring (April-June) salmon guidance efficiency testing period. Ground truthing reference markers were located in the area of the acoustic barrier for use in orienting and calibrating the scale for each weekly aerial photograph. The site of each transducer, marked by surface floats, was mapped from the aerial photographs for use as part of project documentation. Figure 2 is an example of the acoustic barrier site and configuration (May 25, 1994) based on the aerial photograph. A map derived from aerial photographs documenting the acoustic barrier site each week is included in Appendix B.

An essentially constant site and orientation of the acoustic array was maintained throughout the 1994 testing period. A stainless steel cable attached to the shoreline near Walnut Grove and the shoreline along Andrus Island, adjacent to the onsite facility, was used to orient the acoustic array, maintain proper spacing of the transducers, and help anchor the array to resist movement by currents and debris. The anchoring system was successfully maintained the site of the array throughout the 1994 program.

The acoustic array included 21 active transducers. During the first several weeks of testing, an additional three marker buoys and transducers were placed at the downstream end of the array, in case biological guidance testing demonstrated that additional transducers would improve guidance efficiency. These three transducers were not operated as part of the 1994 testing program and were removed in mid-April.

Acoustic Measurements

A key element in evaluating acoustic barrier performance at Georgiana Slough includes measurement of the amplitude and frequency of underwater sound generated by the acoustic barrier. To provide information on characteristics of the acoustic signal, sound pressure level measurements were performed at various sites and water depths. Sound pressure levels were measured when the EESCO acoustic technology was in service, when Sonalysts technology was in service, and as ambient background sound levels in this part of the river. Tabulated results of underwater acoustic measurements (dB) provide information identifying the gradient of sound pressure extending from the acoustic array and the potential zone (area and volume) where exposure of organisms to increased sound levels would occur.

Acoustic measurements were made during two spring surveys and one fall survey. During the spring studies, sound pressure level measurements associated with the EESCO transducers and background measurements were made in the Sacramento River and Georgiana Slough (Figure 5). During the fall studies, the EESCO acoustic array was in service to evaluate the effects of underwater sound on migration rates of adult fish. Sound pressure level measurement sites during the fall studies are shown in Figure 6.

Because of the low-frequency particle acceleration field produced by the Sonalysts transducers, the near-field signal dominated for a range of about 79 feet. Far-field acoustic measurements were not appropriate for characterizing particle displacement, particle velocity, or particle acceleration; hence, sound pressure level measurements have not been included in this report.

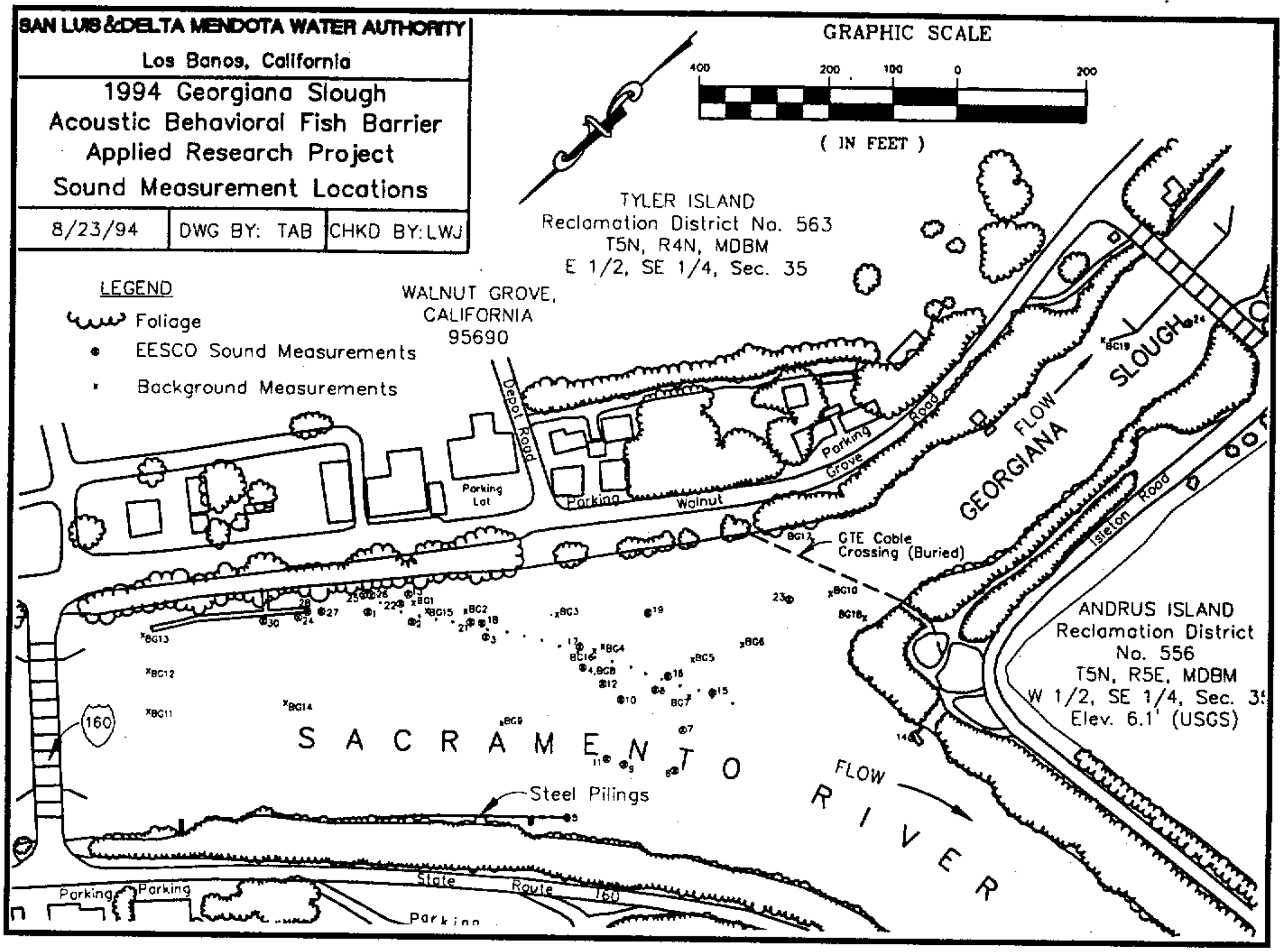

Figure 5

ACOUSTIC MEASUREMENT LOCATIONS DURING OPERATION OF THE EESCO ACOUSTIC SIGNAL AND AMBIENT BACKGROUND (SITES BG) SOUND MEASUREMENTS DURING THE SPRING INVESTIGATIONS

All sound pressure level measurements were performed by Pick Associates. Underwater sound pressure levels were measured using a Bruel and Kjaer (Model 8105) calibrated hydrophone, Kistler Charge (Model 5004D) amplifier set at 0.359 pC/Pa with a linear frequency response from 6 Hz to 180 kHz. A spectrum analyzer (Hewlett Packard Model 3561A) with a frequency response from 2 Hz to 100 kHz was used with a Hewlett Packard Inkjet printer for recording sound spectra at each monitoring site in the field. The acoustic measurement system was powered by a DC-AC power inverter and 12-volt battery. Sound monitoring was performed from a 17-foot boat at each designated monitoring site. Spectral analyses prepared for each site showed the frequency and magnitude of the acoustic signal, which were subsequently used to characterize the acoustic field generated by the EESCO transducers and background levels. Sound pressure measurements were also performed at specific sites used during exposure and predation testing.

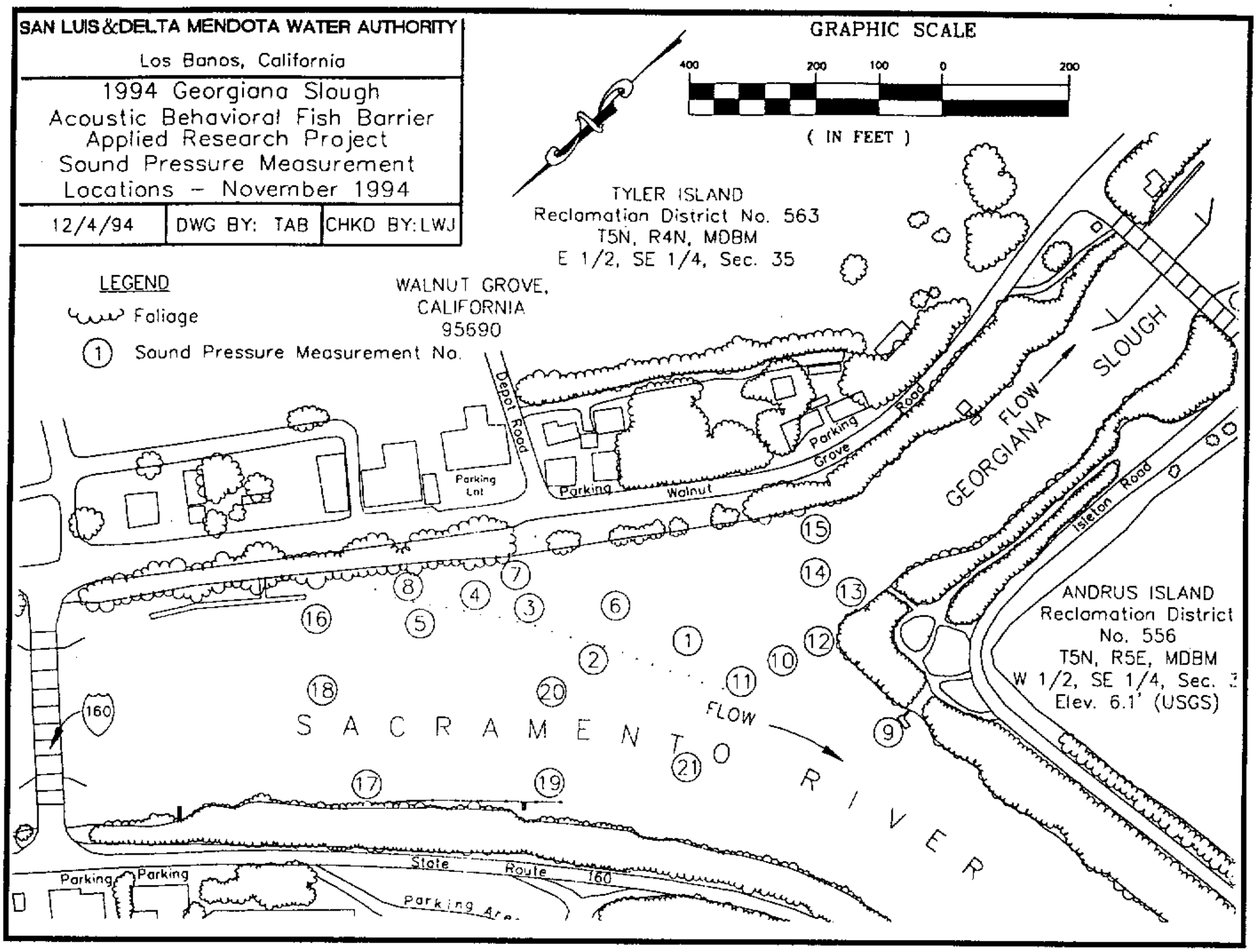

Figure 6
LOCATION OF UNDERWATER SOUND PRESSURE LEVEL MEASUREMENTS ASSOCIATED WITH OPERATION OF THE EESCO ACOUSTIC ARRAY DURING THE FALL INVESTIGATIONS

Measurements were made at various sites and water depths to characterize background acoustic characteristics in the Sacramento River and Georgiana Slough (Figure 5, sites designated BG). Results of the background sound pressure level measurements (Table 2) consistently showed sound pressure levels ranging from about 88 to 97 dB. Background sound levels did not vary substantially in magnitude among sites or at the 5- and 10-foot water depths. Frequency of the peak acoustic signal did, however, vary substantially from one measurement site to another.

Table 3 is a summary of results of underwater sound pressure measurements for the EESCO system during the spring testing period. The maximum measured sound pressure level was 160 dB (300 Hz) at Site 2 (Figure 5) at a depth of 15 feet. Most sound pressure levels measured in the immediate vicinity of the acoustic array ranged from 130 to 150 dB. A biological perspective of sound pressure levels can be seen in lethal thresholds for fish produced by explosives, which range from 229 to 234 dB 1 µPa (Norris and Mohl 1983; cited in Bennett *et al* 1994). A difference of 80 dB (*ie*, 230-150 dB) is equivalent to a 10,000-fold decrease in underwater sound pressure.

Table 2
BACKGROUND SOUND PRESSURE LEVELS NEAR THE ACOUSTIC BARRIER

Site	Measurement Depth (feet)	Frequency (Hz)	Decibels
BG01	5	252.5	90.07
BG02	5	290	89.50
BG03	5	295	93.55
BG04	5	252.5	91.79
BG05	5	262.5	90.42
BG06	5	255	89.44
BG07	5	255	91.01
BG08	5	352.5	89.33
BG09	5	407.5	91.35
BG10	10	407.5	90.75
BG11	10	155	89.06
BG12	10	180	98.84
BG13	10	180	87.75
BG14	10	180	97.20
BG15	10	172.5	90.04
BG16	10	150	91.18
BG17	10	182.5	89.84
BG18	10	192.5	92.43
BG19	10	207.5	91.81
BG20	10	232.5	91.55

Acoustic sound pressure level measurements during operation of the Sonalysts acoustic technology during the spring studies, at a depth of 10 feet, are:

Site	Frequency (Hz)	Decibels
S1	9.2	140.6
S2	9.35	
S3	9.15	108
S4	12.85	125.05
S5	10.0	111.65

Sound pressure levels diminished rapidly with distance away from the acoustic array; however, levels above background were detected about 1/4-mile upstream and downstream of the acoustic array. Sound pressure levels varied with water depth.

Table 3
EESCO SOUND PRESSURE LEVELS NEAR THE ACOUSTIC BARRIER DURING SPRING TESTS

Site	2-Foot Depth		5-Foot Depth		10-Foot Depth		15-Foot Depth		20-Foot Depth		25-Foot Depth	
	300 Hz	400 Hz	300 Hz	400 Hz	300 Hz	400 Hz	300 Hz	400 Hz	300 Hz	400 Hz	300 Hz	400 Hz
E01			147.56	153.24	146.41	145.55	146.84	150.78	148.59	152.75	139.05	
E02			157.04	146.01	158.17	156.74	159.89	151.81	149.84	152.64	152.78	147.54
E03			147.24	151.88	147.79	144.20						
E04	142.01	143.59										
E05				150.80								
E06	139.37	135.70	135.44	133.28	145.80	139.87	146.83	144.07	142.10	143.16	145.33	148.33
E07	136.73	133.48	142.06	134.03	138.37	142.52	147.70	137.20	142.24	138.92	141.45	148.21
E08	141.15	144.09	143.53	142.99	155.96	134.15	146.63	145.94	148.38	140.68	154.32	141.59
E09	130.78	126.62	135.40	132.08	146.56	146.54	139.89	145.79	134.60	139.98	142.05	138.44
E10		137.47	132.70	133.08	140.51	129.78	141.52	139.66	145.73	153.22		
E11	128.59	138.17	130.39	137.61	134.69	136.66	135.07	147.27	135.95	144.33		143.59
E12	136.17	140.18	144.38	142.88	143.95	146.05						
E13					156.00	144.39						
E14					130.73	130.38						
E15			150.27		142.31	146.18	149.73	151.46	149.70	148.38		
E16			141.62	146.62	148.11	140.38	145.22	152.93	137.34	152.53		
E17			153.86	151.06	131.05	153.84	142.55	151.53	139.32	145.10		
E18			152.36	136.64	144.31	136.00	136.48	147.55	149.96	147.13		
E19			127.94	143.87	139.89	142.76	144.53	130.49	139.87	143.76		
E20						138.57						
E21			149.00	146.81	155.97	161.28	152.88	147.63	154.43	150.22		
E22			111.82	111.92	109.63	123.75						
E23			122.87	130.02	119.86	131.56	123.04	132.27	124.61	129.83		
E24							107.47	111.44				
E25			152.23	157.04	154.97	149.61						
E26			142.61	151.20								
E27			140.51	145.75	144.77	150.46	145.49	151.01				
E28			132.46	142.65	134.23	141.49						
E29			142.52	139.83	134.01	145.62	134.82	146.14				
E30			132.22	128.07	123.35	134.89	134.69	126.89				

Sound pressure measurements associated with the EESCO transducers during the fall (Table 4) were similar in frequency and magnitude to measurements during the spring. During the fall studies, most underwater sound pressure level measurements were concentrated at the 10- and 20-foot depths to provide better documentation on acoustic characteristics encountered by migrating adult chinook salmon. Maximum sound pressure level measured during the fall was 155.5 dB (400 Hz) at Site 4 at a depth of 20 feet (Figure 6). Most sound pressure levels in the vicinity of the acoustic array ranged from 135 to 150 dB.

Table 4
EESCO SOUND PRESSURE LEVELS NEAR THE ACOUSTIC BARRIER DURING FALL TESTS

Acoustic measurements made November 4, 1994.

Site	3-Foot Depth		10-Foot Depth		20-Foot Depth	
	300 Hz	400 Hz	300 Hz	400 Hz	300 Hz	400 Hz
1			138.0	147.9	142.8	137.1
2			154.0	150.4	153.2	142.4
3			154.4	147.7	153.6	139.8
4			148.3	143.4	145.6	155.5
5			148.5	150.5	142.3	148.7
6			143.3	150.2	137.6	141.7
7			144.2	153.3	137.6	144.3
8			151.2	152.9		
9			126.3	123.4		
10			127.3	126.0	122.6	131.2
11			121.1	146.7	133.0	146.3
12		129.5				
13			137.2	136.0	123.1	119.3
14			137.7	136.2	132.2	133.9
15			129.8	133.4	124.5	121.2
16			133.0	142.0	115.8	127.8
17			134.9	136.6	123.5	126.1
18			137.1	141.4	133.7	143.4
19			141.0	150.5	130.5	136.9
20			144.5	144.6	134.6	144.0
21			140.5	136.5	137.6	140.8

Sound pressure levels, above background, were measured during the fall studies (EESCO signal) across both the Sacramento River and Georgiana Slough. For example, underwater sound pressure levels at Sites 16, 17, and 18 across the Sacramento River channel (Figure 6) at a depth of 10 feet ranged from 133 to 142 dB (Table 4). Similarly, sound pressure levels at a depth of 10 feet at Sites 13, 14, and 15, across the Georgiana Slough channel ranged from 129.8 to 137.7 dB (Table 4). Results demonstrate that adult chinook salmon, striped bass, and other fish species migrating up the Sacramento River or Georgiana Slough would be exposed to elevated underwater sound pressure levels throughout the cross section of the channel, although sound pressure levels measured at these sites were substantially lower than those immediately adjacent to the acoustic array.

Velocity Measurements

Guidance efficiency associated with operation of the acoustic barrier has been hypothesized to be closely related to water velocity in the Sacramento River and Georgiana Slough. Juvenile chinook salmon swimming performance capability and reactive distance to the acoustic signal are both related to velocity. To gain greater understanding of the interrelationship between guidance efficiency of the acoustic barrier and water velocity for use in developing generic design criteria for acoustic barrier technology applications at other sites, and to determine potential variation in guidance efficiency as a function of water velocity and their vectors in the Sacramento River, the 1994 studies included detailed water velocity measurements at various depths and sites. The U.S. Geological Survey performed a series of velocity measurements in the area adjacent to the acoustic barrier site using an acoustic doppler current profiler (ADCP) velocity measurement technology.

Water velocity was measured at transects upstream and downstream of the acoustic array in the Sacramento River and Georgiana Slough. Water velocity was measured throughout the water column at each transect during surveys between May 24 and May 27. Flows in the Sacramento River and Georgiana Slough during each of three series of velocity measurements are shown in Figures 7, 8, and 9. The surveys were performed during three tidal stages: Series 1 during a low slack, Series 2 during a flood tide, and Series 3 during an ebb tide. Stage height measured in the Sacramento River below Georgiana Slough during these surveys is shown in Figure 10. Detailed velocity measurement data for each survey and transect are included in Appendix C. These data were used to plot water current velocities (streamlines) in the Sacramento River and Georgiana Slough.

Results of Series 1 velocity measurements (low slack tide) are shown in Figure 7 at water depths of 4 feet and 10 feet. Water velocity typically ranged from 1 to 2 feet per second.

Results of Series 2 water velocity measurements (flood tide) are shown in Figure 8 at water depths of 4-feet and 10-feet. Velocity during the flood tide was generally lower than during the low slack tide. In contrast to low slack and ebb tide conditions, water in the Sacramento River downstream of the confluence with Georgiana Slough reverses direction, flowing upstream during the flood tide (Figure 8) under flow conditions occurring during these studies. The reverse flow was consistent throughout the spring period of juvenile salmon guidance evaluations. Flow direction in Georgiana Slough was consistently downstream during all tidal stages during the velocity study (Figures 7, 8, and 9).

Water velocity during Series 3 (ebb tide) are shown in Figure 9 for the 4-foot and 10-foot depths. Velocities during the ebb tide typically ranged from 1 to 2 feet per second in the Sacramento River and 0.5 to 1 foot per second in Georgiana Slough. Water velocity in the Sacramento River downstream of the confluence with Georgiana Slough was typically lower during flood tide (and flow direction reversed) when compared with ebb tide. In contrast, velocity in Georgiana Slough was typically higher, by a factor of about 2, during flood tide (Figure 8) than during ebb tide (Figure 9).

These results demonstrate the complex hydrology in the Sacramento River at the confluence with Georgiana Slough and the importance of tidal stage in determining both the direction and velocity of water movement.

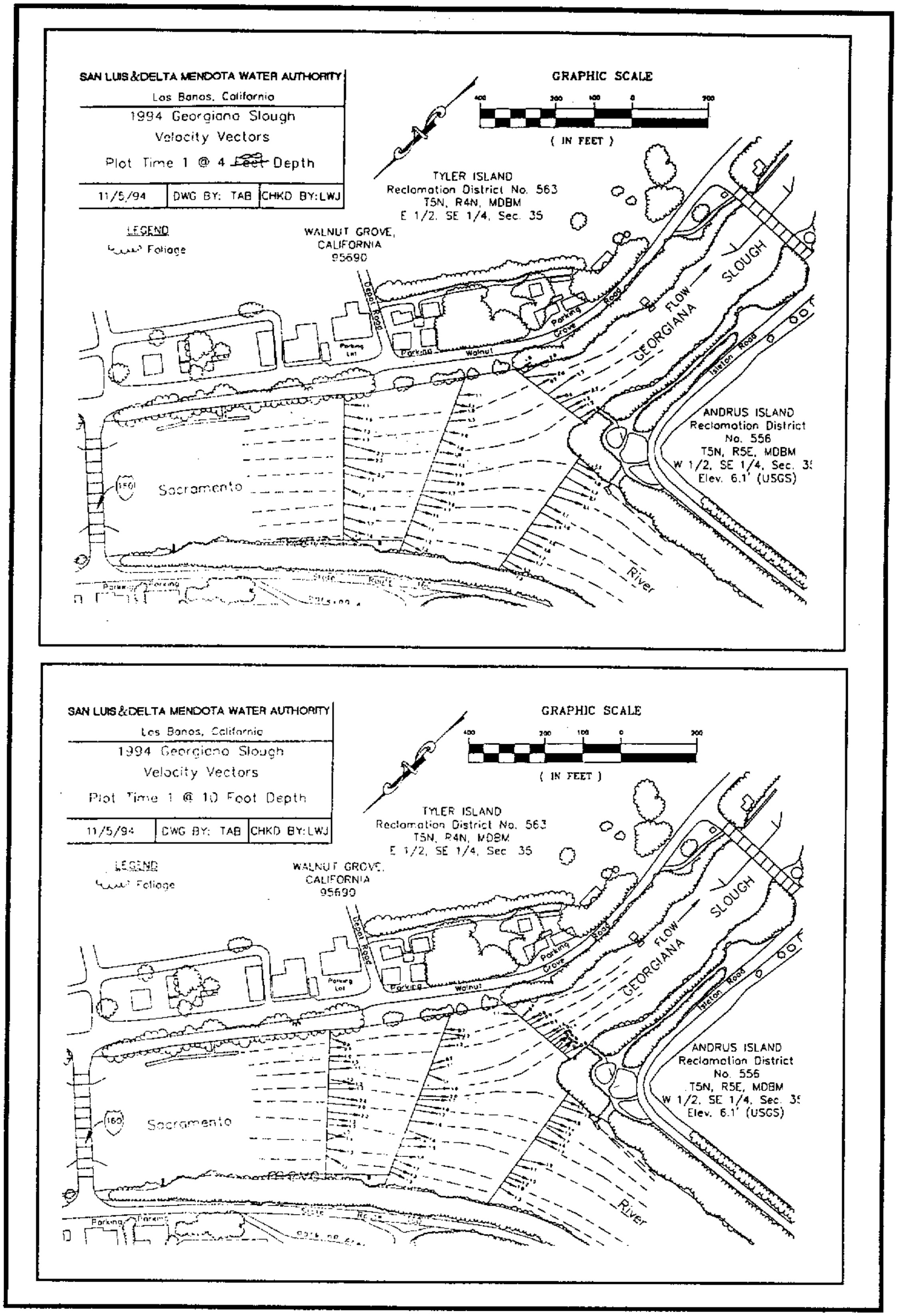

Figure 7

VELOCITY VECTORS IN THE SACRAMENTO RIVER AND GEORGIANA SLOUGH AT WATER DEPTHS OF 4 FEET AND 10 FEET DURING LOW SLACK TIDE

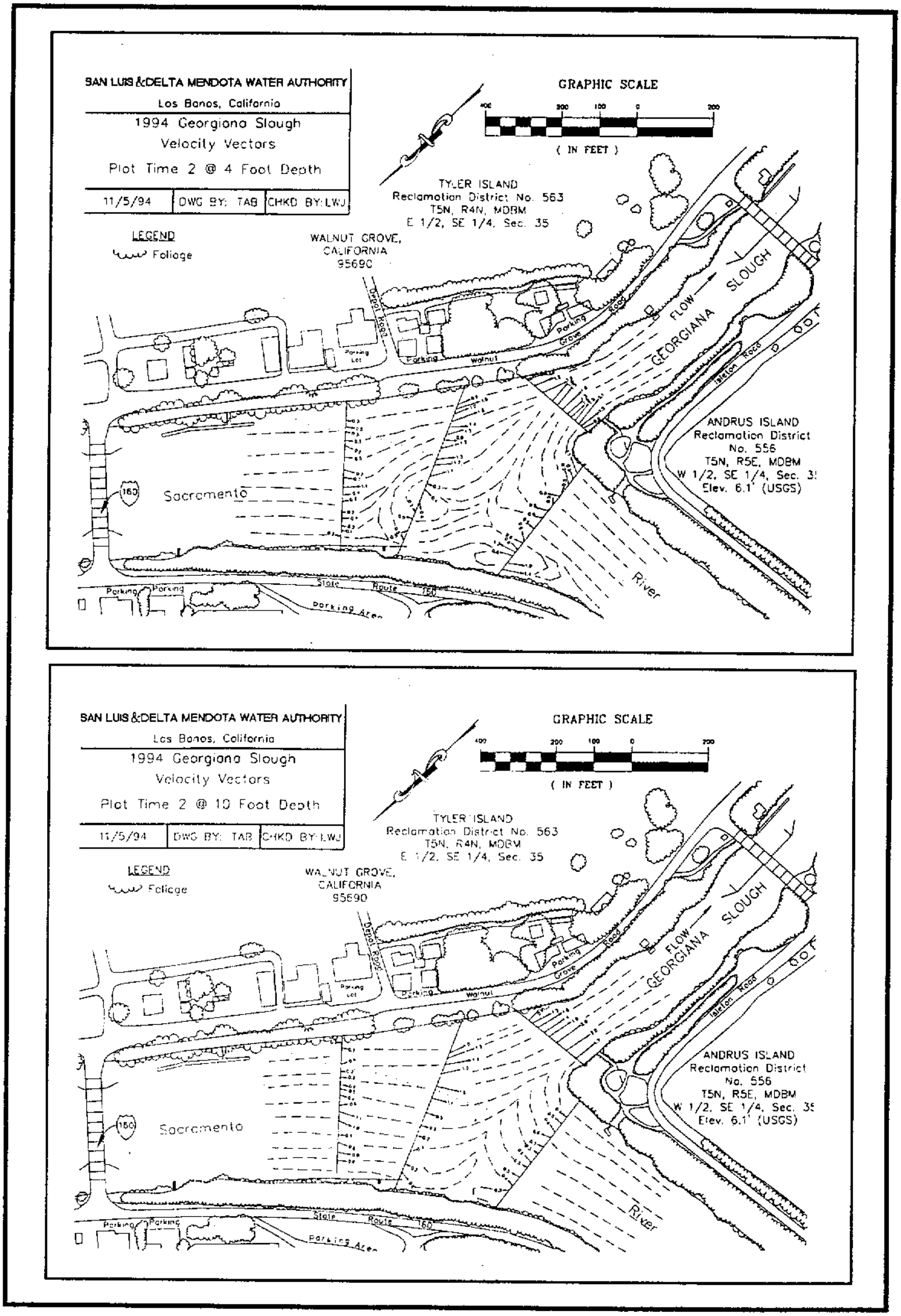

Figure 8
VELOCITY VECTORS IN THE SACRAMENTO RIVER AND GEORGIANA SLOUGH AT WATER DEPTHS OF 4 FEET AND 10 FEET DURING FLOOD TIDE

