Report No. TR-354-02
BIO/WEST, Inc.

EFFECTS OF INTERIM FLOWS FROM GLEN CANYON DAM ON THE AQUATIC RESOURCES OF THE LOWER COLORADO RIVER FROM DIAMOND CREEK TO LAKE MEAD

Phase II Report

Submitted To

Mr. Clay Bravo, Assistant Director
Hualapai Natural Resources Department
P.O. Box 300, 947 Rodeo Way
Peach Springs, Arizona 86434

Mr. David Wegner, Program Manager
Glen Canyon Environmental Studies
P.O. Box 22459
121 East Birch, Suite 307
Flagstaff, Arizona 86002-2459

Submitted By

Richard A. Valdez
Bryan R. Cowdell
Erika E. Prats

BIO/WEST, Inc.
1063 West 1400 North
Logan, Utah 84321

August 1995

EXECUTIVE SUMMARY

An investigation of the aquatic resources of the Colorado River, from Diamond Creek (RM 226) to below Pearce Ferry (RM 286) in Lake Mead, was initiated in May of 1992 by the Hualapai Wildlife Management Department, with technical assistance from BIO/WEST, Inc. The purpose of this investigation was to determine the effects of interim flow releases from Glen Canyon Dam on aquatic resources of the region of the Colorado River bordered by the Hualapai Indian Reservation. Eleven research trips were conducted from June 1992 through January 1995 to sample fishes, macroinvertebrates, and water quality, and to monitor variability in river stage associated with flow changes. The first nine trips were conducted from Diamond Creek to Pearce Ferry, and the last two trips extended sampling upstream to National Canyon. The Colorado River forms 109 miles of the northern boundary of the Hualapai Indian Reservation from near National Canyon (RM 164.5) to near Emery Falls Canyon (RM 273.5). A Phase I Report (Valdez 1994) presented findings for the first seven trips. This Phase II Report presents the integration of data from all 11 trips.

River stage recorded each sampling trip showed a maximum vertical change of about 60 cm for 24 hr, and a net change of about 90 cm over a 3-day period. Most daily stage changes were 40 to 60 cm in narrow canyon reaches, and 20 to 30 cm in more alluvial downstream reaches where stage change was ameliorated by Lake Mead. River fluctuations in the study area were regular and cyclic, with lows of 8,000 to 10,000 cfs between 2:00 am and 4:00 am, and highs of 13,000 to 15,000 cfs between 11:00 am and 1:00 pm, as measured at the Diamond Creek gage.

Conductivity, water temperature, pH, and dissolved oxygen concentrations were measured in the mainstem and in some tributaries with a constant recording Hydrolab Surveyor II or Datasonde with datalogger. Turbidity was measured in the mainstem with a secchi disk. Maximum mainstem water temperature change in summer was about 3°C, from 17°C at Travertine Canyon (RM 229.0) on June 24, 1992 to 20°C at Grand Wash Cliffs (RM 276.0) on July 1. Maximum surface temperature at Pearce Ferry was 24.5°C to 26°C on July 1. Water temperature in fall (September-October) was typically isothermal at about 13°C to 16°C from the river to Pearce Ferry, while December temperature was usually warmer, from 8°C to 10°C, and January temperature was usually colder near Pearce Ferry, from 10°C to 8°C. Temperature of Spencer Creek varied from about 14°C in December to about 29°C in June.

Benthic and drifting macroinvertebrates sampled in the Colorado River and tributaries showed relatively low drift densities in the mainstem, and high benthic and drift densities in Spencer Creek. Densities of drifting macroinvertebrates in Spencer Creek were 40 to 200 times those of the mainstem. Terrestrial and other aquatic forms of macroinvertebrates were dominant, and when compared to more upstream samples show that drift

changes longitudinally downstream. Chironomids, simuliids, and Gammarus lacustris were less common than in upstream reaches.

Fish sampling was conducted in the Colorado River as well as the following tributaries: Diamond Creek, Travertine Falls Creek, Spencer Creek, Surprise Canyon, Lost Creek, and Quartermaster Canyon. Fish were collected with seven primary gear types including electrofishing, gill nets, trammel nets, hoop nets, minnow traps, seines, and angling. Twenty species of fish were captured representing 10 families. Only four of these species, humpback chub (Gila cypha), speckled dace (Rhinichthys osculus), flannelmouth sucker (Catostomus latipinnis), and bluehead sucker (Catostomus discobolus), are native to the Colorado River Basin. Carp and channel catfish were the most common species in the Colorado River, moving into the study area from Lake Mead in large numbers in spring. Red shiners, fathead minnows, and mosquitofish were consistently most common in tributaries, where plains killifish were found in local aggregations. Striped bass, largemouth bass, green sunfish, black crappie, bluegill, threadfin shad, and walleye were lake species that were found in small numbers in tributaries or sheltered riverine habitats. Large numbers of striped bass were found in the Colorado River below Separation Canyon in spring, and numbers were lower through summer, fall, and winter. The endangered species, razorback sucker (Xyrauchen texanus), Colorado squawfish (Ptychocheilus lucius), and bonytail (Gila elegans), were not seen or captured, and only one humpback chub was captured at RM 253.2; the fish probably dispersed downstream from a central population at the Little Colorado River inflow about 191.9 miles upstream.

Few studies have been conducted on the aquatic resources of this lower reach of the Colorado River in Grand Canyon. Fish species composition showed that the reach below Bridge Canyon was dominated by nonnative species, with a large influence from the Lake Mead ichthyofauna. Densities of fish upstream of Bridge Canyon were relatively low. Young flannelmouth suckers and bluehead suckers in tributaries downstream of Bridge Canyon indicate that tributaries may be the only suitable locations for successful reproduction by native species in the area, although larval flannelmouth suckers found in the mainstem indicate some mainstem spawning as well. Mainstem habitats may be too altered by sediment deposits or temperature modification to provide much suitable spawning habitat for native fishes. Also, the large numbers of nonnative species limits the chances for survival of young native fishes.

Sampling in Spencer Creek indicated that a series of water falls about 2 miles upstream of the outflow was a barrier to upstream movement, and the only species found above these falls was the native speckled dace. Perennial flow, good water quality, and good stream habitat make this tributary a suitable candidate as an introduction site for young razorback suckers, particularly above this fish barrier, since the area downstream is dominated by predaceous nonnatives and invaded in spring by channel catfish and carp. Young razorback suckers released above the water falls and allowed to grow past the size of predator susceptibility could use the Lake

Mead inflow as adult habitat. The chances for successful reproduction and recruitment by these stocks cannot be assessed at this time, but would be greatly reduced below fish barriers by large numbers of nonnative fishes in the region.

This investigation revealed that interim flows continue to be manifested as net fluctuating river stages of as much as 90 cm just above the Lake Mead inflow, about 250 miles downstream of Glen Canyon Dam. While these changes may destablized shoreline habitats and periodically affect fish access to tributaries, no direct relationships was identified to current fish population distributions or abundances. Although this region of the Colorado River is far enough downstream from the dam to allow for longitudinal warming of river temperatures, effects of cold releases on primary and secondary production extend into this region and limit food resources for fish. The preliminary determination from this investigation is that interim flows alone do not appear to detrimentally impact aquatic resources of the area. Instead, the synergistic effects of fluctuating flows, low temperatures, absence of spring runoff, and nonnative fishes, have affected the riverine ecosystem throughout Grand Canyon. Effects of interim flows to the lower 45 miles of the study area, downstream of Bridge Canyon, are overwhelmed by fluctuating levels of Lake Mead, massive sediment deposits that have altered channel geomorphology, and the abundance of nonnative fishes residing in the reservoir. Commercial motorized boat traffic (i.e., large jet boats) that transport rafters across flatwater areas (Bridge Canyon to Pearce Ferry) generate sudden and fast-moving waves that may erode banks and destabilize shorelines to a greater degree than dam operations.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

Many individuals contributed to the success of this project; some are listed in Table A-2 of this report acknowledging personnel participating in field trips. Don Bay and Clay Bravo of the Hualapai Natural Resources Department were the principal administrators of this project, and key to its success. Many members of the Hualapai Indian Tribe participated in field trips and logistics coordination, and we particularly thank Morris Samson for his continued involvement. Ben Zimmerman provided key field and administrative support, and technical guidance.

Thanks to Dave Wegner of the Glen Canyon Environmental Studies for his continuing support of this project that has extended knowledge of the Colorado River from Glen Canyon Dam to Lake Mead. Thanks also to his staff, including Mike Yard, Alan Haden, Jeannie Korn, and Bill Vernieu.

Special thanks to Gloria Hardwick, Bill Leibfried, Kirsten Tinning, Alan Kinsolving, Bryan Cowdell, and Erika Prats for serving as project leaders and senior biologists on the project and providing valuable guidance to young biologists of the Hualapai Indian Tribe. Teresa Yates is deserving of special credit for maintaining the equipment and insuring safe and productive sampling trips.

Arizona Game and Fish Department, Grand Canyon National Park, Lake Mead National Recreation Area, and U.S. Fish and Wildlife Service provided permits for sampling the area and handling fish. We thank those agencies and respective representatives, including Bruce Taubert (AGF), Johnny Ray (GCNP), Ross Haley and Denise Freitas (LMNRA), and Debra Bills (USFWS).

Finally, a special word of gratitude to the Grand Canyon River Guides and to OARS for their continued support of these studies, and undying dedication to safety and a better understanding of the Grand Canyon. Thanks especially to Mike Walker, Brad Dimock, Brian Dierker, and Steve Bledsoe.

INTRODUCTION

Effects of interim flows from Glen Canyon Dam were evaluated on the aquatic resources of the lower Colorado River along 109 miles of the northern boundary of the Hualapai Indian Reservation, from near National Canyon (RM 164.5) to near Emery Falls Canyon (RM 273.5). The investigation was administered by the Natural Resources Department of the Hualapai Indian Tribe (HNRD), with technical assistance from BIO/WEST, Inc. The investigation was conducted as part of the Glen Canyon Environmental Studies (GCES) of the Bureau of Reclamation, in cooperation with the National Park Service and the U.S. Fish and Wildlife Service. River logistics were provided by OARS, a commercial river concessionaire from Flagstaff, Arizona.

The purpose of the investigation was to monitor the effects of interim flows from Glen Canyon Dam on aquatic resources of the lowermost reaches of the Colorado River in Grand Canyon. The focus of the investigation was on fish assemblages, and included an evaluation of species composition and distribution, habitat, nonnative fish interactions, and food resources. Eleven trips were conducted from June 1992 through January 1994. The first nine trips were from Diamond Creek (RM 226) to below Pearce Ferry (RM 286), and the last two trips were from National Canyon (RM 164.5) to below Pearce Ferry. The study was designed to integrate with fishery investigations from Lees Ferry to Diamond Creek, from October 1991 through November 1993 (Valdez et al. 1991, Valdez and Hugentobler 1992, Valdez and Ryel 1995). A Phase I Report (Valdez 1994) was prepared that described aquatic resources for the region from Diamond Creek to Pearce Ferry. This Phase II report synthesizes and integrates data collected for the entire study from National Canyon to below Pearce Ferry.

BACKGROUND

Proper management of Glen Canyon Dam is vital to preserving the remaining native ichthyofauna of the Colorado River in Grand Canyon. Before the dam was completed in 1963, the mainstem Colorado River in Grand Canyon supported eight species of native fishes, including Colorado squawfish (Ptychocheilus lucius), humpback chub (Gila cypha), bonytail (Gila elegans), razorback sucker (Xyrauchen texanus), roundtail chub (Gila robusta), flannelmouth sucker (Catostomus latipinnis), bluehead sucker (Catostomus discobolus), and speckled dace (Rhinichthys osculus) (Valdez and Ryel 1995 and references therein). Colorado squawfish, roundtail chub, and bonytail have been extirpated from Grand Canyon, and humpback chub and razorback sucker are federally endangered species. The abundance and distribution of flannelmouth sucker, bluehead sucker, and speckled dace have also diminished in the region. Declines in these native species are attributed to habitat inundation and fragmentation, migration blockage, altered flow regimes, reduced water temperature, altered water quality, and invasion of nonnative fishes.

Patterns and magnitudes of flow of the Colorado River through Grand Canyon are largely regulated by Glen Canyon Dam, although spring runoff and periodic rain storms may increase tributary inflow sufficiently to influence mainstem hydrology. Since August 1, 1991 releases from Glen Canyon Dam have been regulated by interim flow criteria instituted by the Secretary of Interior. Maximum flow is restricted to 20,000 and minimum flow to 5,000 cfs for a maximum of 6 hr at night, and 8,000 cfs from 7:00 am to 7:00 pm. Daily changes are not allowed to exceed 5,000 cfs during low volume months (March, April, May, October, November), 6,000 cfs during medium volume months (January, February, June, December), and 8,000 cfs during high volume months (July, August, September). Ramping rates cannot exceed increases of 8,000 cfs over 4 hr, or hourly increases and decreases of 2,500 and 1,500 cfs, respectively.

Interim flow criteria were implemented to minimize damage to the Grand Canyon ecosystem resulting from previous Glen Canyon Dam operations (U.S. Department of Interior 1988). Since the operation of Glen Canyon Dam potentially impacts all aquatic resources downstream to Lake Mead, an integrated monitoring program was initiated by GCES in 1992 to describe the response of the ecosystem to these interim flows. This investigation was designed to evaluate the effects of dam operations on aquatic resources of lower Grand Canyon as part of the GCES interim flows monitoring program.

Few detailed investigations have been conducted on the aquatic resources of lower Grand Canyon and the Lake Mead inflow (Deacon and Baker 1976, Carothers and Minckley 1978, McCall 1979). Studies conducted as part of GCES Phase I and Phase II (U.S. Department of Interior 1988), prior to this investigation, ended at Diamond Creek (RM 226). This investigation extended the lower boundary of the study area from Diamond Creek to Lake Mead below Pearce Ferry (RM 286) in order to evaluate effects of interim flows throughout the river corridor. The methods used in this investigation were consistent with those employed in Grand Canyon by Arizona Game and Fish Department (AGFD, Angradi et al. 1992) and BIO/WEST, Inc. (Valdez et al. 1993) under GCES Phase II.

OBJECTIVES

The objectives of this investigation applied to the region from National Canyon (RM 164.5) to below Pearce Ferry (RM 286), and were defined to evaluate the effects of interim flows from Glen Canyon Dam on the following:

1. Distribution, abundance, and behavior of native and nonnative adult fish.
2. Distribution, abundance, and behavior of the larval and juvenile stages of native fishes.

3. Reproduction, food habits, and patterns of habitat use of piscivorous nonnative fishes that may prey on native fishes.
4. Environmental conditions in tributary mouths and shallow shoreline habitats.
5. Food base including productivity and algal standing crops.

STUDY AREA

STUDY REGIONS

The study area included 121.5 miles of the Colorado River and selected tributaries from near National Canyon (RM 164.5) to below Pearce Ferry (RM 286.0) (Figure 1). Data from a BIO/WEST fishery investigation conducted in Grand Canyon from 1990 through 1993 (Valdez et al. 1991, 1992; Valdez and Hugentobler 1993, Valdez and Ryel 1995) were integrated for the region from National Canyon to Diamond Creek (RM 226.0) to provide a characterization of fish assemblages along the entire northern boundary of the Hualapai Reservation, i.e., 109 river miles from near National Canyon (RM 164.5) to near Emery Falls Canyon (RM 273.5).

The area from Diamond Creek to Pearce Ferry was designated Region IV, as a continuation of the BIO/WEST studies conducted further upstream (Table 1). Other study regions included Region 0 -- Lees Ferry (RM 0) to Kwagunt Rapid (RM 56.0), Region I -- Kwagunt Rapid to Red Canyon (RM 77.4), Region II -- Red Canyon to Havasu Creek (RM 160.0), and Region III -- Havasu Creek to Diamond Creek (RM 226.0). The area from National Canyon to Diamond Creek was included in Region III.

Table 1. Geomorphic reaches[a] and longitudinal sampling strata of the Colorado River from the eastern boundary of the Hualapai Indian Reservation (RM 165.0) to below Pearce Ferry (RM 286), 1992-93.

Study Region	Geomorphic Reach	Sampling Strata	River Miles	Length (mi)
III	10-Lower Canyon	a. RM 165-RM 169.9	165.0-169.9	4.9
		b. RM 170.0-Lava Falls	170.0-179.4	9.5
		c. Lava Falls-RM 189.1	179.5-189.1	9.6
		d. RM 189.1-RM 200.0	189.2-200.0	10.8
		e. RM 200.0-209 Mile Rapid	200.1-208.9	8.8
		f. 209-Mile Rapid-214-Mile Creek	209.0-213.9	4.9
	11-Lower Granite Gorge	g. 214-Mile Creek-Diamond Creek	214.0-226.0	12.0
IV		a. Diamond Creek-RM 235.0	226.1-235.0	8.9
		b. RM 235.0-Quartermaster Canyon	235.1-259.0	23.9
	12-Lake Mead Inflow	c. Quartermaster Canyon-Dry Canyon	259.1-265.0	5.9
		d. Dry Canyon-Below Pearce Ferry (RM 286)	265.1-286.0	20.9

[a]Based on geomorphic reaches by Schmidt and Graf (1988, 1990).

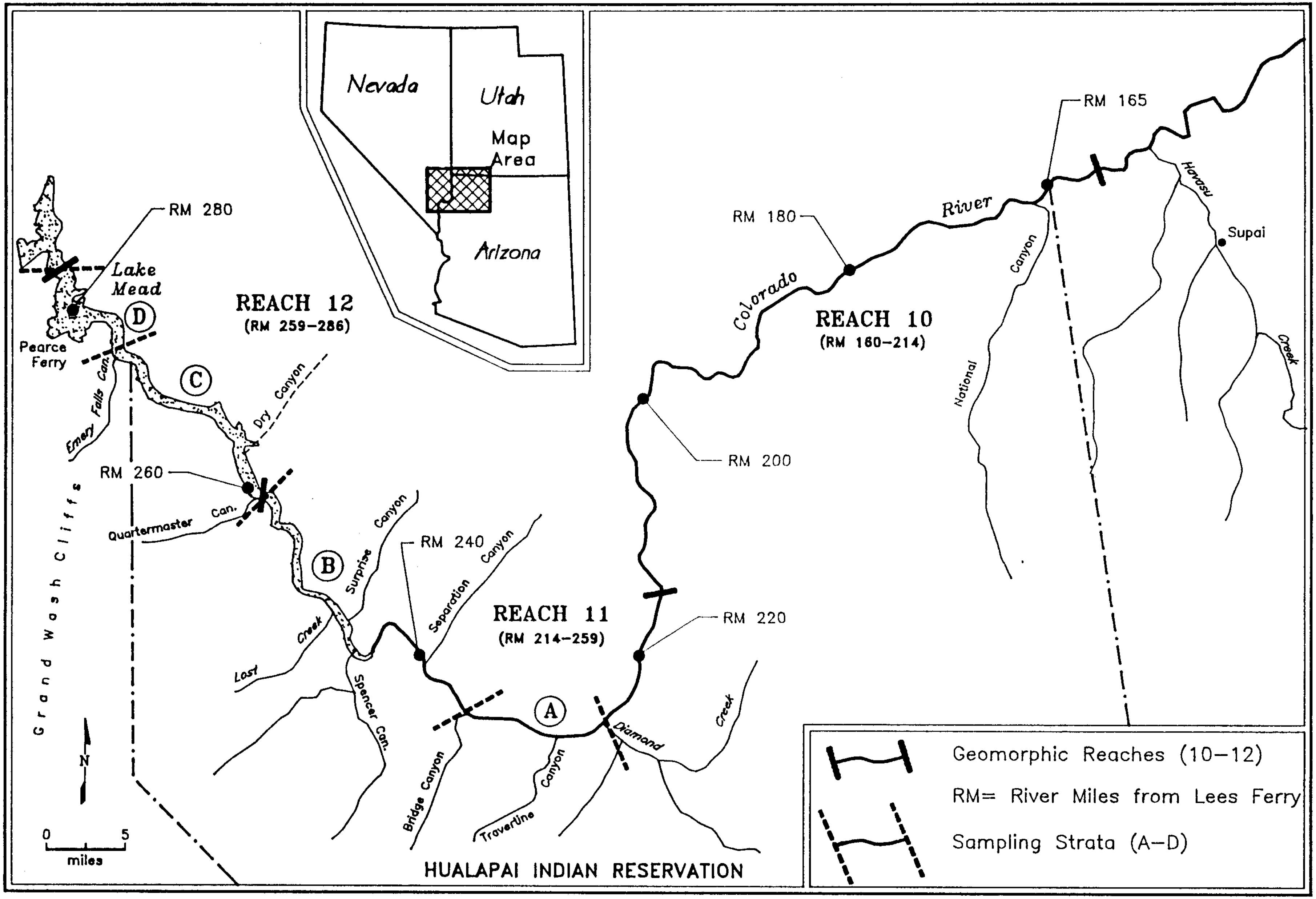


Figure 1. The Colorado River along the northern boundary of the Hualapai Indian Reservation, and Reaches 10-12, with sampling strata A-D from Diamond Creek to below Pearce Ferry.

GEOMORPHIC REACHES

The Colorado River in Grand Canyon was divided into 11 longitudinal geomorphic reaches by Schmidt and Graft (1988), that were used as major sampling units to describe fish assemblages from Lees Ferry to Diamond Creek (Valdez and Ryel 1995). This system of geomorphic stratification was continued for the remainder of the canyon downstream of Diamond Creek. Three geomorphic reaches were identified for the area from National Canyon (RM 165) to Pearce Ferry (RM 286), including Reach 10 (RM 160-214), Reach 11 (RM 214-259), and Reach 12 (RM 259-286). Reach 10 was referred to as the Lower Canyon by Schmidt and Graf (1988), and Reach 11 was referred to as Lower Granite Gorge, but was ended at Diamond Creek. For the purposes of this study, Reach 11 was extended downstream to RM 259, which was designated as the terminus of Lower Granite Gorge (Hamblin and Rigby 1969), and Reach 12 was added to describe the Lake Mead Inflow. Channel gradient, prominent tributaries, and sediments deposits are shown in a longitudinal cross-section of Reaches 11 and 12 in Figure 2.

The Lower Canyon, or Reach 10 (RM 160-214), had an average channel width of 310 ft (94 m), a moderate slope (13 ft/1000 ft), and a bed composition of 32 percent bedrock and boulders (Schmidt and Graf 1988, 1990). The river flowed through moderately erosive sedimentary deposits consisting primarily of Bright Angel shale, and the shoreline was characterized by talus slopes with intermittent alluvial boulder fans. Tertiary lava flows extended downstream of RM 180, shaping much of the shoreline with emergent boulders and cliffs formed by columnar basalt.

Lower Granite Gorge, or Reach 11 (RM 214-259), had an average channel width of 240 ft (73 m), a moderate slope (16 ft/1000 ft), and a bed composed of 58 percent bedrock and boulders. This reach consisted of metamorphic and sedimentary features similar to those in the lower portion of Upper Granite Gorge. Geologic formations consisted primarily of granitic and granodioritic rock of the Zoraster Granite Complex, intermixed with Tapeats Sandstone. Perennial tributaries in this reach included Diamond Creek (RM 225.7), Travertine Canyon (RM 229.1), Spencer Canyon (RM 246.0), Surprise Canyon (RM 248.4), Lost Creek (RM 248.9), and Quartermaster Canyon (RM 259.8).

Reach 12 (RM 259-286) was added to the 11 geomorphic reaches to consider the combined effect of lake inundation and shoreline geomorphology. This reach was the Lake Mead Inflow, and was characterized by an expansive open area downstream of Grand Wash Cliffs, largely inundated by Lake Mead. Original shoreline geology was inundated by the lake and alluvial deposits, and were not directly related to shoreline habitat as in other reaches.

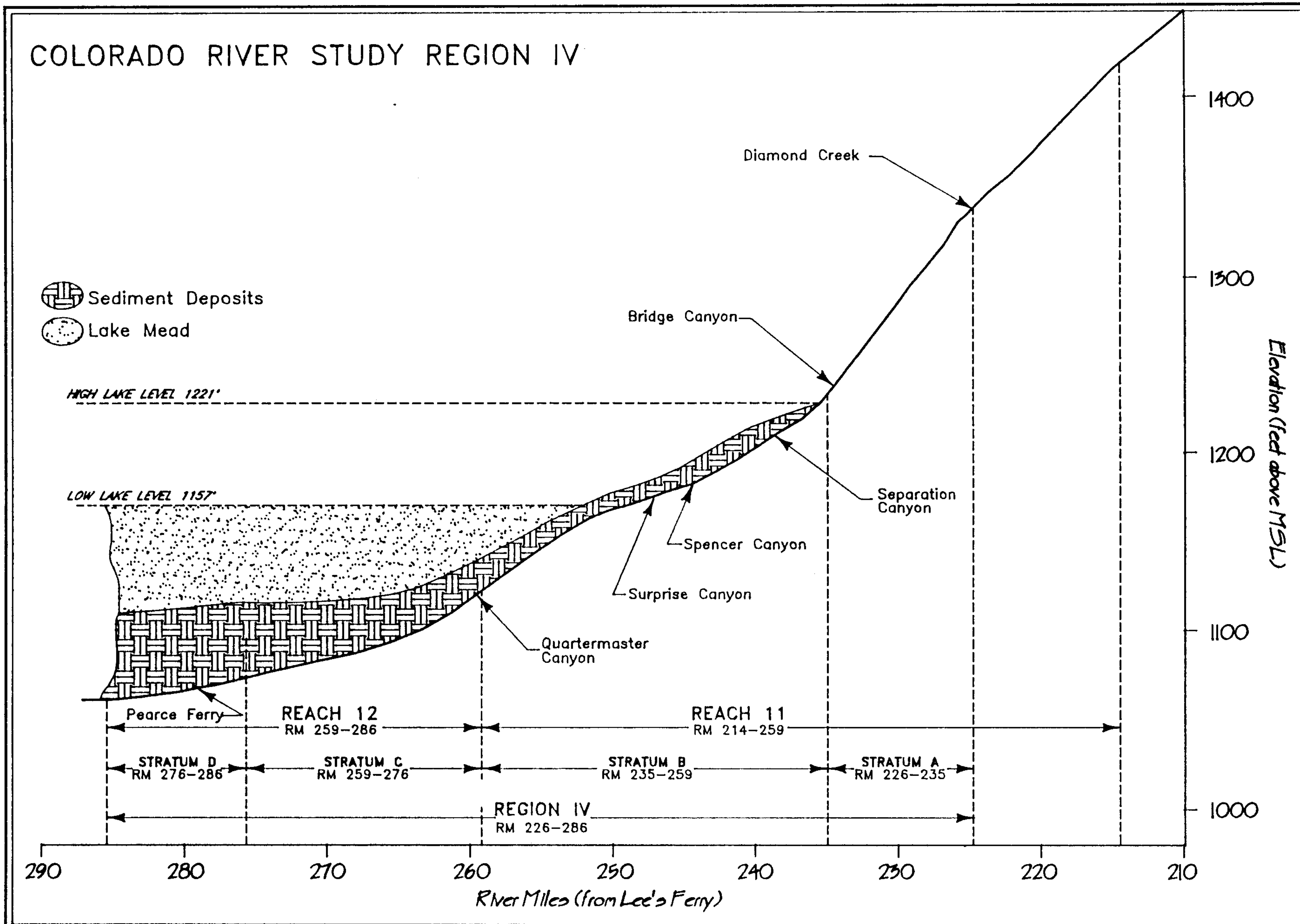


Figure 2. Longitudinal cross-section of Reaches 11-12 of the Colorado River from RM 214 to RM 286.

SAMPLING STRATA

The 121.5-mile reach of river between National Canyon and below Pearce Ferry was divided longitudinally into 11 sampling strata, each with different habitat complexes. The strata from National Canyon to Diamond Creek (III-a through III-g) were designated and described by Valdez and Ryel (1995) and were generally divided on the basis of major habitat units and reaccessible sampling areas. The strata from Diamond Creek to Pearce Ferry were divided by major habitat units and were greatly influenced by the Lake Mead inflow.

Stratum IV-a was a steep (0.16%), swift canyon area that extended 8.9 miles from Diamond Creek (RM 226) to Bridge Canyon (RM 235), and included the segment of river upstream of high-elevation lake deposits. Stratum IV-b was a canyon area that extended for 23.9 miles from Bridge Canyon to Quartermaster Canyon (RM 259), and was also a narrow canyon, but with a more gentle gradient (0.07%), moderated by sedimentary lake deposits accumulated at maximum lake levels. Stratum IV-c was a wide, braided, gentle (0.06%) channel filled with sedimentary lake deposits that extended for 5.9 miles from Quartermaster Canyon to Dry Canyon (RM 265). The deposits were heavily vegetated with coyote willow (Salix exigua), Goodding willow (S. Gooddingii), and tamarisk (Tamarix pentandra), with intermittent talus and vertical rock cliffs. At low lake levels, extensive sediment deposits were exposed and backwaters formed from chute channels and overflow channels. Stratum IV-d was an open alluvial delta and lake inflow that extended 20.9 miles from Dry Canyon to below Pearce Ferry (RM 286), and was characterized by a large open canyon with low gradient (0.04%) and expansive sedimentary lake deposits heavily vegetated with coyote willow, Goodding willow, seep willow (Baccharis), tamarisk, cattails (Typha sp.) and rushes (Juncus torreyi). A small intermittent tributary was at Emery Falls Canyon (RM 274.3).

METHODS

SAMPLING DESIGN AND TRIP SCHEDULE

Sampling of water quality, macroinvertebrates, and fishes was designed to account for spatial and temporal variation. Three geomorphic reaches and 11 sampling strata were identified to longitudinally stratify the area from National Canyon to Pearce Ferry and account for differences in channel geomorphology, shoreline types, and physical distribution of fish habitat. Selection of sampling sites was designed to evenly distribute effort among the geomorphic reaches as well as the perennial tributaries, including Diamond Creek, Travertine Canyon, Spencer Canyon, Surprise Canyon, Lost Creek, and Quartermaster Canyon. Data presented for the mainstem from National Canyon to Diamond Creek were supplemented by other research conducted by BIO/WEST, Inc (Valdez et al. 1991, 1992, Valdez and Hugentobler 1993, Valdez and Ryel 1994).

Temporal sampling was based on seasonal and daily variation. Four annual trips were conducted to represent each of the four seasons, i.e., March-April = spring, May-June = summer, September-October = fall, and December-February = winter. Seven sampling trips were conducted during Phase I of this study, including three in 1992 and four in 1993, and one trip was conducted in 1994 and one in 1995 for Phase II (Table A-1). Sampling was conducted during the four light periods of the day, including dawn, day, dusk, and night to account for daily variation river flow, chemical conditions, and fish behavior with light conditions.

A total of 41 people participated in the seven field trips (Table A-2). A typical crew included three BIO/WEST biologist/boat handlers, three HNRD representatives, and one or two OARS river guides with one or two assistants. Helicopter reconnaissance on June 24, 1992, helped to identify perennial tributaries, locate camp sites, and develop a sampling strategy for the region to provide convenient access to sampling sites with minimal activity in the vicinity of recreational boaters.

RIVER HYDROLOGY

Flow of the Colorado River through the study area was monitored by accessing U.S. Geological Survey (USGS) gaging data at Diamond Creek (gage #09404200). Changes in river level were recorded at each camp site from temporary staff gages, which were related to temporary bench marks (TBM) for future reference to real elevation. Nine TBMs were established during this study (Table A-3), each designated by a 1-cm diameter dot of yellow enamel paint on a vertical rock face above the high water line. Descriptions and photographs of each TBM were taken to allow reoccupation of these sites.

