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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 I Report

Submitted To

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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, located about 240 miles upstream of the upper end of the study reach. Seven research trips were conducted from June 1992 to December 1993 to sample fishes, macroinvertebrates, water quality, and to monitor variability in river stage associated with flow changes.

River stage changes recorded each sampling trip showed maximum daily changes of about 60 cm, and about 90 cm over a 3-day period. Most daily stage changes in narrow canyon reaches were 40 to 60 cm, and 20-30 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 8,000-10,000 cfs between 2:00 am and 4:00 am, and highs of 13,000-15,000 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 through the study area in 1992 was 3°C, from 17.0°C at Travertine Canyon (RM 229.0) on June 24 to 20.0°C at Grand Wash Cliffs (RM 276.0) on July 1. Surface temperature at Pearce Ferry was 24.5 to 26.0°C on July 1. Water temperature ranged from 15.0°C at Bridge Canyon (RM 235.0) on September 27, to 23.0°C at Pearce Ferry (RM 280.0) on October 7. December water temperatures ranged from 8.6°C at Bridge Canyon on December 1, to 10.2°C at Scorpion Island (RM 277.5) on December 11, 1992. Mainstem temperature in 1993 was similar and varied from about 8.5°C in December to about 20°C in September. 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, simulids, 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. Nineteen 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 in large numbers in spring. Red shiners, fathead minnows, and mosquitofish were consistently most common in tributaries, and 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. 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.

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 indicate that these may be the only suitable locations for successful reproduction by native species in the area. Mainstem habitats may be too altered by sediment deposits or temperature modification to provide suitable conditions, and the large number 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 fish 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 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 have been identified to current fish population distributions and levels. 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, limiting 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 effect of fluctuating flows, low temperatures, absence of spring runoff, and particularly nonnative fishes, has 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.

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ACKNOWLEDGEMENTS

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 want to particularly thank Morris Samson for his continued involvement. Ben Zimmerman also provided key field and administrative support, and technical guidance.

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INTRODUCTION

Effects of interim flows from Glen Canyon Dam on the aquatic resources of the lower Colorado River were evaluated from Diamond Creek to Pearce Ferry in Lake Mead, from June 1992 through December 1993. 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.

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. The study was designed to integrate with fishery investigations from Lees Ferry to Diamond Creek, from October 1991 through November 1993 (Valdez et al. 1990, 1991, Valdez and Hugentobler 1992, Valdez and Ryel 1994). Although this Phase I study was originally designed to sample the region from Diamond Creek to Pearce Ferry, this report represents the first step in integrating data collected from the Colorado River and its tributaries along the entire northeastern boundary of the Hualapai Indian Reservation, from near National Canyon (RM 164.5) to near Emery Falls Canyon (RM 273.5). Phase II of this study is a planned expansion of data collection to include the region from National Canyon to Diamond Creek in 1994, following discontinuation of monthly sampling of this region by B/W in November 1993.

This Phase I Report provides analyses and interpretation of data collected in seven field trips from June 1992 through December 1993, and supplements the 1992 Annual Report (Valdez 1993). Reports were submitted following each trip to provide a brief summary of results, and copies of these are available from B/W.

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).

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. Decline of these native species is attributed to habitat inundation and fragmentation, migration blockage, altered flow regimes, reduced water temperature, altered water quality, and invasion of nonnative fishes.

Patterns and magnitude of flow in 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 (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 interim flows on aquatic resources of lower Grand Canyon as part of the GCES 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 (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 Diamond Creek (RM 226) 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 60 miles of the Colorado River and selected tributaries from Diamond Creek (RM 226) to below Pearce Ferry (RM 286) (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 1994) were integrated for the region from National Canyon to Diamond Creek 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).

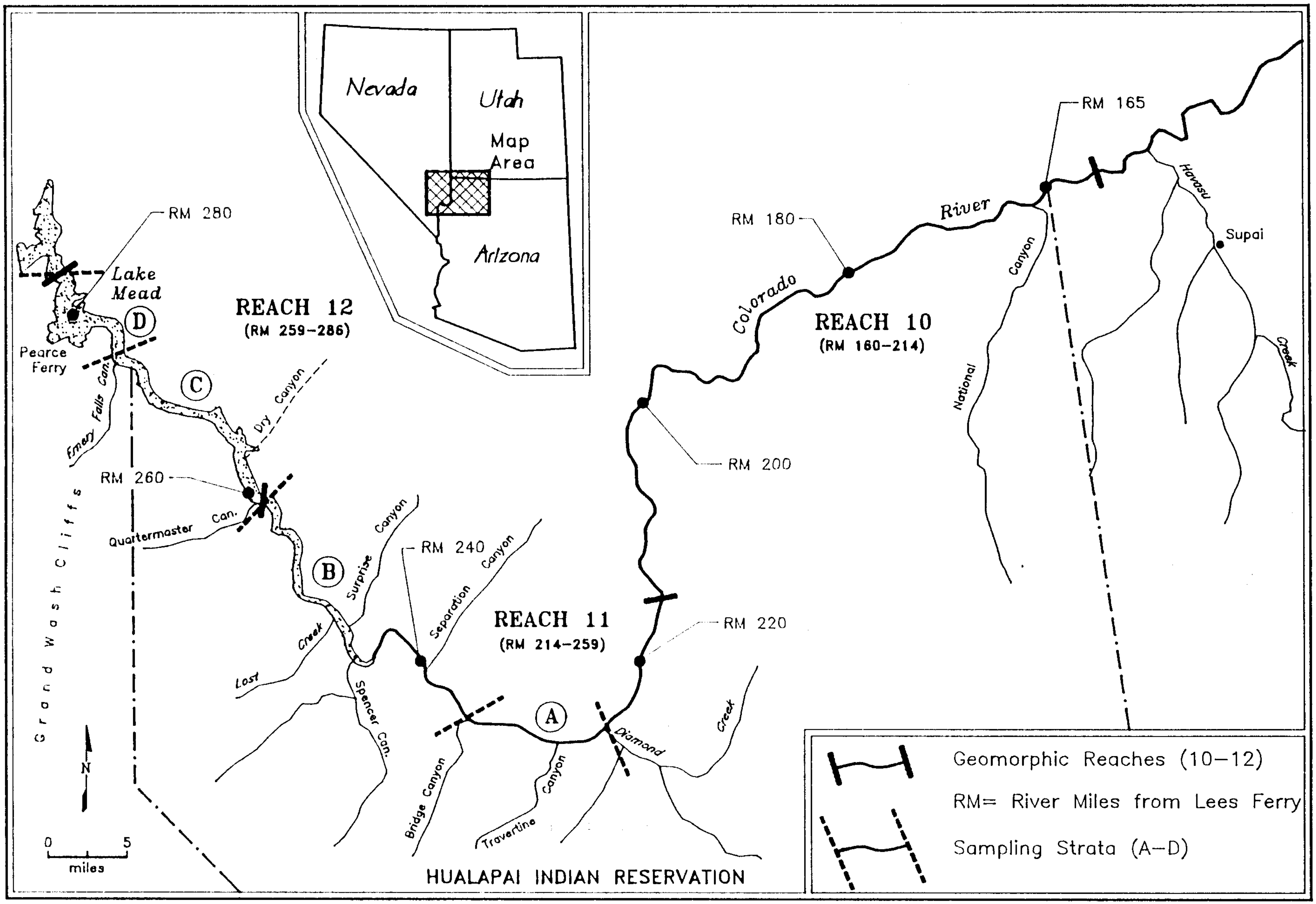


Figure 1. The Colorado River along the northern boundary of the Hualapai Indian Reservation, and Reaches 10-12, with sampling strata A-D from Diamond Creek to below Pearce Ferry.

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 1994). 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 (0.13%), and a bed composition of 32 percent bedrock and boulders (Schmidt and Graf 1988). 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 (0.16%), 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.

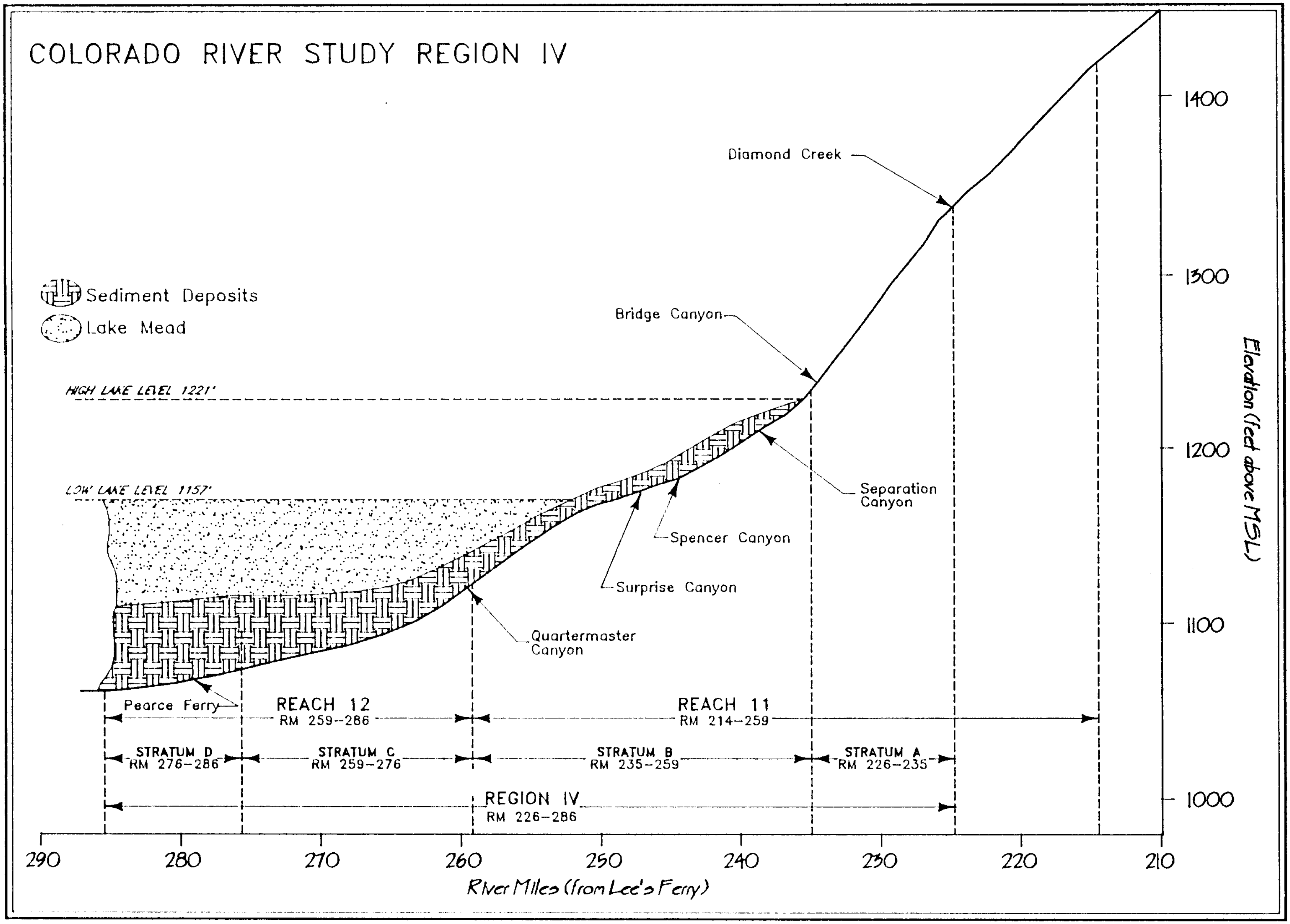


Figure 2. Longitudinal cross-section of Reaches 11-12 of the Colorado River from RM 214 to RM 286.

SAMPLING STRATA

The 60-miles reach of river between Diamond Creek and below Pearce Ferry was divided longitudinally into four sampling strata, each with different habitat complexes. Stratum 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 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 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 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. Two geomorphic reaches and four sampling strata were identified to longitudinally stratify the area from Diamond Creek 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 two 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 derived from other research conducted by BIO/WEST, Inc (Valdez et al. 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 (Table A-1). Sampling was also 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 meassuredfrom 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

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).

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/8 A to 200 V/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/8 A to 150 V/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 method (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

Trammel nets and gill 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 were less efficient (Valdez and Ryel 1994), 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 A and Stratum 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.

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) 1992-93.

	Number of Sampling Efforts							
	1992			1993				
	Trip 1	Trip 2	Trip 3	Trip 4	Trip 5	Trip 6	Trip 7	Totals
Electrofishing								
EL - 220-v DC (Coffelt CPS)	20	52	29	39	61	29	25	255
Gill Nets								
GM - 100'x6'x2"	5	7	8	8	-	-	-	28
GP - 100'x6'x1.5"	13	13	5	4	22	-	-	57
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	-	205
TL - 75'x6'x1.5"x12"	40	36	40	55	26	30	29	256
TM - 50'x6'x1"x12"	4	-	16	9	43	25	44	141
TN - 50'x6'x1.5"x12"	3	33	16	39	18	14	38	161
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	41
Seines								
SA - 10'x3'x1/8" seine	4	-	-	4	7	10	-	25
SB - 30'x4'x1/4" seine	-	11	19	-	-	-	-	30
SG - 30'x5'x1/4" seine	-	5	8	-	-	-	-	13
Angling								
AN - angling with artificial or live bait	1	-	-	-	-	-	-	1
Total	**125**	**206**	**203**	**251**	**208**	**131**	**142**	**1266**

Table 3. Relative sampling effort within 4 strata (A-D) of the mainstem Colorado River from Diamond Creek (RM 226) to below Pearce Ferry (RM 286)[a], 1992-93.

Sample Strata	Gear Type[b]																	
	EL	GM	GP	GX	GS	TK	TL	TM	TN	TW	HM	HS	MT	SA	SB	SG	AN	Totals
A (225.0-235.0)	31	3	3	4	-	14	49	24	24	-	1	-	9	2	-	-	-	164
B (235.1-259.0)	128	4	17	2	-	113	140	61	84	3	-	-	14	15	20	11	1	613
C (259.1-276.0)	70	18	28	26	-	72	58	51	42	-	-	2	14	8	10	1	-	400
D (276.1-286.0)	26	3	9	4	10	6	9	5	11	-	-	1	4	-	-	1	-	89
Totals:	**255**	**28**	**57**	**36**	**10**	**205**	**256**	**141**	**161**	**3**	**1**	**3**	**41**	**25**	**30**	**13**	**1**	**1266**

[a] Significant land marks:

Diamond Creek	RM 225.7	Quartermaster Canyon	RM 259.8
Travertine Canyon	RM 229.1	Dry Canyon	RM 264.5
Bridge Canyon	RM 235.2	Hualapai Indian Reservation Boundaries	RM 164.5-273.5
Separation Canyon	RM 239.5	Emery Falls Canyon	RM 274.3
Spencer Canyon	RM 246.0	Grand Wash Cliffs	RM 276.5
Surprise Canyon	RM 248.4	Grand Canyon National Park/Lake Mead	
Lost Creek	RM 248.9	National Recreation Area Boundary	RM 276.6
Salt Creek	RM 255.5	Pearce Ferry	RM 280.0
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), 1992-1993.