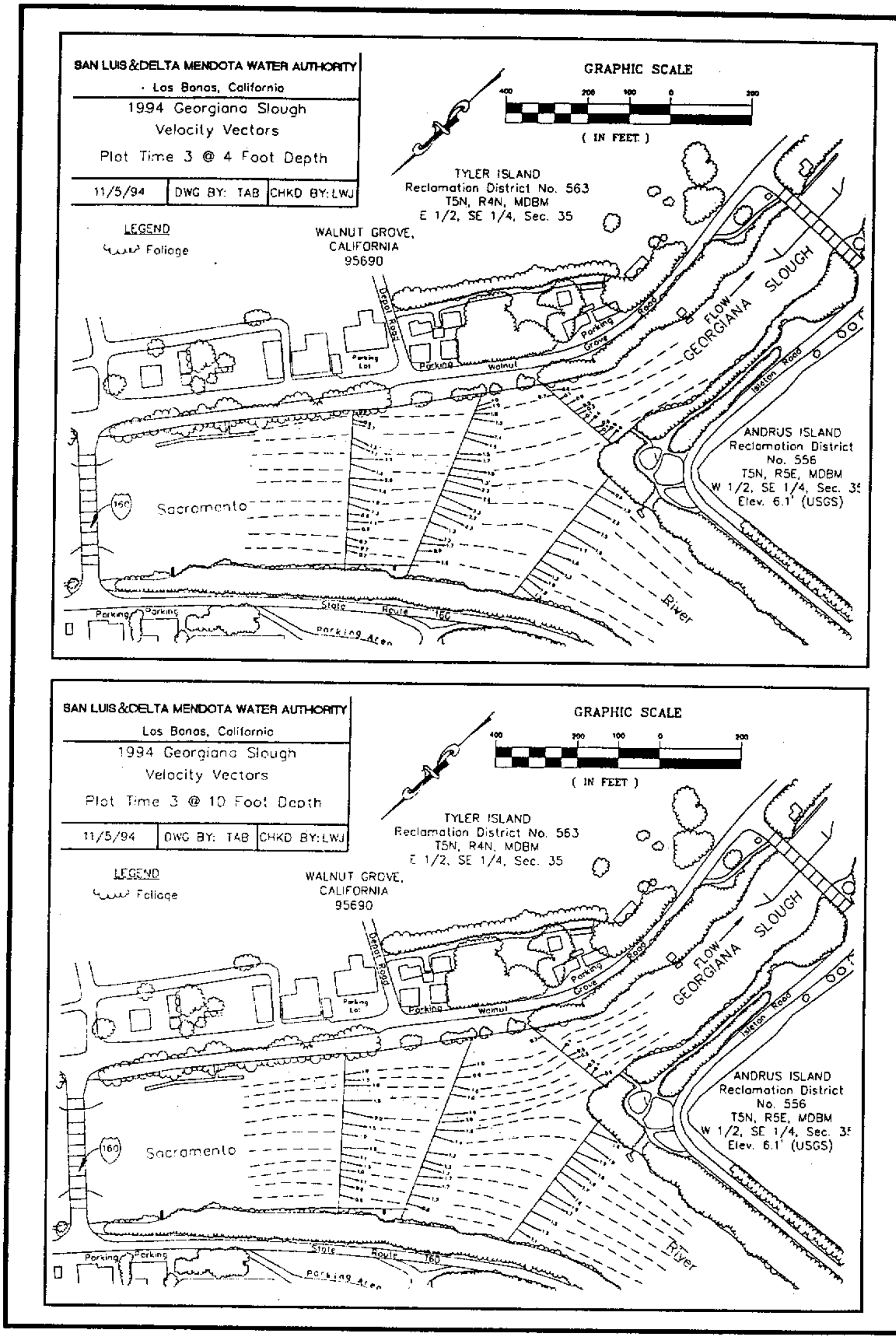

Figure 9

VELOCITY VECTORS IN THE SACRAMENTO RIVER AND GEORGIANA SLOUGH AT WATER DEPTHS OF 4 FEET AND 10 FEET DURING EBB TIDE

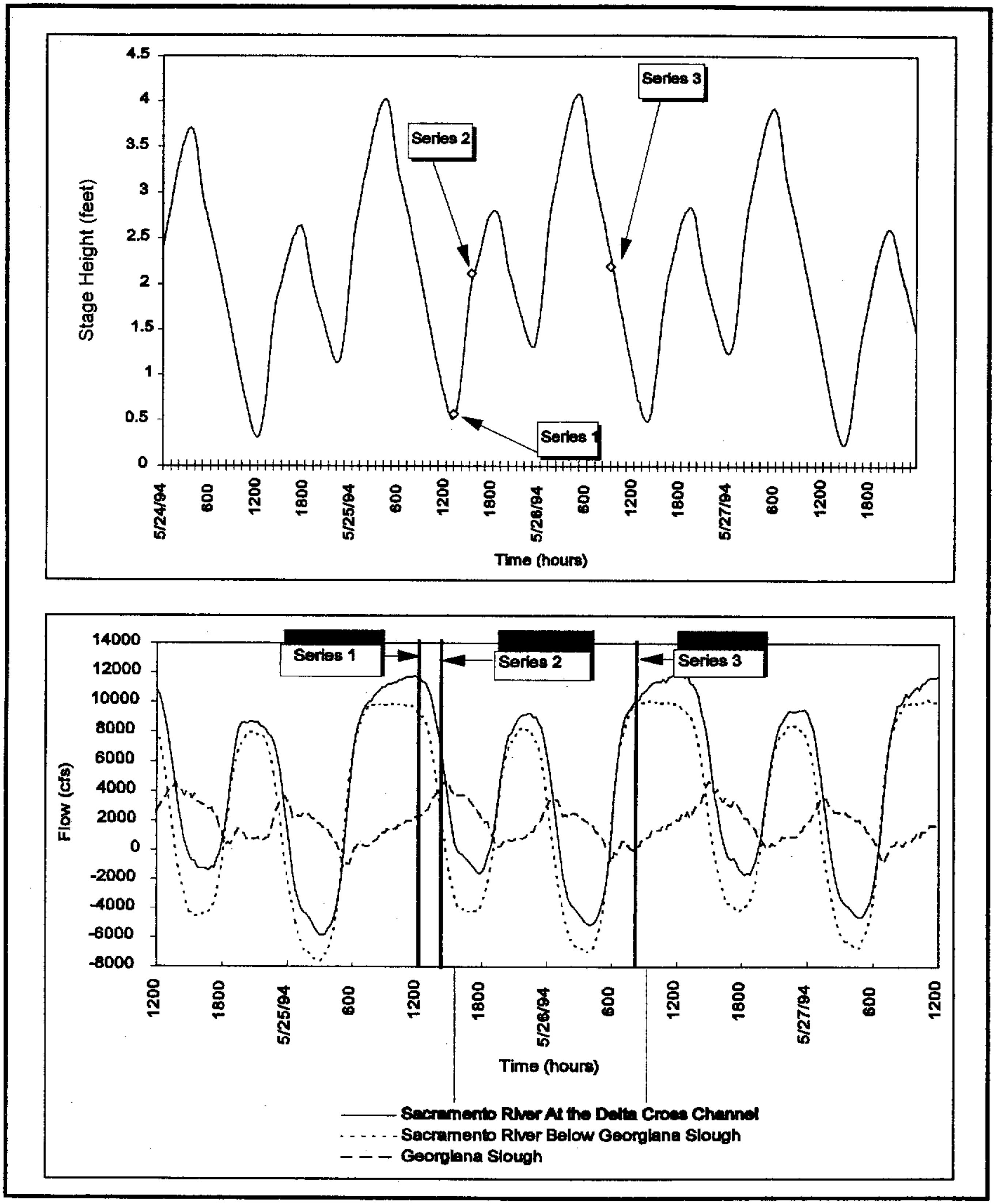

Figure 10
TIDAL CYCLE DURING WATER VELOCITY MEASUREMENTS SHOWN IN FIGURES 7, 8, AND 9

Flow Measurements

To document environmental conditions during the acoustic barrier tests, flow measurements (cubic feet per second at 15-minute intervals calculated based on continuous calibrated line velocity measurement and channel cross-sectional area) were compiled for the Sacramento River. The Geological Survey operates acoustic velocity monitoring systems upstream and downstream of the acoustic barrier in the Sacramento River. Since the Delta Cross Channel was closed during most of the spring testing period (it was opened May 27), flow entering Georgiana Slough was estimated for each 15-minute interval as the difference in flow between monitoring site upstream and downstream in the Sacramento River.

Flow measured in the Sacramento River upstream of the acoustic array, near the Delta Cross Channel, is shown in Figure 11 for April 1 through June 4, 1994. This period encompasses the testing interval for the spring acoustic guidance efficiency tests. The Delta Cross Channel was closed through May 27. Although varying substantially in response to tidal conditions, Sacramento River flow typically ranged between 4,000 and 6,000 cfs (daily average). Maximum instantaneous flows ranged as high as 12,000 cfs during ebb tide and as low as -6,000 cfs (reverse flow) during flood tide.

Average daily flows entering Georgiana Slough during April 1 through May 27 typically ranged from 1,300 to 2,500 cfs. Instantaneous flows varied substantially in response to tidal conditions (Figure 12), with maximum flow above 4,000 cfs during ebb tide and minimum flow about -1,000 cfs during flood tide.

Figure 13 shows Sacramento River flow downstream of Georgiana Slough during the fall surveys (October 1 to November 18). Average daily flow during this period was relatively stable at about 2000 cfs, increasing during the latter part of the study period. Instantaneous flows in a day varied substantially in response to tides. Maximum instantaneous flows exceeded 9,000 cfs; minimums approached -8,000 cfs. These results are consistent with data collected during the spring surveys in showing high downstream flow during ebb tides and substantial reverse flow in response to flood tides.

Both instantaneous flow and tidal condition were included in the analysis of guidance efficiency for juvenile chinook salmon during the spring studies and the direction and rate of adult movement monitored during periods when the acoustic barrier was on and off as part of the fall studies.

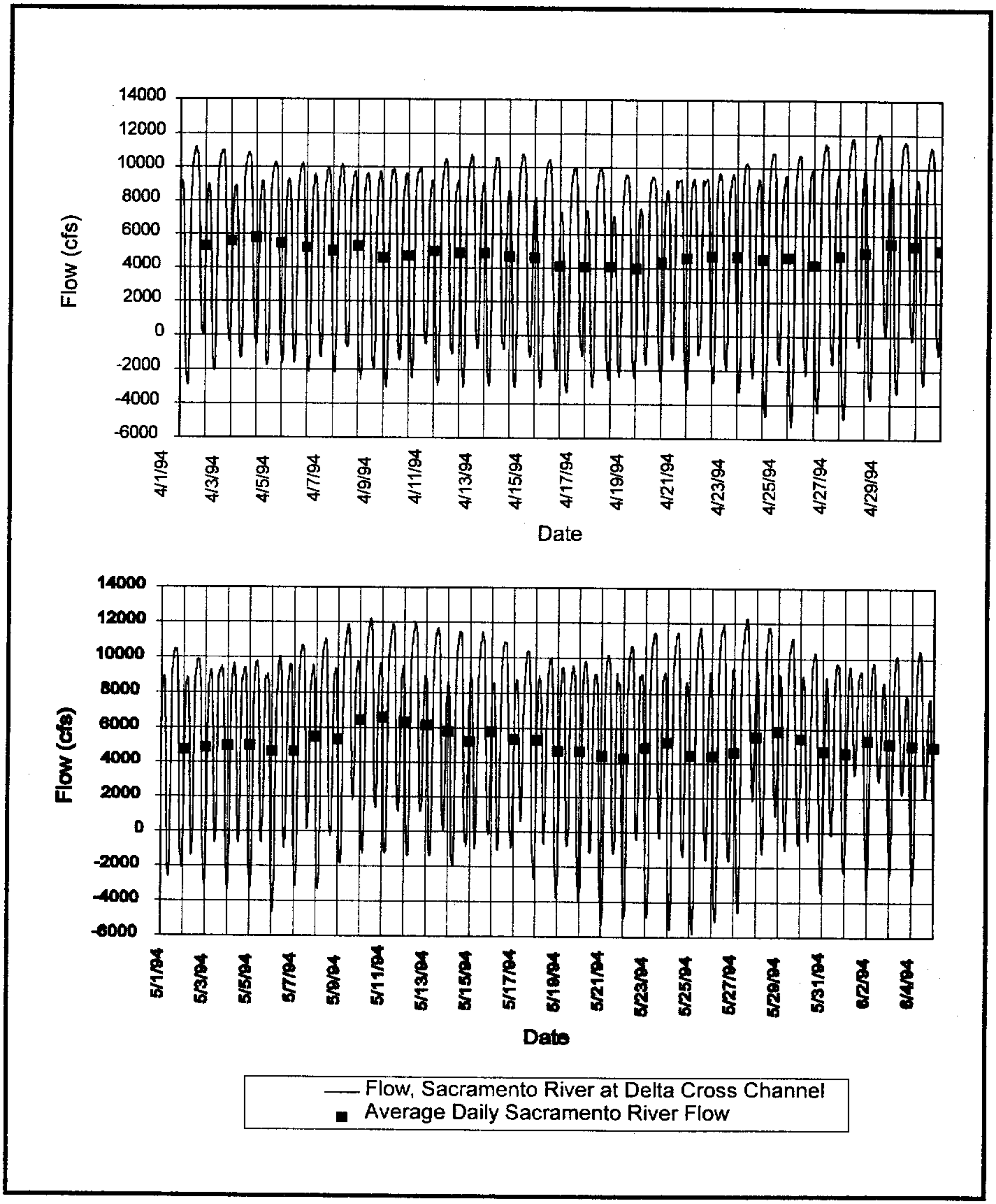

Figure 11
SACRAMENTO RIVER FLOW DURING THE SPRING INVESTIGATIONS

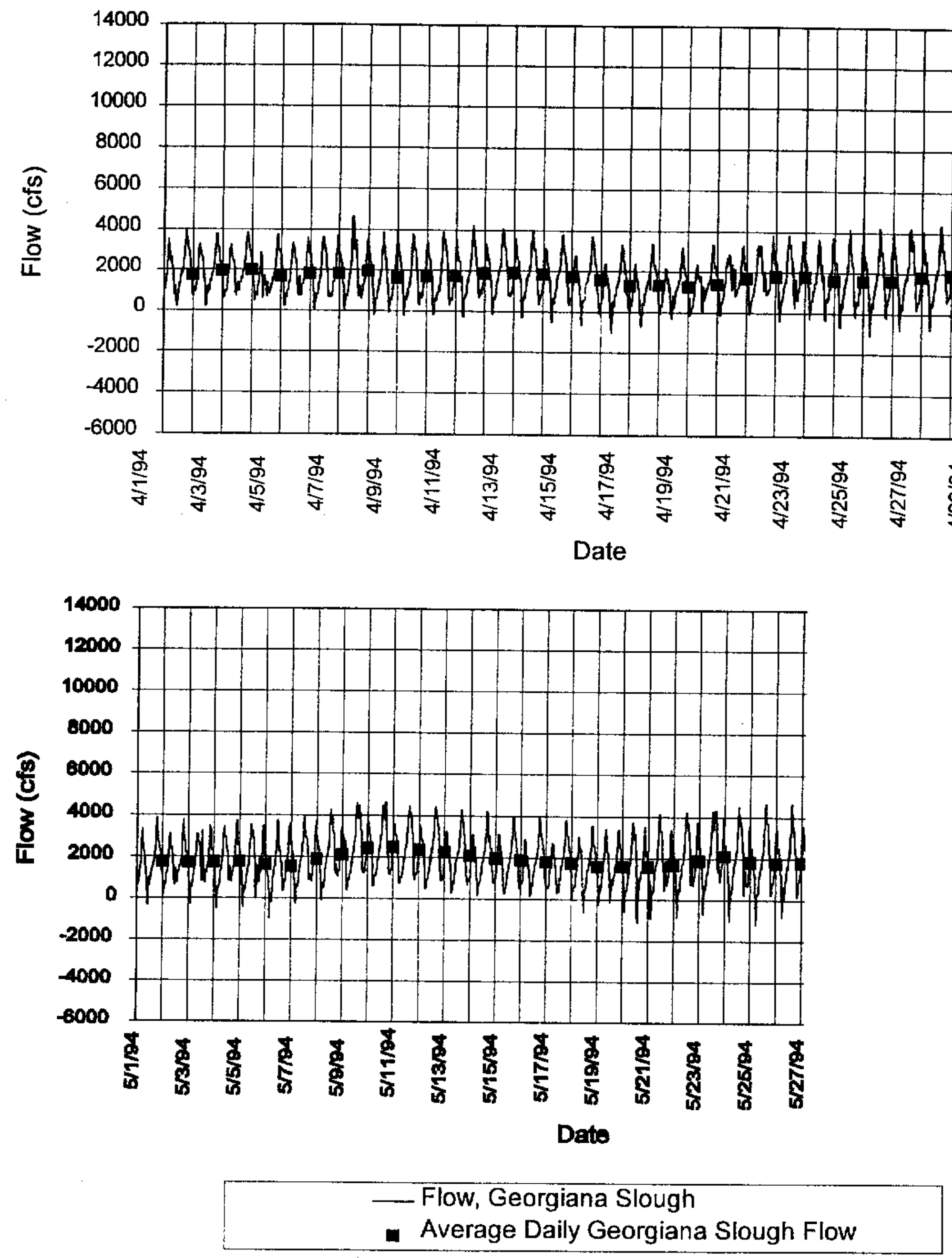

Figure 12
GEORGIANA SLOUGH FLOW DURING THE SPRING INVESTIGATIONS

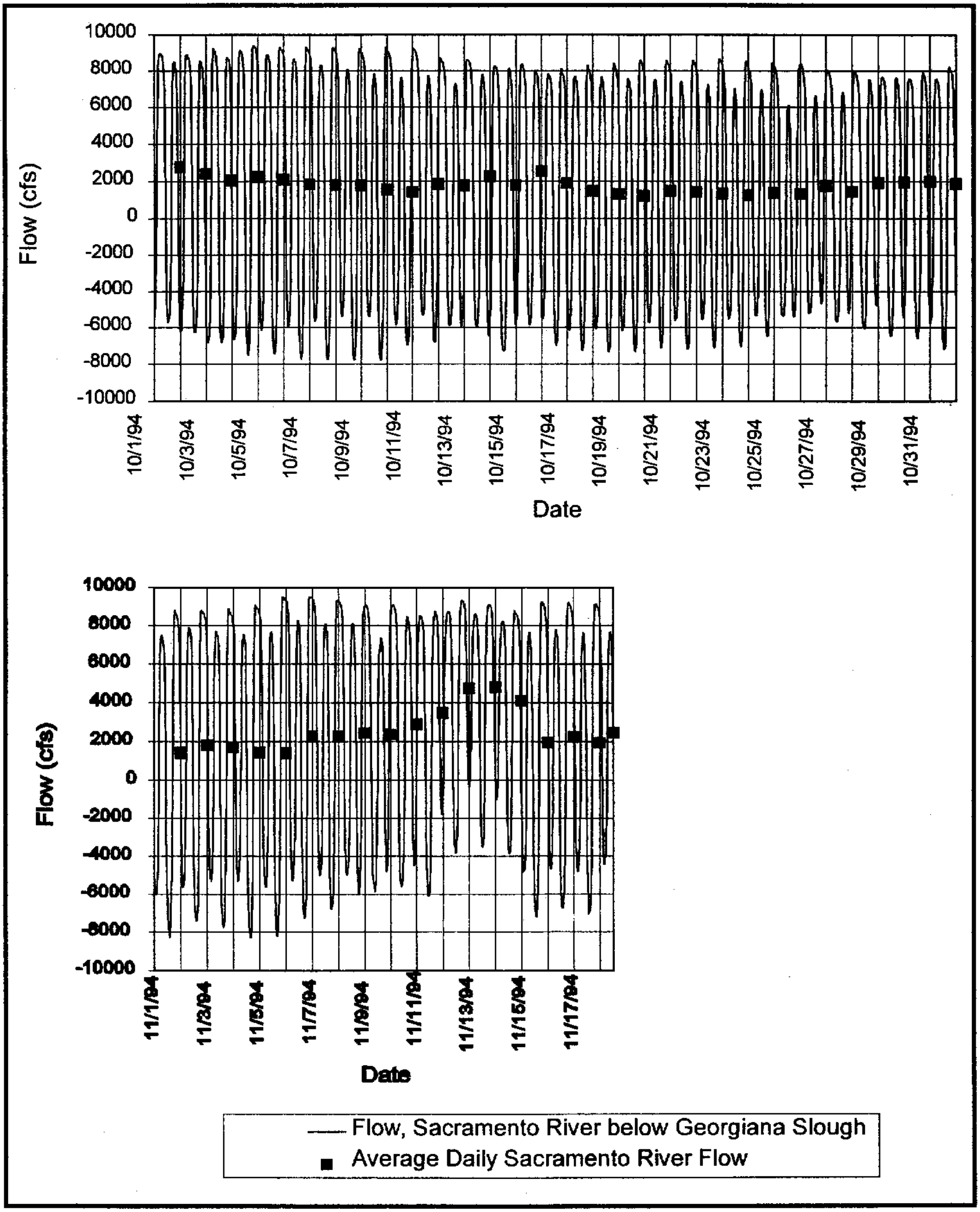

Figure 13
SACRAMENTO RIVER FLOW DURING THE FALL INVESTIGATIONS

Tidal Stage and Stage Height

Water surface elevation was monitored at 15-minute intervals by a DWR tide gauge at the confluence of the Sacramento River and Georgiana Slough and a USGS tide gauge downstream in the Sacramento River. Changes in water surface elevation were used to establish tide stage (flood tide when water surface elevation increased over time; ebb tide when elevation decreased). Tide stage at the site was then used, in association with both guidance efficiency studies (Kodiak trawl collections) during the spring and hydroacoustic monitoring for adult fish passage during the fall as part of the database used in statistical analyses of factors influencing fish behavior in association with acoustic barrier operations.

Water surface elevations (stage height) during the spring acoustic barrier guidance efficiency tests (April 1 - June 4) are shown in Figure 14. Water surface elevations varied in response to both daily tidal conditions and longer-term spring and neap tidal conditions, as well as average daily flow. Water surface elevations at the site had a typical daily range of about 2 to 3.5 feet.

Water surface elevations in the Sacramento River downstream of Georgiana Slough during the fall surveys (October 1 - November 18) are shown in Figure 15. These data are consistent with spring measurements (Figure 14) in showing river stage fluctuations in response to tides.

Water Temperature

Water temperature in the Sacramento River immediately downstream of Georgiana Slough was monitored at 20-minute intervals using a Hugrun Semon Type B temperature recorder. Temperature was measured at a depth of about 6 feet below the surface throughout the spring and fall periods of investigation. Instruments were calibrated under laboratory conditions prior to both the spring and fall surveys.

Water temperatures during April through June 4 are shown in Figure 16. Water temperature increased seasonally, from about 15.5°C (60°F) in early April to over 21°C (70°F) in early June. Water temperature pattern coincided with tide stage and Sacramento River flow and varied both daily and seasonally. During mid-April, mid-May, late May, and early June, water temperature exceeded 20°C (68°F), which contributed to stressful conditions for juvenile chinook salmon collected during Kodiak trawling and beach seining. As a consequence of the higher water temperature, exposure and predation testing with juvenile chinook salmon was terminated in late May. The acoustic barrier guidance efficiency studies were terminated on June 3 due to declining numbers of juvenile chinook salmon being collected in Kodiak trawling and coincident with increasing water temperatures.

Water temperatures during the fall tests (October-December) are shown in Figure 17. Temperature was measured at a depth of about 6 feet, at 20-minute intervals. Water temperature showed a declining trend from about 19°C (66°F) in early October to 10°C (50°F) by late November. Daily variation was substantially less during the fall than during the spring.

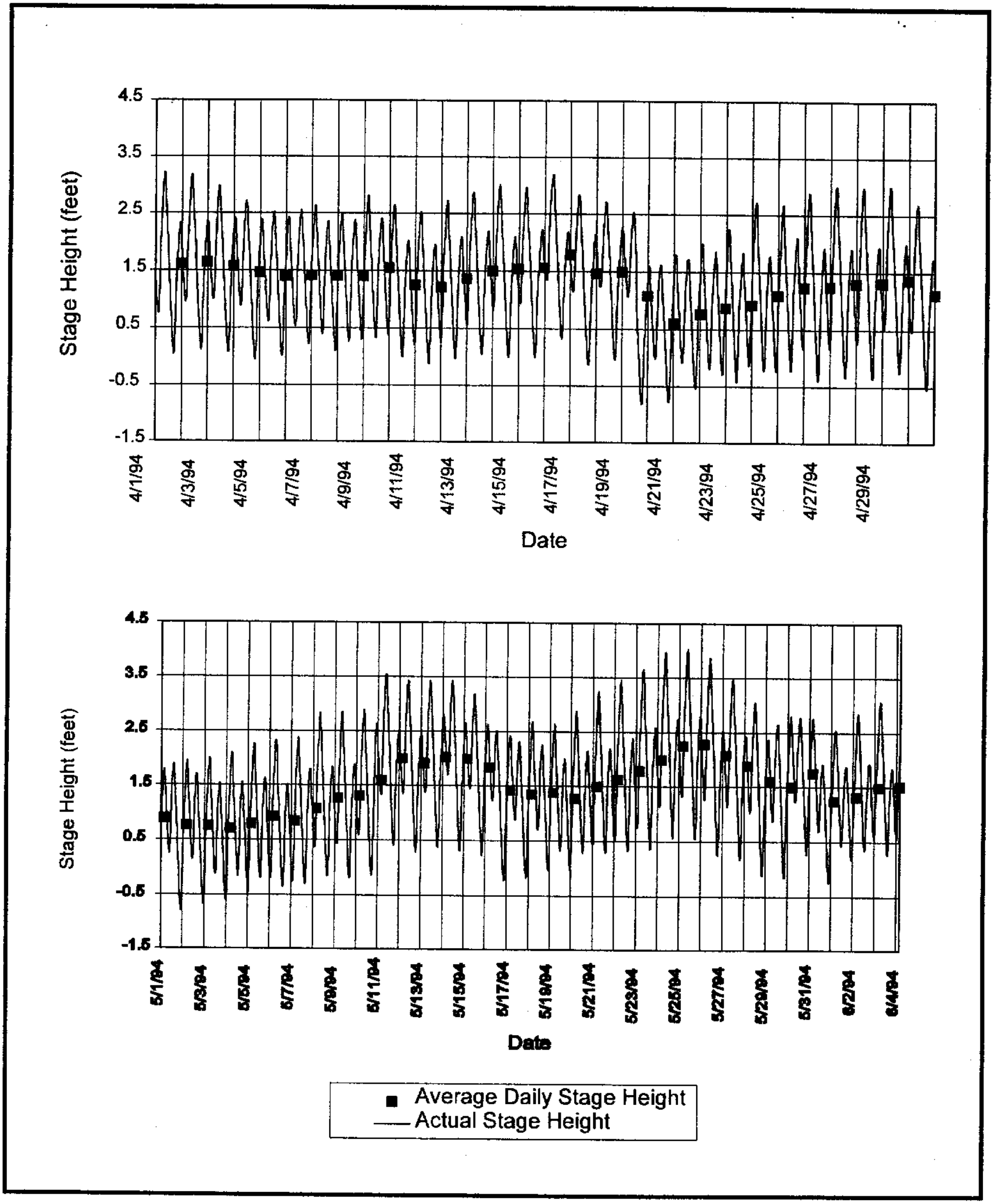

Figure 14
SACRAMENTO RIVER WATER SURFACE ELEVATION DURING THE SPRING INVESTIGATIONS.