WATER QUALITY

Conductivity, water temperature, pH, and dissolved oxygen were measured in the mainstem Colorado River with a constant recording Hydrolab DataSonde II (Table A-4). The instrument was deployed at each camp site from the 37-ft S-rig support raft, and parameters were measured over the period in which a particular camp was occupied. Turbidity was periodically measured from the support raft with a secchi disk (Table A-5), and long-term variation in temperature was monitored at two locations in the Colorado River with thermographs (Ryan TempMentor). Data from USGS records (Diamond Creek gage #09404200) were used to describe historic and ongoing water quality conditions in the mainstem Colorado River, and to evaluate the Hydrolab measurements.

A Hydrolab Datasonde with datalogger was used in Spencer Canyon to record conductivity, water temperature, pH, and dissolved oxygen. The unit was deployed in the inflow, upstream of the high water line and impoundment area to avoid mainstem influences. Long-term variation in temperature was also monitored in Spencer Canyon with a thermograph.

MACROINVERTEBRATE SAMPLING METHODS

Results of macroinvertebrate sampling for the first seven trips are presented in this report. Results of sampling for the trip in 1994 and for the trip in 1995 were presented by Leibfried (1995).

Benthic Macroinvertebrates

Benthic macroinvertebrates (benthos) were sampled in the Colorado River and selected tributaries. Benthos were collected from rocky substrates in tributaries with Hess and Surber samplers, and an Ekman dredge was used in the mainstem where the substrate usually consisted of sand or silt. Although samples were collected in all tributaries, the majority were collected in Spencer Canyon. Three samples were collected at each fish sampling site (multiple-pass) during Trips 5 through 7, and sets of up to five Hess samples were taken at the inflow. Each benthic sample was placed in a labeled Ziploc bag or whirl-pack and preserved in 70 percent ethanol. All samples were returned to the laboratory and sorted.

Drift

Drift was collected in the mainstem Colorado River at several camp sites. Samples were collected during the ascending and descending limbs of the hydrograph, as well as during steady flow to evaluate the influence of flow changes on drift. The drift nets consisted of metal-framed nets attached to steel rods driven into the substrate. The nets were 10 ft long with an aperture area of 12 x 18 in and a mesh size of 560 μm. Screw-on PVC cups were attached to the end of the nets to facilitate removal of the sample. All drift net samples were taken in pairs, with one net positioned to include the water surface and a second net beneath, in the water column (subsurface). Water velocity was measured at the mouth of each drift net with a Swoffer current meter or Marsh-McBirney electronic current meter at the start and end of each sample, and averaged to determine water velocity and volume during the sampling interval. Each drift sample was measured volumetrically and placed in a labeled quart-sized plastic Ziploc bag and preserved in 90 percent ethanol. Drift samples were returned to the laboratory and sorted.

Drift density (DD) was computed as number of organisms in 100 m^3 of water filtered, according to the following formula (Allan and Russek 1985, Valdez et al. 1985):

$$DD = \frac{\text{Number Organisms per Net-Hour}}{\text{Cubic Meters Filtered per Net-Hour}} \times 100$$

Sample drift densities were averaged to compare surface with subsurface sets, and rising, falling, and steady flows.

FISH SAMPLING METHODS

Fish were sampled with seven principal gear types, including electrofishing, gill nets, trammel nets, seines, hoop nets, minnow traps, and angling (Valdez et al. 1993). These gears are also used in the upper Colorado River basin (Valdez 1990).

Electrofishing

Electrofishing in the mainstem Colorado River was conducted with an Achilles SU-16 motorized raft. The electrofishing system was powered by a 5000-W Honda generator (Model EB 5000X). Power from the generator was routed through a Mark XX Complex Pulse System (CPS) developed by Coffelt Manufacturing. The current was transformed from 220-V AC to DC, and the system was usually operated within a range of 110 V and 8 A to 200 V and 12 A, depending on water conductance. A single 12-in diameter, stainless steel, spherical anode (positive electrode) was used from the bow of the boat, and a single spherical cathode (negative electrode) was located at the stern.

Electrofishing in tributaries was conducted primarily with a Coffelt backpack 110-V electrofishing system (model BP-1C). High river levels sometimes provided access to the Lost Creek slough and lower Spencer Canyon with the electrofishing boat for supplemental sampling of these inflows. The backpack unit was typically operated within a range of 100 V and 8 A to 150 V and 12 A, depending on specific conductance.

Electrofishing in the mainstem and tributaries was used primarily to characterize fish assemblages, and determine fish distributions, and relative abundances (i.e., catch per effort). Backpack electrofishing was also used in Spencer Canyon to obtain seasonal estimates of fish numbers by the maximum-likelihood removal estimator (Moran 1951, Zippin 1956, 1958, White et al. 1982). A three-pass estimate was used in two sites, including the inflow (Site 1), and 0.75 miles upstream of the mainstem high water line (Site 2). Site 1 was about 30 m long, with an average width of about 5 m, and Site 2 was about 46 m long and averaged 11 m width. Small mesh seines were used to block upstream and downstream ends of each site to prevent escapement of fish during sampling. Electrofishing was conducted in an upstream direction, and fish of each pass were held separately in live pens.

Spencer Canyon was also sampled with electrofishing to determine seasonal occurrence and upstream distribution of mainstem species. Sampling was conducted up to 2.5 miles upstream of the inflow, and upstream of a series of short falls to determine if these were barriers to upstream fish movement. Surprise Canyon was also sampled with electrofishing.

Gill And Trammel Nets

Gill and trammel nets were used to sample fish along deep shorelines and at tributary inflows. Trammel nets were 75 or 50 ft long and 6 ft deep, with an inner panel of 1.0 or 1.5-in square mesh and outer panels of 12-in square mesh. Gill nets were 100 ft long and 6 ft deep, with 1.5 or 2.0-in square mesh. Longer nets--300 ft long and 6 ft deep, with 2.0-in square mesh--were also used to sample lacustrine and low-velocity riverine habitats. Experimental gill nets with 20-ft panels of 0.5, 1.0, 1.5, 2.0, and 2.5-in square mesh were also used.

Trammel and gill nets were set by attaching one end to the shoreline and weighting the outer end in the river so that the nets fished at or near the bottom. All nets had a foam-core float line and lead-core bottom line. Gill and trammel nets were checked at least every 2 hr, and were usually set within time periods representing day, morning and evening, and at night.

Seines

Seines were used in backwaters, tributaries, tributary mouths, shorelines, and shallow runs to sample small fish in shallow habitats. Three types of seines were used: 10 ft x 3 ft with 1/8-in delta mesh, 30 ft x 4 ft with 1/4-in delta mesh; and 30 ft x 5 ft with 1/4-in delta mesh. Seining was done principally in the day, primarily as a safety factor.

Traps and Angling

Hoop nets and minnow traps were used to trap fish moving along shoreline habitats, at tributary inflows, and to and from tributaries. Hoop nets with 3-ft diameter hoops were set overnight in side channels, backwaters, tributary mouths, and small embayments of the Lake Mead inflow to assess species composition and relative abundance of large shoreline species. Minnow traps were set in backwaters, vegetated areas, tributaries, tributary inflows, and along rocky shorelines to assess species composition and relative abundance of small shoreline species. Each trap was checked at about 24-hr intervals. Angling with artificial lures and live bait (i.e., live red shiners, trot and stink bait) was used to determine the presence of large predators.

Snorkeling

Snorkeling was conducted in tributaries to determine species composition and qualitative abundance of fishes in heavily-vegetated areas, otherwise difficult to sample. Most streams were shallow, and an observer could lay prone or crawl along the bottom while observing fish without disturbing them.

Fish Abundance

Catch-per-effort (CPE) statistics were developed for electrofishing and netting to evaluate spatial and temporal variation in fish abundance. Arithmetic catch-per-effort (i.e., number of fish by species divided by effort) were computed for each sample and averaged for all samples by sample partitions. Net catch rates were presented as number of fish/100 ft of net/100 hr of sampling, and electrofishing catch rates were presented as number of fish/10 hr of sampling.

Estimates of fish in Spencer Canyon were determined from a maximum-likelihood removal estimator, using the computer program MicroFish 3.0 (Van Deventer and Platts 1989). This program was designed to accommodate electrofishing data obtained by the multiple-pass removal method, and is based on a catch-per-effort removal model developed by Moran (1951) and Zippin (1956, 1958). The method is based on the assumptions of constant sample effort, closed population, equal capture probability for all fish within and between samples. Attempts were made to comply with these assumptions by blocking the sampling site, and using the same equipment and crew for each subsequent sampling pass. The estimated number of fish in each sample site was converted to number of fish/100 m^2 for comparison of fish density between sites and seasons.

Processing Fish In The Field

All fish captured were held in live wells, and weighed and measured. Samples containing large numbers of individuals were subsampled, and only the first 100 individuals of a given species were weighed and measured, and the remainder counted and released. Native and game species were measured by total length (TL) and standard length (SL), while all other species were measured by total length.

Native species greater than 150 mm TL were marked with PIT (Passive Integrated Transponder) tags, and released near the location of capture. PIT tags were injected into the peritoneal cavity with a sterile hypodermic needle designed for this purpose (Burdick and Hamman 1993).

Distribution Of Sample Effort

Sample effort by trip, sample strata, and tributary was unevenly distributed (Tables 2, 3, and 4; Figure 3), and indicates the need for additional work in the area to better define seasonal and longitudinal occurrence and abundance of fishes, as well as differences between tributaries. This sampling variation also indicates logistical impediments, such as large rapids that restrict repeated access to some areas.

Sample effort was lowest in Trip 1, reflecting project startup, but increased thereafter and remained approximately even for the two primary mainstem gear types, electrofishing and trammel nets, which accounted for 20 and 60 percent of all sample efforts. Gill nets were used less frequently than trammel nets because they

Table 2. Fish sampling gear with codes, descriptors, and number of sampling efforts per trip in the mainstem Colorado River from Diamond Creek (RM 226) to below Pearce Ferry (RM 286) 1992-95.

	Number of Sampling Efforts											
	1992			1993				1994			1995	
	Trip 1	Trip 2	Trip 3	Trip 4	Trip 5	Trip 6	Trip 7	Trip 8	Trip 9	Trip 10	Trip 11	Totals
Electrofishing												
EL - 220-v DC (Coffelt CPS)	20	52	29	39	61	29	25	27	33	57	35	**407**
Gill Nets												
GM - 100'x6'x2"	5	7	8	8	-	-	-	-	-	-	-	**28**
GP - 100'x6'x1.5"	13	13	5	4	22	-	-	20	-	-	-	**77**
GX - 100'x6' experimental gill net with 20' panels of 0.5, 1.0, 2.0, 2.5" mesh	10	4	10	12	-	-	-	-	-	-	-	**36**
GS - 300'x6'x2"	-	-	4	-	6	-	-	-	-	-	-	**10**
Trammel Nets												
TK - 75'x6'x1"x12"	15	31	48	71	17	23	-	26	9	122	101	**463**
TL - 75'x6'x1.5"x12"	40	36	40	55	26	30	29	-	28	22	-	**306**
TM - 50'x6'x1"x12"	4	-	16	9	43	25	44	-	-	-	21	**162**
TN - 50'x6'x1.5"x12"	3	33	16	39	18	14	38	24	49	36	29	**339**
TW - 75'x6'x0.5"x12"	-	-	-	-	3	-	-	-	-	-	-	**3**
Hoop Nets												
HM - 3' diameter (medium)	1	-	-	-	-	-	-	-	-	-	-	**1**
HS - 2' diameter (small)	-	2	-	-	1	-	-	-	-	-	-	**3**
Minnow Traps												
MT - commercial minnow traps	9	12	-	10	4	-	6	-	1	115	60	**217**
Seines												
SA - 10'x3'x1/8" seine	4	-	-	4	7	10	-	-	1	2	-	**28**
SB - 30'x4'x1/4" seine	-	11	19	-	-	-	-	-	-	-	-	**30**
SC - 15'x4'x1/8" seine	-	-	-	-	-	-	-	-	-	106	38	**144**
SG - 30'x5'x1/4" seine	-	5	8	-	-	-	-	-	2	-	-	**15**
Angling												
AN - angling with artificial or live bait	1	-	-	-	-	-	-	-	-	-	-	**1**
Total	**125**	**206**	**203**	**251**	**208**	**131**	**142**	**137**	**123**	**460**	**284**	**2270**

Table 3. Relative sampling effort within 5 strata (A-E) of the mainstem Colorado River from Diamond Creek (RM 226) to below Pearce Ferry (RM 286)[a], 1992-95.

Sample Strata	Gear Type[b]																		
	EL	BP	GM	GP	GX	GS	TK	TL	TM	TN	TW	HM	HS	MT	SA	SB	SC	SG	AN	Totals
A (225.0-235.0)	81	-	3	3	4	-	85	60	32	62	-	1	-	44	5	-	19	-	-	339
B (235.1-259.0)	201	-	4	24	2	-	236	161	74	166	3	-	-	135	15	20	107	13	1	1162
C (259.1-276.0)	96	-	18	38	26	-	133	76	51	94	-	-	2	34	8	10	18	1	-	605
D (276.1-286.0)	29	-	3	12	4	10	9	9	5	17	-	-	1	4	-	-	-	1	-	104
E (166.3-225.7)	34	5	-	2	-	-	131	10	-	39	-	-	-	126	79	2	-	-	-	428
Totals:	**441**	**5**	**28**	**79**	**36**	**10**	**594**	**316**	**162**	**378**	**3**	**1**	**3**	**343**	**107**	**32**	**144**	**15**	**1**	**2698**

[a] Significant land marks:

National Canyon	RM 166.3	Quartermaster Canyon	RM 259.8
Diamond Creek	RM 225.7	Dry Canyon	RM 264.5
Travertine Canyon	RM 229.1	Hualapai Indian Reservation Boundaries	RM 164.5-273.5
Bridge Canyon	RM 235.2	Emery Falls Canyon	RM 274.3
Separation Canyon	RM 239.5	Grand Wash Cliffs	RM 276.5
Spencer Canyon	RM 246.0	Grand Canyon National Park/Lake Mead	
Surprise Canyon	RM 248.4	National Recreation Area Boundary	RM 276.6
Lost Creek	RM 248.9	Pearce Ferry	RM 280.0
Salt Creek	RM 255.5		
Burnt Spring Canyon	RM 259.5		

[b] See Table 2 for gear codes.

Table 4. Fish sampling gear with codes, descriptions, and number of sampling effort per trip for tributaries of the Colorado River from Diamond Creek (RM 226) to below Pearce Ferry (RM 286), 1992-1995.

Sampling Equipment Gear Code - Description	Number of Samples											
	1992			1993				1994			1995	Totals
	Trip 1	Trip 2	Trip 3	Trip 4	Trip 5	Trip 6	Trip 7	Trip 8	Trip 9	Trip 10	Trip 11	
Diamond Creek (RM 226.0)												
SA - 10'x3'x1/8" seine	-	-	-	-	-	4	4	4	1	5	-	**18**
Travertine Falls Creek (RM 230.4)												
DN - Dip net	-	-	-	-	-	1	-	-	-	-	-	**1**
Spencer Creek (RM 246.0)												
BP - Backpack electrofishing	-	-	3	4	4	10	6	4	12	5	3	**51**
HM - 3' diameter (medium)	2	-	-	-	-	-	-	-	-	-	-	**2**
MT - commercial minnow traps	-	6	-	24	9	14	15	24	14	15	16	**137**
SA - 10'x3'x1/8" seine	3	-	-	-	3	4	4	-	-	-	-	**14**
SB - 30'x4x1/4" seine	-	5	1	-	-	-	-	-	-	-	-	**6**
Surprise Canyon (RM 248.4)												
EL - 220-v DC (Coffelt CPS)	1	-	-	-	-	-	-	-	-	-	-	**1**
BP - Backpack EL (Coffelt BP-1C)	-	-	-	6	1	-	-	3	3	-	-	**13**
HM - 3' diameter (medium)	-	-	1	-	-	-	-	-	-	-	-	**1**
HS - 2' diameter (small)	-	-	2	-	-	-	-	-	1	-	-	**3**
MT - commercial minnow traps	-	4	3	6	3	10	4	4	10	-	-	**44**
SA - 10'x3'x1/8" seine	3	-	-	-	2	3	2	-	-	-	-	**10**
SB - 30'x4x1/4" seine	-	1	4	-	-	-	-	-	-	-	-	**5**
SC - 15'x4'x1/8" seine	-	-	-	-	-	-	-	-	-	4	-	**4**
Lost Creek (RM 248.9)												
EL - 220-v DC (Coffelt CPS)	2	-	-	-	-	-	-	-	-	-	-	**2**
HM - 3' diameter (medium)	1	-	-	-	-	-	-	-	-	-	-	**1**
HS - 2' diameter (small)	-	2	-	2	1	-	-	-	1	-	-	**6**
MT - commercial minnow traps	4	-	-	8	5	-	-	-	4	-	-	**21**
SC - 15'x4'x1/8" seine	-	-	-	-	-	-	-	-	-	1	-	**1**
SG - 300'x6'x2" seine	-	1	-	-	-	-	-	-	-	-	-	**1**

Table 4. Continued.

Sampling Equipment Gear Code - Description	Number of Samples 1992 Trip 1	Trip 2	Trip 3	1993 Trip 4	Trip 5	Trip 6	Trip 7	1994 Trip 8	Trip 9	Trip 10	1995 Trip 11	Totals
Quartermaster Canyon (RM 259.8)												
HM - 3' diameter (medium)	1	-	-	-	-	-	-	-	-	-	-	1
HS - 2' diameter (small)	-	-	-	-	-	-	-	-	1	-	-	1
MT - commercial minnow traps	-	4	-	-	-	-	-	5	5	-	-	14
SA - 10'x3'x1/8" seine	1	-	-	-	-	-	-	-	-	-	-	1
Total	18	23	14	50	28	46	35	44	52	30	19	359

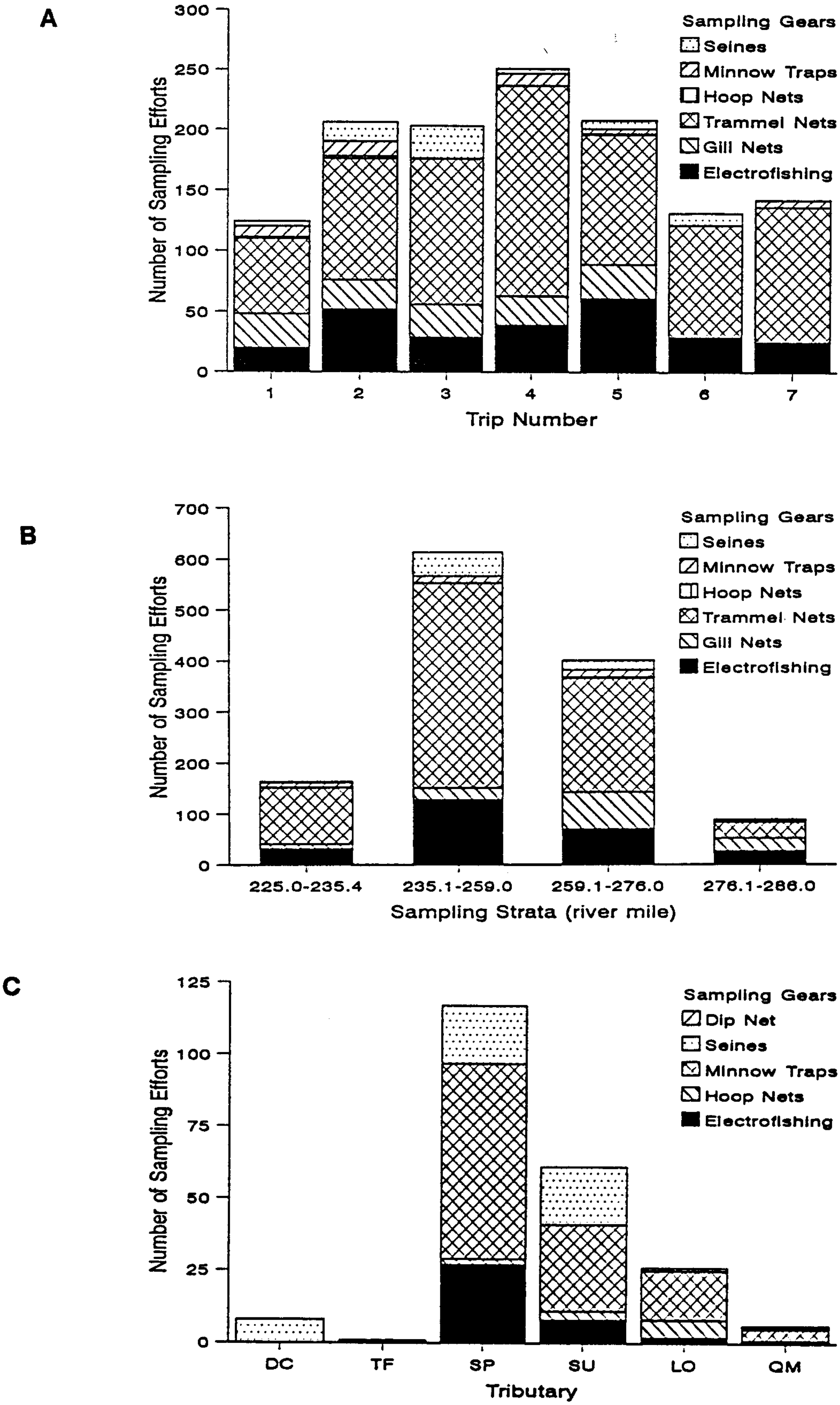


Figure 3. Sample effort by trip (A), sample strata (B), and tributary (C) for the Colorado River from Diamond Creek (RM 226) to Pearce Ferry (RM 286) June 1992-December 1993.

were less efficient (Valdez and Ryel 1995), and caused some abrasions to the fish. Seining and minnow trap efforts were low throughout and inconsistent, indicating a need for greater effort with these shoreline gears for smaller fish, but also reflecting limited numbers of shallow habitats for seining.

Sampling by strata was not comparable because of different stratum lengths, although number of sample efforts per mile resulted in approximately the same relative differences, and indicated a need for additional sampling in Stratum IV-a and Stratum IV-d. This distribution of sampling reflected a greater amount of time spent in the vicinity of tributaries, where camps were established and effort was maximized by sampling the mainstem during crepuscular periods and tributaries during the day. The majority of sample effort in tributaries was in Spencer Creek, primarily because it was the largest perennial stream in the study area. Future investigations will probably continue to focus on Spencer Creek, but this distribution of sampling suggests a need to examine other tributaries as well.

RESULTS

RIVER HYDROLOGY

River hydrology during this study reflected interim flow criteria, and flow at the Diamond Creek gage was maintained in a range of about 8,000 and 15,000 cfs (Figure 4). Weekly variations were evident (low weekend releases), as well as two high flow spikes from floods in the Little Colorado River (165 miles upstream) in January and February 1993. Daily variation for the period of each of the first six sampling trips (Figure 5) was approximately consistent with a complete cycle in each 24-hr period. Lowest flow at the Diamond Creek gage was usually between 2:00 am and 4:00 am, and peak flow was usually between 11:00 am and 1:00 pm (seen at Spencer Canyon 4-5 hr later). Greatest daily magnitude of change during the study was about 7,000 cfs over about 6 hrs on October 8, 1993. Normal daily magnitude was about 4,000 cfs, which was measured as a 60 cm stage change at Spencer Canyon on June 27, 1992 (Figure A-1). Maximum stage change recorded near Spencer Creek was about 90 cm over a 3-day period, from October 2-4, 1993. Stage changes were apparently ameliorated by the presence of Lake Mead in more downstream locations, below about Quartermaster Canyon (RM 259).

WATER QUALITY

Mainstem Colorado River

Mainstem water temperature was similar for 1992, 1993, 1994, and 1995. Maximum longitudinal temperature change for the mainstem in the study area was about 3°C in June 1992, from 17°C at Travertine Canyon (RM 229.1) to 20°C at Grand Wash Cliffs (RM 276.0). Maximum mainstem daily temperature

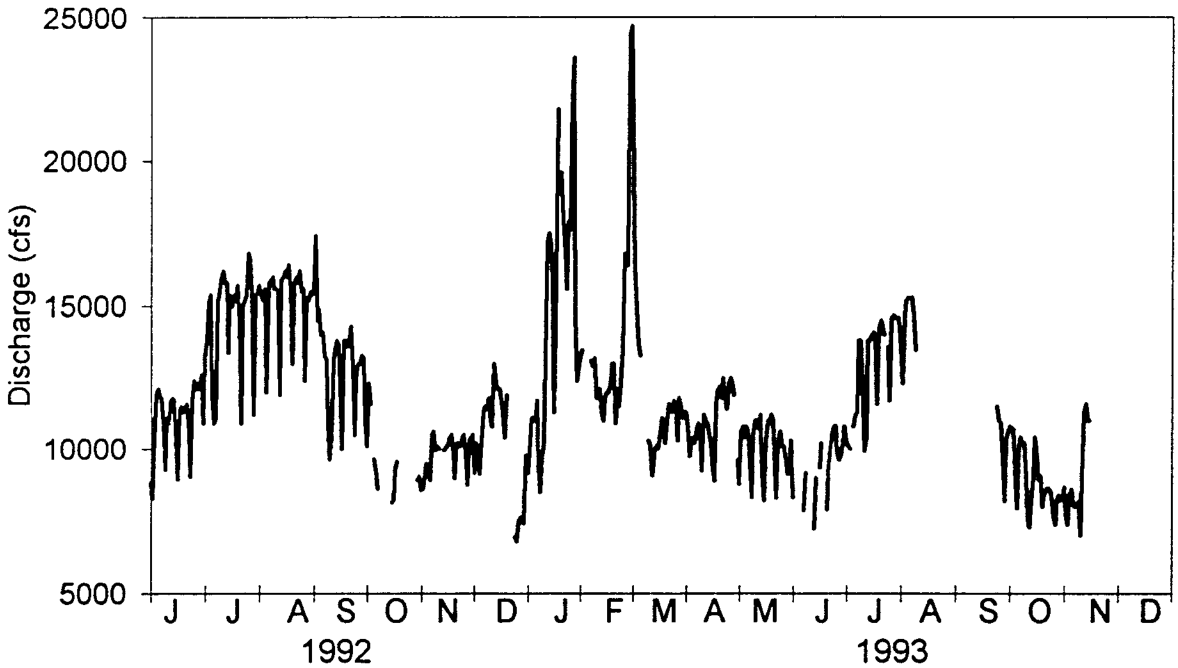


Figure 4. Flow of the Colorado River at Diamond Creek (USGS gage 9404200), from June 1992 through December 1993.

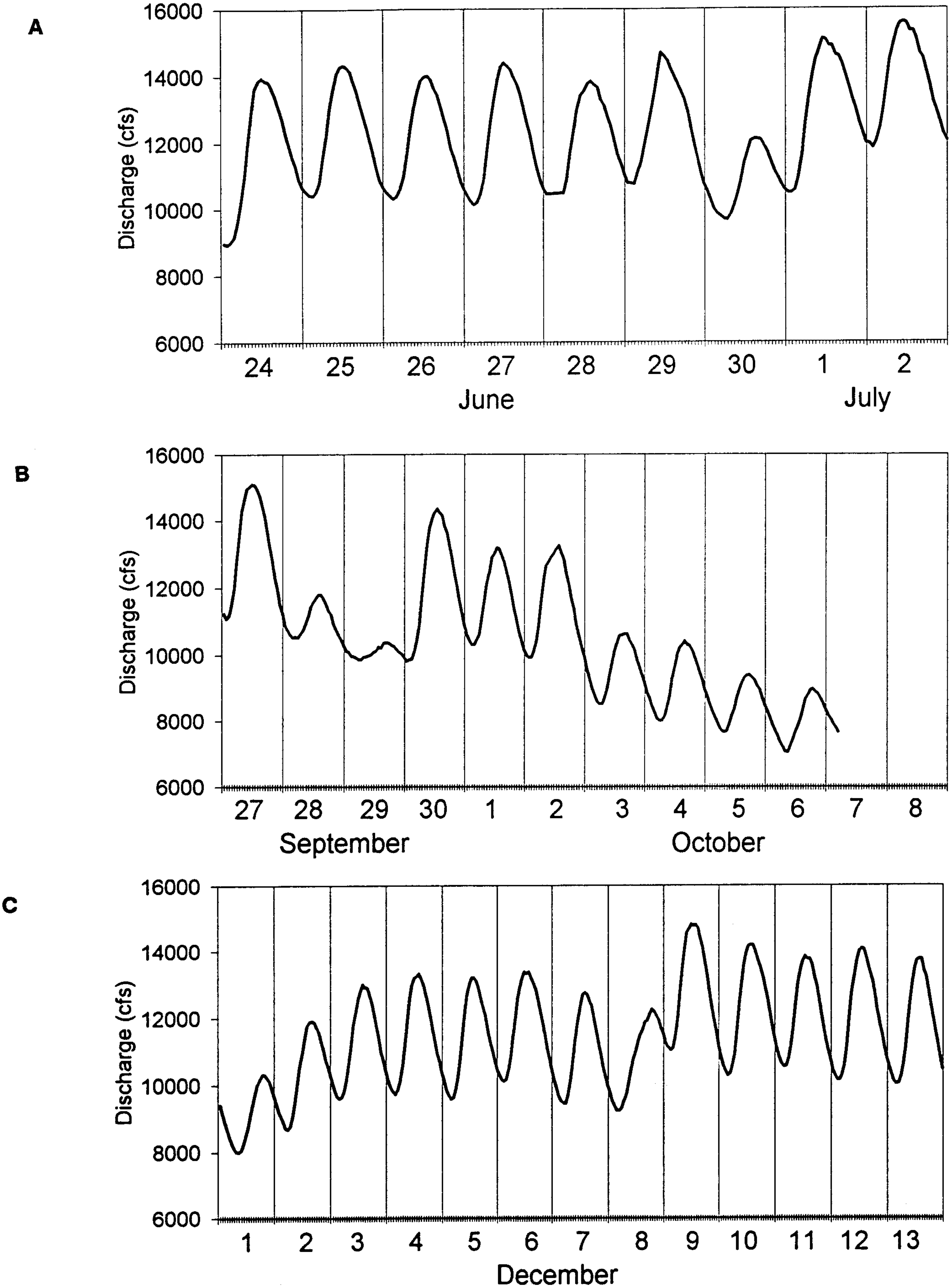
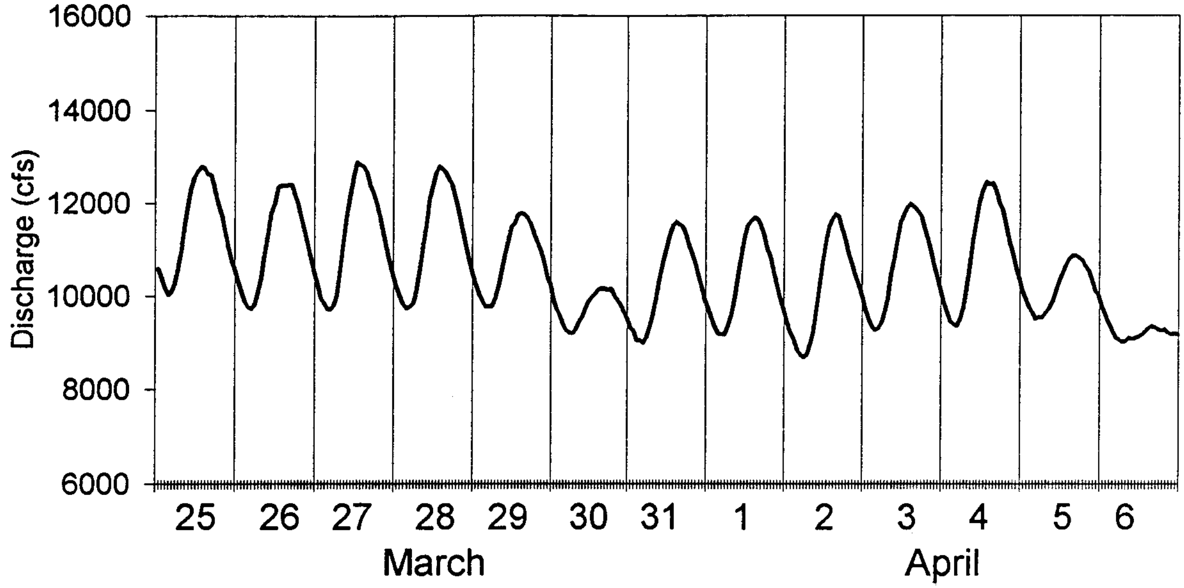
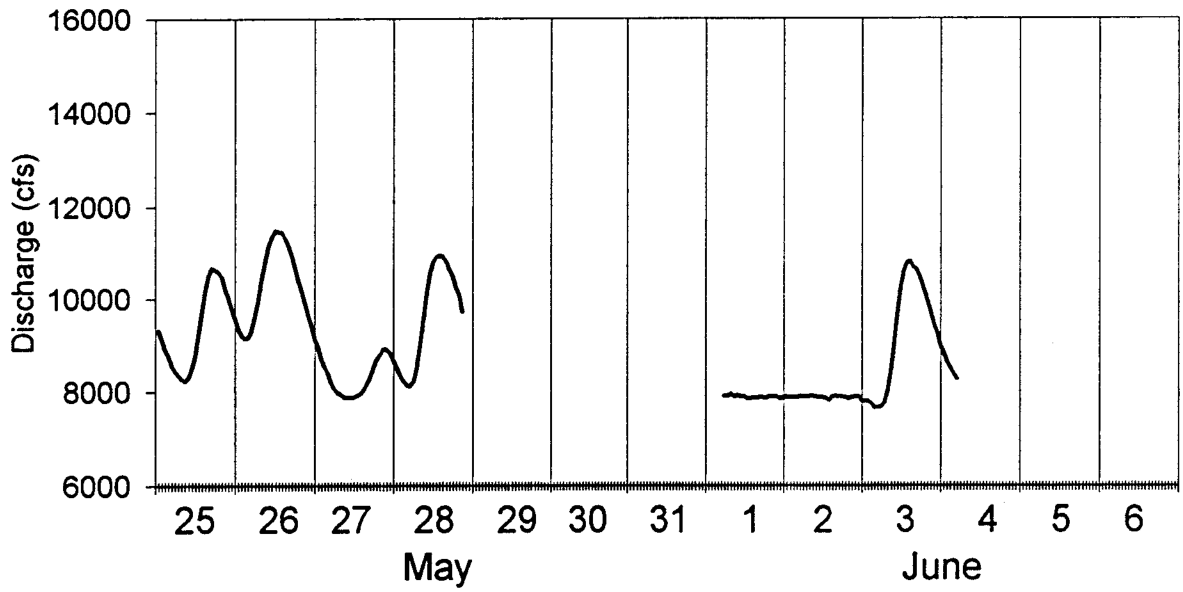


Figure 5. Flow of the Colorado River at Diamond Creek (USGS gage 9404200), for six sampling trips: June 24-July 2, 1992 (A), September 27-October 9, 1992 (B), December 1-13, 1992 (C), March 25-April 6, 1993 (D), May 25-June 6, 1993 (E), and September 28-October 10, 1993 (F).