Sampling Equipment Gear Code - Description	Number of Samples 1992 Trip 1	1992 Trip 2	1992 Trip 3	1993 Trip 4	1993 Trip 5	1993 Trip 6	1993 Trip 7	Totals
Diamond Creek (RM 226.0)								
SA - 10'x3'x1/8" seine	-	-	-	-	-	4	4	8
Travertine Falls Creek (RM 230.4)								
DN - Dip net	-	-	-	-	-	1	-	1
Spencer Creek (RM 246.0)								
BP - Backpack electrofishing	-	-	3	4	4	10	6	27
HM - 3' diameter (medium)	2	-	-	-	-	-	-	2
MT - commercial minnow traps	-	6	-	24	9	14	15	68
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	-	-	7
HM - 3' diameter (medium)	-	-	1	-	-	-	-	1
HS - 2' diameter (small)	-	-	2	-	-	-	-	2
MT - commercial minnow traps	-	4	3	6	3	10	4	30
SA - 10'x3'x1/8" seine	3	-	-	-	2	3	2	10
SB - 30'x4x1/4" seine	-	1	4	-	-	-	-	5
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	-	-	5
MT - commercial minnow traps	4	-	-	8	5	-	-	17
SG - 300'x6'x2" seine	-	1	-	-	-	-	-	1
Quartermaster Canyon (RM 259.8)								
HM - 3' diameter (medium)	1	-	-	-	-	-	-	1
MT - commercial minnow traps	-	4	-	-	-	-	-	4
SA - 10'x3'x1/8" seine	1	-	-	-	-	-	-	1
Total	**18**	**23**	**14**	**50**	**28**	**46**	**35**	**214**

A

B

C

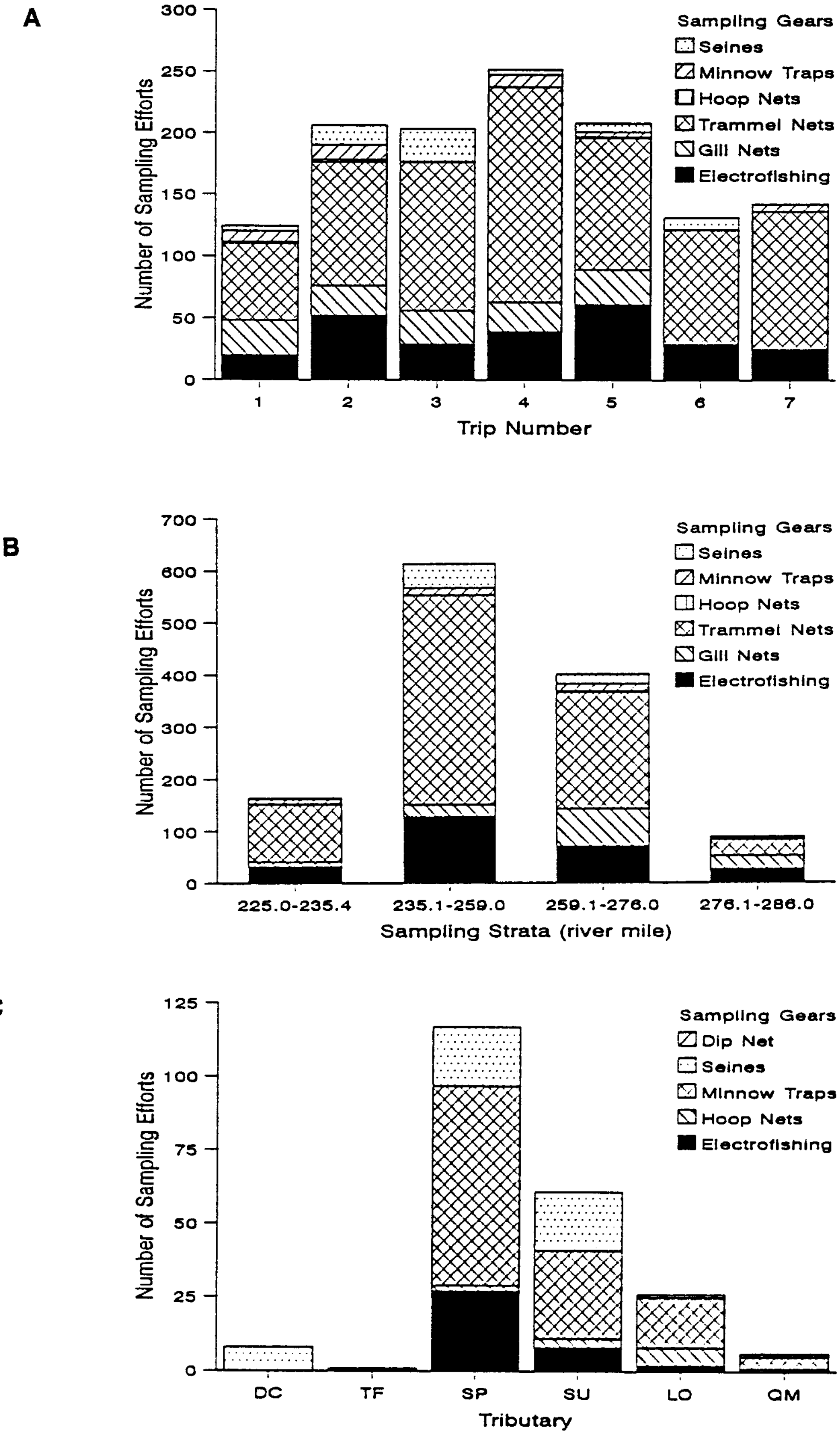


Figure 3. Sample effort by trip (A), sample strata (B), and tributary (C) for the Colorado River from Diamond Creek (RM 226) to Pearce Ferry (RM 286) June 1992-December 1993.

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 in 1992 and 1993. 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 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 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).

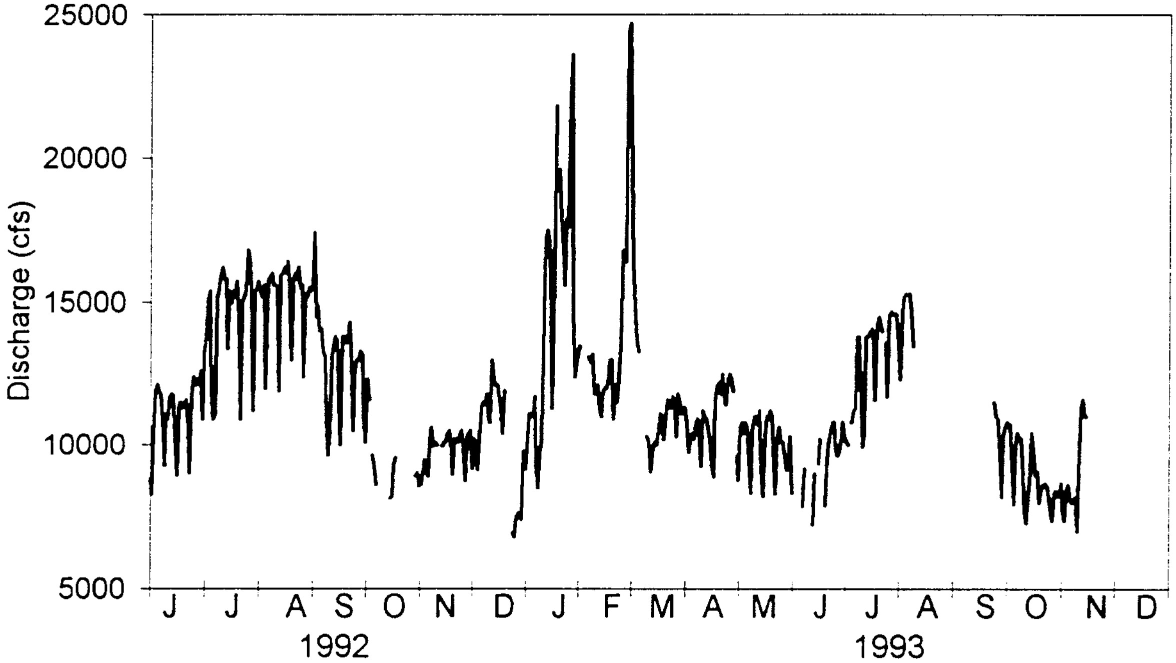


Figure 4. Flow of the Colorado River at Diamond Creek (USGS gage 9404200), from June 1992 through December 1993.

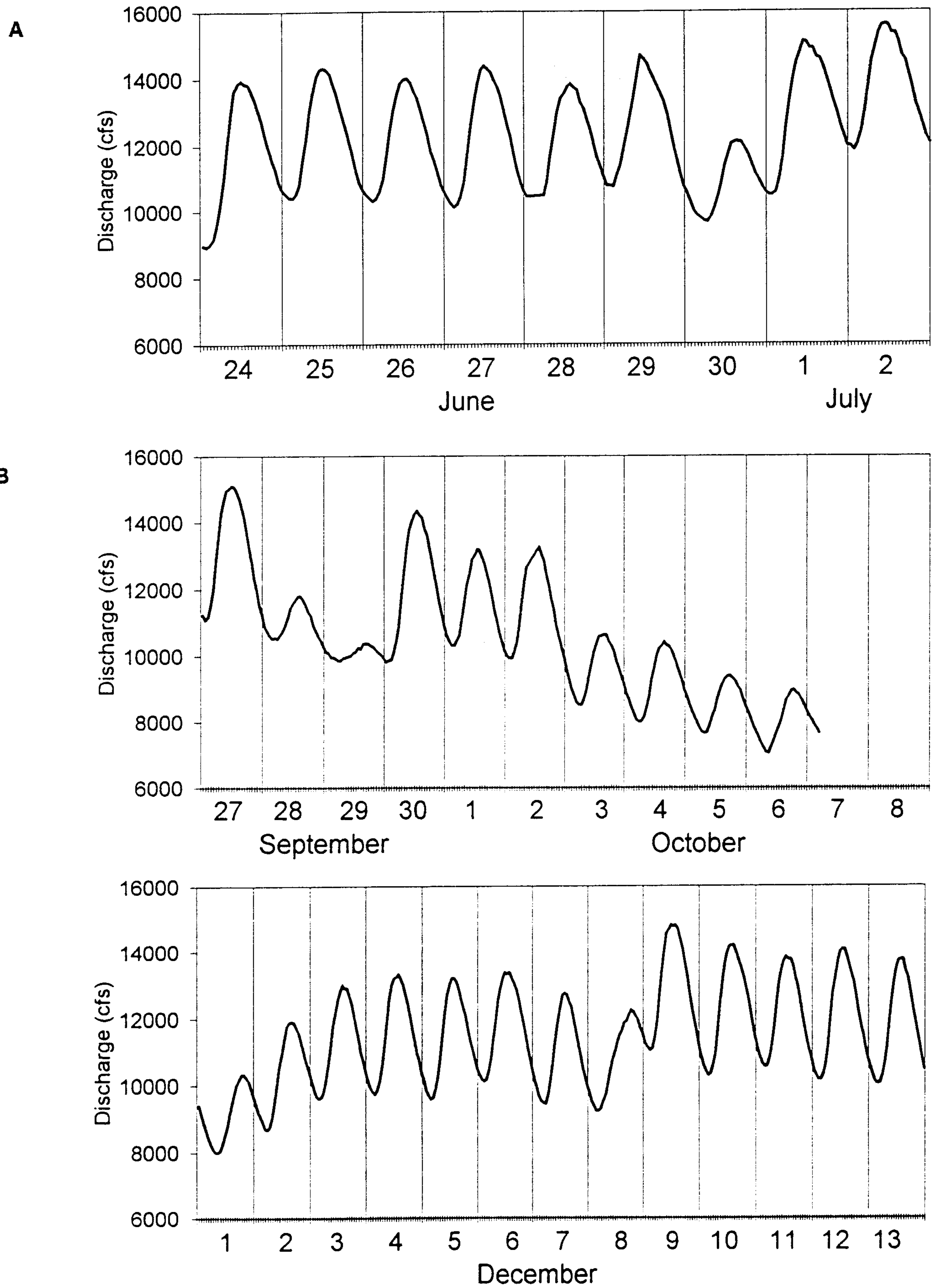
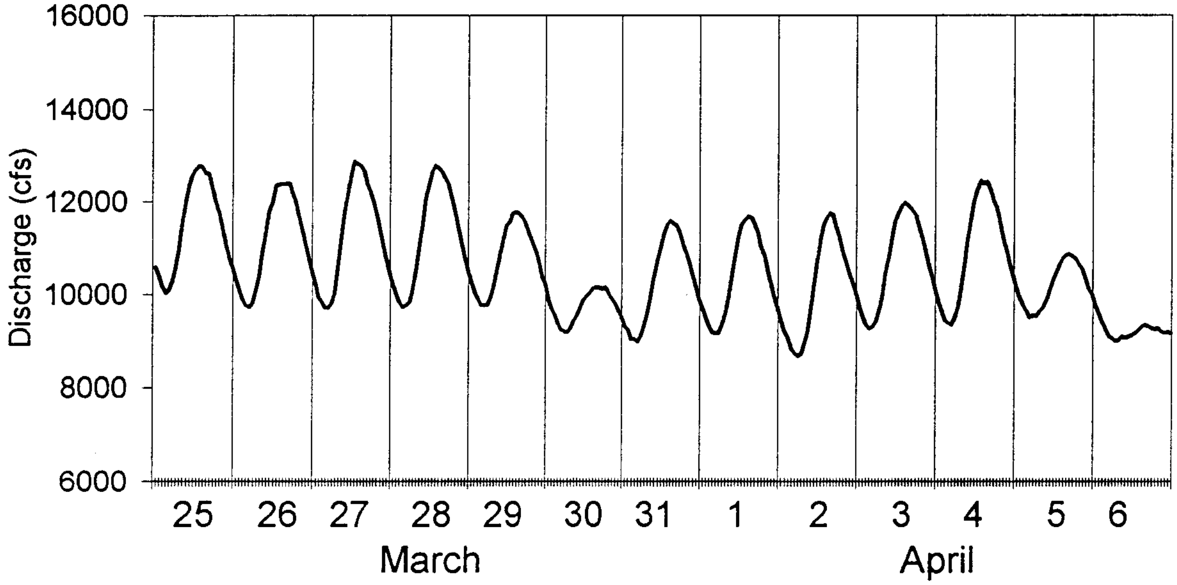
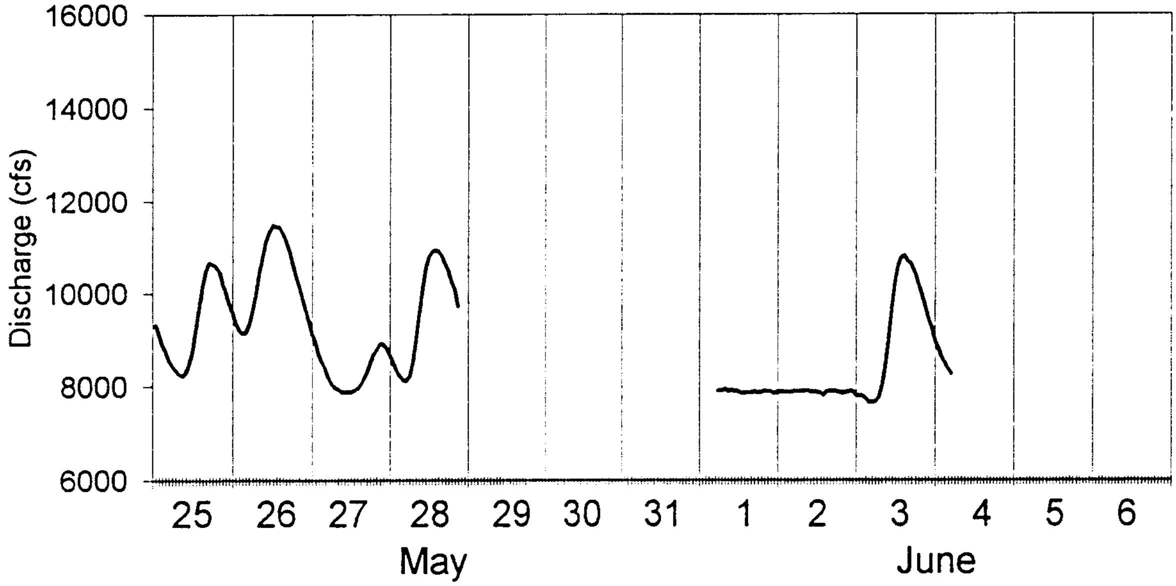


Figure 5. Flow of the Colorado River at Diamond Creek (USGS gage 9404200), for six sampling trips: June 24-July 2, 1992 (A), September 27-October 9, 1992 (B), December 1-13, 1992 (C), March 25-April 6, 1993 (D), May 25-June 6, 1993 (E), and September 28-October 10, 1993 (F).