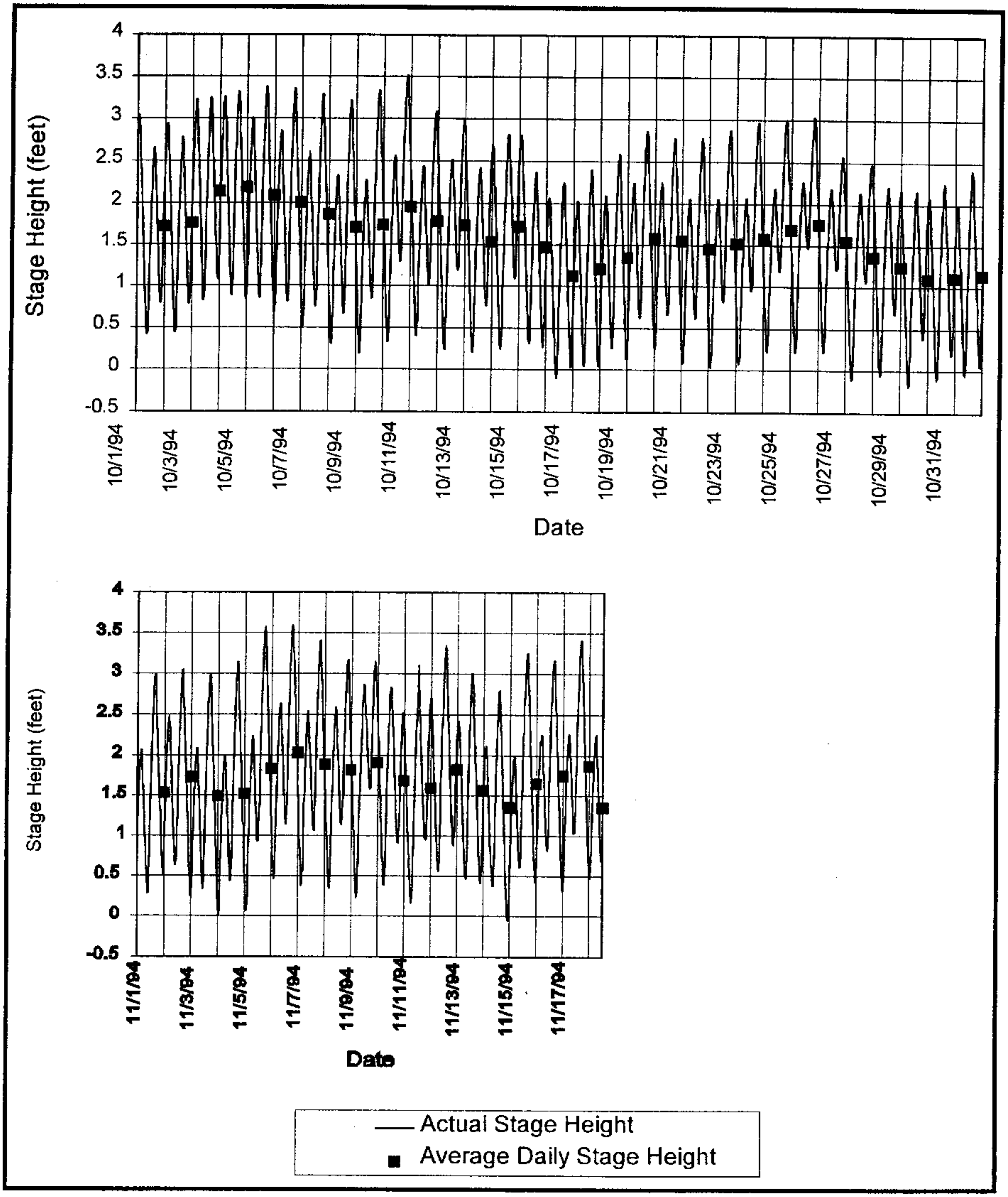

Figure 15
SACRAMENTO RIVER WATER SURFACE ELEVATION DURING THE FALL INVESTIGATIONS

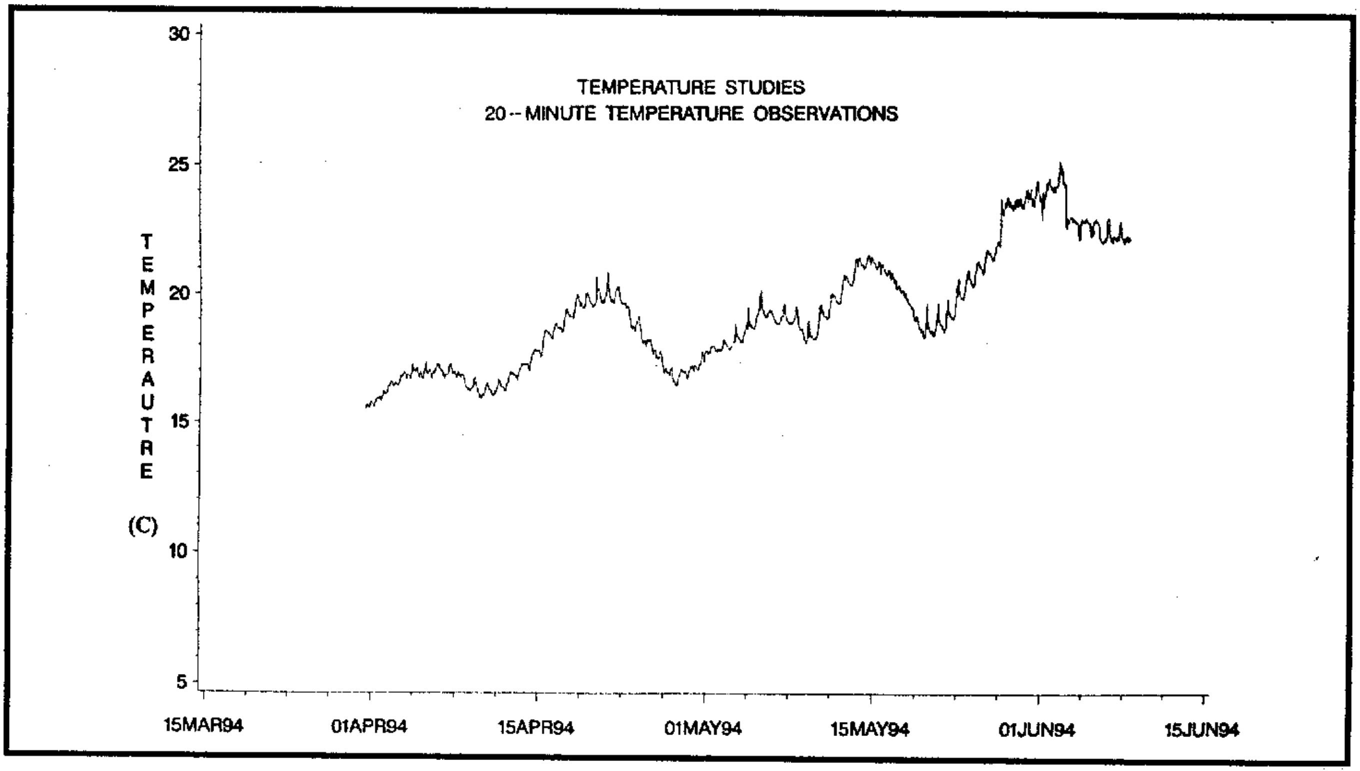

Figure 16
WATER TEMPERATURE MEASURED IN THE SACRAMENTO RIVER AT THE CONFLUENCE WITH GEORGIANA SLOUGH DURING THE SPRING INVESTIGATIONS

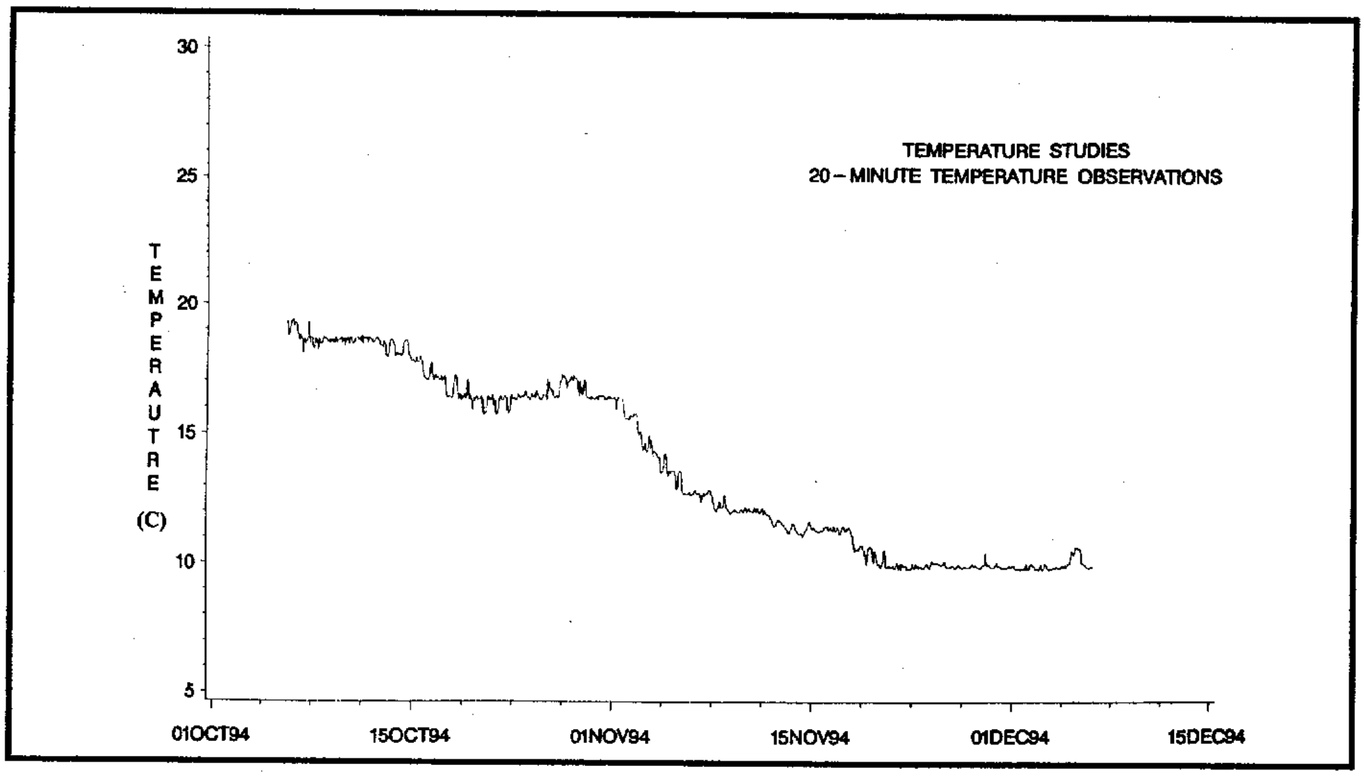

Figure 17
WATER TEMPERATURE MEASURED IN THE SACRAMENTO RIVER AT THE CONFLUENCE WITH GEORGIANA SLOUGH DURING THE FALL INVESTIGATIONS

Chapter 3

Determination of Juvenile Chinook Salmon Guidance Efficiency (EESCO)

One of the primary objectives of the Phase II field investigation was to quantitatively evaluate and document the effectiveness of the acoustic barrier in reducing the numbers of juvenile fall-run chinook salmon smolts entering Georgiana Slough. Phase II investigations were specifically designed to provide replication and statistical power in evaluating the guidance effectiveness of the acoustic barrier for juvenile chinook salmon.

Experimental Design

Biological evaluation of the effectiveness of the acoustic barrier has been experimentally designed to detect differences in the ratio of juvenile fall-run chinook salmon captured in Georgiana Slough and the Sacramento River (expressed as catch-per-unit-effort to adjust for variation in sampling effort) during periods when the acoustic barrier is <u>on</u> and when it is <u>off</u>. Evaluation of the effectiveness of the acoustic behavioral barrier in reducing juvenile chinook salmon migration into Georgiana Slough involved a series of replicated fish collections using Kodiak trawls in the Sacramento River and Georgiana Slough (Figure 18). Kodiak trawl collections were complemented by use of both juvenile chinook salmon mark/recapture studies and hydroacoustic fish monitoring. The experimental design involved a series of 2-day periods with the barrier on followed by 2 days with the barrier off each week. A minimum clearance interval of 4 hours was used at the beginning of each barrier-on and barrier-off period to allow fish between the barrier and sampling nets time for passage before sampling began.

During each weekly test sequence, conducted between April 4 and June 3, Kodiak trawl collections were made both day and night during 2 consecutive days when the barrier was on and 2 days when it was off. Testing was generally conducted Monday through Thursday to avoid interference with recreational boating.

Statistical Analysis of Guidance Efficiency

The ratio of mean catch-per-unit-of-effort of juvenile chinook salmon collected in Georgiana Slough and downstream in the Sacramento River when the barrier was on and when it was off was used to determine guidance efficiency of the acoustic signal. Guidance efficiency of the acoustic barrier, as recommended by Department of Fish and Game statisticians, was calculated as:

$$\%\ \text{efficiency} = (1-(a/b))100 = (1-\Psi)100$$

Where:

$$\Psi = a/b = (A/C)/(B/D) = AD/BC$$

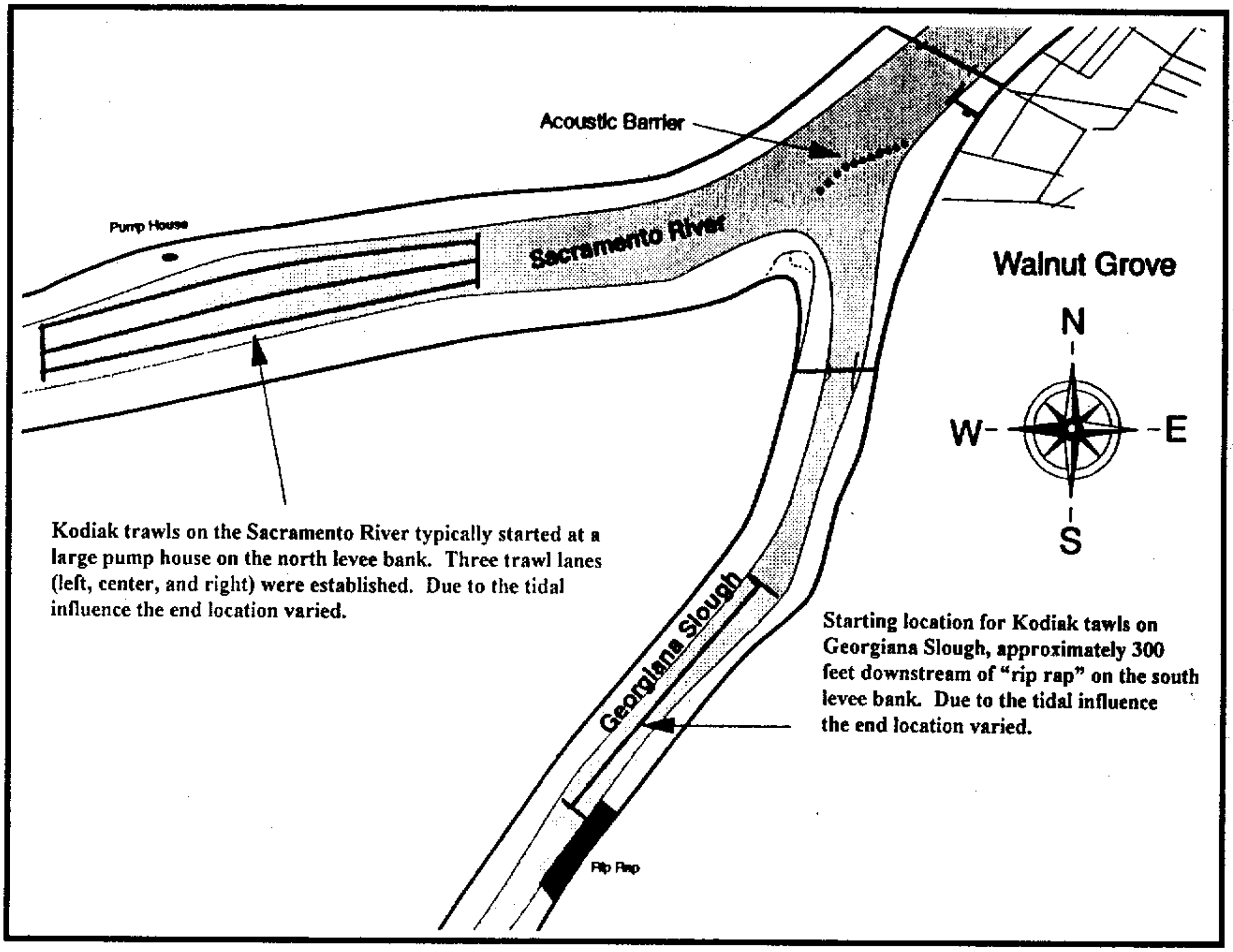

Figure 18
KODIAK TRAWL SAMPLING SITES IN THE SACRAMENTO RIVER AND GEORGIANA SLOUGH

The odds ratio used to statistically evaluate guidance efficiency was based on 2x2 tables as:

	Acoustic Barrier	
	On	Off
Georgiana Slough	A	B
Sacramento River	C	D

where:

A = Mean CPUE in Georgiana Slough when the barrier was on.

B = Mean CPUE in Georgiana Slough when the barrier was off.

C = Mean CPUE in Sacramento River when the barrier was on.

D = Mean CPUE in Sacramento River when the barrier was off.

Since the sampling effort for each cell (for example, sampling in Georgiana Slough when the barrier was on) was uneven, average cell frequencies were used to calculate the odds ratios and to calculate guidance efficiencies. For example, during Test 1 there were 21 Kodiak trawl tows in Georgiana Slough when the acoustic barrier was off, and 28 tows when it was on; additionally, there were 27 tows in the Sacramento River when the barrier was off, and 30 tows when it was on. If estimates were calculated from the sum of raw frequencies, the unequal number of tows for each barrier operation/station configuration could yield biased results. To adjust for variation in sampling effort, densities were calculated as the number of salmon per 1,000 cubic meters of water sampled to provide integers for the frequency tables used in estimating acoustic barrier guidance efficiency.

Estimates and hypothesis testing for the odds ratio were performed using the Mantel-Haenszel test. The test involves several 2x2 tables to account for stratification of the test based on various environmental or operational conditions. For example, 2 x 2 tables comparing mean catch per unit effort in Georgiana Slough and the Sacramento River when the acoustic barrier was on and off were used to test the significance of guidance efficiency for all data and for individual tests including separate tests for day, night, ebb tide, and flood tide. Results of these individual statistical tests provided information useful in evaluating the variance in guidance efficiency among tests and the effects of environmental conditions (*eg*, ebb *vs.* flood tide) on acoustic barrier guidance efficiency.

Analysis of Variance

Analysis of Variance (ANOVA) was used on both the raw and log-transformed data to determine if significant differences exist in salmon densities as measured by catch per unit effort during Georgiana Slough acoustic barrier testing. ANOVA procedures compare differences between fish density for each station/acoustic barrier configuration (at $\alpha = 0.05$). Regardless of whether a significant difference existed between the station/acoustic barrier configurations, an *a priori* comparison was made between samples collected in Georgiana Slough with the barrier in operation and samples collected in Georgiana Slough with the barrier was off. This CONTRAST procedure in the Statistical Analysis System (SAS) tests the hypothesis that there is no significant difference in salmon density in Georgiana Slough with the acoustic barrier in operation and with it off. The ANOVA was run over the entire test period and by individual weekly test cycles.

A multiple-range test was used to test the homogeneity of sample means. The Ryan-Einot-Gabriel (REGWQ) multiple-range test is a step-down multiple-stage test (MST). Some comparison methods, such as the Scheffe or Tukey, can be used to obtain simultaneous confidence intervals. However, by sacrificing the facility for simultaneous confidence intervals, it is possible to obtain simultaneous tests with greater power using an MST. The REGWQ is more powerful than the better-known Duncan or Student-Newman-Keuls (SNK) MSTs. Step-down MSTs first test homogeneity of all the means at a level of γ_K. If the test results in rejection of the hypothesis (all sample means are not the same), then each subset of k-1 means is tested, at level γ_{k-1}; otherwise the procedure stops. The REGWQ arranges the sample means in descending order, from X_1 through X_k. The homogeneity of the means $X_1 \ldots X_j$, i<j, is then rejected by the REGWQ multiple-range test if:

$$\gamma_i - \gamma_j \geq q(\gamma_p;\ p, \upsilon)s \ / \ \mathrm{sqrt}(n)$$

Where:

$$\gamma_p = 1-(1-\alpha)^{p/k} \text{ for } p < k-1$$

And:

$$p = j - i + 1$$

The REGWQ multiple-range test was also used to compare the means for the main effects in the model. This SAS procedure uses adjusted critical ranges to group station means that are not significantly different by assigning the same letter designation. These adjusted ranges do not take into account variability for other main effects (that is, the multiple range test for "flow" does not take into account the variability associated with the "TEST" effect).

Breslow -Day Test for Homogeneity of the Odds Ratios

The Breslow-Day Test for Homogeneity (BDTH) tests the hypothesis that the odds ratios from the q strata are all equal. When this hypothesis is true, the statistic is distributed approximately as chi-square with q-1 degrees of freedom. The statistic is defined as:

$$Q_{BD} = \Sigma_h[n_{h11} - Exp(n_{h11}/\hat{O}R_{MH})]^2 / VAR(n_{h11}/OR_{MH})$$

where Exp and VAR denote the expected value and variance, respectively. It should be noted that the validity of the Cochran-Mantel-Haenszel tests do not depend on any assumption of homogeneity of the odds ratios. Therefore, the BDTH should not be used as an indicator of validity.

Mantel-Haenszel Chi-Square Test

The Mantel-Haenszel chi-square test was also applied to data collected during the Georgiana Slough acoustic barrier study. The Mantel-Haenszel chi-square statistic tests the alternative hypothesis that there is a linear association between the row and column variables (station and acoustic barrier operation). The chi-square distribution has 1 df and is determined as:

$$Q_{MH} = (n-1)r^2$$

where r^2 is the Pearson correlations between the station and acoustic barrier operation. A 2x2 table was constructed for station (Sacramento River = SR; Georgiana Slough = GS) and barrier (acoustic barrier on = ON, acoustic barrier off = OFF). φ = AB/BC = the case/control odds ratio in the Cochran-Mantel-Haenszel (CMH) output. The guidance efficiency of the acoustic barrier was calculated as $(1 - \varphi)*100$. Large values of the CMH statistic imply that the observed and expected frequencies do not closely agree, and therefore we reject the hypothesis of dependence (that is, if the barrier has no effect, the probability of a particular cell frequency is the product of the corresponding marginal probabilities).

The confidence limits are calculated as a function of the overall row and column frequencies. The Mantel-Haenszel estimate of the adjusted odds ratio for a case/control study is:

$$OR_{MH} = [\Sigma_h n_{h11}\, n_{h22}/N_h]/[\Sigma h\, n_{h12}\, n_{h21}/n_h]$$

and $100(1-\alpha)$% test-based confidence interval is calculated as:

$$(OR_{MH} \exp[1 \pm z/\mathrm{sqrt}(Q)])$$

Where:

$$Q = \Sigma_i\Sigma_j\, n_{ij}D_{ij}$$

And:

D_{ij} = Twice the number of discordances

The design of the acoustic barrier experiment and hypothesis testing used several strata to consider possible factors and to adjust for their effects on guidance efficiency under various environmental conditions (strata). Separate 2x2 tables were developed to correspond to a stratum (ebb tide, flood tide, day, night, *etc*) after adjusting the unit measurements of catch per unit effort (number of salmon/1000 m^3 sampled) to account for variation in the volumes of water sampled among collections.

Results of these tests were compiled and reviewed with state and federal statisticians before they were included in the documentation report.

Kodiak Trawl Sample Collection

A Kodiak trawl was used to collect juvenile chinook salmon in Georgiana Slough and the Sacramento River. All trawl samples were collected in a consistent reach of Georgiana Slough and the Sacramento River (Figure 18) with the exception of the mark/recapture tests (May 9, 11, 13 releases), when trawling was in the Sacramento River about 1.8 mile downstream of the acoustic barrier (near KoKet Resort).

The Kodiak trawl has a graded stretch mesh, from 2-inch mesh at the mouth to 1/4-inch mesh at the cod end. Its overall length is 65 feet, and the mouth opening is 6 feet deep and 25 feet wide. A General Oceanics flowmeter (Model 2030 R) was used to estimate the volume of water sampled during each collection for use in calculating catch per unit effort. The net was towed between two identical skiffs operating at an engine speed of about 2,000 RPM. The trawl was equipped with an aluminum-framed cod end, which served as a live car in reducing stress and injury to fish during collection and processing. Trawl duration was about 10 minutes, sampling in an upstream direction. Triplicate trawl samples were collected in both Georgiana Slough and the Sacramento River throughout each testing series.

Trawls in the Sacramento River were performed parallel to the left bank, mid-channel, and right bank (Figure 18) to provide information on the horizontal distribution of juvenile chinook salmon in the Sacramento River downstream of the acoustic barrier. The Kodiak trawl was able to sample within about 30-50 feet of the shoreline, depending on water depth, bank configuration, and the presence of trees, pilings, and other obstacles. As a consequence of the relatively narrow channel width, all trawls in Georgiana Slough were performed at mid-channel. Results (CPUE) of consecutive Kodiak trawls in Georgiana Slough were routinely reviewed throughout the April-June sampling period for evidence that repeated sampling was depleting juvenile salmon abundance in the area surveyed. No evidence was detected of sampling effects on salmon abundance in the slough.

All fish collected were transferred immediately from the live car to buckets filled with river water, where the fish were held during processing. Fish were released downstream of the sampling area after processing. Data collected during each trawl included enumeration and fork length of juvenile chinook salmon and other fish species collected and water volume sampled. Mortality and damage to fish collected was documented. Catch per unit effort was calculated as the number of chinook salmon per minute and the number of chinook salmon per 1000 cubic meters of water sampled during each collection.

Data for collections in which gear failure or net snagging resulted in unreliable collections were excluded from the analysis. Individual samples were voided if the estimated volume sampled was unusually low, suggesting that the flowmeter and net may have become tangled during deployment. Collections were also voided in the event of failure to record specific information on the data sheets, such as the start or end flowmeter readings.

Juvenile Chinook Salmon Guidance Efficiency — Kodiak Trawl Collections

Guidance efficiency of the EESCO acoustic barrier was calculated from results of Kodiak trawl collections in Georgiana Slough and the Sacramento River for juvenile chinook salmon. Table 5 summarizes the testing cycles and numbers of juvenile chinook salmon collected when the acoustic barrier was on and when it was off. Table 6 summarizes acoustic barrier operations during the spring and fall test periods.

Overall, guidance efficiency of the acoustic barrier was estimated to be 57.2%, with lower and upper 95% confidence intervals ranging from 47.7 to 65.0 (Table 7). Results of these statistical analyses demonstrated that the calculated levels of guidance efficiency, comparing catches during periods when the acoustic barrier was on and off, were statistically significant ($p < 0.001$). Probabilities reported in Table 7 for the CMH X^2 statistic are the

Table 5
SUMMARY OF ROUTINE KODIAK TRAWLING,
ACOUSTIC BARRIER GUIDANCE EFFICIENCY STUDY

See Tables 9 and 10 for data on salmon catch per unit effort (density expressed as number of salmon/1,000 cubic meters) in Kodiak trawl collections under various Sacramento River flow and tidal conditions.

			Number of Chinook Salmon Collected			
			Georgiana Slough		Sacramento River	
Test	Start Date	End Date	On	Off	On	Off
	April 4	April 6*	53	0	22	0
	April 11	April 14*	218	109	255	182
1	April 18	April 21	216	398	328	306
2	April 25	April 28	1383	2723	2218	2285
3	May 2	May 5	841	2528	1192	734
4	May 17	May 26	282	410	310	643
5	May 31	June 3	8	15	11	24

* Kodiak trawl collections curtailed before testing cycle was complete based on incidental collection of juvenile winter-run chinook salmon and/or delta smelt.

Table 6
EESCO ACOUSTIC OPERATIONAL SCHEDULE
DURING SPRING AND FALL TESTS

Date	Barrier On/Off	Time	Date	Barrier On/Off	Time
April 5	On	2345	June 15	On	0000
April 7	Off	2359	June 16	Off	2130
April 12	On	2348	June 22	On	0000
April 15	Off	0705	June 23	Off	1605
April 17	On	2150	October 4	On	1700
April 19	Off	2350	October 9	Off	1700
April 24	On	0000	October 17	On	0800
April 26	Off	2358	October 20	Off	0800
May 4	On	0000	October 24	On	0753
May 6	Off	0000	October 26	Off	0805
May 10	On	0000	October 27	On	0832
May 10	Off	0850	October 29	Off	0723
May 11	On	1200	October 31	On	0800
May 13	Off	2359	November 2	Off	0802
May 17	On	1200	November 3	On	0800
May 20	Off	2359	November 5	Off	0800
June 1	On	2300	November 7	On	0922*
June 3	Off	0115	November 9	Off	0813
June 8	On	0000	November 10	On	0803
June 10	Off	0015	November 15	Off	1700

*Off 0936, On 1010

probability of observing the CMH X^2 statistic as large if, indeed, the frequencies are independent. Table 8 presents results of additional statistical analyses stratified to control for test cycle, tide, and diel patterns along with combinations of controlling factors.

