Life History And Ecology of the Humpback Chub (*Gila cypha*) in the Colorado River, Grand Canyon, Arizona

REVISED DATA COLLECTION PLAN

(Contract No. 0-CS-409110)
(BIO/WEST Report No. TR 250-13)

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AGENCY REVIEW DRAFT

10 February 1995

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PREFACE

This Revised Data Collection Plan replaces the Data Collection Plan issued by BIO/WEST, Inc. on January 1, 1991 (Report No. TR 250-01). This Data Collection Plan , issued as a supplement to the Final Report, was drafted early in the project to standardize techniques and establish protocols to provide consistent data collection that were compatible with other GCES investigations. This plan provides detailed descriptions of field sampling methods, care and handling of fish, and database management that were too lengthy to include in the Final Report. A modified scope of work is described for 1993 that reflects findings, and advances ideas from investigations that have extended from October 1990 to December 1992. This new plan also updates field methodologies and techniques developed and refined through the course of the investigation.

This Revised Data Collection Plan was developed in conjunction with the Bureau of Reclamation, Glen Canyon Environmental Studies (GCES), and the Aquatic Coordination Team (ACT). It shall be provided to all members of the BIO/WEST staff, as well as to other investigative groups involved in the fisheries aspect of GCES, including Arizona Game and Fish Department, U.S. Fish and Wildlife Service, Arizona State University, Grand Canyon National Park, The Hopi Tribe, The Navajo Nation, and The Hualapai Tribe.

Substantive changes were made to length of monthly field trips, use of radiotelemetry, and distribution of sampling. These changes were the result of numerous meetings in the field, at BIO/WEST in Logan, and at GCES in Flagstaff, to insure a proper direction for the last year of the field investigation in 1993. Many BIO/WEST personnel had input into this redirection, including the principal-in-charge, principal investigator, project leaders, senior biologists, field biologists, and many professional boating guides. Although some minor changes were made, they were technical in nature and did not alter the objectives or modify the budget of the investigation.

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DATA COLLECTION PLAN

INTRODUCTION

Background

A Data Collection Plan was developed by BIO/WEST, Inc. in January 1991, as part of the requirements of Reclamation Contract No. 0-CS-40-09110, entitled *Characterization of the Life History and Ecology of the Humpback Chub (Gila cypha) in the Grand Canyon*. The background and scope of work for this investigation are described in the contract. This Revised Data Collection Plan updates sampling design, methods, schedules, work activities, logistics, and data collection for 1993.

This Revised Data Collection Plan contains eleven major sections: Introduction, Study Area, Study Design, Hydrology, Water Quality, Habitat, Invertebrate Drift, Fish Sampling Equipment and Methods, Fish Handling Methods, Radiotelemetry, and Data Management Plan. The objectives presented reflect the study objectives common to the four investigative groups; BIO/WEST, Arizona Game and Fish Department (AGF), Arizona State University (ASU), and U.S. Fish and Wildlife Service (Service). The sampling schedule was changed to monthly 16-day trips with three 20-day trips (May, July, September), instead of alternating 20 and 12-day trips defined in the original Data Collection Plan. Fish sampling equipment and methods, as well as fish handling techniques were not substantially changed, but reflect refinements from the experience of sampling. The sections on radiotelemetry, habitat assessment, and water quality detail methodologies developed and refined in this investigation since 1990. The data management plan contains some changes from 1991, mostly added data codes, and a better definition of fields, as well as a description of data collection, entry, and quality control.

This Revised Data Collection Plan was designed for use as a reference by primarily BIO/WEST field staff. It should also be valuable to other fishery investigators in Grand Canyon to understand the approach and methods used by BIO/WEST. Also, administrators and interested parties should find this document helpful in understanding field methods and techniques employed by the scientific investigations in Grand Canyon.

Purpose and Objectives

The purpose of this investigation, as stated in the project contract, was to:

> *"Evaluate the ecological and limiting factors of all life stages of humpback chub in the mainstem Colorado River, Grand Canyon, and the effects of Glen Canyon Dam operations."*

This investigation was designed to coordinate and integrate with other studies, describe physical, chemical, and biological components of the aquatic ecosystem in Grand Canyon; and provide an understanding of principal factors that limit the endangered humpback chub. By itself, this investigation addressed only certain aspects of these components, and shared roles and responsibilities with other investigators. The study objectives for B/W were to determine the following factors effecting humpback chub in the mainstem Colorado River in Grand Canyon:

1. Distribution, abundance and movement.
2. Resource use and availability (i.e., habitat, food).
3. Reproductive capacity and success.
4. Survivorship of early life stages.
5. Important biotic interactions with other species for all life stages.
6. The life history schedule.

These objectives were developed by Reclamation to address Conservation Measures 5 and 7. These objectives were also designed to provide insight into Question 6 and Hypotheses Ho-6.1, Ho-6.1a, and Ho-6.1b.

Question 6: "How do discharge fluctuations and rates of change in fluctuating discharges affect other fish, especially native fish species? Do the USFWS Conservation Measures adequately address this question?"

Ho-6.1: "There is no significant relationship between the population dynamics (including short-term abundance of early life stages and potential predation relationships) of native (especially the humpback chub) and introduced fish species in the mainstem Colorado, including mainstem backwaters and the confluence of the Little Colorado, and the magnitude of fluctuations, minimum discharges and rates of change of fluctuating discharges."

Ho-6.1a: "There is no significant relationship between population dynamics of native and introduced fish species in the mainstem Colorado, including backwaters and tributaries, and the magnitude of discharge fluctuations."

Ho-6.1b: "There is no significant relationship between population dynamics of native and introduced fish species in the mainstem Colorado, including backwaters and tributaries, and the magnitude of minimum discharges."

STUDY AREA

This investigation was conducted in a 364-km (226-mi) area of the Colorado River in Grand Canyon, from Lees Ferry (RM 0) to Diamond Creek (RM 226) (Figure 1), in which the river flows for 24 km (15 mi) within Glen Canyon National Recreation Area (Glen Canyon Dam to Lees Ferry), and 388 km (241 mi) within Grand Canyon National Park (Lees Ferry to Separation Rapid). The lower 121 km (75 mi) of river, downstream of National Canyon (RM 164.5), is bordered on the south by the Hualapai Indian Reservation.

Figure 1. BIO/WEST study area in Grand Canyon and four sample regions.

This area was divided into four study regions and 11 geomorphic reaches in order to approximate uniform distribution of sampling. The four study regions included: (1) Region 0--Lees Ferry to Kwagunt Rapid (RM 56.0), (2) Region I--Kwagunt Rapid to Hance Rapid (RM 76.6), (3) Region II--Hance Rapid to below Havasu Creek (RM 160.0), and (4) Region III--below Havasu Creek to Diamond Creek (RM 226.0). Regions I, II, and III, were sampled from October 1990 through November 1992. Region 0, added in January 1993 extended the investigation upstream. A fifth region--Region IV (Diamond Creek to Pearce Ferry, RM 280)--was investigated by B/W, as part of an aquatic resources study for the Hualapai Indian Tribe and GCES (Valdez 1993, 1994).

Reference landmarks along the river corridor were located to the nearest tenth (0.1) of a river mile (i.e., distance downstream from Lees Ferry along the center of the river) according to Belknap and Evans (1989), and sample sites were entered in the database to the nearest twentieth (0.05) of a river mile where possible in Region I. It should be noted that Lees Ferry is 15.2 river miles downstream of Glen Canyon Dam, and river miles cited in this report are in reference to Lees Ferry and not Glen Canyon Dam.

The following is a description of the four study regions and the geomorphic reaches identified by Schmidt and Graf (1990). Detailed descriptions of Grand Canyon geology are presented in Hamblin and Rigby (1968, 1969).

Region 0 (Lees Ferry to Kwagunt Rapid)

The study was expanded upstream to Lees Ferry in January 1993 to sample additional locations for humpback chub and to provided a more complete characterization of the ichthyofauna of the river. Previous investigators have found humpback chub in several locations in this region, including adults at RM 19.5, 27.5 (below Tiger Wash), RM 33 (Redwall Cavern), RM 55 (above Kwagunt Creek) (Carothers and Minckley 1981); sexually mature males near Tiger Wash (Minckley 1978), juveniles and adults in 1980-81 near Nankoweap Rapid (RM 52) (Kaeding and Zimmerman 1981, 1983); and individuals in 1984-86 downstream of RM 32 (Maddux et al. 1987, Kubly 1990).

This region was 56.0 miles (90.1 km) long from Lees Ferry to Kwagunt Rapid, and was characterized by four geomorphic reaches--Permian Section, Supai Gorge, Redwall Gorge, and Lower Marble Canyon (Table 1; Howard and Dolan 1981, Schmidt and Graf 1990). Average channel widths in the four reaches were 280, 210, 220, and 350 ft (79, 64, 67, and 107 m), respectively, and channel slope was low to moderate. Substrate was composed of 25-30 % bedrock and boulders, and shoreline was typically rock talus with intermittent tributary alluvial fans, sand bars, or earthen banks with vegetation.

Shoreline features in Region 0 were formed primarily by the Toroweap Formation and Coconino Sandstone (RM 2-5); Hermit Shale (RM 5-11.5); the Supai Group, including Esplanade Sandstone (RM 11.5-15), Wescogame, Manakacha, Watahomigi, and Surprise Canyon Formations (RM 15-23); Red Wall Limestone (RM 23-35); and Muav Limestone (RM 37-56).

The Paria River (RM 1.0) and Nankoweap Creek (RM 52.2) were the only perennial tributaries in this region. Several local drainages flowed intermittently during rain spates in June, July, and August, introducing large amounts of sediment into the river. The largest contributor of sediment to this upper portion of the study area was the Paria River. Large alluvial boulder fans at tributary inflows in this region constricted the channel, forming 12 minor and 6 major rapids (Badger Creek, Soap Creek, House Rock, North Canyon, 21-Mile, Nankoweap).

Region I (Kwagunt Rapid to Hance Rapid)

Previous investigations (Kaeding and Zimmerman 1983, Maddux et al. 1987) and B/W's results from 1990 (Valdez et al. 1991), 1991 (Valdez et al. 1992), and 1992 (Valdez et al. 1993) have shown that humpback chub seasonally enter the LCR in spring during spawning activity. It is suspected that many of these fish reside in the mainstem within this region for the remainder of the year. Determining the extent of use of this river region by humpback chub and the effect of dam operations on their habitat were primary objectives of this investigation.

Region I was 33.2 km (20.6 mi) long from Kwagunt Rapid to Hance Rapid, and was characterized by two geomorphic reaches--Lower Marble Canyon and Furnace Flats (Table 1). The river channel in these reaches averaged 107 and 119 m (350 and 390 ft) in width, respectively, and channel slope was low to moderate at 0.10 and 0.21 %, respectively. Substrate was composed of 30-36 % bedrock and boulders, and shoreline was typically rock talus, tapeats ledges, or vertical cliffs with intermittent tributary alluvial fans, sand bars, or earthen banks with vegetation.

Shoreline features in Region I were formed primarily by Bright Angel Shale (RM 47-58), Tapeats Sandstone (RM 58-63), and the Unkar Group (RM 63-76.5) of the Great Unconformity. Soft shales and sandstones of Bright

Angel Shale and Tapeats Sandstone created characteristic ledges and shorelines lined with fractured and collapsed rock fragments.

The Precambrian sedimentary series first appeared in the Nankoweap Formation as an angular unconformity at RM 63, and from that point to RM 65.5, the shoreline was characterized by steep vertical walls, short talus slopes and large angular blocks. Cardenas Basalt and Dox Sandstone of the Unkar Group were angularly juxtaposed downstream of the Palisades Fault, so that from Lava Canyon (RM 65.5) to Escalante Creek (RM 75), the channel was wider and the shoreline composed of boulders and cobble, with intermittent talus slopes and occasional vertical walls.

The only perennial tributary in Region I was the LCR (RM 61.3), which was the largest tributary and contributor of sediment to the Colorado River in Grand Canyon. Large alluvial boulder fans formed 9 minor and 5 major rapids (60-Mile, Lava Canyon, Tanner, Unkar, Nevills) in this region.

Region II (Hance Rapid to below Havasu Creek)

The primary purpose for sampling this region was to refine information on the distribution of humpback chub in Grand Canyon, its abundance by age group, habitat use, and changes in habitat availability with flow. Region II was 134.2 km (83.4 mi) long, and extended from Hance Rapid to below Havasu Creek. This region was composed of four geomorphic reaches, including Upper Granite Gorge, Aisles, Middle Granite Gorge, and Muav Gorge (Table 1). Upper Granite Gorge (RM 77.4-117.8) had the lowest average ratio of top canyon width to mean depth (7.0), the second narrowest average channel width (60 m, 190 ft), and the steepest channel slope (0.23%) of any geomorphic region in Grand Canyon. The river in Upper Granite Gorge flowed primarily through Vishnu Schist (black), Zoroaster Granite (pink), and Hotautu Conglomerate--hard Precambrian formations about 1.8 billion years old, forming steep canyon walls and smooth, scoured shorelines with little talus.

The Aisles reach (RM 117.8-125.5) included Stephen Aisle and Conquistador Aisle, and was characterized by the reappearance of Tapeats Sandstone (RM 120-130), found in Lower Marble Canyon. Average channel width was 70 m (230 ft), and 48 % of the bed was composed of bedrock and boulders.

The river in the Middle Granite Gorge reach (RM 125.5-140.0) flowed through a combination of Precambrian sedimentary rock, volcanic and metamorphic rock consisting of amphibolitic schist, limestones, diabase intrusives, and granitic plutons. These relatively hard materials constricted the river to its narrowest point in Grand Canyon--23 m (76 ft) at RM 135.0. Average channel width in this region was 210 ft (64 m), and the bed was composed of 68 % bedrock and boulders.

The river in Muav Gorge (RM 140.0-160.0) flowed through hard, Precambrian vishnu schist and zoroaster granite, which contained the river to the narrowest average channel width of any geomorphic region in Grand Canyon--55 m (180 ft)--and the highest percentage of bedrock and boulders (78%).

Eight perennial tributaries flowed into the Colorado River in Region II, including Clear Creek (RM 84.1), Bright Angel Creek (RM 87.7), Crystal Creek (RM 98.1), Shinumo Creek (RM 108.6), Tapeats Creek (RM 133.7), Deer Creek (RM 136.3), Kanab Creek (RM 143.5), and Havasu Creek (RM 156.7). These streams typically had low base flows with little effect on mainstem flows and only local effects on water chemistry and biology. Occasionally, high spring flows or severe local thunderstorms produced high tributary flows and short-term effects on mainstem water quantity and quality. The majority of native fishes found in this region were in close proximity to these perennial tributary inflows (Maddux et al. 1986, Valdez et al. 1992).

Region II contained 36 major rapids: Hance, Sockdolager, Grapevine, 83-Mile, Zoroaster, Pipe Springs, Horn Creek, Salt Creek, Granite Creek, Hermit, Boucher, Crystal, Tuna Creek, Sapphire, Turquoise, 104-Mile, Ruby, Serpentine, Bass, Shinumo, 110-Mile, Waltenberg, Forster, Fossil, 128-Mile, Specter, Bedrock, Dubendorff, Tapeats, 135-Mile, Fishtail, Kanab, Matkatamiba, Upset, Sinyala, and Havasu.

Region III (Below Havasu Creek to Diamond Creek)

Sampling in this 65-mile (105 km) region was conducted in the same manner as Region II, with the primary objectives to identify habitats used by humpback chub and other native fish species and to assess the effects of dam operation on these habitats. Radiotelemetry was implemented in this region in 1993 to aid in determining movement, distribution, abundance, and habitat of these lower fish aggregations, as well as changes in habitat availability with changes in flow. This region was determined to be an important nursery and rearing area for native fishes (Maddux et al. 1987). Although juveniles were found in this region, during this investigation, no spawning sites have been identified or prolarvae collected to confirm spawning.

Region III was 66.0 mi (106 km) long from below Havasu Creek to Diamond Creek, and was divided into two geomorphic reaches--Lower Canyon and Lower Granite Gorge (Table 1). Lower Canyon (RM 160.0-213.9) had an average channel width of 94 m (310 ft), a moderate slope (0.13%) and a bed composition of only 32% bedrock and boulders. The river flowed through 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 (RM 213.9-225.0) had an average channel width of 73 m (240 ft), a moderate slope of 0.16%, and a bed composed of 58% bedrock and boulders. This region consisted of metamorphic and sedimentary features similar to those in the lower portion of Upper Granite Gorge. The geologic formations consisted primarily of granitic and granodioritic rock of the Zoroaster Granite Complex, intermixed with Tapeats Sandstone.

This region contained 11 major rapids (164-Mile, Fern Glen, Gateway, Lava Falls, 185-Mile, Whitmore, 205-Mile, 209-Mile, 217-Mile, Granite Spring, and 224-Mile), formed mostly by alluvial tributary fans. There were no significant perennial tributaries in Region III.

STUDY DESIGN

This section describes the elements common to the overall sampling program, including project schedule, sampling design, sampling gear, and fish handling methods.

Project Schedule

This study was initiated in September 1990, and will be completed with the Final Report (Figure 2). Project workshops were held in December of 1990, 1991, 1992, and 1993 to provide ongoing staff coordination, identify and resolve problems, update data collection status, and provide progress reports to Reclamation and GCES.

Figure 2. BIO/WEST project schedule.

Field Trips

A total of 36 monthly field trips were conducted on the Colorado River in Grand Canyon, from Lees Ferry (RM 0) to Diamond Creek (RM 226), starting in October 1990 and ending in November 1993 (Figure 2). Trips were conducted monthly, except for December 1991 and 1992. From October 1990 through November 1992, trip length alternated between 12 and 20 days, resulting in five 12-day trips each in 1991 and 1992 (February, April, June, August, October) and six 20-day trips (January, March, May, July, September, November). The schedule was modified in 1993 to include eight 16-day trips (January, February, March, April, June, August, October, November), and three 20-day trips (May, July, September). Launch dates and sampling locations were coordinated with AGF, when possible, to provide concurrent sampling and comparable data.

Twenty-day trips were conducted to assess composition and distribution of fish, monitor habitat availability and use, determine important biotic interactions between humpback chub and other fish species, and capture humpback chub for implanting radio transmitters. These trips included two field teams, one with 6 BIO/WEST

(B/W) and 1 ACT biologists sampling Region I, and one with 4 B/W and 1 ACT biologists sampling concurrently in Region II. The two teams jointly sampled Region III during the last 5 days of the trip, so that each of the three study regions was sampled with equal effort of about 10 team-days.

Twelve-day trips were conducted primarily to recontact previously radio tagged adult humpback chub, and monitor their movement and habitat use in Region I. These trips involved one field team with 6 B/W and 2 ACT biologists. Fish were usually equipped with radio transmitters during 20-day trips, and tracked and monitored during 12-day trips from October 1990 through November 1992.

Sixteen-day trips were conducted from January through November 1993, when radiotelemetry was discontinued in Region I and implemented in Region II, and Region 0 was added to the sample area. The 16-day schedule allowed teams to allocate more time to tracking fish in Region II, while maintaining sampling frequency and intensity throughout the study area. The number of teams on 16-day trips alternated between one team (February, April, June, August, October) and two teams (January, March, May, July, September, November), with number of personnel as described for 12-day and 20-day trips, respectively.

Reports

Trip reports were completed and submitted within 10 days of the completion of each of the 36 field trips and annual reports were completed at the end of 1990, 1991, and 1992. These reports were submitted to Reclamation and GCES, and distributed to cooperating agencies and interested individuals.

Sampling Design

A stratified random sampling design was implemented to approximate uniform spatial and temporal sampling of fish assemblages and associated physical, chemical, and biological components (Schreck and Moyle 1990). The four study regions (0-III) were longitudinally divided into 11 geomorphic reaches (Schmidt and Graf 1990), each with approximately uniform channel and shoreline characteristics (Table 1). The 11 geomorphic reaches were subdivided into 34 sample strata that ranged from 3.2 to 19.5 km (2.0 to 12.1 mi) in length (Table 2). These strata were the base spatial sampling units, and were considered representative of the geomorphic reaches in which they occurred (Figure 3). The five major tributary inflows in Region II (i.e., Bright Angel Creek, Shinumo Creek, Tapeats Creek, Kanab Creek, and Havasu Creek) were each treated as individual stratum to be selected and sampled at least once seasonally in order to insure adequate temporal characterization of areas where fishes aggregated seasonally. Eight to 16 strata were randomly selected for sampling during each monthly trip. Selected strata were not eliminated from consideration for selection on subsequent trips.

Figure 3. Spatial stratified sampling design for Region II; a-m are sampling strata within geomorphic reaches, Upper Granite Gorge, Aisles, Middle Granite Gorge, and Muav Gorge.

Length of each sampling stratum was determined primarily by the distance of river between large rapids that was repeatedly accessible by research boats and location of temporary riverside camps for setting and retrieving sampling gear and tracking radio tagged fish. Whitewater rapids too large or swift to ascend with small motorized research boats prevented repeated access to sample sites and frequently delineated stratum boundaries.

Sampling was conducted monthly and at different times of day and night to account for temporal variation (Figure 4). Effort was partitioned by season to represent winter (December-February), spring (March-May), summer (June-August), and fall (September-November), and by time of day to represent night, dawn, day, and dusk. Since day length and photoperiod varied with season, a computer program (Sun and Moon Events Worksheet, Heizer Software, Inc., Palo Alto, CA) was used to appropriately adjust time blocks.

Figure 4. Temporal stratified sampling design for seasons (A) and time of day (B).

HYDROLOGY

Flow of the Colorado River and its tributaries in Grand Canyon was evaluated from stream gage records of the U.S. Geological Survey (USGS) (Table 3, Figure 5). Earliest records for the Grand Canyon section of the Colorado River at Lees Ferry were made in 1895. Early records were typically based on single daily measurements, while most gaging stations today record streamflow at 15-min intervals. The most current records are provisional, and subject to verification and change by USGS. Some provisional records were modified for this report, using data from adjacent gaging stations where obvious data irregularities existed. Final published records of the USGS are not expected to vary significantly from those presented in this report.

Figure 5. Locations of stream gages used for hydrology analysis.

A streamflow routing model was developed for this study to provide time and site-specific flow for correlation with radiotelemetry observations of adult humpback chub and collection of drift material. This flow routing model was based on the flood wave theory (Lazenby 1987), using the nearest stream gages for calibration. Stage-discharge relationships were derived from USGS stream gages for determination of flow from channel bathymetry.

Mainstem Colorado River

Flow data for the Colorado River in Grand Canyon were obtained from five USGS stream gages (Figure 5), identified by the following gage numbers and descriptions:

- 09380000 - at Lees Ferry, AZ
- 09383100 - above Little Colorado River, AZ
- 09402500 - near Grand Canyon, AZ
- 09404120 - at National Canyon, AZ
- 09404200 - above Diamond Creek, AZ

Historic records were available from the Lees Ferry gage (1895 to present) and from the Grand Canyon gage (1922 to present), but only intermittent records were available from above the LCR, at National Canyon, and above Diamond Creek (mid-1980s to present). The gage above the LCR was used most frequently because of its proximity to many aspects of this investigation that required time and site-specific streamflow information (e.g., fish movement from radiotelemetry observations, habitat assessment, fish movement into tributaries from channel bathymetry). Missing or aberrant discharge measurements were replaced using routed flow data from the Lees Ferry gage. Because USGS discontinued gaging streamflow above the LCR in April 1993, GCES began collecting flow data in March 1993. A correlation was developed between the two records to adjust the GCES data and provide a consistent record.

Little Colorado River

Flow data for the LCR were obtained from the following two USGS stream gages (Figure 5):

- 09402000 - near Cameron, AZ
- 09402300 - near mouth, AZ

The gage near Cameron provided a historic record of flow for the LCR since 1947. However, the gage was located 72 km (45 mi) upstream of the confluence, and did not record flow from Blue Springs (21 km upstream of the confluence), which was the major source of base flow for the LCR. The gage above the confluence with the mainstem was operated from 1987 to January 1993, when it was disabled by an unusually high flood. GCES measured stage at this location with a Manometer pressure sensor starting in January 1993, but no correlation with discharge was made in time for this report.

Other Tributaries

Flow data for major tributaries in Grand Canyon, other than the LCR, were obtained from the following three USGS stream gages (Figure 5):

- 09382000 - Paria River at Lees Ferry, AZ
- 09403000 - Bright Angel Creek near Grand Canyon, AZ
- 09403780 - Kanab Creek near Fredonia, AZ

Of seven major tributaries identified in the study region, only four had USGS gaging streamflow data--LCR, Paria River, Bright Angel Creek, and Kanab Creek. No USGS gages were located on Shinumo Creek, Tapeats Creek, or Havasu Creek. The gages on the Paria River and Bright Angel Creek were each located within 2 km (1.2 mi) of the mouth, and were valuable for determining annual and seasonal inflow into the Colorado River. The Kanab Creek gage was located about 50 km (31 mi) upstream from the mouth, and reflected general hydrology.

WATER QUALITY

Water quality parameters, analyzed for the mainstem Colorado River, LCR, other tributaries, and special habitats (i.e., riverside springs, tributary inflows, shallow embayments, areas of local fish abundance), included temperature, turbidity, specific conductance, dissolved oxygen, and hydrogen ion concentration (pH). Water quality data were procured from three sources, including portable Hydrolab water quality instruments (Hydrolab Corp, Austin, TX), USGS stream gaging stations, and Ryan Tempmentors (Ryan Instruments, Redmond, WA) deployed and maintained by GCES. Water quality data were collected during monthly field trips to characterize local habitats and supplement other data. Water quality data were usually collected from the Hydrolab hourly for 10-20 days/month, and discontinuous between field trips, since instruments were not left in the field between trips. BIO/WEST used the following Hydrolab water quality instruments:

- Surveyor 2: With Field Data Logger (Model 5100A)
- Surveyor 2: Display Unit (Model: SVR2-SU)
- Surveyor 3: 1100 Surveyor Data Logger (Model SVR3-DL)
- DataSonde 2: (Model 2270 H)

Water temperature was recorded in degrees Celsius (°C), and turbidity (as light transmisivity) was recorded in nephelometric turbidity units (NTUs) with a Hach Model 2100P turbidimeter, and as depth of water clarity with a standard 20-cm diameter Secchi disk. Specific conductance was measured in microSemens per centimeter (µS/cm), adjusted to 25°C. Dissolved oxygen was expressed as milligrams per liter (mg/l), and hydrogen ion concentration in pH units (0-14).

Each Hydrolab instrument was calibrated before and after each field trip. Water quality data were downloaded from data loggers using a laptop or desktop computer and Procomm Plus Version 1.1B communications program

(Datastorm Technologies, Inc., Columbia, MO). Water quality parameters (except turbidity) were recorded at camp locations, sample sites, tributary inflows, and special habitats. Turbidity was measured daily at camp, or with dramatic changes, usually from tributary inflow.

Data from six mainstem gages and six tributary USGS gages were used to provide historic and present overviews of water quality in the mainstem Colorado River and its tributaries (Figure 5). Pre-dam water quality and sediment data were obtained from two mainstem gages (Colorado River at Lees Ferry and Colorado River near Grand Canyon, AZ) and three tributary gages (Paria River at Lees Ferry, LCR near Cameron, and Bright Angel Creek near Grand Canyon). Post-dam data were from gages on the Colorado River below Glen Canyon Dam, above the LCR, at National Canyon, and at Diamond Creek, which were installed in 1983, as part of GCES Phase I to evaluate sediment transport and provide data for a flow routing model. Post-dam data were also obtained from gages (mini-monitors) installed in 1989 on the lower LCR, Bright Angel Creek, Kanab Creek, and Havasu Creek. These mini-monitors recorded water temperature, DO, and conductivity, and included pressure transducers for use with flow-rating curves to yield stream discharge estimates.

Ryan Tempmentors were installed by GCES in several tributaries and mainstem locations to supplement USGS gaging data and to provide data for a temperature model for the Colorado River in Grand Canyon. Tempmentors were located in lower Nankoweap Creek, LCR, Shinumo Creek, Kanab Creek, Tapeats Creek, and Havasu Creek, as well as select locations on the mainstem, such as RM 127 (Middle Granite Gorge).

Methods for gathering water quality parameters were adjusted for particular locations and conditions in this investigation. Water quality parameters in the mainstem were measured with a Hydrolab DataSonde deployed from a 37-ft (11.3-m) raft at each temporary campsite. Parameters were recorded electronically at 1-h intervals, and manual readings were recorded from a Hydrolab Surveyor 2, to supplement the electronic data in case of battery failure. Water temperature associated with fish and drift sampling was recorded with hand held thermometers, calibrated with a Surveyor 2 at the beginning of each trip. Water quality in the LCR was also recorded electronically at 15-min intervals with a Hydrolab DataSonde. DataSondes were deployed only when teams were in the vicinity--about 10 days/month--and temperature data were supplemented with Ryan Tempmentors and CR10 data loggers (Campbell Scientific, Inc., Logan, UT), and USGS ADAPs (Data Collection Platforms). Hydrolab Datasondes or Surveyors were also used to record water quality data in various tributary inflows, which were supplemented with data from Tempmentors or USGS gaging stations, to provide a continuous record of tributary temperature. Water quality parameters of special habitats were measured opportunistically with a Surveyor 2 and results recorded manually.

HABITAT

Riverine habitat was described by physical attributes of the river channel and resultant hydraulic characteristics within defined geomorphic regions. Habitat use by subadult (YOY and juveniles) and adult humpback chub in the Colorado River in Grand Canyon was determined by fish capture locations and radiotelemetry observations. Habitat selection was inferred through comparisons of habitat availability and use, and life-history needs of humpback chub.

Habitat Descriptions and Availability

Since channel geomorphology and predominant shoreline geology are determined by successive rock layers encountered by the river, habitat descriptions were based on geologic formative processes reflected in channel width, channel depth, slope, and shoreline lithology. These change longitudinally and shape hydraulic characteristics, and thus interrelationships of depth, velocity, substrate, and cover of fish habitat. These characteristics were identified at four levels of resolution (i.e., longitudinal geomorphic reaches, shoreline types, hydraulic units, and shoreline microhabitat measurements) containing descriptors consistent with those used by other investigators in the Colorado River Basin (Valdez and Wick 1983, Tyus 1984, Kaeding and Osmundson 1989, Harvey et al. 1993, Stanford 1994), and with an integrated description of resources in Grand Canyon (Werth et al. 1993).

The first level consisted of 11 geomorphic reaches consistent with the designations of Schmidt and Graf (1990), and subsequent levels were embedded within each reach, i.e., 8 shoreline types within each geomorphic reach, 8 hydraulic units within each shoreline type, and 4 microhabitat parameters within each hydraulic unit (Figure 6). A similar classification system was used by Anderson et al. (1986) to analyze aquatic habitat for low and high flows of the Colorado River in Grand Canyon from video imagery, and provided a comparative data set.

Figure 6. Dendogram of a classification system for fish habitat in the Colorado River, Grand Canyon.

Availability of habitat in select subreaches of the mainstem was determined from (1) maps with visual interpretations of macrohabitat and shoreline types, (2) channel bathymetry, (3) velocity isopleths, (4) temperature isopleths, (5) maps with visual interpretation of substrate types, and (6) shoreline fish microhabitat measurements. Map products (1) through (5) were incorporated into the GCES

Geographic Information System (GIS) developed for resource monitoring of the Colorado River in Grand Canyon (Werth et al. 1993). Shoreline microhabitat measurements were integrated into a fisheries database and stored in dBASE IV. Each map product was referenced to an established control network for use as informational layers on the GIS. A multi-temporal, multi-accuracy GIS database was developed to accommodate the different data types and accuracies associated with these maps (Hougaard and Valdez 1994).

Level 1: Geomorphic Reach

The 11 geomorphic reaches described by Schmidt and Graf (1990) were the basis for longitudinal comparisons of fish habitat. Major geologic units at river level, width to depth ratio, channel width, channel slope, and bed composition were described for each reach to provide a longitudinal characterization of fish macrohabitat. A more detailed analysis was conducted for two subreaches with the largest aggregations of humpback chub, the LCR Inflow (LCRI) and Middle Granite Gorge (MGG), and compared with a third subreach with few fish, in order to identify important geomorphic variables in determining reach selection. That analysis compared number of debris fans, slope, and average width to depth ratio. Water temperature was also considered because of the dominating influence of cold hypolimnetic releases from Glen Canyon Dam.

Level 2: Shoreline Types

Shoreline types were classified to reflect predominant formative shoreline geology, and included bedrock, cobble bars, debris fans, sand bars, and talus slopes (Table 4, Figure 7); vegetated banks were identified as a sixth category because of their influence on fish distribution and abundance. Shoreline and macrohabitat types (See Level 3: Hydraulic Unit) were visually delineated at seven map sites and various flows, between RM 59.75 and RM 63.24, to determine changes in availability with fluctuating flows. This classification was similar to that used by Werth et al. (1993), except that rock ledge and rock face were combined into bedrock, and alluvial fan was termed debris fan. This shoreline classification was designed to reflect geomorphic processes and transposition of material with the greatest influence on fish habitat. For example, cobble bars were composed of material rounded and embedded by river processes with limited spaces for fish shelter, while talus slopes consisted of irregular, angular boulders formed from shoreline rockfalls and slides, and providing interstitial spaces with low velocity.

Figure 7. Cross-sections of hypothetical shoreline types.

Surface area of shoreline types and macrohabitat types were delineated irrespective of flow, from the LCR inflow (RM 61.3) to Hance Rapid (RM 76.4) to relate longitudinal shoreline geomorphology with occurrence and densities of juvenile humpback chub, and with shoreline microhabitat measurements (Converse 1995).

Level 3: Hydraulic Units

Fish macrohabitat described the general area occupied by a fish, and was classified on the basis of hydraulic units, including eddies, pools, rapids, return channels, riffles, and runs (Table 5, Figure 8). Terms and definitions for macrohabitats were consistent with those adopted by the American Fisheries Society (Helm 1985), with elements of the GCES/GIS classification scheme for aquatic biology (Werth et al. 1993), and with common usage of terms throughout the Colorado River Basin (Tyus et al. 1982, Valdez et al. 1982, Maddux et al. 1987). These hydraulic units reflected areas of differential fish use distinguishable at the water's surface, so that changes in flow were reflected in changes in surface area, and thus effects of dam operations on fish macrohabitat.

Figure 8. Surface flow pattern of an eddy (A), and cross sections of a rapid (B), riffle (c), and run (d). Sketches of rapid, riffle and run from Helm (1985).

Twenty-five habitat maps were developed for seven sites in the vicinity of the LCR (Figure 9, Table 6) for determination of flow to habitat relationships. These sites were (1) ESPN, RM 60.8-61.0, (2) CAMP, RM 61.0-61.2, (3) LCRI, RM 61.2-61.5, (4) HOPI, RM 62.2-62.4, (5) SALT, RM 62.4-62.6, (6) WHAL, RM 62.6-62.9, and (7) WEEP, RM 63.9-64.2. Aerial photographs at a 1:1200 scale (1 cm = 12 m) were used as base maps to simultaneously delineate macrohabitats and shoreline types for a subreach of river about 400 m long at each site. Two to four maps were developed at each site for different flows during interim flow criteria in 1991 and 1992.