D



E



F

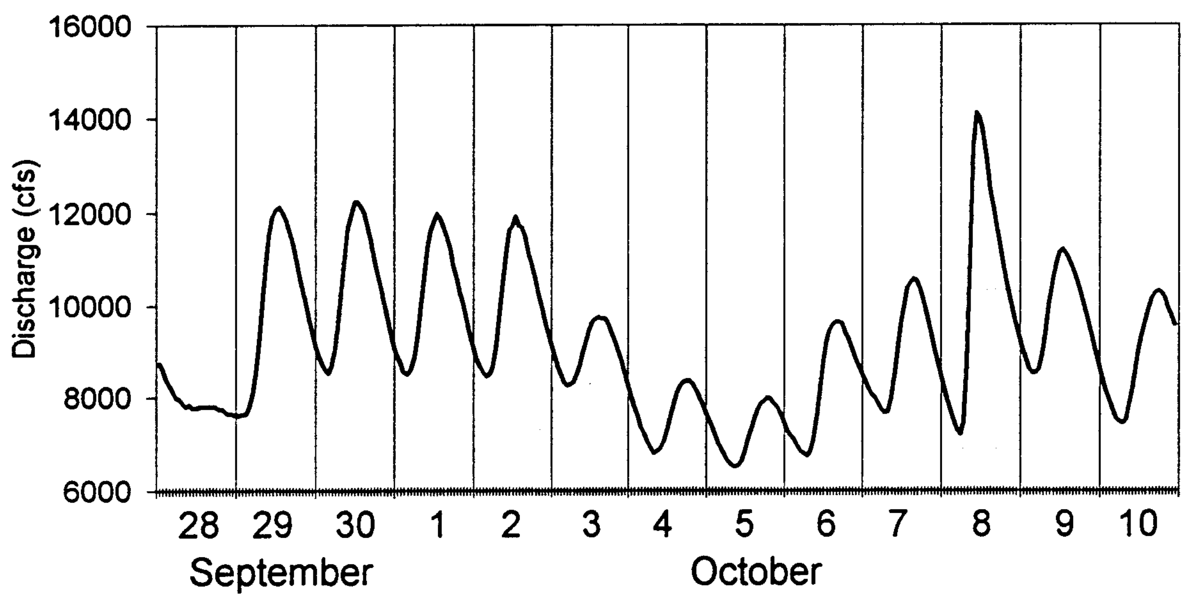


Figure 5. Continued.

fluctuation was about 0.5°C in the steep canyon area above Quartermaster Canyon (Table A-6); respective minima and maxima were 17.0-17.5°C at Travertine Canyon (RM 229.1), 17.5-18.0°C at Spencer Canyon (RM 246.0), 18.0-18.5°C at Lost Creek (RM 249.8), 18.0-19.5°C at Quartermaster Canyon (RM 259.8), 18.0-20.0°C at Grand Wash Cliffs, and 24.5-26.0°C at Pearce Ferry (RM 280.0). Significantly higher summer temperature toward Pearce Ferry was the effect of lake impoundment. Fall mainstem water temperature (September-October) ranged from 14.7°C near Spencer Canyon to 23.0°C near Pearce Ferry. Winter mainstem water temperature (December) remained cold throughout the reach, with a minimum of 8.6°C at Bridge Canyon and a maximum of 10.2°C near Pearce Ferry (Scorpion Island). While daily summer temperature varied by only 0.5°C, winter water temperature was only slightly more variable at 0.8°C. Water temperature for the Colorado River at Spencer Canyon on December 1-4, 1992 varied from about 8.6 to 9.4°C, over a 55-hr period (Figure A-2).

Dissolved oxygen in the mainstem was always near saturation, and on December 1-4, 1992 varied from about 11.1 to 11.9 mg/l (93-100% saturation). Other water quality parameters were also relatively stable; pH varied from about 8.0 to 8.1, and conductivity varied from about 875 to 1,000 uS/cm. Turbidity was relatively high in the mainstem throughout the study period. Secchi disk measurements ranged from 0.03 m in March 1993 to 0.90 m in October 1993.

Tributaries

The continuous recording Datasonde in Spencer Creek revealed strong diel pulses in temperature and dissolved oxygen for June 26-28, 1992 (Figure A-3) and September 30 - October 3, 1992. Water temperature in June varied daily from about 21°C to 29°C, for a change of about 8°C over a 16-hr period. Highest readings were observed about 3:00 pm, and lowest readings about 7:00 am. Diel water temperature in September-October varied from about 20.5°C at 7:00 am to about 26.5°C at 4:00 pm, or about 6°C over a 15-hr period. Daily water temperature in December varied from about 15°C to 17°C, with a change of about 2°C over a 16-hr period. Highest readings were observed about 4:00 pm, and lowest readings occurred between midnight and 9:00 am.

Observed levels of dissolved oxygen varied inversely with water temperature, as expected, i.e. cold water has a greater capacity for dissolved oxygen than warm water. This inverse relationship was particularly evident in June and September-October, when DO decreased with warmer temperature. However, the relationship was not as evident in December, when cooler water temperature allowed for more stable oxygen levels. Dissolved oxygen in Spencer Creek varied from about 6.6 to 8.0 mg/l in June, 4.4 to 7.0 mg/l (50-79% saturation) in September, and 7.0 to 8.0 mg/l (71-82% saturation) in December. Low oxygen level in December may be due, in part, to low stream volume or decreased primary productivity during winter months.

Level of pH in Spencer Creek in 1992 varied from about 8.0 to 8.3 in June, 7.5 to 8.1 in September-October, and 7.7 to 7.9 in December. The low variation in pH indicates that the stream has a fairly high buffering capacity. Conductivity varied from about 650 to 690 uS/cm in June, 650 to 680 uS/cm in September-October, and 640 to 680 uS/cm in December. This variation in conductivity is normal with variation in temperature and stream flow.

MACROINVERTEBRATES

Mainstem Colorado River

Invertebrates found in the drift belonged to two classes: Insecta and Crustacea (Table 5). The predominant insects were chironomids and simuliids, although other aquatic forms did comprise a large portion of the drift during some months. The amphipod (Crustacea), Gammarus lacustris, which is very common further upriver (especially near Glen Canyon Dam, Blinn et al. 1994) accounted for only a small proportion of drift during all seasons. Relative abundance of terrestrial insects varied considerably with season.

Table 5. Mean macroinvertebrate drift densities (number/100 m^3), by season, in the Colorado River between Diamond Creek (RM 226) and Pearce Ferry (RM 286), and in Spencer Creek during 1992-93. L = larvae, P = pupae, A = adult.

Seasons	Chironomidae			Simuliidae			Gammarus		Other	Terrestrial	Total
	L	P	A	L	P	A	A	I			
Colorado River											
1992											
May-Jun	18.2	12.0	18.9	26.7	5.4	6.7	0.0	0.5	4.4	33.6	126.4
Sep-Oct	0.0	2.1	2.1	2.1	0.7	2.1	0.3	1.1	0.9	16.7	28.1
Dec	0.4	0.2	3.4	4.8	0.0	1.1	0.0	0.2	0.2	2.7	13.0
1993											
Mar-Apr	12.0	6.5	6.7	3.0	0.0	1.0	0.0	0.0	0.0	41.9	71.1
May-Jun	27.4	22.7	27.8	11.3	1.5	2.0	0.0	0.0	12.6	50.8	156.1
Sep-Oct	41.8	18.4	28.8	8.3	3.0	1.5	0.0	3.0	118.4	138.3	361.5
Dec	68.0	7.4	40.6	37.2	0.0	3.3	0.0	0.0	26.8	6.8	190.1
Spencer Creek											
1993											
May-Jun	2,332.8	3,571.3	271.6	2,219.1	366.9	8.0	0.0	0.0	5,143.3	701.4	14,614.4

Total drift density varied among sampling trips, but no strong seasonal pattern was apparent. Density of drifting macroinvertebrates in 1992 was greatest in early summer and lowest in winter, but in 1993, total drift density was high in December. The pattern observed in 1992 is typical for temperate North American streams;

drift density increases as immature aquatic insects develop and approach emergence. As expected, terrestrial invertebrates were abundant in warmer months and uncommon in winter.

The discrepancy between drift patterns in Grand Canyon and those usually observed in temperate streams and rivers may be linked to invertebrate species composition. In most lotic systems a large number of the taxa are univoltine (one generation per year). In contrast, a large portion of the invertebrates in the mainstem Colorado River in Grand Canyon are polyvoltine (mainly Chironomidae) and undergo complete life-cycles a number of times during the year. Sampling in December 1993 possibly intercepted a short-term burst in drift density associated with a particular generation of chironomids.

Average surface and subsurface drift densities were highest with decreasing flow, lowest with increasing flow, and intermediate at steady flow (Table 6). Average subsurface drift was always greater than surface drift. Research has shown that increase in drift density results from both flow increases (catastrophic drift) and flow decreases (behavioral drift) (White and Wade 1980; Irvine 1985). Lower drift density with increased flow in Grand Canyon may be explained by the dilution effect of higher flows resulting in lower numbers of organisms in a cubic meter of water.

Tributaries - Spencer Creek

Drift density in May and June of 1993 was much greater in Spencer Creek than in the mainstem (Table 5). Gammarus lacustris were not found in Spencer Creek, and terrestrial insects represented a much smaller proportion of total drift. Drift density in the mainstem was lower than densities reported in most streams and rivers in temperate North America, while density in Spencer Creek was comparatively high (Table 7). This abundance of invertebrates in Spencer Creek is probably one factor accounting for the high densities of fish observed during this investigation.

FISH POPULATIONS

Fish Species Composition And Relative Abundance

Twenty fish species representing 10 families were captured from Diamond Creek to Pearce Ferry (mainstem and tributaries) during this investigation (Table 8, Table A-7). Native fish species were uncommon, representing only about 13 percent of total catch. The only endangered species captured was a female humpback chub (TL=329 mm, WT=293 g) at RM 253.2. Other native species captured included flannelmouth sucker (359), bluehead sucker (56), and speckled dace (3,181). The only native species considered common was the speckled dace.

Table 6. Mean macroinvertebrate drift densities (number/100 m^3) relative to changes in flow in the Colorado River between Diamond Creek (RM 226) and Pearce Ferry (RM 286), 1992-93.

		River Stage					
		Steady		Rising		Falling	
Date		Surface	Subsurface	Surface	Subsurface	Surface	Subsurface
				1992			
Trip 1	(27 Jun)	-	-	170.3	120.0	93.9	60.7
	(29 Jun)	-	-	112.0	107.7	150.0	276.4
	(30 Jun)	-	-	58.0	110.0	-	-
Trip 2	(28 Sep)	94.2	52.6	5.7	27.1	-	-
	(2 Oct)	-	-	2.0	2.8	-	-
	(4 Oct)	-	-	-	-	25.2	26.6
	(5 Oct)	-	-	26.0	17.3	-	-
Trip 3	(2 Dec)	-	-	22.0	30.0	-	-
	(5 Dec)	-	-	10.5	13.3	10.0	14.0
	(8 Dec)	9.3	2.7	6.0	6.0	-	-
1992 Average		**51.8**	**27.7**	**45.8**	**48.2**	**69.8**	**94.4**
				1993			
Trip 4	(28 Mar)	-	-	105.0	106.0	-	-
	(2 Apr)	41.3	34.5	-	-	-	-
Trip 5	(29 May)	-	-	-	-	93.0	167.3
	(1 Jun)	64.0	222.3	-	-	-	-
Trip 6	(4 Oct)	-	-	-	-	-	391.5
	(7 Oct)	-	-	-	331.3	-	-
Trip 7	(8 Dec)	-	203.2	-	-	-	-
1993 Average		**52.7**	**153.3**	**105.0**	**218.7**	**93.0**	**279.4**
Grand Average		**52.2**	**103.1**	**51.8**	**79.2**	**74.4**	**156.1**

Table 7. Maximum drift densities (number/100 m^3) from regulated and unregulated rivers in North America and Great Britain.

Drift Density	Reference
Regulated	
110	Eckblad et al (1984) - Mississippi River
253	Brooker and Hemsworth (1978) - Great Britain
362	Valdez (1994) - Colorado River, Grand Canyon
993	Perry and Perry (1986) - Kooteni River
1,440	Armitage (1977) - Great Britain
157,620	Perry and Perry (1986) - Flathead River
Unregulated	
43	LaPerriere (1983) - Alaska
49	Cowell and Carew (1976) - Florida
160	Stoneburner and Smock (1979) - South Carolina
164	Zimmer (1976) - Skunk River, Iowa
730	Armitage (1977) - Great Britain
6,900	Minshall and Winger (1968) - Wisconsin
14,614	Valdez (1994) - Spencer Creek, Hualapai Indian Reservation, AZ

Table 8. Numbers of fish species captured from the Colorado River and tributaries, from Diamond Creek (RM 226) to below Pearce Ferry (RM 286), June 1992 - January 1995.

Species Code	Common (Scientific) Name	LAR	YOY	JUV	ADU	Total	Per %
Family:	Catostomidae (suckers)						
BH	bluehead sucker (Catostomus discobolus)	-	4	33	19	56	0.2
FM	flannelmouth sucker (C. latipinnis)	11	41	191	116	359	1.3
Family:	Centrarchidae (sunfish)						
BC	black crappie (Pomoxis nigromaculatus)	-	2	-	4	6	<0.1
BG	bluegill (Lepomis macrochirus)	-	-	33	6	39	0.1
GS	green sunfish (Lepomis cyanellus)	-	5	4	7	16	0.1
LM	largemouth bass (Micropterus salmoides)	-	7	29	15	51	0.2
Family:	Clupeidae (herringa)						
TS	threadfin shad (Dorosoma petenense)	-	-	-	320	320	1.2
Family:	Cyprinidae (minnows)						
CP	common carp (Cyprinus carpio)	-	136	124	1,476	1,736	6.3
FH	fathead minnow (Pimephales promelas)	-	15	651	3,341	4,364	15.8
GO	golden shiner (Notemigonus crysoleucas)	-	-	-	1	1	<0.1
HB	humpback chub (Gila cypha)	-	-	-	1	1	<0.1
RS	red shiner (Cyprinella lutrensis)	-	160	920	14,667	16,417	59.5
SD	speckled dace (Rhinichthys osculus)	-	13	4	2,301	3,181	11.5
Family:	Cyprinodontidae (killifishes)						
PK	plains killifish (Fundulus zebrinus)	-	1	8	128	137	0.5
Family:	Ictaluridae (catfishes, bullheads)						
BB	black bullhead (Ameiurus melas)	-	-	1	2	3	<0.1
CC	channel catfish (Ictalurus punctatus)	-	-	23	465	488	1.8
Family:	Percichthyidae (temperate basses)						
SB	striped bass (Morone saxatilis)	-	-	4	103	107	0.4
Family:	Percidae (perches)						
WE	walleye (Stizostedion vitreus)	-	-	-	2	2	<0.1
Family:	Poeciliidae (livebearers)						
GA	mosquitofish (Gambusia affinis)	-	22	28	256	306	1.1
Family:	Salmonidae (trout)						
RB	rainbow trout (Oncorhynchus mykiss)	-	-	1	8	9	<0.1
TOTALS:		**11**	**406**	**2,054**	**23,236**	**27,589**	**100**

Of 359 flannelmouth suckers, 41 were young-of-year (YOY), 191 were juveniles, and 116 were adults; 11 larvae were captured in the mainstem at RM 246.0, about 100 m upstream of the Spencer Creek inflow. Speckled dace captured included 13 YOY, 4 juveniles, and 2,301 adults, and bluehead suckers included 4 YOY, 33 juveniles, and 19 adults. The humpback chub captured at RM 253.2 was an adult.

During this study, a total of 106 native fish were PIT-tagged, including 96 flannelmouth sucker, 19 bluehead suckers, and 1 humpback chub (Table A-8). Eight flannelmouth suckers were recaptured including three that were tagged by other investigations. Of the five fish originally marked and recaptured in this study, four were captured within 0.5 miles of their original release location and one moved 25.1 miles downstream in 7 months.

Nonnative species accounted for about 87 percent of the fish collected during the study (Table 8). The most abundant species in the region was the red shiner (60%), followed by fathead minnow (16%). Common carp, channel catfish, and striped bass were the predominant large species captured throughout the region. All life-stages of carp were encountered, including 136 YOY, 124 juveniles, and 1,476 adults. Of 107 striped bass captured, 103 were classified as adults and 4 were juveniles, and of 488 channel catfish, 23 were juveniles and 465 were adults.

Striped bass and carp were found in large numbers in spring in the Lake Mead inflow indicating a seasonal movement from the lake. Red shiners were common along the shorelines of the inflow below Bridge Canyon, and abundant in lower reaches of tributaries.

Several channel catfish captured near Spencer Canyon had tapeworms protruding from their anal vent. Internal examination revealed large masses of tapeworms in the lower intestine that were tentatively identified as the "catfish tapeworm" (Bothriocephalus claviceps). The "Asian tapeworm" (Bothriocephalus acheilognathi) has been reported in humpback chub from the Little Colorado River (Angradi et al. 1992, Valdez and Ryel 1995), but this parasite was not identified from any fish in this study of lower Grand Canyon.

Mainstem Colorado River

Dramatically fewer fish were found in the mainstem Colorado River than in the tributaries of Region IV. Although red shiners dominated both systems, densities in the mainstem were dramatically lower (Table 9), particularly away from tributary inflows. Carp and channel catfish were common throughout the area, but small numbers of subadults may reflect low reproductive success in the area or perhaps gear selectivity. Lake species such as largemouth bass, crappie, bluegill, and walleye were small in number, and found primarily in lower reaches, while striped bass and threadfin shad were more numerous in spring and summer.

Table 9. Numbers of fish species captured by species and trip from the mainstem Colorado River, from Diamond Creek (RM 226) to below Pearce Ferry (RM 286) June 1992-January 1995.

Family Code - Common Name	1992			1993				1994			1995		
	Trip 1	Trip 2	Trip 3	Trip 4	Trip 5	Trip 6	Trip 7	Trip 8	Trip 9	Trip 10	Trip 11	Total	Per %
Family: Suckers													
BH - bluehead sucker	-	-	-	-	-	1	-	1	-	1	1	4	<0.1
FM - flannelmouth sucker	2	30	6	3	10	7	5	3	9	16	4	95	1.2
Family: Sunfish													
BC - black crappie	1	1	-	-	-	1	2	1	-	-	-	6	0.1
BG - bluegill	-	37	-	-	1	1	-	-	-	-	-	39	0.5
GS - green sunfish	-	1	-	2	4	-	-	-	-	-	-	7	0.1
LM - largemouth bass	1	22	-	-	3	-	9	4	5	-	-	44	0.5
Family: Herrings													
TS - threadfin shad	13	297	-	-	4	-	6	-	-	-	-	320	4.0
Family: Minnows													
CP - common carp	86	150	79	362	247	25	22	63	62	202	48	1,346	16.8
FH - fathead minnow	-	170	4	-	10	8	26	16	1	41	16	292	3.6
GO - golden shiner	-	-	-	-	-	-	-	1	-	-	-	1	<0.1
HB - humpback chub	-	-	-	-	-	1	-	-	-	-	-	1	<0.1
RS - red shiner	86	1128	137	103	696	42	72	104	8	1,680	937	4,993	62.3
SD - speckled dace	1	35	-	-	8	7	3	5	1	92	-	152	1.9
Family: Killifishes													
PK - plains killifish	-	1	-	-	-	-	4	-	-	-	-	5	0.1
Family: Catfishes													
BB - black bullhead	2	-	-	-	-	-	-	-	-	-	-	2	<0.1
CC - channel catfish	44	20	21	37	119	8	7	14	41	35	19	365	4.6
Family: Temperate basses													
SB - striped bass	11	-	3	3	42	2	4	22	13	3	-	103	1.3

Table 9. Continued.

Family Code - Common Name	1992			1993				1994			1995		
	Trip 1	Trip 2	Trip 3	Trip 4	Trip 5	Trip 6	Trip 7	Trip 8	Trip 9	Trip 10	Trip 11	Total	Per %
Family: perches													
WE - walleye	1	-	1	-	-	-	-	-	-	-	-	2	<0.1
Family: live bearers													
GA - mosquitofish	26	40	2	-	105	4	-	1	-	51	2	231	2.9
Family: trout													
RB - rainbow trout	-	-	-	-	3	-	-	1	-	-	-	4	<0.1
Total	**274**	**1932**	**253**	**510**	**1252**	**107**	**160**	**236**	**140**	**2,121**	**1,026**	**8,012**	**100**

Tributaries

Although only 12 of 20 fish species identified in Region IV were found in tributaries, far greater densities of especially small fishes were present (Table 10). While red shiners dominated species composition of all tributaries downstream of Bridge Canyon, composition of other species varied with habitat quality. Greater overall numbers of fishes, including native species, were found in better quality streams (Spencer Creek and Surprise Creek), while lower numbers of fishes and no natives were found in Lost Creek and Quartermaster Creek. Young flannelmouth suckers and speckled dace in Spencer Creek and Surprise Creek indicates successful reproduction in these tributaries. The monospecific ichthyofauna of Diamond Creek and Travertine Creek was notable, and is believed to be related to the steep narrow river subreach between Diamond Creek and Bridge Creek, which is an apparent impediment to upstream movement of some fishes from Lake Mead (See Fish Species Distribution).

Fish Species Distribution

Mainstem Colorado River

The ichthyofauna of the Colorado River changed dramatically downstream of Bridge Canyon (RM 235), for reasons that were not entirely clear. Number of species increased from 11 to 18, and densities of nonnatives increased dramatically (Table 11). Red shiners were markedly absent above Bridge Canyon Rapid, but abundant downstream of this point, while density of speckled dace followed an inverse pattern (Figure 6). Sediment deposits downstream of Bridge Canyon, combined with the impounding effect and a large fish source from Lake Mead, have dramatically altered the riverine ecosystem through ameliorated channel gradient, sedimented mainstem habitats, and entrained nutrients. These changes have apparently favored nonnative species. Moreover, the steep channel from Diamond Creek to Bridge Canyon appears unsuitably swift and depauperate of food for upstream invasion by nonnative cyprinids, such as red shiners and fathead minnows. These species appear to have populated the Lake Mead Inflow by dispersing from tributary population centers, a strategy than may be impeded by swift currents upstream of Bridge Canyon.

Distribution of fish by the four sample strata (Figure 7) further shows the dramatic shift in species composition at Bridge Canyon. While carp are abundant throughout the region, adults account for a greater percentage of the fish composition above Bridge Canyon, demonstrating the diversity of carp for habitat selection. Species composition in Strata IV-b and IV-c, downstream of Bridge Canyon was similar, with red shiner and carp dominant, while composition in Stratum IV-d showed a high percentage of threadfin shad, a lake-dwelling species.

Table 10. Numbers[1] of fish species captured by species and trip in tributaries of the Colorado River, from Diamond Creek (RM 226) to below Pearce Ferry (RM 286) June 1992-January 1995.

Tributary (River Mile) Code - Common Name	1992			1993				1994			1995	
	Trip 1	Trip 2	Trip 3	Trip 4	Trip 5	Trip 6	Trip 7	Trip 8	Trip 9	Trip 10	Trip 11	Total
Diamond Creek (RM 225.7)												
SD - speckled dace	-	-	-	-	-	1	34	22	7	5	-	**69**
PK - plains killifish	-	-	-	-	-	0	0	1	0	0	-	**1**
Travertine Falls (RM 230.4)												
SD - speckled dace	-	-	-	-	-	5	-	-	-	-	-	**5**
Spencer Creek (RM 246.0)												
RS - red shiner	491	35	105	64	151	1,727	1,039	620	194	219	160	**4,805**
SD - speckled dace	0	2	6	12	7	568	367	326	438	597	355	**2,678**
FH - fathead minnow	0	0	23	3	0	27	110	56	3	19	7	**248**
CP - common carp	0	0	0	30	114	4	3	9	2	2	0	**164**
PK - plains killifish	4	0	5	0	0	5	0	6	3	51	23	**97**
FM - flannelmouth sucker	12	3	0	1	8	45	3	5	5	1	0	**83**
CC - channel catfish	0	0	0	5	55	0	0	1	9	0	0	**70**
GS - green sunfish	0	0	0	0	0	0	0	1	0	2	0	**3**
LM - largemouth bass	0	0	0	0	0	0	0	2	0	0	0	**2**
SB - striped bass	0	0	0	0	0	0	0	2	0	0	0	**2**
BH - bluehead sucker	0	0	0	0	0	0	0	0	0	1	0	**1**
RB - rainbow trout	0	0	0	1	0	0	0	0	0	0	0	**1**
Surprise Creek (RM 248.4)												
RS - red shiner	701	60	647	38	388	1164	1872	171	704	624	-	**6,369**
FH - fathead minnow	1571	33	459	22	17	152	727	176	109	505	-	**3,771**
CP - common carp	10	21	41	2	1	0	0	4	32	0	-	**111**
PK - plains killifish	2	0	8	0	12	7	0	2	0	1	-	**32**
FM - flannelmouth sucker	2	0	8	0	12	1	0	0	8	1	-	**32**
GA - mosquitofish	0	0	24	0	0	0	0	0	0	0	-	**24**
SD - speckled dace	0	0	3	1	0	8	3	0	0	1	-	**22**

Table 10. Continued.

Tributary (River Mile) Code - Common Name	1992			1993				1994			1995	
	Trip 1	Trip 2	Trip 3	Trip 4	Trip 5	Trip 6	Trip 7	Trip 8	Trip 9	Trip 10	Trip 11	Total
GS - green sunfish	0	0	2	0	0	0	0	0	1	3	-	**6**
BB - black bullhead								0	1	0	-	**1**
Lost Creek (RM 248.9)												
RS - red shiner	29	1	-	24	1	-	-	-	1	25	-	**81**
CP - common carp	23	1	-	14	-	-	-	-	2	0	-	**40**
FH - fathead minnow	1	0	-	0	0	-	-	-	0	10	-	**11**
CC - channel catfish	1	1	-	4	0	-	-	-	1	0	-	**7**
GA - mosquitofish	5	0	-	0	0	-	-	-	0	1	-	**6**
LM - largemouth bass	3	0	-	0	0	-	-	-	0	0	-	**3**
SB - striped bass	2	0	-	0	0	-	-	-	0	0	-	**2**
Quartermaster Creek (RM 259.8)												
RS - red shiner	167	2	-	-	-	-	-	0	0	-	-	**169**
GA - mosquitofish	45	0	-	-	-	-	-	0	0	-	-	**45**
CC - channel catfish								0	22	-	-	**22**
LM - largemouth bass	2	0	-	-	-	-	-	0	0	-	-	**2**
PK - plains killifish	1	0	-	-	-	-	-	0	0	-	-	**1**
Total	**3,070**	**159**	**1,346**	**221**	**755**	**3,711**	**4,159**	**1,410**	**1,542**	**2,068**	**545**	**18,986**

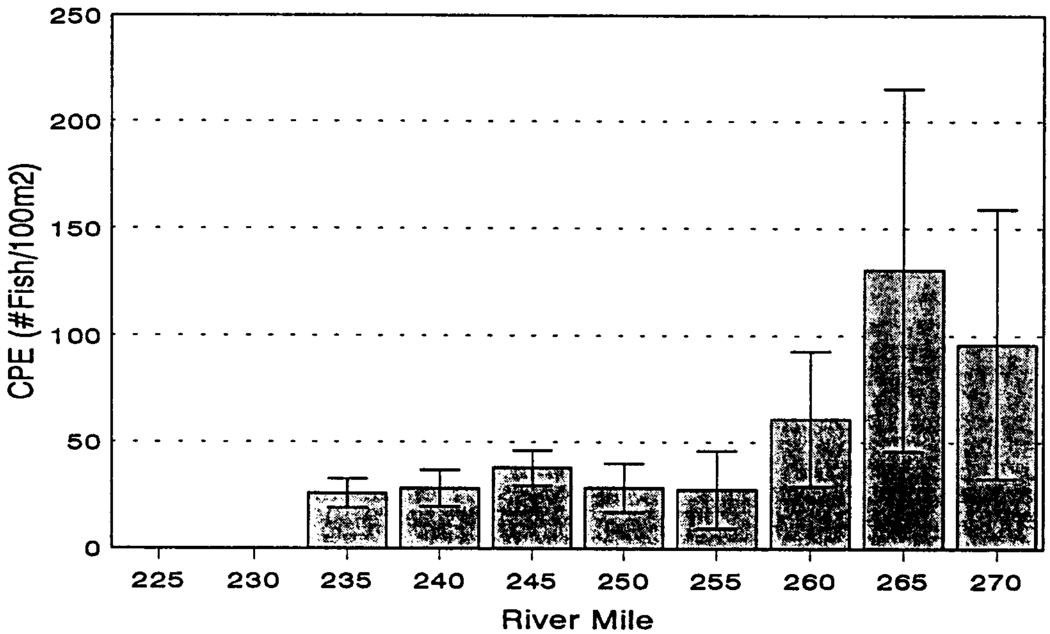
[1]Dashes (-) indicate that tributary was not sampled during trip.