As a result of the complexity of the ratio estimates used in calculating guidance efficiency for the acoustic barrier, a hypothetical example has been prepared, using the data, to illustrate the effects of acoustic barrier guidance on the number of juvenile chinook salmon entering Georgiana Slough. The hypothetical example is based on the overall average catch per unit effort for juvenile chinook salmon collected in the Sacramento River and Georgiana Slough with the acoustic barrier on and with it off. Catch per unit effort is calculated based on the collection of more than 6,500 juvenile salmon when the acoustic barrier was on and 10,000 juvenile chinook salmon when it was off. Average catch per unit effort used in developing this hypothetical example are summarized below:

	Average CPUE	
	Barrier On	Barrier Off
Georgiana Slough	2.80	5.74
Sacramento River	4.00	3.51

Catch per unit effort was subsequently adjusted to account for differential capture efficiency of the Kodiak trawl in Georgiana Slough and the Sacramento River. For purposes of these calculations, flow rates were assumed to be 5,000 cfs in the Sacramento River and 2,000 cfs in Georgiana Slough, based on data presented in Chapter 2. The resulting adjusted percentage distribution in relative fish abundance (based on an estimated trawl capture efficiency of 2.77% in the Sacramento River and 5.33% in Georgiana Slough) is shown below:

	Adjusted Percentage Distribution	
	Barrier On	Barrier Off
Georgiana Slough	13	25
Sacramento River	87	75

Table 7
STATISTICAL ANALYSES OF EESCO ACOUSTIC BARRIER GUIDANCE EFFICIENCY FOR JUVENILE CHINOOK SALMON DURING THE SPRING INVESTIGATIONS
Results from the Mantel-Haenszel Based on Mean Densities

Test Run	% Efficiency						Controlling Parameters
	N	LCB	Value	UCB	CMH	BDTH	
Overall	832	47.7%	57.2%	65.0%	<0.001	.	None
Overall	832	55.9%	59.5%	62.8%	<0.001	<0.001	Test
Overall	832	48.0%	50.6%	53.1%	<0.001	<0.001	Tide
Overall	832	50.9%	53.4%	55.8%	<0.001	<0.001	Test and Tide
Overall	832	49.0%	52.5%	55.8%	<0.001	<0.001	Test and Diel
Overall	832	50.1%	52.7%	55.10%	<0.001	<0.001	Test. Tide, and Diel

BDTH = Probability for Brelow-Day Test for Homogeneity of Odds Ratios statistic.
CMH = Probability associated with computed Cochran-Mantel-Haenszel test statistic.

Excluding Test 5

Test Run	% Efficiency						Controlling Parameters
	N	LCB	Value	UCB	CMH	BDTH	
Overall	663	48.7%	57.1%	64.1%	<0.001	.	None
Overall	663	56.0%	59.6%	62.9%	<0.001	<0.001	Test
Overall	663	52.3%	55.1%	57.7%	<0.001	<0.001	Test and Tide
Overall	663	50.2%	52.8%	55.10%	<0.001	<0.001	Test Tide, and Diel

BDTH = Probability for Brelow-Day Test for Homogeneity of Odds Ratios statistic.
CMH = Probability associated with computed Cochran-Mantel-Haenszel test statistic.

Excluding Night Trawls and Test 5

Test Run	% Efficiency						Controlling Parameters
	N	LCB	Value	UCB	CMH	BDTH	
Overall	513	53.0%	60.1%	66.0%	<0.001	.	None
Overall	513	58.8%	62.0%	64.9%	<0.001	<0.001	Test
Overall	513	55.7%	58.1%	60.4%	<0.001	<0.001	Test and Tide

BDTH = Probability for Brelow-Day Test for Homogeneity of Odds Ratios statistic.
CMH = Probability associated with computed Cochran-Mantel-Haenszel test statistic.

Table 8
STATISTICAL ANALYSES OF EESCO ACOUSTIC BARRIER GUIDANCE EFFICIENCY FOR JUVENILE CHINOOK SALMON,
STRATIFIED FOR VARIOUS ENVIRONMENTAL CONDITIONS
Results from the Mantel-Haenszel Based on Mean Densities

All Data, By Test and Tide, Excluding Test 5

Test Run	% Efficiency					Controlling Parameters
	N	LCB	Value	UCB	CMH	
Test 1						
Ebb	59	74.8%	82.6%	88.0%	<0.001	None
Flood	47	47.0%	50.9%	68.2%	<0.001	None
Test 2						
Ebb	104	43.8%	50.2%	55.9%	<0.001	None
Flood	55	-7.6%	3.7%	13.9%	0.0501	None
Test 3						
Ebb	70	77.7%	81.1%	83.9%	<0.001	None
Flood	65	84.5%	87.0%	89.2%	<0.001	None
Test 4						
Ebb	142	13.0%	49.1%	70.2%	0.014	None
Flood	121	-124.1%	-49.2%	8.9%	0.120	None

CMH = Probability associated with computed Cochran-Mantel-Haenszel test statistic.
All Data, By Test and Tide. Exculding Test 5 and Night Trawls

Test Run	% Efficiency					Controlling Parameters
	N	LCB	Value	UCB	CMH	
Test 1						
Ebb	58	76.1%	83.5%	88.6%	<0.001	None
Flood	34	55.1%	65.8%	73.9%	<0.001	None
Test 2						
Ebb	86	41.3%	47.5%	53.0%	<0.001	None
Flood	53	-7.1%	4.0%	14.0%	0.460	None
Test 3						
Ebb	60	76.2%	79.6%	82.5%	<0.001	None
Flood	48	89.4%	91.0%	92.3%	<0.001	None
Test 4						
Ebb	100	30.5%	58.0%	74.6%	0.001	None
Flood	74	-104.9%	-39.6%	4.9%	0.089	None

CMH = Probability associated with computed Cochran-Mantel-Haenszel test statistic.

Test Run	% Efficiency					Controlling Parameters
	N	LCB	Value	UCB	CMH	
Ebb	454	51.1%	60.0%	67.3%	<0.001	None
Flood	378	24.5%	39.2%	51.0%	<0.001	None

CMH = Probability associated with computed Cochran-Mantel-Haenszel test statistic.

Test Run	% Efficiency					Controlling Parameters
	N	LCB	Value	UCB	CMH	
Day	636	50.2%	58.5%	65.3%	<0.001	None
Night	196	-13.3%	26.6%	52.5%	<0.001	None

CMH = Probability associated with computed Cochran-Mantel-Haenszel test statistic.

Table 8 (continued)
STATISTICAL ANALYSES OF EESCO ACOUSTIC BARRIER GUIDANCE EFFICIENCY FOR JUVENILE CHINOOK SALMON, STRATIFIED FOR VARIOUS ENVIRONMENTAL CONDITIONS
Results from the Mantel-Haenszel Based on Mean Densities

All Data, By Test, Exculding Test 5

Test Run	% Efficiency					Controlling Parameters
	N	LCB	Value	UCB	CMH	
Test 1	106	45.8%	59.1%	69.1%	<0.001	None
Test 2	159	37.5%	44.1%	50.0%	<0.001	None
Test 3	135	80.6%	83.6%	86.2%	<0.001	None
Test 4	263	-24.7%	20.4%	50.3%	0.341	None

CMH = Probability associated with computed Cochran-Mantel-Haenszel test statistic.

All Data, By Test, Excluding Test 5 and Night Trawls

Test Run	% Efficiency					Controlling Parameters
	N	LCB	Value	UCB	CMH	
Test 1	92	60.3%	70.4%	78.0%	<0.001	None
Test 2	139	35.7%	42.2%	48.0%	<0.001	None
Test 3	108	83.9%	86.2%	88.2%	<0.001	None
Test 4	174	-7.3%	29.2%	53.3%	0.104	None

CMH = Probability associated with computed Cochran-Mantel-Haenszel test statistic.

Based on the adjusted distribution, a hypothetical example can be developed in which 100,000 juvenile chinook salmon are migrating downstream in the Sacramento River as they approach the confluence with Georgiana Slough. Results of the hypothetical example are summarized below:

Hypothetical Example of Juvenile Chinook Salmon Passage

	Barrier Off	Barrier On	Change in Salmon Movement
Georgiana Slough	25,000	13,000	-12,000
Sacramento River	75,000	87,000	+12,000
Total	100,000	100,000	

In this hypothetical example, the number of chinook salmon continuing their migration down the Sacramento River would increase from 75,000 with the barrier off to 87,000 with it on, representing a net increase of 12,000 in the relative number of salmon successfully migrating down the Sacramento River. Similarly, in this hypothetical example, 25,000 salmon would enter Georgiana Slough when the acoustic barrier was off, compared with 13,000 when it was on, representing a net decrease of 12,000 in the number of salmon migrating into Georgiana Slough. Although generalized, this example illustrates the potential benefit of acoustic barrier operations on migration pathways for juvenile chinook salmon. However, there is considerable variability in the guidance efficiency of the acoustic barrier in response to such factors as tidally-induced hydraulic flow patterns, which influence acoustic barrier guidance efficiency.

Statistical Analyses of Factors Related to Guidance Efficiency

Statistical analyses were also performed by either stratifying or removing certain questionable portions of the dataset. During the first two weekly test cycles, Kodiak trawls were stopped before a complete 2-day-on/2-day-off series of collections could be performed (Table 5). Sampling was stopped voluntarily to reduce the incidental take of juvenile winter-run chinook salmon and adult delta smelt in the Kodiak trawl collections. As a result, the sampling design was violated in not providing a balanced set of paired collections when the barrier was on and off. Therefore, data from the first 2 weeks of surveys have been eliminated from statistical analyses.

Data analyses were subsequently stratified to examine variation in acoustic barrier guidance efficiency for various testing cycles (weeks of testing) and for various environmental conditions, including tidal stage. Table 9 summarizes flow conditions in the Sacramento River and Georgiana Slough, the number of Kodiak trawl collections, and the corresponding catch per unit effort for juvenile salmon when the acoustic barrier was on and off. A similar summary of Kodiak Trawl data, stratified for ebb and flood tidal conditions is presented in Table 10.

Table 9
SUMMARY OF SALMON COLLECTIONS IN THE SACRAMENTO RIVER AND GEORGIANA SLOUGH UNDER VARIOUS FLOW CONDITIONS

Location	Sacramento River Flow (cfs)	Acoustic Barrier	Number Samples	Number Salmon	CPUE No/1000 m^3
Reverse Flow in Sacramento River*					
Sacramento River	-3527	ON	74	882	1.99
Sacramento River	-3528	OFF	76	1345	3.71
Georgiana Slough	-3794	ON	72	654	2.02
Georgiana Slough	-3734	OFF	87	2095	4.93
Positive Flow in Sacramento River*					
Sacramento River	6648	ON	138	3177	5.08
Sacramento River	6419	OFF	139	2647	3.40
Georgiana Slough	6522	ON	137	1935	3.21
Georgiana Slough	6709	OFF	112	3979	6.37
Reverse Flow in Sacramento River**					
Sacramento River	-1502	ON	42	565	2.25
Sacramento River	-1829	OFF	39	785	3.18
Georgiana Slough	-1613	ON	46	583	2.87
Georgiana Slough	-1557	OFF	55	1081	3.38
Sacramento River Flow 0-6000 cfs**					
Sacramento River	2874	ON	56	679	2.01
Sacramento River	2455	OFF	60	1106	4.38
Georgiana Slough	3315	ON	50	348	1.92
Georgiana Slough	3067	OFF	49	2284	9.30
Sacramento River Flow >6000 cfs**					
Sacramento River	8978	ON	114	2815	5.63
Sacramento River	9197	OFF	116	2101	3.17
Georgiana Slough	8807	ON	113	1658	3.16
Georgiana Slough	9185	OFF	95	2709	5.27

* Average Sacramento River flow (cfs) measured downstream of the confluence with Georgiana Slough.
** Average Sacramento River flow (cfs) measured at the Delta Cross Channel.

Results of statistical analyses, stratifying results of guidance efficiency testing based on various factors included in the experimental design, showed that results of weekly testing cycles generated variable estimates in acoustic barrier guidance efficiency. Data from four weekly testing cycles are summarized in Table 8 (including and excluding Kodiak trawl data collected at night). Statistical analyses showed a significant reduction in Kodiak trawl catch per unit effort at night when compared with consistently higher collections during the daytime. Guidance efficiency estimates, stratified by testing cycle, ranged from 83.6% (95% confidence intervals 80.6 to 86.2; $p < 0.001$) to 20.4% (95% confidence intervals -24.7 to 50.3; $p = 0.34$). Similar variation in estimated guidance efficiency was observed in these analyses when data were excluded for night trawls.

Results of analyses stratified by tidal stage (Table 8) showed that overall acoustic barrier guidance efficiency was higher (average 60.0%; 95% confidence intervals 51.1 to 67.3%; $p < 0.001$) during ebb tide conditions than during flood tide conditions (average guidance efficiency 39.2%; 95% confidence intervals 24.5 to 51.0%; $p < 0.001$). Acoustic barrier guidance efficiency was observed in a number of weekly tests to be greater during ebb tide and substantially less during flood tide, although results varied considerably. Guidance efficiency, for example, during test cycle four was -49.2% during flood tide and +49.1% during ebb tide.

The observed variation in acoustic barrier guidance efficiency as a function of tidal conditions, with lower efficiency during flood tide stage, is consistent with results of flow and velocity measurements (Chapter 2), in which flows reversed direction (moving upstream) in response to flood tides. Due to the configuration of the barrier, we expected the barrier to provide greater guidance during ebb tides than during flood tides. We hypothesized that this flow reversal in response to tidal action, at Sacramento River flow levels during the 1994 guidance efficiency evaluation, contributed directly to the overall estimate of acoustic barrier guidance efficiency and the observed reduction in efficiency in response to tidal action.

Table 10
SUMMARY OF JUVENILE CHINOOK SALMON COLLECTIONS IN THE SACRAMENTO RIVER AND GEORGIANA SLOUGH WITH THE ACOUSTIC BARRIER ON AND OFF

Location	Acoustic Barrier	Number Samples	Number Salmon	CPUE No/1000 m^3
Overall Test				
Sacramento River	ON	211	4059	4.00
Sacramento River	OFF	213	3992	3.51
Georgiana Slough	ON	209	2589	2.80
Georgiana Slough	OFF	199	6074	5.74
Ebb Tide				
Sacramento River	ON	130	2945	4.97
Sacramento River	OFF	113	2131	3.04
Georgiana Slough	ON	116	1608	3.10
Georgiana Slough	OFF	97	2626	4.74
Flood Tide				
Sacramento River	ON	81	1114	2.43
Sacramento River	OFF	100	1861	4.05
Georgiana Slough	ON	93	981	2.43
Georgiana Slough	OFF	104	3448	6.66

Examples of statistical analyses performed as part of the acoustic barrier guidance efficiency evaluation and supporting data base are included in Appendix D. Detailed documentation on all statistical comparisons from the 1994 testing program has been reviewed by the Department of Fish and Game (Philip Law, DFG, personal communication) and is available upon request.

Results of these statistical analyses have shown:

- Overall acoustic barrier guidance efficiency averaged 57.2% (95% confidence intervals, 47.7 to 65.0; $p < 0.001$) and was statistically significant.
- Acoustic barrier guidance efficiency varied among weekly tests, with a range from 20.4 to 83.6%, excluding Test 5.
- Guidance efficiency was typically greater during ebb tide (average 60.0%) than during flood tide (average 39.2%), although there was substantial variability in results of individual weekly testing when stratified to account for tidal effects. Individual weekly test results ranged from guidance efficiency estimates from 82.6 to 49.1% during ebb tide and 87.0 to -49.2% during flood tide.
- Guidance efficiency was generally greater during daytime than at night. However, these analyses were confounded by observations showing a statistically significant decrease in juvenile chinook salmon collections using Kodiak trawls at night when compared with daytime collections.
- The observed reduction in acoustic barrier guidance efficiency during flood tides is consistent with observations of flow and velocity showing flow reversal in the Sacramento River downstream of the acoustic barrier during flood tide. The flow reversal may result in juvenile chinook salmon that had successfully moved downstream in the Sacramento River when the acoustic barrier was on changing direction and moving upstream and into Georgiana Slough in response to tidally driven hydraulic conditions despite acoustic barrier operations.
- Results of the guidance efficiency tests, although promising, reflect environmental conditions such as relatively low Sacramento River flows during the 1994 study period. Additional tests would be required to strengthen the statistical analyses of guidance efficiency and to evaluate performance of the acoustic barrier over a wider range of environmental conditions.

Chinook Salmon Mark/Recapture Tests

A series of mark/recapture studies were performed using juvenile fall-run chinook salmon smolts released into the Sacramento River upstream of the acoustic barrier with recapture downstream in both the Sacramento River and Georgiana Slough (Table 11). Hatchery-reared chinook salmon smolts were marked using various colors of spray-dye and held in the Feather River Hatchery for 72-96 hours prior to release. Results of a quality control test showed 100% dye retention and recognition for a subsample of 56 spray-dyed juvenile chinook salmon 11 days after marking. Marked chinook salmon were transported in a full-sized commercial hatchery truck and released into the Sacramento River 3.2 miles upstream of the acoustic barrier. Mark/recapture tests were performed only when the Delta Cross Channel gates were closed. Paired releases of about the same numbers of marked salmon were made during consecutive periods when the acoustic barrier was on and off. Paired groups (treatment and control) were released using the same fish transport truck and, to the extent possible, at about the same time of day, tide stage, water temperature, and number of released fish.

Differences in the percentage of marked fish recaptured between barrier on and barrier off treatment groups reflect a composite measure of the effect of barrier

Table 11
SUMMARY OF JUVENILE CHINOOK SALMON SPRAY-DYE MARK/RECAPTURE TESTS

Release Site	Date	Barrier Status	Color	Tide	River Temp (°C)	Truck Temp (°C)	Time of Release	Number Released	Sacramento River Recapture	Georgiana Slough Recapture	Total Recapture
Georgiana Sl Bridge	05/05	OFF	Orange	Ebb	19	19	0830	4,200	1	155	156
Sacramento River @ LP 11	05/06****	ON	Green	Ebb	19	19	0930	5,289	215	0	215
Sacramento River @ Vorden Rd	05/09*	OFF	Red	Flood	19	15	1420	24,824	0	0	VOID
Sacramento River @ Vorden Rd	05/11	ON	Dk Green	Slack	19	15	1415	24,837	200***	0	200
Sacramento River @ Vorden Rd	05/13	OFF	Orange	Ebb	21	16	1435	24,922	131***	0	131
Sacramento River @ Vorden Rd	05/17**	ON	Red	Ebb	20	15	1405	8,046	0	0	VOID
Sacramento River @ Vorden Rd	05/18	ON	Green	Flood	20	15	1130	14,892	33	7	40
Sacramento River @ Vorden Rd	05/20	ON	Red	Flood	20		1145	3,954	0	253	253
Sacramento River @ Vorden Rd	05/24	OFF	Orange	Flood	21	15	1315	9,798	67	60	127
Sacramento River @ LP 11	06/01	OFF	Red	Ebb	22		0513	4,210	48	2	50
Georgiana Sl Bridge	06/01	OFF	Green	Ebb	22		0617	4,560	0	312	312
Sacramento River @ LP 11	06/01	OFF	Orange	Flood	23		1100	2,255	10	43	53

* This sample group voided due to the barrier being turned on inadvertently halfway through the sampling period.
** This sample group voided because discharge pipe broke during fish release.
*** Sampling was conducted only in the Sacramento River.
**** Fish released on May 5 and 6 were held onsite prior to release.

guidance efficiency. Results of these mark/recapture tests provide an independent measure of the net effect of acoustic barrier operations in improving juvenile chinook salmon guidance and confirming results of guidance efficiency tests based on Kodiak trawl sampling.

A number of mark/recapture studies were performed between May 5 and June 1 to evaluate various aspects of acoustic barrier guidance efficiency. Mark/recapture studies were performed to provide independent data on acoustic barrier guidance efficiency (releases on May 11, 13, 18, 24) and the influence of tide on movement patterns of juvenile chinook salmon, which would affect acoustic barrier guidance efficiency (May 5, 6, 20; June 1). Additional mark/recapture releases were performed to evaluate collection efficiency of the Kodiak trawl.

A paired set of mark/recapture studies were performed with releases on May 11 (barrier on) and May 13 (barrier off). Both groups of marked fish were released at Vorden Road, on the Sacramento River about 3.2 miles upstream of the acoustic array. Fish were released at this upstream site to allow time to recover from stress associated with release and to disperse more naturally throughout the channel prior to encountering and responding to the acoustic array. The Vorden Road release site provided relatively easy access for the transport truck to the Sacramento River with the use of about 40-50 feet of 12-inch flexible and/or rigid PVC pipe to release fish into the river at a depth of about 2-3 feet.

The release on May 11 (barrier on) contained 24,837 marked (dark green) salmon. The release on May 13 (barrier off) contained 24,922 marked (orange) salmon. Recapture was limited to one sampling site in the mid-channel of the Sacramento River about 1.8 miles downstream of the acoustic barrier. This location was selected to minimize the probability that salmon smolts successfully moving downstream past Georgiana Slough would subsequently move back upstream into Georgiana Slough in response to flood tidal conditions. Kodiak trawling was performed 24 hours per day throughout four continuous days.

It was hypothesized that if the acoustic barrier increased the guidance of juvenile chinook salmon passing downstream in the Sacramento River, then the percentage of marked fish recaptured in this test should be higher when the acoustic barrier was on (treatment) than during the corresponding collections when it was off (control). Results of this mark/recapture study (Table 12) are consistent with Kodiak trawling results in showing increased guidance efficiency for juvenile chinook salmon smolts when the acoustic barrier was on. The percentage of salmon recaptured was 0.81 when the barrier was on and 0.53 when it was off. Based on results of this

Table 12
SUMMARY OF JUVENILE CHINOOK SALMON MARK/RECAPTURE TEST TO EVALUATE ACOUSTIC BARRIER GUIDANCE EFFICIENCY, MAY 11-15, 1994

Acoustic Barrier	Number Released	Number Samples	Number Recaptured Sacramento River	Percent Recaptured	Number per Tow
ON	24,837	87	200	0.81	2.30
OFF	24,922	74	131	50.3	1.77

Notes: Chinook salmon were spray-dyed at Feather River Fish Hatchery prior to release.
Fish were released into the Sacramento River at Vorden Road May 11 (1415 hour; color dark green) and May 13 (1435 hour; color orange).
Kodiak trawling for recaptures was about 1.8 miles downstream of the acoustic barrier in the Sacramento River (adjacent to Koket Resort).

mark/recapture study, it was estimated that the absolute increase in the number of juvenile chinook salmon successfully migrating downstream in the Sacramento River past Georgiana Slough would be increased by 35% (for example, 100 salmon successfully migrating downstream in the Sacramento River when the barrier is on compared with 65 when it is off).

Results of the intensive Kodiak trawling performed in association with the May 11-15 mark/recapture study were also evaluated to determine differences in the rate of salmon migration when the acoustic barrier was on and off. Salmon were released at Vorden Road at 1415 hours on May 11 and at 1435 hours on May 13. Using the time of release and the time at which each marked fish was recaptured, an estimate of the rate of downstream migration was developed. These data were used to evaluate the potential that a behavioral response of juvenile salmon to the acoustic array may result in a delay in downstream migration. Results of the analysis of the rate of recaptures for marked juvenile chinook salmon released into the Sacramento River during periods when the acoustic barrier was on (May 11) and when the acoustic barrier was off (May 13) are shown in Figure 19. Results of this one set of mark/recapture studies suggest that chinook salmon

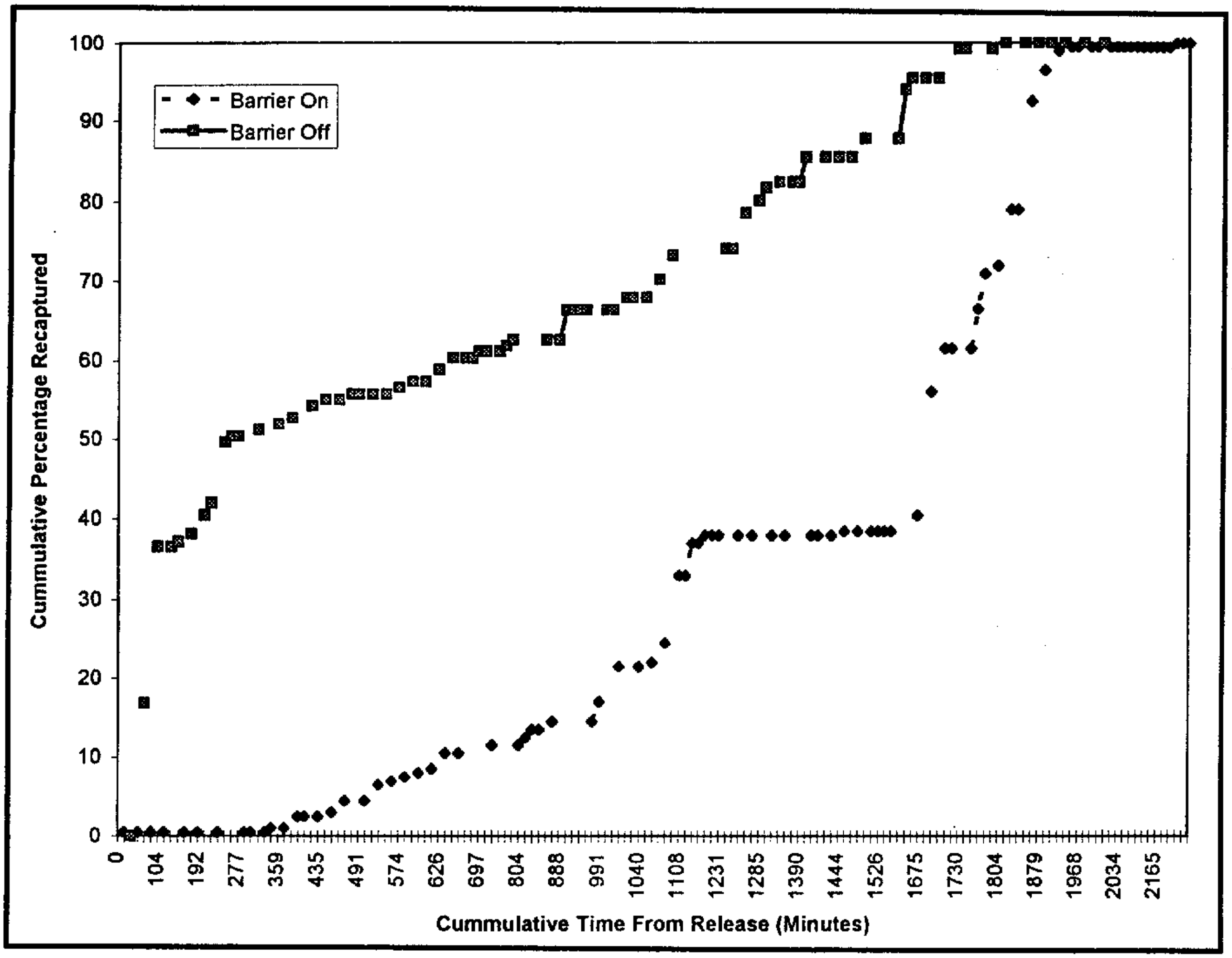

Figure 19
CUMULATIVE RATE OF TRAVEL FOR MARKED CHINOOK SALMON RECAPTURED DURING PERIODS WHEN THE ACOUSTIC BARRIER WAS ON AND OFF

movement downstream was more rapid when the acoustic barrier was off than during the corresponding test when the acoustic barrier was on.

Juvenile chinook salmon used in these two mark/recapture tests were obtained from the Feather River Hatchery. No statistically significant difference was detected in the size distribution, pre-test mortality during marking, or transport to the site[1]. Fish were released at the same site, using the same transport truck and release mechanisms, and were released at almost the same time every day (treatment at 1415 hours; control at 1435 hours). Flow conditions in the Sacramento River and tidal conditions were similar for the two release groups. Factors potentially contributing to the observed differences in the rate of transit and recapture remain unknown, other than natural sampling variability and the potential response to acoustic barrier operations.

A second mark/recapture study was performed with releases on May 18 (barrier on) and May 24 (barrier off). A total of 14,892 marked salmon (treatment) were released when the acoustic barrier was on, and 9,798 marked salmon (control) were released when the acoustic barrier was off. During the period of this mark/recapture study, Kodiak trawls were performed in the Sacramento River and Georgiana Slough using the standard sampling design (Figure 18). Results of this mark/recapture study (Table 13) showed that although a lower percentage of the marked salmon were recaptured when the barrier was on, the ratio of recoveries in the Sacramento River and Georgiana Slough when the barrier was on and off was consistent with results of Kodiak trawl collections. The overall index of acoustic barrier guidance efficiency was 75% for these mark/recapture studies, based on the change in ratio estimates of the percentage of marked fish recaptured between the Sacramento River and Georgiana Slough.

Additional mark/recapture studies were performed to investigate the movement of juvenile chinook salmon in response to tidally-driven hydraulic conditions. Results of flow and velocity measurements (Chapter 2) showed flow reversals in the Sacramento River downstream of Georgiana Slough during flood tide conditions (Figures 8 and 11). Results of acoustic barrier guidance efficiency tests showed lower guidance during flood tides than during ebb tides. Based on results of hydraulic measurements, we hypothesized that juvenile salmon that had successfully migrated downstream in the Sacramento River past Georgiana Slough might, under flood tidal hydraulic conditions, move upstream in the Sacramento River and into Georgiana Slough.

Table 13
SUMMARY OF JUVENILE CHINOOK SALMON MARK/RECAPTURE TEST TO EVALUATE ACOUSTIC BARRIER GUIDANCE EFFICIENCY, MAY 18-26, 1994

		Number Recaptured		Percentage Recaptured	
Acoustic Barrier	Number Released	Sacramento River	Georgiana Slough	Sacramento River	Georgiana Slough
On	8046	33	7	0.41	0.09
Off	9798	67	60	0.68	0.61

Guidance Efficiency = (1-((0.09/0.41)/(0.61/0.68))) 100 = (1-(0.22/0.90)) 100 = 76

Notes: Chinook salmon were spray-dyed at Feather River Hatchery before release. Fish were released into the Sacramento River at Vorden Road.