Figure 9. Locations of five bathymetry map sites (A-E) and seven macrohabitat map sites (1-7) on the Colorado River in Grand Canyon.

Maps were developed by the same observer using visual interpretations of macrohabitat margins and shoreline delineations from two or three established high shoreline vantage points. Binoculars were

used to better define water levels, habitat interfaces, and shoreline types, and all observations were made early and late in the day to minimize solar reflection and water surface disturbances from wind.

Habitat maps were rectified to orthophoto base maps for GCES/GIS monitoring site #5 (Werth et al. 1993), from the LCR to Cardenas (RM 61.3-72). Surface area of each macrohabitat type in square meters, and linear distance of each shoreline type in meters were determined from the GIS, and related to river flow at the midpoint of map development (habitat maps were developed in 35-60 min). A flow routing model described in HYDROLOGY was used to estimate flow at the site during each period of map development.

Level 4: Habitat Parameter

Channel Bathymetry Channel morphology was further described with bathymetry maps of five sites (Figure 9), including (A) Awatubi Canyon, RM 58.5, (B) 60-Mile Canyon, RM 60.1, (C) ESPN Rock, RM 60.8, (D) Carbon Creek, RM 64.7, and (E) LCR Inflow, RM 61.3. The first four sites contained large recirculating eddy complexes regularly used by humpback chub, and the LCR Inflow site was used as a staging area by prespawning adults.

A Super-Hydro bathymetric system was used to map underwater topography of the mainstem (F. Protiva, M. Gonzales, GCES, pers. comm.), and presented as two-dimensional isopleths or three-dimensional bathymetry enhanced with computer imagery. The system consisted of a shore station, located by coordinates with the aid of an Ashtech Global Positioning System (GPS), to track and send position information to a main computer located on a boat. The boat computer included a graphics screen to guide the helmsman along a pre-determined sampling pattern of transects set 10 m apart. Survey readings, including distance and angle, were taken with the aid of a prism on the traversing boat, and simultaneous to measurements of depth (using a Lowrance depth sonar) and velocity (using a Marsh-McBirney current meter). Data point collection interval for depth was adjustable, from once every 2 sec to 4 points/sec; e.g., over 10,000 points were collected to develop a bathymetric map for the LCR site (1.6 km distance of river). Elevational starting points for each map were based on a local coordinate system above the high water line in order to reliably reestablish control points and allow for future resurveys.

Field information was stored on the main computer, and transferred to GCES for processing, and plotting. Data processing included editing erroneous points, generating a database from surveyed points, visual reality check of data points, depth reductions to relative elevation, generation of a surface model, and orientation to established network coordinate points (Werth, et al. 1993). Bathymetric plots were generated with contour intervals of 0.5 m (consistent with GCES/GIS).

Velocity Isopleths Velocity isopleths were also developed with the aid of the Super-Hydro for two sites (Figure 9), including ESPN Rock (RM 60.8) and Carbon Creek (RM 64.7). Velocity was measured 1 m below the water surface with a Marsh-McBirney current meter, and recorded simultaneous to depth readings. Velocity was plotted with contour intervals of 0.1 m/sec. Although flow volume changed during these measurements, and multi-directional velocity shears were common in a single vertical transect, these isopleths provided a characterization of velocity magnitude, and distribution and location of high and low velocity zones, relative to channel morphology.

Temperature Isopleths Thermal isopleths of the LCR inflow were developed from water temperature data collected with hand-held thermometers over a series of points located by a latice grid system. Data were collected May 16, 20, and 21, and July 21, 22, 23, 24, and 25, 1992, and assimilated by four mainstem flow ranges, including (1) 9200-9600 cfs, (2) 12,130-12,809 cfs, (3) 13,947-14,504 cfs, and (4) 17,470-17,798 cfs. A relationship of LCR temperature (at base flow of 230 cfs) to mainstem flow was established, and thermal gradients plotted at 2°C intervals, from 10°C to 24°C.

Substrate Maps Substrate of the LCR inflow was also delineated with the aid of the Super-Hydro, simultaneous to development of bathymetry maps. Observers used the tracking boat or waded in shallow areas to classify substrate according to a modification of the Wentworth system (Table 7). Substrate was segregated as a separate layer of the GIS, and surficial area of each type determined in square meters.

Shoreline Microhabitat Depth, velocity, substrate, and cover of shorelines commonly used by juvenile humpback chub were evaluated to describe habitat attributes and determine relationships of flow to microhabitat. Parameters were measured and classified at three 1-m intervals from shore, along each of ten parallel transects. Depth was measured with a graduated staff, velocity with a

Marsh-McBirney current meter, substrate was classified according to Table 7, and cover was classified as instream, lateral, and overhead (Helm 1985). Measurements were made at 84 sites at different flows to evaluate changes in available habitat components within sites and within shoreline types. These sites were also sampled with electrofishing to relate fish density to shoreline type, and to evaluate effects of dam operations (i.e., fluctuating flows) on juvenile habitat.

Habitat Use

Radiotelemetry was identified by species experts as the most effective method for determining habitat used by the Colorado River endangered fishes (Valdez et al. 1990), and has been applied to humpback chub (Kaeding et al. 1990, Valdez and Nilson 1982, Valdez and Clemmer 1982), Colorado squawfish and razorback sucker (Tyus et al. 1982, Valdez and Masslich 1990), and bonytail (Chart and Cranney 1991). Habitat used by humpback chub and sympatric species in the mainstem was determined from radiotelemetry and capture information, and selection was determined from highest proportion of use. Radio tagged adults (n=75) were located and observed as described in RADIOTELEMETRY-Observations, and habitat use was determined as percentage of radio contacts in respective macrohabitats, i.e., contact locations were mapped for each of two to four daily boat surveillances through the area occupied by radio tagged fish. Efforts to measure microhabitat (depth, velocity, substrate, cover) of radio tagged adults were abandoned because water depth, channel width, and high, multi-directional velocity shears precluded accurate measurements. Macrohabitat of juvenile and YOY humpback chub, and sympatric species, was determined from catch locations associated with electrofishing, nets, seines, minnow traps, and hoop nets. Capture locations of adults were used to supplement and confirm radiotelemetry data, since the latter are generally considered more reliable descriptors of fish habitat (Tyus 1982, Valdez et al. 1990).

Microhabitat of subadult humpback chub (TL<200 mm) was determined within shoreline types sampled with electrofishing (Table 4). Depth, velocity, substrate, and cover were determined from measurements taken along each of ten parallel transects, as previously described in Shoreline Microhabitat. Individual capture locations were not used for microhabitat quantification because electrofishing displaced fish from microhabitat sites (Bovee 1986, Valdez et al. 1990), and sampling within specific shoreline types reduced variation of macrohabitat parameter measurements.

INVERTEBRATE DRIFT

The volume of material (i.e., detritus, macroinvertebrates) drifting in the river was determined for season, time of day, flow magnitude, ramp direction, habitat, and longitudinal location, in order to relate drift material to dam operations and to food habits of fish.

Equipment

Drift nets were made of a rectangular tubular frame (30.48 cm x 45.72 cm) with a 3-m long net of 560 micrometer mesh, and a detachable catchment cup (Figure 10). Nets were placed in pairs, one collecting surface drift and one collecting subsurface drift, and a Swoffer current meter was used to determine net-mouth current velocity at the beginning and end of each set, usually 15-20 min. Volume of water filtered through each net was calculated as:

Volume = whv
where:
Volume = cubic meters of water filtered per hr,
w = width of net opening (45.72 cm),
h = height of net opening (30.48 cm),
v = average water velocity (meters per second) at the net mouth (average of beginning and end velocity).

Figure 10. Drift nets set in tandem to sample near-surface (A) and midwater (B).

In 1991 and 1992, a permanent drift sampling site was established just upstream of the LCR (RM 61.2) to determine the effects of discharge, habitat, and time of day on drifting macroinvertebrates. Drift was sampled monthly to account for seasonal variation, and to provide a long-term data set. Drift was also sampled longitudinally from the LCR (RM 61.2) to Diamond Creek (RM 226).

Analyses

The contents of each drift net was placed in appropriately-labeled whirl-pacs or Ziplock bags, preserved with 70 percent ethanol, and returned to a laboratory. Macroinvertebrates were sorted from detritus, and identified and counted by taxonomic family, genus, or species. Dry weight of remaining detritus (algae, woody debris, etc.) was measured. Sample drift density (macroinvertebrates/100 cubic meters water filtered), as reported by Allen and Russek (1985), was calculated as:

$$\text{Sample Drift Density} = \frac{\text{numbers per net hr}}{\text{m}^3\text{ water filtered per hr}} \times 100 \qquad \text{(Equation 1)}$$

Organisms per 100 cubic meters of water filtered (orgs/100 m^3 wf) and grams dry weight of detritus were used in all statistical analyses (Systat version 5.03, Wilkinson 1992). Analyses of Variance (ANOVAs) with significance levels of $P<0.05$ were used to determine significant differences in data.

FISH SAMPLING EQUIPMENT AND METHODS

Equipment

Inflatable hypalon boats (Achilles Corp., Number 22 Daikyo-Cho, Shinjuku-Ku, Tokyo 160) were used for sampling and radio tracking. These small boats increased access to a greater variety of habitats than previously sampled, and enhanced scientific validity by allowing replication of data collection (Valdez et al. 1993). The sport utility SU-16 model (4.9 m long) was used primarily for electrofishing and radio tracking, and the sport heavy-duty SH-170 model (5.2 m long) was used primarily for netting and radio tracking. The frames for these boats were designed for safety and functionality and were easily disassembled for transport on the larger support rafts.

Standard safety equipment was provided with each boat including: 1) standard first aid kit, 2) 65-foot throw line, 3) throw able floatation device, 4) flip lines, 5) fire extinguisher, 6) extra life jacket, 7) spare paddles or oars, 8) life line, 9) bow line, 10) safety lanyard motor switch, 11) river rescue kit, 12) boat patch kit, 13) motor repair kit, 14) spare motor, propeller, and gas, and 15) Q-beam and battery.

Each electrofishing boat (SU-16) was designed to accommodate up to three biologists -- an operator and one or possibly two netters. The boat was equipped with two subframes, including a front netting deck and rail, and a middle frame with dry compartments, a live well, and a 5-kw generator (Figure 11). Maximum operating weight for an electrofishing boat (load capacity of 3210 pounds) was an estimated 1200 pounds. Each netting/radio tracking boat (SH-170) was designed to accommodate two or three biologists -- an operator and one or two biologists to perform various research tasks such as setting and retrieving fishing nets or radio tracking. The boat was equipped with a single frame with a live well, dry equipment storage compartments, radio tracking equipment, and a breakdown antenna extension boom (Figure 12). Maximum operating weight for a netting/tracking boat (load capacity of 3500 pounds) was an estimated 800 pounds.

Figure 11. Fishery research boats.

Figure 12. Fishery research boats frame design.

Only principal BIO/WEST biologists, experienced in operating research vessels, handled these boats during sampling activities. Maneuvering research vessels through rapids was done by boat operators with the qualifications outlined in the Colorado River Management Plan (CRMP). All BIO/WEST biologists and personnel were familiar with and adhered to the National Park Service's CRMP regulations on river safety, experience, and boating restrictions. A Boat Operating and Safety Plan (BIO/WEST Report No. TR 250-03) was developed by BIO/WEST to insure that all personnel were thoroughly familiar with the safety aspects of the project and that appropriate personnel were properly trained in boat operation.

Care for these boats and motors was essential to sampling the Colorado River in Grand Canyon and to accomplishing the objectives of this scientific investigation. Boat operators were always aware of onboard gas supplies to prevent running short. A regular check of the outboard motor was performed by boat operators, including oil level, condition of propeller and lower spindle. Each engine was allowed to warm up, especially during cold weather, and water pump outlet ports and impeller port were checked for continuous streams of water to insure that the engine coolant system was working. Outboard motors left on boats overnight were tipped up out of the water to prevent mud from settling in the water pump housing. Gas tanks were never run dry to prevent clogging outboard carburetors with residues. Gas tanks and outboard motors were not used as foot steps to prevent damage to handle or spout seals that could cause gasoline leaks. Problems with outboard motors were identified with plastic tape (not duct tape), and the Equipment Coordinator was advised of the problem. During hot summer months air was released from toubes peridoicaly to prevent over pressurization which could loosen patches.

The research boats were usually folded and loaded on larger support boats (33 or 37-ft S-rigs, or 23-ft snouts) for transport to and from riverside camps to reduce boat activity in the canyon, and to minimize personal risk and damage to equipment in traversing large whitewater rapids. Support rafts were provided by OARS, a commercial river concessionaire from Flagstaff, Arizona, contracted by GCES to provide logistical support for research efforts in Grand Canyon.

Fish Capture Methods

Six basic gear types were used by BIO/WEST in the Colorado River in Grand Canyon to sample fish, including electrofishing, gill and trammel nets, seines, minnow traps, hoop and frame nets, and angling. Unique data sheets were developed for each gear type to facilitate data entry and analysis. A section entitled DATA MANAGEMENT PLAN is provided in this document, together with each of the field data sheets used. It was very important that all BIO/WEST personnel were intimately familiar with each data sheet and the codes and entries required for each data field. The accuracy and consistency of data determined the value of this scientific investigation.

Nets

Gill Netting Techniques: Gill nets were the primary gear used to characterize large-fish assemblages in deep shoreline habitats and to capture adult humpback chub for implanting radio transmitters. This gear type was used to compare fish distribution and abundance by area and time, as well as to categorize general fish habitat use in support of radiotelemetry data. These gear types are commonly used to survey and monitor other populations of humpback chub in the Upper Colorado River Basin (Valdez and Clemmer 1982, McAda et al. 1994, U.S. Fish and Wildlife Service 1987).

Gill net mesh sizes were used that would capture a variety of fish sizes including adults and juveniles. The number of fish captured by species from a net set was recorded for calculation of catch-per-unit effort expressed as the number of fish per 100 feet of net per 10 hr.

Gill nets were 30.5 m long and 1.8 m deep, with 3.8 or 5.1 cm-square mesh (100 ft x 6 ft deep, 1.5 or 2-in mesh). Experimental gill nets were also used with four sections of 1.3, 2.5, 3.8, 5.1-cm mesh (0.5, 1, 1.5, and 2-in). Trammel nets were 22.9 m long and 1.8 m deep (75 ft x 6 ft), with three panels of netting--two outer walls of 12-in (30.5 cm) mesh and one inner panel of 1.3, 2.5, or 3.8-cm mesh (0.5, 1, or 1.5-in). Gill and trammel nets were made of double knotted #139 multifilament twine with 1.3-cm (0.5-in) diameter braided polyfoamcore float line and 0.8-cm (5/16-in) leadcore line. White, labeled mooring boat bumpers, 12.7 cm (5-in) in diameter and 45.7-cm (18-in) long, were tied to a line at the distal end of each net to facilitate relocation and retrieval, and to alert boaters to submerged nets. Polypropylene mesh bags were filled with rocks and used as convenient net weights.

Gill nets were generally set from shorelines diagonal to the direction of the current. One end of the float line was anchored to the shore so that the end of the net was within 1 m of the shoreline (Figure 13). A weight bag was attached to the shoreline end of the leadline to anchor the net in position and keep it extended. Experimental gill nets were set with the small mesh nearest the shore. The nets were extended into the channel, with the boat powered in reverse, to maximize fishing efficiency according to conditions at the point of the set. Crew members in the boat bow fed nets out of breathable mesh storage bags removing tangles and any remaining debris to assure a proper set. In areas with current, nets were generally extended downstream, parallel with the current either along eddy lines, runs or pools. In areas with little or no current, nets were placed perpendicular to anticipated fish movements. A second weight was attached to the distal end of the net with a length of line that determined the net height above the river bottom. An extension line was then attached to the float line and the net was lowered into the water until the weight reached the bottom, at which time, the marker/float was attached with a bowline knot. Nets to be set again the next day in the same location were bagged and set on shore above the high water line.

Figure 13. Typical gill or trammel net set.

Nets were generally checked with the outboard engine off and tilted above the boat. The nets were pulled from the water by grabbing the marker float, pulling the distal net weight from the bottom and then hauling the net aboard the boat while slowly moving toward the shoreline attachment point. If the distal net weight became lodged on the bottom it was necessary to start from the shoreline in order to free the weight.

Fish were removed as they were encountered with priority to endangered species, native species, trout and other non-natives in that order. If endangered fish were severely entangled, the netting was cut to free the fish. Fish were identified and enumerated as they were removed from the net and placed in a live well. Each was then measured, weighed and appropriately processed before release. Nets were checked at least every 2 hr to minimize stress and reduce mortality of entangled fish. Nets damaged or clogged with the algae *Cladophora* or debris were removed and replaced with clean ones.

Trammel Netting Techniques: Trammel nets were used in a similar manner to gill nets to characterize fish assemblages and document changes in fish distribution and abundance over time and location. Trammel nets tended to be less stressful on the fish than gill nets because the middle panel of netting tended to form a bag around the fish rather than tightening around their gill opercles impeding respiration. Trammel nets were also used in an active manner by floating nets through areas of fish concentrations, such as during spawning time. This technique worked best in areas of low current and smooth sand bottom to prevent entangling and tearing the nets on bottom debris. Trammel nets consisted of three panels of netting, two outer walls of large mesh and one inner panel of small mesh. The outer walls consisted of #139 multifilament twine netting with a 12-inch mesh. The inner panel consisted of either 1-inch or 1 ½-inch mesh; these mesh sizes have been found most effective for capturing humpback chub with a minimum of damage. All inner panels were constructed of double knotted #139 nylon multifilament twine.

Traps

Hoop Nets: Three sizes of hoop nets were used in various velocity habitats including 0.6 m x 3.0 m x 1.3-cm (2 ft x 10 ft x 0.5-in), 0.9 m x 4.0 m x 2.5-cm (3 ft x 13 ft x 1-in), and 1.2 m x 4.9 m x 1.3-cm (4 ft x 16 ft x 0.5-in) (diameter x length x square mesh). Nets were typically located in tributary streams or their mouths. Two 7.6 m (25-ft) wings made of 2.5-cm (1-in) #15 knotless nylon were attached to the opening of the hoop nets. Hoop nets were set by anchoring the rear of the net with a length of rebar and orienting the mouth in a downstream direction to capture fish moving upstream (Figure 14). Wings were anchored with rocks. Nets were checked at least every 8 hr to minimize stress and mortality to fish. Occasionally nets were set in the mouths of tributary

streams when water in the mainstem was low. These "dry" sets would be inundated when water in the mainstem would rise, and would be checked for captured fish when the water began dropping again.

Figure 14. Typical hoop net set.

Minnow Traps: Unbaited minnow traps were used to sample small fish in a variety of shoreline habitats. Minnow traps were standard Gee minnow traps--44.5 cm (17.5 in) long, 22.9 cm (9 in) diameter, and constructed of galvanized wire and steel. Funneled openings were located at each end of the trap. Traps were placed on the bottom or suspended in the water column depending on conditions. Traps were also set in pods of five as sample repetitions for habitat types. Each trap was tethered to a secure anchor point and discretely flagged for easy relocation. A long length of cord was attached between the anchor point and the trap to prevent stranding with fluctuating water depths. Traps were checked at intervals of no longer than 24 hr (8-12 hr in Region I) to minimize stress and mortality to fish.

Seines

Seines were used to characterize assemblages of small fish in relatively shallow habitats (up to about 1.5 m in depth). Three sizes of seines were used, including 9.1 m x 1.2 m x 0.6-cm (30 ft x 4 ft x 0.25-in), 9.1 m x 1.5 m x 0.6-cm (30 ft x 5 ft x 0.25-in), and 3.0 m x 0.9 m x 0.3-cm (10 ft x 3 ft x 0.125-in) (length x height x square mesh). The float line was constructed of 0.8-cm (0.3125-in) braided polypropylene with hard foam floats at 45-cm (18-in) intervals. The bottom line was made of braided polypropylene line with lead sinkers at 15-cm (6-in) intervals.

Length and width of each seine haul were measured and three water depths recorded; one at the deepest point of the haul, and one each midway between the deepest point and the nearest shore. Length and width of the habitat sampled were also recorded, where applicable. CPUE for seine hauls was expressed as the number of fish per 10 square meters of area seined. Each sheltered habitat sampled was checked for longitudinal thermal gradients prior to seining. If significant temperature differences occurred, extreme care was taken to avoid subjecting fish to thermal shock during seining, holding, and release. After each haul, the seine was held suspended in the water while endangered and native fishes are removed and placed into live wells (buckets). The seine was then beached and a second intensive search made. After all endangered and native fish were removed, the remainder of the fish were placed in a separate live well. Fish captured with seines were identified in the field and released live at the capture location. Specimens that could not be identified afield were preserved in formalin (3 to 5% concentration) and placed in an appropriately-labeled sample jar and noted on the data sheet. Incidental mortalities were also preserved and recorded. All preserved fish were returned to the BIO/WEST laboratories for further identification and processing. Specimens were transferred to the Service, AGF, or NPS as required by scientific collecting

permits. Specimens of federally threatened or endangered species were transferred as soon as possible to AGF together with letters of transfer.

Electrofishing

Electrofishing was used to sample fishes along shorelines and to capture adult humpback chub for implanting radio transmitters. Each electrofishing effort was conducted within a distinct geomorphic shoreline type (i.e., alluvial fan, bedrock, cobble bar, sand bar, talus slope, vegetation) in order to evaluate habitat use and reduce variability in comparing catch rates between habitats and reaches, as well as between flow levels and over time. The number of fish captured by species in a discrete effort was recorded and related to time (seconds of electrofishing from internal system timer) for calculating catch-per-unit effort (CPU) expressed as number of fish per 10 hr of effort.

Electrofishing was conducted from an Achilles SU-16 research boat capable of ascending small and medium-sized rapids for increased access to sample areas (Figure 12). Each boat was designed to meet Occupational Safety and Health Administration (OSHA) safety standards with specialized features such as pressure safety switches, grounded wiring, insulated railing, separate line-channeling for circuits and lights, and rubber gloves, rubber boots, and fiberglass-lined dip nets for netters and boat handler. The system was powered by a 5000-W Yamaha industrial grade generator (Model YG-500-D) or a Honda 5000-W generator (Model EB 5000X), and routed through a Mark XX Complex Pulse System (CPS) developed by Coffelt Manufacturing (Flagstaff, AZ). Stainless steel spheres, were used as electrodes with the anode (positive electrode) mounted on a boom projecting from the bow, and the cathode (negative electrode) suspended from the stern. Anode and cathode were interchanged every 45-60 min of electrofishing to allow for cleaning of the cathode surface by reversing the electroplating process.

In 1990-91, CPS output settings ranged from 15-20 A and 300-350 V, as recommended by Coffelt Manufacturing for electrofishing in the Colorado River below Glen Canyon Dam (N. Scharber, Coffelt Manufacturing, pers. comm.). In 1992, output was reduced to a range of 8-10 A and 200-250 V after "bruise marks" were observed on trout under the higher settings. The lower settings seemed to reduce the incidence of these marks.

During electrofishing runs, one or two dip-netters were positioned in the bow of the boat to capture stunned fish. Crew also made "blind net sweeps" into turbid water in likely habitats such as pocket eddys behind boulders and along shorelines. Dip nets had an opening of 324 square inches (18"x18"), a bag depth of 24 inches, and were constructed of 1/4-inch knotless mesh. One netter was designated to operate a "deadman" foot switch which must be depressed for the system to be operational. The boat operator was also able to quickly shut off power at the

CPS control unit. As fish were netted, they were placed immediately into a live well located just behind the netters.

Electrofishing runs were generally made adjacent to the shoreline and in the direction of the current. The boat was maneuvered among shoreline cover to adequately sample areas used by fish. An electronic timer, built into the CPS, was used to keep track of time associated with each run. All fish captured during electrofishing were processed immediately upon completion of a run within a habitat type. Each fish was visually examined for evidence of injury associated with electrofishing. Bruises, spinal deformities, and prolonged lethargy were noted on data sheets. Target fish such as humpback chub and razorback sucker were processed immediately and released at their capture location. Nontarget fish were processed and released within 0.1 to 0.2 mile from the point of capture.

Nighttime electrofishing was conducted with the aid of two 150-watt floodlights mounted on the safety railing at the bow of the boat. These 110-volt lights were powered by the 5,000-watt generator with the electrical lines isolated from the 220-volt lines for increased safety. The operator also had access to a battery-operated 500,000 candlepower Q-beam spotlight to aid in night time navigation.

Angling

Angling has been used as an effective method for capturing humpback chub in the Upper Colorado River Basin, in Black Rocks and Westwater Canyon (Valdez et al. 1982) and in Yampa Canyon (Tyus and Karp 1989). Cheese balls, commercial salmon eggs, stink bait, grasshoppers, Mormon crickets (Tyus and Minckley 1988), and artificial flies have been used with varying success. Angling was not used extensively in Grand Canyon because of the relative high efficiency and low impact of other sampling methods, and the time and commitment necessary for successful angling of this endangered species. However, angling was used to catch actively feeding rainbow trout for stomach analysis to assess predation on YOY and juvenile humpback chub in the vicinity of the LCR inflow, where concentrations of young chubs were highest.

FISH HANDLING METHODS

Handling fish in the Grand Canyon required particular care and attention, primarily because endangered species were involved, but also because the work was being conducted in a national park, and sampling activities were highly visible in the field and came under regular scrutiny from state and federal resource agencies and the public. A fish handling protocol was therefore, essential to all fishery investigations in Grand Canyon. This section of the Revised Data Collection Plan describes fish handling techniques employed by BIO/WEST biologists in Grand Canyon. These techniques reflect considerable experience with riverine species from other parts of the Colorado

River basin, and were refined to fit the logistical needs and conditions of the canyon. BIO/WEST made every reasonable effort to minimize impacts associated with research on all fish species residing in Grand Canyon National Park, especially the endangered humpback chub and razorback sucker. All methods and procedures employed to capture, hold, anesthetize, and process fish reflect a concerted effort to avoid excessive stress to fish.

Transport and Holding

Captured fish were placed in live wells to minimize stress and enhance recovery. Live wells consisted of 127-L (120-qt) insulated coolers located on each boat, 1.3-L (5-gal) bail buckets carried by seining crews, and 1.2 m x 1.8 m x 1.3-cm mesh (4 ft x 6 ft, 0.5-in) holding pens placed in the river. Small fish were placed in buckets inside of live wells. The live well lid was kept closed during sampling and transport to prevent fish jumping out. Fresh river water was used for contained fish of each sample effort, and changed frequently (every 15 min) when holding time was prolonged or large numbers of fish were being held. Fish showing signs of stress (e.g., increased or irregular respiration, loss of equilibrium, dramatic color change, reddened fins, excessive slime) were isolated in fresh water, carefully monitored, and treated with a salt solution to minimize electrolytic losses (Bulkley et al. 1982, Hattingh et al. 1975). Fish with extended lethargy or obvious injuries were appropriately treated (e.g., Betadine™ was applied to wounds and lernea were removed) and released upon recovery. Dead fish were preserved in an appropriately labeled container, and transferred to the ichthyology collection at Arizona State University. Incidental mortality of humpback chub from this investigation did not exceed 10 per year, the number allowed under BIO/WEST's federal collecting permit.

Fish Processing Procedures

A number of fish processing procedures were used during the course of this investigation. Some were initiated by the original study design, and modified or discontinued, while others were implemented as a result of specific data needs or at the request of the ACT (Figure 15). From October 1990 through July 1991, all humpback chub captured were transported to a central processing station near camp and then returned to their capture location for release--a one-way distance of up to 6.4 km (4 mi). This protocol prolonged holding time and unnecessarily stressed the fish and was modified in August 1991, when humpback chub were processed and released near their capture location. Only adults destined for radio implant were transported to a central processing station. Humpback chub were measured for total length (TL), standard length (SL), and forked length (FL) in millimeters, weighed wet in grams, marked with a PIT tag, and gender determined (for more detailed descriptions of measurements see Data Management Plan, Data Codes, and Appendix B - Data Code Glossary). From October 1990 through July 1991, the left aspect of every humpback chub≥200 mm TL was photographed (35-mm color slide and VHS video) on a white plasticized board marked with a 1-cm grid. Starting in August 1991, 35-mm photographs were taken of every tenth adult that was not a recapture, and videography was discontinued. Primary rays of dorsal and anal fins were also counted for every tenth adult, and ten morphometric dimensions were

measured with venier calipers (Figure 16), accurate to the nearest 0.01 mm, including depth of nuchal hump, head length, snout length, distance between insertion of pelvic and pectoral fins, maximum body depth, caudal peduncle length, maximum caudal peduncle depth, minimum caudal peduncle depth, length of anal fin base, and length of dorsal fin base.

Figure 15. Schedule of fish processing procedures conducted by BIO/WEST.

Figure 16. Morphometrics and meristics recorded for adult humpback chub ≥200 mm TL.

Select adult humpback chub from Region I weighing more than 550 g were surgically equipped with 11-g radio transmitters from October 1990 through January 1991, and every other month through March 1993. Use of 9-g radio transmitters in fish 450-550 g was discontinued because of transmitter limitations. A nonlethal stomach pumping technique was implemented in September 1992, following evaluation of the technique (Wasowicz and Valdez 1994). Scales were taken from chub <200 mm TL to determine age and size at transition from the LCR to the mainstem.

Tissue core samples were taken for genetic analysis during October 1992. Tissue cores were removed with a 3mm biopsy punch from multiple locations including: fins and along the dorsal and peduncle musculature. Samples were preserved in liquid nitrogen and transferred to Dr. Michael Douglas of ASU. Humpback chub sampled in this manner were noted on data sheets along with any other pertinent observations.

Other native species, including flannelmouth sucker, bluehead sucker, and speckled dace were measured for total and standard length (i.e., TL, SL-mm), weighed (g), and those ≥ 150 mm TL were PIT-tagged starting in August 1991. Non-native species were also measured for total and standard length, weighed (lb,oz), examined for reproductive condition and gender, and released. All channel catfish, striped bass, and selected rainbow trout and brown trout were sacrificed for removal of stomachs. Gut contents were preserved in ethanol, placed in labeled whirl-packs, and transported to Leibfried Environmental Services in Flagstaff, Arizona, for identification and quantification of food contents.

Stomach Analysis

Food habit studies generally require sacrificing many fish for stomach removal and examination. In systems with low fish numbers, removal of fish can seriously deplete populations and lethal methods are generally not permitted with endangered species. A nonlethal method of stomach pumps was used to examine food habits of humpback chub in the mainstem Colorado River of Grand Canyon. Studies have shown that stomach pumping is an effective technique for removing gut contents without harming the fish. Fish species which have been tested

effectively include a variety of salmonids, centrarchids, ictalurids, percids, and esocids (Meehan and Miller 1978, Swenson and Smith 1973, Seaburg and Moyle 1964). Stomach pumps have also been used successfully with roundtail chub in the Upper Colorado River Basin (R. Valdez, BIO/WEST, pers. comm.). In all cases, the removal of stomach contents with pumps was not injurious to the fish.

A non-lethal stomach pumping technique was developed and tested in 1992 by BIO/WEST for recovering gut contents of humpback chub in Grand Canyon (Wasowicz et al. 1992). Testing was conducted on surrogate roundtail chub *(Gila robusta)* and initiated with humpback chub in Grand Canyon in September 1992. Only humpback chub were stomach pumped during this investigation.

The stomach pump design (Figure 17) was based on Gengerke's modification of the original Seaburg design (Gengerke et al 1973, Seaburg 1957). Flexible plastic tygon tubing was connected to both ends of a clean, hand-held, rubber bulb, commonly used as an in-line gasoline pump for outboard motors. Fish were mildly anesthetized with MS-222 (~250 mg/l), and the clear outlet tube inserted into the buccal cavity of the fish. A stream of water was pumped through the inlet tube and into the stomach, flushing food items from the digestive tract, through the vent, and into a collecting jar. Flexible tubing minimized the chance of damage to the esophagus and pharyngeal mill, and the hand-held rubber pump allowed for precision in dictating water flow and pressure. Different sized, interchangeable tubes were used for efficient flushing of various sized fish.

Figure 17. Stomach pump used to recover gut contents of adult humpback chub.

Gut contents were appropriately labeled and preserved in 75% ethyl alcohol. Samples were placed in a secure place and transferred to the laboratory at Leibfried Environmental Services in Flagstaff for sorting and identification.

Humpback chub were captured at various times of the day and night to ascertain feeding periodicity relative to flow, time of day, turbidity, and other riverine conditions. Peak feeding times were identified by examining the digested stage of stomach contents.

All fish were held in holding tank for a brief period after pumping to ensure recovery and to identify any anomalous characteristics such as previous marks (e.g., fin punches, fin clips, external fish tags), parasites, wounds, or deformities. Anomalies were recorded in detail on appropriate data sheets and photographed if relevant.

Marks

PIT Tags: A PIT tag (Passive Integrated Transponder) was injected into the parietal cavity (Figure 18) of each humpback chub ≥ 175 mm TL, and starting in February 1991 minimum size of tagging was reduced to 150 mm TL. Each tag was a glass-encapsulated microchip,12 mm long and 1.7 mm in diameter, that emitted a unique 10-digit alphanumeric identifier when activated with a specialized electromagnetic scanner. PIT tags were injected into the peritoneal cavity of a fish just posterior to the pelvic fin (usually the left fin), using a large bore hypodermic needle which was cold steralized after each use (Figure 18). PIT tags were injected only by trained personnel designated by the Principle Investigator or Project Leaders. All native and endangered fish were first thoroughly scanned for the presence of a PIT tag from previous capture. External tags (i.e., Carlin or Floy tags placed by previous investigators) were removed from native fish and replaced with PIT tags, and both tag numbers recorded in the database with corresponding information. These old tags were replaced at the request of the ACT because PIT tags were considered more reliable, with less chance of tag loss, and greater capacity and facility for information retrieval (Burdick and Hamman 1993).

Figure 18. Attachment sites for Carlin dangler tag (A) and Floy anchor tag (B) by previous investigators, and injection site for PIT tag © by this investigation.

Fin marks: Beginning in January 1993, humpback chub 60-150 mm TL (juveniles) were temporarily marked with fin punches (Figure 19) to track longitudinal dispersal. A 3-mm diameter biopsy needle was used to punch various fin combinations specific to river subreaches (Wydoski and Emery 1983). Fish captured between RM 57 and RM 65.5 were marked with a dorsal fin punch; those between RM 65.5 and RM 76.5, with a lower caudal fin lobe punch; those between RM 76.5 and RM 157, with an upper caudal fin lobe punch; and those between RM 157 and RM 225, with a combination dorsal and upper caudal lobe punch.

Figure 19. Juvenile humpback chub with dorsal fin punch (A) and location of scale samples (B).