Table 11. Numbers and percentages (in parentheses) of fish species by sample strata in the mainstem Colorado River from National Canyon (RM 165) to Pearce Ferry (RM 286), June 1992-January 1995.

Strata[b] (River Mile)	Fish Species Codes[a]																				
	BH	FM	BC	BG	GS	LM	TS	CP	FH	GO	HB	RS	SD	PK	BB	CC	SB	WE	GA	RB	TOTAL
165.0-169.9																					0 (-)
170.0-179.4	13 (15)	39 (46)						3 (4)	10 (12)				18 (21)							2 (2)	85 (100)
179.5-189.1	13 (9)	32 (23)						48 (35)	5 (4)				26 (19)			12 (9)				2 (1)	138 (100)
189.2-200.0	18 (10)	21 (11)							1 (1)				143 (78)								183 (100)
200.1-208.9	6 (4)	37 (27)						22 (16)	25 (18)				40 (30)	1 (1)		5 (4)					136 (100)
209.0-213.9		2 (8)											18 (69)			6 (23)					26 (100)
214.0-225.0	1 (4)	8 (35)						2 (9)	1 (4)				10 (44)			1 (4)					23 (100)
225.1-235.0	3 (1)	19 (3)						397 (72)	6 (1)				60 (11)			59 (11)	4 (1)				548 (100)
235.1-259.0	1 (<1)	36 (1)	1 (<1)			8 (<1)	14 (<1)	450 (11)	87 (2)	1 (<1)	1 (<1)	3219 (78)	51 (1)	4 (<1)		195 (5)	41 (1)	2 (<1)	23 (1)		4134 (100)
259.1-275.0		40 (2)	1 (<1)		6 (<1)	4 (<1)	8 (<1)	333 (13)	198 (8)			1570 (63)	41 (2)	1 (<1)		79 (3)	43 (2)		175 (7)	4 (<1)	2503 (100)
275.1-286.0			4 (<1)	39 (5)	1 (<1)	32 (4)	298 (36)	166 (20)	1 (<1)			204 (25)			2 (<1)	32 (4)	15 (2)		33 (4)		827 (100)
TOTALS	**55 (1)**	**234 (3)**	**6 (<1)**	**39 (<1)**	**7 (<1)**	**44 (1)**	**320 (4)**	**1421 (16)**	**334 (4)**	**1 (<1)**	**1 (<1)**	**4993 (58)**	**407 (5)**	**6 (<1)**	**2 (<1)**	**389 (4)**	**103 (1)**	**2 (<1)**	**231 (3)**	**8 (<1)**	**8603 (100)**

[a]See total fish species captured table for fish species codes.
[b]Data from the first seven strata are pooled numbers of fish captured from November 1990-November 1993.
[c]BR = brown trout (Salmo trutta)

A



B

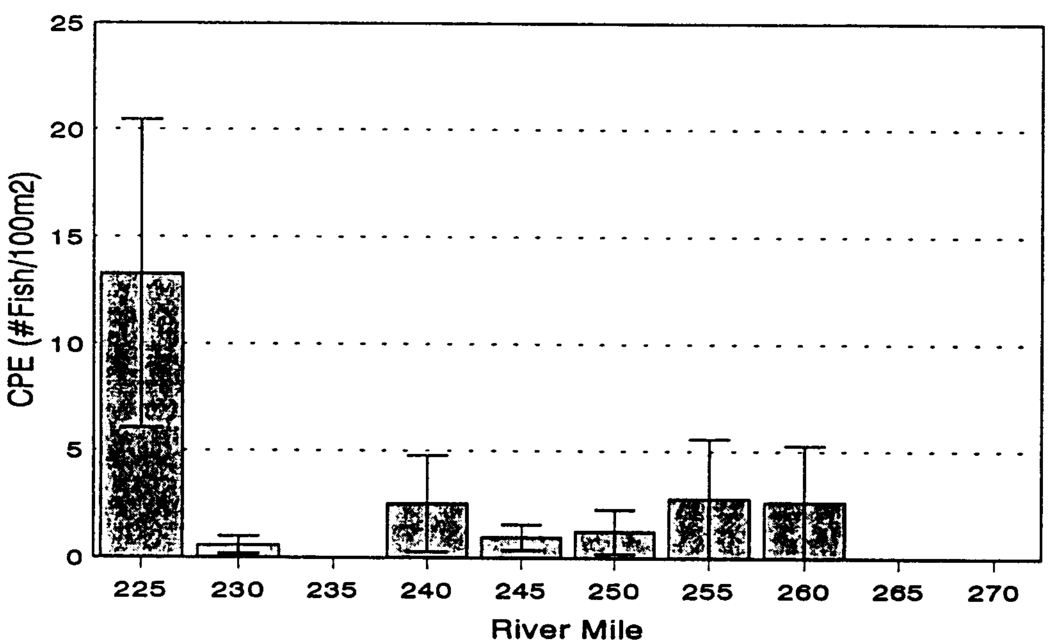


Figure 6. Longitudinal distribution of red shiners (A), and speckled dace (B) from Diamond Creek (RM 225) to Grand Wash Cliffs (RM 275). Arithmetic mean catch-per-effort (CPE) for seine samples.

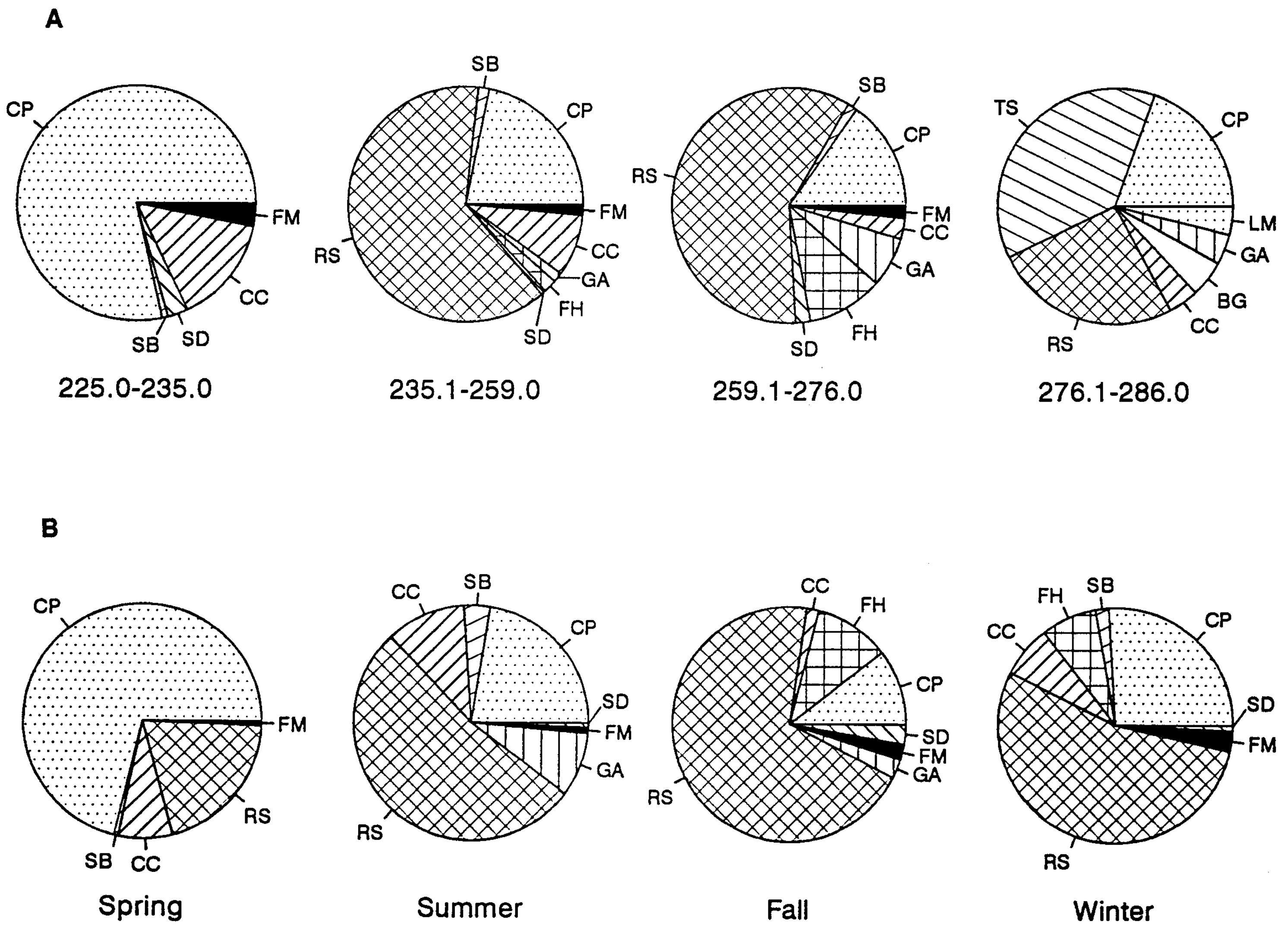


Figure 7. Composition of fish by sample strata (A) and by season (B) for the Colorado River from Diamond Creek to Pearce Ferry, 1992-95.

Only three species (flannelmouth sucker, channel catfish, and carp) were found in all sampling substrata. As expected, the abundance of lentic species, primarily centrarchids and threadfin shad, increased with proximity to Lake Mead. Although red shiner dominated the mainstem ichthyofauna, they were found only downstream of Bridge Canyon Rapid (RM 235.2) during this investigation. From that point downstream, red shiner accounted for 54 percent of the fish captured in the mainstem. The same pattern was observed for fathead minnow. Only native species (flannelmouth sucker, bluehead sucker, speckled dace) or large, highly mobile species (striped bass, channel catfish, common carp) were captured above Bridge Canyon Rapid.

Catch-per-effort calculations based on netting and electrofishing suggest that channel catfish abundance decreased with distance from Lake Mead. This pattern was attributed to a large number of catfish captured during May-June 1993 (Trip 5) (Table 9), while fewer fish were found on subsequent trips. Increased occurrence of carp and channel catfish in the mainstem and Spencer Creek (See Tributaries) suggests immigration of these species into the inflow. The catch rate of striped bass indicates greater abundance toward the lake, while the catch rate of flannelmouth sucker decreased downstream. Lengths and weights of some carp, flannelmouth suckers, striped bass, and channel catfish from the mainstem and tributaries are presented in Table A-9).

The ichthyofauna of the mainstem was similar from National Canyon (RM 165) to Bridge Canyon (RM 235) for the period 1992-94 (Table 11). Native species accounted for a greater proportion of the fish community, particularly upstream of Diamond Creek, where numerous flannelmouth suckers and bluehead suckers were caught. Also, three humpback chub were reported between National Canyon and Diamond Creek, and except for carp and local aggregations of fathead minnows, nonnative species were largely absent.

Recent investigations summarized by Valdez and Ryel (1995) for Region III, from Havasu Creek (RM 156.7) to Diamond Creek (RM 225.7), show a preponderance of carp (32% by number), speckled dace (19%), flannelmouth sucker (18%), and bluehead sucker (15%). This region also yielded 14 humpback chub (2 juveniles, 12 adults; 0.5% by number), and despite the warm temperature, 183 rainbow trout were captured (7%). Hence the Colorado River in Region III has one of the highest compositions of native fishes in Grand Canyon and may be a potential area of recovery for flannelmouth suckers and bluehead suckers, and possibly razorback suckers and humpback chub.

Tributaries

Fish abundance and species composition varied greatly among tributaries (Table 10, Figure 8). Tributaries above Bridge Canyon Rapid (i.e., Diamond Creek and Travertine Creek) contained only speckled dace, while downstream tributaries (i.e., Spencer Creek, Surprise Creek, Lost Creek, Quartermaster Creek) were dominated by nonnative species. Red shiners accounted for more than 50 percent of the fish captured in all downstream

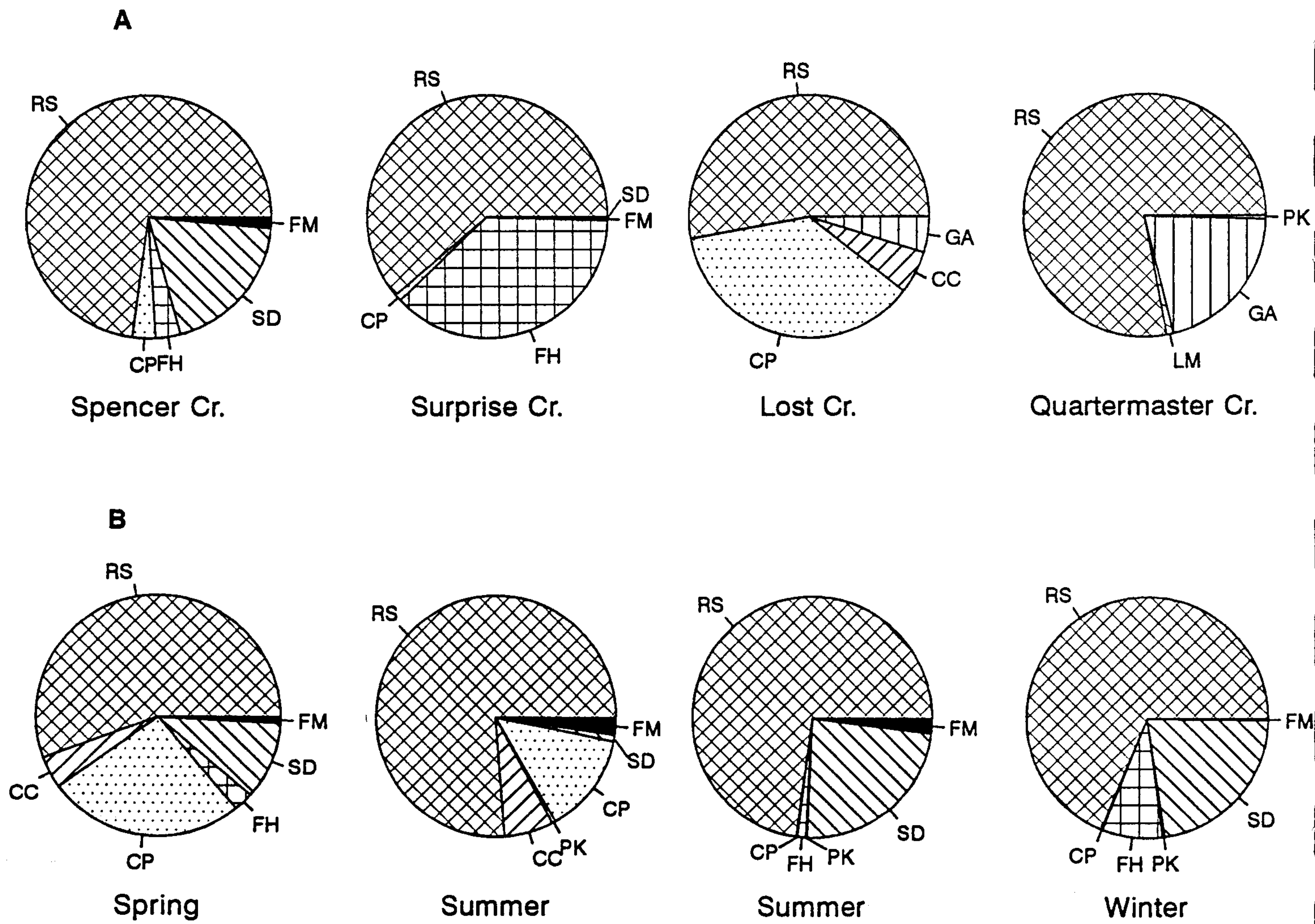


Figure 8. Composition of fish by tributaries (A) and by season within Spencer Creek (B), 1992-93.

tributaries. Native species were also found in these tributaries, although in relatively small numbers. The most common were speckled dace comprising 33 percent of the fish in Spencer Creek. Of 359 flannelmouth suckers captured in Region IV, 115 (31 YOY, 68 juveniles) were found in tributaries, including Spencer Creek (83) and Surprise Creek (32). This indicates that this native species is reproducing in this region, probably in tributaries.

Surprise Creek contained a greater proportion of nonnative species than Spencer Creek; red shiner and fathead minnow accounted for 98 percent of the fish captured in Surprise Creek. Much of the observed difference in fish species composition was a reflection of habitat differences between these two streams. Spencer Creek was a high-gradient, riffle-dominated system suitable to stream dwellers like speckled dace. Conversely, Surprise Creek was composed of large quiescent pools interspersed with shallow runs, habitat more suitable to low-gradient species such as red shiners. Native species were not encountered in Lost Creek or Quartermaster Canyon, probably because habitat in those streams favored nonnative species.

Fish encountered in tributaries were generally smaller than the same species in the mainstem (Table A-9). Mean lengths of channel catfish, striped bass, and flannelmouth suckers in tributaries were less than in the mainstem, while carp tended to be larger in tributaries.

Fish population estimates in Spencer Creek showed variation in density by area and season (Tables 12, 13, 14). Density of red shiner and speckled dace at Site 1 (immediately above the inflow) increased dramatically from May to October and December (Figure 9). In contrast, carp, channel catfish, and flannelmouth sucker were captured in May but not in October and December. A more detailed breakdown of population estimates at Site 1 is presented in Table 12.

Population estimates at the upstream site, Site 2 (0.75 miles upstream), in October and December showed similar results (Figure 9, Table 13); fish abundance was high in October and declined slightly by December. Fish densities were greater at Site 2 than Site 1, and flannelmouth sucker and fathead minnow, not encountered at Site 1 in October, were present upstream. Although no population estimate was conducted at Site 2 in May, a single electrofishing pass produced large numbers of carp and channel catfish, and relatively low numbers of red shiner and speckled dace.

Observed changes in the fish assemblage of Spencer Creek were probably related to a number of factors. Changes in abundance of larger species like carp and channel catfish were probably behavioral, and the result of seasonal immigration for spawning and feeding; carp in May were ripe adults. Changes in the abundance of smaller species may have been related to flash-flood activity that occurred in winter of 1992, and scoured much of the channel and riparian vegetation in Spencer Creek. Flooding apparently displaced smaller species into the mainstem, accounting for low numbers in May, followed by reinvasion in summer and higher densities in October.

Table 12. Results of multiple pass removal, maximum likelihood estimator in Spencer Creek near confluence with Colorado River, May 1993-January 1995.

Fish species	Number captured	Percent of sample	Population estimate (95% CI)	Estimated number/100 m²	Mean length (mm) (S.D.)
			May 1993		
Common carp	58	63	59 (58-62)	22	403 (93)
Red shiner	20	22	24 (20-35)	9	64 (10)
Speckled dace	5	5	5 (5-7)	2	55 (9)
Flannelmouth sucker	5	5	6 (5-15)	2	80 (26)
Channel catfish	5	5	5 (5-7)	2	301 (79)
Total	93	100	100 (93-109)	37	-
			October 1993		
Speckled dace	92	47	122 (92-157)	78	57 (7)
Red shiner	104	53	104 (104-106)	67	55 (8)
Total	196	100	209 (197-221)	145	-
			December 1993		
Red shiner	71	45	122 (71-202)	81	44 (10)
Speckled dace	64	41	82 (64-107)	55	62 (8)
Fathead minnow	22	14	29 (22-47)	19	46 (11)
Total	157	100	235 (162-308)	157	-
			April 1994		
Red shiner	43	53	48 (43-57)	38	-
Speckled dace	38	47	42 (38-50)	33	68 (10)
Total	81	100	91 (81-104)	71	-
			May 1994		
Red shiner	53	50	59 (53-69)	46	-
Speckled dace	50	48	-[a]	-	58 (15)
Plains killifish	2	2	2 (2-2)	2	65 (4)
Total	105	100	152 (105-205)	-	-
			October 1994		
Red shiner	74	77	77 (74-82)	42	-
Speckled dace	13	14	14 (13-19)	8	56 (13)
Fathead minnow	7	7	7 (7-7)	4	58 (3)
Flannelmouth sucker	1	1	1 (1-1)	1	42
Plains killifish	1	1	1 (1-1)	1	41
Total	96	100	101 (96-108)	55	-
			January 1995		
Red shiner	139	85	139 (139-140)	36	-
Speckled dace	10	6	10 (10-11)	3	64 (15)
Plains killifish	14	1	14 (14-16)	4	-
Fathead minnow	1	8	1 (1-1)	<1	-
Total	164	164	164 (164-166)	42	-

[a]Non-descending removal pattern, no population estimate computed.

Table 13. Results of multiple pass removal, maximum likelihood estimator in Spencer Creek approximately 0.9 km above confluence with Colorado River, October 1993-January 1995.

Fish species	Number captured	Percent of sample	Population estimate (95% CI)	Estimated number/100 m^2	Mean length (mm) (S.D.)
			October 1993		
Red shiner	1042	77	1100 (1077-1123)	224	59 (8)
Speckled dace	251	18	260 (252-268)	53	62 (7)
Fathead minnow	25	2	25 (25-25)	5	59 (7)
Flannelmouth sucker	34	3	34 (34-34)	7	123 (24)
Common carp	4	<1	4 (4-6)	1	389 (159)
Total	1356	100	1418 (1395-1441)	289	-
			December 1993		
Red shiner	637	86	647 (639-655)	132	47 (12)
Speckled dace	91	12	161 (91-261)	33	70 (6)
Fathead minnow	4	1	4 (4-4)	1	47 (12)
Flannelmouth sucker	3	<1	5 (3-32)	<1	160 (33)
Common carp	3	<1	3 (3-3)	<1	499 (30)
Total	738	100	760 (747-773)	155	-
			April 1994		
Red shiner	305	72	367 (329-405)	87	-
Speckled dace	68	16	76 (68-87)	18	74 (28)
Fathead minnow	33	8	33 (33-33)	8	-
Flannelmouth sucker	5	1	5 (5-7)	1	183 (21)
Common carp	9	2	9 (9-10)	2	409 (94)
Largemouth bass	2	1	2 (2-7)	<1	209 (11)
Channel catfish	1	<1	1 (1-1)	<1	348
Total	423	100	480 (450-510)	113	-
			May 1994		
Red shiner	55	35	56 (55-59)	13	-
Speckled dace	91	58	95 (91-101)	22	71 (17)
Flannelmouth sucker	4	3	4 (4-4)	1	279 (114)
Common carp	2	1	2 (2-2)	<1	469 (8)
Channel catfish	5	3	5 (5-5)	1	343 (24)
Total	157	100	162 (157-168)	37	-
			October 1994		
Red shiner	44	19	50 (44-61)	38	-
Speckled dace	186	80	239 (197-281)	181	61 (14)
Fathead minnow	1	<1	1 (1-1)	1	60
Plains killifish	1	<1	1 (1-1)	1	51
Bluehead sucker	1	<1	1 (1-1)	1	235
Total	233	100	294 (251-337)	223	-
			January 1995		
Speckled dace	46	100	50 (46-58)	40	69 (15)
Total	46	100	50 (46-58)	40	-

Table 14. Results of multiple pass removal, maximum likelihood estimator in Spencer Creek approximately 1.3-2.0 km above confluence with Colorado River, April 1994-January 1995.

Fish species	Number captured	Percent of sample	Population estimate (95% CI)	Estimated number/100 m^2	Mean length (mm) (S.D.)
			April 1994		
Speckled dace	207	100	-[a]	-	83 (9)
			May 1994		
Speckled dace	158	100	234 (163-305)	72	66 (23)
			October 1994		
Speckled dace	309	100	350 (324-376)	230	67 (18)
			January 1995		
Speckled dace	276	100	322 (289-354)	239	68 (18)

[a]Non-descending removal pattern, no population estimate computed.

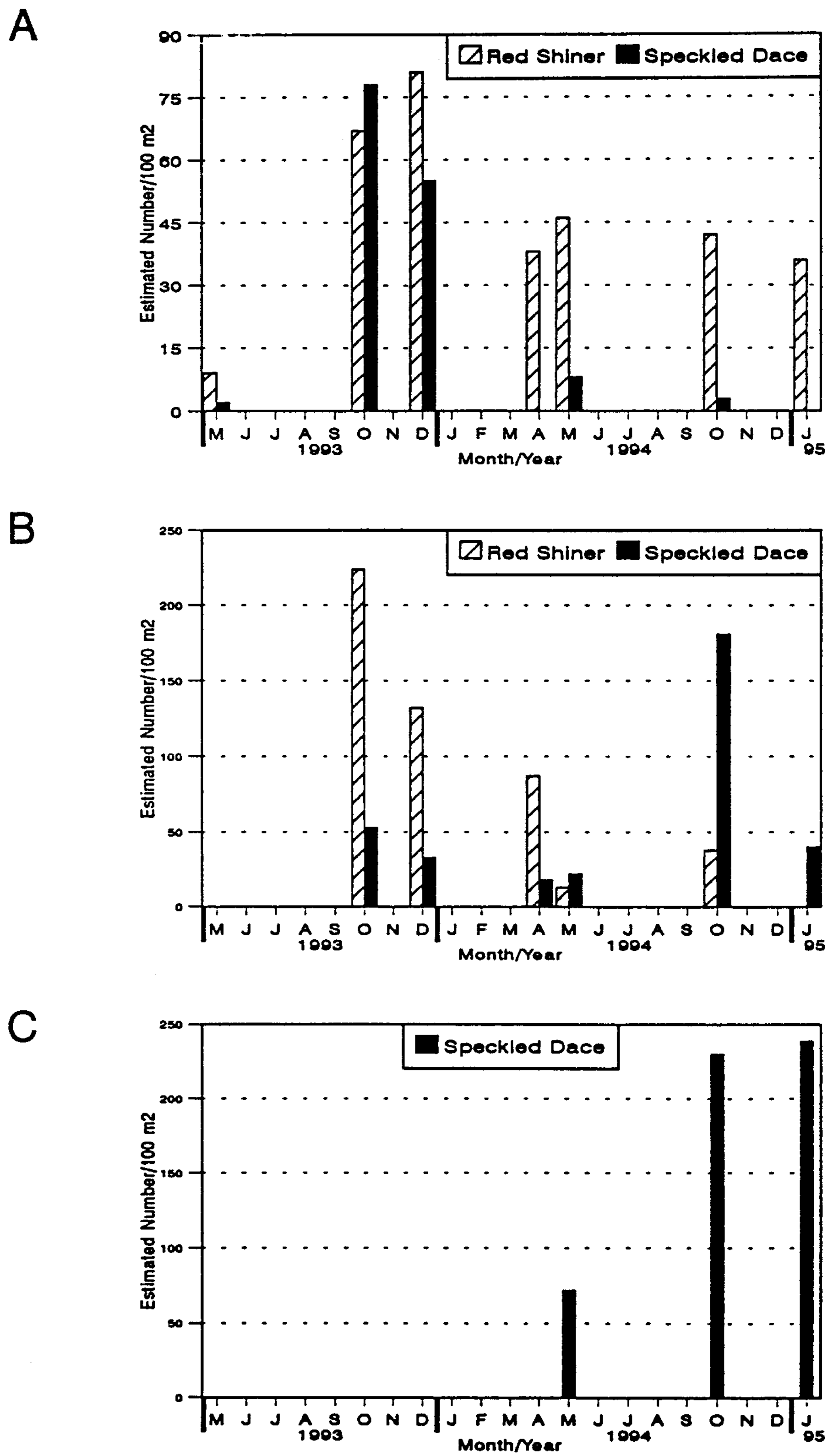


Figure 9. Monthly fish density estimates for Site 1 (Confluence - A), Site 2 (0.9 km upstream - B), and Site 3 (1.3-2.0 km upstream - C) in Spencer Canyon, 1993. Estimates from 3-pass maximum likelihood estimator. See Table 8 for fish species codes.

Longitudinal distribution of fish in Spencer Creek showed the presence of a possible fish barrier at a series of falls about 2 miles from the outflow. Although nonnative species were common in lower Spencer Creek, only speckled dace were found further upstream (Figure 10). The potential barrier consisted of a series of water falls, with one deep, high-velocity (>6 ft/s) chute formed at a channel constriction.

Efficiency Of Sampling Gear

Boat-electrofishing and trammel nets were most effective in the mainstem Colorado River on juveniles and adults of large and medium-size species, such as carp, channel catfish, striped bass, and largemouth bass (Table A-7). Boat-electrofishing was also effective at capturing small fishes such as red shiners, fathead minnows, and mosquitofish along shorelines. Hoop nets had limited success on large and medium size fish in side channels and tributary mouths. Seines were effective at capturing small fish in shallow shoreline habitats, and seines, backpack electrofishing, and minnow traps were all effective in tributaries. Angling with live bait proved to be an effective method for catching striped bass and channel catfish in the mainstem.

DISCUSSION

The Hualapai Indian Reservation is bound on the north by 109 miles of the Colorado River in Grand Canyon, from RM 164.5 (near National Canyon) to RM 273.5 (near Emery Falls Canyon). This is the lowermost third of approximately 300 miles of river between Glen Canyon Dam and Lake Mead. This region of river supports significant aquatic resources, with potential areas for recovery of native fishes that may be enhanced by dam operations (e.g., Spencer Creek for young razorback suckers that could reside as adults in the Lake Mead inflow).

The Colorado River, from National Canyon to Diamond Creek, is part of the lowermost reach of flowing river in lower Grand Canyon. The distance from the dam allows this region to warm to about 15°C to 17°C in summer, making it suitable for reproduction and nurseries for warmwater native fishes. While this region of the Colorado River has numerous native fishes, there appear to be factors that limit populations. These limiting factors appear to be related to low primary and secondary production and hence, to food availability.