1 Mortality for the treatment group was 0.31%; mortality for the control group was 0.25%.

To test this hypothesis, a mark/recapture study was performed on May 20, in which 3,954 marked salmon were released into the Sacramento River downstream of the acoustic array (adjacent to channel marker LP11) when the acoustic barrier was on (Table 11). Although having been released downstream of the acoustic barrier in the Sacramento River (Figure 2), 100% of the marked fish recaptured (253 fish) were collected in Georgiana Slough. Results of this test demonstrate the importance of hydraulic conditions on the behavior and movement of juvenile salmon in the area. Results are also completely consistent with the observation of lower acoustic barrier guidance efficiency during flood tide conditions. Despite the fact that the acoustic barrier was on, these results showed that a large number of juvenile salmon moved upstream in the Sacramento River and entered Georgiana Slough.

In a second test, on June 1, 2,255 marked fish were released into the Sacramento River during a flood tide when the acoustic barrier was off (Table 11). Of these fish, 10 were recaptured in the Sacramento River and 43 were recaptured in Georgiana Slough, further demonstrating the upstream movement of juvenile salmon in response to flood-tide hydraulic conditions.

In mark/recapture studies on May 6 and June 1, marked chinook salmon were released into the Sacramento River downstream of the acoustic array (channel marker LP11) during ebb tide conditions. A total of 5,289 marked salmon were released on May 6, and of the 215 fish recaptured, 100% were recaptured downstream in the Sacramento River. On June 1, 4,210 marked fish were released into the Sacramento River downstream of the acoustic array; 48 were recaptured in the Sacramento River and 2 were recaptured in Georgiana Slough. These results are consistent with the hypothesis that juvenile chinook salmon successfully migrating in the Sacramento River past Georgiana Slough under ebb tide conditions are substantially less likely to migrate into Georgiana Slough than are fish under flood tide conditions.

In mark/recapture studies on May 5, 4,200 marked fish were released into Georgiana Slough on an ebb tide; 155 were recovered in Georgiana Slough and 1 was recovered in the Sacramento River. This result is consistent with releases on June 1; 4,560 marked fish were released into Georgiana Slough on an ebb tide with 100% of the recaptures (312 fish) occurring in Georgiana Slough. No mark/recapture studies were performed with releases into Georgiana during a flood tide.

Results of mark/recapture studies are consistent with guidance efficiency estimates derived from Kodiak trawling in showing:

- Operation of the acoustic array contributed to an overall positive guidance efficiency (75%) for juvenile chinook salmon smolts successfully migrating downstream in the Sacramento River past Georgiana Slough based on results of one mark/recapture test.
- Juvenile salmon released downstream of the acoustic array under ebb tide conditions were collected downstream in the Sacramento River. Juvenile salmon released under flood tide conditions moved upstream, passing into Georgiana Slough, whether the acoustic barrier was on or off.
- Movement patterns of juvenile salmon were consistent with tidally influenced hydraulic conditions at the confluence between the Sacramento River and Georgiana Slough.
- Tidally influenced movement patterns are consistent with the observed reduction in acoustic barrier guidance efficiency under flood tide conditions when compared with ebb tide conditions. These observations support the hypothesis that during the 1994 test period, juvenile chinook salmon moved upstream in response to flood tide conditions (Figure 8), resulting in a reduction in acoustic barrier guidance efficiency during flood tide.
- Results of the mark/recapture test showed that juvenile salmon were recaptured downstream in the Sacramento River more rapidly when the acoustic barrier was off, suggesting a potential delay in downstream movement when the barrier was in service.

Hydroacoustic Monitoring

Hydroacoustic techniques for monitoring the occurrence and relative abundance of juvenile and adult fish have been used successfully in other investigations of the effectiveness of acoustic barriers (Ross *et al* 1993; Nestler *et al* 1992; Dunning *et al* 1992). Hydroacoustic monitoring in the Sacramento River and Georgiana Slough offers the potential for reduced labor costs associated with juvenile sampling (for example, Kodiak trawling) and the ability to detect and monitor the movement of adult fish passing the acoustic barrier. Hydroacoustic monitoring also offers the opportunity for non-invasive measurements, thereby avoiding incidental take of species such as delta smelt and winter-run salmon smolts, which occurs in more conventional sampling. Hydroacoustic monitoring has the capability to detect fish throughout the water column and along both the bottom and channel edges, while Kodiak trawling is limited to the upper 6 feet of the water column and is not effective in sampling immediately adjacent to the shoreline. Hydroacoustic monitoring does not, however, provide information on the species of either juvenile or adult fish. Results of Kodiak trawling during the spring hydroacoustic testing period did, however, show that 98 percent of the fish collected in the upper 6 feet of the water column were juvenile chinook salmon.

Hydroacoustic monitoring was included as part of the 1994 investigations to examine movement patterns of juvenile chinook salmon during the spring using transducers mounted to the gunwale of the boat at a depth of 1.5 feet. Results of these surveys are included in Appendix E and summarized below.

Hydroacoustic testing was conducted over a 10-day operational cycle (4 days barrier on and 6 days barrier off) of the acoustic barrier during May 9-18 by Hydroacoustic Technology, Inc. Data from these hydroacoustic surveys were used to estimate the mass balance of juvenile fish approaching the acoustic barrier and subsequently moving downstream in the Sacramento River and Georgiana Slough when the acoustic barrier was on and when it was off. Results provide an independent estimate of guidance efficiency of the acoustic barrier for comparison with results of Kodiak trawl collections. Results also provide information on the spatial distribution of juvenile fish upstream and downstream of the acoustic barrier.

An HTI Model 240 split-beam hydroacoustic system operating at 200 kHz was used to monitor juvenile fish abundance and distribution. The system included a 15-degree transducer, echosounder/transceiver, digital audiotape (DAT) recorder, echoprocessor, chart recorder, and oscilloscope. The monitoring system was mounted in the stern of a 16-foot fiberglass boat with the transducer placed on an aluminum pole attached to the side. The transducer was oriented vertically, with its face 18 inches below the water surface. Sample rate was 12.5 pings/second.

Hydroacoustic monitoring was conducted from May 9 to 18. During this period, the EESCO acoustic barrier was operated in a cyclic fashion (Table 6), which provided the opportunity to monitor fish abundance and distribution under conditions when the barrier was on (treatment) and off (control). Hydroacoustic monitoring was also performed for a short time when the Sonalysts low-frequency acoustic signal was in operation.

A series of transects was established encompassing areas both upstream and downstream of the acoustic array (Figure 20) in the Sacramento River and Georgiana Slough, where hydroacoustic monitoring was repeated each day. Signals from fish passing through the acoustic beam were recorded on digital audiotape for later analysis. Sampling near the EESCO acoustic barrier included 14 transects in the Sacramento River and 19 transects in

Georgiana Slough (Figure 20). In addition, five parallel transects were sampled adjacent to the barrier, three along the Sacramento River side and two along the Georgiana Slough side (Figure 21). Transect series were typically repeated three times during daytime, evening, and nighttime sampling. In addition, transects near the Sonalysts acoustic transducers (Figure 22) were sampled on May 16.

To evaluate the potential guidance effectiveness of the EESCO acoustic barrier, mean fish abundance was calculated over the entire transect grid in both the Sacramento River and Georgiana Slough. From these abundance values, an effectiveness ratio was calculated by dividing mean fish abundance per square meter in the Sacramento River by mean abundance in Georgiana Slough. The resulting ratio was then evaluated relative to barrier operation, time of day, and tidal stage.

Results of hydroacoustic monitoring for juvenile chinook salmon during May 9-18 failed to show a significant shift in estimated abundance of juvenile fish[2] in Georgiana Slough and the Sacramento River during periods when the acoustic barrier was on and off. Results were not consistent with findings from either Kodiak trawling or mark/recapture studies, which showed a positive acoustic barrier guidance efficiency. Reasons for the discrepancy are unknown but may relate to variability in the short period when hydroacoustic monitoring was done (4 days with the barrier on and 6 days with it off), interaction between tidal and diel effects, or inherent variability in assessing fish abundance and distribution in the Sacramento River and Georgiana Slough. In addition, mobile survey methods may not have provided the resolution required to assess a response to the acoustic barrier, given the limited sampling period. Fixed-aspect hydroacoustics may be more appropriate for this application.

Hydroacoustic monitoring, similarly, did not detect any substantial difference in density of juvenile fish in the Sacramento River in the area of the Sonalysts acoustic signal

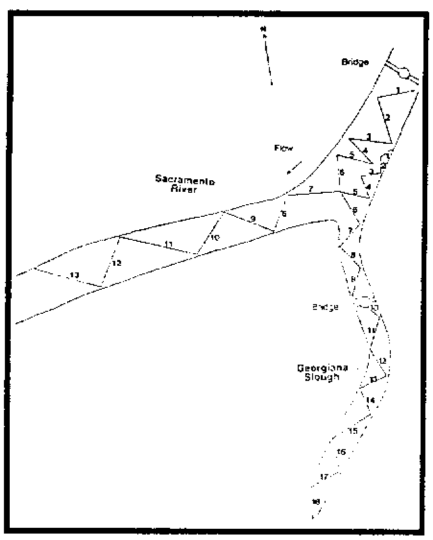

Figure 20
PLAN VIEW: AREA MONITORED
NEAR THE
EESCO
ACOUSTIC DETERRENT SYSTEM
Sacramento River, May 1994

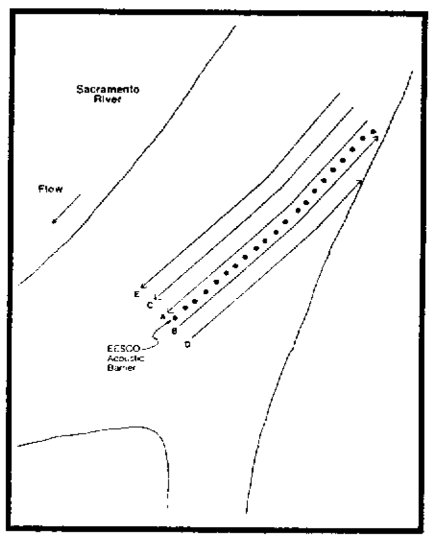

Figure 21
PLAN VIEW: TRANSECTS MONITORED
ADJACENT TO THE
EESCO
ACOUSTIC DETERRENT SYSTEM
Sacramento River, May 1994

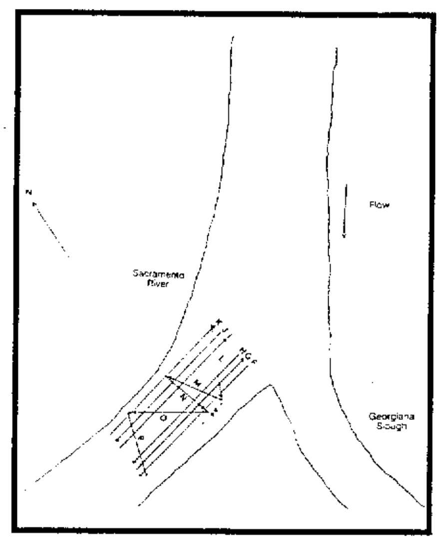

Figure 22
PLAN VIEW: TRANSECTS MONITORED
NEAR THE
SONALYSTS
ACOUSTIC DETERRENT SYSTEM
Sacramento River, May 1994

2 Based on results of Kodiak trawls, juvenile fish were assumed to be predominately chinook salmon.

before, during, or after operation of the Sonalysts low-frequency sound pressures. The Sonalysts transducers were neither configured nor installed to modify fish behavior (that is, not optimized as an array). Hence, results of these limited tests are not representative of the potential effectiveness of the system. In addition, results of the Sonalysts monitoring may be confounded, in part, by the relatively large area in the Sacramento River sampled using the hydroacoustic system relative to the operation of only two transducers. In addition, the lack of definitive information on the effectiveness of the Sonalysts signal may be due to the limited hydroacoustic sampling period (less than 1 day).

Kodiak Trawl Capture Efficiency Evaluation

Gear efficiency studies (mark/recapture tests) were performed to evaluate collection efficiency of the Kodiak trawl in the Sacramento River and Georgiana Slough. Gear efficiency tests were performed only when the acoustic barrier was off.

For the gear efficiency studies, juvenile chinook salmon obtained from Feather River Hatchery were marked with various colored spray dyes. The salmon were transported from the hatchery to on-site holding facilities in a full-sized commercial hatchery transport truck. Before being spray-dyed, fish were held on site in either floating net pens (6 x 4 x 4 feet) in the Sacramento River or in once-through fiberglass holding tanks (10 x 3 x 1.5 feet) to recover from handling and transport stress. After the acclimation period, a subsample of fish was weighed and counted to determine the number of fish per pound. Each subsequent group was weighed to estimate the total number of fish marked. After weighing, the fish were placed in a screened box, where they were spray-dyed the appropriate color[3] using an air compressor. Each lot was spray-dyed in less than 30 seconds. After spray-dying, fish were returned to the holding tank and held 36-48 hours to recover from handling and stress associated with marking. No anesthesia was used during marking.

After the post-marking recovery period, fish were placed in live cars and held in the Sacramento River for an additional recovery period. Mortality during transport, acclimation, marking, and post-marking recovery periods was documented for each release group. Total cumulative mortality for fish marked and used in mark/recapture tests was 0.5% (555 mortalities from 105,050 salmon marked). Before release, marked fish were observed for swimming behavior and avoidance response to shadows and other movement as an indicator of recovery from marking stress.

At the time of release, fish were segregated into three sets of live cars, which were then towed by three boats to release sites along the left bank, right bank, and center of the channel in either the Sacramento River or Georgiana Slough, depending on the specific mark/recapture test being performed. All fish were released simultaneously. Marked fish were released into the Sacramento River about 800 feet downstream of the acoustic

3 Scientific Marking Materials nontoxic spray dye was used.

array, adjacent to the on-site facility denoted by channel marker LP11, about 1,400 feet upstream of the Kodiak trawl recapture site. Salmon were released into Georgiana Slough immediately downstream of the Georgiana Slough Bridge (Figure 2), about 1,400 feet upstream of the Kodiak trawl recapture site. Release groups used in the Kodiak trawl efficiency tests ranged from 4,200 to 5,289 fish per release (Table 11). After release, fish were recaptured as part of routine Kodiak trawling, performed in accordance with standard sampling methods and the sampling design used as part of the acoustic barrier guidance efficiency tests. Juvenile salmon collected in Kodiak trawling were subsequently examined using an ultraviolet (black) light to detect the presence and color of marked fish recaptured as part of these tests.

Mark/recapture Kodiak trawl efficiency tests were performed separately under flood and ebb tidal conditions (Table 11). Results showed that many juvenile chinook salmon released in the Sacramento River under flood tide conditions moved upstream and/or into Georgiana Slough, thereby making results of these releases unacceptable for use in determining Kodiak trawl capture efficiency in either channel. Therefore, results of mark/recapture gear efficiency tests are appropriate only for releases during ebb tides.

Results of ebb-tide releases are summarized in Table 14. Overall, 8,760 marked salmon were released in Georgiana Slough as part of these tests, with a combined recapture of 467 fish representing a recapture efficiency of 5.33%. Results of combined releases in the Sacramento River (May 6 and June 1) had an overall capture efficiency of 2.77% based on 9,499 marked fish released and 263 recaptured. Results show that Kodiak trawl collection efficiency is substantially greater in Georgiana Slough than in the Sacramento River. These results are not surprising given the larger cross-sectional area of the Sacramento River and, therefore, the smaller percentage of the cross-sectional area actually sampled by the Kodiak trawl. Results of a two-sample t-test, however, did not detect a significant difference ($\alpha = 0.05$) in collection efficiency of the Kodiak trawl in Georgiana Slough and the Sacramento River. The statistical power of these mark/recapture gear collection tests was low, however, because of the small sample size.

Guidance efficiency test results were not adjusted to account for differential collection efficiency, because Kodiak trawl efficiency would be the same during collections when the acoustic barrier was on and off. Guidance efficiency estimates are based on a relative comparison of the ratios of salmon density in the Sacramento River and Georgiana Slough in response to acoustic barrier operations and are, therefore, not biased by differential collection efficiency between the two sampling areas. Collection efficiency was, however, included in the calculation of the change in absolute numbers of salmon entering the slough during periods when the acoustic barrier was on and off.

In addition, direct-release studies were performed in which groups of 25 dead marked fish were released directly into the mouth of the Kodiak trawl to determine mesh retention efficiency. Two groups of tests were

Table 14
SUMMARY OF KODIAK TRAWL CAPTURE EFFICIENCY TESTS IN THE SACRAMENTO RIVER AND GEORGIANA SLOUGH — EBB TIDE ONLY

Location	Number Released	Number Recaptured	Percentage Recaptured
Georgiana Slough			
May 5	4200	155	3.69
June 1	4560	312	6.84
	8760	467	5.33
Sacramento River			
May 6	5289	215	4.07
June 1	4210	48	1.14
	9499	263	2.77

Note: Spray-dyed juvenile chinook salmon from the Feather River Fish Hatchery were released at the Georgiana Slough bridge and in the Sacramento River (LP 11) about 800 feet downstream of the acoustic array.

performed, using smaller juvenile fish (25-35 mm) and larger chinook salmon smolts (75-95 mm). During each of these retention studies, Kodiak trawl deployment, retrieval, and sample processing followed routine standard procedures. Test fish were released about 2-3 feet below the surface. Trawling duration after each release was 5 minutes. The Kodiak trawl was equipped with a live car. Four replicate releases were performed for each of the smaller and larger test groups. Results for the juveniles showed an overall average retention of 84%, based on the release of 97 fish and a recapture and retention of 81 fish. Results for the smolts showed a retention of 100%.

Data collected on acoustic barrier guidance efficiency for juvenile chinook salmon in 1994 provide preliminary information useful in developing design criteria for this and other sites. The 1994 tests demonstrate the importance of local hydraulic conditions on fish movement and acoustic barrier guidance. Detailed velocity and hydraulic data are needed, under a range of flow conditions, for use in developing site-specific barrier configurations. In addition, data collected in 1994, although predominantly under low-flow conditions, suggest that barrier design and configuration can be improved or optimized with additional data on the relationship between guidance efficiency and streamflow. Regression analyses of the 1994 data suggest higher guidance efficiency for the Georgiana Slough site under conditions of higher Sacramento River flow and reduced tidally-induced reverse flows. Additional testing in 1995, in which substantially higher flow is expected, will provide additional data on the relationship between flow conditions and guidance efficiency.

Additional consideration should be given to modifying the Georgiana Slough acoustic barrier configuration to provide better guidance during flood tide conditions, when flows reverse flows in the Sacramento River. Preliminary consideration has been given to modifications that:

- Completely ensonify the confluence between the Sacramento River and Georgiana Slough by extending the barrier downstream, and
- Use a dual barrier configuration in a chevron design, with the upstream barrier operated on ebb tide (no reverse flow) and the downstream barrier operated on flood tide (reverse flow).

Concern has been expressed regarding the effects of such barrier modifications on blockage of adult fish migration (striped bass and chinook salmon, for example) into and out of Georgiana Slough. Additional investigations on the effects of acoustic barrier operations on the movement and migration patterns of juvenile and adult fish and the effectiveness of these modifications for increasing overall guidance efficiency for juvenile chinook salmon would be required before the acoustic barrier was modified substantially.

Summary

Results of Kodiak trawl capture efficiency tests have shown:

- Spray-dye marking was performed with minimal (0.5%) mortality.
- Capture efficiency of the Kodiak trawl during ebb tidal conditions was greater in Georgiana Slough (5.33% recapture efficiency) than in the Sacramento River (2.77% recapture efficiency). Results of a two-sample t-test did not detect a significant difference in Kodiak trawl collection efficiency between the Sacramento River and Georgiana Slough, although the power of these tests is low due to small sample sizes.
- The Kodiak trawl captured and retained 84% of 25-35 mm fish and 100% of 75-95 mm smolts.

Chapter 4

Exposure Tests: Acute and Delayed Mortality and Increased Susceptibility to Predation

Concern has been expressed that the effects of exposure to underwater sound pressure levels such as those used in these tests are unknown for various life stages of fish inhabiting the Sacramento River. Exposure to underwater sound pressure levels could possibly result in physiological damage resulting in either acute or delayed mortality. Concern has also been expressed that sublethal damage could occur, resulting in increased susceptibility of fish to predation.

The experimental design of the 1994 Georgiana Slough acoustic barrier research program (Table 1) included study elements designed to provide information on both the effects of underwater sound pressure levels on acute and delayed mortality and on differential susceptibility of prey species (*eg*, chinook salmon smolts) to predation. This chapter provides an overview of the methods and results of these investigations.

Acute and Delayed Mortality Effects

Concern has been expressed regarding the potential mortality and/or sublethal effects resulting from exposure of juvenile winter-run salmon, fall-run chinook salmon, delta smelt, and other fish and macroinvertebrates to the EESCO and Sonalysts acoustic barrier signals. Controlled exposure tests were performed using both technologies to determine the effects of acoustic exposure on target and surrogate species. Mortality immediately after exposure to the acoustic signal and over a minimum 96-hour observation period, in addition to qualitative observations of loss of equilibrium and swimming behavior, were used to assess differential effects between treatment and control groups for each species tested.

Methods

Juvenile fall-run chinook salmon were used as a surrogate species for winter-run chinook salmon. Tests also used subadult delta smelt, larval and juvenile striped bass, inland silversides, catfish, sturgeon, golden shiner, and crayfish. Pacific herring eggs were exposed to the underwater sound pressure levels during incubation as a surrogate for delta smelt eggs. Additional exposure tests used a mixed assemblage of resident fish species collected in the area.

Juvenile chinook salmon were obtained from Feather River Hatchery and from beach seining in the Sacramento River and Georgiana Slough. Larval and juvenile striped bass, catfish, and white sturgeon were obtained from The Fishery, a commercial aquaculturist. Golden shiners were obtained from commercial bait shops. Inland silversides and a mixed assemblage of resident fish species were collected by beach seining in the Sacramento River and Georgiana Slough. Crayfish were obtained through trapping in the Sacramento River. Pacific herring eggs were collected from a subtidal area in Richardson Bay. These taxa were transported to the on-site holding facility and, except for Pacific herring eggs, were tested under ambient freshwater conditions.

Subadult delta smelt (38-64 mm) were collected from the lower Sacramento River using a purse seine in cooperation with scientists from the Department of Fish and Game and the University of California at Davis. Handling and holding techniques for delta smelt were consistent with techniques developed by UCD researchers (Swanson *et al* 1994; Randy Mager and Tina Swansen, UCD, personal communication). After capture, delta smelt were held in 10-liter plastic bags at about 8 parts per thousand salinity, and treated with NOVA AQUA. About 30 smelt were held in each bag. Each bag was infused with oxygen and sealed for transport to the on-site testing facility in insulated ice chests positioned on a foam pad to reduce vibration. On-site, fish were placed in a 310-liter circular tank with a water depth of about 3 feet and a once-through flow rate of about 0.02 m^3/ minute from the Sacramento River.

At the time of these tests, turbidity in the Sacramento River was high, precluding detailed visual observation during the post-treatment holding period. Salinity in the holding tank was increased to 5-8 ppt during the first 24 hours after collection. The fish were then treated with nitrofurazone (10 ppm) for about 1 hour, followed 24 hours later by treatment with formalin (100 ppm). Treatment and control fish were held and treated identically. A total of 119 delta smelt were collected on December 1, with the following pre-test mortality:

December 2	19 fish
December 3	26 fish
December 4	2 fish
December 5	0 fish

Exposure testing was performed about 96 hours after collection and pretest collection and holding mortality had stabilized.

Delta smelt may spawn in the immediate vicinity of the Georgiana Slough acoustic barrier, which would result in prolonged exposure of developing eggs to the underwater acoustic signal. The adhesive eggs of delta smelt remain fixed at one location during the 7-10 day period of embryonic development prior to hatching. Concern has been expressed regarding potentially detrimental effects on embryonic development and hatching success. On December 6, Pacific herring eggs were collected by grappling from an area in Richardson Bay for testing as a surrogate for delta smelt eggs. The Department of Fish and Game (Diana Watters, DFG, personal communication) reported that on December 5, adhesive Pacific herring eggs were spawned on subtidal algae. The algae and attached eggs were placed in an ice chest containing ambient sea water and returned to the on-site testing facility. Herring eggs attached to algae were divided among 8-liter plastic bags filled with ambient sea water from Richardson Bay and used for both treatment and controls. The plastic bags containing the herring eggs and sea water were held in ambient temperature water baths at the site throughout the testing and incubation period. Unlike tests using striped bass larvae (15-minute exposure duration) and other fish species (60-minute exposure duration), Pacific herring eggs were exposed to the acoustic signal for durations of 24 hours, 48 hours, and until incubation was completed, each with corresponding controls. The effects of underwater sound pressure levels on Pacific herring eggs were determined by examining percent hatching success and embryonic and larval morphology through microscopic examination by Dr. Johnson Wang.

Exposure tests were performed to determine differential survival rates for fish exposed to the acoustic signal generated by both the EESCO and Sonalysts technologies and corresponding controls. Tests using each species generally involved 60-minute exposure under field (live car) conditions characteristic of sound pressure levels 9 feet from the acoustic barrier. The live car (3 x 1.5 x 1.5 feet) was constructed using a PVC frame and enclosed in nontoxic, 6-millimeter diagonal, plastic screen mesh. Floats were attached to the top of the live cars, which were floated on the surface during the exposure period for both treatment and control groups. Larval striped bass and Pacific herring eggs were exposed to the underwater sound pressure levels in clear plastic bags.

Comparative measurements were made to determine underwater sound pressure levels in the Sacramento River adjacent to the acoustic barrier and in both the live car and plastic bags. Results showed that sound pressure levels in the live car (134-138 dB) and plastic bags (130-136 dB) were representative of levels in the Sacramento River near the acoustic barrier. Sound pressure levels were 147-150 dB for the EESCO transducers and 140 dB for the Sonalysts transducers. Background sound pressure levels where control fish were exposed during each test were 88-97 dB.

All exposure tests during the spring were in the Sacramento River, with subsequent holding and observation of delayed effects at the on-site facility.

During the fall testing (October-November), inland silversides were exposed to the EESCO system in the Sacramento River (live car tests). Delays in obtaining subadult delta smelt for use in exposure tests precluded the opportunity for continued exposure testing in the Sacramento River after November 15 because of terms and conditions in the winter-run chinook salmon biological opinion for the 1994 Georgiana Slough Acoustic Barrier Project. As an alternative, one EESCO transducer was positioned at mid-depth in a rectangular fiberglass tank (10 x 3 x 1.5 feet) located on-site and provided with ambient river water. Before performing exposure tests in the fiberglass tank using delta smelt, reconnaissance exposure tests were performed using inland silversides. Identical live cars and handling procedures were used in tests in the Sacramento River and in the on-site tank.

Results of the inland silversides test were comparable for immediate and delayed mortality for fish exposed to the underwater sound pressure in the Sacramento River and in the on-site holding tank. Based on these results, additional exposure testing was performed using the on-site holding tank and subadult delta smelt, inland silversides, and Pacific herring eggs. Fish in the holding tank were exposed at a distance of 6 feet from the transducer. Control tests were performed in an identical fiberglass holding tank. A common water supply was used for the exposure tank, the control tank, and all on-site holding facilities.

After exposure to the acoustic signal, treatment and control groups were held on site for observation of immediate and delayed (typically 96-hours or longer) mortality. For each treatment and control group, daily observations on percentage survival were recorded. Additional qualitative observations on the loss of equilibrium, swimming and behavioral activity, *etc*, were documented. In addition, one group of early juvenile catfish (both treatment and controls) were held for 312 hours after testing to examine potential differences in behavior and growth rates following exposure to the acoustic signal. Catfish were fed throughout the post-test holding period. Observations of swimming behavior, mortality, and a subsample of fish for both treatment and control groups were taken at intervals throughout the observation period to assess post-exposure effects.

Results of Exposure Tests

Results of exposure tests are summarized in Table 15; results of individual tests are documented in Appendix F. Tests provided no evidence that exposure to underwater sound pressure levels contributed to differential immediate or delayed mortality as a result of acoustic exposure. The rate of mortality for striped bass larvae during the post-treatment observation period and total mortality (144 hours after exposure) were similar for both treatment and control groups (Figure 23).