Fin clips were used to mark juvenile humpback chub, flannelmouth suckers, and bluehead suckers by Arizona State University beginning in 1991. The purpose for these marks was to distinguish capture location by longitudinal region in the Little Colorado River. ASU used a combination of caudal and pelvic fins to designate original fish captures from one of four regions of the LCR:

1. Chute Falls to Salt Trail Camp: upper caudal lobe plus right pelvic fin.
2. Salt Trail Camp to Sipapu: upper caudal lobe plus left pelvic fin.
3. Sipapu to Powell Canyon Camp: lower caudal lobe plus right pelvic fin.
4. Powell Canyon Camp to Confluence: lower caudal lobe plus left pelvic fin.

ASU removed the entire upper or lower gossamer portion of the caudal fin while avoiding injury to the peduncle and fin ray bases. The pelvic fins were removed at the base allowing the fin to regenerate but providing a longer-term mark.

Preservation of Incidental Mortalities

Humpback chub

Any humpback chub that was an incidental mortality was handled in the following manner:

A. For humpback chub less than 150 mm total length

1. Weighed and measured the fish.
2. Affixed a numbered Carlin tag to the lower jaw so it was clearly visible.
3. Placed the fish in a plastic bag with 95% ethyl alcohol (ketone-free solution provided by AGF).
4. Placed a waterproof tag in the sample bag with the fish that had a field sample identification, species, fish length, weight, date, location of capture, and collector.

B. For humpback chub 150 mm total length or over

1. Weighed and measured the fish.
2. Eviscerated and placed the stomach in 95% ethyl alcohol (did not cut the stomach open!).
3. Skeletonized the fish: filleted and removed the bulk of the flesh leaving the skeleton and head in tact (took 1-2 min to do). Attached a numbered Carlin tag to the jaw of the skeleton. Discarded the flesh (bury) and hung the skeleton to dry.
4. Placed the dried skeleton in a plastic bag with a label with field sample identification, species, fish length, weight, date, location of capture, and collector.

Native fish

All other native species (i.e., flannelmouth suckers, bluehead suckers, speckled dace) were preserved in 10% formalin for 48 hr then transferred to 95% ethyl alcohol. Appropriate data was recorded on data sheets and on sample bags. Specimens were kept in a secure place (e.g., ammo box) to prevent damage and to prevent theft by ravens.

At the end of a trip all specimens were transferred to a designated Project Leader (Bill Leibfried) who in turn transferred these to the AGF designee (Dennis Kubley in 1990-1992, Rob Clarkson in 1993). All information associated with each fish (Carlin tag #, field sample identification, species, fish length, weight, date, location of capture, and collector) was then transferred to the BIO/WEST Principal Investigator, and a "letter of transfer" sent to the Service (F. Baucom) with copies to AGF (R. Clarkson), National Park Service (J. Ray), Arizona State University (M. Douglas), GCES (D. Wegner), and Reclamation (L. Crist).

Non-native fish

Specimens of nonendangered fish that needed to be returned to a laboratory for further examination were preserved in the following manner. Fish that were smaller than 75 mm TL were preserved in a 4 or 5% formalin solution, while fish larger than 75 mm TL were placed in a 10% formalin solution. All fish collected were placed in containers of adequate size to prevent distortion or damage during collection and transportation. Care was taken to not overcrowd specimens in containers. A small incision was made on the right side of the parietal cavity of all specimens greater than 150 mm in length to insure thorough preservation. All collections were labeled with sample number, date and river mile corresponding to that recorded on the data sheet. Labeling was done with permanent markers on the outside of the containers and in pencil on collection labels placed in the container with the fish.

RADIOTELEMETRY

Equipment

Transmitters

Two models of ATS radio transmitters were used in this investigation. The ATS Model 1 BEI 10-18 weighed 9 g and was 3.8 cm long and 1.3 cm diameter. The Model 2 BEI 10-35 weighed 11 g and was 6.0 cm long and 1.3 cm diameter. Both models were oblong with an external antenna at one end that measured about 25 cm long and 1.2 mm diameter.

Frequencies of 40.600 to 40.740 MHZ were used in Grand Canyon. These were separated by 10 KHz intervals (i.e., 40.600, 40.610, 40.620, etc.) to distinguish individual transmitters. This 10 KHz separation yielded 15 different frequencies. The combination of 15 different frequencies and 3 pulse rates (40, 60, and 80 pulses per minute) allowed for a total of 45 unique signatures to identify individual fish. The same combination of frequency and pulse was reused following expiration of a transmitter. Transmitter longevity was a function of battery life. The manufacturer's estimated life for the 9-g transmitters was 50 days. The 11-g transmitters with 40 pulses per minute were expected to transmit 120 days, those with 60 pulses per minute were expected to transmit 100 days, and those with 80 pulses per minute were expected to transmit 75 days. All transmitters were checked prior to implanting and immediately after release of the fish to insure that each transmitter was functional and that frequency and pulse rate were accurately recorded. Frequency and pulse may vary from factory specifications because of temperature, battery age, and varying signal sensitivity from different receivers.

Yard et al. (1990) determined from field tests that signal reception from 9-g external-antenna transmitters was effective at a depth of 4.63 m at a horizontal distance of 48 m on the mainstem Colorado River in Grand Canyon. The same transmitter in the LCR was received at a depth of only 0.91 m at a horizontal distance of 48 m. Internal

antenna transmitters weighing 13 g were simultaneously tested with signal reception in the mainstem of 3.96 m depth at 48 m distance, and in the LCR of 0.85 m depth at 48 m distance.

BIO/WEST tested signal reception depth of 11-g external-antenna transmitters used in this investigation and found an average depth extinction of 4.5 m at 50 m distance (three field trials of 4.5, 4.5, and 4.6 m) (Figure 20). These results were similar to those reported by Yard et al. (1990). A specially developed internal-antenna transmitter (prototype: 13.2 g, 7.5 cm x 1.3 cm) was simultaneously tested to ascertain if the external antenna could be eliminated while maintaining the same transmisivity and battery life with a transmitter of approximately 13 g. Average signal depth extinction for the prototype was 3.2 m at 50 m distance (three field trials of 3.2, 3.2, and 3.2 m), or 29 percent less than the 11-g external-antenna transmitter.

Figure 20. Approximate receiving zones for three remote telemetry stations near the mouth of the Little Colorado River.

BIO/WEST also tested signal reception distance, and found that at 1 m depth, the signal from the 11-g external-antenna transmitter was received at a distance of 1200 m, while that of the prototype was received at only 600 m, or 50 percent of the distance. BIO/WEST concluded from these tests that the internal-antenna prototype was not suitable for our needs in the Grand Canyon, and we continued using the 11-g external-antenna transmitters.

Radio transmitters were implanted without a wax coating following cold sterilization with 70 percent ethyl alcohol. Beeswax coatings have been used in earlier studies to provide an inert surface to minimize risk of rejection and expulsion (Tyus 1988). However, the manufacturers of the transmitters contend that the epoxy resin used to encase the electronic components is non-irritating and is more effectively sterilized than beeswax (M. Shuster, ATS, pers. comm.). Beeswax would have added undesirable weight and bulk to the transmitter, which is critical with the small size of humpback chub.

Transmitter weight could not exceed 2 percent of fish weight (Bidgood 1980, Marty and Summerfelt 1990), thus, 9-g transmitters were implanted only in fish weighing 450 g or more, and 11-g transmitters only implanted in fish weighing 550 g or more. Care was taken to select fish that were healthy and showed no signs of stress. Females were usually not implanted from March through May to prevent stress to these gravid fish and eliminate the risk of transmitter expulsion from enlarging egg masses (Bidgood 1980, Marty and Summerfelt 1990).

Receivers

ATS Receiver: The ATS Model R2000 (Figure 21) is a scanning-programmable receiver, used in this investigation to receive radio frequencies of 40 to 41 MHZ in omni-directional searching, directional triangulation, and in remote stations. This receiver was used because of its light weight, compactness, water

resistant case, and compatibility with ATS radio transmitters. It was easy to use with nearly unlimited capacity to quickly and easily add or delete frequencies. The disadvantage of this unit was that it scanned single preprogrammed frequencies instead of multiple frequencies simultaneously. The unit had an optional scan rate setting of 2, 4, 8, 16, or 32 sec, or 1, 4, 8, or 16 min. If the unit had ten preprogrammed frequencies set at 4 second-intervals (time it scans a single frequency), it scanned all ten frequencies in 40 sec and therefore scanned a given frequency every 36 sec. ATS receivers were normally used at the 4-sec scanning rate and all radiotelemetry searches and surveillences were conducted in a slow, methodical manner with observers using headsets to reduce the possibility of missing audible signals. The characteristic water-drop sound from radio transmitters was audible through the ATS R2000, and the unit had a visual signal strength meter. The ATS R2000 was portable with nickel-cadmium batteries that were rechargeable and replaceable in the field. Twelve-volt marine batteries were sometimes used as power sources when the battery pack was low, but these became cumbersome when tracking from shore.

Figure 21. Radio receivers.

Smith-Root Receivers: The Smith-Root SR-40 (Figure 21) was also used for omni-directional searching. This model receiver was previously used to successfully aerial and boat-track Colorado squawfish (*Ptychocheilus lucius)* and razorback sucker *(Xyrauchen texanus*) in the Green River, Utah (Valdez and Masslich 1992). The SR-40 was preferred for aerial tracking because it simultaneously scanned multiple preprogrammed frequencies. This receiver emitted audible and visual contact signals. A bank with ten red lights corresponding to preset frequencies, enabled trackers to confirm audible with visual signals.

The disadvantage of the SR-40 (Figure 21) was that it accommodated only ten preprogrammed frequencies that were set by the manufacturer. Although it received signals from similar frequencies, it did not register weak signals. Unique frequency/pulse combinations were difficult to distinguish with this unit, particularly when multiple frequencies were contacted (multiple audible and visual signals emit simultaneously), or when two or more fish occupied the same area with transmitters of similar frequency and different pulse rates. Frequencies were also difficult to identify when fewer than five signal contacts occurred. The Smith-Root RF-40 (Figure 21) programmable receiver was used as a companion to the SR-40 in past investigations (Valdez and Masslich 1992), but the unit is no longer manufactured. The SR-40 was used as a backup to the ATS R2000, or the two units were used simultaneously to insure complete surveillance coverage. Although the battery pack for the SR-40 was separate from the receiver, keeping these batteries charged was difficult with different users and various power drains.

Antennas

Omni-directional Larsen-Kulrod whip antennas were used with ATS R2000 and SR-40 receivers for searching radio signals. Smith-Root loop antennas were used for locating signals by triangulation. Breakage and fraying of the external sheath of the coaxial cable at the handle base of the loop antenna and near the base plate of the whip antenna required frequent checking and periodic maintenance. All antennas were carefully checked before every use. Small breaks or frays in the coaxial cable weaken or void signal strength. Loss of contact with the grounding sheath of the coaxial cable could deactivate one side of a directional antenna and cause large errors in triangulation.

Remote Stations

Remote stations deployed for this investigation were established under the guidance of Grand Canyon National Park. Two remote telemetry stations were established in 1991 and 1992 near the mouth of the LCR to monitor movement of radio tagged fish to and from the LCR. One station (KLCR), located immediately upstream of the LCR confluence (RM 61.3) and on the east bank of the Colorado River, had a directional yagi antenna aimed across the river at the upper mouth of the LCR. The second station (KRSH) was located downstream of the LCR confluence (RM 62.1) on the west bank of the Colorado River with a directional yagi antenna aimed across the river in line with the shallowest point in the channel. The antennas were not aimed directly across the LCR because previous tests (Yard et al. 1990) showed signal impedance from high conductance during clear flows. These stations were each equipped with a directional Proline low band yagi antenna (30 to 75 MHZ). These two stations operated February through August of 1991 and 1992, and were dismantled after 1992.

A third remote station (KILR) was deployed in mid-August of 1991 and operated through January 1992, about 1 km upstream of the LCR confluence on the east bank of the Colorado River. This station was equipped with an omni-directional Larsen-Kulrod whip antenna to monitor daily near-surface activity of radio tagged fish from RM 59.9 to RM 61.3.

Two omnidirectional stations, established in Middle Granite Gorge, were operated February through September 1993 (KBNE, RM 126.1), and March through September 1993 (KMGG, RM 127.4).

Each remote station was equipped with an ATS Model R2000 receiver (data logger compatible) and a DCC-II Model R5041 data logger. Data were downloaded at the beginning and end of each field trip (during field trips) with a portable computer. The receiver and data logger were housed in pad-locked weather-resistant boxes to prevent damage from elements and vandalism. Each station was properly identified in case it was discovered by someone not familiar with the project. The weather-proof boxes and yagi or omnidirectional antennas were painted drab brown to camouflage the station and reduce visibility.

Problems with power supply and static surges associated with electrical storms were the main problems with remote stations in Grand Canyon. A solar powered recharger was incorporated into each station to resolve power problems, although lack of adequate solar radiation in the canyon during winter months resulted in lower power supply, and cold winter temperatures adversely affected battery efficiency. Grounding cables were used to minimize risk of static from electrical storms.

Radio tracking

Aerial Radio tracking

Aerial tracking was sometimes conducted prior to a field trip to locate radio tagged fish thought to be outside of routine tracking areas. Aerial tracking was conducted from a helicopter, at an altitude of 500 to 1,000 feet and speeds of up to 80 mph.

Two types of radio receivers were used for aerial tracking, a Model 2000 ATS programmable receiver and a Smith-Root SR-40 simultaneous scanning receiver. Each was attached to one of two Larsen-Kulrod omni-directional whip antennae mounted to the skids of the helicopter (Figure 22). The antenna on the pilot's side was connected to the Model 2000 ATS receiver and the antenna on the passenger's side was connected to the SR-40 receiver. Output signals from both receivers were routed through a switch box to two sets of headphones, one for the tracker and one for the pilot. This enabled the tracker to switch back and forth between the two receiver outputs.

Figure 22. Diagram of radiorecievers, antennas, swiches, and headsets used with aerial tracking of radiotagged fish.

All active transmitter frequencies were programmed into the Model 2000 ATS programmable receiver prior to each aerial tracking effort. A list of all frequencies and pulse rates for active transmitters, as well as last known locations of transmitters was made available to the tracker. Surveillance flights usually proceeded in a downstream direction for the entire length of the study area. Since the SR-40 had the capability to simultaneously scan all frequencies, the chance of missing signals was minimized and tracking speed was not as restricted as with cycling search receivers such as the ATS.

When a signal or signals were received by the SR-40, the pilot was asked to remain stationary or circle the area slowly in a counter clockwise rotation so that the pilot side, or programmable receiver antenna, was located on the inside of the rotation for constant signal reception. The tracker then tuned the programmable receiver to the most likely frequency in the area. The transmitter signal was identified when the signal from the scanning receiver matched the signal from the programmable receiver. The pulse rate of the transmitter was easily

determined since only three highly separable rates are used, 40, 60 or 80 pulses per minute. Fish location could be determined by listening to variation in signal strength with orientation of the antenna. Generally the 'on ground' resolution of the fish location was within 0.1 to 0.2 miles. Once a frequency had been confirmed, the fish location was plotted on a map for later transfer to the field crew. The aerial tracking continued until all transmitters were located or a reasonable search had been conducted. Aerial surveillances by helicopter were conducted three times, but discontinued because fidelity by radio tagged fish to specific areas precluded the need for widespread searches.

Ground Radio Tracking

Surveillance: Surveillance radio tracking was conducted from the research and logistic boats during downstream travel, beginning from Lees Ferry and continuing to the take out point for each trip. Radio receivers were stowed in water-proof boxes in whitewater sections, but remained accessible so that tracking efforts could continue once rapids had been negotiated. Tracking was conducted from more than one boat, if possible, to monitor both sides of the channel.

Radio tracking was done with either the Smith-Root SR-40 scanner or the ATS Model 2000 programmable receiver using Larsen-Kulrod omni-directional whip antennas mounted on large metallic base plates such as cargo boxes. Contacts made from the larger S-rigs had to be confirmed and pinpointed later by using a smaller research boat. If a radio contact was made from a support boat at a location where a return trip is considered impractical, the operator of the support boat was asked to make an effort to land the boat so that the location of the fish could be determined.

Multiple surveillance runs were made daily through the region of river occupied by radio tagged fish. The purpose for this surveillance was to determine diel patterns of near-surface activity and long-range movements. Signal locations were marked on 1:2400-scale aerial photographs, and a confidence level of 1 (high, <10 m), 2 (medium, 10-100 m) or 3 (low, 100-400 m) was assigned to each location as an index of observer confidence for range of location accuracy, i.e., triangulation was usually inaccurate at night, in proximity to canyon walls, during inclement weather, and with faint or inconsistent signals. Habitat type was recorded at each radio contact location, and water clarity was measured at least once daily with a Secchi disk, and beginning in March 1992, turbidity as NTUs was measured daily. Locations of implanted fish were plotted on mylar overlay maps and later digitized into a GIS system.

Observation: Individual radio tagged adult humpback chub were observed for periods of 2 to 72 hr to characterize local movement and habitat use by season, time-of-day, turbidity, flow, ramping rate, and magnitude of flow change. Local movement or activity was defined as movement within macrohabitats or habitat

complexes, and was represented two-dimensionally as horizontal movement. Fish chosen for monitoring were not randomly selected because each cannot consistently be contacted in water deeper than about 4.5 m. Thus, fish were monitored when their radio signal was audible. When a fish was contacted, an attempt was made to determine its general location from the boat using an ATS Model 2000 receiver and a directional loop antenna. When the general location was established, the tracking boat was taken to the shore nearest the fish with care to not to disturb the fish. An ATS Model 2000 programmable receiver and directional loop antenna were used from shore to triangulate the position of the fish in the channel.

A fish that would potentially be monitored for 2 hr was first observed for 30 min to determine if its position was static or dynamic. If the fish was stationary, its location was triangulated and marked. The fish was then monitored for an additional 1.5 hr to determine habitat use. Triangulation sightings were marked for all locations where the fish remained stationary for 30 min or more during the 1.5 hr monitoring period. If the fish was moving, its movements were monitored for an undetermined amount of time to ascertain its behavior and or movement patterns in relation to various factors including: 1) stage change; 2) local macrohabitats and/or; 3) other radio tagged fish in the area. If the fish became stationary, it was monitored as described for a stationary fish.

Fish monitored for longer than 2 hr were carefully observed for habitat use and movements particularly during changes in flow stage. Each movement by a fish and each area occupied for longer than 30 min was mapped on a mylar overlay over a 1:2400 scale photograph of the area, with sequential observations conducted every 0.5 hr. River stage, monitored on temporary bench marks with an abney level, was recorded for each observation for the fish. Generally, fish monitored for 24 hr were checked every 1 to 2 hr or more frequently if river stage was changing rapidly.

Variation in river stage was monitored with temporary staff gages surveyed to temporary bench marks (TBM). These TBMs were established at strategic locations in the study area in order to relate fish movement and habitat use to river stage. Each TBM was surveyed into one of the 50 permanent USGS bench marks at a latter date so that relative stage changes could be related to absolute changes and thus to specific flow releases from the dam. The temporary staff gages were employed only during field trips for radiotelemetry monitoring and habitat mapping. The temporary staff gages were emplaced as near as possible to the sample site (location of radio tagged fish) or within an area to be mapped. Readings were taken from the temporary staff gage as needed.

A detailed hand drawn map or a detailed map using a mylar overlay on an aerial photo (depending on photo availability) was prepared for each fish that was monitored. Distance and direction of all movements were recorded on the map and in the telemetry log relative to time and stage of the river. Locations and movements

between subsequent locations were transferred to GIS files as a record of movement for comparison with channel bathymetry, macrohabitat, substrate type, temperature, and flow.

Observation periods were divided into blocks for analysis, each spawning time between consecutive locations. A given observation period was usually composed of many blocks, each representing a sample of movement by fish under specific conditions. To standardize blocks for analysis, only those with elapsed time of 0.25-1.0 hr were used, and included 1831 blocks (90% of total) with a total elapsed time of 962.8 hr. Detectable fish movement during a block was defined as movement ≥5 m, the approximate observer triangulation error. Proportion of movement (Pm) was used as an index of fish movement or activity:

$$P_m = BM/BT \qquad \text{(Equation 2)}$$

where: BM = number of blocks with movement, and
BT = total number of blocks

Categories of season, time-of-day and turbidity were the same as described for surveillance. Mainstem flow in 0.5-hr intervals was determined from the Colorado River USGS gaging station (#9383100) just above the LCR confluence. Flow was classified as high (≥ 10,000 cfs) or low (< 10,000 cfs), with the dividing point close to the mean flow during observations (mean: 10,874 cfs; range: 4778 - 29,916 cfs). Absolute ramping rates were calculated from flow measurements nearest the start and end times of an observation period, and were classified as high (≥ 300 cfs/h) or low (< 300 cfs/h). Ramping rates ranged from 0 to 8833 cfs/h and averaged 454 cfs/h during observations. Periods of continuous 24-hr observations were used to evaluate fish movement under research and interim flow regimes, since flow changes typically cycled through 24 hr. Proportion of movement from 24-hr observations was also related to magnitude of flow change, i.e., the difference between high and low flows within a flow cycle.

Radiotelemetry in Middle Granite Gorge was used primarily for tracking movement and dispersal of adults from a small disjunct aggregation of humpback chub prior to the expected spawning period of April and May. The area was surveyed and radio tagged fish were monitored in the same manner as described for the LCR inflow area.

At the conclusion of monitoring, habitat measurements were taken at all locations where the fish was stationary for at least 30 min. Habitat measurements taken at each point included depth, velocity, substrate, temperature, overhead cover, and lateral structure. Procedures for measuring each of these microhabitat parameters are presented in Data Management Plan - Data Collection In the Field. All radiotelemetry information was recorded on data sheets as described in the Data Management Plan - Data Forms.

Remote Telemetry

Two directional remote telemetry stations were deployed to evaluate use of the LCR confluence by identifying specific times in which radio tagged fish were present (Figure 20). Maximum antenna range was approximately 500 m, as determined by deploying test tags at a 1-m depth at increasing distances up- and downstream from each station. Upstream or downstream movement to and from these monitored areas was inferred from surveillance locations identified before and after contact by a station. Season and duration of use of the LCR confluence, and specific timing of movements by adults between the mainstem and LCR, were determined with this monitoring system.

Three omni-directional remote telemetry stations were deployed to assess near-surface activity of radio tagged fish in the LCR inflow aggregation (KILR) and Middle Granite Gorge aggregation (KBON and KMGG). Although antenna ranges were not established for KBON or KMGG, effective ranges were assumed to be similar to KILR, or about 1500 m. To permit comparisons with telemetry surveillance data, only remote telemetry data collected during field trips (when turbidity data were collected) were analyzed. Average proportion of radio contacts with remote telemetry (APRC) was also used as an index of near surface activity:

$$APRC = \sum(CO/CE)/n \qquad \text{(Equation 3)}$$

where: CO = number of radio contacts within a specified time period,
CE = number of possible contacts within the same time period,
n - number of time periods.

Average APRC was related to turbidity and time-of-day, but seasonal effects could not be evaluated because KILR was operated only during non-spawning periods, and an appropriate spawning season could not be identified for the Middle Granite Gorge aggregation. Diel periods and high-low turbidity levels were the same as defined for telemetry surveillance. For statistical analysis, values of APRC and APFC were arcsin transformed (Sokal and Rohlf 1969).

Fish Handling Procedures for Radio implant

Fish captured for radio tagging were handled with particular care and attention to minimize stress in preparation for surgical implant. The fish were held in a separate live well for transportation to a central surgical station and constantly monitored for signs of stress. Surgical equipment was kept clean and available in a designated 10'x20' Springbar tent to minimize preparation time. Two 80-quart coolers were used as live wells, one with anesthesia, and one with fresh river water for postsurgical recovery.

In the event an implantable size fish was captured some distance from a central surgical station, or the crew was unable to safely return to the station (e.g., low water), the fish could be radio implanted at a temporary field

station close to the point of capture. Each research vessel carried a full complement of surgical apparatus including surgical instruments, sterilizing agent and reservoirs, portable work tables, radio transmitters and receivers, and live wells. In 1990-1992, crews returned to the central surgical station for all implants.

Surgical Procedures

A surgical protocol was established from procedures developed by Valdez and Nilson (1982) and Kaeding et al. (1990) for humpback chub; Tyus (1982) for Colorado squawfish; and Valdez and Masslich (1989) for Colorado squawfish and razorback sucker. Fish were selected for radio implant based on weight, condition, and location of capture. Transmitter weight could not exceed 2% of fish weight (Bidgood 1980, Marty and Summerfelt 1990), such that 9-g transmitters were implanted in fish weighing ≥450 g, and 11-g transmitters were implanted in fish weighing W≥550 g. Care was taken to select fish that were healthy and showed no signs of stress. Females were not implanted from March through May to prevent stress to gravid fish, avoid resorption of eggs from handling, and eliminate the risk of transmitter expulsion from enlargening egg masses (Bidgood 1980, Marty and Summerfelt 1990).

Surgical implants were performed in an enclosed tent at a central processing station in a riverside camp to minimize exposure to blowing sand and reduce the risk of infection. Two trained members of the B/W staff were designated with the primary responsibility of insuring that all aspects of surgical procedures were followed and monitored. The surgical procedures were practiced by these individuals so that a surgery could be completed within 6 min (first incision to last suture). Three people were involved with surgery--a surgeon, an assistant, and an anesthetist to administer anesthesia and monitor respiration of the fish. Prior to surgery, each fish was measured and weighed, and all surgical instruments were cold-sterilized with 90% isopropyl alcohol and allowed to air dry on a disposable sterile cloth. Two 5-gallon buckets were placed above the level of the surgical table, one with anesthetic solution and one with fresh river water. Each bucket was drained with a 5-foot length of tygon tubing allowing the anesthetist to alternately irrigate the gills of the fish with anesthetic or fresh water, according to the reaction of the fish. Small spring C-clamps were used to control flow through the tubing. Fish were anesthetized with Finquel®, a brand of tricaine methanesulfonate (MS-222), at a concentration of 100 mg/l for 2-4 min, or until fish lost equilibrium and rolled on its side in the holding tank, but continued moderate opercular movement (25-30 movements per minute). During surgery, gills were bathed with anesthetic at 50 mg/l, as needed, and then with fresh water about half way through the surgery to expedite post-surgical recovery.

Primary Incision: The fish was removed from the anesthetic by the anesthetist and placed on a surgical cradle. The surgeon then wiped the abdomen with sterile saline and made a 2-3-cm long incision at one of two locations; abdominal midline or lateral to the midline. The midline incision was located on the belly about 2 cm anterior

to the pelvic girdle along the *linea alba* (Figure 23). The lateral incision was on the left side of the fish, midway between the pectoral and pelvic fins and about 1 cm from the *linea alba*.

Figure 23. Primary abdonminal incision on linea alba (A) or lateral to the midline (B), and external antennae (C) of implanted radio transmitter in adult humpback chub.

Incisions along the *linea alba* have been the standard procedure for most transmitter implants (Hart and Summerfelt 1975, Marty and Summerfelt 1986, Marty and Summerfelt 1990, Bidgood 1980, G. Klontz, Univ. of Idaho, pers. comm.). Midline incisions are conventionally used in abdominal surgeries in veterinarian practices because the *linea alba* is a fascial plane that is stronger than muscle fibers with little nerve and vascular tissue (Marty 1991; V. Seggern, W.L. Gore and Assoc., pers. comm.; and Cosgrove, Univ. of Calif., Davis). Studies show that properly-sutured midline incisions are nearly as strong as those of the lateral wall (Marty and Summerfelt 1990). Lateral incisions were used in the Upper Colorado River Basin on humpback chub (Valdez and Clemmer 1982, Kaeding et al. 1990) and Colorado squawfish and razorback suckers (Tyus 1988, Valdez and Masslich 1992). Lateral incisions were preferred in these species to reduce irritation of the suture line from visceral pressure, and lessen the likelihood of abrasion of sutures with the river bottom. Marty and Summerfelt (1986) noted that the ventral body wall thickened rapidly lateral to the midline, making surgery difficult. Incisions of the lateral body wall generally bleed more than incisions of the midline because the body wall is more vascularized. It is important to avoid bleeding because clots lead to the formation of adhesions (Rosin 1985) that are the first step in the process of transintestinal expulsion. Incision location was not mentioned as a factor of transmitter expulsion by Marty and Summerfelt (1990), but Tyus (1988) felt that incision site may have a bearing on transmitter expulsion.

The radio transmitter was inserted through the primary incision and positioned on the pelvic girdle with the antenna protruding through the abdominal wall, posterior to the pelvic girdle and anterior to the vent.

Antenna Exit: A drawback of external-antenna transmitters is the need to expose the antenna to insure proper signal transmission. The point where the antenna protrudes from the body cavity can be an avenue for bacterial invasion. This area is often aggravated by the rotating action at the antenna caused by water currents. Many methods have been used for passing the external antenna through the body cavity. Winter et al. (1978) used a knitting needle to tunnel a cavity under the skin to an exit point. Ross and Kleiner (1982) used an eyed, curved rug needle sleeved with 0.5-cm diameter plastic tubing to pass the antenna the length of the abdomen and through the wall. Chart and Cranney (1991) used the same shielded needle technique to implant 86 hatchery-reared bonytail (*Gila elegans)* for release into the Green River, Utah. These techniques led to problems with possible damage to the peritoneal cavity and vital organs, as well as possible bacterial contamination.

Two techniques were used in this investigation to pass the transmitter antenna through the abdominal wall. One involved passing the antenna through a small incision with mosquito forceps and suturing anteriorly and posteriorly at the exit point. The second technique used a specially-designed "sleeved needle antenna guide" (SNAG), developed by BIO/WEST.

The SNAG consisted of a gently curved 20-cm long hollow stainless steel needle inside a 15-cm long hollow stainless steel sheath. The inside diameter of the inner needle was 0.06 inches (1.52 mm), which accommodated the antenna, with an outside diameter of 0.05 inches (1.27 mm). The sheathed needle was inserted in the primary incision and guided to a point posterior to the pelvic girdle where the needle is pushed through the abdominal cavity. The sheath was removed and the antenna threaded through the needle. The needle was pulled through the antenna exit leaving the antenna in place. This technique allowed for the abdominal tissue to seal the antenna exit, and reduced the risk of bacterial invasion. The antenna was pulled through the exit hole while guiding the radio transmitter through the primary incision to a position on the pelvic girdle. The trailing antenna was clipped in line with the end of the hypural plate of the fish to prevent fraying of the tail fin. When a fish was recaptured with a non-functioning radio transmitter, it was weighed and measured, and examined to document recovery or complications associated with radio implant procedures. Photographs were taken of the fish do document general condition,a nd of the primary incision and antenna exit to document rate and degree of healing or signs of necrosis. Protruding antennae from expired transmitters were cut approximately 1-2 cm from the body wall to remove frictional drag and reduce stress to the fish. Expired transmitters were not removed from fish.

Suture Material: Three to five sutures were required to properly close the primary incision. Two types of suture material were used; CV3 Gortex non-absorbable and 3-0 Maxon absorbable. CV3 Gortex was used on the first 31 fish implanted from October 1990 through March 1991. The 3-0 Maxon absorbable suture was used for 23 fish implanted from May through November 1991, and was the preferred suture material. The 3-0 Maxon is a polygluconate monofilament suture that was absorbable over long-term (G. Marty, Univ. of Calif, Davis, pers. comm.). Monofilament suture was less likely to wick water and bacteria into the peritoneum, as was possible with Gortex sutures. Long-term absorption (90 days) allowed the incision ample time to heal before the sutures dissolved, particularly in the 8° to 10°C temperatures of the Colorado River in Grand Canyon. A PH 26 curved needle was standard with each suture material. Other investigators have used 3-0 prolene sutures (Ethilon™) with Colorado squawfish and razorback suckers (Tyus 1988, Valdez and Masslich 1992), humpback chub (Valdez and Nilson 1982, Kaeding et al. 1990), and bonytail (Chart and Cranney 1991).

The CV3 Gortex suture (developed by W.L. Gore and Associates) was originally selected because of its handling ease, excellent tensile strength, and incorporation by healing tissue. However, at least some inflammation was noted around the sutures of the first six fish recaptured, indicating that the porosity of the suture allows bacterial

wicking from the unsterile river environment into the peritoneal cavity (V. Seggern, W.L. Gore and Assoc., pers. comm.).

DATA MANAGEMENT PLAN

BIO/WEST's extensive background working with endangered fish in the Colorado River system has enabled the development of robust data management procedures through refinement of proven methods. This Data Management Plan evolved from a series of steps: 1. planning; 2. development of Data Collection Forms; 3. staff training; 4. preliminary use of Forms in field; 5. refinement of collection techniques and Forms; 6. Data collection; 7. data analysis; and 8. reporting, interpretation of data. Rigorous quality control checks were incorporated in the field and in the office. All procedures for data collection and management presented in this document were designed and implemented to maximize quality control during transition from field observation to final report.

Project Planning

Before this project was begun the principle investigator and the field and data management staff, and agency representatives met to discuss the overall study design (Figure 24). Study design dictated the sampling strategy, data collection methods and projected analyses. A stratified random sampling design was implemented to approximate uniform spatial and temporal sampling of fish assemblages and associated physical, chemical, and biological components (greater detailed of project design is presented in STUDY DESIGN). During this investigation a number of sampling techniques were used to meet the project objectives. Standard fishery assessment was done in a manner that seasonal and longitudinal patterns could be evaluated distinctly from environmental variables such as flow from Glen Canyon Dam. Data forms were designed that corresponded to each sampling technique used (i.e.,., netting, electrofishing, trapping, etc).

Figure 24. Organizational Flow for Coordinating Data Management and Graphics Services.

Data forms

Ten data forms were used to record data for this investigation. These data forms were developed to simplify and assure completeness of data collection in the field. Specific forms were developed for each sampling technique or group of similar techniques. Standard sampling techniques included netting with gill and trammel nets, and trapping with hoop, frame and minnow traps, seining and electrofishing. Data collection associated with each of these techniques was recorded on forms 1 through 3. Form 1 was used for netting and trapping data; Form 2 was used for electrofishing data; and Form 3 for seining data. These forms are presented sequentially in

Appendix A. On the reverse of each of these forms (Page 2) information about individual captured fish was recorded.

Netting and trapping data were made up of information related to the location of the net or trap (the header) and information related to each specific sample unit or repetition (a Glossary of terms is provided in Appendix B). Header information included the sample type, gear, trip number, date, reach and location in river miles and left or right side of the river channel, clipboard number, crew, and habitat characteristics. The information that was associated with an individual sample event included a unique sample number, the start and end time for an event, the weather, air and water conditions during the time sampled, and a summary of the fish captured.

Electrofishing was conducted as runs within discrete habitat units. A single pass was conducted within a unit. Multiple passes were not performed so there was no need for separation of header and sample information. Sample type, number, trip, date, reach, clipboard and crew were recorded, as well as information characterizing the habitat and sampling conditions. Voltage, amperage, run duration, turbidity and lighting conditions all effected the catch of fish in a run, due to performance of the equipment and ability of crew dip-netting fish. These parameters were also recorded.