D



E



F

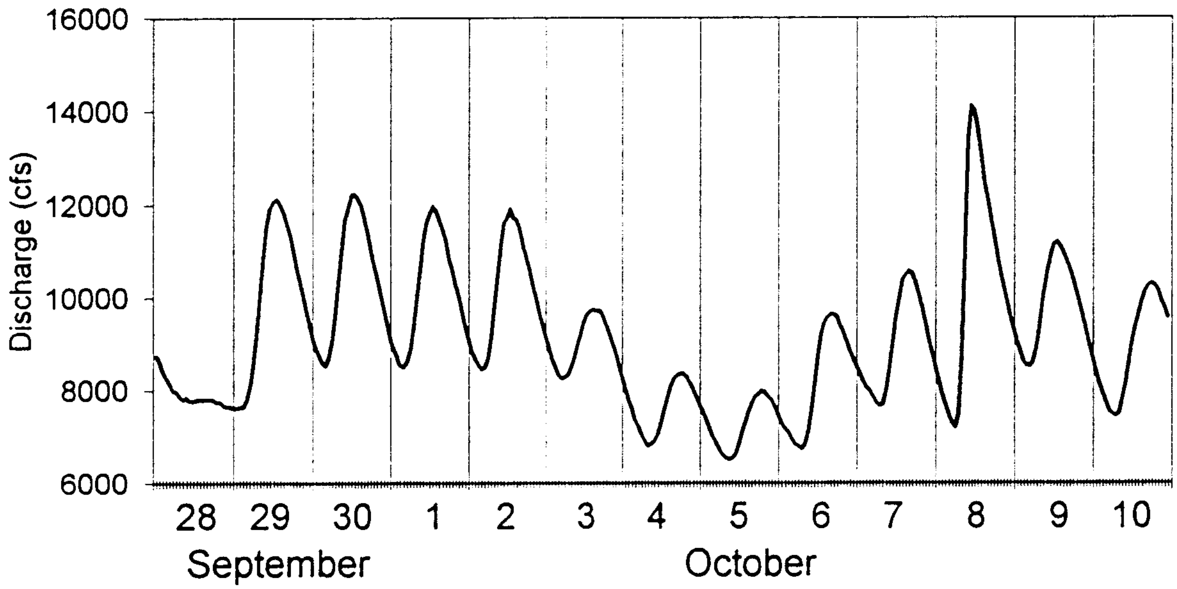


Figure 5. Continued.

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. 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 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 in September, and 7.0 to 8.0 mg/l 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

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-June	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

is very common further upriver (especially near Glen Canyon Dam) accounted for only a small proportion of drift during all seasons. Relative abundance of terrestrial insects varied considerably with season.

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

Nineteen fish species representing 10 families were captured in Region IV (mainstem and tributaries) during this investigation (Table 8, Table A-7). Native fish species were uncommon, representing only about 7 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 (158), bluehead sucker (1), and speckled dace (1071). The only native species considered common was the speckled dace.

Of 158 flannelmouth suckers, 25 were young-of-year (YOY), 109 were juveniles, and 24 were adults. All but one speckled dace captured were adults, and the humpback chub and bluehead sucker (TL=249 mm) were adults. During the entire study only one PIT-tagged fish, a flannelmouth sucker, was recaptured (Table A-8). This individual was recaptured at the location (RM 230.7) where it was originally marked, suggesting that it remained in the same section of river for about 2 months. According to length and weight measurements, this flannelmouth sucker increased in length (3 mm) and weight (24 g) from October to December.

Nonnative species accounted for about 93 percent of the fish collected during the study (Table 8). The most abundant species in the region was the red shiner (61%), followed by fathead minnow

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), May 1992 - December 1993.

Species Code	Common (Scientific) Name	LAR	YOY	JUV	ADU	Total	Per %
Family:	Catostomidae (suckers)						
BH	bluehead sucker (Catostomus discobolus)	0	0	0	1	1	<0.1
FM	flannelmouth sucker (C. latipinnis)	0	25	109	24	158	0.9
Family:	Centrarchidae (sunfish)						
BC	black crappie (Pomoxis nigromaculatus)	0	2	0	3	5	<0.1
BG	bluegill (Lepomis macrochirus)	0	0	33	6	39	0.2
GS	green sunfish (Lepomis cyanellus)	0	2	3	4	9	<0.1
LM	largemouth bass (Micropterus salmoides)	0	7	25	8	40	0.2
Family:	Clupeidae (herringa)						
TS	threadfin shad (Dorosoma petenense)	0	0	0	320	320	1.8
Family:	Cyprinidae (minnows)						
CP	common carp (Cyprinus carpio)	0	135	86	1014	1235	6.9
FH	fathead minnow (Pimephales promelas)	0	15	647	2701	3363	18.8
HB	humpback chub (Gila cypha)	0	0	0	1	1	<0.1
RS	red shiner (Cyprinella lutrensis)	0	160	867	9943	10970	61.3
SD	speckled dace (Rhinichthys osculus)	0	0	1	1070	1071	6.0
Family:	Cyprinodontidae (killifishes)						
PK	plains killifish (Fundulus zebrinus)	0	0	8	41	49	0.3
Family:	Ictaluridae (catfishes, bullheads)						
BB	black bullhead (Ameiurus melas)	0	0	0	2	2	<0.1
CC	channel catfish (Ictalurus punctatus)	0	0	1	321	322	1.8
Family:	Percichthyidae (temperate basses)						
SB	striped bass (Morone saxatilis)	0	0	3	64	67	0.4
Family:	Percidae (perches)						
WE	walleye (Stizostedion vitreus)	0	0	0	2	2	<0.1
Family:	Poeciliidae (livebearers)						
GA	mosquitofish (Gambusia affinis)	0	22	22	207	251	1.4
Family:	Salmonidae (trout)						
RB	rainbow trout (Oncorhynchus mykiss)	0	0	1	3	4	<0.1
TOTALS:		**0**	**366**	**1806**	**15737**	**17909**	**100**

(19%). Common carp, channel catfish, and striped bass were the predominant large species captured throughout the region. All life-stages of carp were encountered, including 135 YOY, 86 juveniles, and 1014 adults. Of 67 striped bass captured, 64 were classified as adults and 3 as juveniles, and all but one channel catfish were classified as adults.

Striped bass found in the mainstem in June 1992 were primarily small males with pink, maturing gonadal sacs, indicating the fish were 2 to 3 weeks from spawning. During Trip 5 a large number of carp were found in spawning condition in the mainstem and in Spencer Canyon. Red shiner were also observed spawning in tributaries at this time.

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 1994), but 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 immature 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.

Tributaries

Although only 12 of 19 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

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) May 1992-December 1993.

Family Code - Common Name	1992 Trip 1	 Trip 2	 Trip 3	1993 Trip 4	 Trip 5	 Trip 6	 Trip 7	Total	Per %
Family: Suckers									
BH - bluehead sucker						1		1	<0.1
FM - flannelmouth sucker	2	30	6	3	10	7	5	63	1.4
Family: Sunfish									
BC - black crappie	1	1				1	2	5	0.1
BG - bluegill		37			1	1		39	0.9
GS - green sunfish		1		2	4			7	0.2
LM - largemouth bass	1	22			3		9	35	0.8
Family: Herrings									
TS - threadfin shad	13	297			4		6	320	7.1
Family: Minnows									
CP - common carp	86	150	79	362	247	25	22	971	21.6
FH - fathead minnow		170	4		10	8	26	218	4.9
HB - humpback chub						1		1	<0.1
RS - red shiner	86	1128	137	103	696	42	72	2264	50.4
SD - speckled dace	1	35			8	7	3	54	1.2
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	256	5.7
Family: Temperate basses									
SB - striped bass	11		3	3	42	2	4	65	1.4
Family: perches									
WE - walleye	1		1					2	<0.1
Family: live bearers									
GA - mosquitofish	26	40	2		105	4		177	3.9
Family: trout									
RB - rainbow trout					3			3	0.1
Total	274	1932	253	510	1252	107	160	4488	100

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) May 1992-December 1993.

Tributary (River Mile) Code - Common Name	1992 Trip 1	Trip 2	Trip 3	1993 Trip 4	Trip 5	Trip 6	Trip 7	Total
Diamond Creek (RM 225.7)								
SD - speckled dace	-	-	-	-	-	1	34	**35**
Travertine Falls (RM 230.4)								
SD - speckled dace	-	-	-	-	-	5	-	**5**
Spencer Creek (RM 246.0)								
RS - red shiner	491	35	105	64	151	1727	1039	**3612**
SD - speckled dace	0	2	6	12	7	568	367	**962**
FH - fathead minnow	0	0	23	3	0	27	110	**163**
CP - common carp	0	0	0	30	114	4	3	**151**
FM - flannelmouth sucker	12	3	0	1	8	45	3	**72**
CC - channel catfish	0	0	0	5	55	0	0	**60**
PK - plains killifish	4	0	5	0	0	5	0	**14**
RB - rainbow trout	0	0	0	1	0	0	0	**1**
Surprise Creek (RM 248.4)								
RS - red shiner	701	60	647	38	388	1164	1872	**4870**
FH - fathead minnow	1571	33	459	22	17	152	727	**2981**
CP - common carp	10	21	41	2	1	0	0	**75**
PK - plains killifish	2	0	8	0	12	7	0	**29**
GA - mosquitofish	0	0	24	0	0	0	0	**24**
FM - flannelmouth sucker	2	0	8	0	12	1	0	**23**
SD - speckled dace	0	0	3	1	0	8	3	**15**
GS - green sunfish	0	0	2	0	0	0	0	**2**
Lost Creek (RM 248.9)								
RS - red shiner	29	1	-	24	1	-	-	**55**
CP - common carp	23	1	-	14	-	-	-	**38**
CC - channel catfish	1	1	-	4	0	-	-	**6**
GA - mosquitofish	5	0	-	0	0	-	-	**5**
LM - largemouth bass	3	0	-	0	0	-	-	**3**
SB - striped bass	2	0	-	0	0	-	-	**2**
FH - fathead minnow	1	0	-	0	0	-	-	**1**

Table 10. Continued.

Tributary (River Mile) Code - Common Name	1992 Trip 1	1992 Trip 2	1992 Trip 3	1993 Trip 4	1993 Trip 5	1993 Trip 6	1993 Trip 7	Total
Quartermaster Creek (RM 259.8)								
RS - red shiner	167	2	-	-	-	-	-	169
GA - mosquitofish	45	0	-	-	-	-	-	45
LM - largemouth bass	2	0	-	-	-	-	-	2
PK - plains killifish	1	0	-	-	-	-	-	1
Total	**3070**	**159**	**1346**	**221**	**755**	**3711**	**4159**	**13,421**

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

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 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 large fish source of 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.

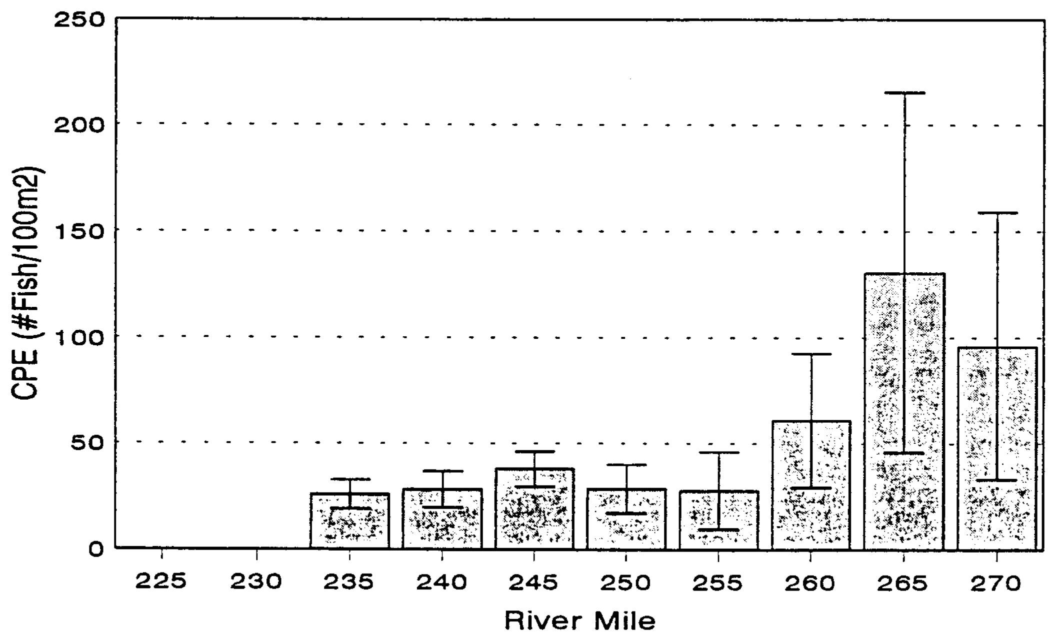
Distribution of fish by the four sample strata (Figure 7) further shows the dramatic shift in species composition at Bridge Canyon. While carp are abundant throughout the region, adults account for a greater percentage of the fish composition above Bridge Canyon, demonstrating the diversity of carp for habitat selection. Species composition in Stratum B and C, downstream of

Table 11. Numbers and percentages (in parentheses) of fish species by sample strata from National Canyon (RM 165) to Pearce Ferry (RM 286).

Strata[b] (River Mile)	Fish Species Codes[a]																				
	BH	FM	BC	BG	GS	LM	TS	CP	FH	HB	RS	SD	PK	BB	CC	SB	WE	GA	RB	BR	TOTAL
165.0-169.9	3 (6)	7 (15)						23 (49)	6 (13)			1 (2)			1 (2)				6 (13)		47 (100)
170.0-179.4	3 (5)	10 (17)						33 (56)	1 (2)			3 (5)							7 (12)	2 (3)	59 (100)
179.5-189.1	57 (14)	99 (24)						96 (23)	14 (3)	2 (<1)		131 (32)	1 (<1)		1 (<1)	1 (<1)			8 (2)	1 (<1)	411 (100)
189.2-200.0	16 (8)	9 (4)						29 (14)	38 (18)	1 (<1)		109 (52)	5 (2)		1 (<1)				1 (<1)	2 (1)	211 (100)
200.1-208.9	7 (6)	7 (6)						32 (28)	4 (4)			60 (52)	2 (2)		2 (2)						114 (100)
209.0-213.9	2 (5)	4 (10)						24 (57)	1 (2)						9 (22)	1 (2)			1 (2)		42 (100)
214.0-225.0	9 (4)	28 (13)						68 (31)	6 (3)			84 (39)			14 (6)	3 (1)			5 (2)		217 (100)
225.1-235.0	1 (<1)	8 (3)						197 (78)				7 (3)			37 (15)	2 (1)					252 (100)
235.1-259.0		24 (1)	1 (<1)			3 (<1)	14 (1)	347 (21)	29 (2)	1 (<1)	999 (62)	11 (1)	4 (<1)		135 (8)	24 (1)	2 (<1)	21 (1)			1615 (100)
259.1-275.0		31 (2)	1 (<1)		6 (<1)	1 (<1)	8 (<1)	271 (15)	188 (10)		1061 (59)	36 (2)	1 (<1)		51 (3)	24 (1)		123 (7)	3 (<1)		1805 (100)
275.1-286.0			3 (<1)	39 (5)	1 (<1)	31 (4)	298 (37)	156 (19)	1 (<1)		204 (25)			2 (<1)	33 (4)	15 (2)		33 (4)			816 (100)
TOTALS	**98 (2)**	**227 (4)**	**5 (<1)**	**39 (1)**	**7 (<1)**	**35 (1)**	**320 (6)**	**1276 (23)**	**288 (5)**	**4 (<1)**	**2264 (40)**	**442 (8)**	**13 (<1)**	**2 (<1)**	**284 (5)**	**70 (1)**	**2 (<1)**	**177 (3)**	**31 (1)**	**5 (<1)**	**5589 (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



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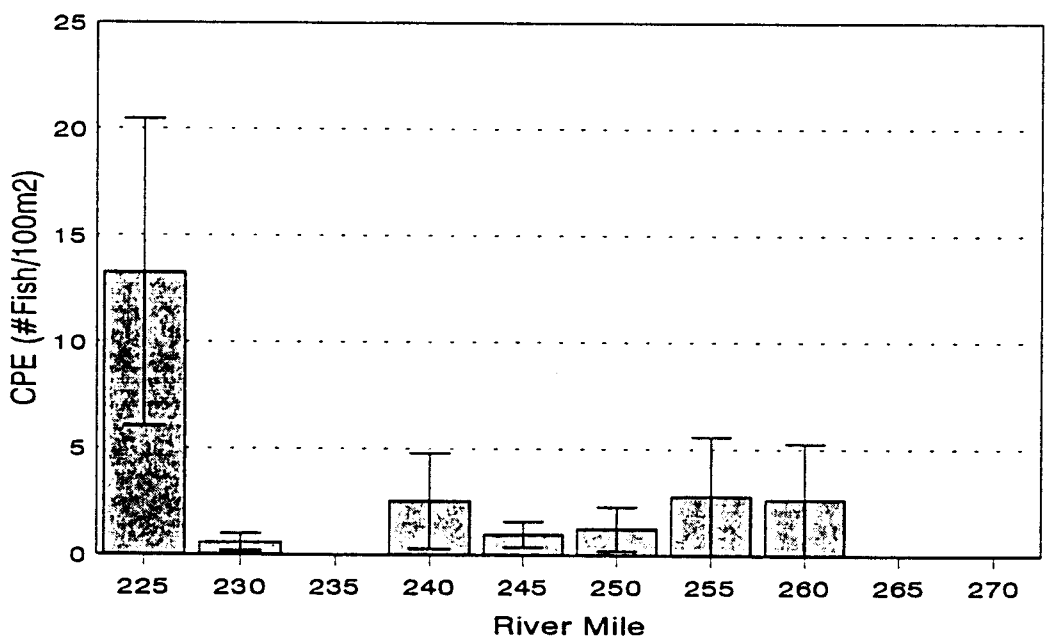

Figure 6. Longitudinal distribution of red shiners (A), and speckled dace (B) from Diamond Creek (RM 225) to Grand Wash Cliffs (RM 275). Arithmetic mean catch-per-effort (CPE) for seine samples.