The Colorado River, from Diamond Creek to Pearce Ferry, is the most dynamic reach of river between Glen Canyon Dam and Lake Mead. It represents the transition between the relatively steep gradient of Grand Canyon and the sediment-filled channel inundated by Lake Mead. At maximum lake elevation (1,221 ft MSL), the Colorado River is inundated as far upstream as RM 235.5 (base of Bridge Canyon Rapid), or about 82% of the 54 miles from Diamond Creek to Pearce Ferry. Recent minimum lake elevation is approximately 1,157 ft MSL, which backs the lake to about Maxson Canyon (RM 252.5). While cold hypolimnetic releases from Glen Canyon

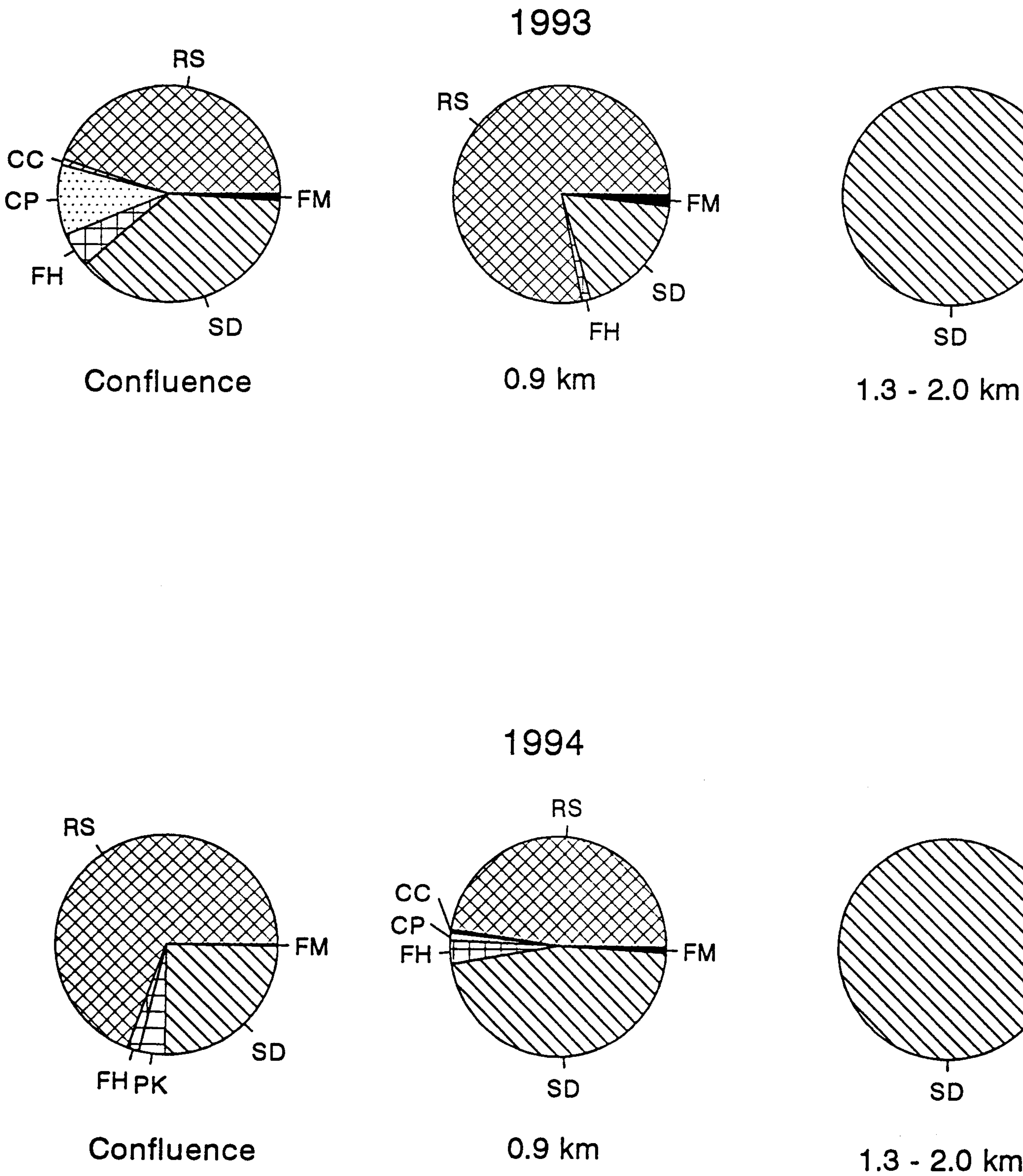


Figure 10. Percent species composition at three locations in Spencer Canyon, based on maximum likelihood estimates at Sites 1 (inflow) and 2 (0.75 mi) and seining upstream of 1.25 mi. See Table 8 for fish species codes.

Dam have limited invertebrate production throughout Grand Canyon, the channel downstream of Bridge Canyon is filled with sediment deposits and lined with riparian vegetation within increased densities of macroinvertebrates. Varying seasonal and annual inundation of this lower reach of Grand Canyon enhances biological, physical, and chemical dynamics and may sometimes result in high levels of productivity from nutrient deposits and upwellings. This dynamic nature greatly complicates an objective evaluation of the effects of interim flows from Glen Canyon Dam on aquatic resources because measured variables, such as fish species composition and abundance, macroinvertebrate densities, and water quality parameters may change dramatically in response to Lake Mead elevation and not necessarily to interim flows. The dynamic nature of the area needs to be better understood in order to isolate the effects of variables such as flow magnitude and ramping rates.

Although the Diamond Creek inflow is 240 miles downstream of Glen Canyon Dam, magnitude and patterns of release from the dam directly and indirectly affect aquatic resources. Flow magnitude and ramping rates--although ameliorated with distance from the dam--affect river stage that in turn affects fish habitat and depth of inflow areas. Daily maximum stage change of 60 cm (2 ft) was measured in June 1992 (~4,000 cfs change in flow), and a 3-day maximum change of 90 cm (3 ft) in October 1993 (~7,000 cfs change in flow). The magnitude of these changes is sufficient to temporarily alter habitat availability in backwaters, shallow side channels, ledge shorelines, and tributary inflows.

Releases of cold hypolimnetic water from Glen Canyon Dam also affect river temperatures in this lower reach of Grand Canyon. At an estimated maximum warming rate of about 1°C/35 miles, water released at 10°C from Glen Canyon Dam is expected to warm to about 17°C at Diamond Creek, about 240 miles downstream of the dam. Temperature measured in 1992, 1993, and 1994 confirmed this longitudinal warming effect with summer temperatures of 17°C near Diamond Creek. This temperature is within a range suitable for spawning, hatching, and rearing of all warmwater species of Colorado River fishes.

The following is a discussion of the findings of this investigation in 1993 relative to each of the five study objectives.

DISTRIBUTION, ABUNDANCE AND BEHAVIOR OF ADULT FISH

Eight species of fish were captured between National Canyon (RM 164.5) and Bridge Canyon (RM 235.0), compared to 20 species found downstream of Bridge Canyon. The marked increase in fish species (richness) and numbers per species (evenness) at Bridge Canyon was the result of high lake level sediment deposits that have dramatically altered the aquatic ecosystem. These deposits, combined with the impounding lake effect have ameliorated channel gradient, sedimented mainstem habitats, and entrained nutrients, favoring nonnative species.

Of the eight species found between National Canyon and Bridge Canyon, 46 percent of individuals were native, while only 2 percent of individuals below Bridge Canyon were native. Carp, flannelmouth sucker, and speckled dace were the main fish species above Bridge Canyon, while carp and channel catfish were the dominant large fishes in the lake inflow, increasing in numbers in the mainstem and tributaries in spring and early summer, along with striped bass and threadfin shad. Red shiners dominated small forms in the mainstem and tributaries, but were notably absent above Bridge Canyon Rapid. The steep channel from Diamond Creek to Bridge Canyon was apparently unsuitably swift and depauperate of food for upstream invasion by nonnative cyprinids, such as red shiners and fathead minnows. These species appear to have populated the Lake Mead Inflow by dispersing from tributary population centers, a strategy that may be impeded by swift currents at tributary inflows upstream of Bridge Canyon (i.e., Diamond Creek, Travertine Creek).

Adult flannelmouth suckers were found in the steep upper canyon as well as the alluvial lower portion of the area. Young flannelmouth suckers were found in tributaries below Bridge Canyon, indicating that these were used as spawning or nursery areas, or both. Only one adult humpback chub and one adult bluehead sucker were found downstream of Bridge Canyon. Speckled dace were rare in the mainstem, but numerous in tributaries.

The effect of interim flows on native fishes in Region IV could not be fully assessed because of low numbers of individuals were widely dispersed. While vertical stage changes of 40-60 cm were common, the seasonal appearance of large nonnative mainstem species in tributaries indicated unimpeded access to larger tributaries (i.e., Spencer Creek, Surprise Creek). Stage changes also temporarily altered shoreline habitat availability, but native species were too few to assess effects. Changes in elevation of Lake Mead more dramatically altered fish habitat than interim flows, by inundating or exposing vast sediment deposits and vegetated banks. Bathymetry of the river channel near Spencer Creek and Lost Creek reveals a relatively flat, sedimented bottom with few deep pools and irregularities for fish habitat. Daily summertime traffic from large, hardbottom, motorized boats shuttling rafters from Separation Canyon to Pearce Ferry generates sharp and more dramatic waves than daily flow fluctuations. These boat-generated waves erode shorelines in the narrow canyon between Separation Canyon and Emory Falls and may have a greater effect on bank stability that dam operations, or at least contribute to the problem.

Distribution, abundance, and behavior of nonnative species may also be affected by interim flows, but these have probably been determined largely by cold releases from Glen Canyon Dam. Red shiners, although abundant in tributaries (Surprise, Spencer, Lost, Quartermaster) and tributary inflows, were not found upstream of Bridge Canyon. Since water temperature increased only 1 °C in June, from Diamond Creek (RM 226.0) to Spencer Canyon (RM 246.0), it does not appear that cold water temperature restricted upstream dispersal of this species. Instead, the steeper gradient above Bridge Canyon provided few opportunities for quiet, sheltered habitat preferred by red shiners. Furthermore, the absence of deep, perennial tributary streams upstream of Separation

Canyon (RM 239.5) limits spawning and nursery opportunities provided further downstream at Surprise, Spencer, Lost, and Quartermaster canyons. Possibly, red shiner move upstream in a system like the Colorado River by establishing populations in tributaries from which individuals disperse to other potential spawning tributaries. This "tributary hopping" strategy should have enabled the red shiner to access Travertine Canyon and Diamond Creek, but the species is absent from these streams.

Upstream movement of other lake species, such as striped bass was unlikely impeded by Bridge Canyon Rapid, although far greater densities were found immediately below and increasingly downstream in spring. Striped bass from Lake Mead ascend the Colorado River in Grand Canyon in spring, presumably to spawn, and need the right combination of water temperature (15-19°C, Sublette et al. 1990 and references therein), turbidity (high turbidity is tolerated), and TDS (<1880 mg/l) to deposit demersal eggs that mature and hatch in 34-62 hr (15-21°C) as they drift back to the reservoir. Striped bass have been found as far upstream as the Little Colorado River (nearly 175 miles above Bridge Canyon), although the numbers of adults are usually small.

DISTRIBUTION, ABUNDANCE, AND BEHAVIOR OF LARVAE AND JUVENILES

The only young native fish species captured in the study area were flannelmouth suckers and speckled dace below Bridge Canyon. The majority of suckers were in tributaries, indicating that either the fish were spawned, hatched, and reared in these streams, or moved into these streams from nearby mainstem spawning sites. Mainstem temperatures appear suitably warm (>16°C) for spawning by native suckers. Young speckled dace were similarly found primarily in tributaries. Small numbers of flannelmouth sucker larvae found in the mainstem above Spencer Creek suggests mainstem spawning by this native species, possibly on cobble bars found in the area. Further sampling in the mainstem is needed during warm months to determine the extent of mainstem spawning by native species.

Young of red shiners, fathead minnows, plains killifish, and mosquitofish were common to abundant in tributaries and tributary inflows below Bridge Canyon. Most reproduction by these species appears to occur in the tributaries and individuals disperse into the mainstem. This inflow area appears to be a large source of nonnative cyprinids to upper Lake Mead, and appears to provide a principal source of forage for striped bass and channel catfish migrating into the area in spring.

Estimates of fish and macroinvertebrate densities in Spencer Creek reveal a very productive stream, and only native speckled dace above a natural upstream fish barrier 2 miles above the outflow. Speckled dace in the lower 2 miles have been largely displaced by red shiners, which could be preying on young flannelmouth suckers hatched in this tributary. The area above the falls may be a suitable release site for young razorback suckers, because of the absence of nonnative predators, and the presence of suitable habitat and food.

REPRODUCTION, FOOD HABITS, AND HABITAT USE

Flannelmouth suckers appear to be spawning in Spencer Creek and Surprise Creek, as indicated by the presence of young suckers in those tributaries. Carcasses of adult flannelmouth suckers were found in 1992 and 1993 in Spencer Creek, indicating recent spawning. Although mainstem spawning by warmwater native species is restricted throughout Grand Canyon by cold hypolimnetic releases, the Colorado River between Diamond Creek and Pearce Ferry is the warmest, and possibly most suitable for spawning by native species. Longitudinal warming in summer allows the river to reach temperatures of 16-18 °C between Diamond Creek and Grand Wash Cliffs. Reproduction by flannelmouth suckers may be occurring in the mainstem near Spencer Creek as indicated by larvae found in July of 1994 at a cobble bar upstream of the creek inflow.

Stomachs of channel catfish, walleye, and striped bass from the Lake Mead Inflow indicate the red shiners are a primary item in the diet of these predators. Native fishes have not been found in stomachs of fish from the area, but numbers are so low and unlikely to be discovered in stomachs.

Habitats of fish in the Lake Mead Inflow are ill-defined, and except for tributary inflows, aggregations of fish were rare in 1992-93. Diverse and broken shorelines seem to be selected by flannelmouth suckers, while carp and channel catfish seemed more indescriminant, and striped bass more pelagic. While notable changes in tributary inflows were seen from interim flows, greater changes in fish habitat occurred with changes in Lake Mead elevation and large winter and spring floods from tributaries.

ENVIRONMENTAL CONDITIONS OF TRIBUTARY MOUTHS AND SHORELINES

The tributary inflows below Bridge Canyon (Surprise, Spencer, Lost, Quartermaster canyons) supported high numbers of fishes, compared to other tributaries further upstream in Grand Canyon (Valdez and Ryel 1995). Fish are attracted to tributary inflows by an influx of food (aquatic and terrestrial macroinvertebrates) and warm water temperatures, and these serve as attractants to native and nonnative fishes. Clearly, these inflows experience the greatest physical, chemical, and biological changes during fluctuating flows of any mainstem habitats. Maintaining the environmental integrity of these inflows by providing mainstem flows that promote species diversity and abundance is vital to ecosystem health. However, inspite of inflow changes from interim flows, greater changes in outlet channel morphology were seen with large winter and spring floods from these tributaries. Large floods in Spencer Creek in winter 1993 shifted the outflow channel by nearly 50 m, and braided the outflow extensively. Large sand deposits at the mouth of Surprise Canyon from tributary floods also temporarily impounded the stream, and could impede fish access.

Jet boats, from Pearce Ferry to Bridge Canyon and back, to transport rafters across flatwater generate wakes that appear to have considerable erosional effect on shorelines. These wakes are sharp and fast-moving waves that hit the shore suddenly and tend to cause collapse of earthen and sand banks. While the focus of effects to the aquatic ecosystem is on dam operations, it is also valuable to understand the magnitude of effect from other sources.

PRODUCTIVITY AND ALGAL STANDING CROPS

Productivity and algal standing crops are difficult to measure in a stochastic western river such as the Colorado River. These parameters become even more difficult to assess in lake inflow regions such as the lower 45 miles of the study reach, which may be inundated by Lake Mead with water of different temperature, water quality, and nutrient levels than the inflowing river. These parameters are often too variable to allow comparison between areas and over time. Productivity and algal standing crops have not been evaluated in this area because of this dynamic nature and high variability of measurements.

RECOMMENDATIONS

The following are recommendations resulting from the Hualapai Aquatic Resources Study.

1. Continued Studies: Continued studies of the aquatic ecosystem of the Colorado River in lower Grand Canyon are recommended with several provisions. While background information is still needed from the region, particularly species lists and standing crops of primary and secondary producers (e.g., algae, benthic invertebrates), continuing assessments of dam operations are vital. These assessments should be framed as studies with stated purpose and objectives and driven by specific hypotheses. These hypotheses should address specific effects of dam operations and should be statistically testable, whenever possible. Gathering background information is an essential aspect of hypothesis testing and helps to add to existing information of the area, but survey-type studies are not advised at this time. The information gathered from sound hypothesis tests becomes a valuable addition to the baseline database and essential information for future management decisions of Glen Canyon Dam.

2. Integrate Database: Data gathered from the Hualapai Aquatic Resources Study is a valuable piece of information that links the entire flowing Colorado River between Glen Canyon Dam and Lake Mead. Existing data should be assimilated and integrated into the Grand Canyon Database being established by GCES. Future studies should insure data compatibility to facilitate further integration. Data compatible with GIS should be identified and formatted for use with other data types from this and other studies. The integration of all available databases from this region of Grand Canyon (e.g., fisheries, water quality, bathymetry, riparian vegetation, birds, etc.) will provide an excellent database to describe the existing environment of the area as well as facilitate comparative analyses for evaluating dam operations.

3. Risk Analysis of Non-Native Fish Invasion: The Lake Mead inflow contains a high diversity of non-native fishes with the highest potential access to the Colorado River in Grand Canyon of any adjoining area or tributary. Knowing the species composition, behavior, and invasion potential of each life stage of the inflow fishes is essential to evaluating the risk of implementing a selective withdrawal structure on Glen Canyon

Dam. The subject of potential invasion by non-native fishes upstream into the Colorado River could be the subject of a specific investigation designed to evaluate streamflow, temperature, and habitat characteristics in the invasion corridor. Life history and habitat requirements of each species should be evaluated in order to determine if the river immediately upstream is suitable for spawning, nursing, and rearing, and the likelihood of invasion.

4. <u>Habitat Evaluation</u>: Fish habitat in lower Grand Canyon appears to be most immediately affected by (1) Glen Canyon Dam operations, (2) Lake Mead elevation changes, (3) tributary floods, and (4) commercial power boat operations. Although Diamond Creek is about 240 miles downstream of Glen Canyon Dam, dam operations cause the river in this area to fluctuate up to 60 cm per day and 90 cm over a 3-day period. The effect of these fluctuations on fish habitat are not fully understood, but the methods for evaluating this hypothesis are more evident following this study. Clearly, the effects of Lake Mead fluctuations need to be separated from the effects of Glen Canyon Dam operations. Key fish habitats above the lake inflow are shorelines and tributary inflows, while key habitats in the inflow appear to be at tributary inflows and a few shorelines with rock outcrops or instream structure. Despite daily fluctuations from Glen Canyon Dam operations and seasonal fluctuations from Lake Mead, the most dramatic and sudden changes to fish habitat occur from late winter and late summer tributary floods. These floods cause major changes in channel morphology of tributaries and inflows at the Colorado River, and their effects should continue to be monitored with SuperHydro bathymetry. Also, commercial power boat traffic to and from Separation Canyon and Pearce Ferry generates sharp, fast-moving waves that appear to have a dramatic erosive effect on the shoreline; the magnitude and frequency of these waves should be evaluated to separate effects from dam operations and Lake Mead elevation changes.

5. <u>Evaluate Spawning Potential For Native Fishes</u>: The lower region of Grand Canyon, downstream of National Canyon, warms to a temperature range of 14°C to 17°C in summer, which is suitable for spawning by native fishes. Sampling times, sites, and methods should be timed to determine the extent and location of spawning by native fishes (i.e., flannelmouth sucker, bluehead sucker, speckled dace, razorback sucker). Locations in which recently spawned fish or larvae have been retrieved should be targeted, and sample gear should include larval light traps, small mesh seines, and drift nets. The potential for spawning by native fishes in especially the Lake Mead inflow may be substantial, especially if the suitability of areas is improved through river management.

6. <u>Investigate Potential For Razorback Sucker Introductions</u>: The Lake Mead inflow is a productive, relatively warm region that may be a suitable reintroduction site for razorback suckers. Although razorback suckers have not been captured in the region, flannelmouth suckers are numerous and the presence of young fish suggests spawning in tributaries and possibly the mainstem by flannelmouths. Hence, despite large numbers of non-native fishes in the inflow region, flannelmouth suckers are spawning successfully. Razorback suckers may be successfully reared in Spencer Creek upstream of a fish barrier, where only speckled dace presently occur. If this becomes a desirable recovery option for razorback suckers, the availability of suitable food items will need to be assessed to determine optimum stocking size of fish. Papoulias and Minckley (1992) determined that larval and post-larval razorback suckers require zooplanktors for food since their mouth position is terminal prior to a more ventral position with more benthic food habits. Releasing young razorback suckers in areas devoid of zooplanktors would result in low survival and poor health of individuals from low food availability.

7. <u>Tributaries</u>: Spencer Creek, Surprise Creek, Quartermaster Creek, and Lost Creek have the highest densities of fish of any areas in lower Grand Canyon. Although a large number of these fish are non-natives, native species are common, indicating that these tributaries are valuable habitats for native fish assemblages.

Continued studies of tributaries are recommended, but these should be directed to test specific hypotheses or to determine the suitability of the stream for existing native fishes or introduced razorback suckers.

8. Integration: A synthesis, integration, and interpretation of all aquatic resources data collected between National Canyon and Pearce Ferry is recommended. The primary purpose for this synthesis is to evaluate the existing condition of the Colorado River and its tributaries for this lower region of Grand Canyon. Sufficient information exits to provide a characterization of the region, the effects of the Lake Mead inundation, past Glen Canyon Dam operations, and present and future dam operations. While this lower region of Grand Canyon continues to be affected by fluctuating releases, the principal effects to the aquatic ecosystem are related to thermal modification from hypolimnetic releases from Glen Canyon Dam and to the resultant changes in productivity, primarily related to the shift from heterotrophy (large influx of organics with some local production) to autotrophy (in situ production, occurring primary upstream). This change in productivity has greatly altered the aquatic ecosystem of the region and hence, the fish assemblages. The invasion by nearly 20 species of nonnative fishes has greatly aggravated conditions for the native ichthyofauna by intensifying competition, predation, and parasitism. Understanding the behavior of the fishes in the Lake Mead inflow and their likely responses to dam operations (e.g., thermal augmentation, steady releases) will enable managers to better understand the risks of certain management options. Since this inflow is the most likely source of an undesirable invasion of nonnative fishes into Grand Canyon proper, it is imperative that the status, trends, and behaviors of these fishes are understood.

LITERATURE CITED

Allan, J.D., and E. Russek. 1985. The quantification of stream drift. Canadian Journal of Fisheries and Aquatic Sciences 42:210-215.

Angradi, T.R., R.W. Clarkson, D.A. Kinsolving, D.M. Kubly and S.A. Morgensen. 1992. Glen Canyon Dam and the Colorado River: responses of the aquatic biota to dam operations. Prepared for the Bureau of Reclamation, Upper Colorado Region, Glen Canyon Environmental Studies, Flagstaff, AZ. Cooperative Agreement No. 9-FC-40-07940. Arizona Game and Fish Department, Phoenix, AZ. 155 pages.

Armitage, P.D. 1977. Invertebrate drift in the regulated River Tees, and an unregulated tributary Maize Beck, below Cow Green dam. Freshwater Biology 7:167-183.

Blinn, D.W., L.W. Stevens, and J.P. Shannon. 1994. Interim flow effects from Glen Canyon Dam on the aquatic food base in the Colorado River in Grand Canyon National Park, Arizona. In cooperation with the Glen Canyon Environmental Studies Program National Park Service Cooperative Agreement CA 8024-8-0002. 136 pp + appendix.

Brooker, M.P., and R.J. Hemsworth. 1978. The effect of the release of an artificial discharge of water on invertebrate drift in the River Wye, Wales. Hydrobiologia 59:155-163.

Burdick, B.D. and R.L. Hamman. 1993. A study to evaluate several tagging and marking systems for Colorado squawfish, razorback sucker, and bonytail. Final Report to U.S. Fish and Wildlife Service, Denver, CO. 56 pp.

Carothers, S.W. and C.O. Minckley. 1978. A survey of the fishes, aquatic invertebrates, and aquatic plants of the Colorado River and selected tributaries from Lee's Ferry (Mile 0) to Separation Rapids (Mile 240). Quarterly progress report submitted to the U.S. Bureau of Reclamation by the Museum of Northern Arizona, Contract No. 7-07-30-Z0026.

Cowell, B.C., and W.C. Carew. 1976. Seasonal and diel periodicity in the drift of aquatic insects in a subtropical Florida stream. Freshwater Biology 6:587-594.

Deacon, J.E. and J.R. Baker. 1976. Aquatic investigation on the Colorado River from Separation Canyon to the Grand Cliffs, Grand Canyon National Park. Submitted to Grand Canyon National Park. Contract No. PX821060350. 26 pp.

Eckblad, J.W., C.S. Volden, and L.S. Weilgart. 1984. Allochthonous drift from backwaters to the main channel of the Mississippi River. The American Midland Naturalist 111:16-22.

Hamblin, W.K. and J.K. Rigby. 1969. Guidebook to the Colorado River, Part 2: Phantom Ranch in Grand Canyon National Park to Lake Mead, Arizona-Nevada. Brigham Young University, Provo, UT.

Irvine, J.R. 1985. Effects of successive flow perturbations on stream invertebrates. Canadian Journal of Fisheries and Aquatic Sciences 42:1922-1927.

LaPerriere, J.D. 1983. Alkalinity, discharge, average velocity, and invertebrate drift concentration in subarctic Alaskan streams. Journal of Freshwater Ecology 2:141-151.

McCall, T. 1979. Fishery investigation of Lake Mead, Arizona-Nevada, from Separation Rapids to Boulder Canyon, 1978-79. Final Report to U.S. Department of Interior, Water and Power Resources Service, Contract No. 8-07-30-X0025. Arizona Game and Fish Department, Kingman, AZ. 197 pp.

Minshall, G.W., and P.V. Winger. 1968. The effect of reduction in stream flow on invertebrate drift. Ecology 49:580-582.

Moran, P.A.P. 1951. A mathematics theory of animal trapping. Biometrika 38:307-311.

Papoulias, D. and W.L. Minckley. 1992. Effects of food availability on survival and growth of larval razorback suckers in ponds. Transactions of the American Fisheries Society 121:340-355.

Perry, S.A., and W.B. Perry. 1986. Effects of experimental flow regulation on invertebrate drift and stranding in the Flathead and Kootenai Rivers, Montana, USA. Hydrobiologia 134:171-182.

Schmidt, J.C. and J.B. Graf. 1988. Aggradation and degradation of alluvial sand deposits, 1965-1986, Colorado River, Grand Canyon National Park, Arizona - Executive Summary. U.S. Geological Survey, Open-File Report 87-561. Tucson, AZ. 15 pp.

Schmidt, J.C. and J.B. Graf. 1990. Aggradation and degradation of alluvial sand deposits, 1965 to 1986, Colorado River, Grand Canyon National Park, Arizona. U.S. Geological Survey, Professional Paper No. 1439. Salt Lake City, UT. 74 pp.

Stoneburner, and L.A. Smock. 1979. Seasonal fluctuations of macroinvertebrate drift in a South Carolina piedmont stream. Hydrobiologia 63:49-56.

Sublette, J.E., M.D. Hatch, and M. Sublette. 1990. The Fishes of New Mexico. University of New Mexico Press, Albuquerque, NM.

U.S. Department of Interior. 1988. Glen Canyon Environmental Studies Final Report. Bureau of Reclamation, Upper Colorado Region, Salt Lake City, UT. 84 pp + Appendices (NTIS No. PB88-183348/AS).

Valdez, R.A. 1990. The endangered fish of Cataract Canyon. Final Report prepared for the United States Department of Interior, Bureau of Reclamation, Salt Lake City, UT. Contract No. 6-CS-40-03980, Fisheries Biology and Rafting. BIO/WEST Report No. 134-3. 94 pp + appendices.

Valdez, R.A. 1993. Effects of interim flows from Glen Canyon Dam on the aquatic resources of the lower Colorado River from Diamond Creek to Lake Mead. Quarterly Report to Hualapai Wildlife Management Department and Glen Canyon Environmental Studies. BIO/WEST, Inc., Logan, UT.

Valdez, R.A. 1994. Effects of interim flows from Glen Canyon Dam on the aquatic resources of the lower Colorado River from Diamond Creek to Lake Mead, Phase I Report. Annual Report to Hualapai Natural Resources Department and Glen Canyon Environmental Studies. BIO/WEST, Inc., Logan, UT.

Valdez, R.A., J.G. Carter, and R.J. Ryel. 1985. Drift of larval fishes in the upper Colorado River. Proceedings of the Western Association of Fish and Wildlife Agencies and the Western Division American Fisheries Society. Snowmass, CO. 171-185 pp.

Valdez, R.A., W.J. Masslich, W.C. Leibfried. 1991. Characterization of the life history and ecology of the humpback chub (Gila cypha) in the Grand Canyon. Annual report to Bureau of Reclamation, Contract No. 0-CS-40-09110. BIO/WEST Report No. TR-250-02. 74 pp.

Valdez, R.A., W.J. Masslich, W.C. Leibfried. 1992. Characterization of the life history and ecology of the humpback chub (Gila cypha) in the Grand Canyon. Annual report to Bureau of Reclamation, Contract No. 0-CS-40-09110. BIO/WEST Report No. TR-250-04. 222 pp.

Valdez, R.A., and M. Hugentobler (editors). 1993. Characterization of the life history and ecology of the humpback chub (Gila cypha) in the Grand Canyon. Annual Report - 1992 to Bureau of Reclamation, Contract No. 0-CS-40-09110. BIO/WEST Report No. TR-250-06. 168 pp + appendices.

Valdez, R.A., W.J. Masslich, L. Crist, and W.C. Leibfried. 1993. Field Methods for studying the Colorado River fishes in Grand Canyon National Park. Proceedings of the First Biennial Conference on Research in Colorado Plateau National Parks. Flagstaff, AZ. 23-36 pp.

Valdez, R.A. and R.J. Ryel. 1995. Life history and ecology of the humpback chub (Gila cypha) in the Grand Canyon, Arizona. Final Report to Bureau of Reclamation, Contract No. 0-CS-40-09110. BIO/WEST Report No. TR-250-08.

Van Deventer, J.S., and W.S. Platts. 1989. Microcomputer software system for generating population statistics from electrofishing data-user's guide for Microfish 3.0. General Technical Report INT-254, USDA Forest Service, Intermountain Research Station, Ogden, UT.

White, R.G., and D.T. Wade. 1980. A study of fish and aquatic macroinvertebrate fauna in the South Fork Boise River below Anderson Ranch Dam with emphasis on effects of fluctuating flows. College of Forestry, Wildlife, and Range Sciences, University of Idaho, Technical Completion Report 14-06-100-9220, Moscow, ID.

White, G.C., D.R. Anderson, K.P. Burnham, and D.L. Otis. 1982. Capture-recapture and removal methods for sampling closed populations. Los Alamos National Laboratory, LA-8787-NERP, Los Alamos, NM.

Zimmer, D.W. 1976. Observations of invertebrate drift in the Skunk River, Iowa. Proceedings of the Iowa Academy of Science 82:175-178.

Zippin, C. 1956. An evaluation of the removal method of estimating animal populations. Biometrics 12:163-189.

Zippin, C. 1958. The removal method of population estimation. Journal of Wildlife Management 22:82-90.

APPENDIX A

Table A-1. Dates, camp sites and sample locations for seven trips on the Colorado River, from Diamond Creek (RM 226) to below Pearce Ferry (RM 286), 1992-95.

Date	Camp Site	Sample Locations (RM)
	Trip No. 1 (June 24 - July 2, 1992)	
Jun 24-25	Travertine Canyon (RM 229.1)	RM 228.3 - 229.8
Jun 26-27	Spencer Canyon (RM 246.0)	RM 245.4 - 246.1
Jun 28-29	Lost Creek (RM 249.7)	RM 247.1 - 249.7
Jun 30	Quartermaster (RM 259.8)	RM 250.3 - 262.3
Jul 1-2	Pearce Ferry (RM 280)	RM 274.0 - 280.0
	Trip No. 2 (September 27 - October 9, 1992)	
Sep 27-28	Bridge Canyon (RM 235.2)	RM 234-237.5
Sep 29-Oct 2	Spencer Canyon (RM 246.0)	RM 245.4-249.5
Oct 3-4	Below Quartermaster (RM 260.5)	RM 250.3-263
Oct 5-6	Braided Area (RM 268.5)	RM 266-274
Oct 7-9	Park Boundary (RM 277.5)	RM 274.0-280.0
	Trip No. 3 (December 1 - 13, 1992)	
Dec 1-3	Bridge Canyon (RM 235.2)	RM 234.2 - 236.0
Dec 3-6	Above Spencer (RM 245.0)	RM 241.6 - 249.1
Dec 6-7	Below Lost Creek (RM 249.7)	RM 249.1 - 249.4
Dec 7-9	Burnt Spring (RM 259.7)	RM 249.5 - 271.5
Dec 9-11	Braided Section (RM 267.5)	RM 270.0 - 272.8
Dec 11-13	Scorpion Island (RM 277.5)	RM 271.8 - 279.5
	Trip No. 4 (March 25 - April 6, 1993)	
Mar 25-26	Bridge Canyon (RM 235.2)	RM 233.8-235.2
Mar 26-Apr 1	Above Spencer Creek (RM 242.2)	RM 241.8 to 250.2
Apr 1-2	Burnt Canyon (RM 259.5)	RM 259.5 to 261.1
Apr 2-5	RM 268.1 (above former Braided area)	RM 268.1 to 276.6
Apr 5-6	Pearce Ferry (RM 280)	RM 274.3 to 280.0
	Trip No. 5 (May 25 - June 6, 1993)	
May 25-26	Bridge Canyon (RM 235.2)	RM 233.8-235.2
May 26-31	Above Spencer Creek (RM 245.2)	RM 241.8 to 250.2
May 31-Jun 1	Below Burnt Spring Canyon (RM 259.5)	RM 259 - RM 262
Jun 1-3	RM 265.0	RM 264 - RM 268
Jun 3-6	Scorpion Island	RM 276 - RM 282
	Trip No. 6 (September 28 - October 10, 1993)	
Sep 28-30	Travertine Falls (RM 230.5)	RM 227.5 - 230.7
Sep 30-Oct 4	Above Spencer Creek (RM 245.2)	RM 242.5 - 249.1
Oct 4-7	Above Salt Creek (RM 253.9)	RM 252.9 - 260
Oct 7-9	Scorpion Island (RM 279)	RM 273 - 278.5
Oct 9-10	Pearce Ferry (RM 280)	Derig
	Trip No. 7 (December 1 - 13, 1993)	
Dec 1-4	Travertine Falls (RM 230.5)	RM 228.5 - 230.7
Dec 4-9	Spencer Creek (RM 246.0)	RM 242.5 - 249.1
Dec 9-11	Near Bat Caves (RM 266)	RM 259.9
Dec 11-13	Scorpion Island (RM 279)	RM 274.7 - 279

Table A-1. Continued.