Seining data recorded included the header and location information described above and information to further characterize the habitat. Habitat length, width, and depths were recorded along with temperature, substrate, sample length and width. Lighting and weather conditions may also have effected fish use, and so were also recorded. If seining was done in a tributary stream, the location was described as number of meters upstream from the main river and the stream name was recorded. A summary of fish captured during each run was recorded on each Form (1-3) and individual fish characteristics such as total length, weight, gender, and any anomalous marks from sampling like bruising were recorded on the reverse, Page 2.

Forms 4, 4b and 5 were used for radiotelemetry. Telemetry observation data were recorded on Form 4 and 4b. Header and location information was recorded as for other sample types, and start and end time, observation mode, benchmark, and map key were added. A Fish information section was added that described the fish being observed and the radio signal that was being picked up by our receivers (PIT tag, radio size, frequency, and pulse rate). Telemetry observations were conducted on a single mostly stationary fish, with repeated incidence. Every 15 minutes a set of conditions observed was recorded. Data recorded included time, Habitat, distance moved from last observation, gage reading which indicated relative change of water stage, ambient light, turbidity and weather condition. Habitat measurements were initially recorded on the reverse of this form (depth, velocity, cover, substrate), but were later discontinued because of high variability. Because some observations were done for 24 hr or longer, an adidtional form (Form 4b) was used to continue the observation data.

Telemetry surveillance data were recorded on Form 5. A surveillance run was conducted several times during a day to characterize when radio implanted fish were in locations that they could be contacted by our radios. This enabled us to characterize the general habitat use of these fish over the course of a 24 hour period. Header information was recorded and a range of locations surveyed for radio signals was noted. Time, location, river channel side, and the identification of the fish, frequency and pulse were recorded. Since radio signals can be obscured and mutated by surrounding features, a confidence level was added to each radio contact both on observation and surveillance forms.

Meristic data for humpback chub were recorded on Form 6. Data describing the specific morphology of each humpback chub captured was first recorded on a chub meristics data form, then also recorded on the sampling form by which it was collected. This duplication of effort greatly increased the accuracy of BIO/WEST's humpback chub database used for all analyses. The cross-check between file types allowed us an additional opportunity to verify catch numbers for a given sample or group of samples. Data recorded included the sample information by which the fish was captured, sample type, number, trip number, reach and clipboard, and the individual fish information, general and specific. General information included total length, forked length, standard length, weight, gender, sexual maturity. The specific information included (see Glossary in Appendix B), nuchal depth, caudal peduncle length, and maximum diameter, and minimum diameter, head length, snout length, dorsal and anal fin base length, body depth, number of dorsal and anal fin rays, whether the fish had been tagged prior to our capture, whether or not it had been radio implanted, the location of release, and its disposition upon release.

Water Quality data were recorded on Form 7 initially, but were later written into waterproof bound journals kept with the water analysis equipment as a backup for data logged electronically. Journals were removed at the end of each research trip, photocopied and returned to the equipment boxes. The data logger files were downloaded after each trip and re-formatted into dBase files (see File List). Data recorded on Form 7 included, location, river mile, date and time, weather, habitat characteristics such as water fluctuation, ambient temperature, and the water quality parameters, dissolved oxygen, pH, Conductivity, turbidity, Redox and the battery life of the meter being used.

Form 8 was used to record information on juvenile humpback chub habitat use. Header information was included with a detailed survey of a small reach of shoreline habitat. Location, including river mile, and river channel side was recorded along with shoreline type, general and specific habitat types, local temporary bench mark used. Depth, flow direction, velocity at 0.2, 0.6 and 0.8 of the depth, substrate an cover were all recorded at up to 10 different transects at distances of 0.5m, 1.5m, and 2.5m from the shoreline.

Stage level reference point location information was recorded on Form 9. Data such as reference point number, photo number, and river mile were recorded as a header. Vertical distance from a reference point, initial date and time of measurement and units of measurement were recorded along with stage and stage change over time.

Drift data were recorded on Form 10. Date, time, elapsed time, habitat, river location and stage, velocity and net height were recorded as a header. Later in the laboratory, information was added regarding contents of net samples. Organisms identified to family, life stage and dry weight were recorded.

Training

All key field personnel were trained in proper procedures for completing all data forms. Each team had a waterproof copy of the **DATA CODE HANDBOOK** (Appendix B), with descriptions of data forms, and each field that required a response and a list of appropriate responses in a clipboard alongside the data sheets. This ensured adherence to BIO/WEST's defined data codes, and still provided flexibility through COMMENT and DESCRIPTION fields for the input of new or unusual observations. At Project Workshop meetings held twice-yearly, the adequacy of current data forms was discussed. Changes to forms were evaluated by the group and the principle investigator, and incorporated into those forms and the DATA CODE HANDBOOK. This continual re-evaluation of data collection needs made our database reflect the observations of our professional biologists in the field as closely as possible.

Data Collection in the Field

Each Team Leader was responsible for the security and accuracy of all data collected in the field and for transfer of the data sheets to the Database Manager at BIO/WEST. Data Forms were recorded in pencil on water-resistant bond paper and kept in numbered metal clipboards, reducing the amount of dirt and water on forms. Completed data forms were transferred to water tight containers located on the OARs support boats at the end of each work day. Each Team Leader checked the data forms daily for completeness and clarity, and corrected any omissions or errors. Performing this step while in the field was of benefit since the day's events were still fresh and the input of other team members could be easily enlisted. At the end of the sampling trip the Team Leader reviewed the data forms again ensuring that the sequence of sample numbers was consecutive, and that recorded data were legible and in the proper format. The data were hand-carried back to BIO/WEST and transferred to the Database Manager at the end of each trip.

Office Handling of Data Forms

Upon their transfer to the database manager, data forms were organized either sequentially by sample number or river mile, and photocopied. One copy of all data forms and other data media (i.e., mylar map overlays, slides, videotapes) was maintained in BIO/WEST's Logan office in locked fire-proof storage, another copy was

maintained at the office of Leibfried Environmental Services, in Flagstaff, Arizona and a third copy was sent to the GCES office in Flagstaff. Data were entered into an electronic database from original data forms. Any changes to data recorded on forms was done in colored ink and initialed by the responsible individual. A tracking sheet (Figure 25) accompanied the original data sheets in the Logan office, detailing the data management procedures that had been performed. Final copies of all working data files are stored in a fire-proof safe on site at BIO/WEST's Logan office.

Figure 25. Data tracking sheet.

Data Analysis

Data were entered into electronic files at the end of each trip (trip data files) by staff members familiar with the biological conditions encountered in Grand Canyon. This further increased the accuracy level of BIO/WEST's database since data were not only checked for accuracy against a written data form, but also against a set of probable conditions. BIO/WEST used dBASE IV™ to store and maintain data, and dBASE IV™ , SYSTAT™, Number Cruncher™, and EXCEL™ for data analysis. Error trapping programs were custom-designed to match each data form. These error trapping programs were used to check our electronic data for omitions, duplication, incorrect data codes, and values outside a probable range. Error trapping programs were run for all data forms at the completion of entry after each field trip. The Humpback chub meristics file was also printed in its entirety and each entry checked visually to eliminate errors. Humpback chub data such as PIT tag number, recapture status and total length were cross checked against the fish collection file as an additional verification of data. After errors had been identified, a report was printed and errors manually fixed. When a trip data file was error free it was appended to an aggregate file (See Table 4) used for analyses. Summary reports of BIO/WESTs monthly findings were published in trip reports fifteen days after the end of each field trip. These reports contained a printout of data regarding humpback chub captured (total length, PIT tag number, date, location, gender, sexual maturity, recapture status, and disposition upon release), and a draft summary of other species captured and effort expended.

Table 8 lists the specifications for the BIO/WESTdatabases (Aggregate data files), detail of the file structures is presented in Appendix C - Data File Structures.

BIO/WEST has also incorporated some humpback chub data into a Geographic Information System (GIS). The GIS data are distinct and link to field-specific data. Some of the GIS information layers are being developed by GCES, but those developed by B/W are digitized using Arc/CAD™ software on an IBM compatible PC. They are maintained and further developed using Arc/INFO™ software on a Sun Sparcstation 2, and are compatible with the GCES GIS database. The GIS products are in the process of being developed, so the quantity of GIS

data in the following tables is only an estimate at this time. Table 9 lists the specifications for the BIO/WEST mainstem GIS database.

Other Data Media

Other types of data media used on this project included photographs and video footage of individual fish for use in meristic analyses, habitat photographs, aerial photographs, and photographs and video footage of sampling techniques. Habitat maps produced on mylar, and fathometer tapes were also used in the collection of habitat information. Still photographs taken with slide film were stored in vinyl slide pages in three ring binders. These slide pages were filed by content (i.e. chub, habitat, and technique), by year, trip, and date and stored in a safe location in the BIO/WEST office. Video footage was filed similarly, though grouping of content types was not possible since the tape was continuous. Maps and aerial photographs were filed in map cases in alphabetical order.

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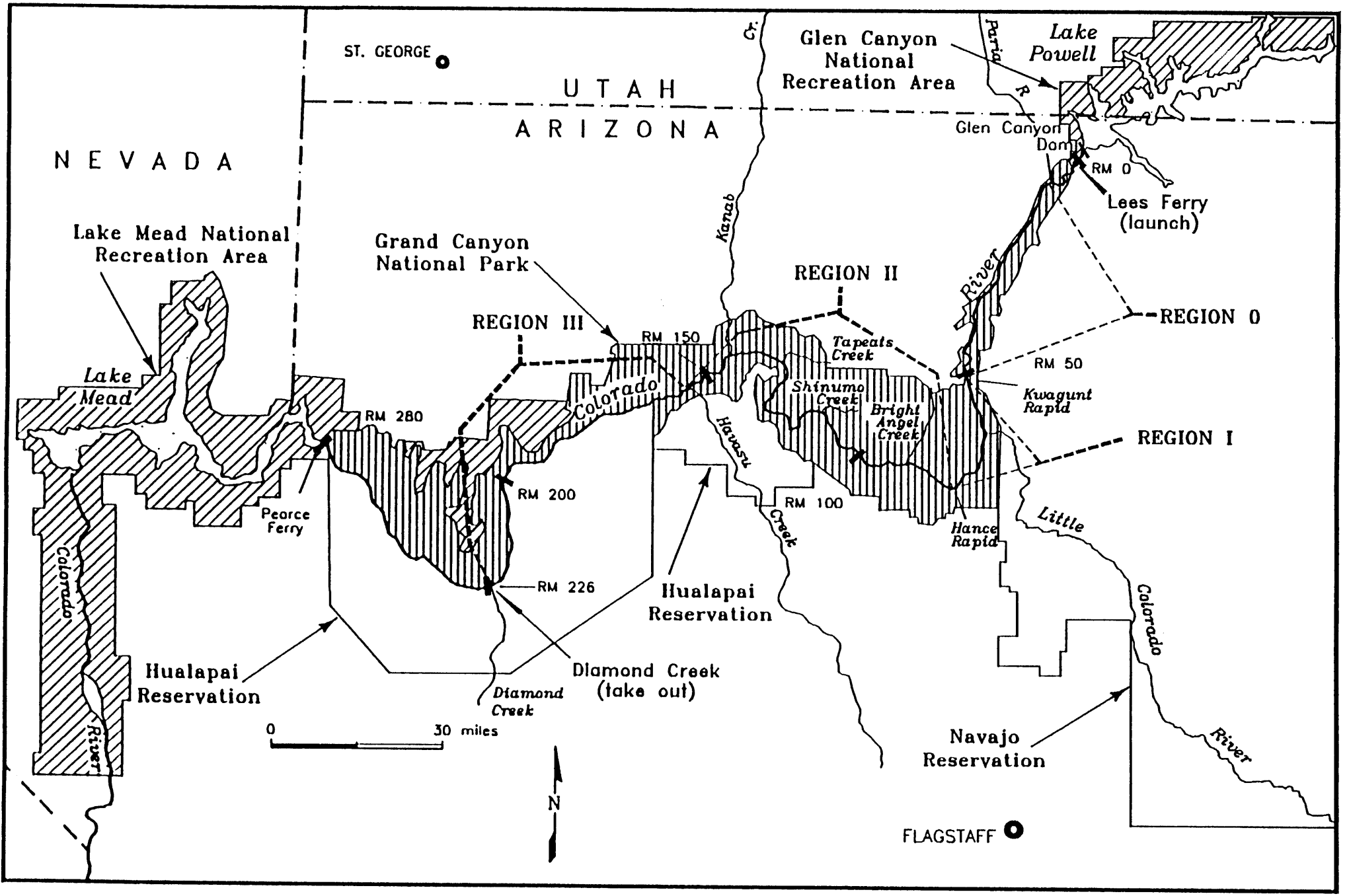

Figure 1. BIO/WEST study area in Grand Canyon and four sample regions.

TASKS	1990				1991												1992												1993												1994												1995							
	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A
Project Workshops				•												•												•												•																				
Data Collection Plan				•																																														•									
12- Day Trips		°		°		°		°		°		°		°				°		°		°		°		°																																			
20- Day Trips			°		°		°		°		°		°		°		°		°		°		°		°		°					°		°		°																									
16- Day Trips																													°	°	°	°		°		°		°	°																						
Trip Reports		•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•
Annual Reports							•												•												•												•																
Database Integration																																																							•					
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• Deliverable or Event

° Scheduled Trips

Figure 2. BIOWEST project schedule.

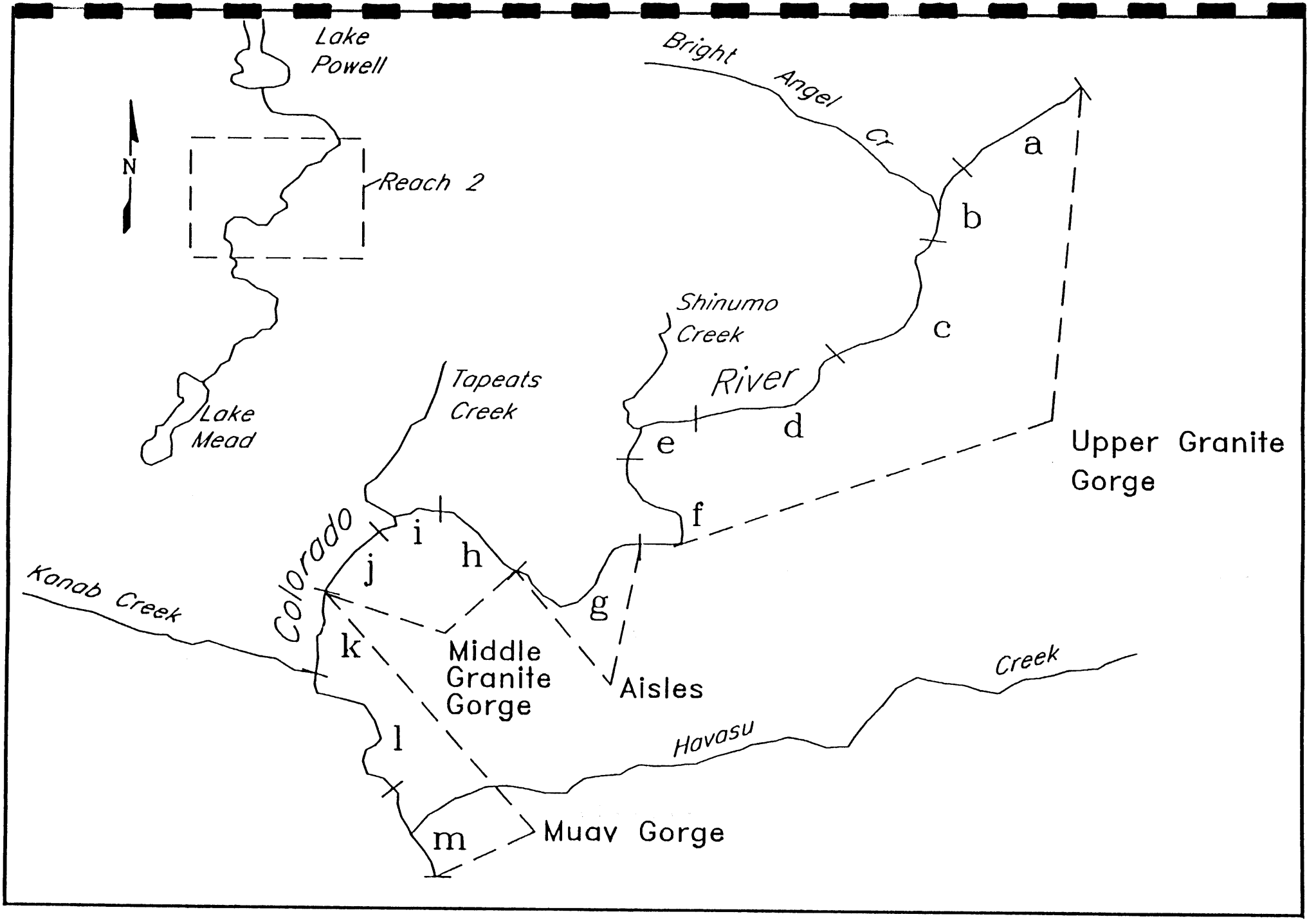
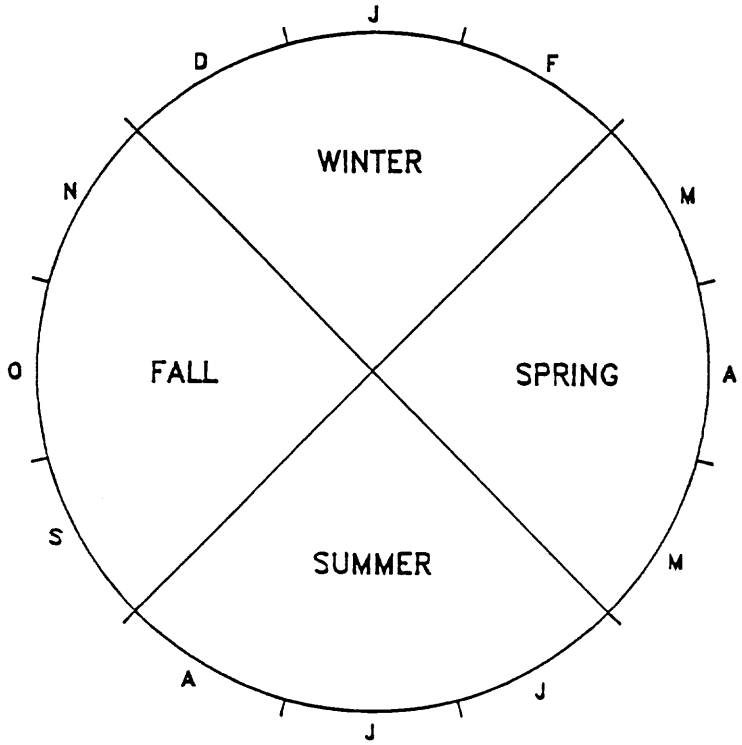


Figure 3. Spatial stratified sampling design for Region II; a-m are sampling strata within geomorphic reaches, Upper Granite Gorge, Aisles, Middle Granite Gorge, and Muav Gorge.

A. SEASONS



B. TIME OF DAY

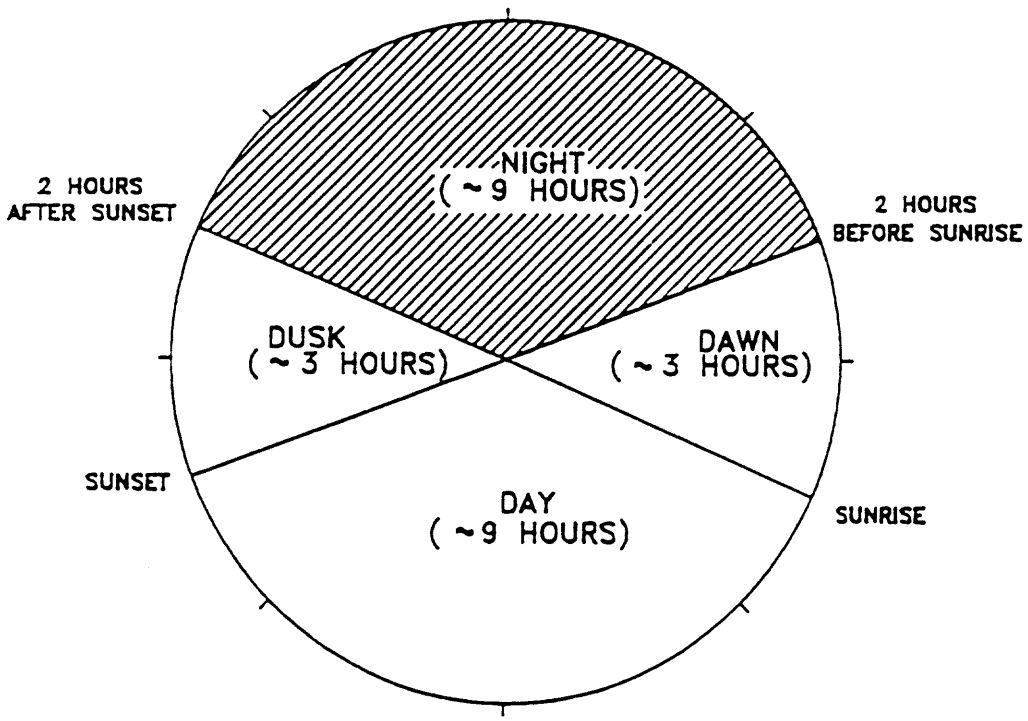


Figure 4. Temporal stratified sampling design for seasons (A) and time of day (B).

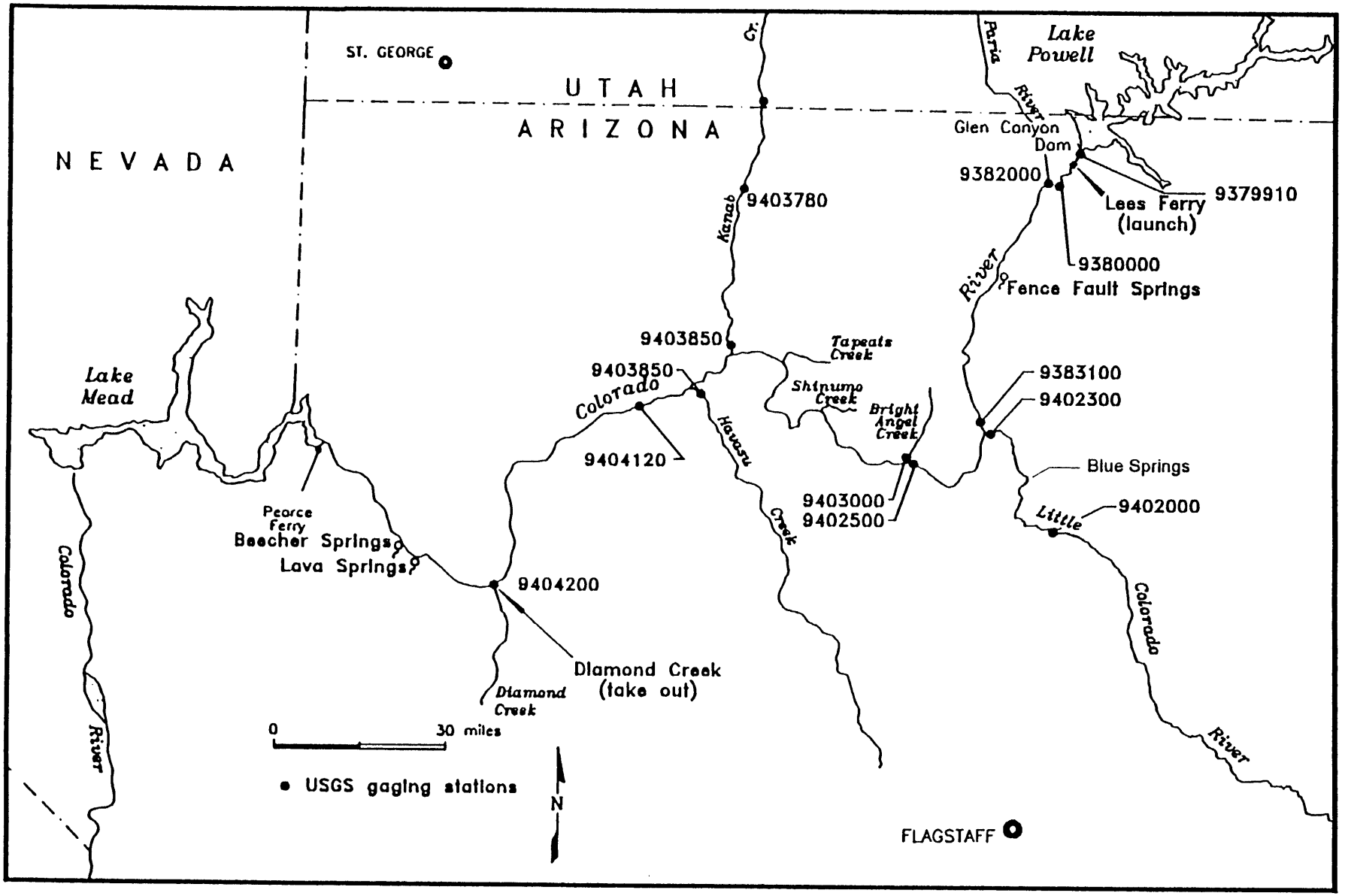


Figure 5. Locations of stream gages used for hydrology analysis.

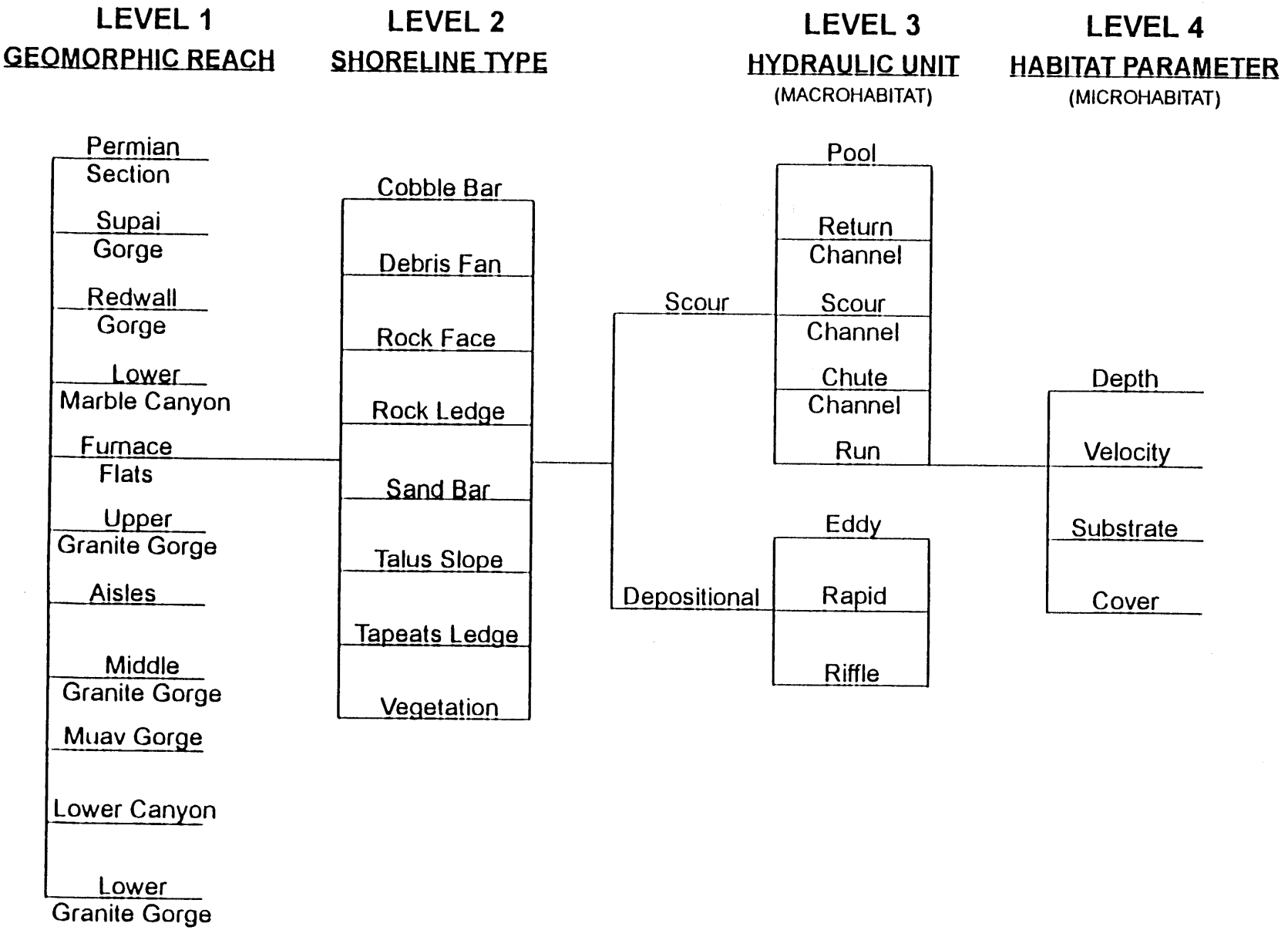
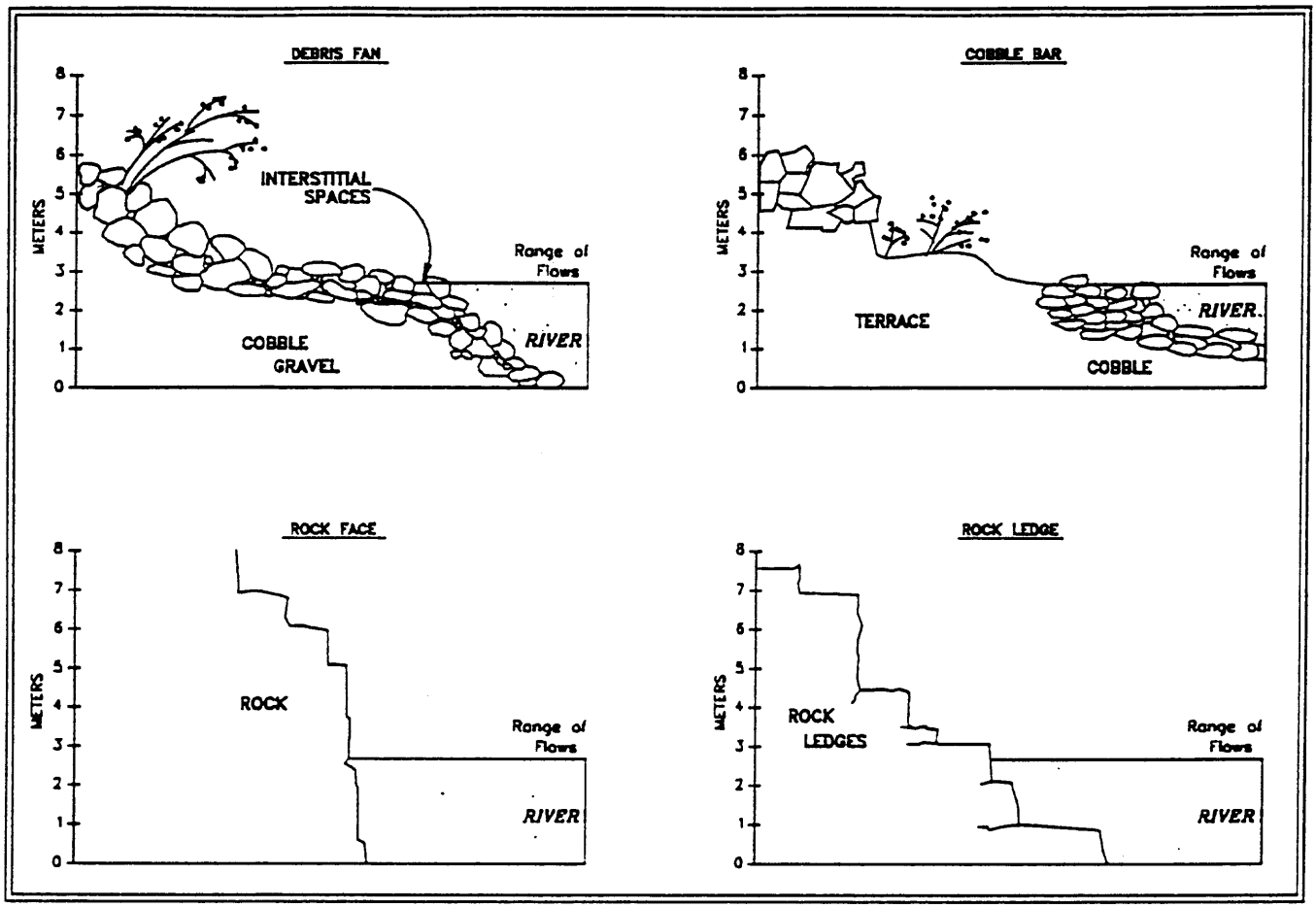


Figure 6. Dendrogram of a classification system for fish habitat in the Colorado River, Grand Canyon.



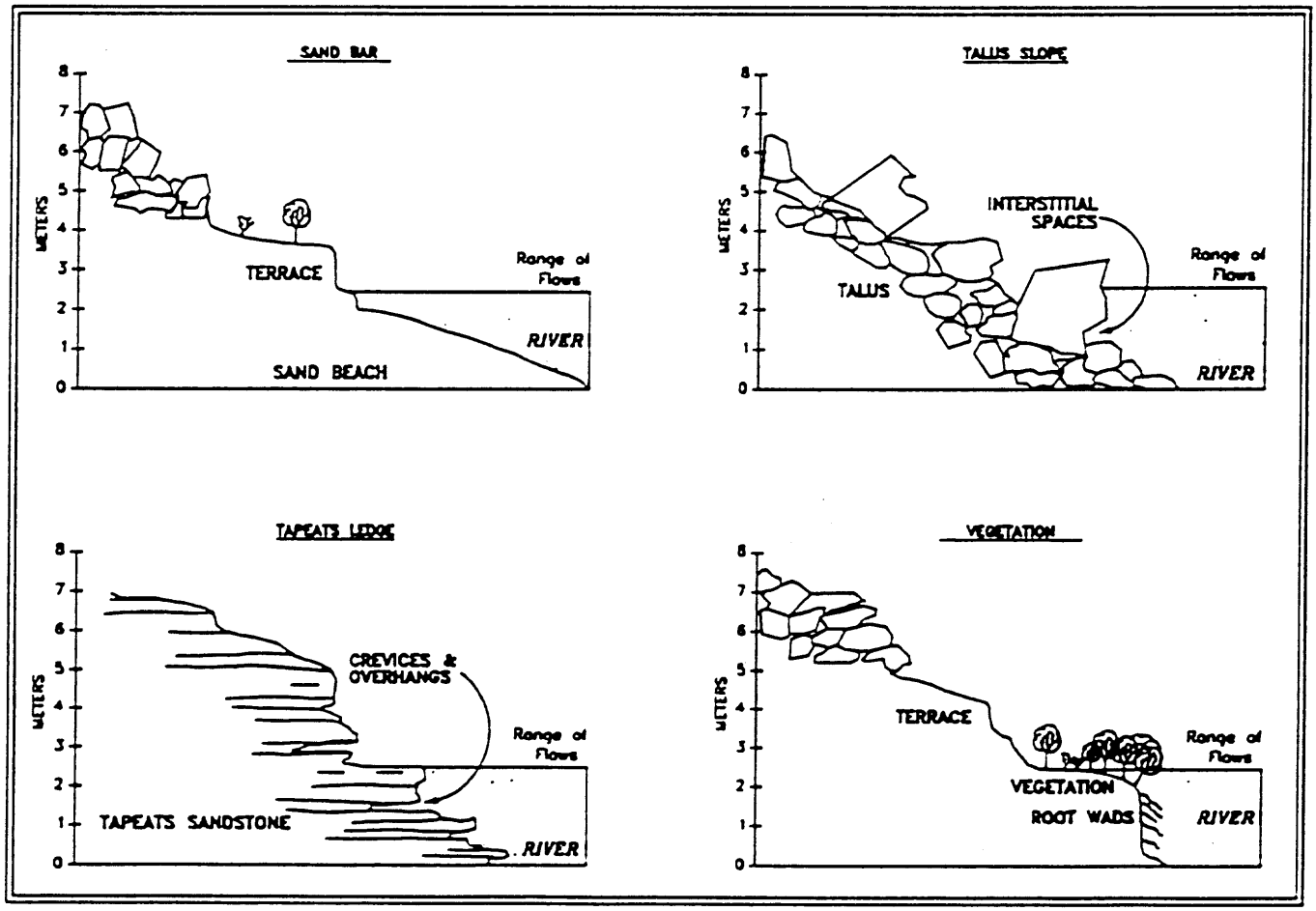


Figure 7. Cross-sections of hypothetical shoreline types.