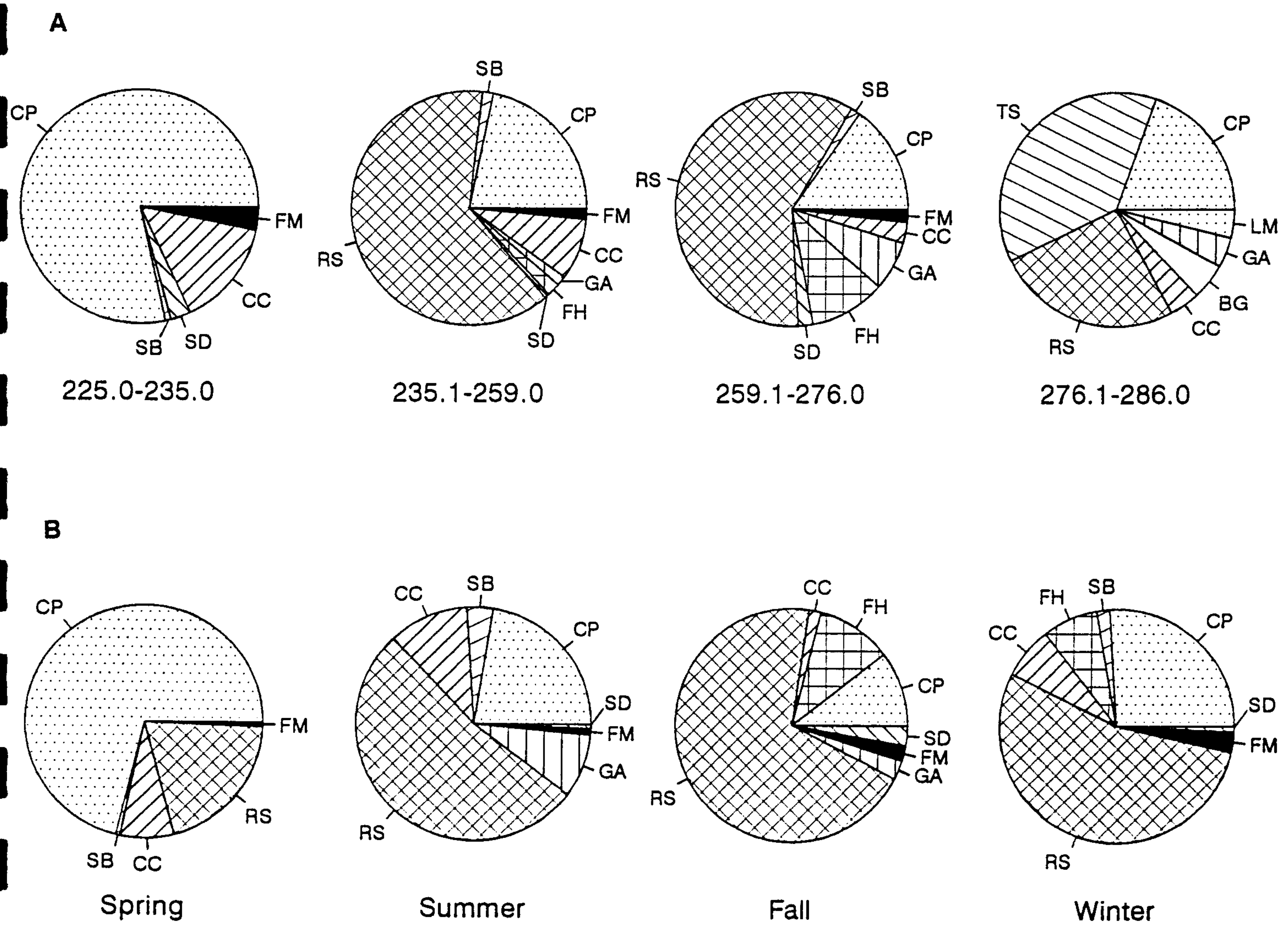

Figure 7. Composition of fish by sample strata (A) and by season (B) for the Colorado River from Diamond Creek to Pearce Ferry, 1992-93.

Bridge Canyon was similar, with red shiner and carp dominant, while composition in Stratum D showed a high percentage of threadfin shad, a lake-dwelling species.

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 these investigations. 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 proximity to 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. Catch rate of striped bass indicate greater abundance toward the lake, while 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 1992-93 (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.

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 fish captured in all downstream tributaries. Nevertheless, native species were also found in these tributaries, although in relatively small numbers. The most common were speckled

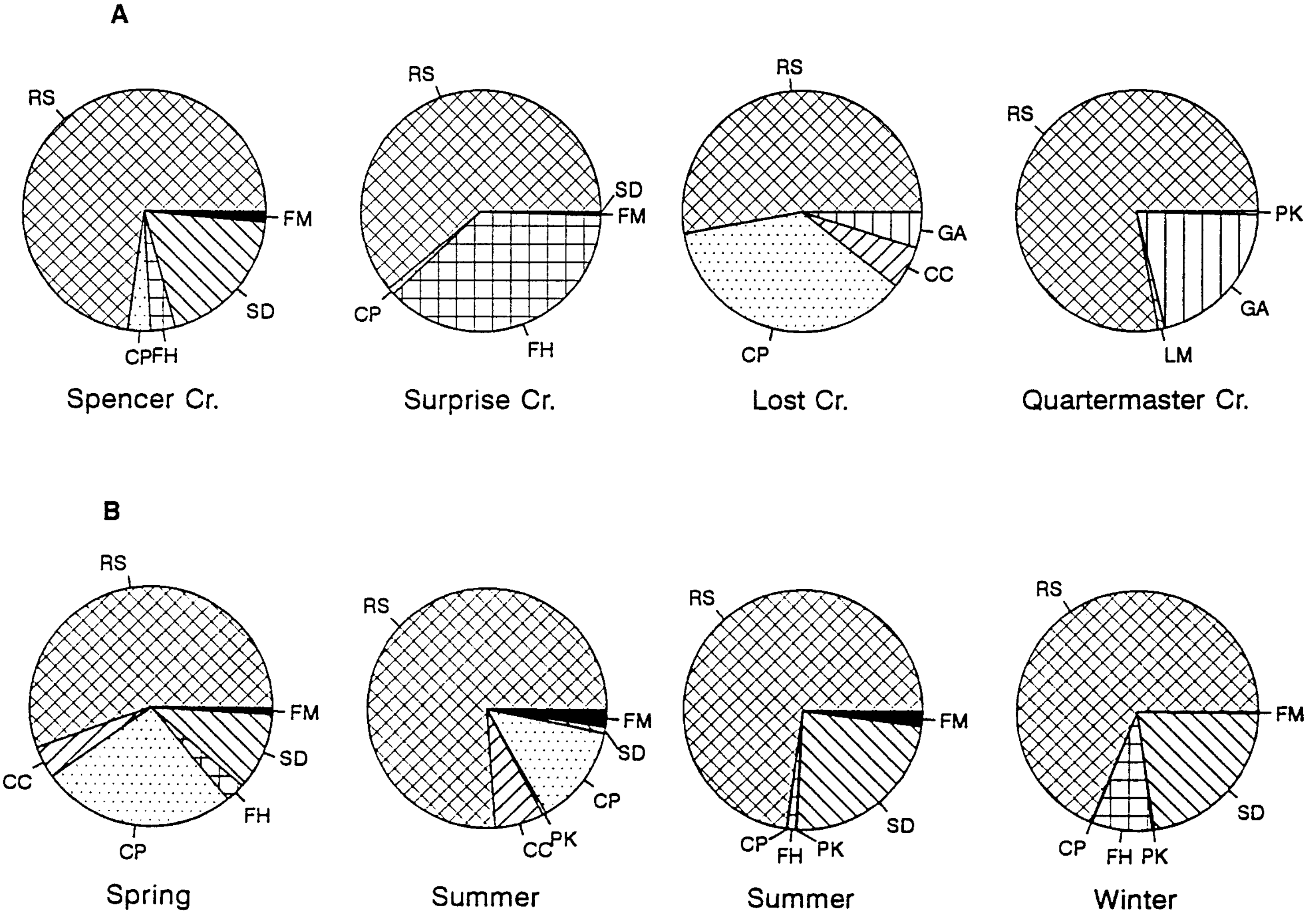

Figure 8. Composition of fish by tributaries (A) and by season within Spencer Creek (B), 1992-93.

dace comprising 19 percent of the fish in Spencer Creek. Of 158 flannelmouth suckers captured in Region IV, 95 (25 YOY, 70 juveniles) were found in tributaries, primarily Spencer Creek (72) and Surprise Creek (23). 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 fish captured. 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 a large slow 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 was 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. 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 ichthyofauna 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

A

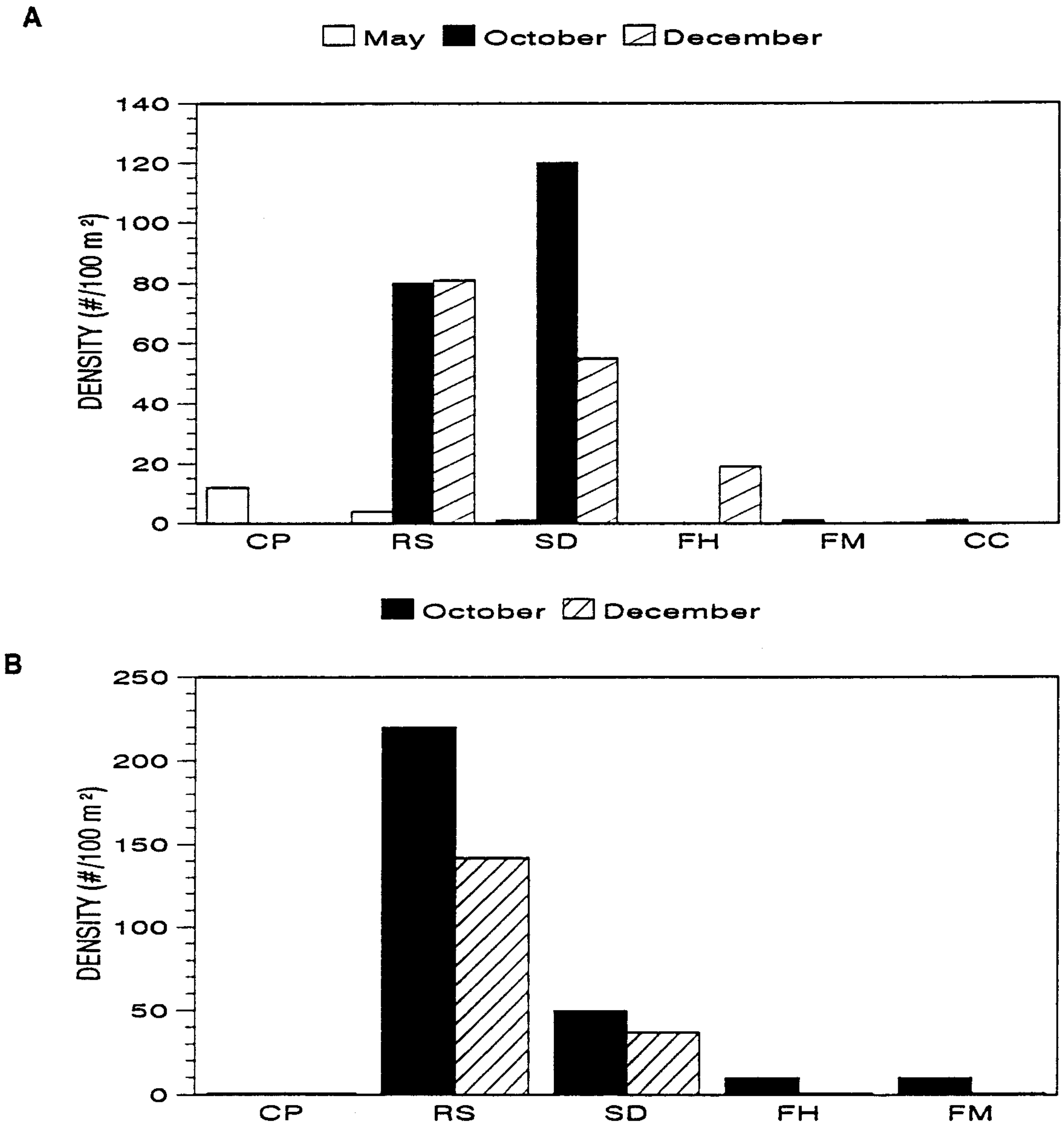

Figure 9. Fish density estimates for Site 1 (A) and Site 2 (B) in Spencer Canyon, 1993. Estimates from 3-pass maximum likelihood estimator. See Table 8 for fish species codes.

Table 12. Results of the 3-pass maximum likelihood estimator conducted at Site 1 (near confluence with main channel) in Spencer Creek.

Fish species	Number captured	Percent of sample	Population estimate (95% CI)	Estimated number/100 m^2	Mean length (mm) ± (1 SD)
May 1993					
Common carp	60	65	61 (60,64)	12	403 (± 93)
Red shiner	20	22	24 (20,35)	4	64 (± 10)
Speckled dace	5	5	5 (5,7)	1	55 (± 9)
Flannelmouth sucker	5	5	6 (5,15)	1	80 (± 26)
Channel catfish	3	3	3 (3,8)	1	301 (± 79)
Total	93	-	100 (93,109)	20	-
October 1993					
Red shiner	115	41	116 (115,119)	80	55 (± 8)
Speckled dace	163	59	190 (167,213)	120	57 (± 7)
Total	278	-	296 (282,310)	190	-
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	-	235 (162,308)	157	-

Table 13. Results of the 3-pass maximum likelihood estimator conducted at Site 2 (0.75 mi upstream of confluence with main channel) in Spencer Creek.