Table 15
SUMMARY OF ACUTE MORTALITY TESTS FOR
FISH EXPOSED FOR 60 MINUTES TO UNDERWATER SOUND PRESSURE LEVELS
GENERATED BY EESCO AND SONALYSTS

	Life Stage	Exposure (minutes)	Number Tested			Percentage Survival (Delayed)		
			Control	EESCO	Sonalysts	Control	EESCO	Sonalysts
In-River Exposure*								
Striped Bass	Larvae	15	198	227	—	90	90	—
	Juvenile	60	90	133	108	91	93	97
Sturgeon	Juvenile	60	40	60	40	100	95	100
Chinook Salmon	Smolt	60	55	60	100	96	93	99
Catfish	Juvenile	60	854	411	421	94	98	89
Golden Shiner	Juv/Adult	60	37	84	10	89	89	70
Inland Silversides	Adult	60	180	180	—	84	86	—
In-Tank Exposure**								
Inland Silversides	Adult	60	100	150	—	93	93	—
Delta Smelt	Subadult	60	35	35	—	86	91	—

*Exposed at 3 meters from the sound source in the Sacramento River.
**Exposed at 2 meters from the sound source with an on-site fiberglass holding tank.

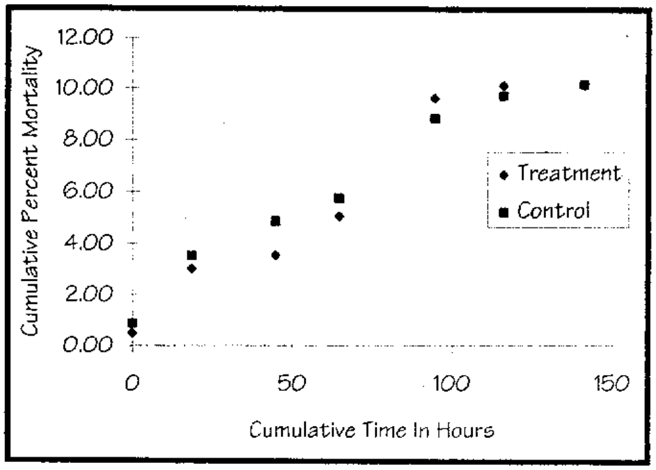

Figure 23
MORTALITY OF LARVAL STRIPED BASS
FOLLOWING EXPOSURE TO THE
EESCO UNDERWATER SOUND PRESSURE LEVELS
AND CONTROLS

Survival at the end of the post-test observation period was similar for both control and EESCO and Sonalysts treatment groups for striped bass, sturgeon, juvenile chinook salmon, catfish, golden shiner, and inland silversides (Figures 24-29). With the exception of golden shiners exposed to the Sonalysts signal, in which only 10 fish were tested, survival through the post-exposure observation period exceeded 80% for both treatment and control groups for all taxa included in these in-river exposure tests.

Results of exposure tests using the EESCO acoustic signal in the on-site holding tank were similar for both treatment and control groups of inland silversides and delta smelt (Table 15). Survival of inland silversides averaged 93% in both treatment and control groups 96 hours after exposure (Figure 30). Results of these exposure tests conducted on site in a fiberglass holding tank are consistent with results of in-river tests. Survival of delta smelt 96 hours after exposure was 86% for control groups and 91% for treatment groups.

A limited number of exposure tests were performed using a mixed assemblage of fish species collected using beach seines at reference locations in the Sacramento River and Georgiana Slough near the test site. Although not statistically valid because of small sample sizes, results were consistent with those of the more extensive program in showing no substantial increase in mortality following exposure to either the Sonalysts or EESCO acoustic signal when compared with controls (Table 16).

Results of an exposure test using adult crayfish (Table 16) showed no mortality during the post-test observation period (EESCO acoustic signal) for either treatment or controls. These results are consistent with observations from crayfish trapping (Chapter 6), in which no mortality was observed in crayfish collected immediately adjacent to the acoustic barrier when the barrier was on (treatment), when compared with periods when the barrier was off (control) or at crayfish trapping locations outside the influence of the acoustic barrier.

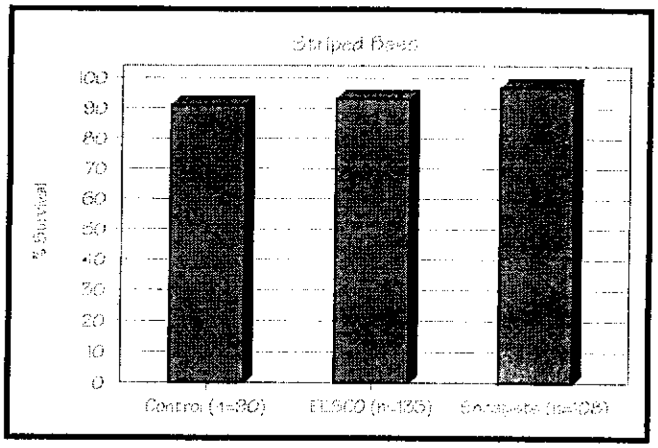

Figure 24
SURVIVAL OF JUVENILE STRIPED BASS
96 HOURS OR MORE AFTER EXPOSURE TO
EESCO AND SONALYSTS ACOUSTIC SIGNALS AND
CORRESPONDING CONTROLS

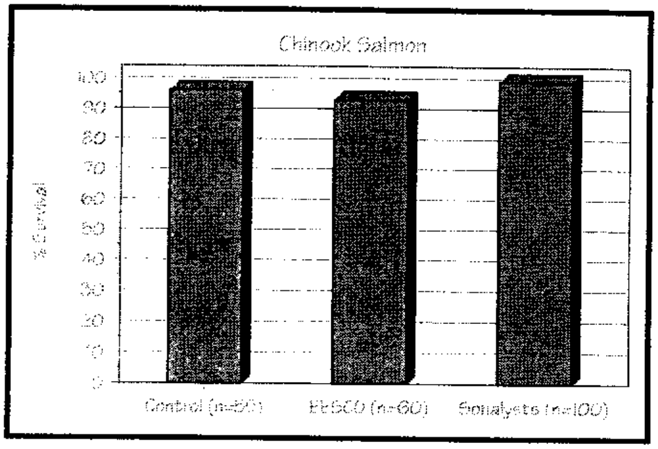

Figure 26
SURVIVAL OF JUVENILE CHINOOK SALMON
96 HOURS OR MORE AFTER EXPOSURE TO
EESCO AND SONALYSTS ACOUSTIC SIGNALS AND
CORRESPONDING CONTROLS

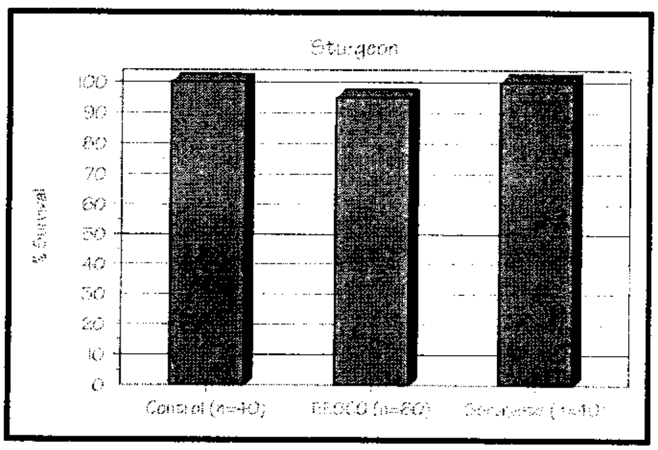

Figure 25
SURVIVAL OF JUVENILE STURGEON
96 HOURS OR MORE AFTER EXPOSURE TO
EESCO AND SONALYSTS ACOUSTIC SIGNALS AND
CORRESPONDING CONTROLS

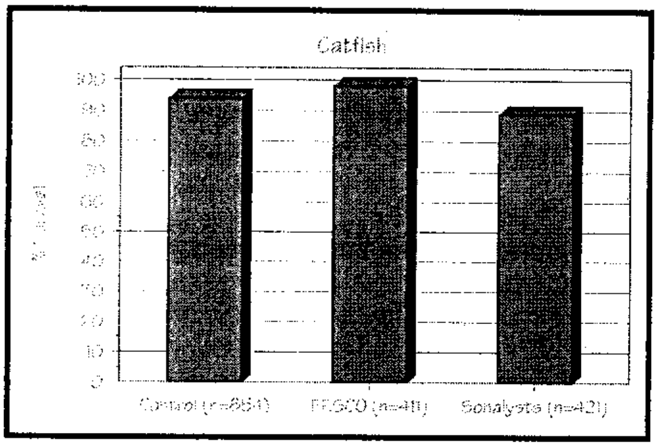

Figure 27
SURVIVAL OF JUVENILE CATFISH
96 HOURS OR MORE AFTER EXPOSURE TO
EESCO AND SONALYSTS ACOUSTIC SIGNALS AND
CORRESPONDING CONTROLS

Observation of juvenile catfish over a 312-hour post-test period showed that fish exposed to the acoustic signal and controls were actively swimming. Fish were fed a commercial diet throughout the post-test observation period, and both groups were actively foraging. The two groups showed similar patterns of aggregation in the holding tank. There was no apparent lethargic behavior, loss of equilibrium, or increased mortality rate for fish exposed to the acoustic signal when compared with controls. There was no length difference in subsamples from each of the treatment and control groups immediately after exposure to the acoustic signal and after the 312-hour post-test holding period.

Video and direct field observations during in-river exposure tests did not show any evidence of loss of equilibrium or abnormal swimming behavior (*eg*, fright response, twitching, consistent efforts to escape the live car) when fish were exposed to underwater sound pressure levels. During post-exposure observations, fish that had been exposed to both the Sonalysts and EESCO acoustic signals appeared to behave consistently with controls, actively orienting to water currents and showing a rapid avoidance response to shadows and researcher activity. In contrast, inland silversides tested in the on-site holding tank appeared to be lethargic and showed evidence of loss of equilibrium during exposure to the acoustic signal. No similar response was observed for any fish tested in the Sacramento River when exposed to either the EESCO or Sonalysts acoustic signal. Following the in-tank exposure, silversides rapidly resumed normal swimming behavior similar to that observed for controls. Delta smelt tested in the on-site holding tanks did not show evidence of lethargic swimming behavior or loss of equilibrium during or after exposure to the EESCO acoustic signal.

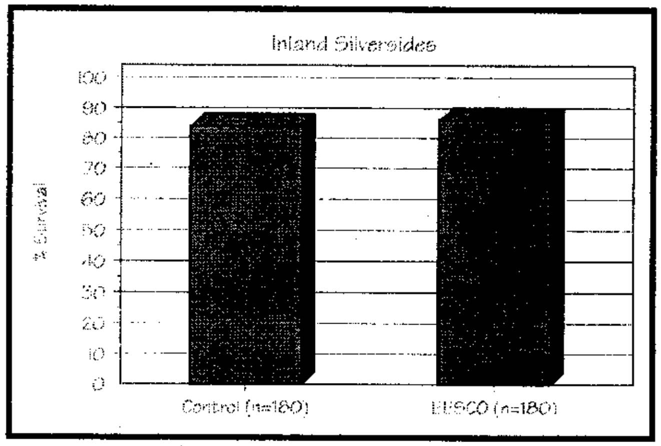

Figure 29
SURVIVAL OF JUVENILE INLAND SILVERSIDES 96 HOURS OR MORE AFTER EXPOSURE TO THE EESCO ACOUSTIC SIGNAL AND CORRESPONDING CONTROLS

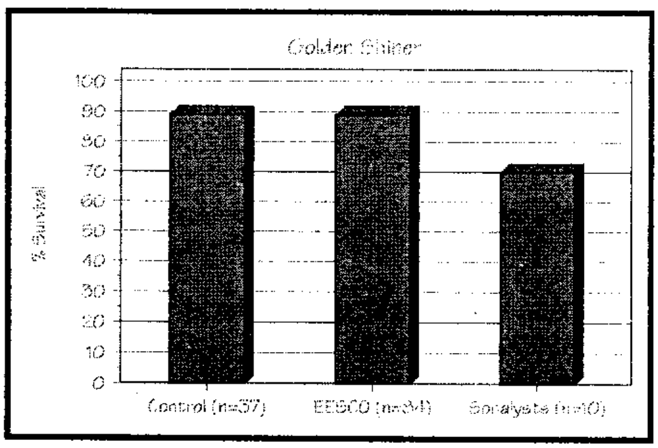

Figure 28
SURVIVAL OF JUVENILE GOLDEN SHINER 96 HOURS OR MORE AFTER EXPOSURE TO EESCO AND SONALYSTS ACOUSTIC SIGNALS AND CORRESPONDING CONTROLS

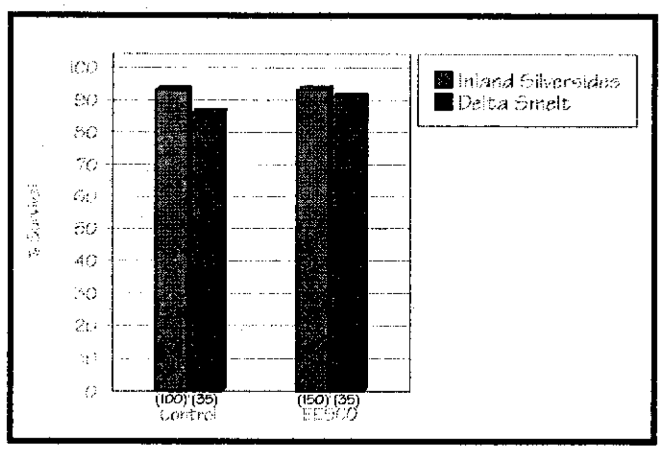

Figure 30
SURVIVAL OF INLAND SILVERSIDES AND DELTA SMELT EXPOSED TO THE EESCO ACOUSTIC SIGNAL IN ON-SITE EXPOSURE TESTS AND CORRESPONDING CONTROLS

Table 16
SUMMARY OF EXPOSURE TEST RESULTS FOR FISH AND CRAYFISH
COLLECTED NEAR THE CONFLUENCE OF THE SACRAMENTO RIVER AND GEORGIANA SLOUGH
Exposure tests were 60-minute duration, 3 meters from the sound source in the Sacramento River.

	Control		EESCO		Sonalysts	
	Number Alive*	Number Dead	Number Alive**	Number Dead	Number Alive***	Number Dead
Smallmouth Bass	9	0	11	1	19	1
Largemouth Bass	10	0	7	0	11	0
Tule Perch	4	0	2	1	5	1
Silversides	6	0	5	2	0	1
Bluegill	1	1	—	—	—	—
Sacramento Sucker	2	4	4	0	—	—
Gambusia	—	—	4	0	3	1
Goby	4	0	5	1	2	0
Splittail	3	1	3	1	—	—
Sacramento Squawfish	—	—	0	2	—	—
Golden Shiner	—	—	1	0	—	—
Crayfish	10	0	10	0	—	—

* Delayed mortality observation period ranged from 99-141 hours.
** Delayed mortality observation period ranged from 97-119 hours.
*** Delayed mortality observation period ranged from 141-142 hours.

As a surrogate species for delta smelt, Pacific herring eggs were exposed to the EESCO acoustic signal for various durations during incubation. Pacific herring eggs are adhesive and their incubation period (about 10 days) is similar to that of delta smelt. Hatching success was consistently high (>95%) for both treatment and control groups. Results of embryonic examinations, performed by Dr. Johnson Wang, are shown in Table 17 for herring eggs exposed to the acoustic signal for 24 hours, 48 hours, and 312 hours, in addition to controls. After the incubation period, eggs and larvae were categorized as: (1) hatched larvae showing normal embryonic development; or (2) aborted eggs, abnormal embryonic development, or abnormal larvae. Frequency of abnormal embryonic development for test groups exposed to the acoustic signal throughout most of their incubation period (312 hours) and controls was not significantly different ($p > 0.05$). The treatment group had 6.7% embryonic abnormalities (22 of 330 larvae), compared with 5.7% (23 of 404 larvae) for controls. After the incubation testing period, larvae were actively swimming after exposure to the acoustic signal for 312 hours.

Table 17
TEST RESULTS FOR PACIFIC HERRING EGGS
EXPOSED TO THE
EESCO ACOUSTIC SIGNAL DURING INCUBATION

Exposure Duration (hours)	Hatched Normal Embryo	Aborted or Abnormal Embryo	Total Observed	Percentage Abnormal
24	84	3	87	3.4
48	144	6	150	4.0
312	77	3	80	3.8
12	231	19	250	7.6
Total	536	31	567	5.5
Control	240	11	251	4.4
Control	141	12	153	7.8
Total	381	23	404	5.7

Overall, results of these tests provide no evidence that exposure to the acoustic signal generated by either the EESCO or Sonalysts transducers contributed to increased mortality for a variety of life stages and species of fish and crayfish. Survival for chinook salmon and delta smelt, two of the principal test species of concern, was consistent among individuals exposed to the acoustic signal and for controls. Mortality rates for striped bass larvae and the frequency of embryonic abnormalities for incubating Pacific herring eggs showed no statistically significant difference between treatment and controls. Observations of fish tested in the Sacramento River showed no evidence of a loss of equilibrium or abnormal swimming behavior when exposed to underwater sound pressure levels. Inland silversides tested in the on-site tank showed evidence of lethargic behavior during testing but rapidly recovered during the post-test observation period. No similar change in behavior was observed for inland silversides tested in the river.

Increased Susceptibility to Predation

Observations at a number of water diversion sites have shown an increase in the susceptibility of juvenile fish to predation losses. Increased predation losses have been associated with accumulation or concentration of predatory fish (such as squawfish and striped bass) near the diversion structure and with behavioral and physiological changes in the response of prey species to hydraulic gradients and other features of diversion facilities (Mesa 1994). Operation of the acoustic barrier at Georgiana Slough could increase susceptibility of juvenile chinook salmon or other juvenile fish to increased predation. Exposure of prey species to underwater sound may cause adverse physiological effects, resulting in increased susceptibility to predators (*eg*, reduced predator avoidance response).

Controlled predation exposure tests were performed to provide additional information on changes in the susceptibility of juvenile chinook salmon and juvenile striped bass to predation as a consequence of exposure to the acoustic signal (physiological effects). Comparative tests were performed for prey exposed to the acoustic signal produced by the EESCO and Sonalysts transducers. The objective was to establish a quantitative relationship between the exposure of juvenile chinook salmon and striped bass to the acoustic signal and increased vulnerability to predation by subadult striped bass.

Methods

Prey were individually marked (fin clip) into two treatment groups (left pelvic mark, right pelvic mark). After marking, juvenile fish were segregated according to marking location and returned to a flow-through holding tank or live car. Fish were not fed during pre-test holding. Before each test, groups of 5-15 fish from each of the two marked groups were placed in live cars (about 3 x 1.5 x 1.5 feet) and allowed a minimum of 4 hours to recover from the effects of handling. One randomly selected marked group (either left or right mark) was then exposed for 60 minutes to the EESCO or Sonalysts acoustic signal in the Sacramento River at a distance of about 9 feet from a sound transducer. The second tag group (control) was handled identically but was not exposed to the acoustic signal. After exposure to the acoustic signal, the treatment and control groups of prey were combined in a single live car to mix tags and immediately released into a live car (6 x 4 x 4 feet) suspended in the Sacramento River. The live car contained a population of three to five subadult striped bass (about 10-16 inches long) collected from the Sacramento River, used as predators. Predators were not fed for 24 hours before each test. Prey were allowed to remain in the live car for about 60 minutes, or until about half the prey was consumed. The test was then stopped, and the remaining prey was recovered and examined to determine the frequency of prey exposed to the acoustic signal (treatment) and controls. Survivors were not used in subsequent trials.

After each test, the number of juvenile fish remaining that had been exposed to the acoustic signal and those from controls were determined based on fin marks. Survival rates for prey in the treatment and control groups were then determined based on the ratio of number of prey eaten and number remaining alive after each test. A ratio estimate of differential prey consumption was used to determine the potential increase in prey susceptibility to predation as a consequence of exposure to each acoustic signal. Predation tests were replicated for each prey species and for the two acoustic technologies.

Instantaneous mortality rates of prey exposed to the acoustic signal and control groups of juvenile fish were used to determine if vulnerability to predation increases as a result of short-duration exposure to the acoustic pressure levels produced by the two technologies. The mortality rate was calculated from the proportion of fish surviving from each group (number at finish divided by number at start). A chi-square analysis was used to test for statistical significance of observed differences in predation rates in each sound exposure test.

Results of predation tests are most sensitive in detecting increased vulnerability to predation associated with acoustic signal exposure in those tests where about 50% of the prey is consumed by predators. Bams (1967) and Coutant (1973) discussed the reasons for limiting the number of prey consumed in each valid test. The changing ratio of prey availability between treatment and controls during a test introduces a progressive bias when no prey is consumed and when all prey in a test is consumed. Turbid water in the Sacramento River and Georgiana Slough, however, precluded visual observation during the predation tests. To control the potential bias, each test was considered to be valid only if the percentage of prey remaining alive after the test was between 25% and 75%. Tests failing to meet these criteria were excluded from subsequent analyses.

Results of Predation Tests

Results of predation studies using juvenile striped bass and juvenile chinook salmon as prey exposed to underwater sound pressure levels generated by the EESCO and Sonalysts transducers are summarized in Table 18. Numbers of juvenile striped bass consumed by predators (subadult striped bass) were similar for both treatment (32 consumed) and controls (38 consumed) in tests with the EESCO technology. Results were similar for juvenile striped bass after exposure to the Sonalysts sound pressure levels (10 consumed) and corresponding controls (11 consumed). Tests using juvenile chinook salmon as prey did not provide valid estimates because very few prey were consumed from either the treatment or control groups.

Results of similar predation studies using kokanee and cutthroat trout as prey (Bennett *et al* 1994) showed no significant increase in predation rates following exposure to underwater sound ranging from 100 to 5,600 Hz at sound pressure levels ranging from 140 to 167 dB. Prey in these tests were reported to show no reduction in their ability to avoid capture by predators compared to control fish, and there was no evidence that predators (bull trout and squawfish) preferentially selected specific sizes of prey for either ensonified or control groups. Results of these studies did, however, show that bull trout exposed to an underwater sound pressure level of 167 dB at 5,600 Hz and squawfish exposed at 140 dB (100 Hz) experienced a statistically significant reduction in the number of prey eaten when compared with controls. Investigations in 1994 at the Georgiana Slough site did not include tests

Table 18
PREDATION SUSCEPTIBILITY FOR JUVENILE STRIPED BASS AND CHINOOK SALMON FOLLOWING EXPOSURE TO UNDERWATER SOUND PRESSURE LEVELS

EESCO
(60-minute exposure, 3 meters from source)

	Striped Bass	Chinook Salmon
Number of Tests	12	5
Number of Prey Alive		
Control	58	31
Treatment	64	33
Number of Prey Consumed		
Control	38	4
Treatment	32	2

Sonalysts
(60-minute exposure, 3 meters from source)

	Striped Bass	Chinook Salmon
Number of Tests	2	3
Number of Prey Alive		
Control	5	45
Treatment	6	45
Number of Prey Consumed		
Control	11	0
Treatment	10	0

in which predators were exposed to underwater sound pressure levels associated with acoustic barrier operations.

Results from individual predation studies using juvenile striped bass and juvenile chinook salmon as prey are summarized in Table 19. Statistical analyses for individual tests meeting the criteria for prey consumption (25-75% prey survival) show no evidence of preferential susceptibility of prey following exposure to underwater sound pressure levels used in these investigations. Results of a chi-square test for juvenile striped bass exposed to the EESCO signal were not statistically significant (P = 0.54). No significant difference in predation susceptibility was detected for juvenile striped bass (EESCO exposure) using a Cochran-Mantel-Haenazel test (P = 0.56). Although the sample size was substantially smaller (Table 19), juvenile chinook salmon did not exhibit a significant increase in predation following exposure to the EESCO signal in either the chi-square test (P = 0.36) or Cochran-Mantel-Haenazel test (P = 0.36). Results of these analyses are consistent with results of predation studies conducted for juvenile kokanee and cutthroat trout reported by Bennett *et al.* (1994).

Table 19
RESULTS OF INDIVIDUAL PREDATION SUSCEPTIBILITY TESTS FOR JUVENILE STRIPED BASS AND CHINOOK SALMON EXPOSED TO EESCO AND SONALYSTS ACOUSTIC TECHNOLOGIES

	Control			Treatment				
	Number Tested	Number Survivors	Percentage Survival	Number Tested	Number Survivors	Percentage Survival	Overall % Survival	Chi-square analysis
				Juvenile Striped Bass as Prey				
EESCO	8	3	38	8	4	50	44	
	8	4	50	8	6	75	63	
	8	8	100	8	6	75	88	Void
	8	2	25	8	7	88	56	
	8	4	50	8	8	100	75	
	8	3	38	8	6	75	56	
	8	7	88	8	4	50	69	
	8	5	63	8	6	75	69	
	8	6	75	8	6	75	75	
	8	4	50	8	1	13	31	
	8	6	75	8	5	63	69	
	8	6	75	8	5	63	69	
Sonalysts	8	1	13	8	2	25	19	Void
	8	4	50	8	4	50	50	
				Juvenile Chinook Salmon as Prey				
EESCO	6	2	33	6	5	83	58	
	6	6	100	6	5	83	92	Void
	6	6	100	6	6	100	100	Void
	5	5	100	5	5	100	100	Void
	12	12	100	12	12	100	100	Void
Sonalysts	15	15	100	15	15	100	100	Void
	15	15	100	15	15	100	100	Void
	15	15	100	15	15	100	100	Void

Discussion

The Sacramento River near Walnut Grove and Georgiana Slough is an area where delta smelt, winter-run chinook salmon, and a number of other species have been found. The area represents potential delta smelt spawning habitat. Therefore, the acoustic sound barrier has the potential to adversely affect delta smelt and other species by:

- Blocking access to spawning and juvenile rearing habitat.
- Interfering with spawning behavior.
- Affecting egg and larval development.
- Interfering with feeding, directly or indirectly, through effects on the number, distribution, or behavior of planktonic food organisms.

Operation of the acoustic barrier may adversely affect adult delta smelt migration in the Sacramento River and/or Georgiana Slough. Operation of the acoustic barrier could create a blockage, delaying the upstream migration of adult delta smelt, chinook salmon, and other species (Chapter 5) and the downstream migration of juveniles. Acoustic barrier operations might cause delta smelt to avoid otherwise suitable spawning habitat. The potential magnitude of this effect is unknown and cannot be determined using available data.

Operations of the acoustic barrier, particularly over extended periods, may result in a localized reduction in abundance or species composition of resident fish populations, including delta smelt, inhabiting the Sacramento River and Georgiana Slough near the acoustic barrier. The potential effects of acoustic barrier operations on resident fish populations is known only from limited tests in 1994 (Chapter 6). The alignment of the acoustic array has been developed to ensure that a portion of the Sacramento River and Georgiana Slough remain unobstructed to provide a pathway for adult upstream migration.

To determine if exposure to the acoustic signal affected delta smelt, exposure experiments were part of the 1994 investigations. One transducer was suspended at mid-depth in a rectangular fiberglass tank. Subadult delta smelt were placed in the tank about 6 feet from the transducer and exposed for 1 hour. After exposure, both the treatment and control groups were held on-site for at least 96 hours. The exposed fish did not show evidence of lethargic swimming behavior or loss of equilibrium. Survival after 96 hours was 86% for the control group and 91% for the treatment group. These results suggest that the acoustic signal had no effect on delta smelt survival.

Operation of the acoustic barrier might cause an accumulation of predators and increased susceptibility of prey, such as delta smelt, to predation losses. Observations during the investigations were insufficient to conclude whether there was an accumulation of predatory species associated with the barrier.

Operations of the acoustic barrier might adversely affect the hatch of delta smelt eggs spawned near the barrier. Planktonic food organisms utilized by hatched larvae also may be adversely affected by operation of the barrier. Copepods and opossum shrimp used by delta smelt and other species may be affected by the signal. Losses of delta smelt eggs, larvae, and juvenile fish may result from these effects. Pacific herring eggs, used as a delta smelt surrogate in exposure studies, may not be appropriate in elucidating effects on delta smelt. Pacific herring eggs exposed continuously to the acoustic signal showed no evidence of abnormal development or reduced hatching success when compared to controls.

Summary

Results of exposure and predation tests performed using both the EESCO and Sonalysts acoustic signals have shown:

- Acute and delayed mortality for a variety of fish species, including juvenile chinook salmon, striped bass, sturgeon, catfish, golden shiners, and inland silversides, apparently did not increase following a 60-minute exposure to underwater sound pressure levels 9 feet from the sound source.
- Delta smelt exposed to the EESCO signal (60-minute exposure at 6 feet) did not show increased mortality between treatments (91% survival) and controls (86% survival).
- Mortality rate for larval striped bass exposed to the EESCO acoustic signal was similar between treatments and controls.
- Pacific herring eggs exposed to the EESCO acoustic signal for 24-312 hours during incubation did not show evidence of reduced hatching success or increased embryonic abnormalities when compared with controls.
- Results of predation studies provided no evidence of a statistically significant increase in juvenile striped bass (prey) predation following exposure to the EESCO sound signal at a distance of 9 feet for 60 minutes.

Insufficient data were collected to evaluate predation susceptibility for juvenile striped bass exposed to the Sonalysts signal or for juvenile chinook salmon exposed to either the EESCO or Sonalysts transducers.

Chapter 5

Blockage/Delay in Migration of Adult Striped Bass and Fall-Run Chinook Salmon

Adult striped bass and chinook salmon migrate upstream in the Sacramento River to spawn. Operation of the acoustic barrier has the potential to block or delay movement of these fish in both Georgiana Slough and the Sacramento River. Particular concern exists regarding blockage or delay in upstream migration of adult winter-run chinook salmon. To investigate the behavioral response of adult chinook salmon and striped bass, a series of ultrasonic tagging and hydroacoustic studies was performed.