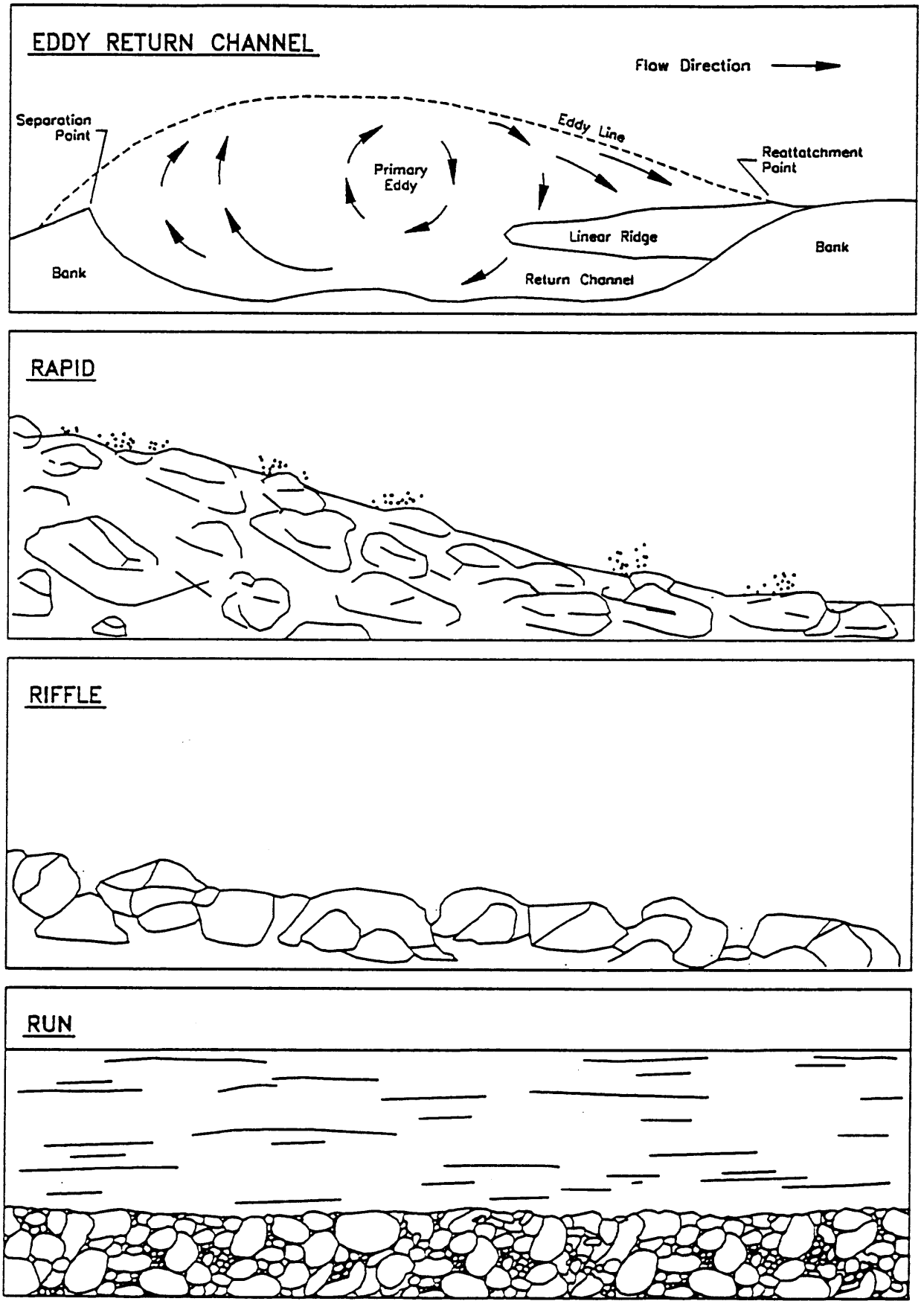


Figure 8. Surface flow pattern of an eddy (A), and cross sections of a rapid (B), riffle (C), and run (D). Sketches of rapid, riffle and run from Helm (1985).

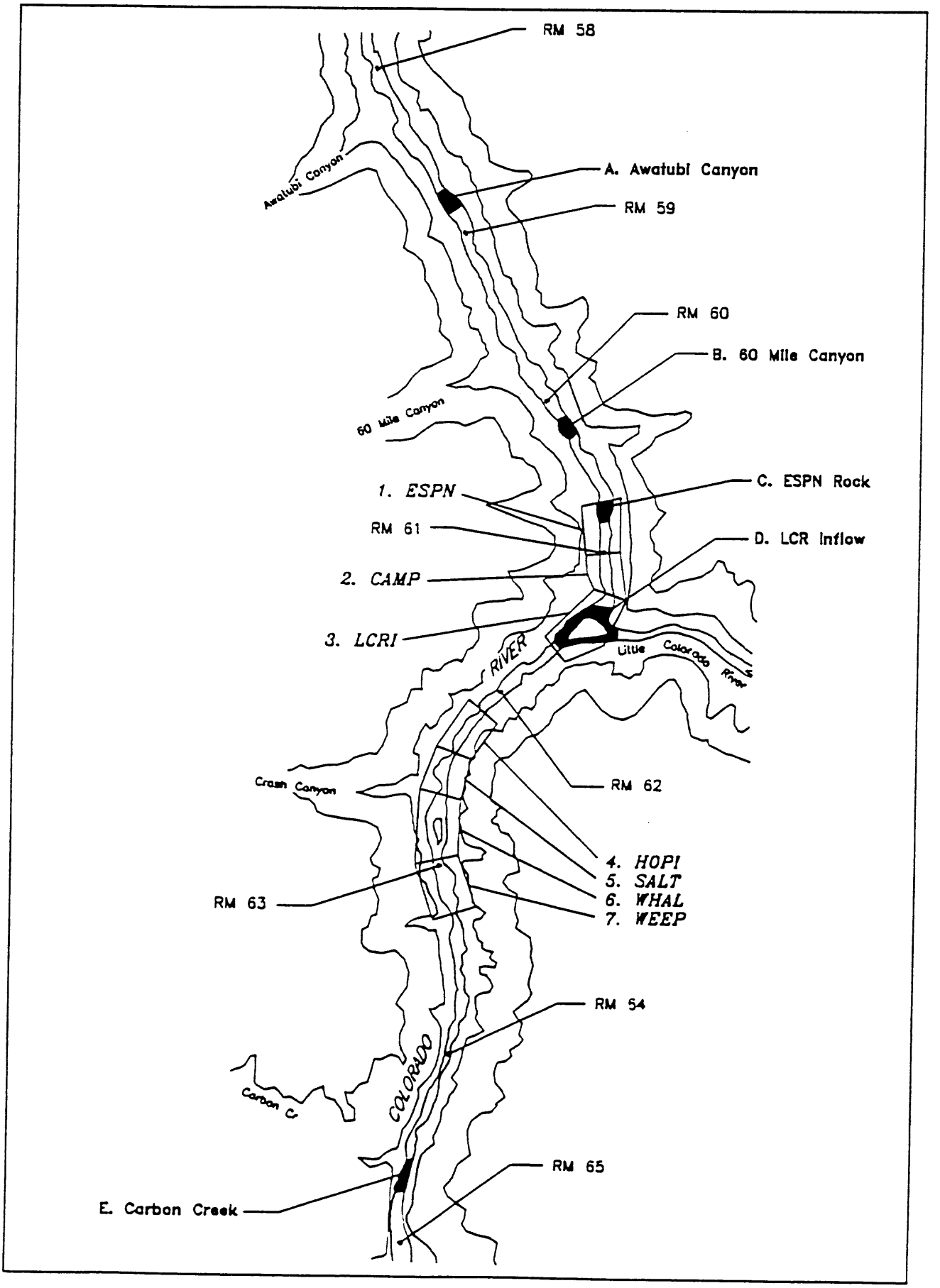


Figure 9. Locations of five bathymetry map sites (A-E) and seven macrohabitat map sites (1-7) on the Colorado River in Grand Canyon.

Scanned Photograph

Not available at this printing

Figure 11. Fishery research boats

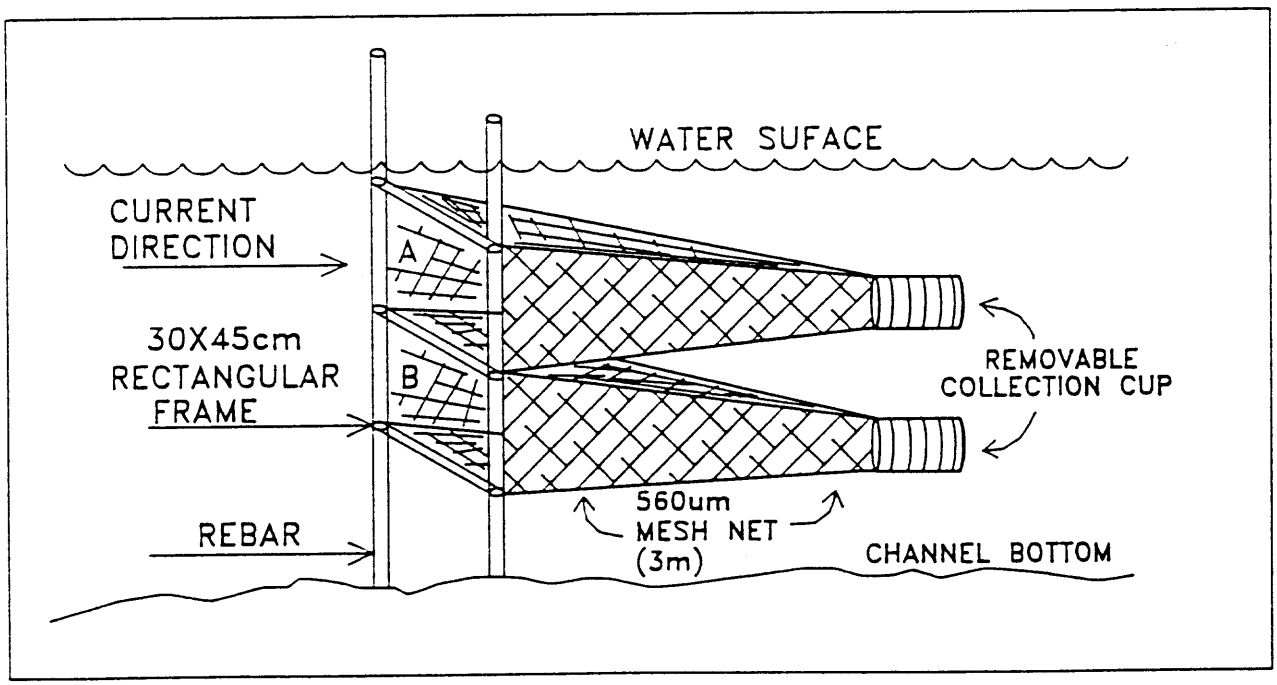


Figure 10. Drift nets set in tandem to sample near-surface (A) and midwater (B).

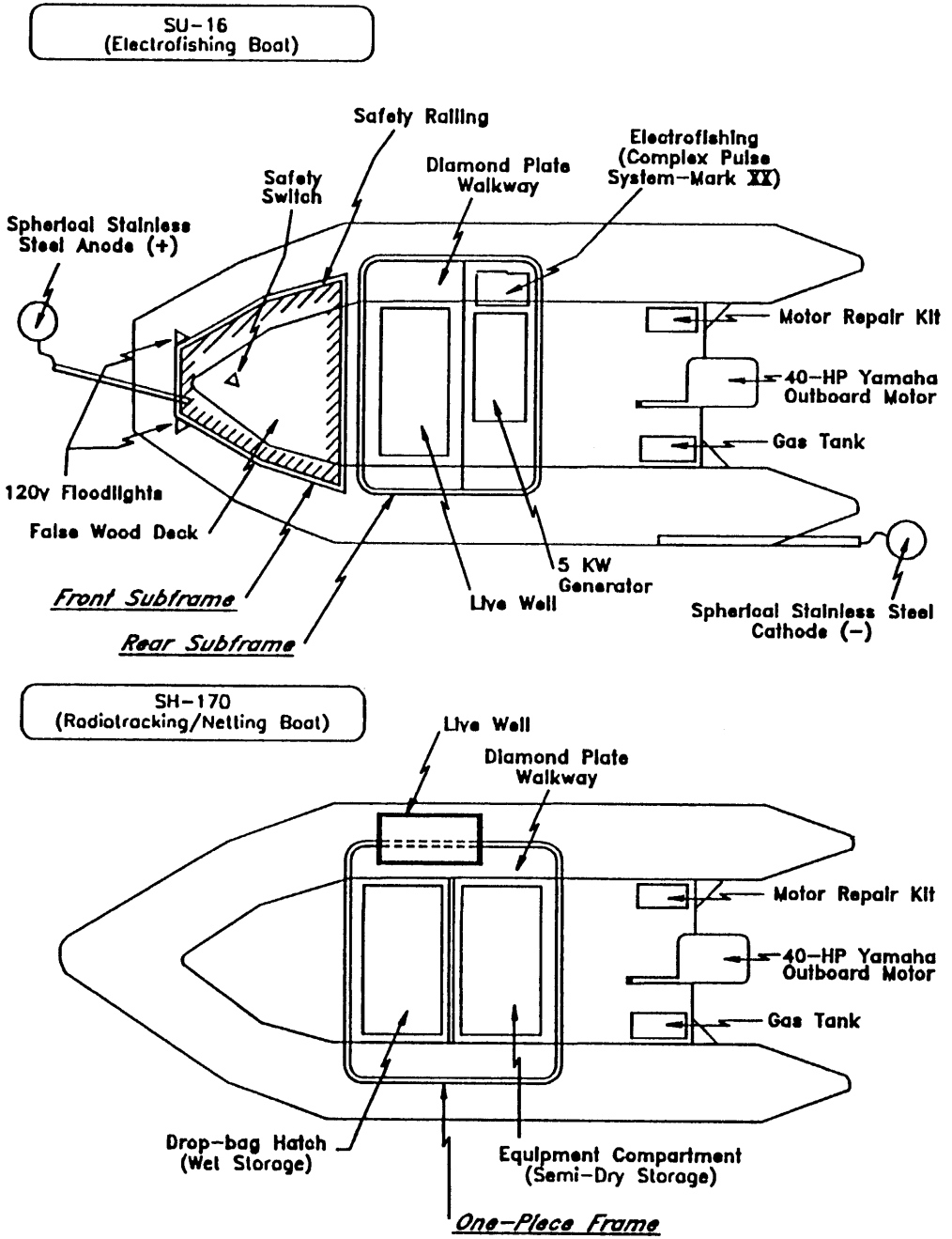


Figure 12. Fishery research boats frame design.

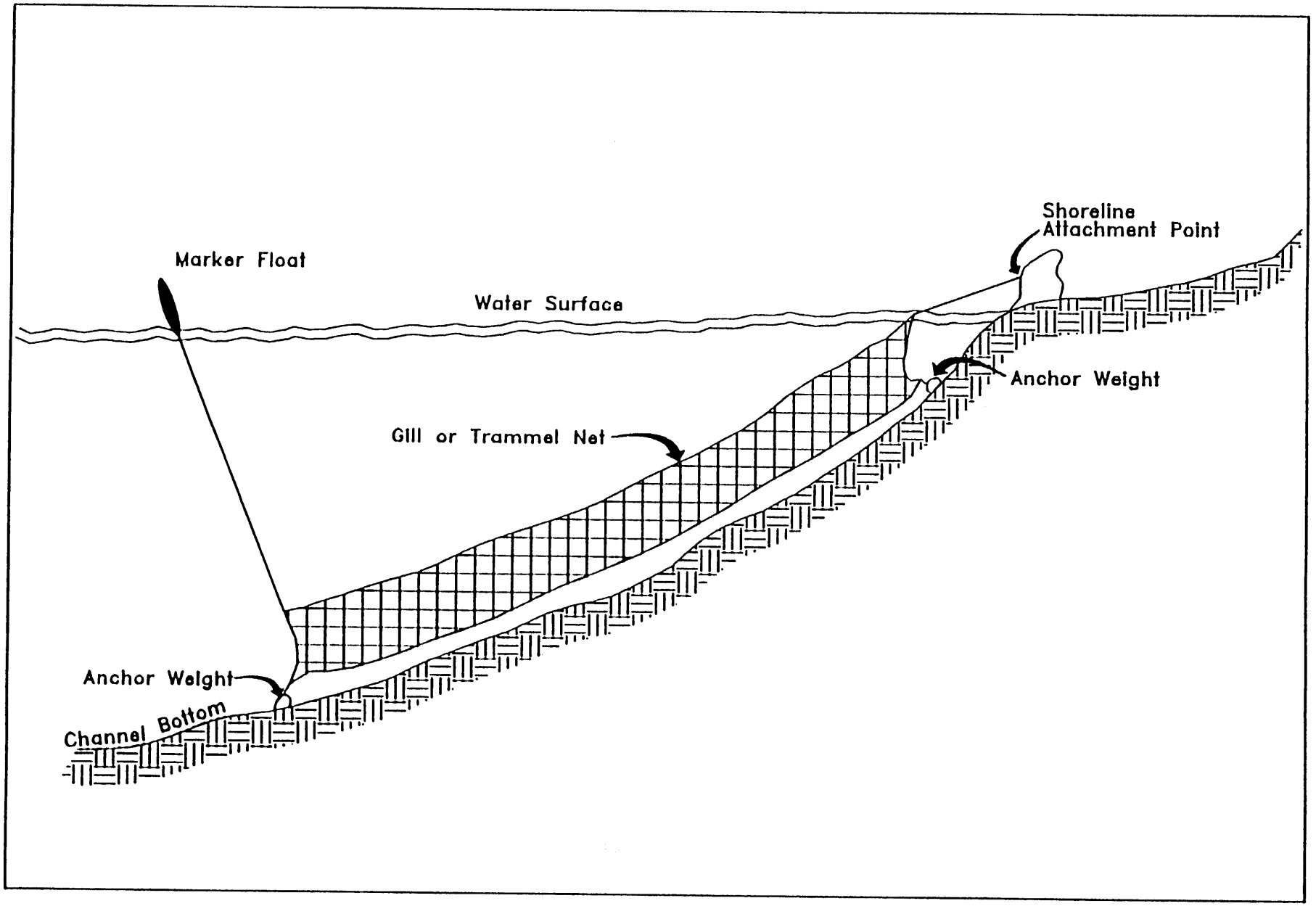


Figure 13. Typical gill or trammel net set.

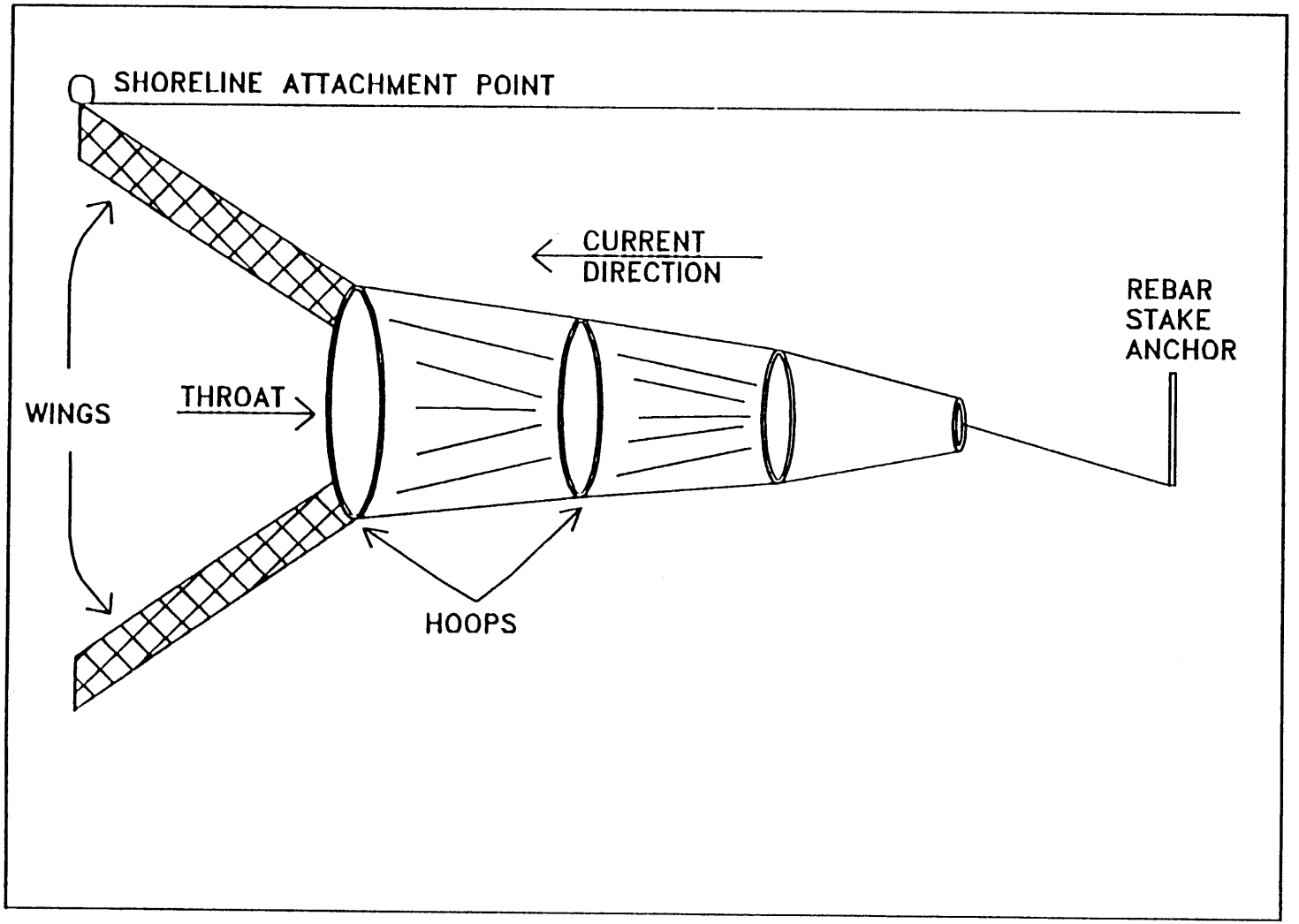
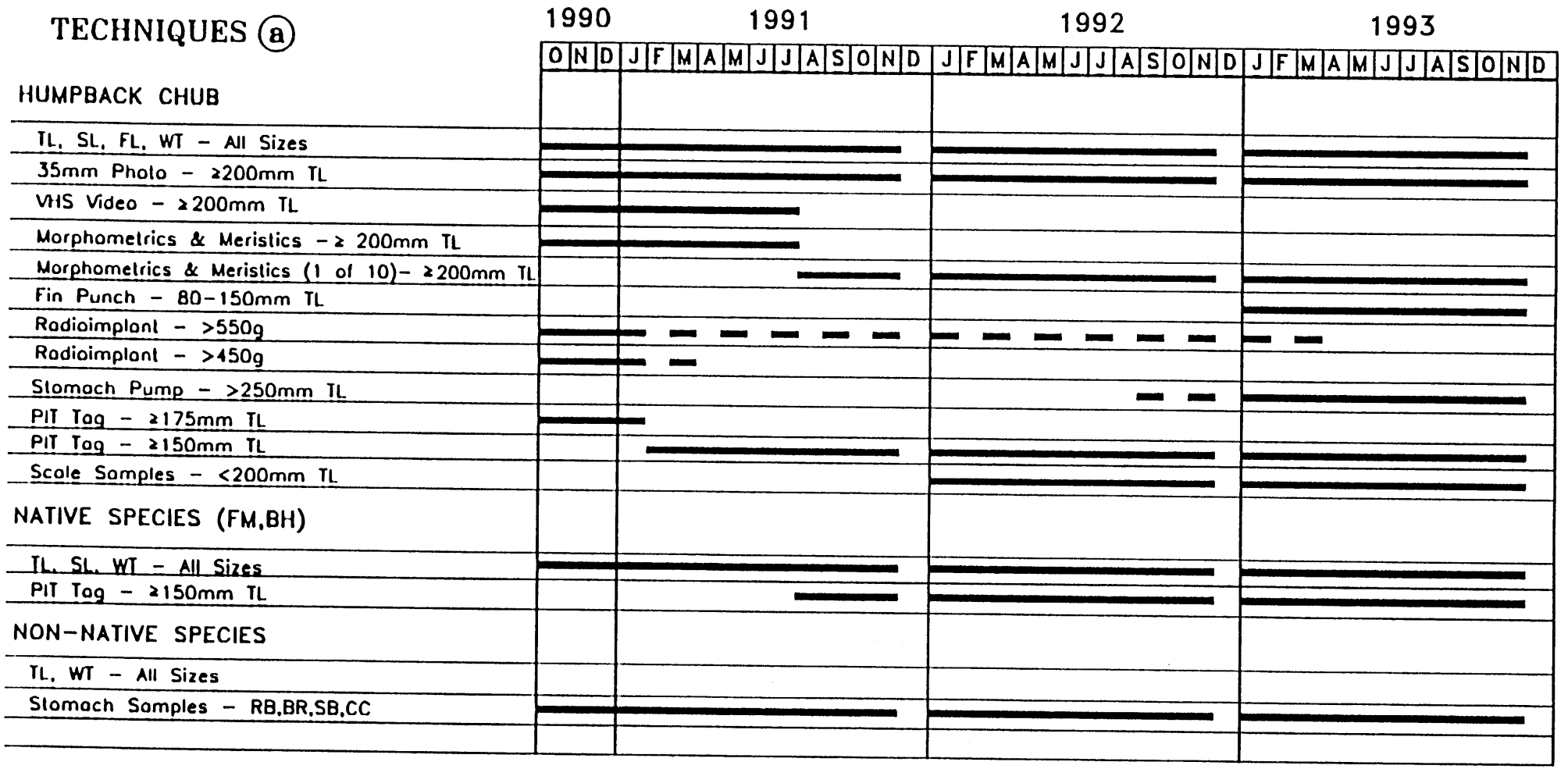
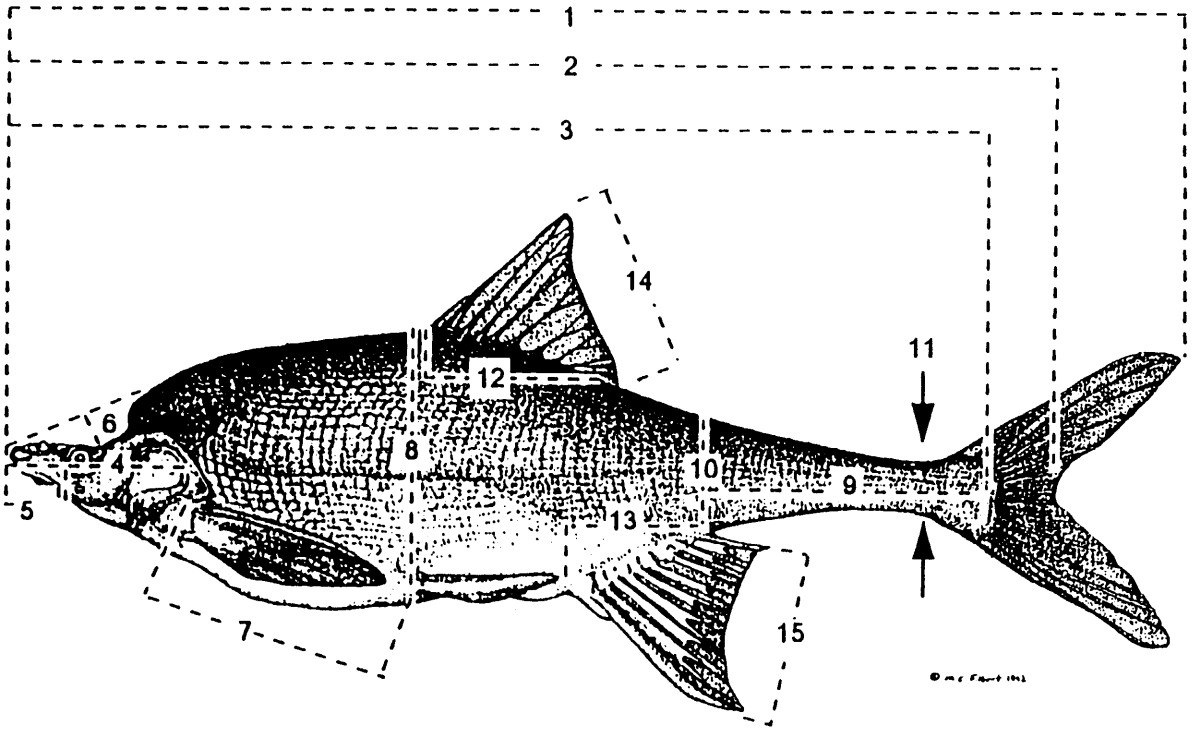


Figure 14. Typical hoop net set.



(a) TL= total length, SL= standard length, FL= forked length, WT= weight
FM= flannelmouth sucker, BH= bluehead sucker, RB= rainbow trout
BR= brown trout, SB= striped bass, CC= channel catfish.

Figure 15. Schedule of fish processing procedures conducted by BIO/WEST.



1) Total length
2) Forked length
3) Standard length
4) Head length
5) Snout length
6) Nuchal hump depth
7) Insertion of pectoral to pelvic fins
8) Maximum total body depth
9) Caudel pedurale length
10) Maximum caduel pedurale depth
11) Minimum caduel pedural depth
12) Base of dorsal fin
13) Base of anal fin
14) Dorsal ray count
15) Anal ray count

Figure 16. Morphometrics and meristics recorded for adult humpback chub ≥200 mm total length.

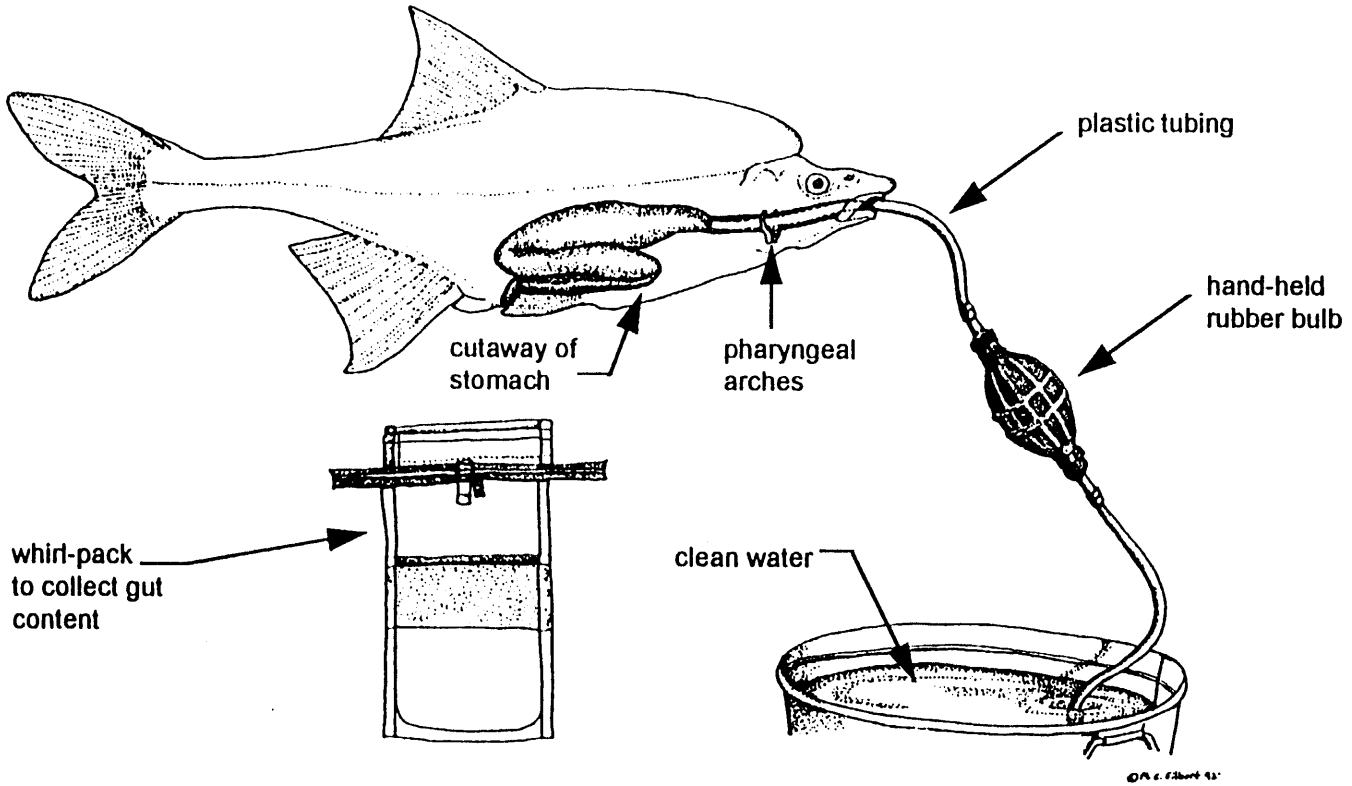


Figure 17. Stomach pump used to recover gut contents of adult humpback chub.