Date	Camp Site	Sample Locations (RM)
	Trip No. 8 (March 30 - April 11, 1994)	
Mar 30 - 31	Travertine Falls (RM 230.5)	RM 228.6 - 230.8; RM 225.7
Mar 31 - Apr 5	Spencer Creek (RM 246.0)	RM 242 - 250.1
Apr 5 - 6	Above Salt Creek (RM 253.9)	RM 252.0 - 254.2
Apr 6 - 8	Below Bat Cave (RM 270.1)	RM 259.9 - 272.3
Apr 8 - 11	Scorpion Island (RM 279.0)	RM 274.0 - 279.0
	Trip No. 9 (May 26 - June 7, 1994)	
May 26-27	RM 233.7 Above 234 Mile Rapid	RM 232.5 - 233.6
May 27-Jun 1	RM 245.3 Upstream of Spencer	RM 244.8-248.9
Jun 1-3	RM 250.3 Shady Ledges	RM 250.6-253.2
Jun 3-4	RM 259.8 Quartermaster Creek	RM 259.5-261.2
Jun 4-5	RM 265 Upstream of Bat Caves	RM 264.3-266.3
Jun 5-7	RM 274.3 Emery Falls	RM 273.3-274.8
	Trip No. 10[a] (September 15 - October 7, 1994)	
Sep 15-18	Travel from Lees Ferry	-
Sep 19	Cove Canyon (RM 174.3)	RM 171-179
Sep 20-21	Hells Hollow (RM 182.4)	RM 180-185
Sep 22-23	Granite Park (RM 208.9)	RM 206-208.9
Sep 24	214 Mile Creek (RM 214.0)	RM 212-216
Sep 25-26	Travertine Falls (RM 230.4)	RM 228-230.8
Sep 27	Bridge Canyon (RM 235.0)	RM 233-235
Sep 28	Below Separation Canyon (RM 242.5)	RM 239-244
Sep 29 - Oct 1	Spencer Canyon (RM 246.0)	RM 244-248
Oct 2	Above Surprise Canyon (RM 248.0)	RM 247-250
Oct 3	Above Maxson Canyon (RM 250.6)	RM 250-255
Oct 4	Below Bat Cave (RM 270.0)	RM 268-270
Oct 5-6	Emery Falls (RM 273.5)	RM 270-276
	Trip No. 11[a] (January 3 - 23, 1995)	
Jan 3-7	Travel from Lees Ferry	-
Jan 8-9	Hells Hollow (RM 182.4)	RM 180-185
Jan 10-11	Granite Park (RM 208.9)	RM 206-208.9
Jan 12	224 Mile Camp (RM 224.5)	RM 223.5-225
Jan 13	Travertine Falls (RM 230.4)	RM 228-230.8
Jan 14	Bridge Canyon (RM 235.0)	RM 233-235
Jan 15	Below Separation Canyon (RM 242.5)	RM 239-244
Jan 16-19	Spencer Canyon (RM 246.0)	RM 244-248
Jan 20	Granite Fin Camp (RM 249.6)	RM 247-250
Jan 21	Below Bat Cave (RM 270.0)	RM 268-270
Jan 22	Emery Falls (RM 273.5)	RM 270-276
Jan 23	Pearce Ferry (RM 286.0)	-

[a]Sampling was extended from National Canyon (RM 166.4) to Pearce Ferry (RM 286.0) for Trips 10 and 11.

Table A-2. Personnel participating in 1992-95 field trips.

Name	Trip	Agency, Address, Phone Numbers
Richard Valdez	1, 7	BIO/WEST, Inc., 1063 W. 1400 N., Logan, UT 84321 (801)752-4202
Bryan Cowdell	10, 11	BIO/WEST, Inc., 1063 W. 1400 N., Logan, UT 84321 (801)752-4202
Bill Leibfried	5, 7, 9-11	BIO/WEST, Inc., 4 Aztec Street, Flagstaff, AZ 86001 (602)774-8069
Gloria Hardwick	4-10	BIO/WEST, Inc., 4 Aztec Street, Flagstaff, AZ 86001 (602)774-8069
Randall Filbert	5-8	BIO/WEST, Inc., 1063 W. 1400 N., Logan, UT 84321 (801)752-4202
Kirsten Tinning	1-4	BIO/WEST, Inc., 4 Aztec Street, Flagstaff, AZ 86001 (602)774-8069
Erika Prats	2, 3, 10, 11	BIO/WEST, Inc., 4 Aztec Street, Flagstaff, AZ 86001 (602)774-8069
Chris Heck	3	BIO/WEST, Inc., 1063 W. 1400 N., Logan, UT 84321 (801)752-4202
Brian Dierker	1, 2	BIO/WEST, Inc., 4 Aztec Street, Flagstaff, AZ 86001 (602)774-8069
Teresa Yates	3, 4, 6-11	BIO/WEST, Inc., 4 Aztec Street, Flagstaff, AZ 86001 (602)774-8069
Alyssa Reischauer	2	BIO/WEST, Inc., 4 Aztec Street, Flagstaff, AZ 86001 (602)774-8069
Alan Kinsolving	2	Aquatics International, 575 Lake Mary Road, Flagstaff, AZ 86001 (602)774-9428
Clay Bravo	1, 4	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Morris Samson	1-10	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Travis Magenty	1	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Mario Bravo	1	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Warren Powskey	1- 3, 6	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Soloise Powski	5	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Ben Zimmerman	3-5, 7, 9-11	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Jerry Cook	2, 4	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Alvin Dashee	6	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Stan Dashee	7	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Wallace Wilson	7	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Johnny Matuck	6	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Mike Vaughn	10, 11	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Danny Lee, Jr.	10, 11	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254

Table A-2. Continued.

Name	Trip	Agency, Address, Phone Numbers
Richard Beecher	11	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Connie Graham	10	Hualapai Wildlife Management Department, P.O. Box 300, 947 Rodeo Way, Peach Spring, AZ 86434 (602)769-2254
Ross Haley	1	Resource Management Specialist, Lake Mead Recreation Area, 601 Nevada Highway, Boulder City, NV 89005 (702)293-8946
Denise Freitas	1	Resource Management Specialist, Lake Mead Recreation Area, 601 Nevada Highway, Boulder City, NV 89005 (702)293-8946
Debra Bills	5	U.S. Fish and Wildlife Service
Stuart Reeder	3, 7, 8, 11	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Lars Neimi	1, 5, 9, 10	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Steve Bledsoe	3, 7, 8, 10, 11	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Kelly Burke	1, 2	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Rachael Running	3, 11	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Chris Geanious	2	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Kelly Smith	2, 5	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Allistair Bleifuss	4	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Ann Cassidy	4	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Tony Anderson	4, 5	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Kelly Johnson	5	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Curtis (Whale) Hansen	6	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Bob Grusy	6	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Elizabeth Fuller	6, 7	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Valerie Saylor	4	GCES, P.O. Box 22459, Flagstaff, AZ 86002 (602)556-7868
Melissa Richmond	10	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526

Table A-3. Locations and descriptions of temporary bench marks (TBM) established along the Colorado River, from Diamond Creek (RM 226) to below Pearce Ferry (RM 286), 1992-93.

TBM Number[a]	Date	Description
		Trip No. 1 (1992)
L 246.0 (Spencer Canyon)	Jun 26	First large rock point about 100 m downstream of Spencer Creek at end of vegetated sand beach on river left.
R 249.0 (Lost Creek)	Jun 28	Upstream base of large prominent rock fin, at upstream end of large vegetated sand beach on river right.
L 259.8 (Quartermaster)	Jun 30	Downstream end of large travertine formation about 200 m upstream of Quartermaster stream at end of large vegetated sand beach on river left.
		Trip No. 2 (1992)
L 234.9 (Bridge Canyon)	Sep 29	Upstream end of Bridge Canyon Rapid, downstream side of shearwall.
L 262.0 (Below Quartermaster)	Oct 4	Upstream side of beach, above large rectangular rock.
		Trip No. 3 (1992)
L 235.1 (Above Bridge Canyon)	Dec 2	Upstream of Bridge Canyon Rapid beach, on shear wall near fanged rock-upper end of beach.
		Trip No. 5 (1993)
R 245.4 (Above Spencer Canyon)	May 26	Shear wall at upper end of beach.
		Trip No. 6 (1993)
L 230.5 (Travertine Falls)	Sep 29	Under rock overhang in rock depression at upstream end of boat eddy - just above rapid.
R 253.2	Oct 5	Downstream portion of small sand beach about 20' above river, at base of cliff and gentle slope, under small overhang facing river.

[a] L = left river bank, facing downstream; R = right river bank, facing downstream.

Table A-4. Locations and times of water quality measurements[a] using a Hydrolab Surveyor II, Hydrolab Datasonde with datalogger, and Secchi disk, 1992-93.

Sample Site (River Mile)	Observation Period (Dates) Time (Hours)
Hydrolab Surveyor II	
Travertine Canyon (RM 229.1)	Jun 25-Jun 26, 1992 1030-0800 (21.5 hrs)
Spencer Canyon (RM 246.0)	Jun 26-Jun 28, 1992 1230-1043 (46.2 hrs)
Lost Creek (RM 249.7)	Jun 28-Jun 30, 1992 1206-0744 (43.7 hrs)
Quartermaster (RM 259.8)	Jun 30-Jul 1, 1992 1245-1339 (24.9 hrs)
Colorado River at Spencer Canyon[b]	Dec 1-Dec 4, 1992 2008-0639(58.5 hrs)
RM 255.2	Mar 25-Mar 26, 1993 1624-1227
RM 242.2	Mar 26-Mar 30, 1993 1637-0849
Surprise Canyon	Mar 30-Mar 30, 1993 1003-1607
Lost Creek	Mar 31-Mar 31, 1993 1100-1801
Burnt	Apr 1-Apr 2, 1993 1630-0907
RM 268.1 above Braided	Apr 2-Apr 5, 1993 1440-0704
Lake Mead	Apr 5-Apr 5, 1993 1139-1815
RM 234.9 - Bridge Canyon	May 25-May 26, 1993 2009-1225
RM 245.6 above Spencer	May 26-May 31, 1993 1718-0759
RM 259.5 across from Burnt	May 31-Jun 1, 1993 1535-0820
RM 265.0 below Dry Canyon	Jun 1-Jun 3, 1993 1724-0706
RM 279.5 behind Scorpion	Jun 3-Jun 5, 1993 1729-1739
RM 230.5 - Travertine Falls	Sep 29-Sep 30, 1993 1124-1258
RM 245 above Spencer	Sep 30-Oct 2, 1993 1958-0938
RM 246.0 - Spencer Creek	Oct 2-Oct 4, 1993 1111-1148

Table A-4. Continued.

Sample Site (River Mile)	Observation Period (Dates) Time (Hours)
RM 253.9 below Spencer	Oct 4-Oct 7, 1993 1656-0835
RM 279.0 behind Scorpion	Oct 7-Oct 9, 1993 1800-0951
RM 230.5 - Travertine Falls	Dec 2-Dec 4, 1993 0925-1203
RM 216.0 - Spencer Creek	Dec 4-Dec 9, 1993 1538-1143
RM 266.0	Dec 9-Dec 10, 1993 1601-1417
RM 279.0 behind Scorpion	Dec 11-Dec 12, 1993 1432-1637
Hydrolab Datasonde w/Datalogger	
Spencer Creek (100 m above outflow)[b]	Jun 26-Jun 28, 1992 0815-1015(26 hrs)
Spencer Creek (100 m above outflow)[b]	Sep 30-Oct 3, 1992 1300-0800(66 hrs)
Spencer Creek (100 m above outflow)[b]	Dec 3-Dec 6, 1992 1500-0930(66.5 hrs)
Lost Creek (200 m above outflow)	Jun 29-Jun 30, 1992 0900-0900 (24 hrs)
RM 235.2 - Bridge Canyon	Mar 25-Mar 26, 1993 1603-1241
RM 242.2	Mar 26-Mar 27, 1993 1658-1309
RM 242.2	Mar 28 - Mar 29, 1993 1517-1320
RM 246 - Spencer Creek	Mar 29-Mar 31, 1993 ?-0933
RM 249 - Lost Creek	Mar 31-Apr 1, 1993 1245-1140
Burnt Creek	Apr 1-Apr 2, 1993 1630-0905
RM 268.1	Apr 2-Apr 5, 1993 1438-0920
RM 236.5 - Bridge Canyon	May 25-May 26, 1993 1702-1230
RM 245.7	May 26-May 30, 1993 1715-0920
RM 249.0	May 30-May 31, 1993 ?-1015
RM 230.5	Dec 1-Dec 4, 1993 1643-0947

Table A-4. Continued.

Sample Site (River Mile)	Observation Period (Dates) Time (Hours)
Spencer Creek	Dec 4-Dec 9, 1993 1300-1120
RM 266.0	Dec 9-Dec 11, 1993 1535-0919

[a] Water quality parameters included temperature, pH, dissolved oxygen, conductivity.

Table A-5. Turbidity measurements (Secchi disk readings) taken in the mainstem Colorado River between Diamond Creek (RM 226) and Pearce Ferry (RM 286), 1992-95.

Sample Site (River Mile)	Date/Time of Observation	Secchi Depth (m)
	Trip No. 4	
235.2	Mar 25, 1993/1624	0.03
235.2	Mar 26, 1993/1014	0.03
242.2	Mar 27, 1993/1159	0.03
242.2	Mar 28, 1993/1523	0.04
242.2	Mar 29, 1993/0937	0.04
259.5	Apr 1, 1993/1630	0.04
268.1	Apr 2, 1993/1440	0.06
268.1	Apr 4, 1993/1445	0.57
	Trip No. 5	
234.9	May 26, 1993/0823	0.25
245.6	May 27, 1993/1648	0.25
245.6	May 28, 1993/1038	0.30
245.6	May 29, 1993/1617	0.50
265.0	Jun 2, 1993/1541	0.50
	Trip No. 6	
230.5	Sep 29, 1993/1124	0.30
230.5	Sep 30, 1993/1013	0.42
245.0	Oct 1, 1993/1720	0.70
245.0	Oct 2, 1993/0938	0.90
279.0	Oct 7, 1993/1001	0.55
	Trip No. 7	
230.5	Dec 2, 1993/0925	0.05
230.5	Dec 4, 1993/0921	0.07
246.0	Dec 8, 1993/1344	0.40
246.0	Dec 9, 1993/1143	0.40
246.0	Dec 10, 1993/1417	0.40
	Trip No. 8	
230.5	Mar 31, 1994/1156	0.10
246.0	Apr 1, 1994/0957	0.12
246.0	Apr 2, 1994/1458	0.21
246.0	Apr 3, 1994/1556	0.28
246.0	Apr 4, 1994/1329	0.30
246.0	Apr 5, 1994/1102	0.40
253.9	Apr 6, 1994/0946	0.33
270.1	Apr 7, 1994/1300	0.35
279.0	Apr 9, 1994/0848	0.33
279.0	Apr 10, 1994/1253	0.33
	Trip No. 9	
233.7	May 27, 1994/1138	1.80
245.3	May 28, 1994/0728	0.33
245.3	May 29, 1994/0751	1.80
259.8	Jun 4, 1994/0802	1.05

Table A-5. Continued.

Sample Site (River Mile)	Date/Time of Observation	Secchi Depth (m)
	Trip No. 10	
174.3	Sep 19, 1994/1304	0.27
174.3	Sep 20, 1994/1303	0.28
182.4	Sep 21, 1994/1224	0.31
208.9	Sep 22, 1994/1555	0.42
208.9	Sep 23, 1994/1000	0.45
214.0	Sep 24, 1994/1213	0.15
230.4	Sep 26, 1994/1000	0.10
230.4	Sep 27, 1994/1641	0.10
242.5	Sep 28, 1994/0754	0.25
246.0	Sep 30, 1994/0717	0.30
246.0	Oct 1, 1994/0826	0.60
246.0	Oct 2, 1994/0706	1.00
250.6	Oct 4, 1994/0719	1.10
270.0	Oct 5, 1994/1028	0.50
273.6	Oct 6, 1994/1152	0.50
	Trip No. 11	
182.3	Jan 9, 1995/1030	0.30
208.9	Jan 10, 1995/1616	0.25
208.9	Jan 11, 1995/1011	0.25
208.9	Jan 12, 1995/1313	0.05
224.6	Jan 13, 1995/1022	0.05
230.5	Jan 14, 1995/0730	0.10
242.5	Jan 15, 1995/1603	0.15
246.0	Jan 16, 1995/1339	0.20
246.0	Jan 17, 1995/1514	0.15
246.0	Jan 18, 1995/1554	0.25
246.0	Jan 19, 1995/0850	0.25
246.0	Jan 20, 1995/0956	0.20
270.0	Jan 21, 1995/1436	0.20
273.3	Jan 22, 1995/1418	0.20
273.3	Jan 23, 1995/0851	0.20

Table A-6. Minimum and maximum water temperatures (°C) recorded for the mainstem Colorado River and selected tributaries, from Diamond Creek (RM 226) to below Pearce Ferry (RM 286), 1992-1995.

Location (River Mile)	Dates										
	Jun 92	Sep-Oct 92	Dec 92	Mar-Apr 93	May-Jun 93	Sep-Oct 93	Dec 93	Mar-Apr 94	May-Jun 94	Sep-Oct 94	Jan 95
MAINSTEM COLORADO RIVER											
Travertine Falls (RM 230.5)	17.0-17.5	-	-	-	-	13.5-14.5	8.0-11.0	12.0-13.0	-	14.5-15.5	10.0-10.5
Bridge Canyon (RM 235.0)	-	14.5-15.0	8.0-10.0	11.0-15.0	16.5-16.5	-	-	-	16.0-17.0	15.0-15.0	10.0-10.5
Spencer Canyon (RM 246.0)	17.0-19.0	14.0-17.0	9.0-10.0	10.0-12.0	16.0-17.5	13.0-15.0	10.0-11.0	13.0-14.0	16.5-20.0	14.5-15.0	8.5-10.0
Near Bat Cave (RM 266.0)	-	14.0-17.0	9.0-9.0	-	16.0-18.5	-	10.0-11.0	14.0-14.5	17.5-20.0	15.0-16.0	8.5-9.0
Emmery Falls (RM 274.0)	-	-	10.0-10.0	-	-	15.0-16.0	10.5-11.0	12.0-14.0	17.5-19.5	14.5-16.0	8.5-9.0
TRIBUTARIES											
Spencer Creek (RM 246.0)	23.0-29.0	24.0-24.0	14.0-14.0	15.0-22.0	17.0-25.5	20.0-27.0	13.0-16.0	17.0-21.0	21.5-30.0	20.0-25.0	11.0-13.0
Surprise Creek (RM 248.4)	24.0-26.5	17.0-17.0	10.5-26.0	12.0-12.0	24.0-27.0	23.5-31.0	12.0-12.0	19.0-19.0	26.0-30.0	23.0-27.0	-
Lost Creek (RM 248.9)	19.0-27.0	14.5-16.5	-	21.0-24.0	24.0-25.0	-	-	-	28.0-28.0	21.0-21.0	-

Table A-7. Numbers of fish species and life stage captured with 18 gear types in the Colorado River and tributaries, from Diamond Creek RM 226 to below Pearce Ferry (RM 286), June 1992-January 1995.

Gear Types	Life Stage	Fish Species Codes																			
		BH	FM	BC	BG	GS	LM	TS	CP	FH[a]	GO	HB	RS[a]	SD[a]	PK	BB	CC	SB	WE	GA	RB
EL	Y			2			5		40												
	J		11			3	24		59				6					3			
	A	1	17	2		4	11	228	820	49	1		1602	26	1		41	26		48	
	T	1	28	4		7	40	228	919	49	1		1608	26	1		41	29		48	
BP	Y		1							1											
	J		47				1		29	1			6	3		1					1
	A	1	8			1	1		168	214			2822	1346	26		70	2			
	T	1	56			1	2		197	222			3048	2179	26	1	70	2			1
GM	Y																				
	J																				
	A								8									1	1		
	T								8									1	1		
GP	Y																				
	J																				
	A								15								13	17			1
	T								15								13	17			1
GX	Y																				
	J																				
	A																8	1			
	T																8	1			
GS	Y																				
	J																				
	A								7												
	T								7												
TK	Y																				
	J																				
	A	1	8	1			1		124								119	8			
	T	1	8	1			1		124								119	8			

Table A-7. Continued.

Gear Types	Life Stage	Fish Species Codes																			
		BH	FM	BC	BG	GS	LM	TS	CP	FH[a]	GO	HB	RS[a]	SD[a]	PK	BB	CC	SB	WE	GA	RB
TL	Y																				
	J																				
	A		9						104			1					67	8	1		2
	T		9						104			1					67	68	1		2
TM	Y																				
	J																				
	A		4	1			1	1	23							2	62	20			1
	T		4	1			1	1	23							2	62	20			1
TN	Y																				
	J																				
	A	1	8		2		1		110								50	17			
	T	1	8		2		1		110								50	17			
HM	Y																				
	J																	1			
	A								4				158							1	
	T								4				158					1		1	
HS	Y																				
	J		1														23				
	A							1	18				1				7				
	T		1					1	18				1				30				
MT	Y								5	2											
	J		8			1			2				20								
	A					2				354			1533	253	75						
	T		8			3			7	356			1553	253	75						
SA	Y		19				2		60	12			160	2						22	
	J		19							541			556	1	4					18	
	A									1906			4905	309	7					135	
	T		38				2		60	2459			5621	341	11					175	

Table A-7. Continued.

Gear Types	Life Stage	BH	FM	BC	BG	GS	LM	TS	CP	FH[a]	GO	HB	RS[a]	SD[a]	PK	BB	CC	SB	WE	GA	RB
		Fish Species Codes																			
SB	Y		6			2			31												
	J		15						29	105			262		4					4	
	A		1							393			585	9	19					22	
	T		22			2			60	498			847	9	23					26	
SC	Y	1	3			3								11	1						
	J		5						3	3			53							6	
	A									219			2601	75						48	
	T	1	8			3			3	572			3104	90	1					54	
SG	Y																				
	J		18		33		4		1				17								
	A				4			90	1	166			460	23						2	
	T		18		37		4	90	2	166			477	23						2	
AN	Y																				
	J																				
	A																4	3			
	T																4	3			
DN	Y																				
	J																				
	A													5							
	T													5							
Total	**Y**	**1**	**29**	**2**	**-**	**5**	**7**	**-**	**136**	**15**	**-**	**-**	**160**	**13**	**1**	**1**	**-**	**-**	**-**	**22**	**-**
	J	**-**	**124**	**-**	**33**	**4**	**29**	**-**	**123**	**650**	**-**	**-**	**920**	**4**	**8**	**2**	**23**	**4**	**-**	**28**	**1**
	A	**4**	**55**	**4**	**6**	**7**	**15**	**320**	**1402**	**3301**	**1**	**1**	**14667**	**2046**	**127**	**3**	**441**	**103**	**2**	**256**	**4**
	T	**5**	**208**	**6**	**39**	**16**	**51**	**320**	**1661**	**4322**	**1**	**1**	**16417**	**2926**	**136**	**6**	**464**	**107**	**2**	**306**	**5**

[a]All fish not classified by age group, total will differ from age group sum.

Table A-8. Summary information associated with PIT-tagged fish for trips 1-11, 1992-95.

Species	PIT Tag	Recapture	TL (mm)	WT (g)	Gender	Date	River	River Mile
FM	7F7F3E524F	N	420	623	M	920624	CO	229.20
FM	7F7F287E72	N	360	0	M	920627	CO	246.10
FM	7F7F143B74	N	367	375	U	921003	CO	260.30
FM	7F7F1F1322	N	329	314	M	921004	CO	259.80
FM	7F7F480E49	N	322	260	F	921201	CO	234.90
FM	7F7F284128	N	282	163	U	921201	CO	234.90
FM	7F7F264F09	N	361	382	F	921201	CO	234.90
FM	7F7F480106	N	227	106	U	930328	CO	245.50
FM	7F0C5C1D5C	N	332	381	U	930526	CO	233.50
FM	7F7F480366	N	397	566	U	930530	CO	248.90
FM	7F7B081724	N	387	519	M	930601	CO	266.70
FM	1F1E2D3264	N	380	481	F	930929	CO	227.80
BH	1F20031B23	N	249	161	U	930929	CO	229.00
FM	1F1E2B1107	N	294	206	M	930930	CO	230.45
FM	1F200E7241	N	228	108	M	930930	CO	230.50
FM	1F1F5B7077	N	387	491	F	930930	CO	230.65
HB	1F1F74212D	N	329	293	F	931004	CO	253.20
FM	1F0F642747	N	346	363	F	931009	CO	273.80
FM	1F1F5B7077	Y	390	515	F	931204	CO	230.70
FM	1F200C5065	N	412	679	F	931211	CO	274.40
BH	7F751F6970	N	310	306	M	940330	CO	230.00
FM	7F7F214927	N	331	353	U	940407	CO	272.20
FM	1F122C2C77	N	264	188	F	940408	CO	270.10
FM	7F7D17311C	Y	534	1439	F	940527	CO	245.20
FM	1F1F777457	N	172	38	M	940528	SP	246.00
FM	1F1F586307	N	471	178	M	940528	SP	246.00
FM	1F1F642A34	N	242	119	M	940528	SP	246.00
FM	7F7D400379	N	365	478	F	940531	CO	246.00
FM	7F7F3E6713	N	351	510	F	940602	CO	253.00
FM	1F1F6A5404	N	243	140	F	940603	CO	259.70
FM	7F7F287B4B	N	379	515	M	940603	CO	259.80
FM	7F7B02444C	N	336	306	M	940603	CO	260.00
FM	7F7F1F1C4F	N	323	323	F	940603	CO	260.00
FM	7F7F273379	N	418	758	M	940604	CO	265.20
FM	1F204D363E	N	334	309	M	940919	CO	171.80
FM	1F20410000	N	408	672	M	940919	CO	172.00
BH	1F200A7443	N	355	503	F	940919	CO	172.80
FM	1F200D0F25	N	324	336	M	940919	CO	174.00
FM	1F200D0F25	N	282	199	M	940920	CO	173.40
BH	1F20467506	N	250	148	M	940920	CO	181.50
FM	1F200E7F34	N	406	628	M	940920	CO	181.50
BH	1F20415030	N	294	258	M	940920	CO	181.50
FM	1F2051135D	N	459	856	M	940920	CO	181.50
BH	1F1F64617D	N	289	235	F	940920	CO	181.50
FM	1F1F604022	N	264	178	M	940920	CO	181.50

Table A-8. Continued

Species	PIT Tag	Recapture	TL (mm)	WT (g)	Gender	Date	River	River Mile
FM	1F20530B63	N	330	308	M	940920	CO	181.50
FM	1F1F63203F	N	358	454	F	940921	CO	180.80
FM	1F2022021D	N	340	416	M	940921	CO	180.80
BH	1F2014634A	N	305	323	M	940921	CO	180.80
FM	1F14325843	N	266	190	M	940921	CO	180.80
FM	1F20262378	N	297	244	M	940921	CO	180.85
FM	1F1F6E5C78	N	376	512	M	940921	CO	180.85
FM	1F20454933	N	401	627	F	940921	CO	180.85
BH	1F20431668	N	321	327	M	940921	CO	183.00
FM	1F1F5F5112	N	464	965	M	940922	CO	208.00
FM	1F1F780F3B	N	394	574	M	940922	CO	208.00
FM	1F1F683624	N	395	493	M	940922	CO	208.00
FM	1F20257428	N	402	601	M	940922	CO	208.00
FM	1F1E2B5444	N	358	461	F	940922	CO	208.00
FM	1F201C287D	N	387	616	M	940922	CO	208.00
FM	1F1E40146F	N	430	710	M	940922	CO	208.00
FM	1F20257428	Y	396	585	M	940922	CO	208.00
FM	1F1F62055B	N	325	271	M	940922	CO	208.40
BH	1F1E430E72	N	239	120	M	940922	CO	208.40
FM	1F1F665309	N	315	263	M	940922	CO	208.40
FM	1F234A0L73	N	354	432	U	940923	CO	205.80
FM	1F10660467	N	289	236	U	940923	CO	205.80
BH	1F1F5C6C7A	N	270	211	F	940923	CO	207.85
BH	1F20185C4D	N	307	315	U	940923	CO	207.85
FM	1F1F571853	N	339	342	M	940923	CO	207.85
FM	1F1F73321D	N	335	352	M	940923	CO	208.90
BH	1F1E422A57	N	270	179	M	940923	CO	208.90
FM	1F7A302017	N	241	127	M	940924	CO	214.00
FM	7F7B016604	N	375	459	F	940924	CO	214.00
FM	7F7D085C5E	Y	403	643	M	940924	CO	214.00
BH	1F1F792029	N	259	167	M	940924	CO	214.00
FM	1F204F747E	N	259	145	M	940925	CO	214.40
FM	1F1F6C3224	N	285	211	U	940926	CO	227.10
FM	1F20476515	N	246	127	U	940926	CO	227.10
FM	1F1F624E12	N	321	294	F	940926	CO	228.80
FM	1F200D062E	N	312	257	F	940926	CO	229.80
FM	1F1F7D281D	N	240	125	U	940926	CO	229.90
BH	1F2044017C	N	273	198	U	940927	CO	234.90
FM	1F1F71361B	N	410	565	U	940928	CO	238.60
FM	1F2047007A	N	230	108	U	941001	CO	246.50
FM	1F1E43136D	N	326	258	U	941002	CO	248.00
FM	1F20093008	N	368	391	F	941002	CO	248.40
BH	1F2043116D	N	271	239	M	950108	CO	180.90
FM	1F7A3D7733	N	271	210	M	950108	CO	180.90
BH	1F7B6E2D4B	N	231	158	F	950108	CO	180.90

Table A-8. Continued

Species	PIT Tag	Recapture	TL (mm)	WT (g)	Gender	Date	River	River Mile
FM	1F14325843	Y	272	216	M	950108	CO	180.90
FM	1F1E483F3C	N	262	185	M	950108	CO	180.90
FM	1F78221631	N	259	163	M	950108	CO	181.60
FM	7F7F186D24	Y	236	126	M	950108	CO	181.60
FM	1F1F780842	N	390	601	M	950108	CO	181.70
FM	7F1F780842	N	351	403	M	950108	CO	181.70
FM	1F78683C3F	N	338	379	F	950108	CO	182.30
FM	1F7B0D7920	N	352	469	M	950108	CO	182.30
FM	1F7B0D1346	N	361	291	M	950108	CO	182.30
BH	1F1E4C4C2B	N	291	261	M	950109	CO	180.90
FM	1F77702852	N	285	216	M	950110	CO	180.90
FM	1F78384071	N	259	152	M	950110	CO	206.70
FM	7F7D40150C	N	330	381	M	950110	CO	207.80
FM	1F7A20784F	N	331	501	M	950110	CO	207.80
BH	7F7B020645	N	358	490	F	950110	CO	207.80
FM	7F7B020B0B	N	255	158	M	950110	CO	207.80
FM	7F7B02562B	N	274	214	M	950110	CO	207.90
FM	7F7B03542D	N	322	362	F	950110	CO	207.90
FM	7F7B02562B	Y	275	214	M	950110	CO	207.90
BH	7F7D401022	N	235	135	M	950110	CO	207.90
FM	7F7D7C353C	N	292	212	M	950111	CO	208.90
FM	1F7B562F61	N	362	422	M	950112	CO	224.80
FM	1F78717206	N	272	190	M	950112	CO	225.30
FM	7F7B02444C	Y	376	400	U	950114	CO	234.90

Table A-9. Mean length (± 1 SD) of flannelmouth sucker, striped bass, channel catfish, and common carp by trip in the Colorado River from Diamond Creek (RM 226) to below Pearce Ferry (RM 286) and tributaries, 1992-93. TL - total length, WT = weight, N = number of fish.