Fish species	Number captured	Percent of sample	Population estimate (95% CI)	Estimated number/100 m^2	Mean length (mm) ± (1 SD)
		October 1993			
Common carp	4	<1	4 (4,6)	<1	389 (± 159)
Red shiner	1042	77	1100 (1077,1123)	220	59 (± 8)
Speckled dace	251	18	260 (252,268)	50	62 (± 7)
Fathead minnow	25	2	25 (25,25)	10	59 (± 7)
Flannelmouth sucker	40	3	40 (40,41)	10	123 (± 24)
Total	1362	-	1426 (1403,1449)	290	-
		December 1993			
Common carp	3	<1	3 (3,3)	1	499 (± 30)
Red shiner	710	86	721 (713,729)	142	47 (± 12)
Speckled dace	106	13	186 (106,290)	37	70 (± 6)
Fathead minnow	3	<1	3 (3,3)	1	47 (± 12)
Flannelmouth sucker	3	<1	5 (3,32)	1	160 (± 33)
Total	825	-	851 (837,865)	168	-

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.

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.

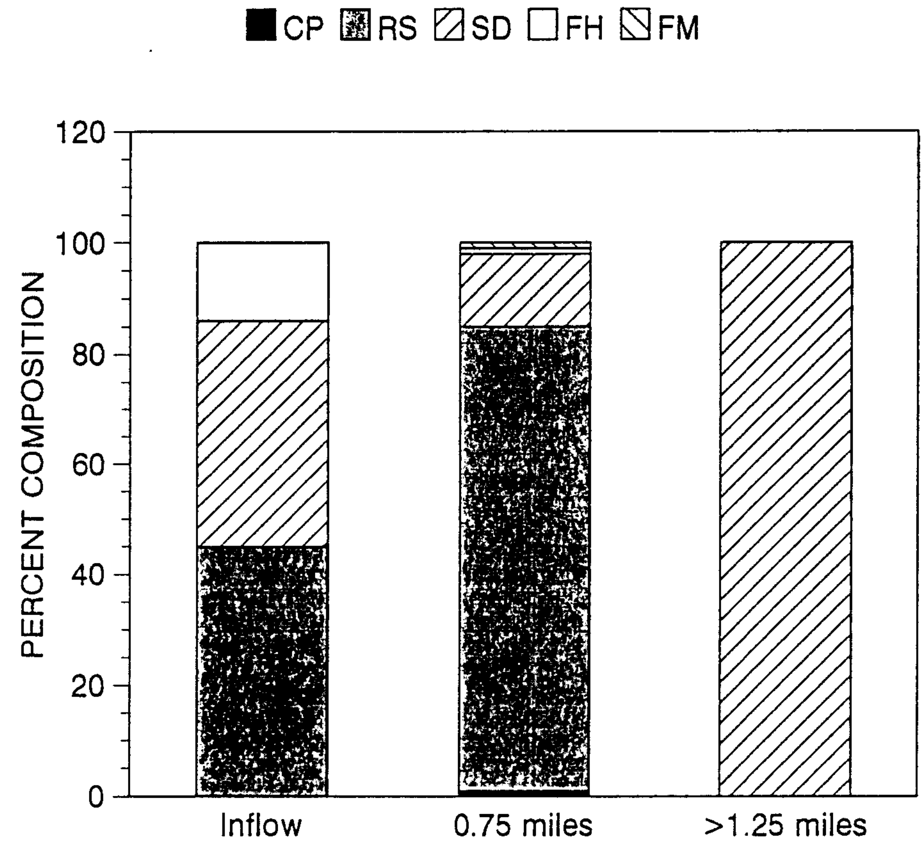

Figure 10. Percent species composition at three locations in Spencer Canyon, based on maximum likelihood estimates at Sites 1 (Inflow) and 2 (0.75 mi) and seining upstream of 1.25 mi. See Table 8 for fish species codes.

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 suitable 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 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 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 interim flows. The dynamic nature of the area needs to be understood to better isolate the effects of variables such as flow magnitude and ramping rates.

Although the study area (Diamond Creek to Pearce Ferry) 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 in the study area, 240 miles downstream of the dam. Temperature measured in 1992 and 1993 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 findings in 1993 relative to each of the five study objectives, and integrated with 1992 results.

DISTRIBUTION, ABUNDANCE AND BEHAVIOR OF ADULT FISH

Seventeen fish species were found in Region IV in 1992 and 19 in 1993, the most of any comparable reach of river between Glen Canyon Dam and Lake Mead. The ichthyofauna was similar from National Canyon to Bridge Canyon, consisting primarily of carp, and small numbers of flannelmouth sucker, bluehead sucker and speckled dace. A marked increase in fish species (richness) and numbers per species (evenness) at Bridge Canyon (RM 235) 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.

Carp and channel catfish were the dominant large fishes in this 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, indicating that these were used as spawning or nursery areas, or both. Only one adult humpback chub and one adult bluehead sucker were found in the study area in 1992-93. 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, 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. Regular travel by large, hardbottom, motorized boats shuttling rafters from Separation Canyon to Pearce Ferry generated a sharp and more dramatic wave than daily flow fluctuations, which continually eroded shorelines in the study area.

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) 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, Cheek et al. 1985), 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 were flannelmouth suckers and speckled dace. 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. Further sampling in the mainstem is needed during warm months to determine mainstem spawning by native species.

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.

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 in the study area (Surprise, Spencer, Lost, Quartermaster canyons) supported the highest abundances of fishes, as reported from other tributaries further upstream in Grand Canyon (Valdez et al. 1991, 1992). Fish are attracted to tributary inflows by an influx of food (aquatic and terrestrial macroinvertebrates) and warm water temperature. 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.

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 for the Hualapai Aquatic Resources Study:

1. Continue to survey the Colorado River from National Canyon to Pearce Ferry to determine species composition, relative abundance, and behavioral aspects of fishes and macroinvertebrates relative to interim flows and Lake Mead elevation.

2. Measure habitat parameters (depth, velocity, substrate) of shorelines, tributary inflows, side channels, and backwaters to ascertain effects of interim flows and Lake Mead elevations. Camera stations should be used to enhance visual monitoring of particularly tributary inflows and backwaters.

3. Map sample sites, native fish collection sites, water quality sites, channel bathymetry, and surface area of habitats on GIS.

4. Develop SuperHydro mainstem bathymetry of inflows at Spencer Canyon, Surprise Canyon, Lost Canyon and RM 253.2 (location of humpback chub capture).

5. Quantitatively survey lower reaches of Spencer Canyon and Surprise Canyon to determine fish species composition, abundance, and distribution. Examine or collect specimens of young fish from these tributaries to determine presence or absence of native species, e.g., razorback suckers.

6. Survey tributaries in spring and mainstem in summer to determine presence or absence of spawning by native fish, e.g., flannelmouth suckers or razorback suckers.

7. Continue to document water quality, particularly of the Colorado River at inflows of tributaries, and at the river-lake interface to qualitatively describe effect of lake level on temperature, dissolved oxygen, pH, conductivity, nutrient levels, and algal species.

8. Photograph and map tributary inflows in order to quantify fish habitat dynamics with river stage changes, including water depth, velocity, resting areas, and mixing zones.

9. Preserve specimens of fish parasites to ascertain the presence of the Asian tapeworm in this reach and species infected. Specimens should be taken from eviscerated fish such as channel catfish, carp, striped bass, as well as in whole fish such as red shiners, fathead minnows, mosquitofish, and plains killifish.

10. Integrate data from this and other investigations in the Grand Canyon and Lake Mead to provide information for an assessment of risk associated with upstream invasion by nonnative fishes, such as red shiner, striped bass, and channel catfish.

11. Provide information for a Grand Canyon River Management Plan, that specifically details purpose, objectives, strategies, tasks, time schedule, and facility, logistics and personnel requirements.

12. Coordinate the aquatic resource studies with concurrent studies of riparian habitats.

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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), 1992-93.

Date	Camp Site	Sample Locations
	Trip No. 1 (June 24 - July 2, 1992)	
Jun 24-25	Travertine Canyon (RM 229.1)	Traverine Canyon Area (RM 228.3 - 229.8)
Jun 26-27	Spencer Canyon (RM 246.0)	Spencer Canyon Area (RM 245.4 - 246.1) and Tributaries
Jun 28-29	Lost Creek (RM 249.7)	Lost Creek, Surprise Canyon Area (RM 247.1 - 249.7)
Jun 30	Quartermaster (RM 259.8)	Quartermaster Canyon Area (RM 250.3 - 262.3)
Jul 1-2	Pearce Ferry (RM 280)	Pearce Ferry Area (RM 274.0 - 280.0)
	Trip No. 2 (September 27 - October 9, 1992)	
Sep 27-28	Bridge Canyon (RM 235.2)	Bridge Canyon Area (RM 234-237.5)
Sep 29-Oct 2	Spencer Canyon (RM 246.0)	Spencer, Surprise Canyon Area (RM 245.4-249.5) and Tributaries
Oct 3-4	Below Quartermaster (RM 260.5)	Quartermaster Canyon Area (RM 250.3-263)
Oct 5-6	Braided Area (RM 268.5)	Braided Area (RM 266-274)
Oct 7-9	Park Boundary (RM 277.5)	Pearce Ferry Area (RM 274.0-280.0)
	Trip No. 3 (December 1 - 13, 1992)	
Dec 1-3	Bridge Canyon (RM 235.2)	Bridge Canyon Area (RM 234.2 - 236.0)
Dec 3-6	Above Spencer (RM 245.0)	Spencer Canyon Area (RM 241.6 - 249.1) and Tributaries
Dec 6-7	Below Lost Creek (RM 249.7)	Lost Creek (RM 249.1 - 249.4)
Dec 7-9	Burnt Spring (RM 259.7)	Lost Creek to Res. Bound. (RM 249.5 - 271.5)
Dec 9-11	Braided Section (RM 267.5)	Above Res. Bound. (RM 270.0 - 272.8)
Dec 11-13	Scorpion Island (RM 277.5)	Lake Mead Inflow (RM 271.8 - 279.5)
	Trip No. 4 (March 25 - April 6, 1993)	
March 25-26	Bridge Canyon (RM 235.2)	Bridge Canyon Area (RM 233.8-235.2)
March 26-April 1	Above Spencer Creek (RM 242.2)	Above Spencer Creek to below Lost Creek (RM 241.8 to 250.2) including Spencer Creek (RM 246.0), Surprise Creek (RM 248.2), Lost Creek (RM 248.9)
April 1-2	Burnt Canyon (RM 259.5)	Burnt Canyon to below Quartermaster Canyon (RM 259.5 to 261.1)
April 2-5	RM 268.1 (above former Braided area)	RM 268.1 to 276.6
April 5-6	Pearce Ferry (RM 280)	RM 274.3 to 280.0

Table A-1. Continued.

Date	Camp Site	Sample Locations
	Trip No. 5 (May 25 - June 6, 1993)	
May 25-26	Bridge Canyon (RM 235.2)	Bridge Canyon Area (RM 233.8-235.2)
May 26-31	Above Spencer Creek (RM 245.2)	Above Spencer Creek to below Lost Creek (RM 241.8 to 250.2) including Spencer Creek (RM 246.0), Surprise Creek (RM 248.2), Lost Creek (RM 248.9)
May 31-June 1	Below Burnt Spring Canyon (RM 259.5)	RM 259 - RM 262
June 1-3	RM 265.0	RM 264 - RM 268
June 3-6	Scorpion Island	RM 276 - RM 282 (9approx.) 2 net sets below Pearce Ferry
	Trip No. 6 (September 28 - October 10, 1993)	
Sept 28-30	Travertine Falls (RM 230.5)	RM 227.5 - 230.7
Sept 30-Oct 4	Above Spencer Creek (RM 245.2)	RM 242.5 - 249.1 including Spencer Creek (RM 246), Surprise Creek (RM 248.40, and the mouth of Lost Creek (RM 248.I4)
Oct 4-7	Above Salt Creek (RM 253.9)	RM 252.9 - 260 including the mouth of Quartermaster Creek (RM 259.9)
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 including Spencer Creek (RM 246), Surprise Creek (RM 248.4), the mouth of Lost Creek 9RM 248.9) and above Salt Creek (RM 253.2)
Dec 9-11	Near Bat Caves (RM 266)	RM 259.9 including mouth of Quartermaster Creek and main channel from RM 264.5 - 267
Dec 11-13	Scorpion Island (RM 279)	RM 274.7 - 279 including Lake Mead.

Table A-2. Personnel participating in 1992-93 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
Gloria Hardwick	4, 5, 6, 7	BIO/WEST, Inc., 1840 W. Kaibab Ln. Suite 100, Flagstaff, AZ 86001 (602)774-8069
Randall Filbert	5, 6, 7	BIO/WEST, Inc., 1063 W. 1400 N., Logan, UT 84321 (801)752-4202
Kirsten Tinning	1, 2, 3, 4	BIO/WEST, Inc., 1840 W. Kaibab Ln. Suite 100, Flagstaff, AZ 86001 (602)774-8069
Erika Prats	2, 3	BIO/WEST, Inc., 1840 W. Kaibab Ln. Suite 100, 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., 1840 W. Kaibab Ln. Suite 100, Flagstaff, AZ 86001 (602)774-8069
Teresa Yates	3, 4, 6, 7	BIO/WEST, Inc., 1840 W. Kaibab Ln. Suite 100, Flagstaff, AZ 86001 (602)774-8069
Alyssa Reischauer	2	BIO/WEST, Inc., 1840 W. Kaibab Ln. Suite 100, Flagstaff, AZ 86001 (602)774-8069
Bill Leibfried	5, 7	BIO/WEST, Inc., 1840 W. Kaibab Ln. Suite 100, 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, 2, 3, 4, 5, 6, 7	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, 2, 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
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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

Table A-2. Continued.

Name	Trip	Agency, Address, Phone Numbers
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
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	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Lars Neimi	1, 5	OARS, P.O. Box 1969, Flagstaff, AZ 86002 (602)774-0526
Steve Bledsoe	3, 7	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	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

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)
<u>Hydrolab Surveyor II</u>	
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

Table A-4. Continued.

Sample Site (River Mile)	Observation Period (Dates) Time (Hours)
RM 245 above Spencer	Sep 30-Oct 2, 1993 1958-0938
RM 246.0 - Spencer Creek	Oct 2-Oct 4, 1993 1111-1148
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
<u>Hydrolab Datasonde w/Datalogger</u>	
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

Table A-4. Continued.

Sample Site (River Mile)	Observation Period (Dates) Time (Hours)
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
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), 1992-93.

Sample Site (River Mile)	Date/Time of Observation	Secchi disk readings (m)
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
234.9	May 26, 1993/0823	0.25
245.6	May 27, 1993/1648	0.25
245.6	May 28, 1993/0804	0.30
245.6	May 28, 1993/1038	0.30
245.6	May 29, 1993/1617	0.50
265.0	Jun 2, 1993/0806	0.60
265.0	Jun 2, 1993/1001	0.60
265.0	Jun 2, 1993/1541	0.50
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
230.5	Dec 2, 1993/0925	0.50
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

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

Location (River Mile)	Dates	Water Temperature	
		Min.	Max.
MAINSTEM COLORADO RIVER			
Travertine Canyon (RM 229.1)	Jun 25-26	17.5	17.0
Spencer Canyon (RM 246.0)	Jun 26-28	18.0	17.5
Lost Creek (RM 249.7)	Jun 28-30	18.5	18.0
Quartermaster Canyon (RM 259.8)	Jun 30-Jul 1	18.0	19.5
Grand Wash Cliffs (RM 276.0)	Jul 1-Jul 2	18.0	20.0
Pearce Ferry (RM 280.0)	Jul 1-Jul 2	24.5	26.0
Bridge Canyon (RM 235.0)	Sep 27-Sep 28	15.0	15.0
Spencer Canyon (RM 246.0)	Sep 29-Sep 30	14.7	17.5
Quartermaster Canyon (RM 259.8)	Oct 3-Oct 4	14.7	17.5
Travertine Cleft (RM 268.0)	Oct 5-Oct 6	15.0	17.0
Grand Wash Cliffs (RM 276.0)	Oct 7-Oct 8	15.0	15.0
Pearce Ferry (RM 280.0)	Oct 7-Oct 8	20.0	23.0
Bridge Canyon (RM 235.0)	Dec 1-Dec 3	8.6	8.6
Above Spencer Canyon RM 245.0)	Dec 3-Dec 6	9.3	9.7
Below Lost Creek (RM 249.7)	Dec 6-Dec 7	9.7	9.9
Burnt Spring Canyon (RM 259.7)	Dec 7-Dec 9	10.0	10.2
Braided Area (RM 267.5)	Dec 9-Dec 11	9.90	10.2
Scorpion Island (RM 277.5)	Dec 11-Dec 13	9.0	10.2

Table A-6. Continued.