Ultrasonic Tagging

Concern has been expressed regarding the potential behavioral response of adult fish exposed to the acoustic array, which may block or delay upstream migration. To examine the behavioral response of adult chinook salmon and striped bass to acoustic barrier operations, ultrasonic tagging techniques were used to evaluate the migration rate of individually identifiable fish through the area where exposure to the acoustic signal is expected. Ultrasonic tags emit a unique high-frequency signal that identifies individual fish and allows monitoring of their behavior and migration rates. Although the use of ultrasonic tagging is experimental in the Sacramento River, this approach was selected for use as part of the 1994 Georgiana Slough acoustic barrier investigations to be compatible with ultrasonic tagging and monitoring of adult chinook salmon behavior in Montezuma Slough conducted by the Department of Fish and Game. Selection of ultrasonic tags, coordination of tag frequencies, joint tagging effort, and compatible monitoring systems with those selected for use by Fish and Game were all factors considered in the selection and application of ultrasonic tagging techniques for examining the behavior and migration rates of adult chinook salmon and striped bass in response to acoustic barrier operations.

Ultrasonic Tag Monitoring Methods

Continuous ultrasonic tag monitoring stations (Sonotronics Model USR-90) were established in Georgiana Slough about 1/4 mile downstream of the confluence with the Sacramento River, in the Sacramento River about 1/4 mile downstream of the acoustic barrier, and in the Sacramento River about 1/2 mile upstream of the acoustic barrier (Figure 31). Each tag-receiving station continuously monitored and recorded the individual tag identification code (based on signal frequencies; Sonotronics tracking tags Model CT-82) and the time of fish passage. One additional portable tag receiver (Sonotronics Model USR-91) was used to track and monitor tagged fish movement in the study area.

The ultrasonic tag monitoring system continually scanned the range of available tag frequencies and recorded relevant tag data and the time of each observation on a computer (Hewlett Packard Model HP-100). Each monitoring system was independently powered by a 12-volt battery and was enclosed in a watertight housing. Coaxial cable between the hydrophone and monitoring system was less than 10 feet long to minimize the frequency of detecting extraneous acoustic and radio signals. Each of

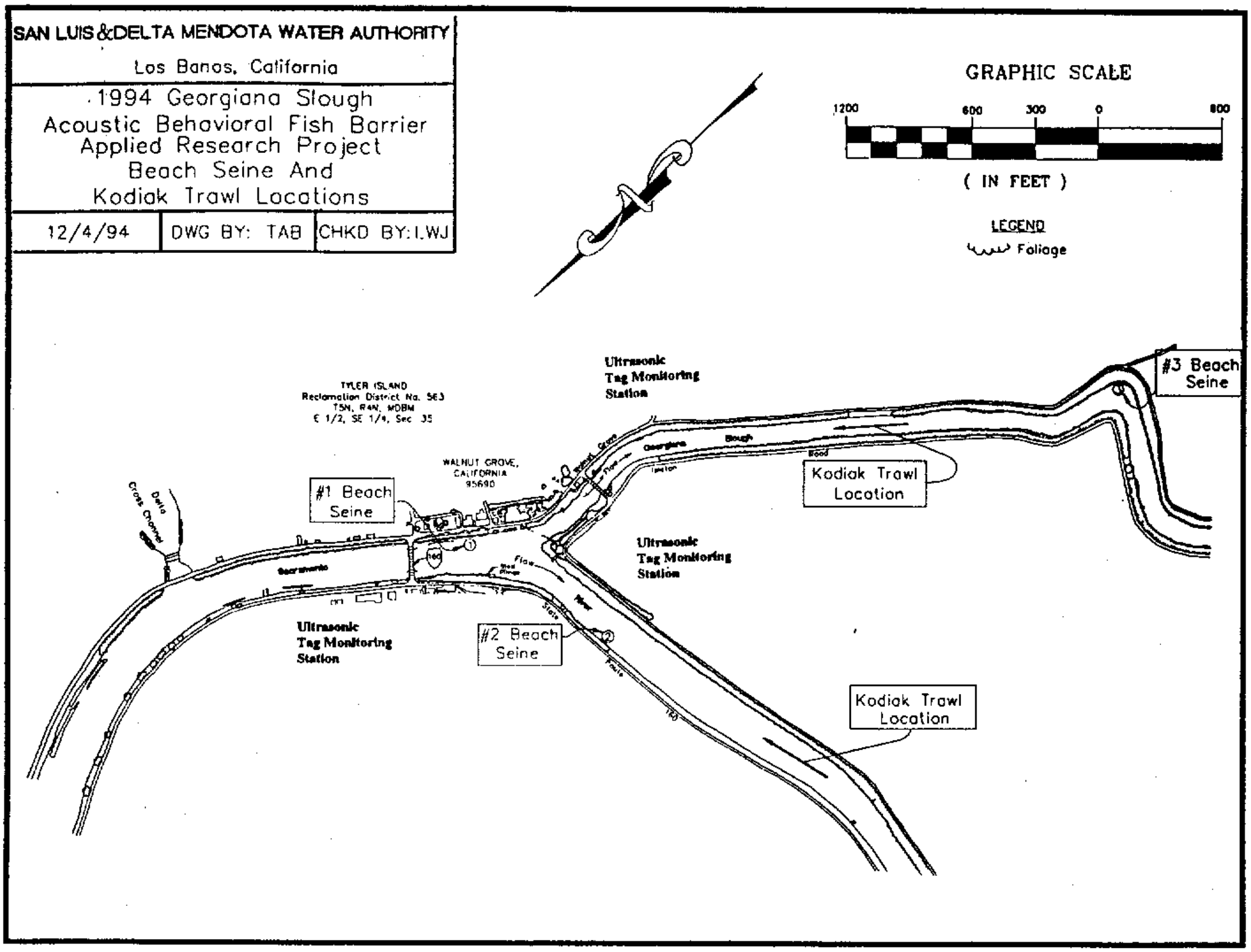

Figure 31
LOCATION OF CONTINUOUSLY MONITORING ULTRASONIC TAG DETECTION SYSTEMS IN THE SACRAMENTO RIVER AND GEORGIANA SLOUGH USED DURING SPRING AND FALL INVESTIGATIONS

the recording systems was checked about twice a week, and all accumulated data were downloaded and archived weekly. Data were subsequently analyzed statistically to identify individual tags based on characteristics of the pulse interval and signal frequency for each tag provided by the manufacturer.

A portable tag detection unit was also used to monitor the presence of tagged fish. A series of 15 tag-monitoring sites established upstream and downstream of the acoustic barrier were monitored once or twice a day 4 to 5 days each week. The portable tag detection system provided an independent check of the presence of marked fish.

Periodically throughout the spring and fall testing periods, calibration and quality assurance checks were performed on the detection of ultrasonic tags by the three continuous monitoring systems. Ultrasonic tags were either suspended in the water column or towed behind a boat to determine the range at which tags could be detected at each monitoring station and to confirm that tag detection data (pulse interval, frequency, time) were being accurately recorded. Quality assurance checks of the continuously recording tag monitoring systems also verified the influence of radio signals, tag frequency drift, noise interference by pumps, detection and erroneous recording of underwater depth finders, and interference caused by tag echoes from riprap along levees resulting in the recording of erroneous signals and, on occasion, difficulty detecting known (control) tags.

Adult Striped Bass Tagging Results (Spring)

Ultrasonic tagging was performed as part of the spring investigations, in which adult striped bass (longer than 16 inches) were tagged in the lower Sacramento River and lower San Joaquin River and subsequently released (Table 20). Adult striped bass were collected in spring spawning areas using gill-nets as part of the Fish and Game striped bass tagging studies. A total of 23 striped bass were tagged on May 12 and 13 in the lower bay; an additional 15 striped bass were collected and tagged in the Sacramento River at Knights Landing. Ultrasonic tags were mounted externally on adult striped bass immediately posterior to the dorsal fin. Two striped bass tagged as part of this effort were subsequently recaptured by anglers.

Operation of the EESCO acoustic array during the spring testing period is summarized in Table 6, Chapter 3.

Throughout the spring monitoring period for ultrasonic tags, we experienced difficulty in both tag detection and recording using the continuous monitoring systems. A number of hardware problems were identified and corrected. A number of software problems were also identified. The tag monitoring system did not operate consistently nor reliably during the spring. On a number of occasions, the monitoring system failed to detect known (control) tags in the area and also recorded a large number of erroneous signals. Tag monitors were subsequently returned to the manufacturer, where electronic filter systems were installed in an effort to increase the reliability of tag detection. By late June the tag monitoring systems appeared to be functioning, but no usable data could be recovered on the passage of adult striped bass through the test area nor their behavioral response to acoustic barrier operations.

Adult Fall-Run Chinook Salmon Tagging Results (Fall)

Ultrasonic tagging was performed during the fall to examine the behavioral response of adult fall-run chinook salmon when exposed to the acoustic array. Adult chinook salmon were collected, primarily using gill-nets, in cooperation with similar Fish and Game tagging studies in Suisun Bay at Montezuma Slough. One adult salmon was captured in a gill-net in the Sacramento River downstream of the acoustic barrier and tagged for use in this study. In fyke-nets downstream of the acoustic barrier, two salmon were captured in the Sacramento River and one in Georgiana Slough (Table 21). All these were tagged and released as part of this investigation. Ultrasonic tags were inserted through the mouth and esophagus into the stomach of adult salmon prior to release.

A total of 42 adult salmon were tagged and released as part of the Georgiana Slough investigations; an additional 60 salmon were tagged and released by Fish and Game as part of its Montezuma Slough salinity control structure tests. Ultrasonic tags were coordinated with the manufacturer to avoid overlap and redundancy in tag frequency codes.

Operation of the EESCO acoustic array during the fall testing period is summarized in Table 6, Chapter 3..

Results of fall adult chinook salmon tag monitoring were analyzed statistically to determine whether or not the rate of salmon passage was significantly affected by acoustic barrier operations. Based on statistical analyses of ultrasonic tag monitoring data collected during the fall, 56 observations on 25 tagged salmon were identified and included as part of this analysis (Table 22).

A number of adult salmon were detected passing the acoustic barrier moving both upstream and downstream, resulting in multiple observations. Data on fish transit times — both upstream and downstream in the Sacramento River — were analyzed statistically using a Shapiro-Wilk test for normality, which showed that neither the raw data nor log-transformed data were normally distributed. Subsequent statistical analyses using a nonparametric Wilcoxin-Rank sum on the raw data demonstrated a statistically significant difference in adult chinook salmon transit time between monitoring sites during periods when the acoustic barrier was on (mean transit time 49 minutes) and when the acoustic barrier was off (mean transit time

Table 20
SUMMARY OF ADULT STRIPED BASS TAGGED USING ULTRASONIC TRANSMITTERS, SPRING INVESTIGATIONS

Date	Time of Release	Tag Code	Location	Sex	Fork Length (mm)	Condition
May 12	0923	2444	Broad Slough	M	560	Good
	1022	2255	Broad Slough	F	585	Good
	1136	456	Antioch	M	505	Good
	1142	348	Antioch	M	675	Good
	1145	464	Antioch	M	532	Good
	1147	3335	Antioch	M	651	Good
	1234	276	Antioch	M	509	Good
	1359	2273	Antioch	M	517	Good
	1402	2426	Antioch	F	725	Good
May 13	0826	288		M	662	Good
	1130	2354	Sacramento River	F	620	Good
	0832	2435	Antioch	F	450	Good
	0834	2336	Antioch	F	752	Good
	1125	2543	Sacramento River	M	1040	Good
	1000	357	Antioch	F	568	Good
	1130	455	Sacramento River	F	560	Good
	1030	383	Antioch	M	500	Good
	1130	366	Sacramento River	F	607	Good
	1140	356	Sacramento River	M	460	Good
	1145	338	Sacramento River	M	415	Good
	1250	384	Sacramento River	F	710	Good
	1255	446	Sacramento River	M	455	Good
	1301	2453	Sacramento River	M	552	Good
May 19	0900-1045	3344	Sacramento River*	M	440	Good
		249	Sacramento River*	F	620	Good
		2263	Sacramento River*	M	620	Good
		2327	Sacramento River*	M	440	Good
		2525	Sacramento River*	M	530	Good
		285	Sacramento River*	M	480	Good
		554	Sacramento River*	M	790	Good
		2228	Sacramento River*	M	570	Good
	1045-1330	555	Sacramento River*	M	520	Good
		294	Sacramento River*	F	520	Good
		347	Sacramento River*	M	540	Good
		2246	Sacramento River*	M	610	Good
		258	Sacramento River*	M	850	Good
		375	Sacramento River*	M	580	Good
		465	Sacramento River*	M	480	Good

*Striped bass tagged and released at Knights Landing.

Table 21
SUMMARY OF ADULT CHINOOK SALMON TAGGED USING ULTRASONIC TRANSMITTERS, FALL INVESTIGATIONS

Tag Number	Fork Length (mm)	Sex	Release Date	Release Location	Collection Method
1	900	M	09/27	Montezuma Slough	Gill net
2	755	F	11/01	Montezuma Slough	Gill net
3	670	F	09/27	Montezuma Slough	Gill net
4	792	M	11/01	Montezuma Slough	Gill net
5	805	F	11/08	Montezuma Slough	Gill net
6	830	M	11/08	Montezuma Slough	Gill net
7	598	M	09/27	Montezuma Slough	Gill net
8	720	M	11/01	Montezuma Slough	Gill net
9	755	F	09/27	Montezuma Slough	Gill net
10	780	M	10/28	Sacramento. River	Gill net
11	585	M	11/08	Montezuma Slough	Gill net
12	600	F	11/08	Montezuma Slough	Gill net
13	757	F	09/27	Montezuma Slough	Gill net
14	990	M	11/01	Montezuma Slough	Gill net
15	632	M	09/27	Montezuma Slough	Gill net
16	708	F	11/01	Montezuma Slough	Gill net
17	925	F	11/08	Montezuma Slough	Gill net
19	1035	M	09/27	Montezuma Slough	Gill net
20	940	M	11/01	Montezuma Slough	Gill net
21	657	M	09/27	Montezuma Slough	Gill net
25	870	F	09/27	Montezuma Slough	Gill net
26	620	M	11/01	Montezuma Slough	Gill net
27	873	F	09/27	Montezuma Slough	Gill net
28	890	M	11/01	Montezuma Slough	Gill net
31				Test Tag	
32	910	M	11/01	Montezuma Slough	Gill net
33	671	M	09/27	Montezuma Slough	Gill net
34	620	M	11/01	Montezuma Slough	Gill net
35	760	M	11/01	Montezuma Slough	Gill net
36	850	M	11/08	Montezuma Slough	Gill net
37	800	F	11/08	Montezuma Slough	Gill net
38	824	M	09/27	Montezuma Slough	Gill net
39	620	F	11/01	Montezuma Slough	Gill net
40	560	F	09/27	Montezuma Slough	Gill net
41	810	F	11/01	Montezuma Slough	Gill net
42	800	F	11/01	Montezuma Slough	Gill net
43	625	F	11/08	Montezuma Slough	Gill net
44	855	M	11/08	Montezuma Slough	Gill net
45	826	M	09/27	Montezuma Slough	Gill net
46	560	M	11/02	Sacramento River	Fyke trap
47			10/27	Sacramento River	Fyke trap
48	880	M	11/02	Georgiana Slough	Fyke trap
49	800	M	11/08	Montezuma Slough	Gill net

106 minutes). These transit time estimates are based on both upstream and downstream movement and provide no evidence that operation of the acoustic barrier delayed fish passage. The transit time data were subsequently stratified to include only observations for fish migrating upstream, resulting in a similar pattern of significant differences in which the transit time for adult salmon was shorter when the acoustic barrier was on (average transit time 13 minutes; n=4) than when the acoustic barrier was off (average transit time 50 minutes; n=10) ($p < 0.001$).

Additional statistical analyses using ANOVA on the log-transformed transit time data included acoustic barrier operations

Table 22
FREQUENCY DISTRIBUTION OF THE RATE OF FISH MOVEMENT MEASURED DURING THE FALL HYDROACOUSTIC SURVEYS DURING PERIODS WHEN THE ACOUSTIC BARRIER WAS ON AND OFF

Acoustic Barrier Off		Acoustic Barrier On	
Travel Time (minutes)	Sacramento River Flow	Travel Time (minutes)	Sacramento River Flow
5	-6,710	4	8,180
6	-5,660	5	7,460
7	-4,570	8	-7,320
11	-4,650	8	7,460
13	-5,660	10	200
13	8,980	12	-5,180
16	-560	12	6,490
17	-3,820	14	8,180
19	8,010	15	-7,020
29	8,690	16	7,500
51	7,190	16	9,280
56	-2,150	17	-3,870
72	9,130	21	-5,520
78	9,400	24	-1,520
85	7,750	35	-6,550
86	190	43	4,890
94	-3,890	63	-4,170
96	-8,240	69	7,230
101	7,150	167	1,610
108	-8,140	167	1,610
141	-8,100	167	1,610
149	6,660	195	-400
154	7,350		
161	2,810		
178	7,750		
182	9,480		
182	9,390		
186	-3,620		
190	9,390		
192	-4,970		
208	-6,260		
217	7,070		
228	8,890		
277	-8,200		

(barrier on and off), tide condition (ebb and flood), direction of fish movement, day and night passage (diel), and various interaction terms. The ANOVA was statistically significant ($F=4.54$; DF 22; $p=0.0001$). Log-transformed transit time for adult chinook salmon passage was statistically associated with acoustic barrier operation, ($p=0.0002$) direction of fish movement ($p=0.0001$), and the interaction of tide and direction of fish movement ($p=0.0428$). The coefficient of determination (r^2) was 0.76. Results of a Shapiro-Wilk test on the residuals from the ANOVA showed that they were normally distributed.

Results of ultrasonic tag monitoring for adult chinook salmon during the fall tests have shown that:

- Operation of the acoustic barrier did not block the upstream migration of adult salmon in either the Sacramento River or Georgiana Slough;
- Adult chinook salmon transit time did not show evidence that the acoustic barrier operations resulted in a delay in upstream migration. In fact, rates of adult passage were significantly less ($p < 0.001$) when the acoustic barrier was on than when it was off.

Hydroacoustic Monitoring

Hydroacoustic monitoring was performed as part of the fall investigations to test two basic hypotheses during periods when the acoustic barrier was operational and non-operational. The hypotheses were:

- No statistically significant difference exists between the frequency of fish moving upstream and downstream in response to acoustic barrier operations;
- No statistically significant difference exists in the migration rate of adult chinook salmon and other fish longer than 18 inches included in the database (during periods when the acoustic barrier was on and off).

Data from the fall hydroacoustic surveys were used to evaluate blockage or delays in adult migration in response to acoustic barrier operations. In addition, data were used to examine the influence of environmental factors (principally tidally driven Sacramento River flow) on fish movement.

The hydroacoustic monitoring system consisted of two pairs of transducers, a scientific echo sounder, chart recorder, oscilloscope, and microcomputer equipped with an echo signal processor. Each transducer produced a high frequency (420 kHz) signal, which was amplified by the echo sounder at a 40 log (R) time-varied-gain to compensate for the loss of signal strength due to absorption and geometric spreading of the acoustic beam with distance from the transducer.

Pairs of transducers were mounted on either side of the Sacramento River and oriented parallel to the river bottom (Figure 32). The beams of each pair of transducers were overlapped so that a portion of the ensonified volume was covered by both beams and an area on either side of the common region was sampled by only one transducer of the pair. Using this configuration, the direction of fish movement could be determined by the sequence of returned echoes entering and exiting the acoustic field of each transducer. The acoustic signal was calibrated before and after the field study, using a target of known acoustic size, to equalize system sensitivity for each transducer. Calibration information was used to adjust the acoustic system for a detection threshold of fish 18 inches and longer.

Hydroacoustic monitoring was performed 24-hours a day for 12 day s, October 24 to November 5, 1994. The computer-controlled multiplexer sampled each pair of transducers during six 5-minute periods each hour. Sampling rate was established at five pings per second. Each transducer of the pair sampled on alternate pings. Based on examination of preliminary data, the sampling regime was modified so that the transducer at location 1 (near the mouth of Georgiana Slough) was sampled during four 10-minute periods each hour and the second pair of transducers was sampled during four 5-minute periods each hour. Data recorded for each echo received included ping number, range from transducer, transducer number, narrow and wide beam response amplitude, and narrow and wide beam pulse width. Data were reviewed in the field, then analyzed more extensively after the monitoring. Hydroacoustic results were considered acceptable in identifying an individual fish given that results met three criteria: redundancy (a minimum of four hits per target); exceedance by the target of a predetermined threshold length (18 inches); and trace cohesiveness.

The velocity of fish movement was calculated based on the time required for a fish to swim through the hydroacoustic beam. The distance of the path of the fish movement through the acoustic beam varies both with the range of the fish and its trajectory. Although there may be substantial variability in trajectories of individual of fish moving through the acoustic beam, rate calculations were based on the assumption that all fish followed an average trajectory that could then be calculated based on the geometry of the hydroacoustic beam.

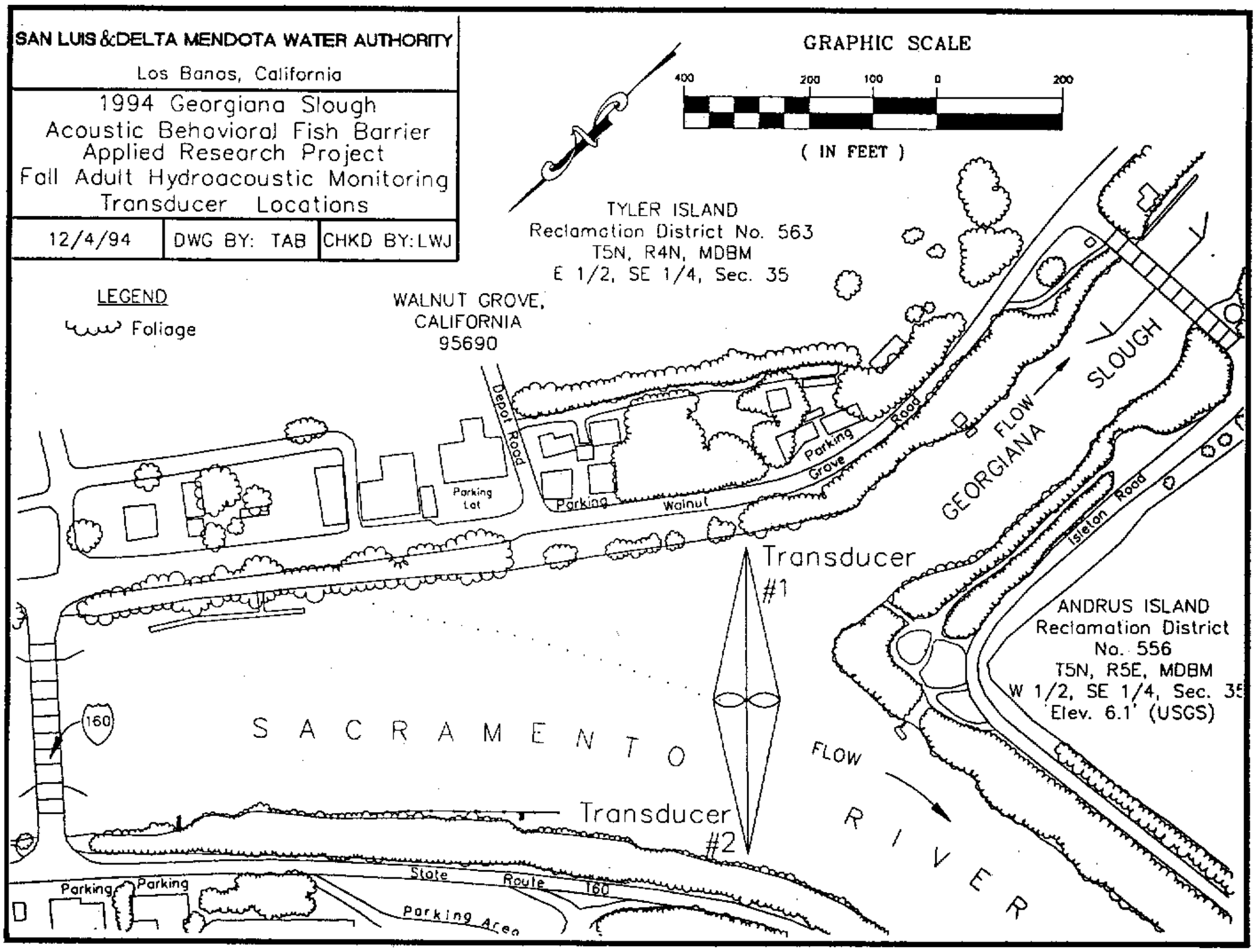

Figure 32
LOCATION OF THE BIOSONICS FIXED-POSITION TRANSDUCERS USED TO MONITOR ADULT FISH PASSAGE DURING THE FALL INVESTIGATIONS

Additional information on methods, results, and data for the fall hydroacoustic monitoring surveys are included in Appendix G.

During the period of hydroacoustic observations, rate and direction of movement could be determined for 3,279 fish. Those fish included in the analysis were estimated to be at least 18 inches long, but species could not be determined. During the observation period, recreational angling, gill-netting, and fyke-netting documented the presence of adult chinook salmon, steelhead trout, striped bass, smallmouth bass, and other fish species.

During the hydroacoustic surveys, 2,145 fish included in the database were observed while the acoustic barrier was on and 1,134 fish were observed when it was off; upstream and downstream movement was distributed about equally, as shown below:

	Direction of Movement		
	Upstream	Downstream	Total
Barrier On	1075	1070	2145
Barrier Off	554	580	1134

Observations of fish passing the hydroacoustic beam did not necessarily represent independent observations of individual fish. The database may contain multiple observations for fish that passed repeatedly through the counters. Milling behavior, for example, could lead to multiple observations with fish moving upstream and downstream and may account for the larger number of observations when the acoustic barrier was on (for example, a behavioral response to the acoustic signal, resulting in a delay in movement and increased milling behavior).

The average rate of fish passage was 1.1 m/s when the acoustic barrier was on and 1.2 m/s when it was off. Distribution of calculated passage rates is shown in Figure 33. Fish moving downstream are classified by a negative speed, and fish moving upstream are classified by a positive speed.

ANOVA was used to compare differences between the rate of fish movement and acoustic barrier operations (on and off), while taking into account variability associated with Sacramento River flow and tidal conditions. A Ryan-Einot-Gabriel (REGWQ) multiple range test was also used to evaluate differences in the direction and rate of movement in association with acoustic barrier operations. Results of these statistical analyses did not detect a significant difference between the rate of movement and acoustic barrier operations. A chi-square test of the rate of fish passage with respect to barrier operations demonstrated no significant differences during periods when the acoustic barrier was on and off. The direction and rate of Sacramento River flow was found, however, to be a significant factor associated with the rate of fish movement.

A Pearson chi-square test was used to evaluate the direction of fish passage when the acoustic barrier was on and off. Chi-square tests were stratified based on Sacramento River flow and tidal conditions. During ebb tides, a greater proportion of fish moved downstream when the acoustic barrier was on than when it was off, and a greater proportion also moved upstream when the barrier was on. In analyses using Sacramento River flow, the pattern was similar. When flows were moving downstream, the proportion of fish moving downstream was greater when the acoustic barrier was on than when it was off, and when flows were moving upstream the proportion of fish moving upstream was also greater when the acoustic barrier was on.