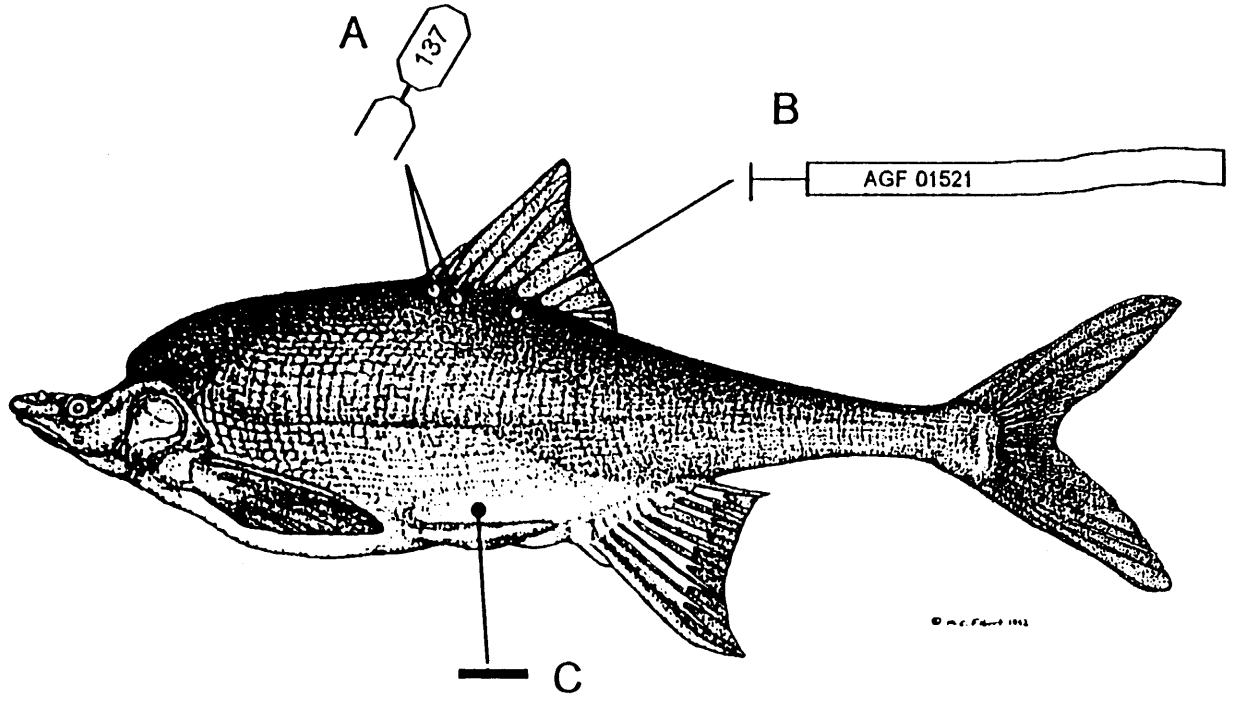


Figure 18. Attachment sites for Carlin dangler tag (A) and Floy anchor tag (B) by previous investigators, and injection site for PIT tag (C) by this investigation.

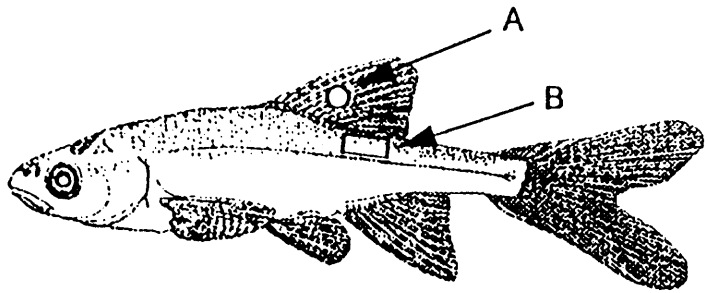


Figure 19. Juvenile humpback chub with dorsal fin punch (A) and location of scale samples (B).

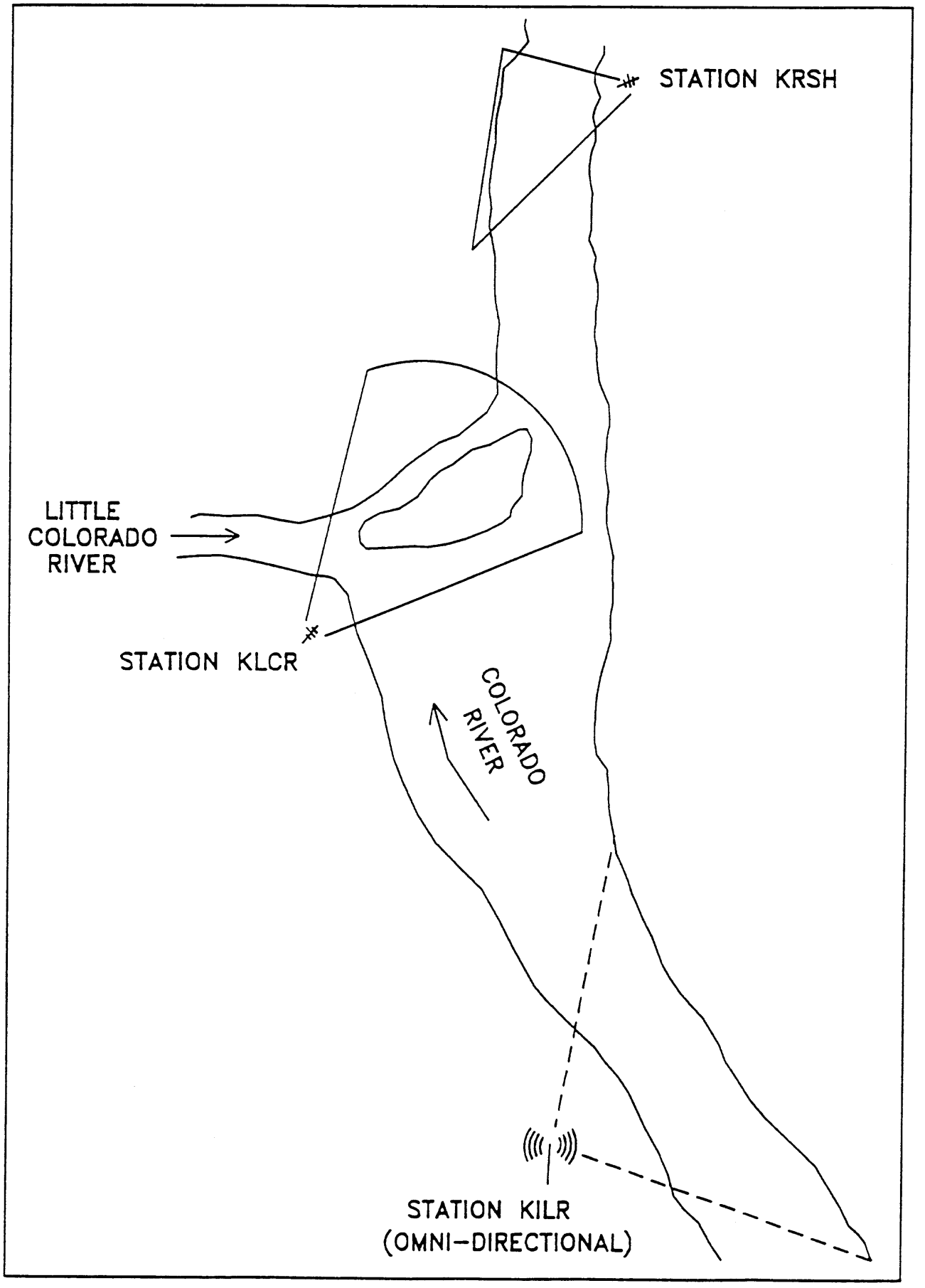
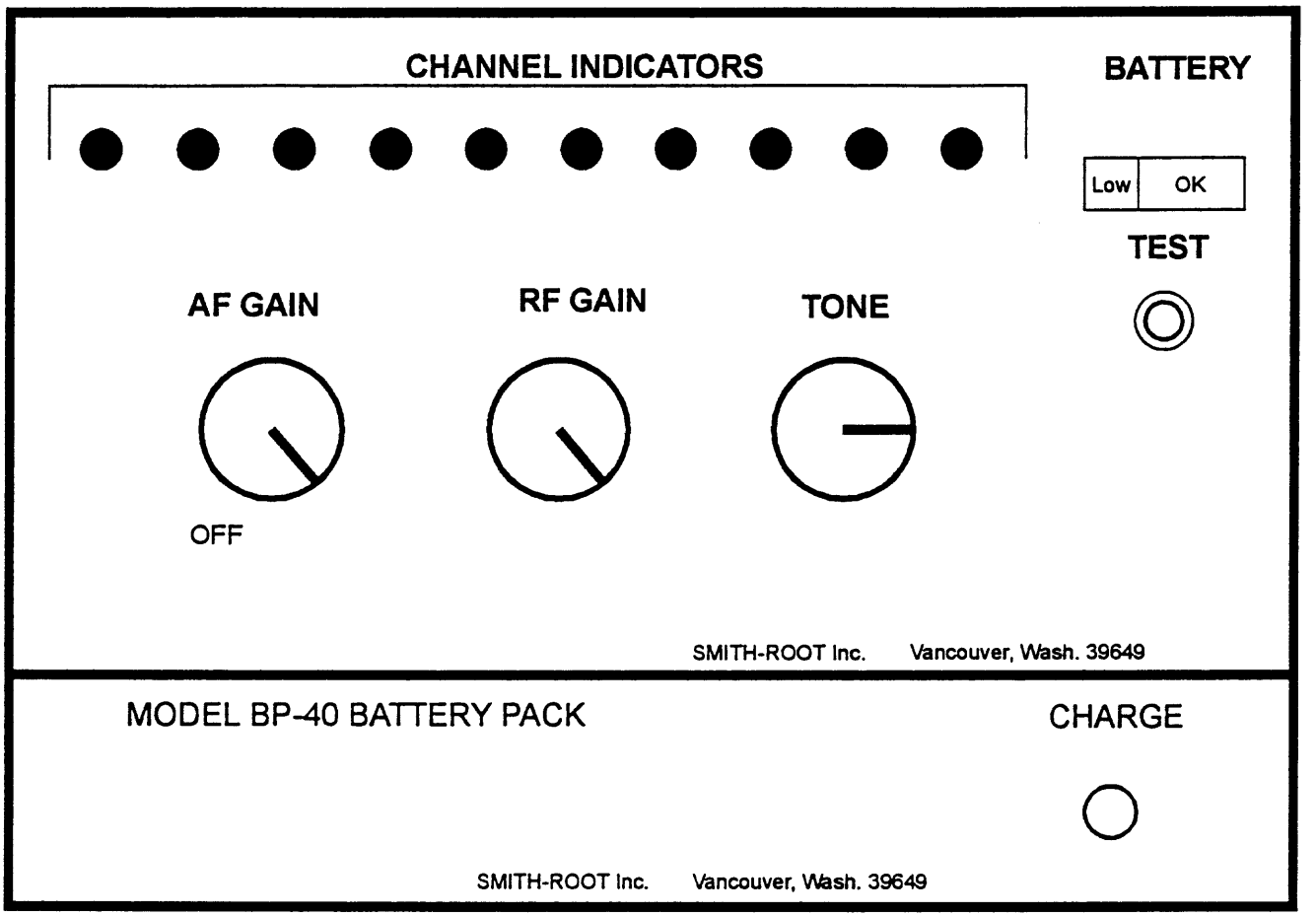


Figure 20. Approximate receiving zones for three remote telemetry stations near the mouth of the Little Colorado River.



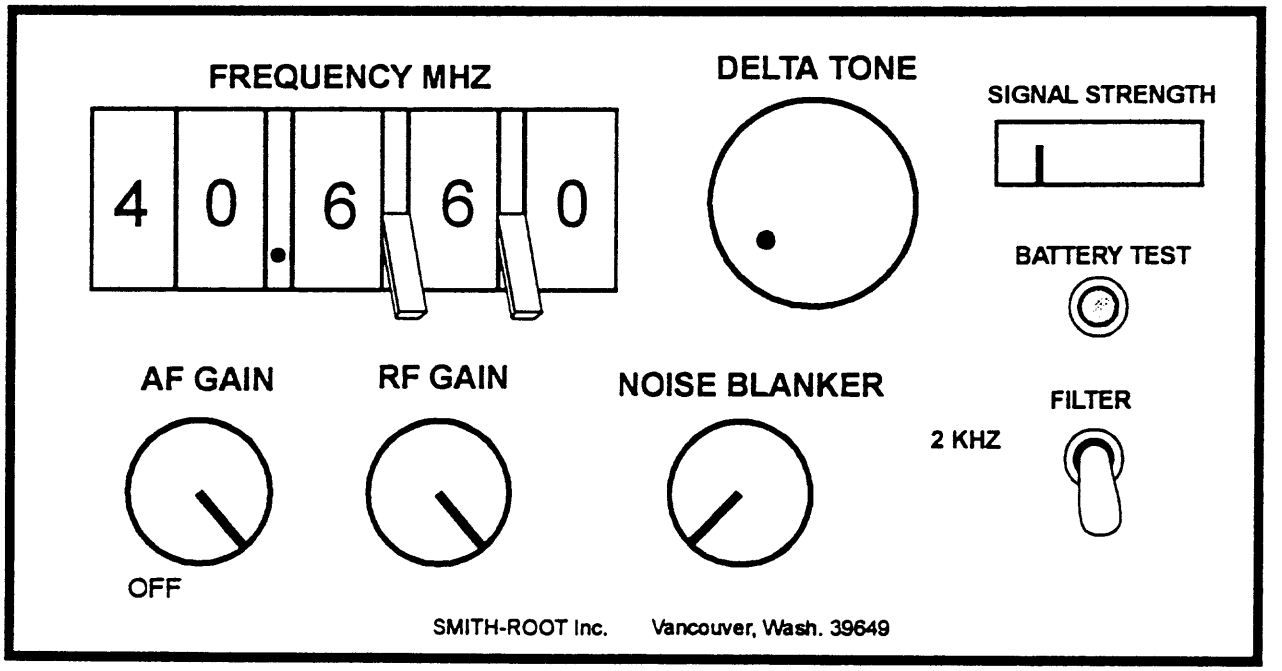


Figure 21. Radio receivers.

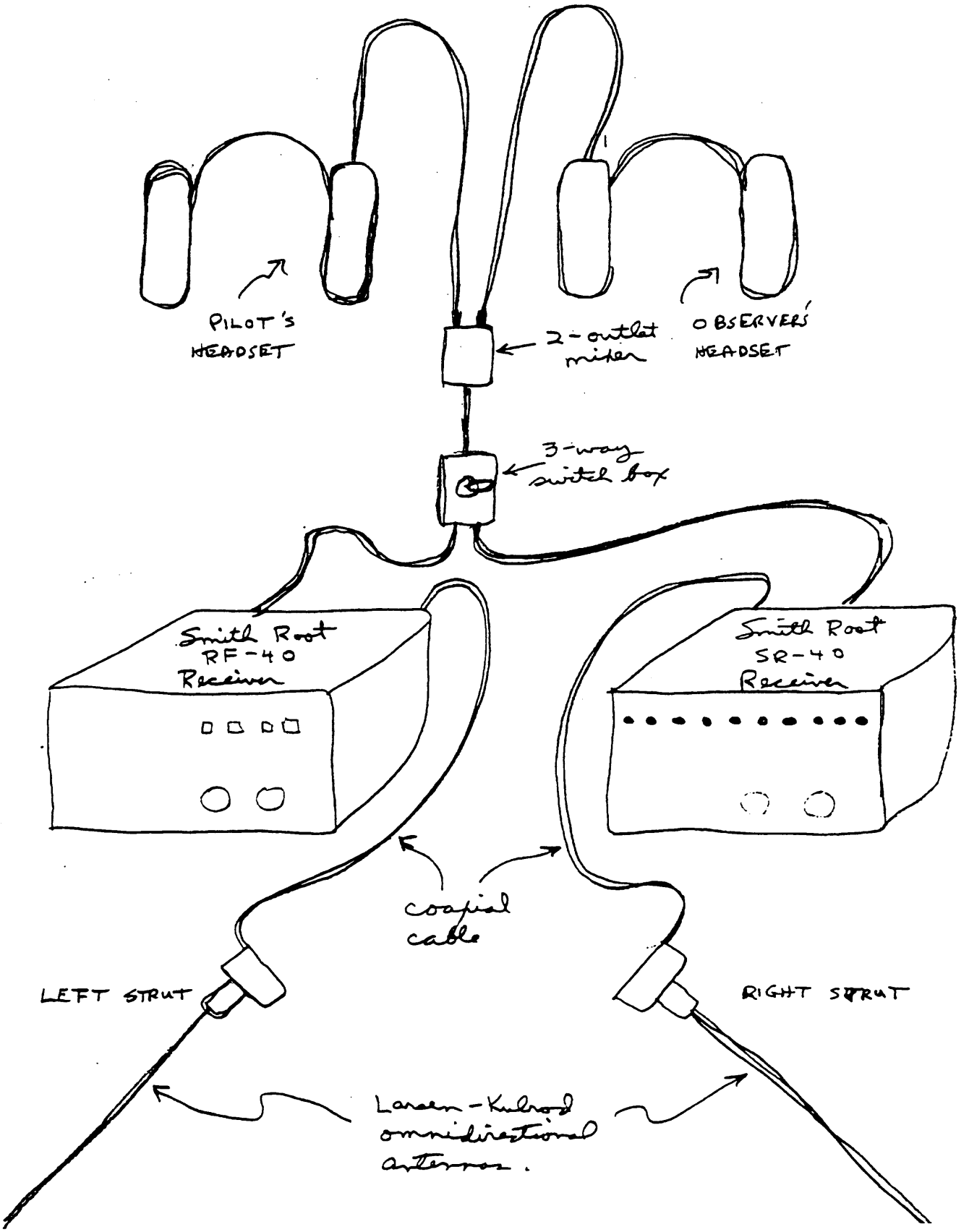


Figure 22. Diagram of radio receivers, antennas, swiches, and headsets used with aerial tracking of radio tagged fish.

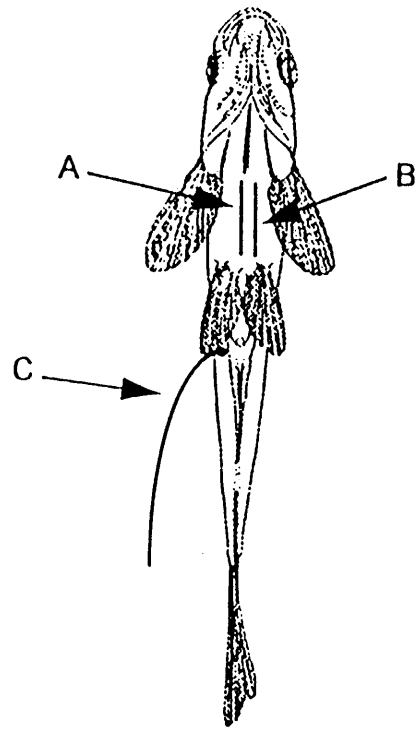


Figure 23. Primary abdominal incision along the *linea alba* (A) or lateral to the midline (B), and external antennae © of implanted radio transmitter in adult humpback chub.

Organizational Flow for Coordinating Data Management and Graphics Services

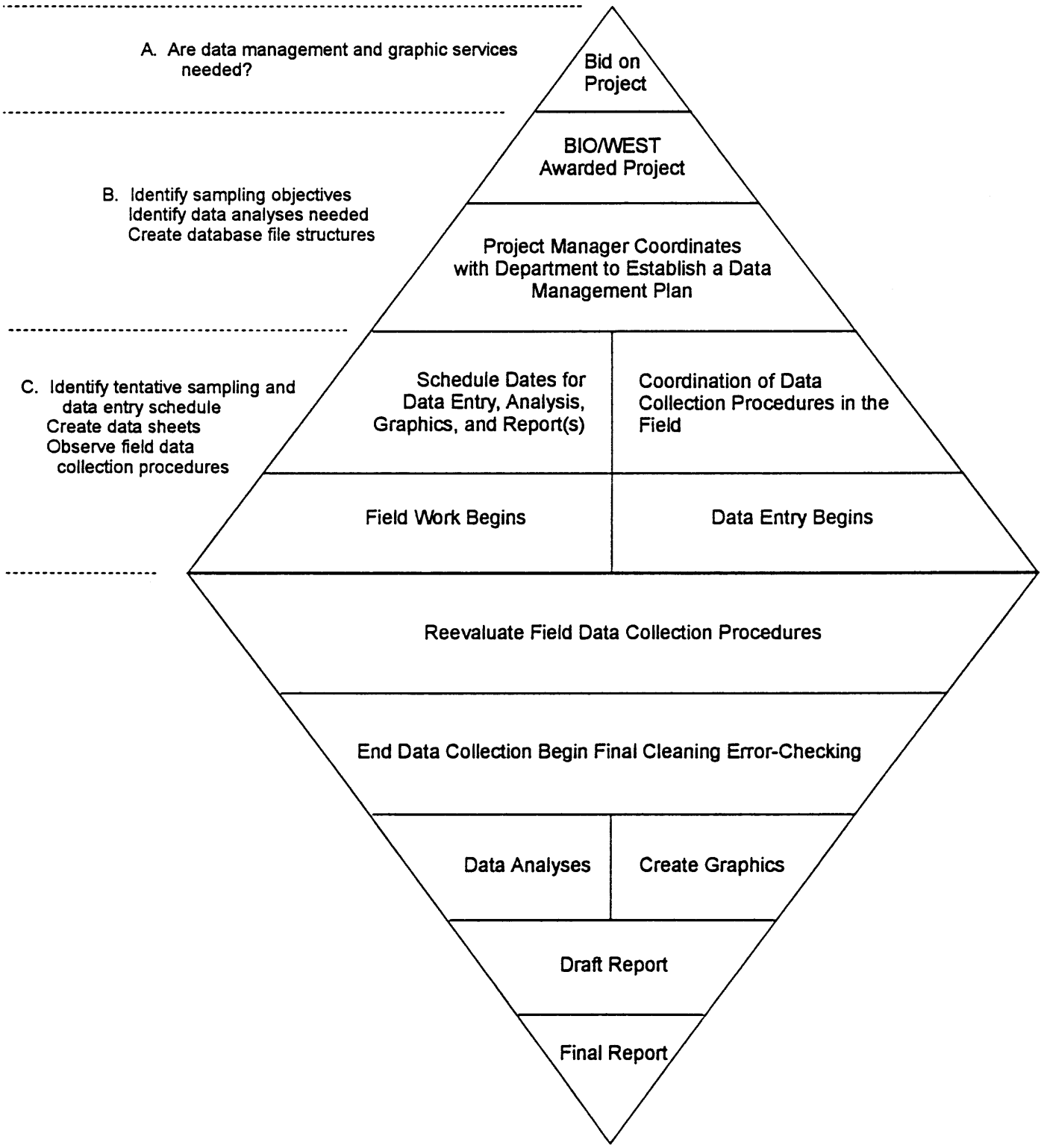


Figure 24. Organizational Flow for Coordinating Data Management and Graphics Services.

MONTHLY DATA CHECKING SHEET

Date	Initials	
☐☐		Get data from crew leaders.
☐		Copy data sheets.
☐		Mail original drift net sheets to Bill Leibfried.
☐		Mail data copies to Dave Wegner and Bill Leibried.
☐		File data copies in office.
☐		Enter chub data.
☐		Summarize other data for trip report, Generate Table 3.
☐		Compare numbers from sampling sheets to chub numbers - fix errors.
☐		Generate Table 4, chub data.
☐		Enter sampling and fish data.
☐		Run checking programs (Netchk, Elecchk, Seinchk)
☐		Fix errors, visually check all single, sample_num, species, YOY, juv, adu, total fields
☐		Visually check every 10th entire record
☐		Do chubupdt - fix new errors - archive old files
☐		Do chubchk
☐		Do fishcomb - fix new errors - archive old files
☐		Do fishchk
☐		Do elapsed.prg, review ###.ERR text file - visually check all records with elapse time >10 hr or <0.
☐		Do sample area calc. for seine file, visually check odd records.
☐		Do recapture update.
☐		Make aggregate files - archive all files.
☐		Do YOY etc, adjustments by running Domake_age and Ageupdt.
☐		Copy adjusted files back to network and archive.

Figure 25. Data tracking sheet.

Table 1. Characteristics of geomorphic reaches[a] within the four study regions of the Colorado River in Grand Canyon.

Study Region	Extent of Reach (river miles)	Name of Geomorphic Reach	Major Geologic Units at River Level[b]	Description of Reach Width	Average Ratio of Top Width to Mean Depth	Average Channel Width (feet)	Channel Slope	Percentage of Bed Composed of Bedrock and Boulders
0	0-11.3	Permian Section	Kaibab Limestone Toroweap Formation Coconino Sandstone Hermit Shale	Wide	11.7	260	.00099	42
	11.3-22.6	Supai Gorge	Supai Group	Narrow	7.7	210	0.0014	81
	22.6-35.9	Redwall Gorge	Redwall Limestone	Narrow	9.0	220	0.0015	72
I	35.9-61.5[c]	Lower Marble Canyon	Muav Limestone Bright Angel Shale Tapeats Sandstone	Wide	19.1	350	0.0010	36
	61.5-77.4	Furnace Flats	Tapeats Sandstone Unkar Group	Wide	26.6	390	0.0021	30
II	77.4-117.8	Upper Granite Gorge	Zoroaster Plutonic Complex Trinity and Elves Chasm Gneisses Vishnu Schist	Narrow	7	190	0.0023	62
	117.8-125.5	Aisles	Tapeats Sandstone Vishnu Schist	Narrow	11	230	0.0017	48
	125.5-139.9	Middle Granite Gorge	Tapeats Sandstone Unkar Group Vishnu Schist	Narrow	8.2	210	0.0020	68
	139.9-159.9	Muav Gorge	Muav Limestone	Narrow	7.9	180	0.0012	78
III	159.9-213.9	Lower Canyon	Basalt Muav Limestone Bright Angel Shale	Wide	16.1	310	0.0013	32
	213.9-225.0	Lower Granite Gorge	Vishmu Schist	Narrow	8.1	240	0.0016	58

[a]Adopted from Schmidt and Graf (1988, 1990), with slight variation in river miles (0.1 mi) for Middle Granite Gorge, Muav Gorge, and Lower Canyon; features identified at 24,000 cfs.
[b]From Hamblin and Rigby (1969)
[c]Regions 0 and I divided at RM 56.0; See Table 2-1

Table 2. Lengths of sample strata within the 11 geomorphic reaches.

Study Region	Geomorphic Reach	Sample Strata	River Miles	Length km(mi)
0	1 - Permian Section	a. Paria - Badger Creek	1.0-8.0	11 .3 (7.0)
		b. Badger Creek - Soap Creek	8.0-11.3	5.3 (3.3)
	2 - Supai Gorge	c. Soap Creek - Sheer Wall	11.3-14.5	5.1 (3.2)
		d. Sheer Wall - House Rock	14.5-17.0	4.0 (2.5)
		e. House Rock - North Canyon	17.0-22.6	9.0 (5.6)
	3 - Redwall Gorge	f. North Canyon - Tiger Wash	22.6-26.5	6.3 (3.9)
		g. Tiger Wash - Vasey's	26.5-35.9	15.1 (9.4)
	4 - Lower Marble Canyon	h. Vasey's - President Harding Rapid	35.9-43.7	12.6 (7.8)
		i. President Harding Rapid - Nankoweep	43.7-52.0	13.4 (8.3)
		j. Nankoweep - Kwagunt	52.0-56.0	6.4 (4.0)
I	4 - Lower Marble Canyon	a. Kwagunt - LCR	56.0-61.5	8.9 (5.5)
	5 - Furnace Flats	b. LCR - Chuar Rapid	61.5-65.5	6.4 (4.0)
		c. Chuar Rapid - Unkar Rapid	65.5-72.5	11.3 (7.0)
		d. Unkar Rapid - RM 77.4	72.5-77.4	7.9 (4.9)
II	6 - Upper Granite Gorge	a. Hance Rapid - Cremation Canyon	77.4-86.5	14.6 (9.1)
		b[a]. Bright Angel Creek	86.5-89.0	4.0 (2.5)
		c. Pipe Creek - Crystal Rapid	89.0-98.0	14.5 (9.0)
		d. Crystal Rapid - Bass Rapid	98.0-107.8	15.8 (9.8)
		e[a]. Shinumo Creek	107.8-109.8	3.2 (2.0)
		f. 110-mile Rapid - RM 117.8	109.8-117.8	12.9 (8.0)
	7 - Aisles	g. Aisles	117.8-125.5	12.4 (7.7)
	8 - Middle Granite Gorge	h. RM 125.5 - Dubendorf SSR	125.5-131.7	9.8 (6.2)
		i[a]. Tapeats Creek	131.7-134.5	4.5 (2.8)
		j. 134 Mile Rapid - RM 140.0	134.5-139.9	8.7 (5.4)
	9 - Muav Gorge	k[a]. Kanab Creek	139.9-143.8	6.3 (3.9)
		l. Kanab Rapid - Sinyala Rapid	143.8-153.5	15.6 (9.7)
		m[a]. Havasu Creek	153.5-159.9	10.3 (6.4)
III	10 - Lower Canyon	a. RM 160 - RM 169.9	159.9-169.9	15.8 (9.8)
		b. RM 169.9 - Lava Falls	169.9-179.4	15.3 (9.5)
		c. Lava Falls - RM 189.1	179.4-189.1	15.6 (9.7)
		d. RM 189.1 - RM 200.0	189.1-200.0	17.5 (10.9)
		e. RM 200.0 - 209-Mile Rapid	200.0-208.9	14.3 (8.9)
		f. 209-Mile Rapid - 214 Mile Cr	208.9-213.9	8.0 (5.0)
	11 - Lower Granite Gorge	g. 214-Mile Cr - Diamond Creek	213.9-226.0	19.6 (12.1)

[a]Tributary strata

Table 3. Stream gages used for hydrology analysis.

USGS Station Number	Station Name	Location[a]	Drainage Area (mi^2)	Period of Record (water years)
9380000	Colorado River at Lees Ferry, AZ	RM 0.0	111,800	1895-present
9383100	Colorado River above LCR, AZ	RM 61.2	N/A	Apr 1983-present
9402500	Colorado River near Grand Canyon, AZ	RM 87.4	~141,600	1925-present
9404120	Colorado River at National Canyon, AZ	RM 166.5	N/A	Apr 1983-present
9404200	Colorado River above Diamond Creek, AZ	RM 226.0	N/A	Apr 1983-present
9402000	Little Colorado River near Cameron, AZ	45 mi ups	26,459	1947-present
9402300	Little Colorado River near mouth, AZ	0.5 mi ups	26,964	1989-Jan 1993[bc]
9382000	Paria River at Lees Ferry, AZ	1.1 mi ups	1,410	1923-present
9403000	Bright Angel Creek near Grand Canyon, AZ	0.5 mi ups	101	1923-1974
9403780	Kanab Creek near Fredonia, AZ	31 mi ups	1,085	1963-1980

[a]RM = river miles downstream from Lees Ferry.
ups = distance upstream from Colorado River confluence.
[b]data inconsistent
[c]discharge based on stage elevations, periodically adjusted based on stream channel measures.

Table 4. Shoreline types and definitions associated with fish habitat of the Colorado River in Grand Canyon.

SHORELINE TYPE	DEFINITION
Bedrock	Exposed underlying parental rock material.
Cobble Bar	Cobble transported and rounded by main channel activity, characteristically well worked and imbricated. May show embededness.
Debris Fan	Material transported from a tributary during flood events, primarily boulders and cobble rounded by transport processes. Material is often embedded, and the angle of repose is generally flatter than talus.
Sand Bar	Predominantly exposed sand.
Talus Slope	Unconsolidated colluvium, predominantly angular boulders, deposited by rockfalls or rockslides from canyon walls. Talus is characteristically not embedded, and has a steeper angle of repose than alluvial fans.
Vegetation	Inundated plant material, consisting of stems, leaves, and/or root wads.

Table 5. Fish macrohabitat types and definitions for the Colorado River in Grand Canyon. Illustrations of each habitat type are provided in Fig. 8.

MACROHABITAT TYPE	DEFINITION
Eddy	A circular current of water, sometimes quite strong, diverging from and initially flowing contrary to the main current. It is usually formed at a point at which the flow passes some obstruction or on the inside of river bends (Helm 1985). In the Colorado River, an eddy forms in a channel expansion where flow separates from the bank, creating a zone of relatively weak recirculating current (Rubin et al. 1990). Bars accumulate at the weak points of flow where the current separates from the bank (separation point) and where flow reattaches to the bank (reattachment point). Increasingly restricted countercurrent behind the reattachment bar creates a recirculating eddy return channel.
Pool	A portion of the stream with reduced current velocity, often with water deeper than the surrounding areas, and which is frequently usable by fish for resting and cover (Helm 1985). In the Colorado River, a pool usually occurs in a deepened scour basin, and there may be small surface boils and upwellings.
Rapid	A relatively deep stream section with considerable surface agitation and swift current. Some waves may be present. Rocks and boulders may be exposed at all but high flows. Drops up to one meter (Helm 1985). In the Colorado River, rapids are whitewater, high velocity area caused by a constriction and drop in elevation. A rapid is deeper than a riffle, and has large, broken standing waves.
Return Channel	A topographic feature of a recirculating eddy that serves as the main pathway for upstream circulation, and forms a narrow channel (Rubin et al. 1990). When flows are below the crest of the reattachment bar, a sheltered body of water forms, bound on three sides by land with one opening to the river. A return channel is one type of backwater.
Riffle	A shallow rapids where the water flows swiftly over completely or partially submerged obstructions to produce surface agitations, but standing waves are absent (Helm 1985).
Run	An area of swiftly flowing water, without surface agitation or waves, which approximates uniform flow and in which the slope of the water surface is roughly parallel to the overall gradient of the stream reach (Helm 1985).

Table 6. Habitat map areas completed at various flows of the Colorado River in Grand Canyon, 1990-1993.

Map Site	Flow Range	Midpoint	Date (time)
ESPN (RM 59.75-61.00)	5,318-5,467	5,385	May 19, 1991 (1300-1400)
	11,089-11,089	11,089	August 19, 1991 (1830-1856)
	14,792-15,502	14,920	May 22, 1991 (1130-1230)
	17,249-16,749	17,148	August 18, 1991 (0850-0920)
	12,378-12,016	12,085	June 17, 1992 (1130-1245)
CAMP (RM 61.00-61.25)	5,318-5,268	5,234	May 20, 1991 (0830-0930)
	11,297-11,237	11,250	August 19, 1991 (1730-1750)
	15,017-14,888	14,888	May 21, 1991 (1515-1630)
	17,651-17,249	17,500	August 18, 1991 (0800-0834)
	12,916-12,443	12,696	June 17, 1992 (1015-1100)
LCRI (RM 61.25-61.50)	5,335-5,451	5,400	May 19, 1991 (1000-1130)
	11,446-11,326	11,400	August 18, 1991 (1800-1830)
	14,856-14,984	14,920	May 21, 1991 (1330-1430)
	16,451-16,155	16,300	August 18, 1991 (1000-1032)
	8,000	8,000	May 30, 1993 (0630-0700)
HOPI (RM 62.20-62.40)	10,052-10,043	10,050	September 16, 1991 (1530-1618)
	16,122-15,762	16,000	August 20, 1991 (1030-1050)
	11,979-11,643	11,708	June 18, 1992 (1215-1250)
SALT (RM 62.40-62.60)	9,257-10,266	10,266	May 20, 1991 (1720-1815)
	10,043-10,057	10,054	September 16, 1991 (1415-1508)
	14,824-14,888	14,952	May 22, 1991 (0830-0930)
	14,920-14,600	14,500	August 20, 1991 (1200-1230)
WHAL (RM 62.60-63.00)	14,920-14,920	14,920	May 22, 1991 (1810-1900)
WEEP (RM 63.00-63.25)	10,033-10,023	10,030	September 16, 1991 (1630-1718)
	17,517-17,115	17,300	August 20, 1991 (0830-0850)
	8,500	5,500	May 29, 1993 (1500-1530)

Table 7. Modified Wentworth classification for substrate particle sizes (Cummins 1962).