Location (River Mile)	Dates	Water Temperature	
		Min.	Max.
TRIBUTARIES			
Spencer Creek (RM 246.0)	Jun 26	28.5	29.0
Surprise Creek (RM 248.4)	Jun 29	26.5	26.5
Quartermaster Creek (259.8)	Jun 30	19.0	20.0

Table A-7. Numbers of fish species and life stage captured with 17 gear types in the Colorado River and tributaries, from Diamond Creek RM 226 to below Pearce Ferry (RM 286), May 1992-December 1993.

Gear Types	Life Stage	Fish Species Codes																		
		BH	FM	BC	BG	GS	LM	TS	CP	FH	HB	RS	SD	PK	BB	CC	SB	WE	GA	RB
EL	Y			2			5		40											
	J		11			3	21		56			6					2			
	A	1	6	2		4	7	228	525	32		1330	20	1		32	16		47	
	T	1	17	4		7	33	228	621	32		1336	20	1		32	18		47	
BP	Y									1										
	J		42							1		6								1
	A								151	92		2034	530	5		60				
	T		42						151	94		2040	530	5		60				1
GM	Y																			
	J																			
	A								8								1	1		
	T								8								1	1		
GP	Y																			
	J																			
	A								15							13	9			
	T								15							13	9			
GX	Y																			
	J																			
	A															8	1			
	T															8	1			

Table A-7. Continued.

Gear Types	Life Stage	Fish Species Codes																		
		BH	FM	BC	BG	GS	LM	TS	CP	FH	HB	RS	SD	PK	BB	CC	SB	WE	GA	RB
GS	Y																			
	J																			
	A								7											
	T								7											
TK	Y																			
	J																			
	A		5						100							61	3			
	T		5						100							61	3			
TL	Y																			
	J																			
	A		5						98		1					55	6	1		2
	T		5						98		1					55	6	1		2
TM	Y																			
	J																			
	A		4	1			1	1	21						2	61	20			1
	T		4	1			1	1	21						2	61	20			1
TN	Y																			
	J																			
	A		3		2				68							21	5			
	T		3		2				68							21	5			

Table A-7. Continued.

Gear Types	Life Stage	Fish Species Codes																		
		BH	FM	BC	BG	GS	LM	TS	CP	FH	HB	RS	SD	PK	BB	CC	SB	WE	GA	RB
HM	Y																			
	J																1			
	A								4			158							1	
	T								4			158					1		1	
HS	Y																			
	J															1				
	A							1	15			1				6				
	T							1	15			1				7				
MT	Y		4						5	2										
	J											20								
	A									112		470	177	10						
	T		4						5	114		490	177	10						
SA	Y		19				2		60	15		160							22	
	J		19							541		556	1	4					18	
	A									1906		4905	306	6					135	
	T		38				2		60	2459		5621	307	10					175	
SB	Y		6			2			31											
	J		15						29	105		261		4					4	
	A		1							391		582	6	19					22	
	T		22			2			60	496		843	6	23					26	

Table A-7. Continued.

Gear Types	Life Stage	Fish Species Codes																		
		BH	FM	BC	BG	GS	LM	TS	CP	FH	HB	RS	SD	PK	BB	CC	SB	WE	GA	RB
SG	Y																			
	J		18		33		4		1			18								
	A				4			90	1	168		463	26						2	
	T		18		37		4	90	2	168		481	26						2	
AN	Y																			
	J																			
	A															4	3			
	T															4	3			
DN	Y																			
	J																			
	A												5							
	T												5							
TOTAL		**1**	**158**	**5**	**39**	**9**	**40**	**320**	**1235**	**3363**	**1**	**10970**	**1071**	**49**	**2**	**322**	**67**	**2**	**251**	**4**

Table A-8. Summary information associated with PIT-tagged fish for trips 1-7, 1992-93.

Date[a]	Species	PIT-Tag	TL (mm)	WT (g)	Gender[b]	Recapture	RM
920624	FM	7F7F3E524F	420	623	M	No	229.2
920627	FM	7F7F287E72	360	-	M	No	246.1
921003	FM	7F7F143B74	367	375	U	No	260.3
921004	FM	7F7F1F1322	329	314	M	No	259.8
921204	FM	7F7F480E49	322	260	F	No	246.9
921205	FM	7F7F284128	282	163	U	No	242.2
921207	FM	7F7F264F09	361	382	F	No	258.8
930321	FM	7F7F480106	-	106	-	No	245.5
930526	FM	7F0C5C1D5C	332	381	U	No	233.4
930530	FM	7F7F480366	397	567	U	No	246.1
930531	FM	7F7F22006C	221	137	U	No	260.0
930601	FM	7F7B081724	387	519	M	No	266.6
930929	FM	1F1E2B1107	294	206	M	No	230.5
930929	BH	1F20031B23	249	161	U	No	229.0
930929	FM	1F1E2D3264	380	481	F	No	227.7
930929	FM	1F1F5B7077	387	491	F	No	230.7
930930	FM	1F200E7241	228	108	M	No	230.5
931001	HB	1F1F74212D	329	293	F	No	253.2
931008	FM	1F0C701F46	410	639	F	No	274.0
931009	FM	1F0F642747	346	363	F	No	273.8
931204	FM	1F1F5B7077	390	515	F	Yes	230.7
931211	FM	1F200C5065	412	679	F	No	274.4

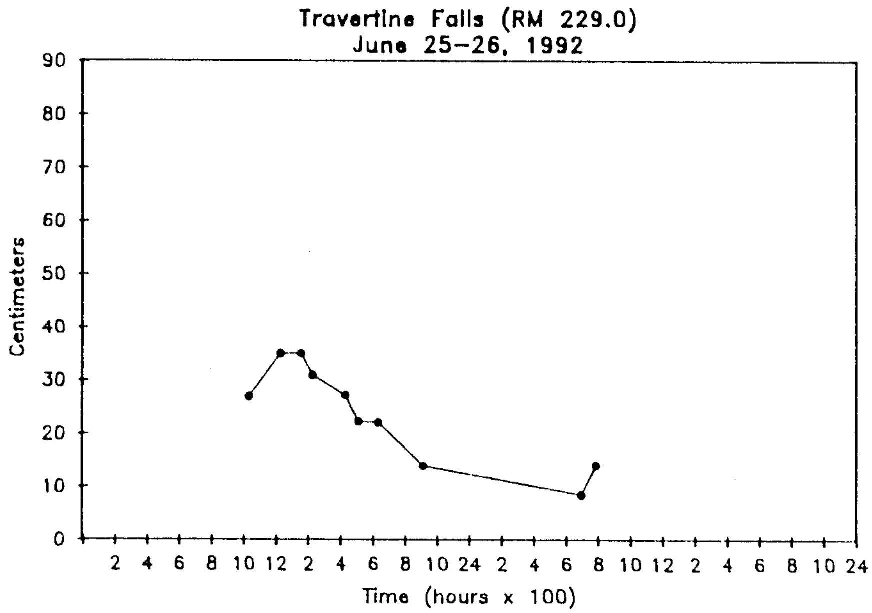
[a]e.g., 920624 = June 24, 1992
[b]M = male, F = female, U = undetermined, - = not examined.

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

Table A-9. Continued.

Species	Trip 1	Trip 2	Trip 3	Trip 4	Trip 5	Trip 6	Trip 7
WT (g)	-	-	-	1	2 (±4)	14 (±9)	31 (±17)
N	-	-	-	1	19	37	2
Striped bass							
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	-	-



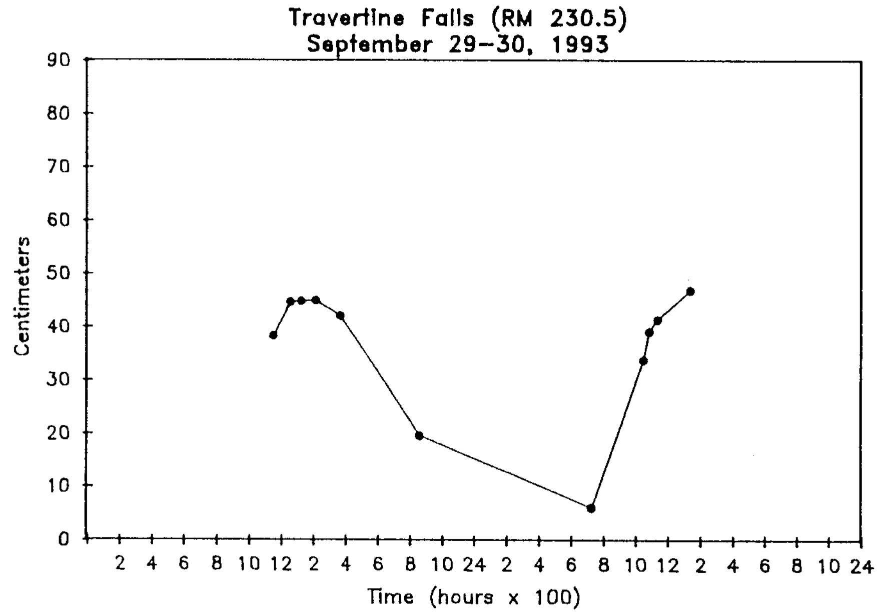


Figure A-1. Relative changes in river stage recorded at various locations in the mainstem Colorado River during 1992-93.

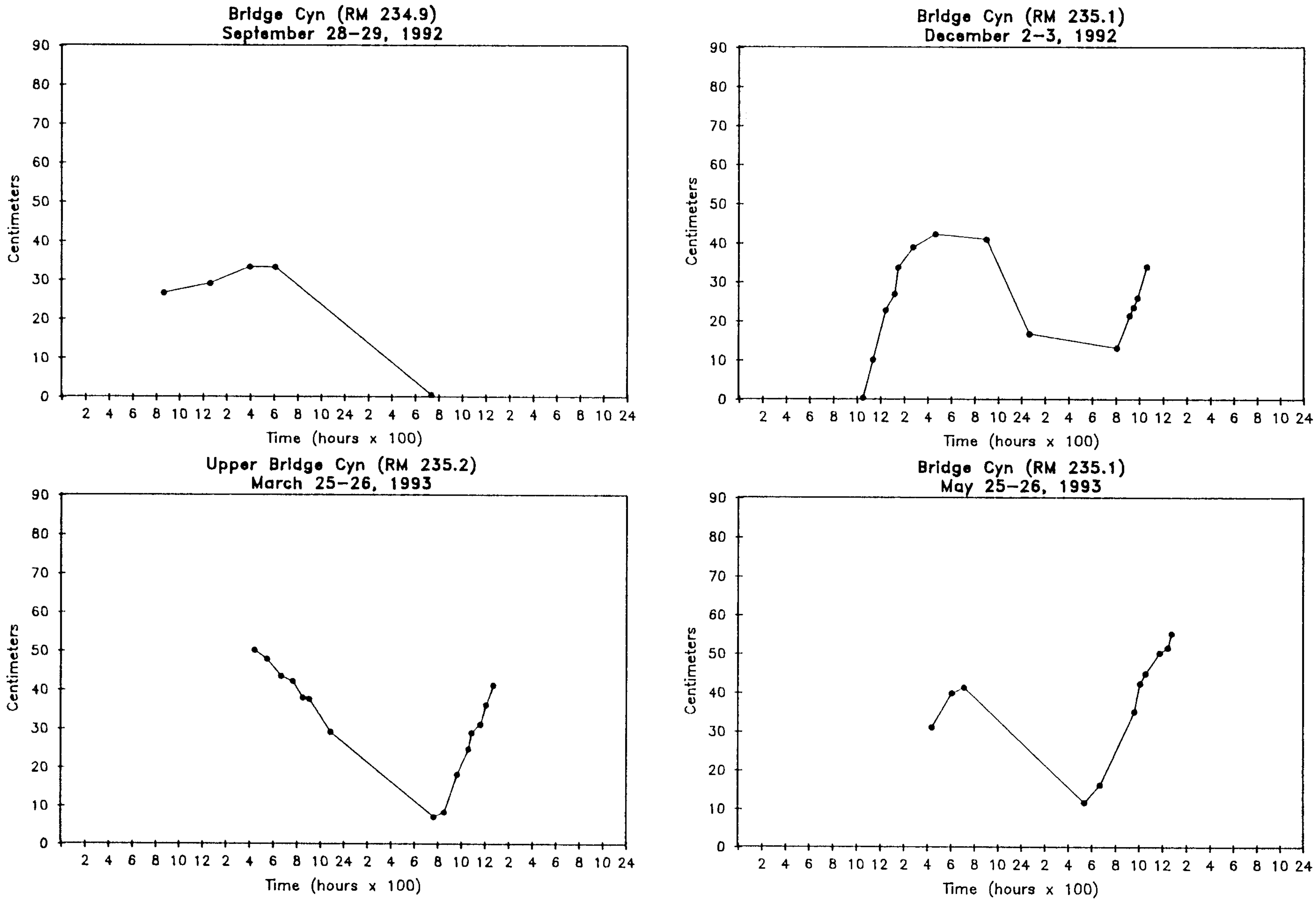


FIGURE A-1. CONTINUED.

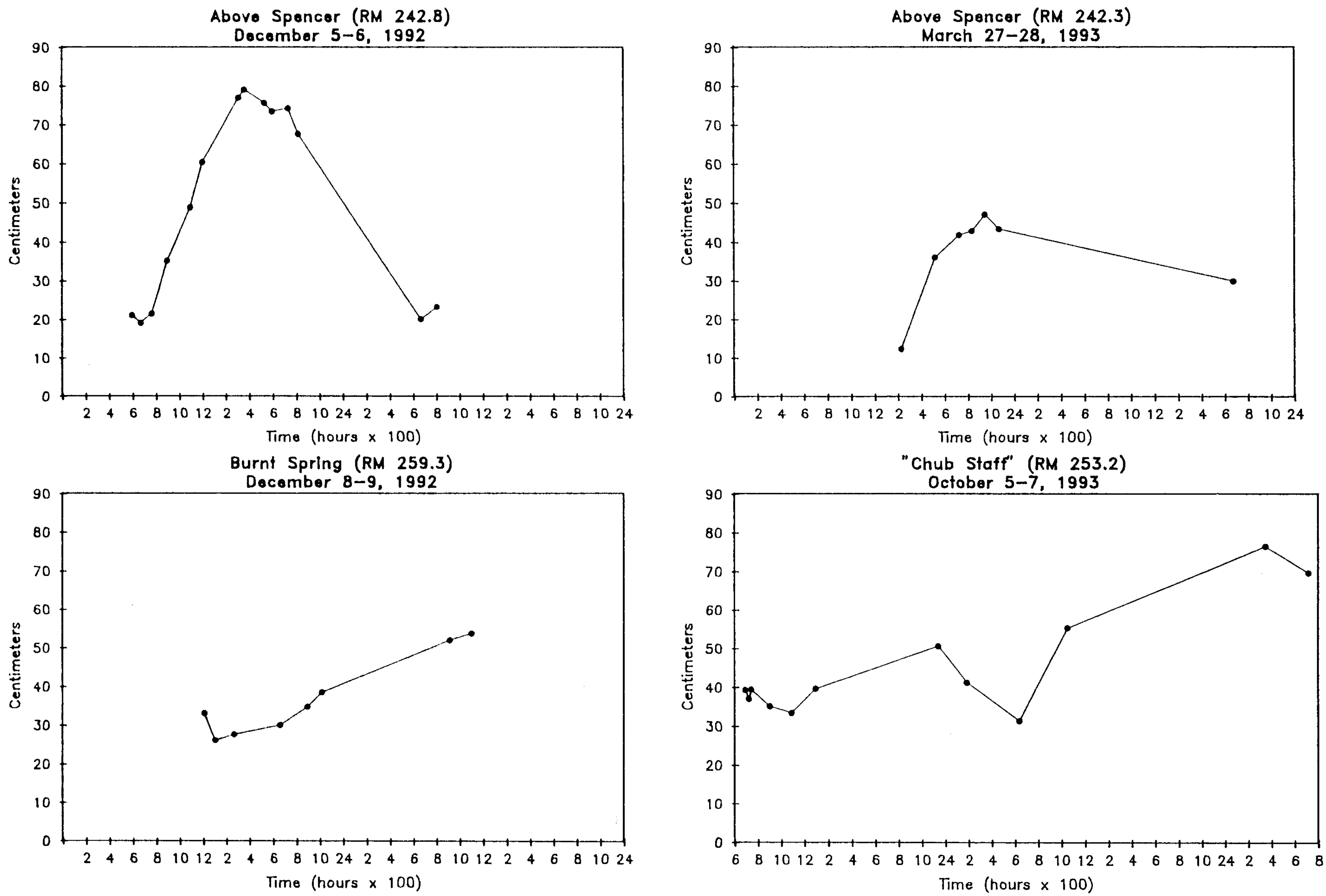


FIGURE A-1. CONTINUED.