Species	Trip 1	Trip 2	Trip 3	Trip 4	Trip 5	Trip 6	Trip 7
			Main Channel				
Common Carp							
TL (mm)	403 (±114)	323 (±156)	481 (±46)	-	256 (±227)	385 (±89)	235 (±133)
N	87	145	79	-	27	12	10
WT (g)	980 (±515)	1161 (±523)	1440 (±575)	-	1522 (±924)	837 (±460)	340 (±458)
N	82	83	79	-	14	12	10
Flannelmouth sucker							
TL (mm)	390 (±30)	83 (±72)	237 (±97)	227	203 (±136)	341 (±62)	302 (±119)
N	2	30	6	1	8	6	5
WT (g)	623	345 (±31)	153 (±134)	106	192 (±235)	381 (±180)	356 (±269)
N	1	2	6	1	8	6	5
Striped bass							
TL (mm)	440 (±108)	-	266 (±4)	-	395 (±94)	503	452 (±75)
N	8	-	3	-	34	1	4
WT (g)	796 (±352)	-	189 (±13)	-	561 (±431)	1019	672 (±410)
N	8	-	3	-	32	1	4
Channel catfish							
TL (mm)	341 (±70)	297 (±47)	313 (±51)	290 (±42)	310 (±53)	354 (±51)	309 (±35)
N	36	21	21	32	105	8	5
WT (g)	356 (±214)	201 (±112)	283 (±149)	210 (±128)	289 (±168)	388 (±287)	215 (±91)
N	36	20	21	32	104	8	5
			Tributaries				
Common carp							
TL (mm)	419 (±58)	288 (±168)	-	-	-	389 (±138)	499 (±25)
N	22	3	-	-	-	4	3
WT (g)	906 (±503)	708 (±29)	-	-	-	2915 (±3970)	-
N	20	2	-	-	-	4	-
Flannelmouth sucker							
TL (mm)	-	-	69 (±9)	65	59 (±22)	113 (±28)	160 (±27)
N	-	-	8	1	20	47	3
WT (g)	-	-	-	1	2 (±4)	14 (±9)	31 (±17)
N	-	-	-	1	19	37	2
TL (mm)	187 (±4)	-	-	-	-	-	-
N	2	-	-	-	-	-	-
WT (g)	85	-	-	-	-	-	-
N	1	-	-	-	-	-	-
Channel catfish							
TL (mm)	248	-	-	319 (±79)	290 (±53)	-	-
N	1	-	-	9	28	-	-
WT (g)	142	-	-	241 (±146)	199 (±83)	-	-
N	1	-	-	4	23	-	-

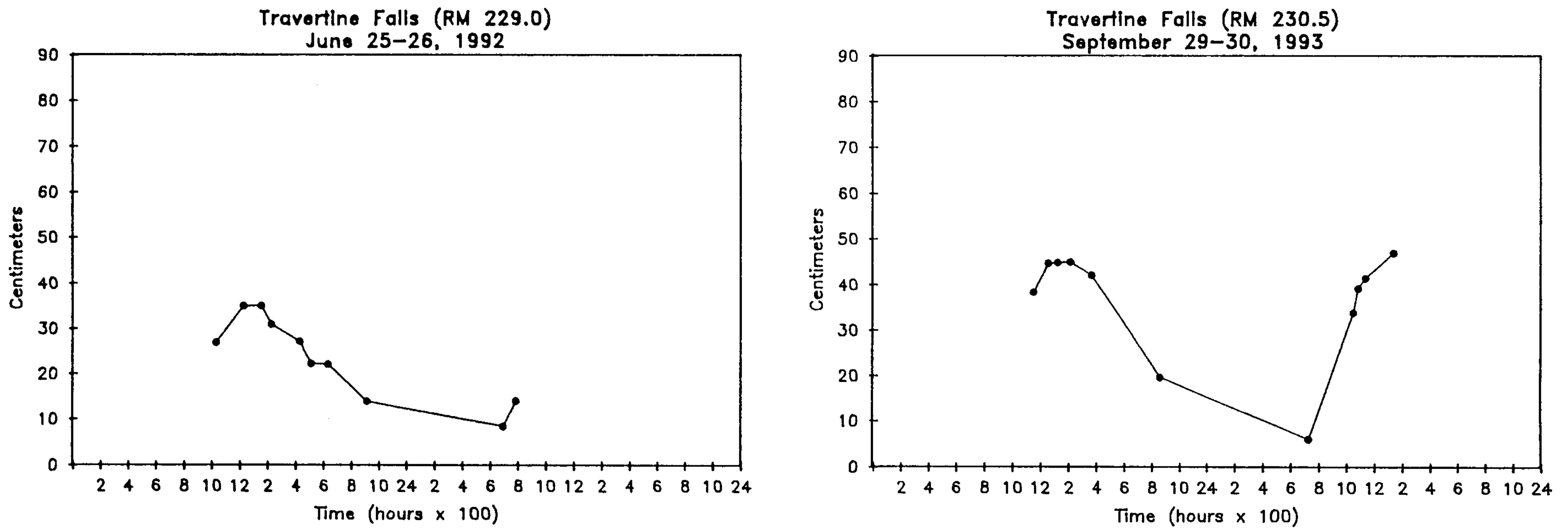


Figure A-1. Relative changes in river stage recorded at various locations in the mainstem Colorado River during 1992-93.

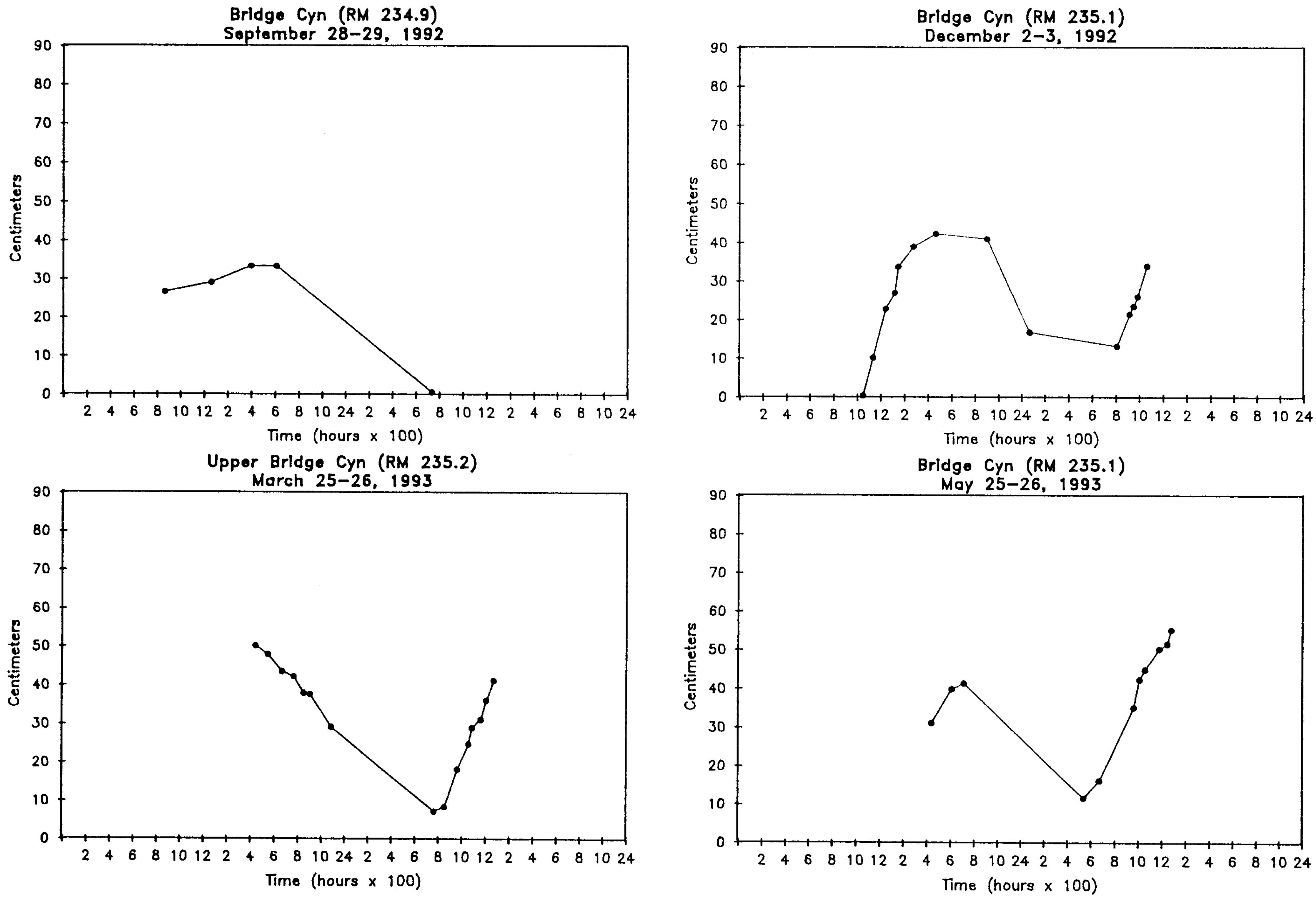


FIGURE A-1. CONTINUED.

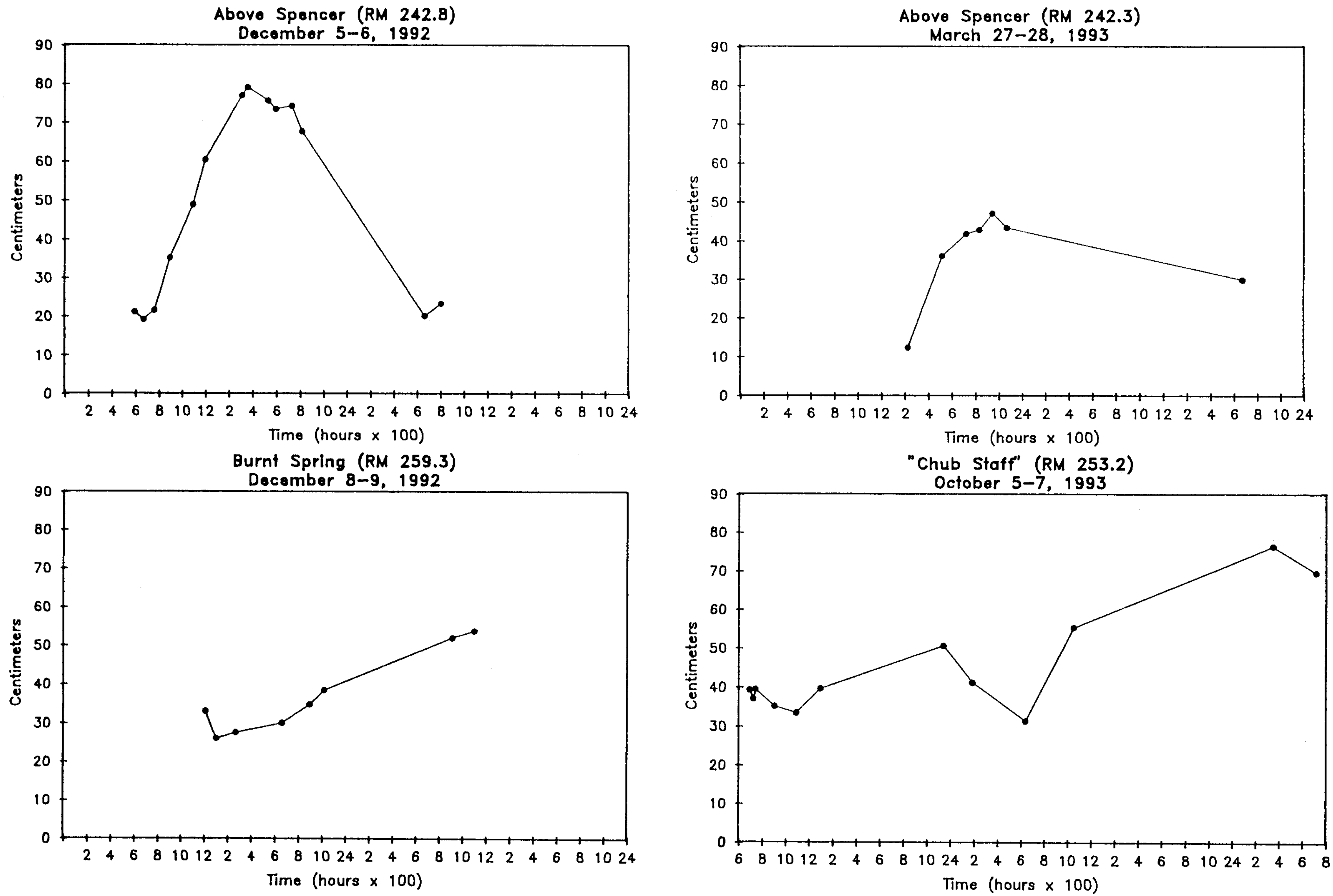
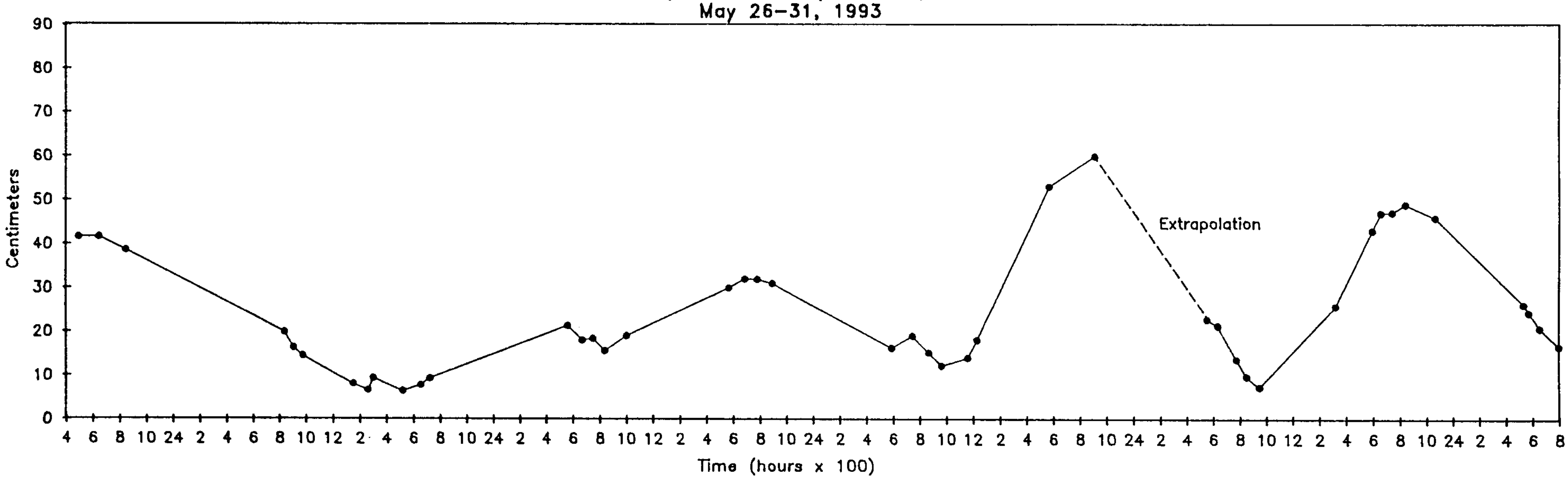


FIGURE A-1. CONTINUED.

Spencer Creek (RM 245.4)
May 26–31, 1993



Spencer Creek (RM 246.0)
October 2–4, 1993

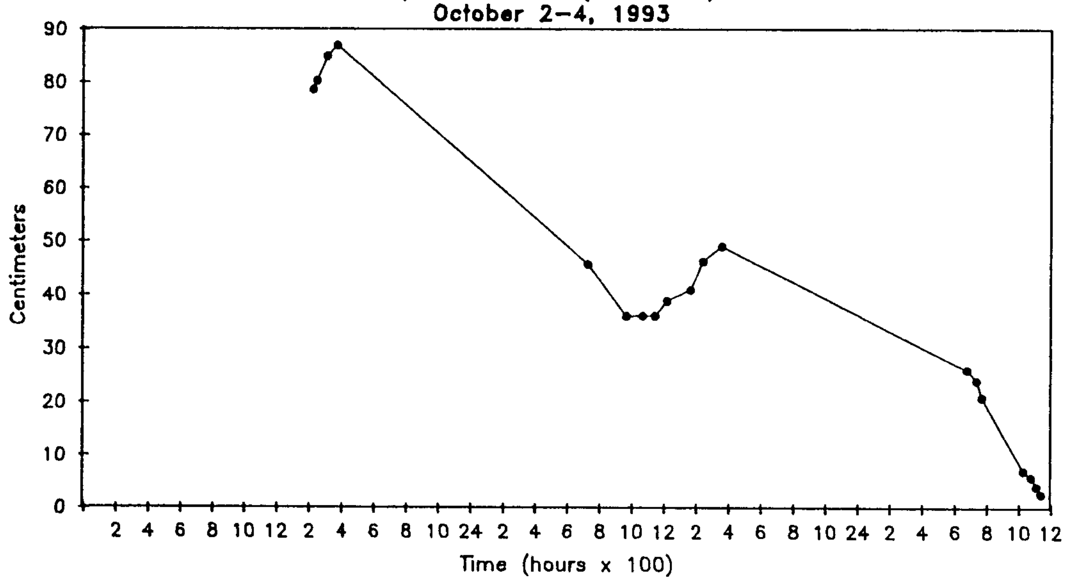


FIGURE A-1. CONTINUED.

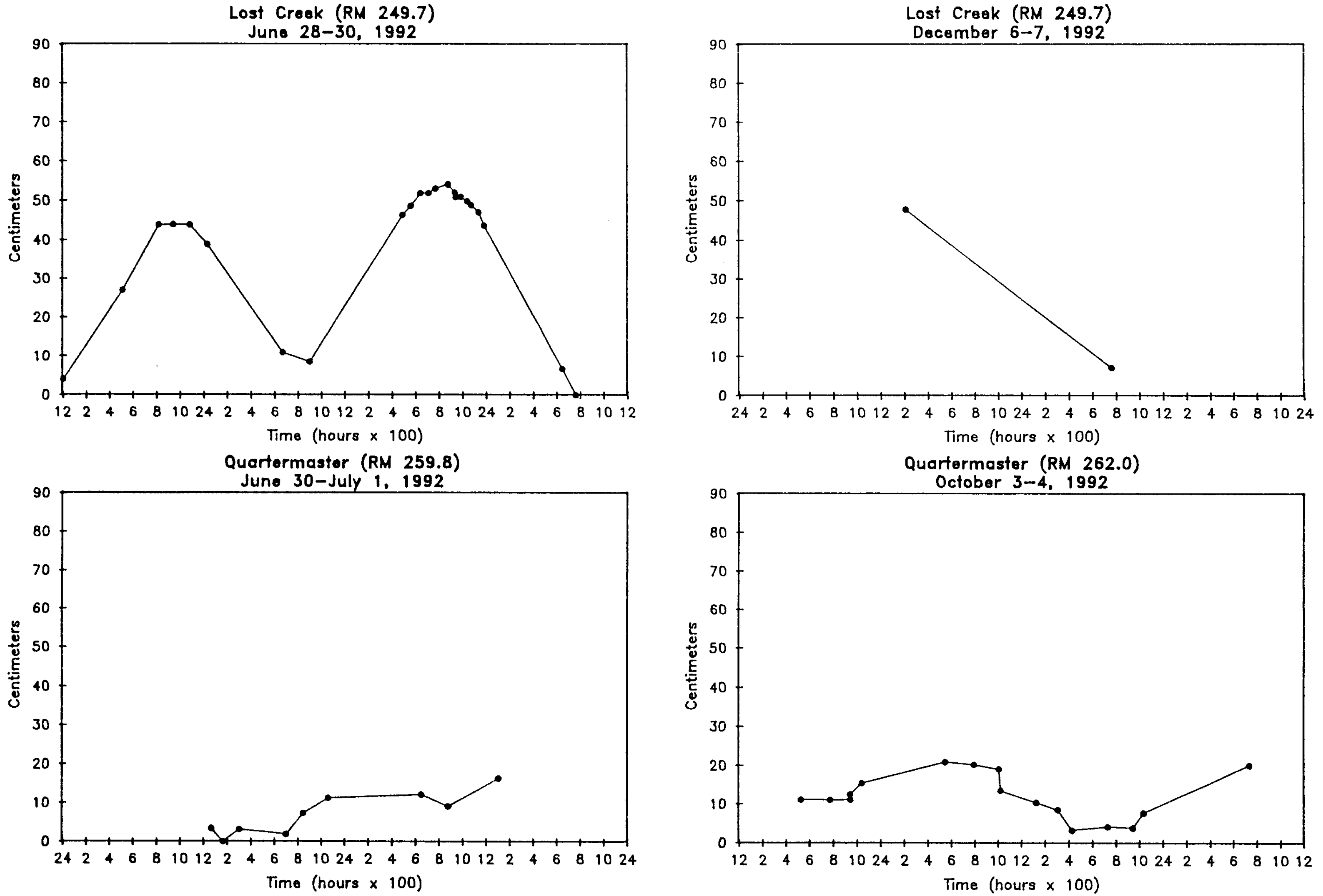
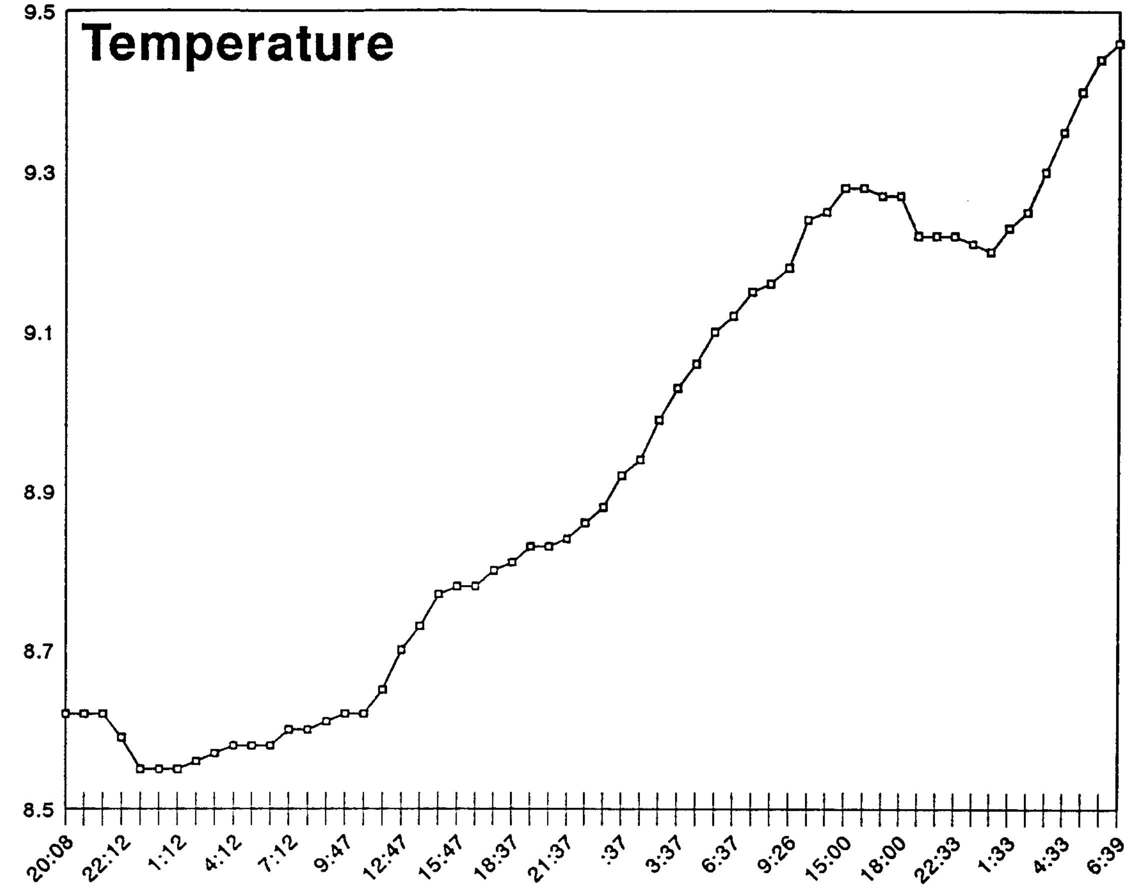


FIGURE A-1. CONTINUED.



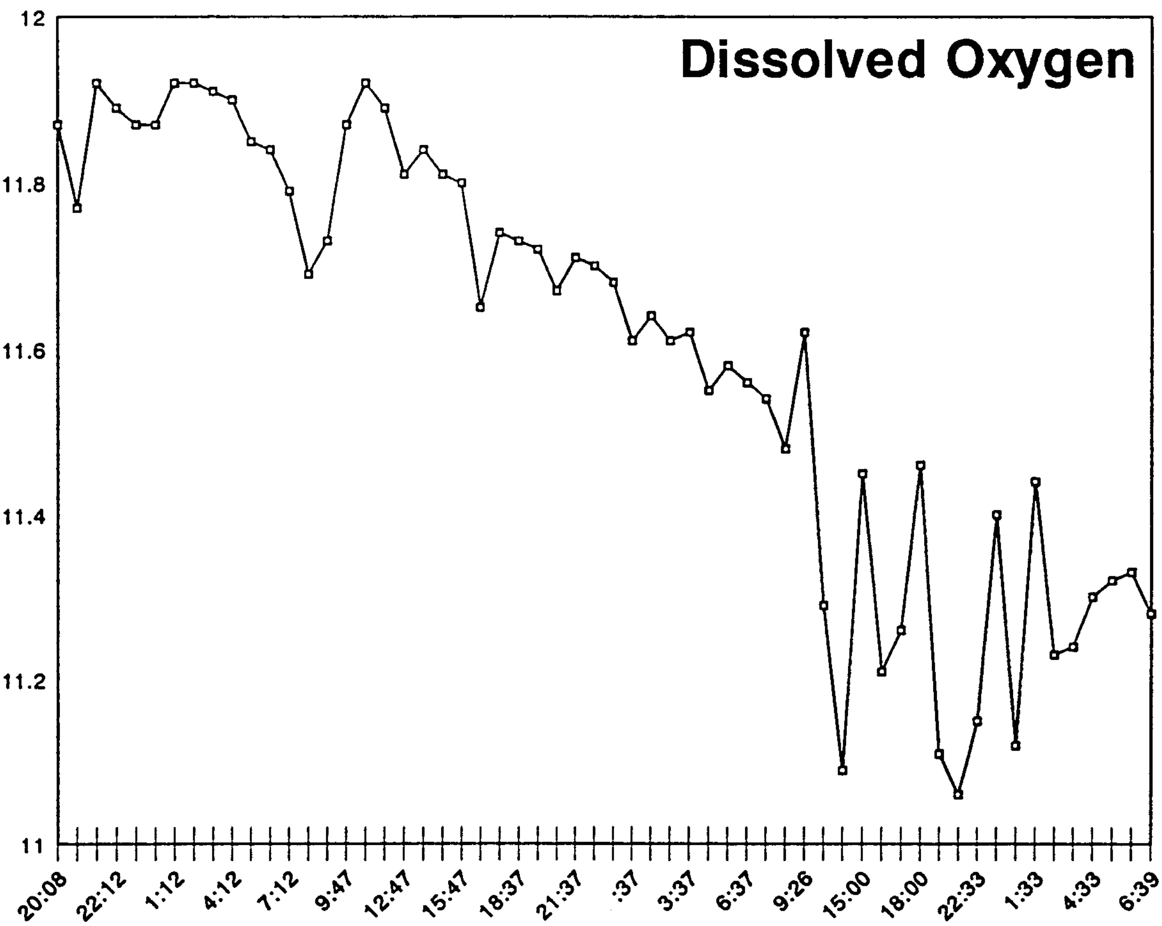
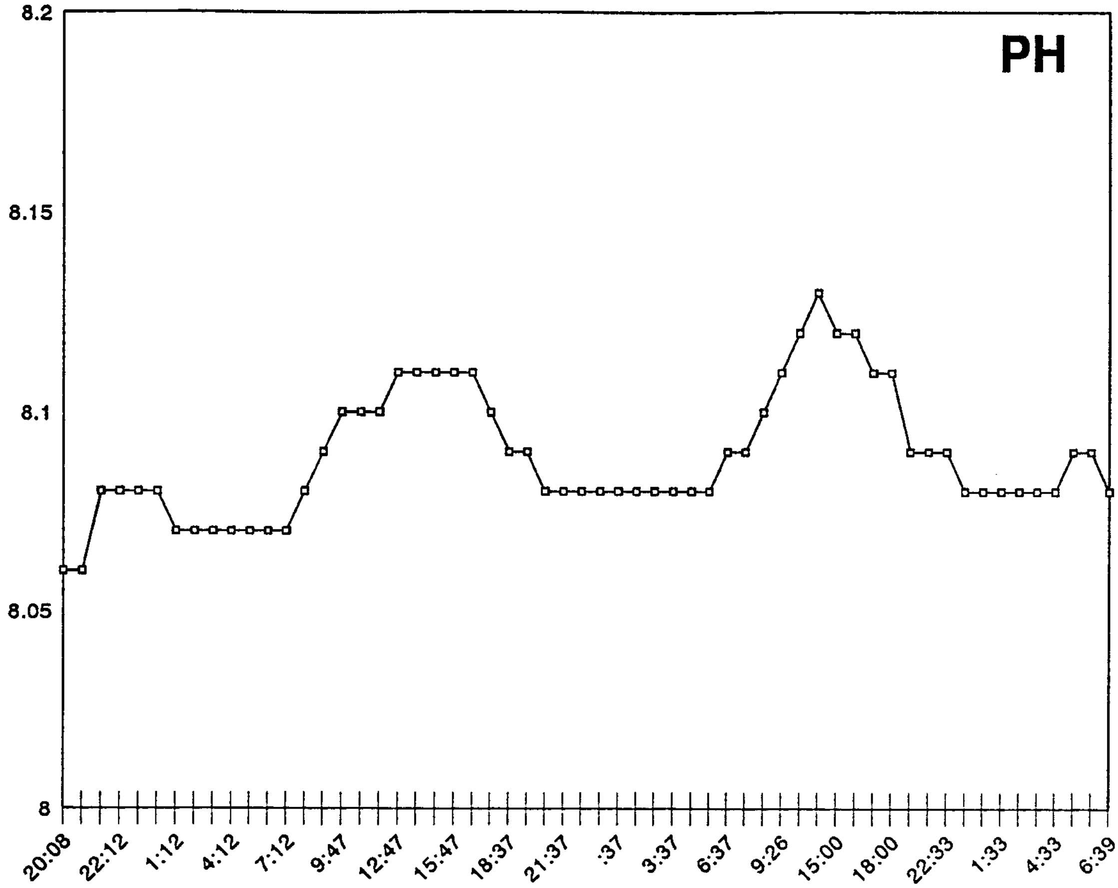


Figure A-2. Water quality parameters from the mainstem Colorado River at Spencer Canyon recorded with a Hydrolab Surveyor II on December 1-4 (2008-0639), 1992.