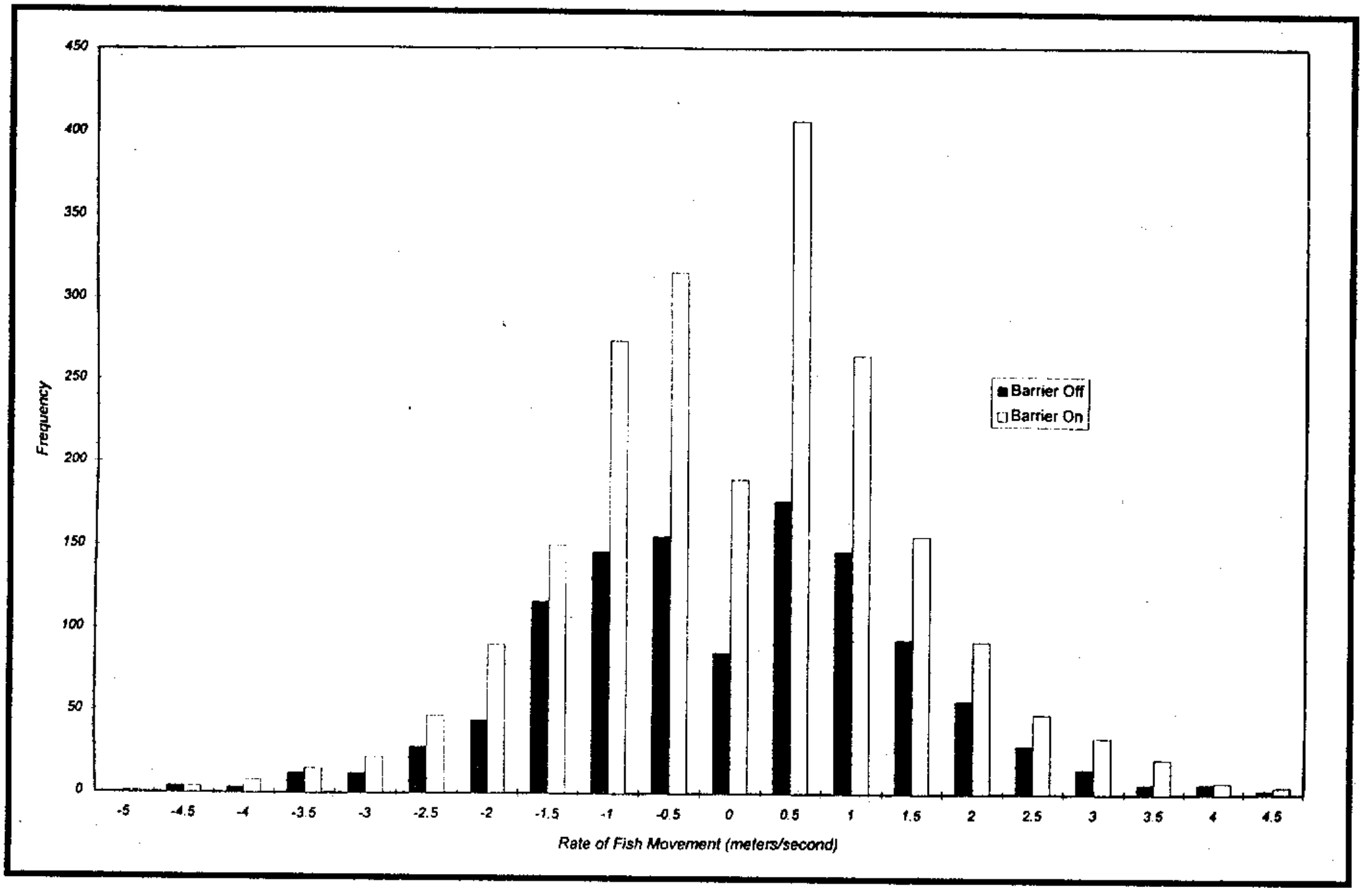

Figure 33
FREQUENCY DISTRIBUTION OF THE RATE OF FISH MOVEMENT MEASURED DURING THE FALL HYDROACOUSTIC SURVEYS DURING PERIODS WHEN THE ACOUSTIC BARRIER WAS ON AND OFF

Summary

Results of ultrasonic tagging and hydroacoustic monitoring during the fall are summarized below.

- Ultrasonic tagging resulted in a relatively low number of adult salmon passage observations when the acoustic barrier was on and off.
- Upstream migration of adult chinook salmon is not blocked by operation of the acoustic barrier.
- Results of these tests provide no evidence that acoustic barrier operations contribute to a delay in adult salmon migration in either Georgiana Slough or the Sacramento River, although results of hydroacoustic monitoring suggest the possibility of increased milling behavior when the acoustic barrier was in operation.
- Adult chinook salmon (monitored using ultrasonic tagging) and potentially other adult fish (monitored with hydroacoustics) were observed moving both upstream and downstream in the Sacramento River when the acoustic barrier was on and when it was off. The direction of movement was not statistically associated with acoustic barrier operations.
- Hydroacoustic monitoring does not represent individual observations and may include multiple observations of the same fish passing through the counting beam.

- Hydroacoustic monitoring could not determine species composition of fish passing through the area.
- The rate and direction of adult chinook salmon passage was statistically related to environmental factors, principally the magnitude and direction of Sacramento River flow as influenced by tides, in addition to acoustic barrier operations (significantly faster passage when the acoustic barrier was on).
- Results of hydroacoustic monitoring consistently show the influence of Sacramento River flow and tides on the direction and movement of fish.

Chapter 6

Effects of Acoustic Barrier Operations on Resident Fish and Crayfish Populations

Acoustic barrier operations in the Sacramento River near the confluence with Georgiana Slough may adversely affect habitat suitability for resident fish and crayfish. A variety of fish species inhabit the area on a permanent or seasonal basis including, but not limited to, catfish, tule perch, squawfish, splittail, chinook salmon, and striped bass. Operation of the acoustic barrier could contribute to behavioral avoidance of the area, resulting in reduced habitat suitability and utilization by resident fish and crayfish populations. To investigate this potential, the 1994 investigations included periodic fish surveys (beach seining, angler surveys, crayfish trapping).

Beach Seining

Fish were collected using beach seines periodically during May and June to provide information on relative species composition and abundance of various species in the immediate area of the acoustic barrier (Figure 34) and at nearby reference sites in the Sacramento River and Georgiana Slough. Fish were collected when the acoustic barrier was in service (on) and when it was out of service (off). During periods of low water level (reduced Sacramento River flow and ebb tide), there is a small area adjacent to the acoustic barrier where a beach seine can be deployed successfully. The acoustic barrier alignment (Figure 2, Chapter 2) traverses the beach seining area; hence, results of these collections provide a measure of habitat use by resident fish and potential effects of acoustic barrier operations. Results from reference sites in the Sacramento River and Georgiana Slough provide a baseline for comparison with results from the immediate vicinity of the acoustic array.

Collections were made at all sites using a 100-foot beach seine with 1/4-inch mesh. To the extent possible, the specific site and area swept by the beach seine was standardized at each sampling site. The area swept at each site was relatively constant among surveys; therefore, catch can be used as an estimate of catch per unit effort for comparisons between sampling dates at a site. The area sampled did vary from one site to another; therefore, comparisons among sites are qualitative. Data collected during beach seine surveys included the number, species, and length of fish collected; time of day; and acoustic barrier operations.

Underwater sound pressure levels measured near site 1 were about 150 dB at site 1 and 120-125 dB at site 2. Although sound pressure level was not measured at site 3, this site was far enough downstream in Georgiana Slough that sound pressure levels should not have increased due to acoustic barrier operations. Background sound levels, such as those expected at site 3, typically range from 88-97 dB (Chapter 2).

Results of beach seining at each of the three sites are summarized in Tables 23, 24, and 25. The total number of fish collected varied substantially among sampling dates at all three sites. Juvenile chinook salmon, splittail, inland silversides, goby,

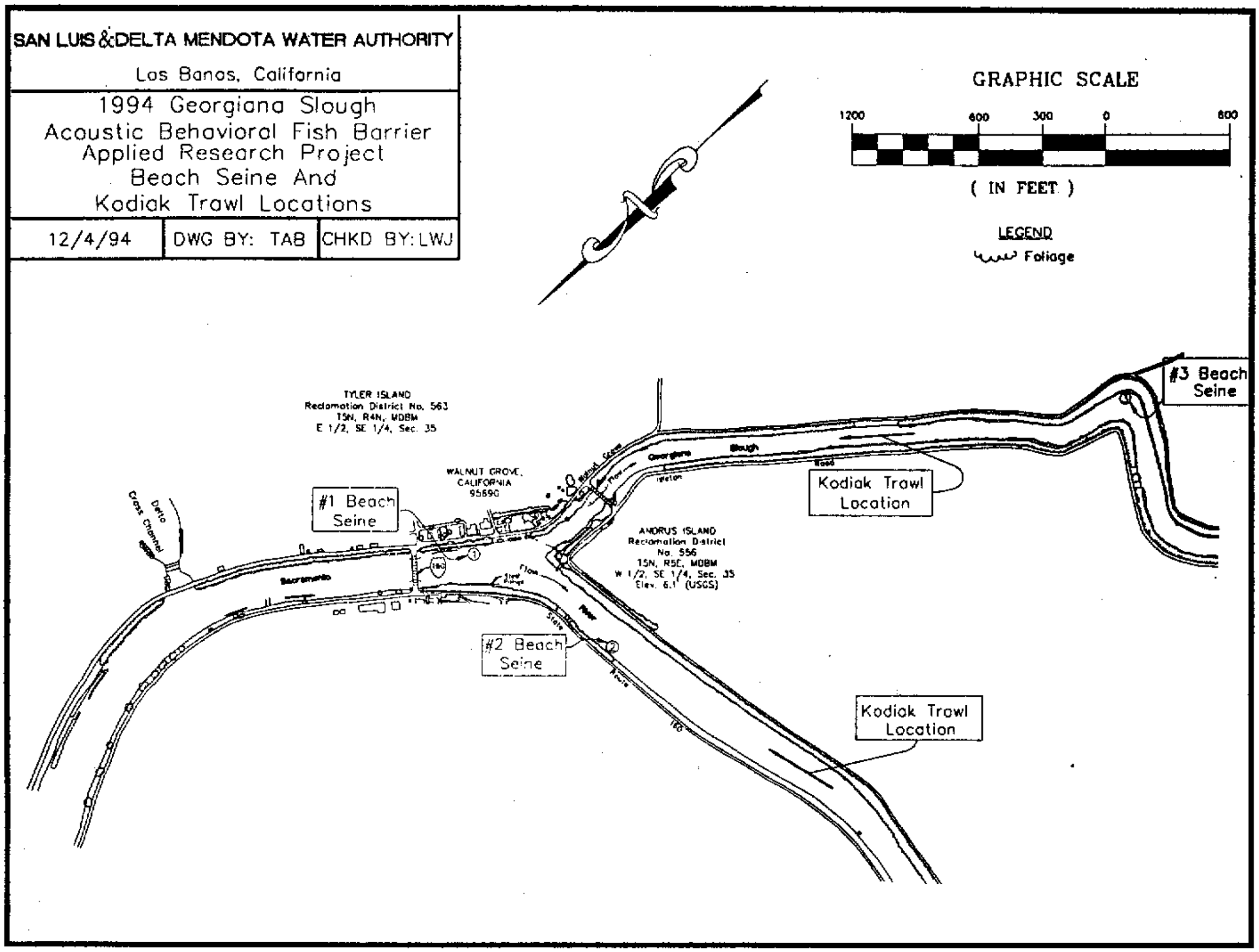

Figure 34
BEACH SEINING SITES IN THE SACRAMENTO RIVER AND GEORGIANA SLOUGH

squawfish, largemouth bass, and suckers were typically the most abundant fish taxa collected.

It was hypothesized that if acoustic barrier operations resulted in an avoidance response and reduced habitat utilization, then lower numbers of fish and fewer taxa should be consistently observed adjacent to the acoustic array when it was operating.

For site 1, adjacent to the acoustic barrier, there was no consistent pattern in either the number of fish collected or the number of taxa collected when the acoustic barrier was on or when it was off. The most juvenile chinook salmon (143) were collected on April 12, and the most juvenile splittail (123) were collected on May 20; during both periods the acoustic barrier was on (Table 23). Underwater sound pressure levels were about 150 dB when the EESCO acoustic barrier was on and 88-97 dB when it was off. Beach seining collections at site 1 during paired sampling days when the acoustic barrier was on and off are compared below.

Table 23
BEACH SEINING RESULTS FROM SITE 1,
SACRAMENTO RIVER ADJACENT TO THE ACOUSTIC ARRAY

Date:	04/12	04/14	04/26	04/28	05/03	05/20	06/01	06/03	06/06	06/09	06/13	06/15	06/20	06/20	06/22
Barrier Operations:	On	On	On	Off	Off	On	Off	On	Off	On	Off	On	Off	Off	On
Chinook Salmon	143	10	1		7										
Splittail						123		7			1	3	5	6	1
Silversides										1		7	33	26	4
Goby					15	25	11		2	1	8	3	11	7	2
Smallmouth Bass							4	9			1				
Largemouth Bass								1			2	1			1
Suckers								1							
Squawfish				44	14										
Striped Bass															
Tule Perch															
Gambusia															
Other Fish															
Shad	1														
Unidentified			8												
Total Fish	144	10	9	44	36	148	15	18	2	2	12	14	49	39	8
Total Taxa	2	1	2	1	3	2	2	4	1	2	4	4	3	3	4

Table 24
BEACH SEINING RESULTS FROM SITE 2,
SACRAMENTO RIVER DOWNSTREAM OF THE ACOUSTIC ARRAY

Date:	04/12	04/14	04/26	04/28	05/03	05/25	06/01	06/03	06/08	06/09	06/13	06/15	06/20	06/22
Barrier Operations:	On	On	On	Off	Off	On	Off	On	Off	On	Off	On	Off	On
Chinook Salmon	1	32	2	4	30									
Splittail						5	17	1			1	4	19	
Silversides	2	1	15				2	55		3	2	3		11
Goby						21	11	3	12	8	16	20	1	28
Smallmouth Bass											1			
Largemouth Bass							1				1		4	1
Suckers											1			
Squawfish				127	6	3			4					2
Striped Bass														
Tule Perch														
Gambusia														
Other Fish														
Shiner	1		4											
Unidentified														
Bluegill							2							
Roach							13							
Total Fish	4	33	21	131	36	29	46	59	16	11	22	27	24	42
Total Taxa	3	2	3	2	2	3	6	3	2	2	6	3	3	4

Table 25
BEACH SEINING RESULTS FROM SITE 3, GEORGIANA SLOUGH

Date:	04/12	04/14	04/26	04/28	05/03	06/01	06/03	06/06	06/06	06/09	06/13	06/15	06/20	06/20	06/22
Barrier Operations:	On	On	On	Off	Off	Off	On	Off	Off	On	Off	On	Off	Off	On
Chinook Salmon	14	20	9	2	1										
Splittail						1000	20	440					4	5	15
Silversides						7	5				2	2			
Goby					7	5	4	14	3		5	2		1	
Smallmouth Bass		1					1	5	1		1				
Largemouth Bass	1							34	2		7	24	27	6	17
Suckers							1	29	1						2
Squawfish				13	4										
Striped Bass															
Tule Perch								6			4	8	6		1
Gambusia								7			2	1	5	20	9
Unidentified Fish			17												
Bluegill			3	4							2	1			1
Shiner											6		1		
Catfish												1			1
Roach														1	
Total Fish	15	21	29	19	12	1012	31	535	7	0	29	39	43	33	46
Total Taxa	2	2	3	3	3	3	5	7	4	0	8	7	5	5	7

Date	Barrier	Number of Fish	Number of Taxa
April 28	On	9	2
April 28	Off	44	1
June 1	Off	15	2
June 3	On	18	4
June 6	Off	2	1
June 9	On	2	2
June 13	Off	12	4
June 15	On	14	4
June 20	Off	49	3
June 20	Off	39	3
June 22	On	8	4

These comparisons do not show a consistent reduction in fish usage in response to acoustic barrier operations. Overall, data at this site provided no evidence that operation of the acoustic barrier contributed to a general decline in either abundance or diversity of fish in the area. As with other sites, results among sampling dates varied substantially in the number of fish collected and in species composition of fish collected.

Results of beach seining at site 2, downstream in the Sacramento River, and site 3, downstream in Georgiana Slough, also reflect a pattern of high variability among collections (Tables 24 and 25). Site 3, which was 0.56 mile from the acoustic barrier, served as a reference site. Site 2, which was within the area of increased acoustic pressure, was characterized by sound levels (120-125 dB) substantially below those at Site 1 (150 dB). All three sites were characterized by a silt-sand bottom with minimal rooted aquatic vegetation. Beach seining at all sites was generally done during low tides, sampling in water up to about 4 feet deep. All three sites are adjacent to deep water areas and had relatively high water velocities, particularly during ebb tides. Because of the limited number of beaches suitable for seining in the area, it was difficult to select sampling sites that were identical, with the exception of exposure to elevated acoustic sound pressure levels. As a consequence of variation among sites and difficulty in collecting samples, results represent general trends but do not support rigorous statistical analyses.

Results of beach seining, in combination with Kodiak trawl and other collection methods, provide information on species composition and relative abundance of the fish community in Georgiana Slough and the Sacramento River adjacent to the acoustic array. Although results are limited to the spring, they do provide information on species that may be exposed to underwater sound pressure levels resulting from acoustic barrier operations.

Crayfish Trapping

Crayfish trapping was performed in the area adjacent to the acoustic barrier between April 6 and June 28 (spring tests). Ten trapping sites were sampled for comparable periods with the acoustic barrier on and off. Trapping was performed simultaneously at sites immediately upstream of the acoustic barrier, immediately downstream of the acoustic barrier, and farther downstream of the acoustic barrier in the Sacramento River and Georgiana Slough (Figure 35). Although the sites represent a gradient of sound pressure levels, none was completely outside of the influence of the acoustic barrier for use as a reference site or true control.

Baited traps were used at each of the 10 sites. Each trap (typical commercial crayfish traps) was constructed using a metal frame and 1/4-inch wire mesh and was equipped with internal fykes to improve collection efficiency. Each trapping set was about 24 hours. Each trap collection was coordinated to coincide with periods when the acoustic barrier was on or off so that resulting collections could be evaluated in accordance with acoustic barrier operations.

Results of crayfish trapping during the spring acoustic tests are summarized in Figure 36 and Table 26. Trapping results show that crayfish are relatively abundant

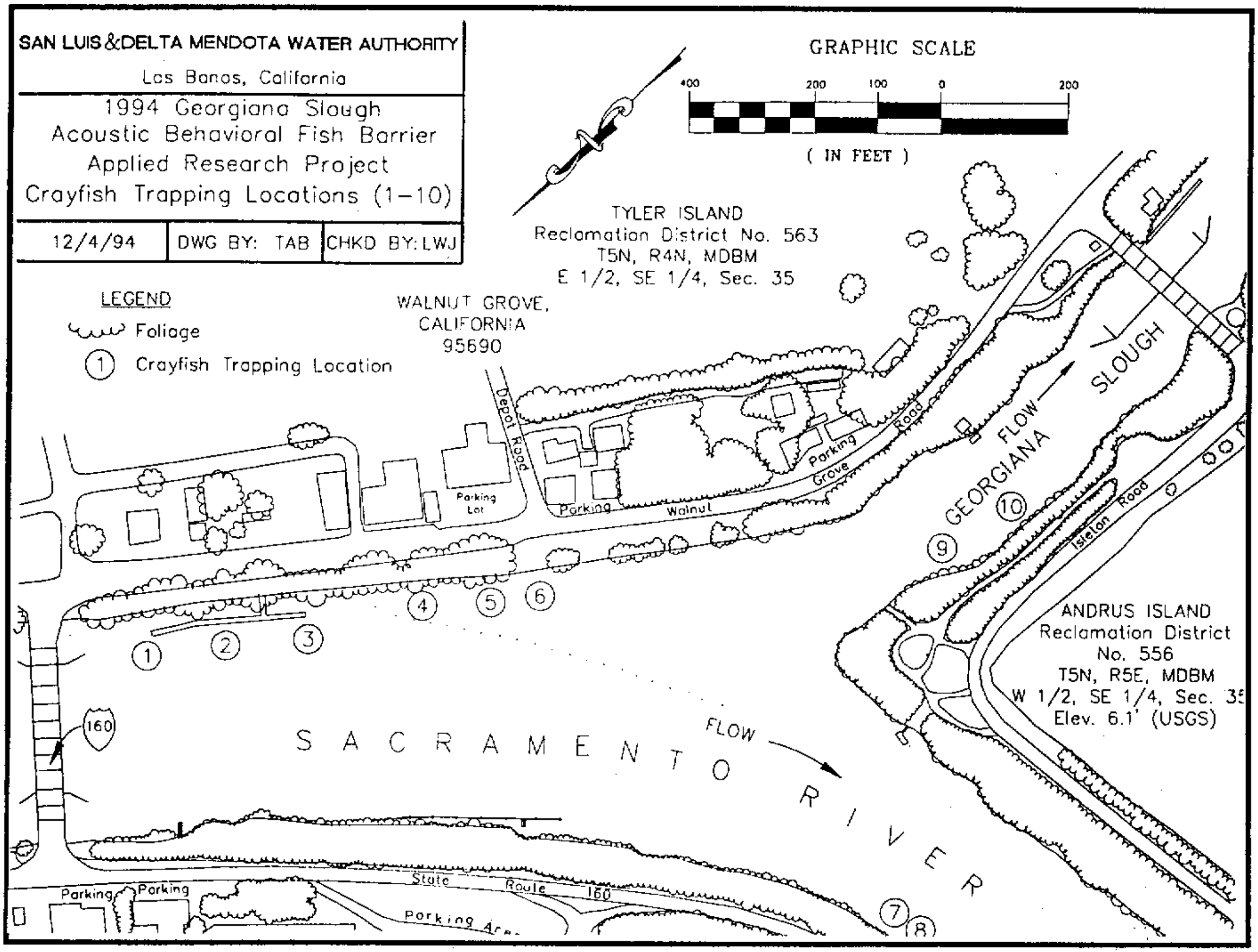

Figure 35
CRAYFISH TRAPPING SITES IN THE SACRAMENTO RIVER AND GEORGIANA SLOUGH

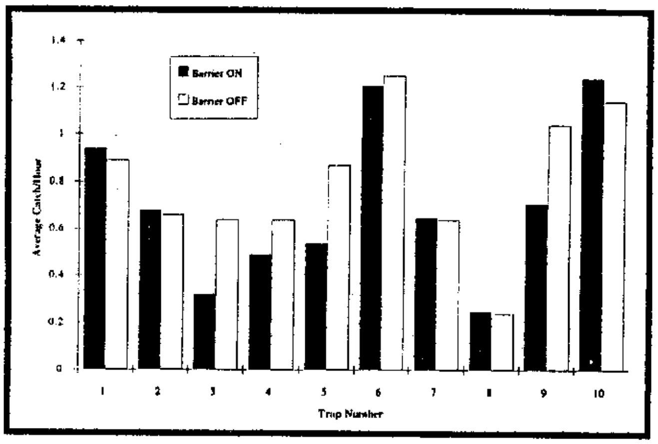

Figure 36
CRAYFISH CATCH-PER-UNIT-EFFORT DURING SPRING STUDIES WITH THE ACOUSTIC BARRIER ON AND OFF

at the confluence between the Sacramento River and Georgiana Slough. Crayfish moved throughout the area, as evidenced by crayfish marked at one site being recaptured at other sites. Crayfish marked and released in the area of the acoustic barrier were recaptured in the immediate vicinity of the barrier as well as at more distant sites.

Catch per unit of effort at trapping sites 3, 4, and 5 (Figure 35), which were closest to the acoustic barrier, showed, overall, lower catches when the acoustic barrier was on than when it was off (Figure 36). At most

Table 26
CRAYFISH TRAP COLLECTIONS NEAR THE ACOUSTIC ARRAY
Surveys performed April-June 1994

Trap Number	Barrier Operations	Total Sampling Time (hours)	Number Crayfish	Catch/Hour Average	SD	Percentage Mark/Recaptured
1	ON	248	233	0.94	0.50	9
	OFF	219	191	0.89	0.47	10
2	ON	248	167	0.68	0.35	6
	OFF	218	147	0.66	0.36	9
3	ON	246	79	0.32	0.15	5
	OFF	219	134	0.64	0.46	4
4	ON	274	132	0.49	0.36	17
	OFF	195	126	0.64	0.25	8
5	ON	273	142	0.54	0.38	7
	OFF	219	186	0.87	0.73	13
6	ON	272	325	1.21	0.77	13
	OFF	218	272	1.25	0.83	15
7	ON	247	159	0.65	0.53	17
	OFF	220	141	0.64	0.39	14
8	ON	223	57	0.25	0.17	8
	OFF	220	55	0.24	0.15	5
9	ON	247	179	0.71	0.73	9
	OFF	228	235	1.04	1.15	6
10	ON	225	269	1.24	1.09	9
	OFF	224	258	1.14	1.09	10

other sites, catch per unit of effort was similar during periods when the barrier was on and off (Figure 36). The exception was site 9 (Figure 35), at which catches were lower when the barrier was operating. Since site 9 was not in the immediate vicinity of the acoustic barrier, the lower catch per unit effort may reflect sampling variability or factors other than acoustic barrier operations.

Results of these trapping studies suggest that there may be a reduction in crayfish use of the area immediately adjacent to the acoustic barrier (about 300 feet), but the effect appears to diminish rapidly based on the similarity in crayfish catch per unit effort at sites immediately upstream (sites 1 and 2) and downstream (site 6; Figure 35) when the acoustic barrier was on and off.

Limited additional crayfish trapping was performed during the fall investigations. Crayfish trapping occurred November 14-15 when the acoustic barrier was on and November 21-22 when it was off. Catch per unit of effort (number of crayfish per hour) was recorded for each of the crayfish trapping sites (Figure 35). Results of this limited set of collections are summarized below:

	Catch per Unit Effort (Number/Hour)	
Crayfish Trap	November 14-15 Barrier On	November 21-22 Barrier Off
1	0.20	0.09
2	0.05	0.19
3	0.30	0.05
4	0.30	0.05
5	0.15	0.19
6	0.20	0.19
7	0.10	0.05
8	0.10	0.09
9	1.22	0.37
10	0.15	0.05

In general, crayfish were more abundant on November 14-15 than on November 21-22 in collections throughout the area. Although results were highly variable, there was no apparent pattern of reduced catch per unit effort in the area adjacent to the acoustic barrier (sites 3-5), as was the case during the more extensive spring surveys. Results of the fall collections, although not conclusive, suggest that the pattern of crayfish movement and the potential response to acoustic barrier operations may vary to a greater degree than suggested by the spring surveys.

Recreational Angling Surveys

Periodically during the spring testing period, fish were collected in the immediate vicinity of the acoustic barrier using hook-and-line and natural bait when the barrier was on and during corresponding periods when the barrier was off. Each hook-and-line survey was performed from either fixed shoreline or boat anchoring sites and included documentation on the actual time spent fishing for use in subsequent calculations of catch per rod-hour. Data were recorded on the time, species, size, and site for each fish caught. After identification and length measurement all fish were released. Results of hook-and-line surveys provide information on species composition and recreational angler catch per unit effort during periods when the acoustic barrier was on and off.

Results of recreational angling (Table 27) showed a substantially higher catch (1.8 fish per rod-hour) when the acoustic barrier was off than when it was on (0.83 fish per rod-hour). Although the data suggest a possible effect of acoustic barrier operations, they are too limited to evaluate potential behavioral response of striped bass and other predatory fish or the consistency of the response among species over a range of environmental conditions when the acoustic barrier was in service. Striped bass accounted for the majority of fish caught when the acoustic barrier was on (96% of fish collected) and when it was off (99% of fish collected).

Factors contributing to the apparent reduction in angler success when the acoustic barrier was on remain unknown, but it may have to do with changes in the distribution and/or behavior of either predators (*eg*, striped bass) or potential prey (*eg*, juvenile chinook salmon) in response to acoustic barrier operations. Results of these surveys do not, however, suggest that striped bass are accumulating in the area of the acoustic barrier in response to increased vulnerability of prey. Catch per unit of effort in these studies was highly variable within and among surveys, apparently related, in part, to tidal conditions and currents. Angler survey results focused on specific sites immediately adjacent to the acoustic barrier and did not provide data that could be used to define the geographic area where striped bass catch per unit effort may change in response to acoustic barrier operations.

Table 27
RECREATIONAL ANGLING SUCCESS IN THE IMMEDIATE VICINITY OF THE ACOUSTIC ARRAY
Surveys performed April 11-21 and June 7-23.

	Barrier Operations	
	On	Off
Hours Fished	36.6	27.1
Rod Hours	1'13.1	93.4
Number of Striped Bass	70	116
Number of Other Fish	3	1
Catch per Unit Effort (fish per rod-hour)	0.83	1.80

Summary

Results of the resident species investigations near the acoustic barrier have shown:

- A diverse group of juvenile fish are abundant in the Sacramento River and Georgiana Slough. Species include chinook salmon, splittail, silversides, large- and smallmouth bass, gobies, squawfish, striped bass, and others.
- A variety of juvenile fish were collected in beach seine surveys in the immediate vicinity of the acoustic array when the acoustic barrier was on and when it was off. No qualitative pattern was apparent in either the abundance or the number of species collected associated with periods when the acoustic barrier was in operation, although no statistical evaluation was made of these data.
- Crayfish were abundant and widely distributed in the area during both spring and fall surveys.
- Crayfish moved throughout the area, as evidenced by results of mark/recapture studies. However, movement into and out of the area immediately adjacent to the acoustic array was not correlated with barrier operations.
- Crayfish catch per unit effort during the spring studies was lower at the three trapping sites closest to the acoustic barrier when the acoustic barrier was on than when it was off. In a limited series of collections during the fall, no difference in catch per unit effort was detected at these sites.
- The area where reduced crayfish catch per unit effort was observed during the spring studies appears to extend about 300 feet (100 meters) upstream and downstream of the acoustic array, although catch per unit effort was also lower when the acoustic barrier was in service at one site (site 9) farther downstream in Georgiana Slough, away from the acoustic barrier.
- Results of angling surveys showed that striped bass were the most abundant species caught when the acoustic barrier was on (96% of fish collected) and when it was off (99% of fish collected).
- Catch per unit effort in the recreational angler surveys immediately adjacent to the barrier (within 50-100 feet) was lower when the acoustic barrier was on (0.83 fish/rod-hour) than when it was off (1.8 fish/rod-hour). Factors contributing to the reduction are unknown.

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