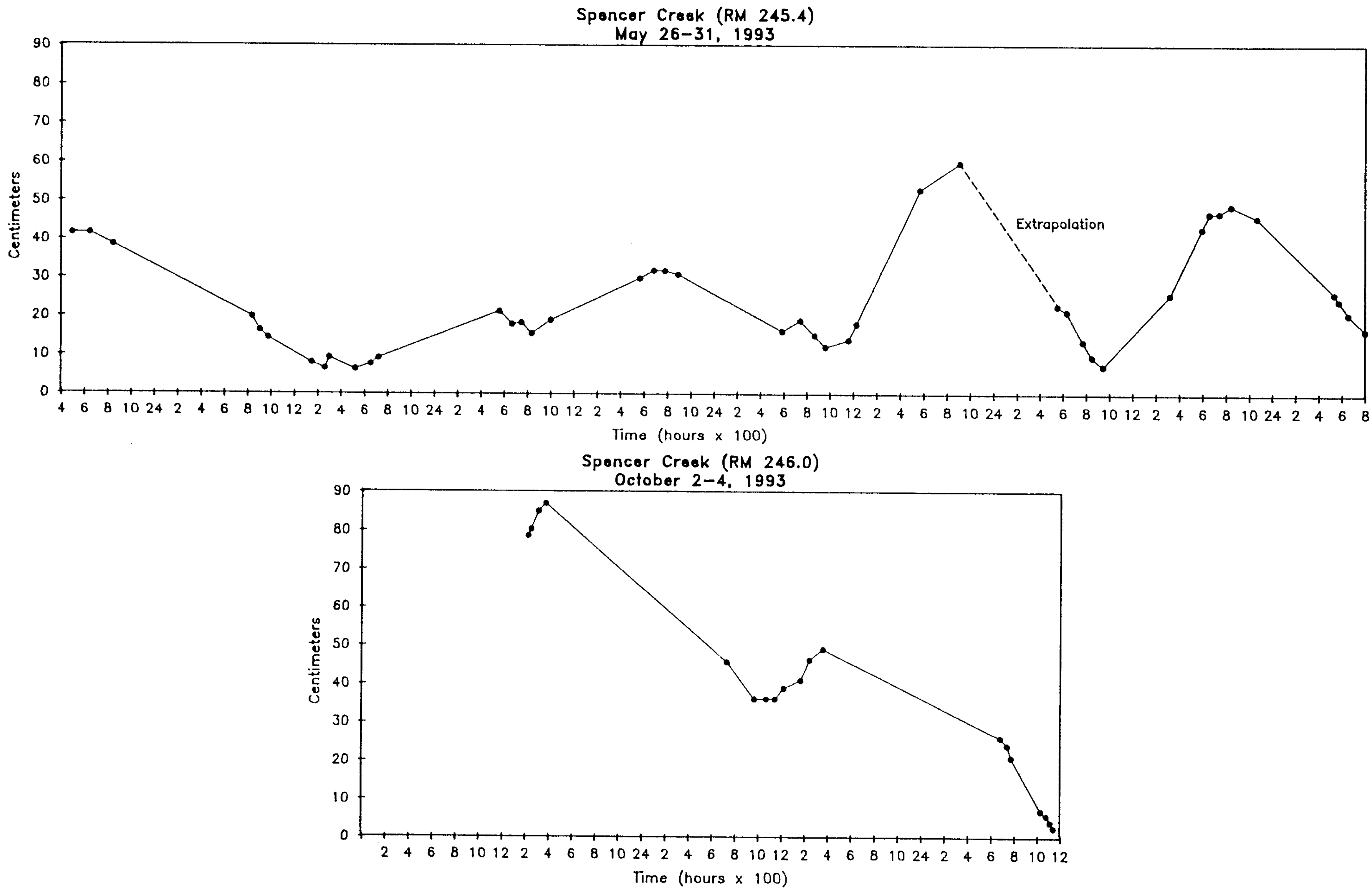


FIGURE A-1. CONTINUED.

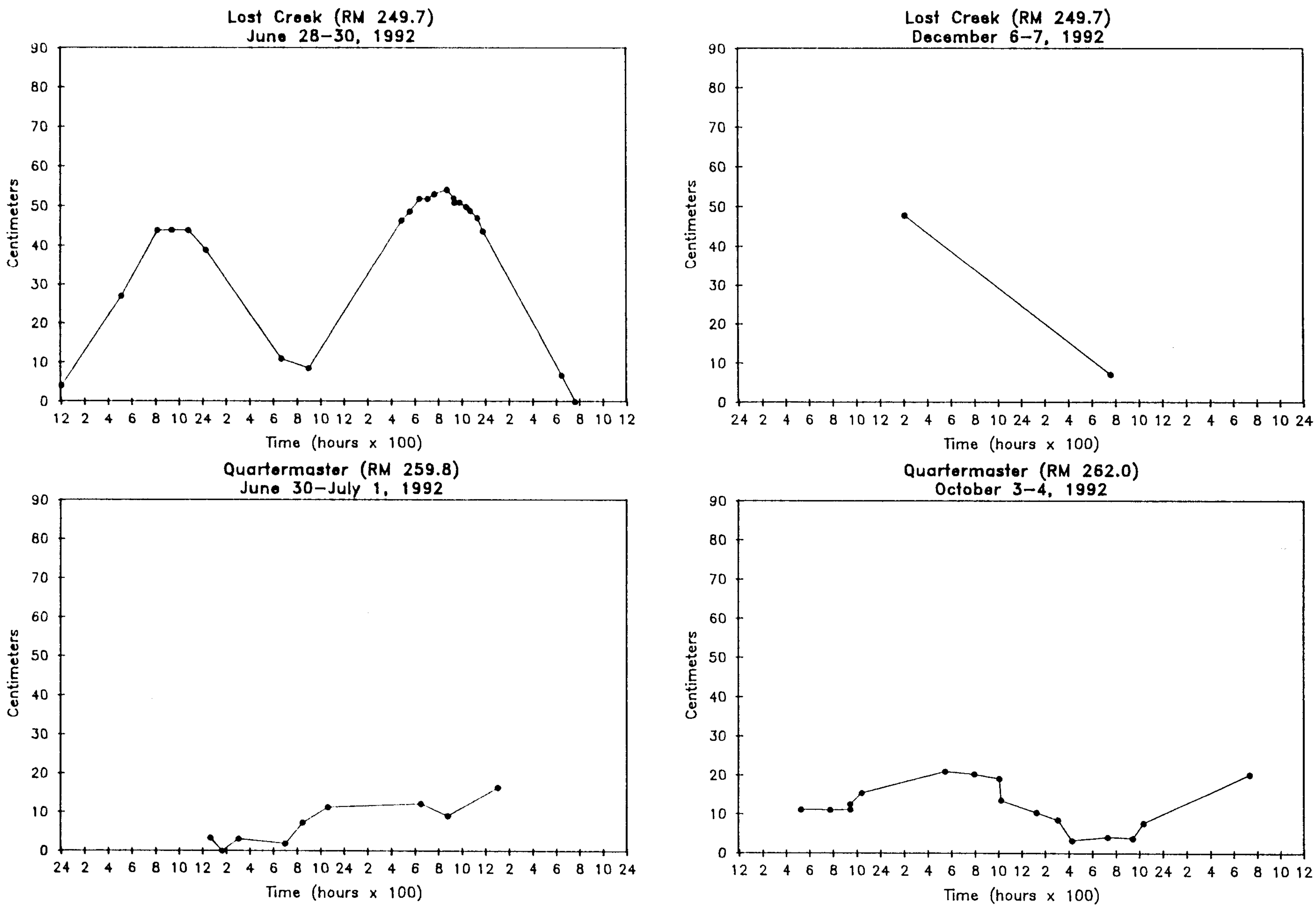
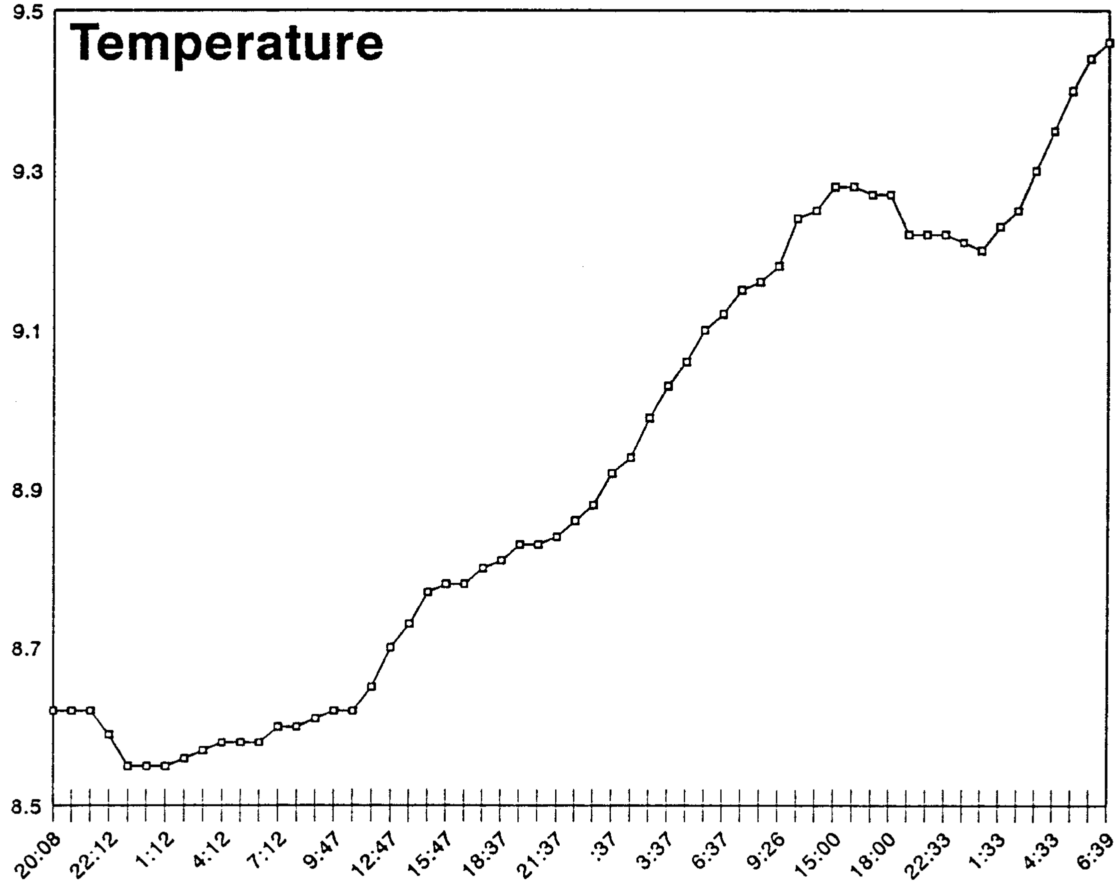


FIGURE A-1. CONTINUED.



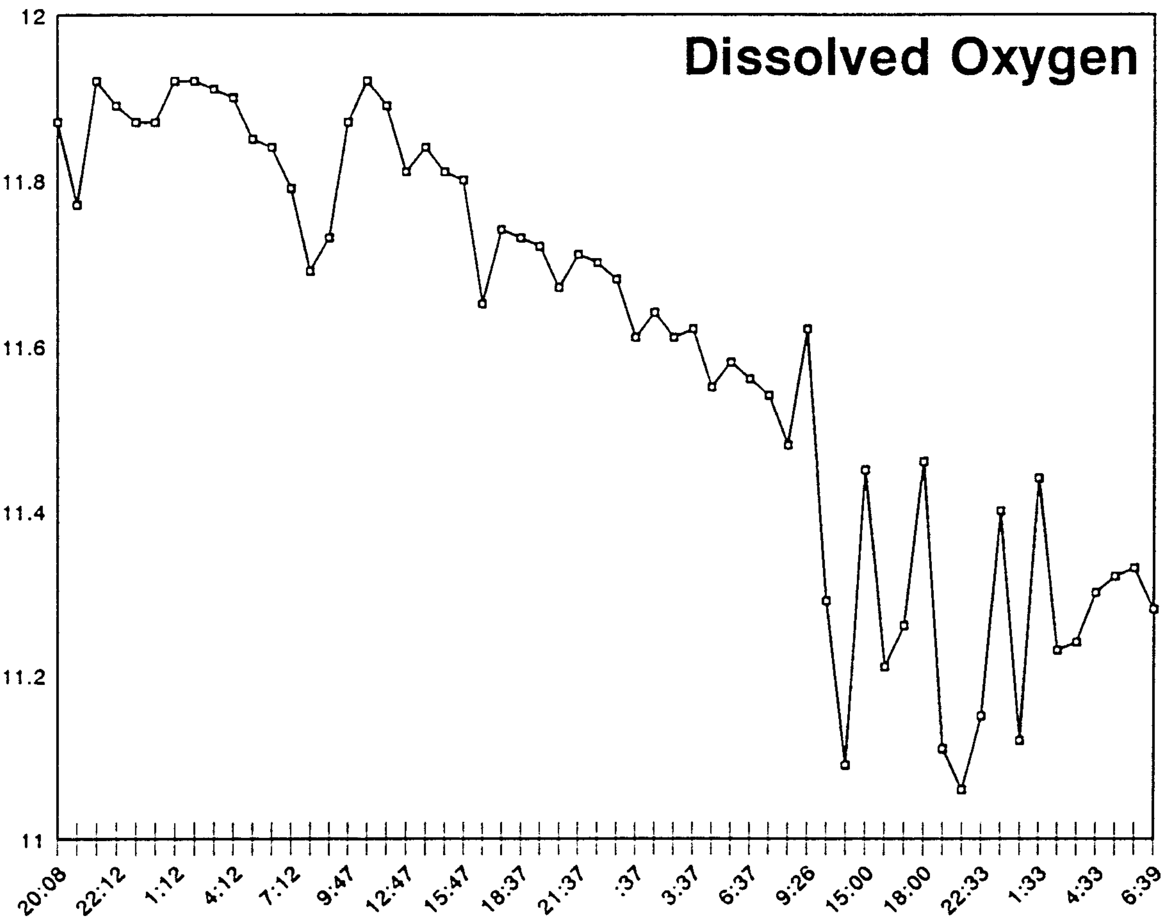


Figure A-2. Water quality parameters from the mainstem Colorado River at Spencer Canyon recorded with a Hydrolab Surveyor II on December 1-4 (2008-0639), 1992.