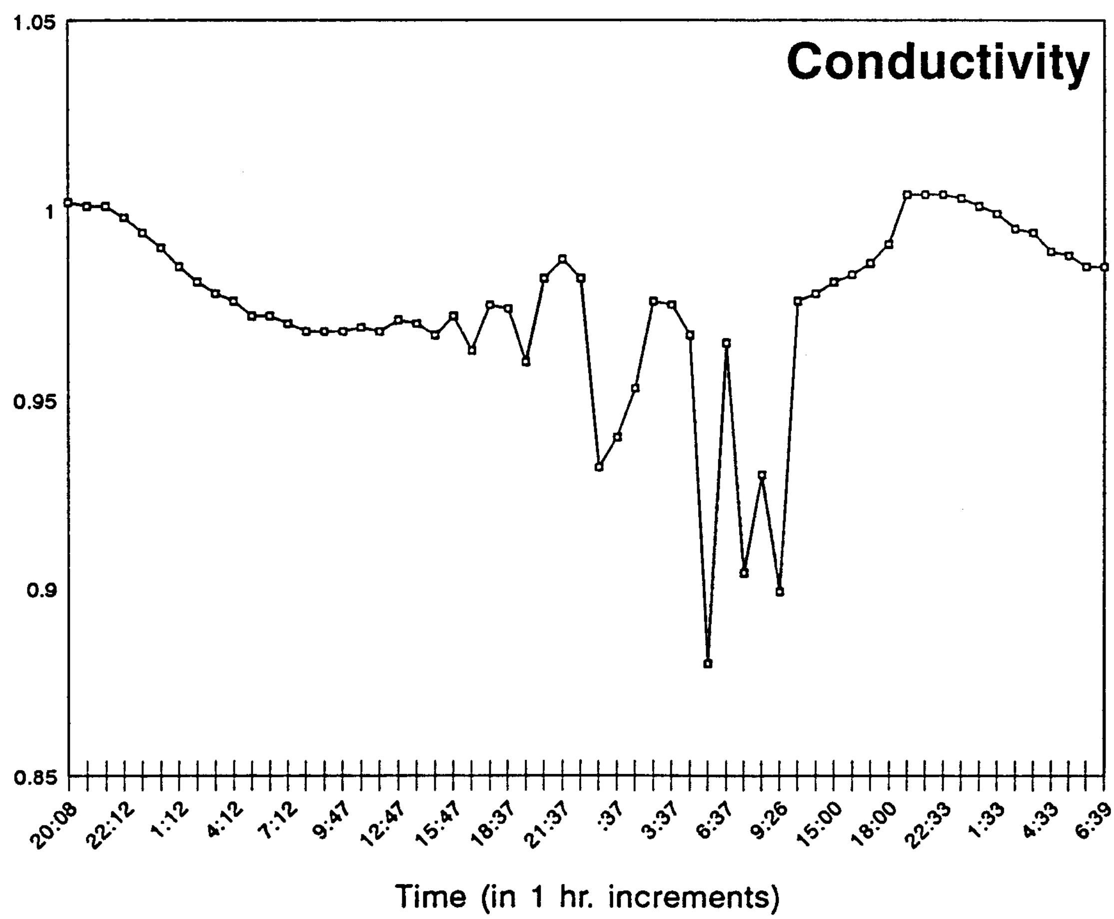


FIGURE A-2. **CONTINUED.**

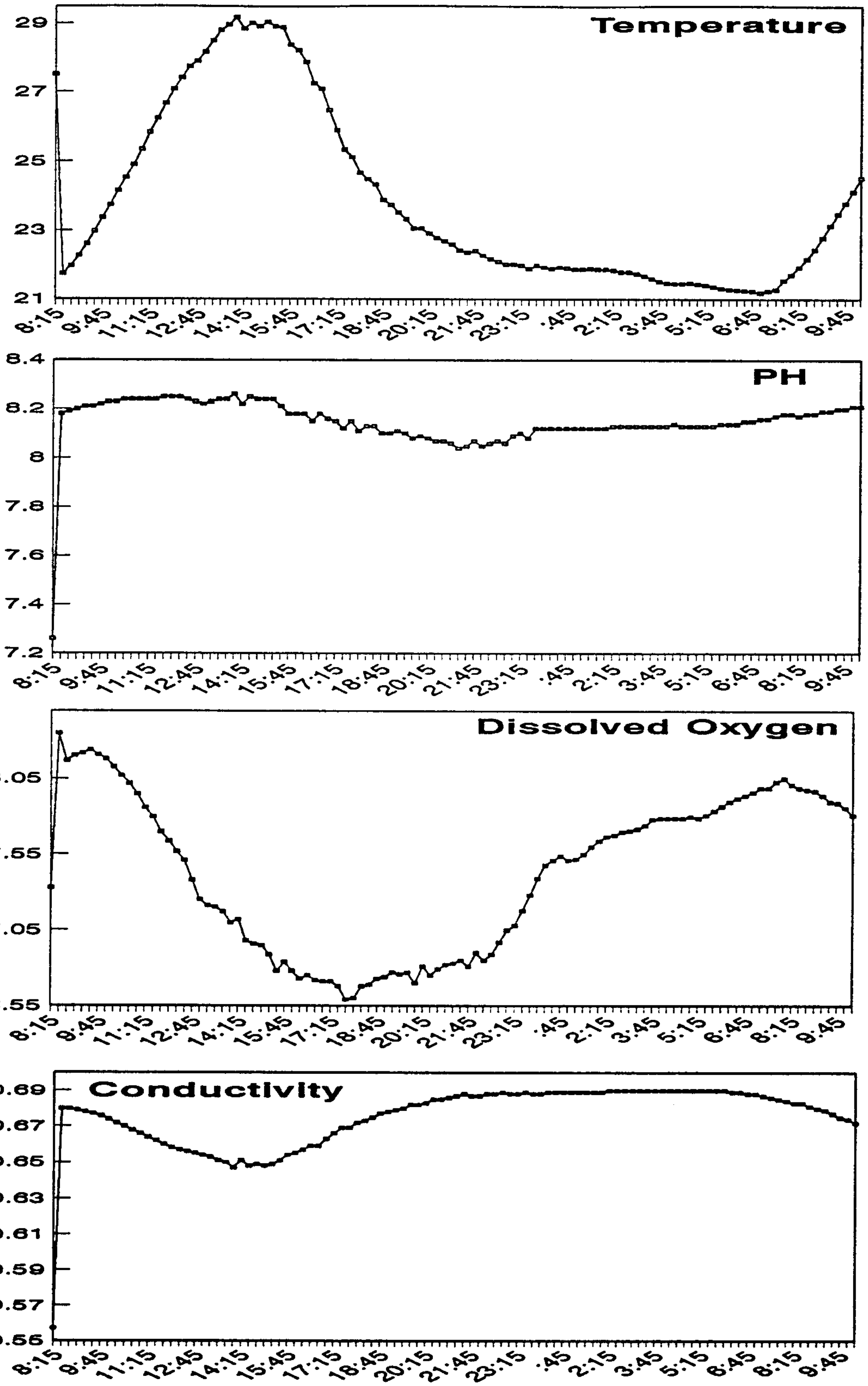


Figure A-3. Water quality parameters from Spencer Canyon recorded with a Hydrolab Datasonde on 26-28 June (0815-1015 hrs), 1992 (A), 30 September - 3 October (1300-0700 hrs), 1992 (B), 3-6 December (1500-0900 hrs), 1992 (C).

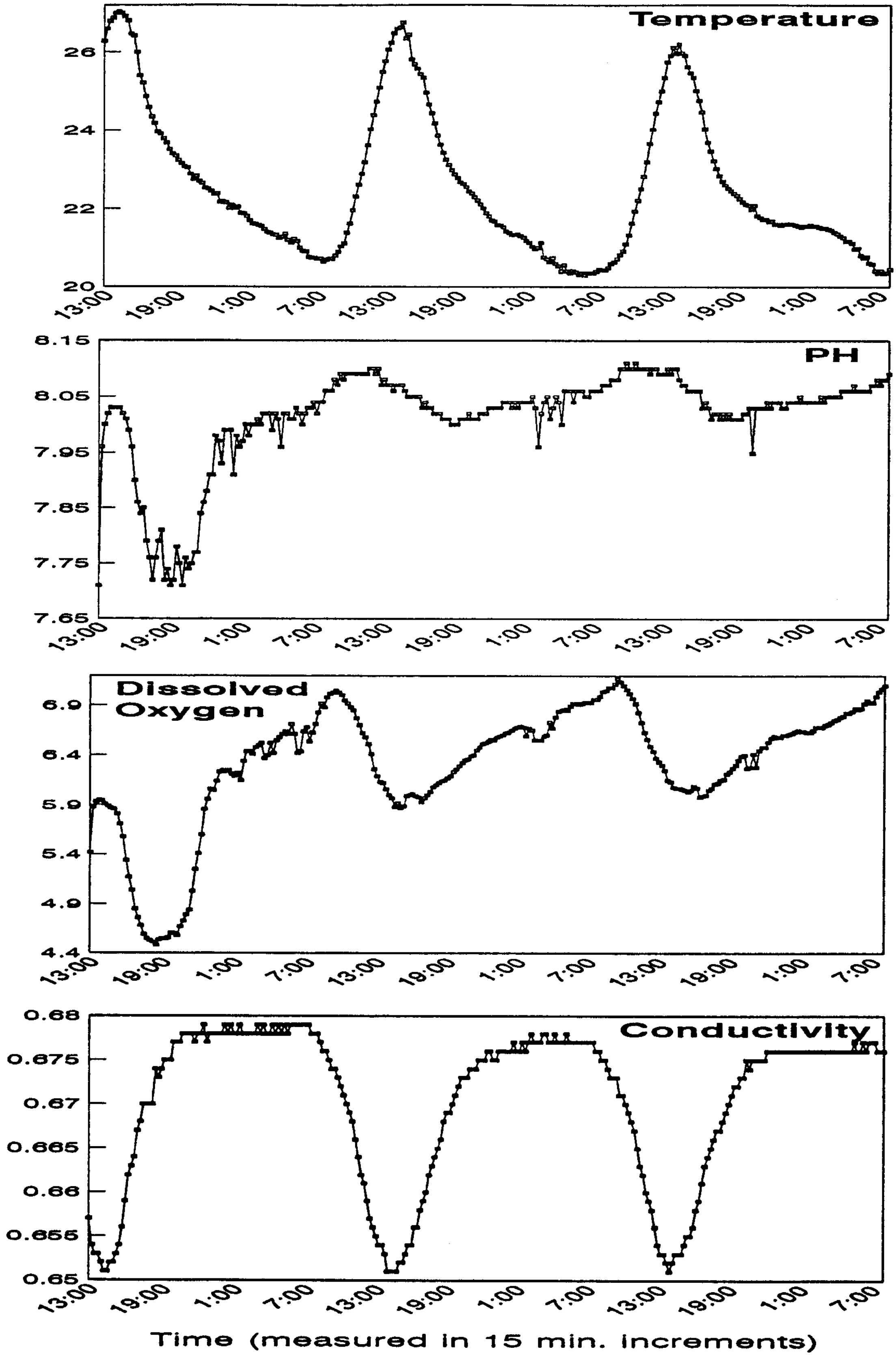


FIGURE A-3. CONTINUED.

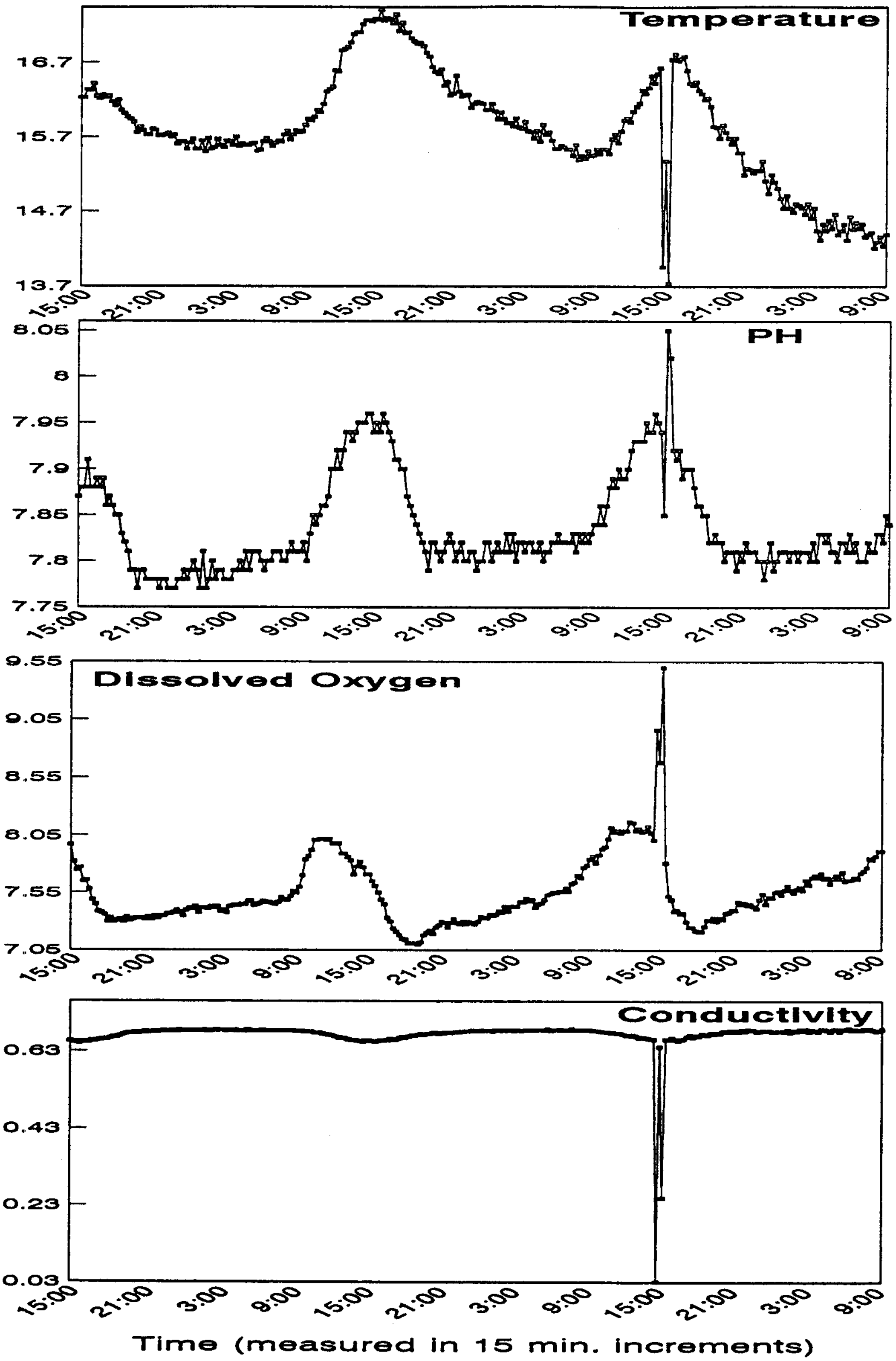


FIGURE A-3. CONTINUED.

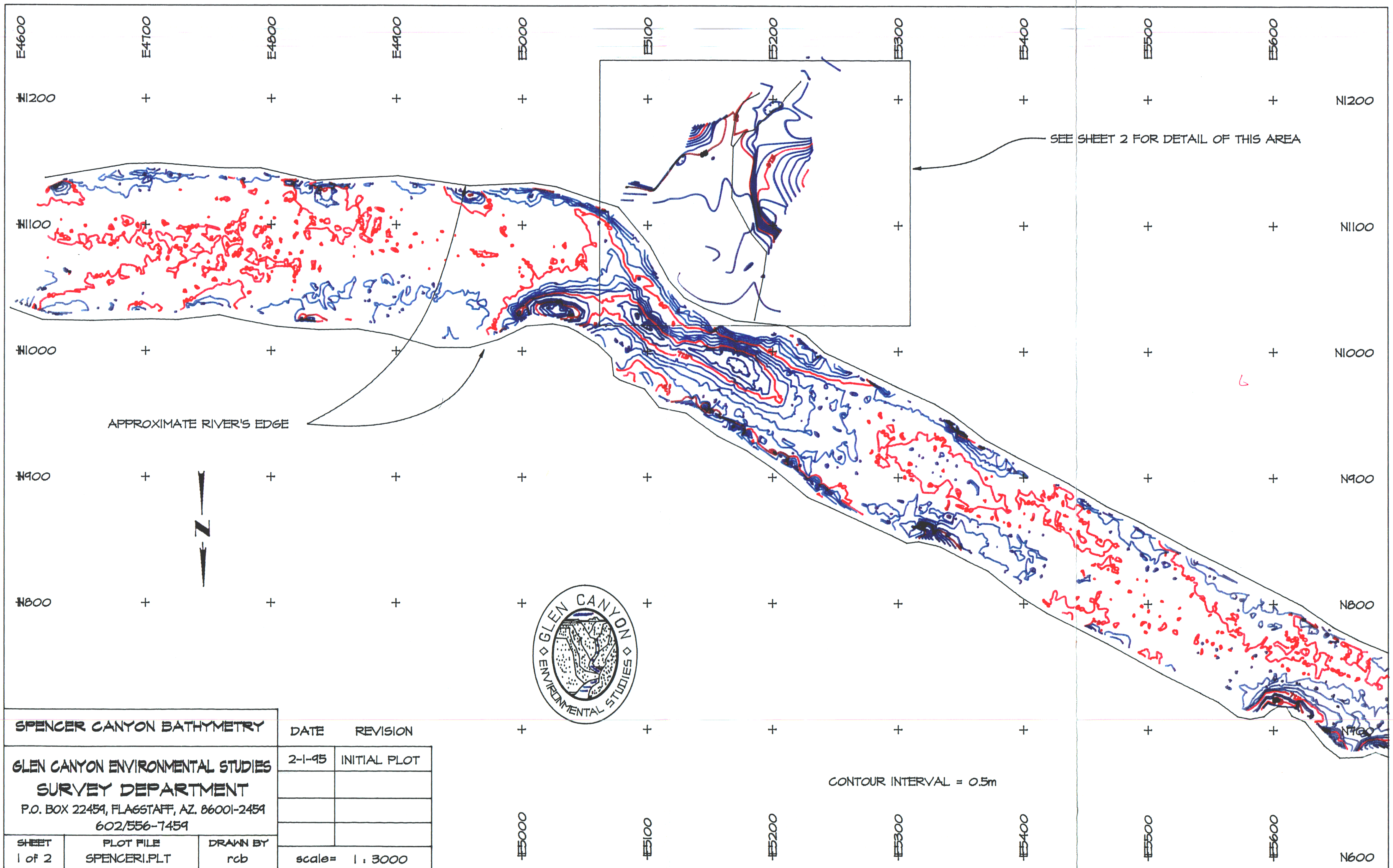


Figure A-4a. Bathymetry of the Colorado River at the Spencer Creek inflow (~RM 245.8-246.2). Initial plot.

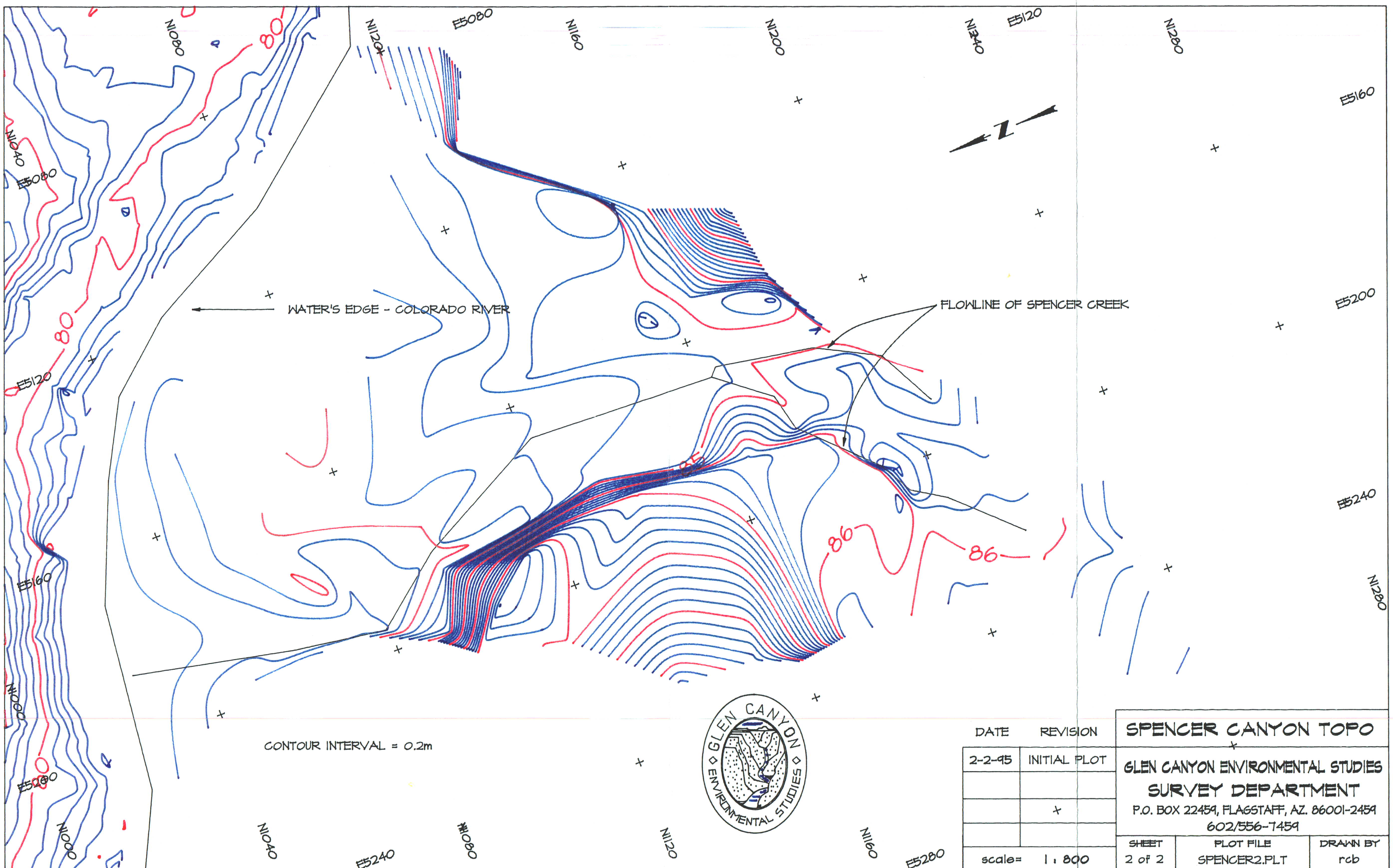
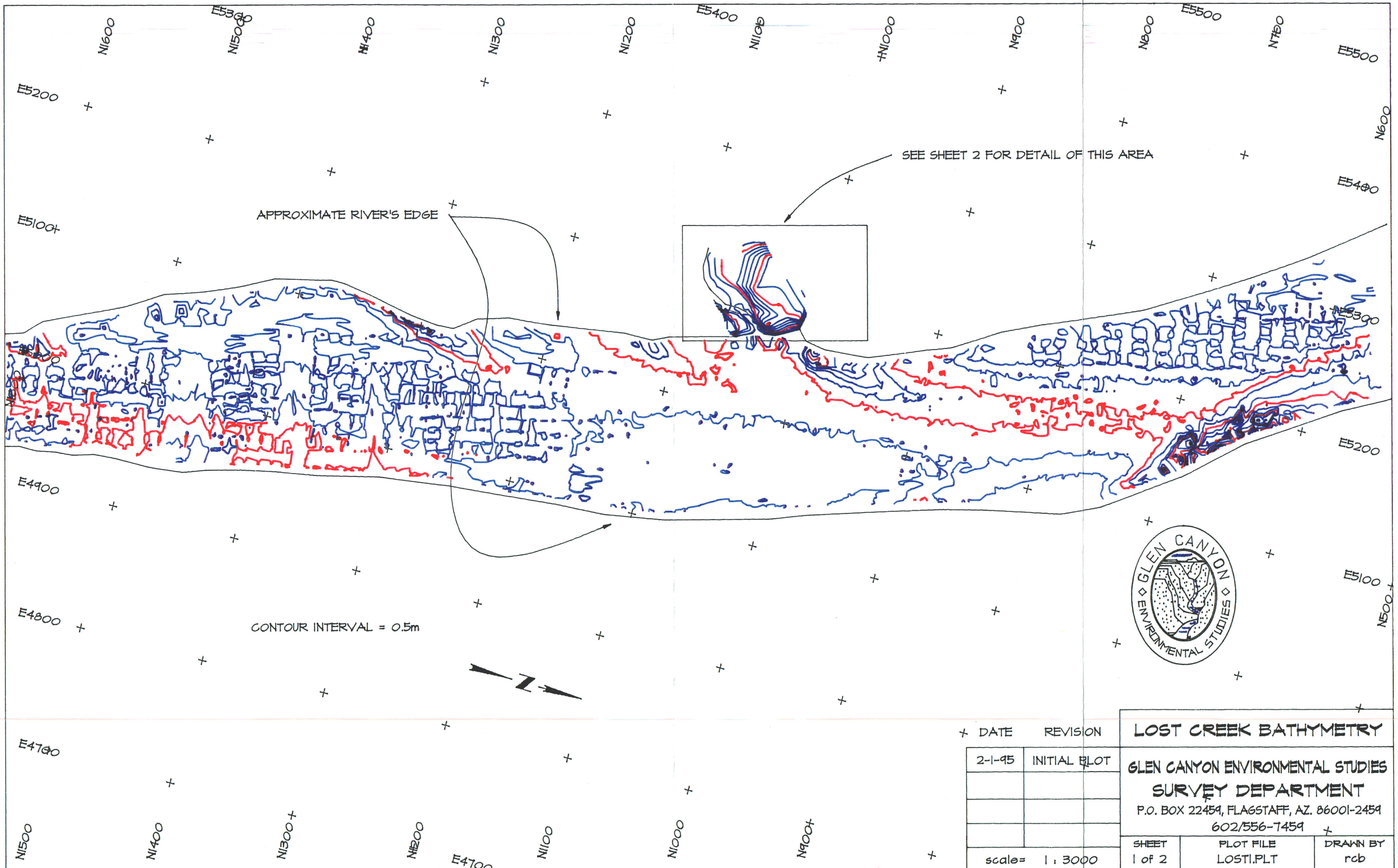


Figure A-4b. Bathymetry of the Spencer Creek inflow at RM 246.0. Initial plot.



DATE	REVISION
2-1-95	INITIAL PLOT
scale=	1 : 3000

LOST CREEK BATHYMETRY

GLEN CANYON ENVIRONMENTAL STUDIES
SURVEY DEPARTMENT
P.O. BOX 22459, FLAGSTAFF, AZ. 86001-2459
602/556-7459

SHEET	PLOT FILE	DRAWN BY
1 of 2	LOST1.PLT	rcb

Figure A-4c. Bathymetry of the Colorado River at the Lost Creek inflow (~RM 248.8-249.2). Initial plot.

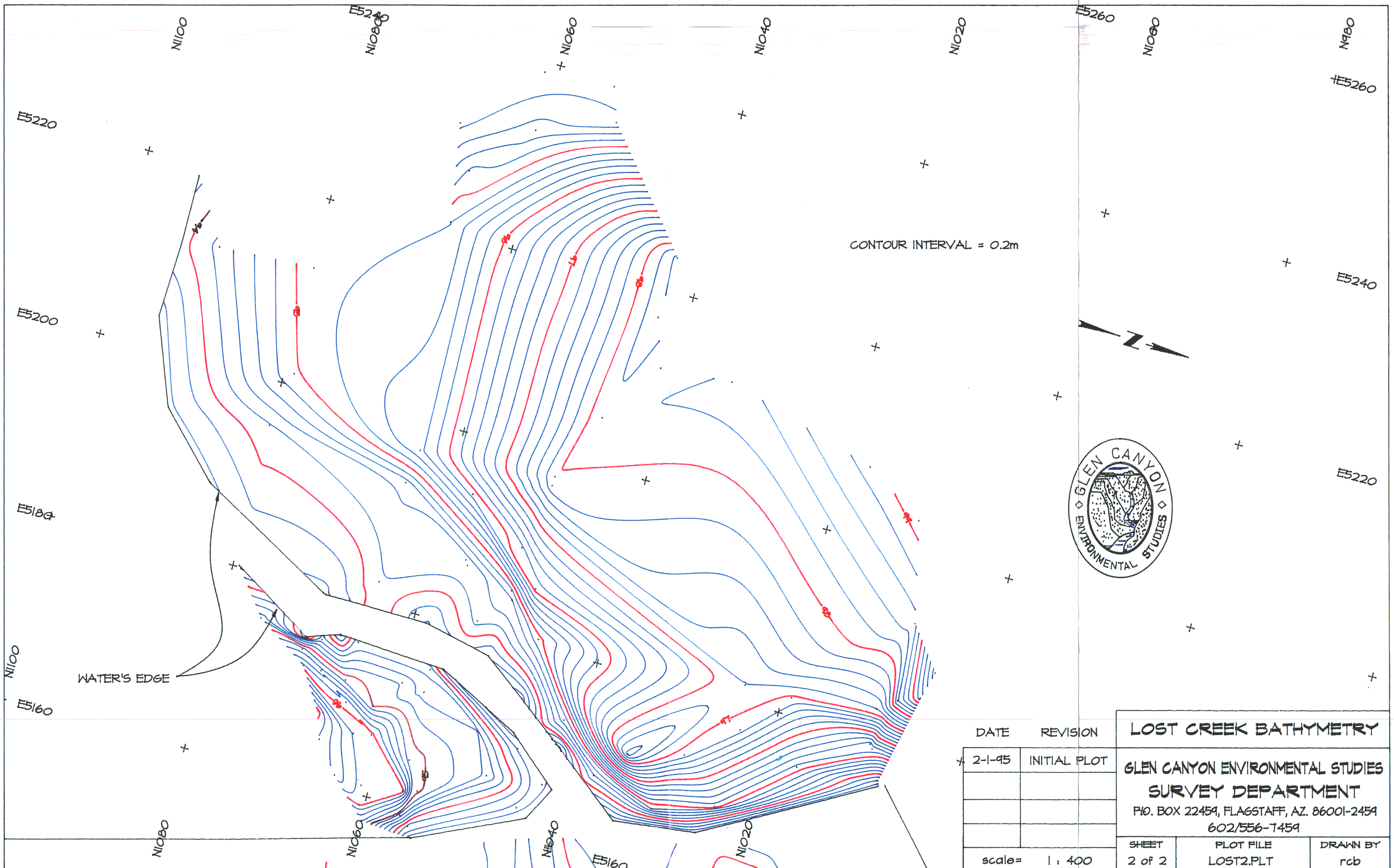


Figure A-4d. Bathymetry of the Lost Creek inflow at RM 249.0. Initial plot.