Classification	Particle size range (mm)
Boulder	>256
Cobble (Rubble)	64 - 256
Pebble	32 - 64
	16 - 32
Gravel	8 - 16
	4 - 8
	2 - 4
Very coarse sand	1 - 2
Coarse sand	0.5 - 1
Medium sand	0.25 - 0.5
Fine sand	0.125 - 0.25
Very fine sand	0.0625 - 0.125
Silt	0.0039 - 0.0625
Clay	<0.0039

Table 8. Database specifications for BIO/WEST Humpback Chub Studies.

File Name	# Records	Record Length	Size (bytes)	Anticipated # Records	Contents
NETTING.DBF	16,643	192	3,080,614	16,643	Netting and trapping sample data, Oct 1990 - Nov 1993
ELECTRO.DBF	4,612	182	850,018	4,612	Electrofishing sample data, Oct 1990 - Nov 1993
SEINE.DBF	958	217	202,814	958	Seining sample data, Oct 1990 - Nov 1993
CHUB.DBF	6,294	214	1,235,258	6,294	Humpback Chub morphometrics and meristics, Oct 1990 - Nov 1993
FISH.DBF	26,542	163	4,194,948	26,542	All fish capture data, Oct 1990 - Nov 1993
SURVEIL.DBF	1,600	111	290,626	1,600	Radiotelemetry surveillance, Oct 1990 - Nov 1992
OBSERV_H.DBF	260	206	29,854	260	Header for radiotelemetry observations, Oct 1990 - Nov 1992
OBSERV_M.DBF	2,025	149	302,975	2,025	Movement for radiotelemetry observations, Oct 1990 - Nov 1992
SCALES.DBF	157	133	22,099	157	Humpback Chub scale analyses, Oct 1990 - Nov 1993
JUVHAB.DBF	282	155	44,832	282	Juvenile habitat measurements, Oct 1990 - Nov 1993
DRIFT.DBF	570	218	125,030	570	Drift net sample analysis data, Oct 1990 - Nov 1993
FOOD.DBF	552	253	142,570	552	Stomach pumping analysis data, 1993
REMOTE.DBF	26,583	14	452,493	26,583	Remote radiotelemetry station data, Oct 1990 - Nov 1992
DATASOND.DBF	43,586	45	2,000,000	43,586	Datasonde water quality data, Oct 1990 - Nov 1993
SURVEYOR.DBF	5,161	51	265,000	5,161	Surveyor II water quality data, Oct 1990 - Nov 1993

Table 9. GIS database specifications for BIO/WEST humpback chub studies.

GIS Data	# Files	Anticipated Size (bytes)	Contents
Sampling Location Maps	2	~1,000,000	Net and trap locations plotted on orthophoto overlays
Surficial Habitat Maps	27	~100,000	Surficial hydraulic features outlined on aerial photos for four selected sites
Hydraulic Maps	2	~3,000,000	Surficial hydraulic features and shoreline types mapped on orthophoto overlays from LCR to Tanner
Bathymetric Maps and topo (LCR confluence)	15	~12,000,000	Bathymetry and topo for LCR confluence and rm 58.5, 60.1, 60.8, 64.7
Velocity and bathymetry maps (rm 58.5, 60.1, 60.8, 64.7)	250	~2,000,000	Velocities for rm 58.5, 60.1, 60.8, 64.7
Substrate Maps	1	~45,000	Substrates outlined for LCR confluence
Temperature Maps	67	~190,000	Temperature isopleths for LCR confluence
Fish Photographs	240	depends on resolution	Digitized fish slides

APPENDIX A - DATA FORMS

FORM 1

Page __ of __
SET _____

BIO/WEST GRAND CANYON STUDY

(Colorado River Mainstem)

Netting and Trapping

Sample Type: _ Trip: 9 3 - _ _ Reach: _ CB #: _ Date: _ _ _ _ _ _ (YY MM DD) RM: _ _ _ ._ _ Gear: _ _

Hab1: _ _ Hab2: _ _ Hab3: _ _ Side: _ Profile (Y/N): _ Max Depth: _ _ ._ft Sub1: _ _ Sub2: _ _

Fish Pres (Y/N): _ No. Bottles: _ Habitat Photo: Camera: _ _ Roll: _ _ Frame: _ _-_ _ Crew: _ _ ,_ _ ,_ _

Comments: _____

Sample #:	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _	_ _ _
Start Date:	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
Start Time:	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
End Time:	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
End Date:	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
Ambient Light:	_ _	_ _	_ _	_ _	_ _	_ _
Weather:	_ _	_ _	_ _	_ _	_ _	_ _
Turbidity:	_	_	_	_	_	_
AirT(c):	_ _. _	_ _. _	_ _. _	_ _. _	_ _. _	_ _. _
McT:	_ _. _	_ _. _	_ _. _	_ _. _	_ _. _	_ _. _
HabT:	_ _. _	_ _. _	_ _. _	_ _. _	_ _. _	_ _. _
Fluctuations:	_ _	_ _	_ _	_ _	_ _	_ _

SUMMARY

SPECIES	Y J A	Y J A	Y J A	Y J A	Y J A	Y J A
HB	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --
FM	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --
BH	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --
RB	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --
BR	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --
CC	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --
CP	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --
__	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --
__	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --	-- -- --

FORM 2

Page __ of __
RUN _____

BIO/WEST GRAND CANYON STUDY

(Colorado River Mainstem)

Electrofishing

Sample Type: E Sample No: _ _ _ Trip: 9 3 - _ _ Reach: _ CB #: _ Date: _ _ _ _ _ _
YY MM DD

Start RM: _ _ _ ._ _ End RM: _ _ _ ._ _ Start Time: _ _ _ _ End Time: _ _ _ _ Sec: _ _ _ _ _

Volts: _ _ _ Amps: _ _ ._ Amb Light: _ _ (SU, CL=cloudy PC, SH=shadow NI, ML=moonlight DD=dawn/dusk)

Hab1: _ _ Hab2: _ _ Hab3: _ _ Sub1: _ _ Sub2: _ _ AirT(c): _ _ ._ McT: _ _ ._ HabT: _ _ ._

Turbidity _ Weather: _ _ Fluctuations: _ _ Fish Pres (Y/N): _ No. Bottles: _

Crew: _ _ ._ _ _ ,_ _

Comments: _____

SPECIES SUMMARY

Species	YOY	JUV	ADU	Total
H B	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
F M	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
B H	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
R B	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
B R	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
C C	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
C P	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
F H	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
_ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
_ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
_ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _

BIO/WEST GRAND CANYON STUDY

(Colorado River Mainstem)

Seining

Sample Type: S Sample No: _ _ _ Trip: 9 3 - _ _ Reach: _ CB #: _ Date: _ _ _ _ _ _
YY MM DD

RM: _ _ _ ._ _ Gear: _ _ Start Time: _ _ _ _ Hab1: _ _ Hab2: _ _ Hab3: _ _

Sub1: _ _ Sub2: _ _ AirT(c): _ _ ._ McT: _ _ ._ HabT: _ _ ._ Quant Y/N: _ Subsamp Y/N: _

Ambient Light: _ _(SU=sunny CL=cloudy PC=partly cloudy SH=shadow NI=night ML=moonlight DD=dawn/dusk)

Weather: _ _ Turbidity: _ Fluctuation: _ _

Hab L: _ _ _ ._m Hab W: _ _ _ ._m Sa L: _ _ _ ._m Sa W: _ _ _ ._m

MaxDepth: _ _ ._ft D_1: _ _ ._ft D_2: _ _ ._ft Fish Pres (Y/N): _ No. Bottles: _

Habitat Photo: Camera: _ _ Roll: _ _ Frame: _ _ Crew: _ _ ._ _ ,_ _

Comments: _____

Species	LAR	YOY	JUV	ADU	Total
H B	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
F M	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
B H	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
R B	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
B R	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
C C	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
C P	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
F H	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
_ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
_ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _
_ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _	_ _ _ _

INDIVIDUAL FISH LENGTHS

Sample #	Species	TL	SL	WT	PIT Tag No.	Recap (Y/N)	Old Tag	P/V	Shore Y/N	Sex	Ripe	Disp	Rel. Loc.
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]
---	--	---	---	----	----------	-	------	-	-	-	--	--	---[1,2]

[1]- Photo / [2]- Video

FORM 4

BIO/WEST GRAND CANYON STUDY

(Colorado River Mainstem)

Telemetry Observations

Sample No: _ _ _ Trip: _ _ Reach: _ CB #: _ Date: _ _ _ _ _ _

Start Time: _ _ _ _ End Time: _ _ _ _ River: _ _ RM: _ _ _ ._ <Locate:_ 2H:_ 24H:_ Mode Test Flow:_ Implant:_>

Habitat Map #: _ _ _ _ _ _ Benchmark: _ _ _ _ _ _ Confidence: _

Habitat Photo: Camera _ _ Roll: _ _ Frame: _ _-_ _ Crew: _ _, _ _, _ _

Fish Information

Species: H B PIT tag: _ _ _ _ _ _ _ _ _ _ _ TL: _ _ _ Wt.: _ _ _ _ Radiotag Size: _ _ g

Freq 1: 40._ _ _ Freq 2: 40._ _ _ Pulse 1 (#/min): _ _ Pulse 2: _ _ Surgeon: _ _

Time	RM	Hab	Distance Moved	Gage	Rel Stage	Abs. Stage	Ambient Light	Weather	Turbidity

COMMENTS

FORM 4, Page 2

Habitat Measurements:

Hab1: _ _ Hab2: _ _ Depth: _ _ ._m V 0.2: _ ._ m/s V 0.6: _ ._ m/s V 0.8: _ ._ m/s

V Bottom: _ ._ m/s AirT(c): _ _ _ McT: _ _ ._ HabT: _ _ ._ Sub1: _ _ Sub2: _ _

Cover: Over: _ _ Lat: _ _ In: _ _ Turb: _ DO: _ _ mg/l pH: _ ._ Cond: _ _ _ _ umhos/cm

---

Habitat Sketch:

FORM 4-b

BIO/WEST GRAND CANYON STUDY

(Colorado River Mainstem)

Telemetry Observations

Sample No: _ _ _ Trip: _ _ Reach: _ CB #: _ Date: _ _ _ _ _ _

PIT tag: _ _ _ _ _ _ _ _ _ _ _ Freq 2: 40._ _ _ Pulse 2: _ _

Time	RM	Hab	Distance Moved	Gage	Rel Stage	Abs. Stage	Ambient Light	Weather	Turbidity

COMMENTS

BIO/WEST GRAND CANYON STUDY

(Colorado River Mainstem)

Telemetry Surveillance

Sample No: _ _ _ Trip: _ _ Reach: _ CB#: _ <Aerial: _ Boat: _ Foot: _>

Date: _ _ _ _ _ _ Time: Start _ _ _ _ End _ _ _ _ RM _ _ _ . _ to _ _ _ . _
Y Y M M D D

Ambient Light: _ _ (SU=sunny CL=cloudy PC=partly cloudy SH=shadow NI=night ML=moonlight DD=dawn/dusk)

Weather _ _ Turbidity _ _ Sechi Disk _ _ m Fluctuations: _ _

Crew: _ _, _ _, _ _

Time	RM	Side	Frequency	Pulse	Confidence	Hab2	Cover

orm 6

BIO/WEST GRAND CANYON STUDY
Chub Meristics

ITTag No.: _ _ _ _ _ _ _ _ _ _ DATE: _ _ - _ _ - _ _ SAMPLE #: _ - _ _ _ _ - _ _ _ - _ - _ TL (mm): _ _ _ FL: _ _ _ SL: _ _ _ WT (g): _ _ _ _
EX: _ RIPE: _ _ P_1-P_2: _ _ . _ ND: _ _ . _ CPL: _ _ _ . _ CPMD: _ _ . _ CPND: _ _ . _ HL: _ _ . _ SNL: _ _ . _ DFB: _ _ . _ AFB: _ _ . _ BD: _ _ _ . _
D: _ _ A: _ _ RECAP: _ TAG: _ _ _ _ _ DISP: _ _ CAM: _ _ ROLL: _ _ FRAME: _ _ - _ _ VIDEO: _ _ RM RELEASE: _ _ _ . _ RADIOTAG (Y/N): _

ITTag No.: _ _ _ _ _ _ _ _ _ _ DATE: _ _ - _ _ - _ _ SAMPLE #: _ - _ _ _ _ - _ _ _ - _ - _ TL (mm): _ _ _ FL: _ _ _ SL: _ _ _ WT (g): _ _ _ _
EX: _ RIPE: _ _ P_1-P_2: _ _ . _ ND: _ _ . _ CPL: _ _ _ . _ CPMD: _ _ . _ CPND: _ _ . _ HL: _ _ . _ SNL: _ _ . _ DFB: _ _ . _ AFB: _ _ . _ BD: _ _ _ . _
D: _ _ A: _ _ RECAP: _ TAG: _ _ _ _ _ DISP: _ _ CAM: _ _ ROLL: _ _ FRAME: _ _ - _ _ VIDEO: _ _ RM RELEASE: _ _ _ . _ RADIOTAG (Y/N): _

ITTag No.: _ _ _ _ _ _ _ _ _ _ DATE: _ _ - _ _ - _ _ SAMPLE #: _ - _ _ _ _ - _ _ _ - _ - _ TL (mm): _ _ _ FL: _ _ _ SL: _ _ _ WT (g): _ _ _ _
EX: _ RIPE: _ _ P_1-P_2: _ _ . _ ND: _ _ . _ CPL: _ _ _ . _ CPMD: _ _ . _ CPND: _ _ . _ HL: _ _ . _ SNL: _ _ . _ DFB: _ _ . _ AFB: _ _ . _ BD: _ _ _ . _
D: _ _ A: _ _ RECAP: _ TAG: _ _ _ _ _ DISP: _ _ CAM: _ _ ROLL: _ _ FRAME: _ _ - _ _ VIDEO: _ _ RM RELEASE: _ _ _ . _ RADIOTAG (Y/N): _

ITTag No.: _ _ _ _ _ _ _ _ _ _ DATE: _ _ - _ _ - _ _ SAMPLE #: _ - _ _ _ _ - _ _ _ - _ - _ TL (mm): _ _ _ FL: _ _ _ SL: _ _ _ WT (g): _ _ _ _
EX: _ RIPE: _ _ P_1-P_2: _ _ . _ ND: _ _ . _ CPL: _ _ _ . _ CPMD: _ _ . _ CPND: _ _ . _ HL: _ _ . _ SNL: _ _ . _ DFB: _ _ . _ AFB: _ _ . _ BD: _ _ _ . _
D: _ _ A: _ _ RECAP: _ TAG: _ _ _ _ _ DISP: _ _ CAM: _ _ ROLL: _ _ FRAME: _ _ - _ _ VIDEO: _ _ RM RELEASE: _ _ _ . _ RADIOTAG (Y/N): _

ITTag No.: _ _ _ _ _ _ _ _ _ _ DATE: _ _ - _ _ - _ _ SAMPLE #: _ - _ _ _ _ - _ _ _ - _ - _ TL (mm): _ _ _ FL: _ _ _ SL: _ _ _ WT (g): _ _ _ _
EX: _ RIPE: _ _ P_1-P_2: _ _ . _ ND: _ _ . _ CPL: _ _ _ . _ CPMD: _ _ . _ CPND: _ _ . _ HL: _ _ . _ SNL: _ _ . _ DFB: _ _ . _ AFB: _ _ . _ BD: _ _ _ . _
D: _ _ A: _ _ RECAP: _ TAG: _ _ _ _ _ DISP: _ _ CAM: _ _ ROLL: _ _ FRAME: _ _ - _ _ VIDEO: _ _ RM RELEASE: _ _ _ . _ RADIOTAG (Y/N): _

ITTag No.: _ _ _ _ _ _ _ _ _ _ DATE: _ _ - _ _ - _ _ SAMPLE #: _ - _ _ _ _ - _ _ _ - _ - _ TL (mm): _ _ _ FL: _ _ _ SL: _ _ _ WT (g): _ _ _ _
EX: _ RIPE: _ _ P_1-P_2: _ _ . _ ND: _ _ . _ CPL: _ _ _ . _ CPMD: _ _ . _ CPND: _ _ . _ HL: _ _ . _ SNL: _ _ . _ DFB: _ _ . _ AFB: _ _ . _ BD: _ _ _ . _
D: _ _ A: _ _ RECAP: _ TAG: _ _ _ _ _ DISP: _ _ CAM: _ _ ROLL: _ _ FRAME: _ _ - _ _ VIDEO: _ _ RM RELEASE: _ _ _ . _ RADIOTAG (Y/N): _

ITTag No.: _ _ _ _ _ _ _ _ _ _ DATE: _ _ - _ _ - _ _ SAMPLE #: _ - _ _ _ _ - _ _ _ - _ - _ TL (mm): _ _ _ FL: _ _ _ SL: _ _ _ WT (g): _ _ _ _
SEX: _ RIPE: _ _ P_1-P_2: _ _ . _ ND: _ _ . _ CPL: _ _ _ . _ CPMD: _ _ . _ CPND: _ _ . _ HL: _ _ . _ SNL: _ _ . _ DFB: _ _ . _ AFB: _ _ . _ BD: _ _ _ . _
D: _ _ A: _ _ RECAP: _ TAG: _ _ _ _ _ DISP: _ _ CAM: _ _ ROLL: _ _ FRAME: _ _ - _ _ VIDEO: _ _ RM RELEASE: _ _ _ . _ RADIOTAG (Y/N): _

BIO/WEST GRAND CANYON STUDY

(Colorado River Mainstem)
Water Quality

---

ocation: __ __ RM: __ __ __.__ (Mainstem) Date: __ __ __ __ __ __ Time: __ __ __ __ Weather: __ __

luctuation: __ __ Sechi Disc: __ __.__ AirT(C): __ __ __ McT: __ __.__ HabT: __ __.__

.O.(mg/l): __ __.__ pH __.__ Cond. (umhos) __.__ __ __ Redox: __ __ __ __ Battery Level: __ __ __ __
omments:

---

ocation: __ __ RM: __ __ __.__ (Mainstem) Date: __ __ __ __ __ __ Time: __ __ __ __ Weather: __ __

luctuation: __ __ Sechi Disc: __ __.__ AirT(C): __ __ __ McT: __ __.__ HabT: __ __.__

.O.(mg/l): __ __.__ pH __.__ Cond. (umhos) __.__ __ __ Redox: __ __ __ __ Battery Level: __ __ __ __
omments:

---

ocation: __ __ RM: __ __ __.__ (Mainstem) Date: __ __ __ __ __ __ Time: __ __ __ __ Weather: __ __

luctuation: __ __ Sechi Disc: __ __.__ AirT(C): __ __ __ McT: __ __.__ HabT: __ __.__

.O.(mg/l): __ __.__ pH __.__ Cond. (umhos) __.__ __ __ Redox: __ __ __ __ Battery Level: __ __ __ __
omments:

---

ocation: __ __ RM: __ __ __.__ (Mainstem) Date: __ __ __ __ __ __ Time: __ __ __ __ Weather: __ __

luctuation: __ __ Sechi Disc: __ __.__ AirT(C): __ __ __ McT: __ __.__ HabT: __ __.__

.O.(mg/l): __ __.__ pH __.__ Cond. (umhos) __.__ __ __ Redox: __ __ __ __ Battery Level: __ __ __ __
omments:

JUVENILE HABITAT DATA SHEET

DATE _ _ _ _ _ _

SAMPLE NO. _____ RMI ___ ___ ___.___ ___ RIVER RIGHT ____ LEFT ____

BM ID _____ STAGE (start) _____ (end) _____
TIME (start) _____ (end) _____

HAB1 ____ HAB2 ____
SHORELINE TYPE: TALUS ____ TAPEATS LEDGE ____ SAND BEACH ____ CLIFF ____
ALLUVIAL FAN ____ VEGETATION ____ OTHER _____

RECORDERS: _____, _____, _____

TRANSECT no.	DIST. from shore	DEPTH (feet)	FLOW DIR (+ or -)	VELOCITY (mps) (1)	VEL (2)	VEL (3)	SUBSTRATE (see codes)	LAT	COVER OV	IN
_1_	0.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_1_	1.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_1_	2.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_2_	0.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_2_	1.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_2_	2.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_3_	0.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_3_	1.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_3_	2.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_4_	0.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_4_	1.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_4_	2.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_5_	0.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_5_	1.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_5_	2.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_6_	0.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_6_	1.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_6_	2.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_7_	0.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_7_	1.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__
_7_	2.5 m	__._	__	__.__	__._	__.__	__/__	__	__	__

STAGE LEVEL REFERENCE POINT LOCATION

SHEET ____ OF ____

POINT NO:__.__ __ __ __ RIVER MILE:__ __ __.__ (LEFT/RIGHT) PHOTO NO.____/____/____

LOCATION DISCRIPTION:

LOCATION SKETCH:

STAGE DISCHARGE MEASUREMENTS: DATE:_____ TRANSMITTER FREQUENCIES: 40:_____, 40:_____, 40:_____

VERTICAL DISTANCE FROM REFERENCE POINT: _____
INITIAL DATE/TIME OF MEASUREMENT (- -) / (:)
UNITS OF MEASURE _____

DATE	TIME	STAGE A	STAGE B	STAGE C	STAGE D	STAGE E	RELATIVE CHANGE (+/-)
							0.00

DRIFT NET SAMPLES

Date: _____ Time: _____-_____ Elapsed Time: _____RM: _____ River Stage: ____

V_1: _____,_____,_____ V_2: _____,_____,_____ H_1:_____ H_2:____ Habitat: _____

Description: _____

_____

For Lab use only:

Black Fly	Midges	Gammarus	other	Misc.	% Clado.
adult: pupae: larvae: drwt:	adult: pupae: larvae: drwt:	mat: imm: drwt:	adult: imm: drwt:	terr: drwt:	drwt:

Date: _____ Time: _____-_____ Elapsed Time: _____RM: _____ River Stage: ____

V_1: _____,_____,_____ V_2: _____,_____,_____ H_1: ____ H_2: ____ Habitat: _____

Description: _____

_____

For Lab use only:

Black Fly	Midges	Gammarus	other	misc	% Clado
adult: pupae: larvae:	adult: Pupae: larvae:	mat: imm: drwt:	adult: imm: drwt:	terr: drwt:	drwt:

Date: _____ Time: _____-_____ Elapsed Time: _____RM: _____ River Stage: ____

V_1: _____,_____,_____ V_2: _____,_____,_____ H_1:_____ H_2:____ Habitat: _____

Description: _____

_____

For Lab use only:

Black Fly	Midges	Gammarus	other	Misc.	% Clado.
adult: pupae: larvae: drwt:	adult: pupae: larvae: drwt:	mat: imm: drwt:	adult: imm: drwt:	terr: drwt:	drwt:

APPENDIX B - DATA CODE GLOSSARY

LIFE STAGE / LENGTH BREAKDOWN FOR FISH IN THE GRAND CANYON

SPECIES			LIFE STAGE DESIGNATION all lengths in mm TL		
Common Name	B/W Code	Scientific Name	Young of the Year Y-O-Y (mm TL)	Juvenile (mm TL)	Adult
Humpback chub	HB	Gila cypha	Dec-Apr 30: 100 May 30: 30 June 30: 40 July 30: 50 Aug 30: 60 Sept 30: 70 Oct 30: 80 Nov 30: 90	Dec-Apr 101-199 May 31-199 June 41-199 July 51-199 Aug 61-199 Sept 71-199 Oct 81-199 Nov 91-199	>=200
Flannelmouth sucker	FM	Catostomus latipinnis	<= 50	>50 - 199	>=200
Flannelmouth varient	FV		<= 50	>50 - 199	>=200
Flannelmouth x Razorback Hybrid	FR		<= 50	>50 - 199	>=200
Razorback sucker	RZ	Xyrauchen texanus	<= 50	>50 - 199	>=200
Bluehead sucker	BH	Catostomus discobolus	<= 50	>50 - 149	>=150
Speckled dace	SD	Rhynichthys osculus	<= 25		> 25
Rainbow trout	RB	Oncorhynchus mykiss	<= 75	> 75 - 199	>=200
Brown trout	BR	Salmo trutta	<= 75	> 75 - 199	>=200
Brook trout	BK	Salvelinus fontinalis	<= 75	> 75 - 199	>=200
Plains killifish	RK	Fundulus zebrinus	<= 25		> 25
Striped bass	SB	Morone saxatilis	<= 85	> 85 - 199	>=200
Walleye	WE	Stizostedion vitreum	<= 170	> 170 - 339	>=340
Common carp	CP	Cyprinus carpio	<= 75	> 75 - 199	>=200
Fathead minnow	FH	Pimiphales promelas	<= 25		> 25
Channel catfish	CC	Ictalurus punctatus	<= 60	> 60 - 199	>=200
Black bullhead	BB	Ameiurus melas	<= 50	> 50 - 199	>=200

DESCRIPTION OF FIELDS FOR DATA FORM 1, 2, 3
(Colorado River Mainstem)

Fish/Habitat Sampling

Field	Width	Type	Description
AirT	3	numeric	1-3 = air temperature in °C
Ambient Light	2	alphanumeric	2 = light conditions at time of sample SU = sunny CL = cloudy (> 50% cloud cover) PC = partly cloudy (< or= 50% cloud cover) SH = shadow NI = night ML = moonlight DD = dawn/dusk
Amps	4.1	decinumeric	1-4 = amperage level from Mark-XX
CB#	1	numeric	1 = clipboard #
Crew	6	alphanumeric	1-2 = principal crew member 3-4 = recorder 5-6 = assistant i.e. RV = Rich Valdez BM = Bill Masslich LC = Larry Crist
Date	6	numeric	1-2 = Year, 1992 = 92 3-4 = Month, June = 06 5-6 = Day of Month
D_1	3.1	decinumeric	1-3 = depth halfway to one side of backwater
D_2	3.1	decinumeric	1-3 = depth halfway to other side of backwater
Disposition	2	alphanumeric	2 = disposition of fish RA = returned alive (no radio implant) RI = radio implanted RR = returned with active radio transmitter RN = returned with non-active radio transmitter (removed external antennae but did not re-implant RS = returned alive with stomach contents removed

Field	Width	Type	Description
			DP = dead, preserved DR = dead, released (non-native fish) DS = dead, stomach contents preserved
Elapsed Time	4	numeric	1-4 = duration of net or trap sets recorded in tenths of hours i.e. 2.4 hr
End Time	4	numeric	1-4 = end of sample time
Fish Pres(Y/N)	1	alphanumeric	1 = were fish preserved Y = yes N = no
Fluctuations or Fluct.	2	alphanumeric	1-2 = Stage change between start time and end time RI = rising FA = falling SL = steady low SH = steady high
Gear	2	alphanumeric	1-2 = EL = electrofishing FR = frame net SA = 10'x3'x1/8" seine SB = 30'x4'x1/4" seine SG = 30'x5'x1/4" seine DL = larval fish drift net DR = invert drift net SU = surber AQ = aquarium net KS = kick screen TK = 75'x6'x1"x12" Trammel net TL = 75'x6'x1 1/2"x12" Trammel net TF = floated Trammel net TM = 50'x6'x1"x12" Trammel net TN = 50'x6'x1.5"x12" Trammel net TW = 75'x6'x1/2"x10" Trammel net TZ = TL with attached floats TY= TK with attached floats GM = 100'x6'x2" Gill net GP = 100'x6'x1 1/2" Gill net GX = experimental Gill net GZ = 60' experimental Gill net GY = 50'x6'x1.5" Gill net GF = floated Gill net

Field	Width	Type	Description
			MT = Minnow trap HL = Large hoop net (4' diam.) HM = Medium hoop net (4' diam.) HS = Small hoop net (2' diam.) AN = angling
Habitat Photo	(Compound Field)		
Camera	2	alphanumeric	1-2 = camera identifier 01 = B/W camera #1 02 = B/W camera #2 LC = Larry Crist's camera BL = Bill Leibfried's camera BM = Bill Masslich's camera
Roll	2	numeric	1-2 = photo roll number
Frame	4	numeric	1-4 = photo frame numbers
Hab1	2	alphanumeric	1-2 = general habitat MC = main channel TS = tributary stream SC = side channel
Hab2	2	alphanumeric	1-2 = specific habitat BA = backwater ED = eddy EM = embayment RI = riffle RU = run SH = shoreline PO = pool RC = return channel
Hab3	2	alphanumeric	1-2 = shoreline habitat TS = talus scree SW = shear wall LE = ledge BE = bedrock SI = silt SA = sand CO = cobble BO = boulder CB = cut bank VG = vegetation DF = debris flow

Field	Width	Type	Description
Hab L	5.1	decinumeric	1-5 = length of habitat seined
Hab W	5.1	decinumeric	1-5 = width of habitat seined
HabT	4.1	decinumeric	1-4 = temperature of habitat sampled
Hours	4.1	decinumeric	1-4 = hours gear set between checks
Max Depth	4.1	decinumeric	1-4 = maximum depth at gear location
McT	4.1	decinumeric	1-4 = main channel temperature

Field	Width	Type	Description
No. Bottles	1	numeric	1 = number of bottles with preserved fish
Old Tag	6	alphanumeric	1-6 = old tag number with color and size i.e. 003CSG for small green Carlin tag #003; 003FLY for yellow Floy tag #003 UCRP2 = upper caudal plus right pelvic clips UCLP2 = upper caudal plus left pelvic clips LCRP2 = lower caudal plus right plevic clips LCLP2 = lower caudal plus left pelvic clips LC = lower caudal punch UC = upper caudal punch DP = dorsal punch UCDP = upper caudal and dorsal punch
PIT Tag	10	alphanumeric	1-10 = unique number transmitted by PIT tag
P[1]	1	alphanumeric	1 = photo taken Y = yes N = no
Profile(Y/N)	1	alphanumeric	1 = cross section fathometer profile was taken Y = yes N = no
Quant Y/N	1	logical	1 = was sample done quantitativly
Reach	1	numeric	1 = Reach (0=above LCR,1=LCR, 2=Granite Gorge, 3=Lower)
Recap(Y/N)	1	alphanumeric	1 = fish is a recapture Y = yes N = no
Rel. Loc.	4.1	decinumeric	1-4 = point of release of fish in RM to the nearest 0.05 mile below Lee's Ferry
Ripe	2	alphanumeric	2 = state of gonadal maturity of fish TU = tubercled only TC = tubercled and colored MI = running milt EG = expressible eggs SP = spent CO = colored only

Field	Width	Type	Description
RM	5.1	decinumeric	1-5 = miles downstream from Lees Ferry in 0.05 mile increments where possible
Sa L	4.1	decinumeric	1-4 = sample length (in meters)
Sa W	4.1	decinumeric	1-4 = sample width (in meters)
Sample No or Sample #	7	alphanumeric	1-3 = sequential sample no.
Sample Type	1	alphanumeric	1 = Sample type E = Electrofishing N = Gill/Trammel nets S = Seining T = Traps, i.e. hoop nets, minnow traps D = Drift netting A = Angling
Seconds	5	numeric	1-5 = total time from Mark-XX clock
Sex	1	alphanumeric	1 = gender of fish M = male F = female I = immature U = undetermined
Side	1	alphanumeric	1 = side of river channel where net or trap is anchored R = river right (looking downstream) L = river left (looking downstream)
SL	3	numeric	1-3 = standard length of fish
Species Code or Species	2	alphanumeric	1-2 = code for fish species HB = humpback chub SD = speckled dace CC = channel catfish FM = flannelmouth sucker BH = bluehead sucker RB = rainbow trout CP = carp BR = brown trout BK = brook trout RZ = razorback sucker FV = flannelmouth sucker variant

Field	Width	Type	Description
			PK = Plaines/Rio Grande killifish SB = striped bass FH = fat head minnow WE = walleye FR = flannelmouth x razorback sucker FZ = flannelmouth x razorback sucker SU = unidentified sucker YB = yellow bullhead BB = black bullhead
SPECIES SUMMARY (Compound Field) **SEE LENGTH BREAKDOWN SHEET**			
ADU	4	numeric	1-4 = number of adults caught
JUV	4	numeric	1-4 = number of juveniles caught
LAR	4	numeric	1-4 = number of larval caught
YOY	4	numeric	1-4 = number of YOY caught
Total	4	numeric	1-4 = total number caught by species
Start Date	6	numeric	1-6 = day a sample is begun
Start Time	4	numeric	1-4 = start of sample time 6am = 0600 6pm = 1800
Subsamp Y/N	1	logical	1 = was sein effort a subsample of habitat
Sub1	2	alphanumeric	1-2 = dominant substrate SI = silt SA = sand GR = gravel CO = cobble BO = boulder BE = bedrock OR = organics
Sub2	2	alphanumeric	1-2 = secondary substrate Same codes as Sub1
TL	3	numeric	1-3 = total length of fish in mm
Trip	2	Numeric	1-2 = Trip No. for year (0-12)

Field	Width	Type	Description
Turbidity or Turb	2	alphanumeric	1-2 = turbidity C = clear L = low >or= 0.5m secchi disk H = high turbidity <or= 0.5m secchi disk
V[1]	1	alphanumeric	1 = video footage taken Y = yes N = no
Volts	3	numeric	1-3 = voltage setting for Mark-XX
Weather	2	alphanumeric	1-2 = weather condition SU = sunny CS = clear skies (SU) CL = cloudy (>50% cloud cover) PC = partly cloudy (< or = 50% cloud cover) OV = overcast RA = raining SN = snow
WT	4	numeric	1-4 = weight of fish in grams

DESCRIPTION OF FIELDS FOR DATA FORM 4 & 5
(Colorado River Mainstem)

Radiotelemetry

Field	Width	Type	Description
Abs. Stage	6	numeric	1-6 = absolute stage change from initial temporary staff gage reading
Aerial	1	alphanumeric	1 = radiotracking was done by aircraft Y = yes N = no
AirT	3	numeric	1-3 = air temperature in °C
Ambient Light	2	alphanumeric	2 = light conditions at time of sample SU = sunny CL = cloudy (> 50% cloud cover) PC = partly cloudy (< or= 50% cloud cover) SH = shadow NI = night ML = moonlight DD = dawn/dusk
Benchmark	6	alphanumeric	1-6 = unique code describing location of temporary stage benchmarks
Boat	1	alphanumeric	1 = radiotracking was done from boat Y = yes N = no
CB#	1	numeric	1 = clipboard #
Cond.	4	numeric	1-4 = conductance in umhos/cm
Confidence	1	numeric	1 = confidence rating on fish location 1 = high, excellent reception 2 = low, poor reception 3 = very low, don't use
Cover (Compound Field - fill out each)			
Over	2	alphanumeric	1-2 = overhead cover OB = overhanging bank SV = streamside vegetation NC = no cover