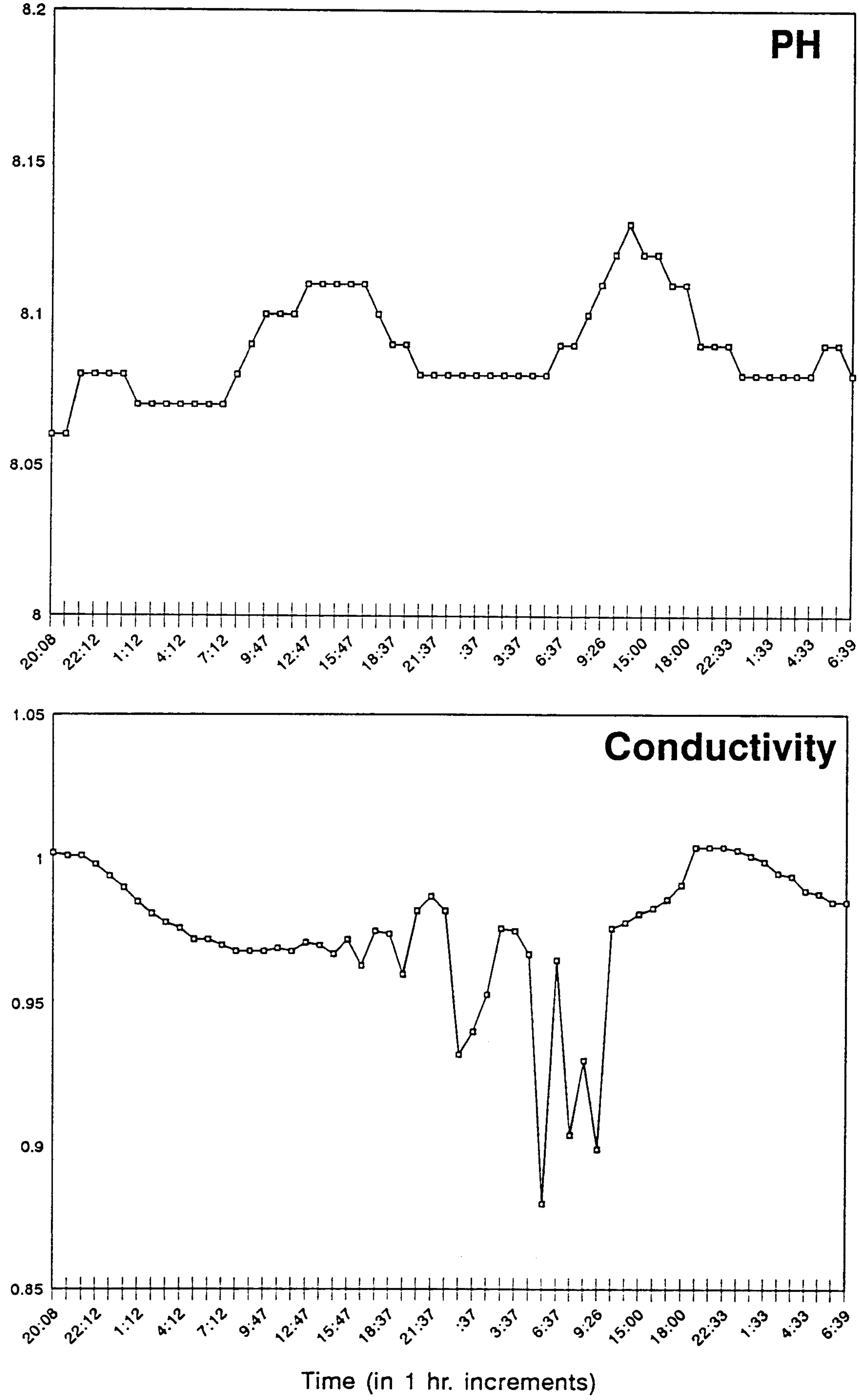


FIGURE A-2. **CONTINUED.**

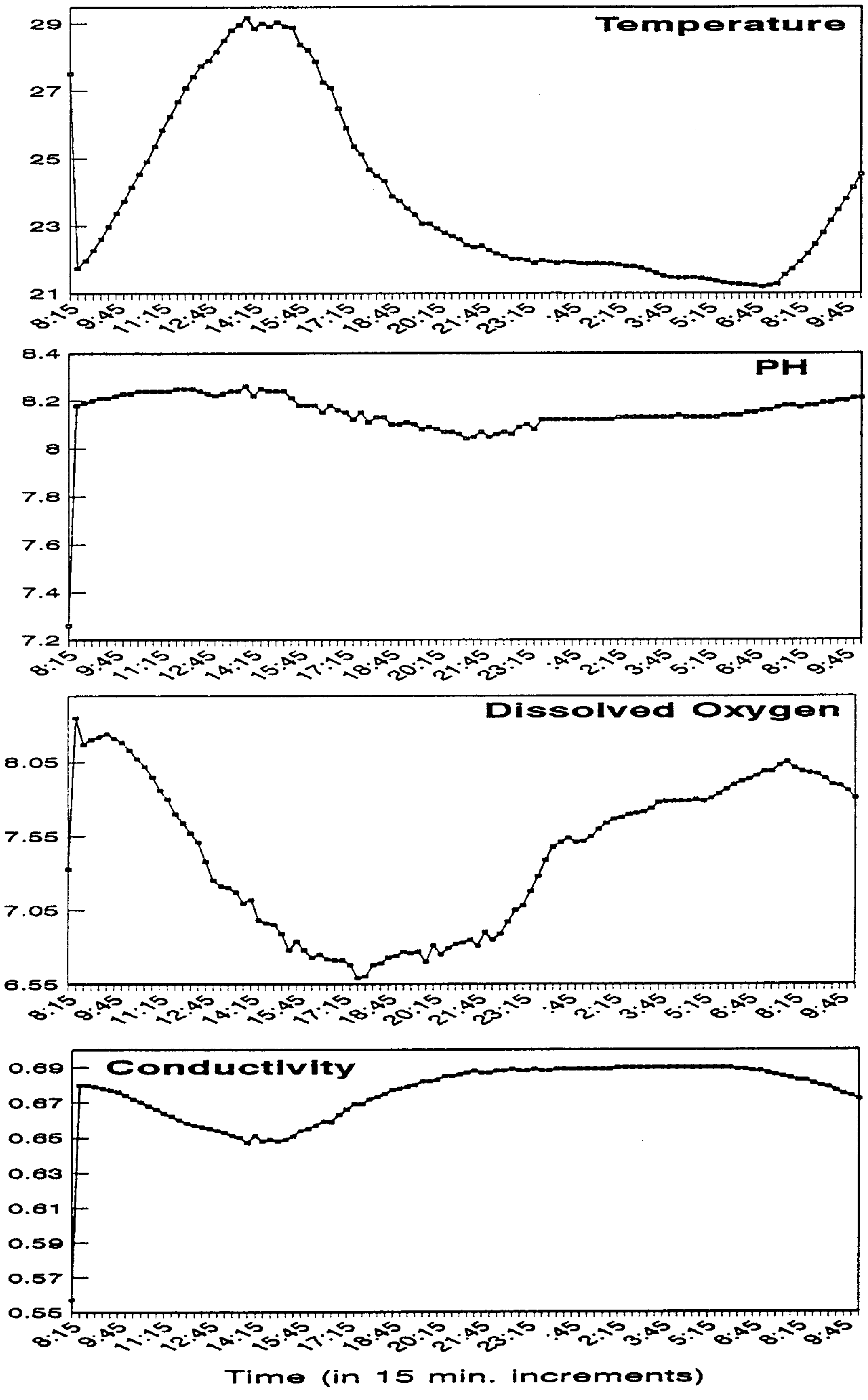


Figure A-3. Water quality parameters from Spencer Canyon recorded with a Hydrolab Datasonde on 26-28 June (0815-1015 hrs), 1992 (A), 30 September - 3 October (1300-0700 hrs), 1992 (B), 3-6 December (1500-0900 hrs), 1992 (C).

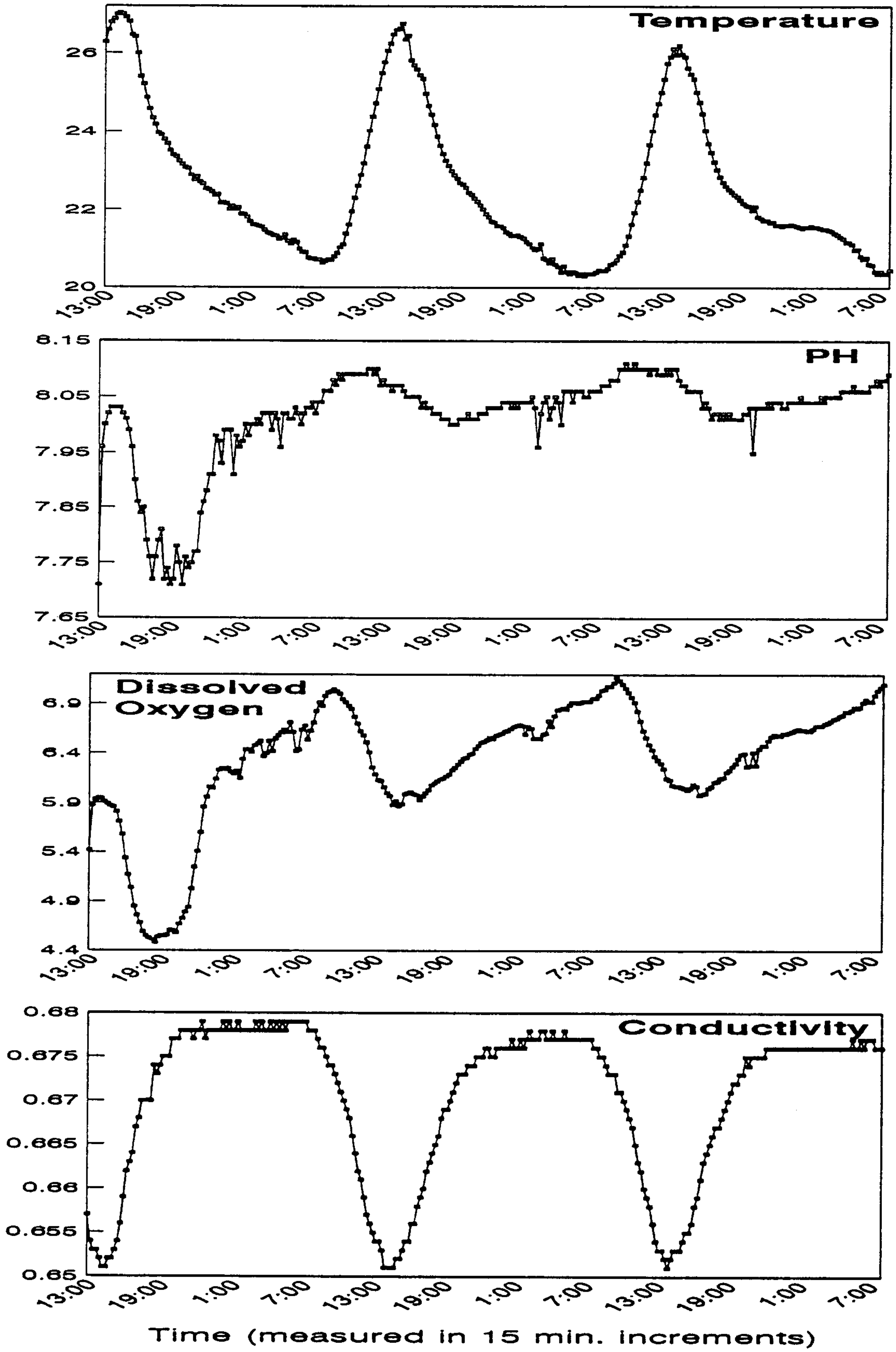


FIGURE A-3. CONTINUED.

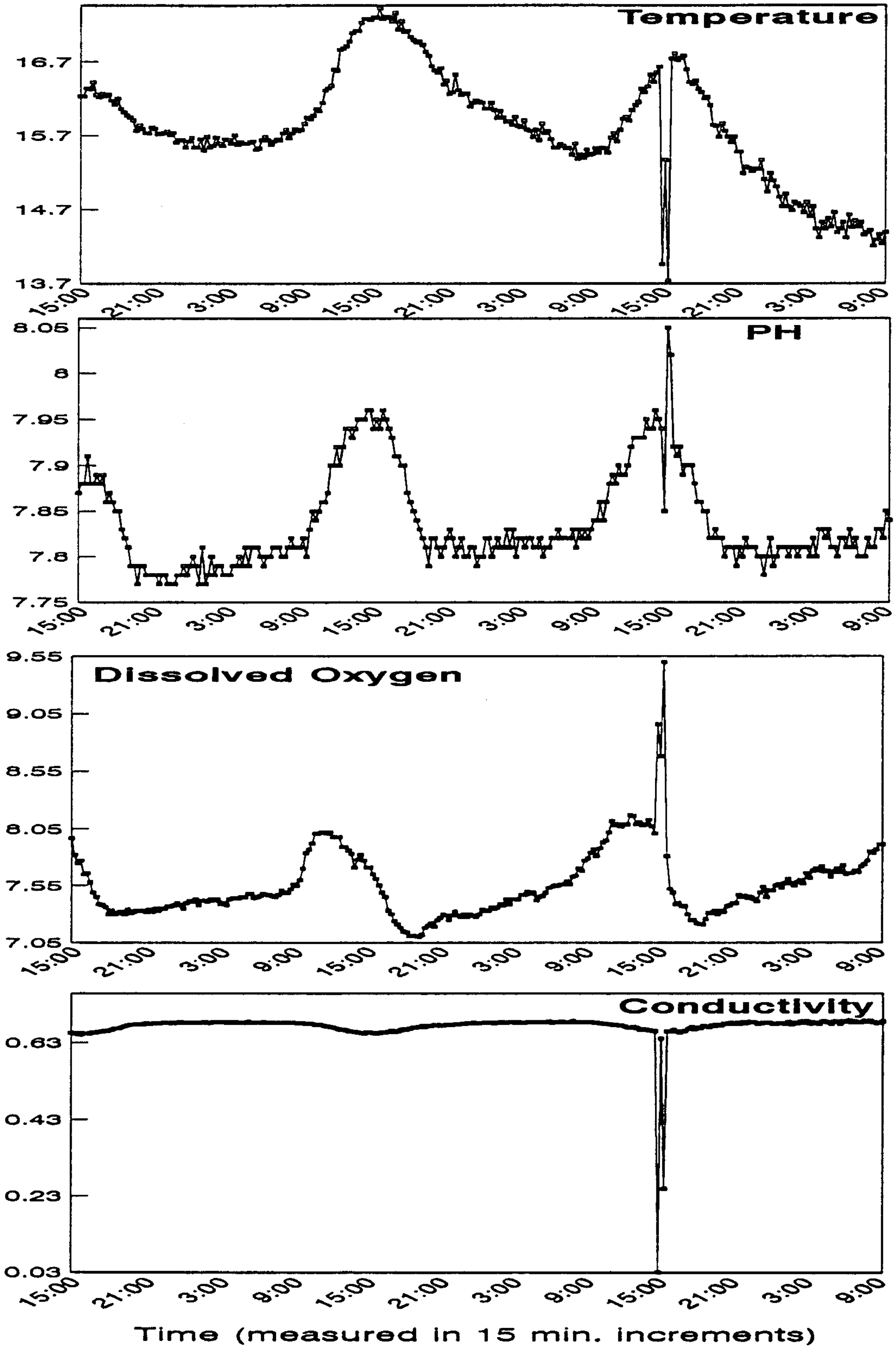


FIGURE A-3. **CONTINUED.**