Field	Width	Type	Description
Lat	2	alphanumeric	1-2 = lateral cover VW = vertical rock well BO = boulders NC = no lateral cover
In	2	alphanumeric	1-2 = instream cover BO = boulder LG = log jam SS = sand shoal RJ = rock jetty NC = no instream cover
Crew	6	alphanumeric	1-2 = principal crew member 3-4 = recorder 5-6 = assistant i.e. RV = Rich Valdez BM = Bill Masslich LC = Larry Crist BL = Bill Leibfried
Date	6	numeric	1-2 = Year, 1992 = 92 3-4 = Month, June = 06 5-6 = Day of Month
Depth	4.1	decinumeric	1-4 = depth at gear location
Distance Moved	6	numeric	1-6 = distance moved by fish in meters since last observation
DO	2	numeric	1-2 = dissolved oxygen in mg/l
End Time	4	numeric	1-4 = end of sample time
Fluctuations or Fluct.	2	alphanumeric	1-2 = Stage change between start time and end time RI = rising FA = falling ST = steady
Frequency	3	numeric	1-3 = frequency of radiotag in field
Freq 1	3	numeric	1-3 = frequency of radiotag from manufacturer
Freq 2	3	numeric	1-3 = frequency of radiotag in field

Field	Width	Type	Description
Gage	6	numeric	1-6 = reading on temporary staff gage
Habitat Photo	(Compound Field)		
Camera	2	alphanumeric	1-2 = camera identifier 01 = B/W camera #1 02 = B/W camera #2 LC = Larry Crist's camera BL = Bill Leibfried's camera BM = Bill Masslich's camera
Roll	2	numeric	1-2 = photo roll number
Frame	4	numeric	1-4 = photo frame numbers
Hab1	2	alphanumeric	1-2 = general habitat MC = main channel TS = tributary stream SC = side channel
Hab2	2	alphanumeric	1-2 = specific habitat BA = backwater ED = eddy EM = embayment RI = riffle RU = run SH = shoreline PO = pool RC = return channel
Hab	2	alphanumeric	2 = specific habitat (Hab2) of fish being observed, same codes as Hab2
HabT	4.1	decinumeric	1-4 = temperature of habitat sampled
Habitat Map No.	6	alphanumeric map	1-6 = unique number corresponding to a habitat
McT	4.1	decinumeric	1-4 = main channel temperature
Mode (Compound field, check one)			
	2	alphanumeric	1-2 = sampling mode IM = implant LO = locate 2H = 2-hour 24 = 24-hour

Field	Width	Type	Description
			TF = test flow
pH	3.1	decinumeric	1-3 = pH
PIT Tag	10	alphanumeric	1-10 = unique number transmitted by PIT tag
Pulse	2	numeric	1-2 = pulse rate in field
Pulse 1	2	numeric	1-2 = pulse rate from manufacturer (#/min)
Pulse 2	2	numeric	1-2 = pulse rate in field
Radiotag Size	2	numeric	1-2 = weight specifications 09 = 9 grams 11 = 11 grams 16 = 16 grams
Reach	1	numeric	1 = Reach (0=above LCR, 1=LCR, 2=Granite Gorge, 3=Lower)
Rel. Stage	6	numeric	1-6 = relative stage change since last observation
River	2	alphanumeric	1-2 = location of radiotagged fish CO = Colorado River LC = Little Colorado HC = Havasu Creek
RM	5.1	decinumeric	1-5 = miles downstream from Lees Ferry
RM ___ to ___	4.1	numeric	1-4 = surveillance area, start RM to end RM
Sample No or Sample #	7	alphanumeric	1-3 = sequential sample no.
Secchi Disc	2	numeric	1-2 = depth to which sechi disc markings can be seen
Side	1	alphanumeric	1 = side of river channel where net or trap is anchored R = river right (looking downstream) L = river left (looking downstream)
Species	2	alphanumeric	1-2 = humpback chub
Start Time	4	numeric	1-4 = start of sample time

Field	Width	Type	Description
			6am = 0600 6pm = 1800
Sub1	2	alphanumeric	1-2 = dominant substrate SI = silt SA = sand GR = gravel CO = cobble BO = boulder BE = bedrock OR = organics
Sub2	2	alphanumeric	1-2 = secondary substrate
Surgeon	2	alphanumeric	2 = initials of team member that implanted radiotag
Time	4	numeric	4 = time of signal observation or attempt
TL	3	numeric	1-3 = total length of fish in mm
Trip	2	numeric	1-2 = Trip No. for year (0-12)
Turbidity or Turb	2	alphanumeric	1-2 = turbidity C = clear L = low> or = 0.5m secchi H = high turbidity < or = 0.5m secchi
V 0.2	3.1	decinumeric	1-3 = velocity at 0.2 depth at fish
V 0.6	3.1	decinumeric	1-3 = velocity at 0.6 depth at fish
V 0.8	3.1	decinumeric	1-3 = velocity at 0.8 depth at fish
V Bottom	3.1	decinumeric	1-3 = velocity at bottom at fish
Weather	2	alphanumeric	1-2 = weather condition SU = sunny CS = clear skies CL = cloudy (> 50% cloud cover) PC = partly cloudy (< or = 50% cloud cover) OV = overcast RA = raining SN = snow

Field	Width	Type	Description
WT	4	numeric	1-4 = weight of fish in grams

TABLE C3 - DESCRIPTION OF FIELDS FOR DATA FORM 6
(Colorado River Mainstem)

See Chub Diagram for measurement locations

Chub Meristics

Field	Width	Type	Description
A -	2	numeric	number of anal fin rays
AFB -	2.1	decinumeric	anal fin base
BD -	3.1	decinumeric	maximum body depth
CAM -	2	alphanumeric	camera number
CPND -	2.1	decinumeric	caudal peduncle depth (minimum)
CPL -	3.1	decinumeric	caudal peduncle length
CPMD -	2.1	decinumeric	caudal peduncle depth (maximum)
D -	2	numeric	number of dorsal fin rays
Date -	6	numeric	1-2 = Year, 1992 = 92
			3-4 = Month, June = 06
			5-6 = Day of Month
DFB -	2.1	decinumeric	dorsal fin base
DISP -	2	alphanumeric	disposition
FL -	3	numeric	fork length
FRAME -	4	numeric	range of film frames
HL -	2.1	decinumeric	head length
ND -	2.1	decinumeric	nuchal depression
P_1-P_2 -	2.1	decinumeric	distance between the insertion of the pectoral and pelvic fins
PIT Tag No. -	10	alphanumeric	1-10 = unique number transmitted by PIT tag

Field	Width	Type	Description
RADIOTAGGED -	1	alphanumeric	(Y or N)
RECAP -	1	alphanumeric	recapture (Y, N, or S for tag scar)
Ripe -	1	alphanumeric	running milt or expressing eggs, tuberculated or colored
RM RELEASE -	3.1	decinumeric	release point
ROLL -	2	numeric	film roll number
Sample # -	8	numeric	composite entry made up of Sample Type, Sample No, Trip, Reach, and CB#.
Sex -	1	alphanumeric	male, female, immature, or undetermined
SL -	3	numeric	standard length
SNL -	3.1	decinumeric	snout length
TAG -	6	alphanumeric	number and type of old external tag
TL -	3	numeric	total length
WT -	4	numeric	weight in grams

(Refer to other definition sheets for response options for similar fields)

DESCRIPTION OF FIELDS FOR DATA FORM 7
(Colorado River Mainstem)

Water Quality Sampling

Field	Width	Type	Description
AirT	3	numeric	1-3 = air temperature in °C
Cond.	4	numeric	1-4 = conductance in umhos/cm
Date	6	numeric	1-2 = Year, 1992 = 92 3-4 = Month, June = 06 5-6 = Day of Month
D.O	3.1	decinumeric	1-3 = dissolved oxygen in mg/L
Fluctuations or Fluct.	2	alphanumeric	1-2 = Stage change between start time and end time RI = rising FA = falling ST = steady
HabT	4.1	decinumeric	1-4 = temperature of habitat sampled
McT	4.1	decinumeric	1-4 = main channel temperature
pH	3.1	decinumeric	1-3 = pH
Redox	4	numeric	1-4 = redox potential of water
RM	5.1	decinumeric	1-5 = miles downstream from Lees Ferry
Sechi Disc	2	numeric	1-2 = depth to which sechi disc markings can be seen
Time	4	numeric	4 = time of observation
Weather	2	alphanumeric	1-2 = weather condition SU = sunny CS = clear skies CL = cloudy (> 50% cloud cover) PC = partly cloudy (< or = 50% cloud cover) OV = overcast RA = raining SN = snow

APPENDIX C - DATA FILE STRUCTURES

Note:

Type	
C	= Character
N	= Numeric
L	= Logical

File: CHUB.DBF
Contents: Humpback chub morphometrics and meristics, Oct 1990-Nov1993

Field	Type	Size	Dec	Description
PIT_TAG	C	10	0	PIT tag number
DATE	C	6	0	Date (year,month,day)
RIVER	C	2	0	River or tributary code
METER	N	4	0	Meters above tributary mouth (±20m)
TYPE	C	1	0	Type of sample
GEAR	C	2	0	Gear code
SAMPLE_NUM	C	3	0	Sample number
TRIP	C	5	0	Trip code
REACH	C	1	0	Mainstem Colorado River reach code
CLIPBOARD	C	1	0	Clipboard number
TL	N	3	0	Total length (mm)
FL	N	3	0	Fork length (mm)
SL	N	3	0	Standard length (mm)
WT	N	4	0	Weight (g), ±1g
SEX	C	1	0	Sex code
RIPE	C	3	0	Gonadal maturity code
P1_P2	N	4	1	Distance between insertions of pectoral and pelvic fins (mm)
ND	N	4	1	Nuchal depression depth (mm)
CPL	N	5	1	Caudal peduncle length (mm)
CPMAXD	N	4	1	Maximum caudal peduncle depth (mm)
CPMIND	N	4	1	Minimum caudal peduncle depth (mm)
HEAD_LN	N	4	1	Head length (mm)
SNOUT_LN	N	4	1	Snout length (mm)
DORSAL_FB	N	4	1	Dorsal fin base (mm)
ANAL_FB	N	4	1	Anal fin base (mm)
BODY_DEPTH	N	5	1	Body depth (mm)
DORSAL_RAY	N	2	0	Number of dorsal fin rays
ANAL_RAY	N	2	0	Number of anal fin rays
RECAPTURE	C	1	0	Recaptured fish
OLD_TAG	C	10	0	Old tag number if fish is recapture
DISP	C	2	0	Disposition code
CAMERA_NUM	C	2	0	Camera number
ROLL_NUM	C	2	0	Roll number
FRAME_NUM	C	5	0	Frame numbers
VIDEO_NUM	C	2	0	Video number
RM_CAPTURE	N	6	2	River mile of capture location (to 1/20 rm)
RM_RELEASE	N	6	2	River mile of release location (to 1/20 rm)
RADIO	C	1	0	Radio-tagged fish
COMMENTS	C	60	0	Comments

File: NET_MC.DBF
Contents: Netting and trapping sample data, Oct 1990-Nov 1993 (humpback chub)

Field	Type	Size	Dec	Description
TYPE	C	1	0	Type of sample
TRIP	C	5	0	Trip code
REACH	C	1	0	Mainstem Colorado River reach code
CLIPBOARD	C	1	0	Clipboard number
DATE	C	6	0	Date (year,month,day)
RIVER	C	2	0	River or tributary code
RM	N	6	2	River mile (to 1/20 rm)
METER	N	4	0	Meters above tributary mouth (±20m)
GEAR	C	2	0	Gear code
HAB1	C	2	0	General habitat
HAB2	C	2	0	Specific habitat
HAB3	C	2	0	Shoreline habitat
SIDE	C	1	0	Side of river looking downstream
PROFILE	C	1	0	Cross-section fathometer profile status
MAX_DEPTH	N	4	1	Maximum depth at gear location (m)
SUB1	C	2	0	Dominant substrate
SUB2	C	2	0	Secondary substrate
FISH_PRES	C	1	0	Fish or other materials preserved
NO_BOTTLES	N	1	0	Number of bottles with preserved materials
CAMERA_NUM	C	2	0	Camera number
PHOTO_ROLL	C	2	0	Roll number
FRAME_NUM	C	5	0	Frame numbers
CREW	C	8	0	Initials of crew members
SINGLE	C	1	0	Marks one of multiple records for a sample
SAMPLE_NUM	C	3	0	Sample number
TIME_SET	N	4	0	Net set time
TIME_PULL	N	4	0	Net pull time
END_DATE	C	6	0	Net pull date (year,month,day)
TIME_ELAPS	N	5	2	Elapsed time
LIGHT	C	2	0	Ambient light
WEATHER	C	2	0	Weather
TURBIDITY	C	2	0	Turbidity
TEMP_AIR	N	4	1	Air temperature (°C)
TEMP_MC	N	4	1	Main channel temperature (°C)
TEMP_HAB	N	4	1	Habitat temperature (°C)
FLUCT	C	2	0	River stage change
SPECIES	C	2	0	Fish species code
YOY	N	4	0	Number of young-of-year fish
JUV	N	4	0	Number of juvenile fish
ADU	N	4	0	Number of adult fish
TOTAL	N	4	0	Total number of fish
COMMENTS	C	0	0	Comments
MAP_ID_NUM	C	4	0	Unique net location ID to link with GIS

File: ELEC_MC.DBF
Contents: Electrofishing sample data, Oct 1990-Nov 1993 (humpback chub)

Field	Type	Size	Dec	Description
TYPE	C	1	0	Type of sample
SAMPLE_NUM	C	3	0	Sample number
TRIP	C	5	0	Trip code
REACH	C	1	0	Mainstem Colorado River reach code
CLIPBOARD	C	1	0	Clipboard
DATE	C	6	0	Date (year,month,day)
RIVER	C	2	0	River or tributary code
START_RM	N	6	2	River mile at start of sample (to 1/20 rm)
END_RM	N	6	2	River mile at end of sample (to 1/20 rm)
METER	N	4	0	Meters above tributary mouth (±20m)
TIME_START	N	4	0	Sample start time
TIME_END	N	4	0	Sample end time
SECONDS	N	5	0	Seconds electrofished
VOLTS	N	3	0	Voltage setting
AMPS	N	4	1	Amperage level
LIGHT	C	2	0	Ambient light
HAB1	C	2	0	General habitat
HAB2	C	2	0	Specific habitat
HAB3	C	2	0	Shoreline habitat
SUB1	C	2	0	Dominant substrate
SUB2	C	2	0	Secondary substrate
TEMP_AIR	N	4	1	Air temperature (°C)
TEMP_MC	N	4	1	Main channel temperature (°C)
TEMP_HAB	N	4	1	Habitat temperature (°C)
TURBIDITY	C	2	0	Turbidity
WEATHER	C	2	0	Weather
FLUCT	C	2	0	River stage change
FISH_PRES	C	1	0	Fish or other materials preserved
NO_BOTTLES	N	1	0	Number of bottles of preserved materials
CAMERA_NUM	C	2	0	Camera number
PHOTO_ROLL	C	2	0	Roll number
FRAME_NUM	C	5	0	Frame number
CREW	C	8	0	Initials of crew members
SINGLE	C	1	0	Marks one of multiple records for a sample
SPECIES	C	2	0	Fish species code
YOY	N	4	0	Number of young-of-year fish
JUV	N	4	0	Number of juvenile fish
ADU	N	4	0	Number of adult fish
TOTAL	N	4	0	Total number of fish
COMMENTS	C	60	0	Comments

File: SEIN_MC.DBF
Contents: Seining sample data, Oct 1990-Nov 1993 (humpback chub)

Field	Type	Size	Dec	Description
TYPE	C	1	0	Type of sample
SAMPLE_NUM	C	3	0	Sample number
TRIP	C	5	0	Trip code
REACH	C	1	0	Mainstem Colorado River reach code
CLIPBOARD	C	1	0	Clipboard number
DATE	C	6	0	Date (year,month,day)
RIVER	C	2	0	River or tributary code
RM	N	7	2	River mile (to 1/20 rm)
METER	N	4	0	Meters above tributary mouth (±20m)
GEAR	C	2	0	Gear code
TIME_START	N	4	0	Sample start time
HAB1	C	2	0	General habitat
HAB2	C	2	0	Specific habitat
HAB3	C	2	0	Shoreline habitat
SUB1	C	2	0	Dominant substrate
SUB2	C	2	0	Secondary substrate
TEMP_AIR	N	4	1	Air temperature (°C)
TEMP_MC	N	4	1	Main channel temperature (°C)
TEMP_HAB	N	4	1	Habitat temperature (°C)
QUANT	C	1	0	Quantitative seine haul
SUBSAMPL	C	1	0	Subsampled habitat
LIGHT	C	2	0	Ambient light
WEATHER	C	2	0	Weather
TURBIDITY	C	2	0	Turbidity
FLUCT	C	2	0	River stage change
HABL	N	5	1	Habitat length (m)
HABW	N	5	1	Habitat width (m)
SAMP_LN	N	5	1	Sample length (m)
SAMP_WID	N	5	1	Sample width (m)
SAMP_AREA	N	7	2	Sample area (m^2)
MAX_DEPTH	N	4	1	Maximum depth of habitat (ft)
DEPTH_1	N	4	1	Depth halfway between max and one side (ft)
DEPTH_2	N	4	1	Depth halfway between max and other side (ft)
FISH_PRES	C	1	0	Fish or other materials preserved
NO_BOTTLES	N	1	0	Number of bottles of preserved materials
CAMERA_NUM	C	2	0	Camera number
PHOTO_ROLL	C	2	0	Roll number
FRAME_NUM	C	5	0	Frame number
CREW	C	8	0	Initials of crew members
SINGLE	C	1	0	Marks one of multiple records for a sample
SPECIES	C	2	0	Fish species code
LAR	N	4	0	Number of larval fish
YOY	N	4	0	Number of young-of-year fish
JUV	N	4	0	Number of juvenile fish
ADU	N	4	0	Number of adult fish
TOTAL	N	4	0	Total number of fish
COMMENTS	C	60	0	Comments

File: FISH_MC.DBF
Contents: All fish capture data. Oct 1990-Nov 1993 (humpback chub)

Field	Type	Size	Dec	Description
TYPE	C	1	0	Type of sample
SAMPLE_NUM	C	3	0	Sample number
TRIP	C	5	0	Trip code
REACH	C	1	0	Mainstem Colorado River reach code
CLIPBOARD	C	1	0	Clipboard
DATE	C	6	0	Date (year,month,day)
GEAR	C	2	0	Gear code
HAB1	C	2	0	General habitat
HAB2	C	2	0	Specific habitat
HAB3	C	2	0	Shoreline habitat
SUB1	C	2	0	Dominant substrate
SUB2	C	2	0	Secondary substrate
SPECIES	C	2	0	Fish species code
TL	N	3	0	Total length (mm)
SL	N	3	0	Standard length (mm)
LB	N	2	0	Pounds
OZ	N	2	0	Ounces
WT	N	4	0	Weight (g), ±1g
PIT_TAG	C	10	0	PIT tag number
RECAPTURE	C	1	0	Recaptured fish
OLD_TAG	C	10	0	Old tag number if fish is recapture
PHOTO	C	1	0	Photographs taken
VIDEO	C	1	0	Video footage taken
SEX	C	1	0	Sex
RIPE	C	2	0	Gonadal maturity code
DISP	C	2	0	Disposition code
RIVER	C	2	0	River or tributary code
RM	N	6	2	River mile of capture location (to 1/20 rm)
METER	N	4	0	Meters above mouth of tributary (±20m)
RM_RELEASE	N	6	2	River mile of release location (to 1/20 rm)
COMMENTS	C	60	0	Comments

File: SURVEIL.DBF
Contents: Radiotelemetry surveillance, Oct 1990-Nov 1992

Field	Type	Size	Dec	Description
SAMPLE_NUM	C	3	0	Sample number
TRIP_NUM	C	2	0	Trip code
REACH	C	1	0	Mainstem Colorado River reach code
CLIPBOARD	C	1	0	Clipboard number
SINGLE	C	1	0	Marks one of multiple records for a sample
MODE	C	2	0	Type of surveillance
START_DATE	N	6	0	Date at start of surveillance (year,month,day)
START_TIME	N	4	0	Time at start of surveillance
END_DATE	N	6	0	Date at end of surveillance (year,month,day)
END_TIME	N	4	0	Time at end of surveillance
TIME_ELAPS	N	6	2	Time elapsed during surveillance
START_RMI	N	5	1	Starting river mile of surveillance (to 1/20 rm)
END_RMI	N	5	1	Ending river mile of surveillance (to 1/20 rm)
LIGHT	C	2	0	Ambient light
WEATHER	C	2	0	Weather code
TURBIDITY	C	1	0	Turbidity code
SECHI_DISK	N	4	2	Secchi depth (m)
NTU	N	6	1	Turbidity (NTU)
FLUCT	C	2	0	River stage change during surveillance
CREW	C	8	0	Initials of crew members
DATE	N	6	0	Date of individual fish contact (year,month,day)
TIME	N	4	0	Time of individual fish contact
RIVER	C	2	0	River or tributary code
RM	N	6	2	River mile (to 1/20 rm)
SIDE	C	1	0	Side of river looking downstream
FREQ	N	3	0	Tag frequency (40.XXX MHz)
PULSE	N	3	0	Tag pulse rate (pulses/minute)
CONFIDENCE	C	1	0	Observer confidence in location accuracy
HAB2	C	2	0	Specific habitat
COVER	C	2	0	Instream cover
PIT_TAG	C	10	0	PIT tag number
COMMENTS	C	75	0	Comments

File: OBSERV_H.DBF
Contents: Header for radiotelemetry observations, Oct 1990-Nov 1992

Field	Type	Size	Dec	Description
SAMPLE_NUM	C	3	0	Sample number
TRIP_NUM	C	2	0	Trip code
REACH	C	1	0	Mainstem Colorado River reach code
CLIPBOARD	C	1	0	Clipboard number
SINGLE	C	1	0	Marks one of multiple records for a sample
START_DATE	N	6	0	Date at start of observation (year,month,day)
START_TIME	N	4	0	Time at start of observation
END_DATE	N	6	0	Date at end of observation (year,month,day)
END_TIME	N	4	0	Time at end of observation
TIME_ELAPS	N	6	0	Time elapsed during observation
RIVER	C	2	0	River or tributary code
RM	N	6	2	River mile (to 1/20 rm)
MODE	C	2	0	Mode of observation
HAB_MAP_NO	C	10	0	Habitat map number
BENCHMARK	C	6	0	Temporary benchmark code
CONFIDENCE	N	1	0	Observer confidence in location accuracy
CAMERA_NUM	C	2	0	Camera number
PHOTO_ROLL	C	2	0	Roll number
FRAME_NUM	C	5	0	Frame numbers
CREW	C	8	0	Initials of crew members
PIT_TAG	C	10	0	PIT tag number
TL	N	3	0	Total length when implanted (mm)
WT	N	4	0	Weight when implanted (g), ±1g
SEX	C	1	0	Sex
TAG_SIZE	N	2	0	Weight of tag (g)
FREQ_1	N	3	0	Original tag frequency
FREQ_2	N	3	0	Strongest tag frequency observed
PULSE_1	N	2	0	Original tag pulse rate
PULSE_2	N	2	0	Tag pulse rate during observation
SURGEON	C	2	0	Initials of surgeon

File: OBSERV_M.DBF
Contents: Movement for radiotelemetry observations, Oct 1990-Nov 1992

Field	Type	Size	Dec	Description
SAMPLE_NUM	C	3	0	Sample number
TRIP	C	5	0	Trip code
REACH	C	1	0	Mainstem Colorado River reach code
CLIPBOARD	C	1	0	Clipboard number
SINGLE	C	1	0	Marks one of multiple records for a sample
PIT_TAG	C	10	0	PIT tag number
START_DATE	N	6	0	Date at start of observation block (year,month,day)
START_TIME	N	4	0	Time at start of observation block
START_RMI	N	6	2	River mile location at start of observation block (to 1/20 rm)
START_HAB	C	2	0	Specific habitat at start of observation block
START_GAGE	N	5	1	River stage at start of observation block
START_LITE	C	2	0	Ambient light at start of observation block
START_WEAT	C	2	0	Weather code at start of observation block
START_TURB	C	2	0	Turbidity code at start of observation block
END_DATE	N	6	0	Date at end of observation block (year,month,day)
END_TIME	N	4	0	Time at end of observation block
END_RMI	N	6	2	River mile location at end of observation block (to 1/20 rm)
END_HAB	C	2	0	Specific habitat at end of observation block
MOVEMENT	N	3	0	Movement during observation block (m)
END_GAGE	N	5	1	River stage at end of observation block
END_LITE	C	2	0	Ambient light at end of observation block
END_WEAT	C	2	0	Weather code at end of observation block
END_TURB	C	2	0	Turbidity code at end of observation block
TIME_ELAPS	N	6	2	Time elapsed during observation block
GAGE	N	6	1	River stage change during observation block (cm)
STAGE_RATE	N	7	2	Rate of river stage change (cm/hr)

File: REMOTE.DBF
Contents: Remote radiotelemetry station data, Oct 1990-Nov 1993

Field	Type	Size	Dec	Description
JUL_DATE	N	3	0	Julian date
TIME	N	4	0	Time
FREQ	N	3	0	Tag frequency (40.XXX MHz)
PULSE	N	3	0	Tag pulse rate (pulses/minute)

File: DRIFT_MC.DBF
Contents: Drift net sample analysis data, Oct 1990-Nov 1993 (humpback chub)

Field	Type	Size	Dec	Description
DATE	N	6	0	Date of sample (year,month,day)
TIME	N	4	0	Time of sample
RM	C	5	0	River mile (to 1/20 rm)
STAGE	C	2	0	River stage change
HAB	C	2	0	Habitat
DEPTH	C	3	0	Height of net above water surface (cm)
SIMADU	N	7	2	Number of adult simuliids
SIMPUP	N	7	2	Number of pupa simuliids
SIMLAR	N	7	2	Number of larval simuliids
CHIRADU	N	7	2	Number of adult chironomids
CHIRPUP	N	7	2	Number of pupa chironomids
CHIRLAR	N	7	2	Number of larval chironomids
GAMMADU	N	7	2	Number of adult gammarus (>7mm)
GAMMIMM	N	7	2	Number of immature gammarus (<7mm)
OTHER	N	7	2	Number of other aquatic invertebrates
TERR	N	7	2	Number of terrestrial insects
CLADDRWT	N	7	4	Cladophora dry weight (g)
CLADPER	N	2	0	Percent cladophora
LABVOL	N	3	0	Sample volume after preservation (ml)
FIELDVOL	N	3	0	Sample volume before preservation (ml)
REHYDVOL	N	3	0	Sample volume after rehydration in lab (ml)
CMH	N	7	2	Water filtered through net (Cubic meters per hour)
NOTES	C	100	0	Specific notes about sample

File: FOOD.DBF
Contents: Stomach pumping analysis data, 1993

Field	Type	Size	Dec	Description
TYPE	C	1	0	Type of sample
SAMPLE_NUM	C	3	0	Sample number
TRIP	C	5	0	Trip code
REACH	C	1	0	Mainstem Colorado River reach code
CLIPBOARD	C	1	0	Clipboard
DATE	N	6	0	Date of sample (year,month,day)
RIVER	C	2	0	River or tributary code
RM	N	5	1	River mile (to 1/20 rm)
SPECIES	C	3	0	Species of fish stomach pumped
AGE	C	2	0	Age of fish (adult or juvenile)
SEX	C	1	0	Sex
TL	N	3	0	Total length (mm)
SL	N	3	0	Standard length (mm)
LB	N	3	0	Weight in pounds
OZ	N	3	0	Weight in ounces
WT	N	4	0	Weight in grams
PIT_TAG	C	10	0	PIT tag number
GAMMADU	N	3	0	Number of adult gammarus (>7mm)
GAMMIMM	N	3	0	Number of immature gammarus (<7mm)
SIMADU	N	3	0	Number of adult simuliids
SIMLARV	N	3	0	Number of larval simuliids
SIMPUP	N	3	0	Number of pupa simuliids
CHIRADU	N	3	0	Number of adult chironomids
CHIRPUP	N	3	0	Number of pupa chironomids
CHIRLAR	N	3	0	Number of larval chironomids
ANNELID	N	3	0	Number of annelids
OTHER	N	3	0	Number of other aquatic insects
TERR	N	3	0	Number of terrestrial insects
CLADOVOL	N	3	0	Volume of cladophora (ml)
NEMOTODES	L	1	0	Presence of nematodes
TAPEWORMS	L	1	0	Presence of tapeworms
FISH	L	1	0	Presence of fish
MEMO	C	200	0	Details of sample

File: DSOND_MC.DBF
Contents: Datasonde water quality data, Oct 1990-Nov 1993 (humpback chub)

Field	Type	Size	Dec	Description
DATE	N	6	0	Date (year,month,day)
TIME	N	4	0	Military time
RIVER	C	2	0	River or tributary code
RM	N	6	2	River mile (to 1/20 rm)
TEMP	N	5	2	Temperature (°C)
PH	N	5	2	pH
COND	N	6	3	Conductivity
DO	N	5	2	Dissolved oxygen
BATT	N	5	2	Battery voltage

File: SURV_MC.DBF
Contents: Surveyor II water quality data, Oct 1990-Nov 1993 (humpback chub)

Field	Type	Size	Dec	Description
DATE	N	6	0	Date (year,month,day)
TIME	N	4	0	Military time
RIVER	C	2	0	River or tributary code
RM	N	6	2	River mile (to 1/20 rm)
TEMP	N	5	2	Temperature (°C)
PH	N	5	2	pH
TRUEDO	N	5	2	Dissolved oxygen
COND	N	6	3	Conductivity
ORP	N	6	3	Oxidation-reduction potential
BATT	N	5	2	Battery voltage

File: JUVHAB.DBF
Contents: Juvenile habitat measurements, Oct 1990-Nov 1993

Field	Type	Size	Dec	Description
SAMPLE_NUM	C	3	0	Sample number
TRIP	C	5	0	Trip code
REACH	C	1	0	Mainstem Colorado River reach code
DATE	N	6	0	Date (year,month,day)
RIVER	C	2	0	River or tributary code
RM	N	5	2	River mile (to 1/20 rm)
SIDE	C	1	0	Side of river looking downstream
TBM	C	8	0	Temporary benchmark location code
GAGE_BEG	N	4	0	River stage at beginning of sample
GAGE_END	N	4	0	River stage at end of sample
TIME_BEG	N	4	0	Time at start of sample
TIME_END	N	4	0	Time at end of sample
LC_MC_FLOW	N	5	0	Approximate discharge in cfs
SHORETYPE	C	15	0	Shoreline type
CREW	C	8	0	Initials of crew members
FISHPRESNT	C	1	0	Fish present
COMMENTS	C	20	0	Comments
TRAN_NUM	N	2	0	Transect number
DIST_05_DP	N	5	2	Depth 0.5 meters from shore (ft)
DIST_05_VL	N	5	2	Velocity at 0.6 depth, 0.5 meters from shore (ft/s)
DIST_05_S1	C	2	0	Dominant substrate 0.5 meters from shore
DIST_05_S2	C	2	0	Secondary substrate 0.5 meters from shore
DIST_10_DP	N	5	2	Depth 1.0 meter from shore (ft)
DIST_10_VL	N	5	2	Velocity at 0.6 depth, 1.0 meter from shore (ft/s)
DIST_10_S1	C	2	0	Dominant substrate 1.0 meter from shore
DIST_10_S2	C	2	0	Secondary substrate 1.0 meter from shore
DIST_15_DP	N	5	2	Depth 1.5 meters from shore (ft)
DIST_15_VL	N	5	2	Velocity at 0.6 depth, 1.5 meters from shore (ft/s)
DIST_15_S1	C	2	0	Dominant substrate 1.5 meters from shore
DIST_15_S2	C	2	0	Secondary substrate 1.5 meters from shore
DIST_25_DP	N	5	2	Depth 2.5 meters from shore (ft)
DIST_25_VL	N	5	2	Velocity at 0.6 depth, 2.5 meters from shore (ft/s)
DIST_25_S1	C	2	0	Dominant substrate 2.5 meters from shore
DIST_25_S2	C	2	0	Secondary substrate 2.5 meters from shore

File: SCALES.DBF
Contents: Humpback chub scale analysis, Oct 1990-Nov 1993

Field	Type	Size	Dec	Description
BOX	C	2	0	Box number of slide location
FISH_NO	C	2	0	Sequential fish number
SINGLE	C	1	0	Marks one of multiple scales per fish
SAMPLE_NO	C	8	0	Unique sample identifier
DATE	N	6	0	Date (year,month,day)
SPECIES	C	2	0	Fish species code
RIVER_MILE	N	6	2	Mainstem river mile (to 1/20 rm)
METERS	N	5	0	Meters from tributary mouth (for AGF scales)
TL	N	3	0	Total length (mm)
SL	N	3	0	Standard length (mm)
SCALE_RAD	N	4	1	Length from nucleus to scale margin (μm)
NO_CIRC	N	2	0	Total number of circuli
A1	N	4	1	First annulus from nucleus (μm)
NO_CIRC_A1	N	2	0	Number of circuli to first annulus
A2	N	4	1	Second annulus from nucleus (μm)
NO_CIRC_A2	N	2	0	Number of circuli to second annulus
A3	N	4	1	Third annulus from nucleus (μm)
NO_CIRC_A3	N	2	0	Number of circuli to third annulus
A4	N	4	1	Fourth annulus from nucleus (μm)
NO_CIRC_A4	N	2	0	Number of circuli to fourth annulus
A5	N	4	1	Fifth annulus from nucleus (μm)
NO_CIRC_A5	N	2	0	Number of circuli to fifth annulus
A6	N	4	1	Sixth annulus from nucleus (μm)
NO_CIRC_A6	N	2	0	Number of circuli to sixth annulus
X	N	4	1	Length from nucleus to transitional check (μm)
NO_CIRC_X	N	2	0	Number of circuli to transitional check
AGE	N	1	0	Age of fish when scale collected
YEAR_CLASS	N	4	0	Year fish was hatched
RELIABLE	C	1	0	Reliability of scale information
PCX	N	5	2	Proportional total length at trans. check
BCX	N	5	2	Back-calculated total length at trans. check (mm)
BC1	N	5	2	Back-calculated total length at first annulus (mm)
PC1	N	5	2	Proportional total length at first annulus
BC2	N	5	2	Back-calculated total length at second annulus (mm)
BC3	N	5	2	Back-calculated total length at third annulus (mm)
BC4	N	5	2	Back-calculated total length at fourth annulus (mm)
BC5	N	5	2	Back-calculated total length at fifth annulus (mm)
BC6	N	5	2	Back-calculated total length at sixth annulus (mm)