APPENDIX 4

EVALUATION OF THE INSTREAM FLOW REQUIREMENTS OF THE NATIVE FISHES OF ARAVAIPA CREEK, ARIZONA BY THE INCREMENTAL METHODOLOGY

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ABSTRACT

A study of the instream flow requirements of the native fishes of Aravaipa Creek in southeast-central Arizona was done in 1980-1981 using the Incremental Methodology. An IFG4 hydraulic simulation of the changes in physical habitat was completed for a typical stream reach located about 3/4 mile upstream from the eastern boundary of Aravaipa Canyon Primitive Area. For this simulation, field measurements of stream parameters (e.g. water depth and velocity, bottom substrate) were made at discharges of 11.1, 16.5 and 24.4 ft.^{3}/sec. and used to simulate stream conditions for discharges from 5 to 40 ft.^{3}/sec.

Probability-of-use curves were developed for two endemic, riffle-dwelling cyprinids, Meda fulgida and Tiaroga cobitis, from frequency-of-capture data on water depths and velocities which were collected by electrofishing in Aravaipa Creek and the Gila River, New Mexico during the summer and fall. This analysis revealed that adult Meda were most commonly collected at water velocities of 1.3 to 2.7 ft./sec. and were rarely found in areas with velocities less than 0.6 ft./sec. or greater than 3.0 ft./sec. Meda apparently preferred water depths of 0.60 to 0.75 feet and were not collected at depths less than 0.2 feet or greater than 1.2 feet. Although adult Tiaroga were collected at velocities from 0 to 3.6 ft./sec., they preferred a velocity of about 2.0 ft./sec. Adult Tiaroga were collected at depths of 0.1 to 1.0 feet, but were found most commonly at 0.4 to 0.6 feet. Adult Meda apparently preferred bottom substrates of sand and gravel, whereas adult Tiaroga preferred areas with gravel and cobble substrate.

Based on changes in Weighted Usable Area (WUA) at the study site, a discharge of 20 ft.^{3}/sec. provided the most available habitat for adult Meda and Tiaroga. WUA decreased rapidly at discharges less than 10 ft.^{3}/sec. for both species. A minimum discharge of 13 ft.^{3}/sec. at the BLM's East Aravaipa gaging station would be an acceptable minimum flow for adult Meda and Tiaroga during low-flow periods in the summer and fall. Stream flow dropped below this recommended minimum discharge during much of the summer of the 1982 water year. Thus, any additional water removals from the drainage upstream from the Aravaipa Canyon Primitive Area would reduce preferred habitats for adult Meda and Tiaroga in Aravaipa Creek during low-water years.

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T. Hardin completed the computer analysis in a professional and timely fashion. D. Hoppe (USFWS) and Dr. D. Weigmann reviewed the draft manuscript and provided helpful editorial suggestions. Members of the Cooperative Instream Flow Service Group (CIFSG) in Fort Collins, Colorado, especially Ken Bovee, gave expert advice and provided the computer analysis of our habitat data for Meda and Tiaroga. K. Spence typed the manuscript and the final report with her typical patience and professional competence.

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INTRODUCTION

Background

Funds for this study were made available to the senior author in 1980 after a Phase II Instream Flow Study of Arizona streams by the Arizona Game and Fish Department (AGFD) was terminated by a joint agreement between the U.S. Fish and Wildlife Service and AGFD. At the time the Arizona Phase II study was terminated with AGFD, New Mexico State University (NMSU) had just completed a Phase II Instream Flow Study of three New Mexico rivers (Turner et al. 1980). Because the two graduate students who had performed the New Mexico Phase II Study were still available, the senior author agreed to use the remaining unspent Arizona Phase II funds ($13,125.00 of $35,000.00 initially allocated to AGFD) for instream flow work on Arizona waters. This research was authorized as a modification to the original New Mexico instream flow study with the New Mexico Department of Game and Fish continuing as an administrative coordinator of the contract.

Selection of Study Sites

The streams originally selected for instream flow studies by AGFD included Aravaipa Creek, Black River at Buffalo Crossing in the Apache-Sitgreaves National Forest, and West Clear Creek, a tributary of the Verde River. All previous surveying work at the original AGFD study sites on the three streams had been destroyed by severe floods during the 1979 water year. Thus, our instream flow study in Arizona was essentially starting over as far as fieldwork was concerned. After an on-site evaluation of Aravaipa Creek in February 1980, we decided to retain this stream as a study site. At this time, Aravaipa Creek was

considered a high priority stream by the AGFD because it was one of very few Arizona streams which still supported an essentially unmodified representation of the native Gila River ichthyofauna (Minckley 1973). In addition, the Safford District Office of the Bureau of Land Management (Safford-BLM) was managing the Aravaipa Canyon as a Primitive Area and had just completed the Aravaipa Canyon Wilderness Final Environmental Statement.

We had been advised by AGFD personnel to eliminate West Clear Creek as a potential study site, but were not given any specific recommendations on alternative study sites. During 1980, we contacted the Tucson and Pinetop offices of the AGFD, Safford District Office of the BLM, and the Apache-Sitgreaves National Forest about potential study sites in eastern Arizona. The BLM at Safford was especially helpful and provided a helicopter and pilot for an aerial reconnaisance of several potential study sites in their district including: Bonita Creek, Eagle Creek and the Gila River. We made on-site evaluations of Eagle Creek upstream from the water pumping station and of the following streams on the Apache-Sitgreaves National Forest: Black River at Buffalo Crossing, West and East Forks of the Black River, Blue River and Campbell Blue Creek. Because of the lack of any impending changes in the instream flow regime of these streams and limited funding, we decided to concentrate our efforts on Aravaipa Creek; the poor accessibility of the Gila River "box" upstream from Safford and the highly modified nature of the ichthyofauna at this potential site were the main reasons for eliminating the Gila River from potential consideration.

During the process of our selection of instream flow study streams in 1980, the senior author was contacted by the Phoenix District Office

of the BLM and Dr. Randy McNatt, U.S. Fish and Wildlife Service (USFWS) about doing an instream flow study on the Burro Creek drainage in west-central Arizona. After preparation of a cooperative agreement between BLM and USFWS, a contract was awarded to the senior author to conduct an instream flow study of the Burro Creek drainage using the CIFSG's Incremental Methodology (Turner and Tafanelli 1983).

Aravaipa Creek

With the exception of the incision of the channel in sections not protected by bedrock and the elimination of cienegas in the floodplain above the canyon portion, Aravaipa Creek has apparently retained much of its original physical character and almost all of its native flora and fauna (Minckley 1981). Although temporary diversion dams of mounded sand and gravel are used to irrigate several hundred acres above the USGS gaging station near Mammoth, Arizona (USGS 1981), man's impact on Aravaipa Creek and its flora and fauna is minor when compared to other streams of the Sonoran desert (Minckley 1981). In particular, introduced fishes have remained rare and the native ichthyofauna is still composed of five cyprinids: spikedace (*Meda fulgida*), loach minnow (*Tiaroga cobitis*), roundtail chub (*Gila robusta grahami*), longfin dace (*Agosia chrysogaster*), speckled dace (*Rhinichthys osculus*); and two catostomids: Sonora sucker (*Catostomus insignis*) and desert sucker (*Catostomus* or *Pantosteus clarki*). Although all of these fishes of the Gila River drainage have experienced reductions in their distribution in Arizona because of reservoir construction and regular dessication in many of the originally permanent reaches (Minckley 1973), the status of *Meda fulgida* and *Tiaroga cobitis* have been most seriously impacted.

Listing packages for these two species are currently being prepared by the USFWS and both species are being considered for "threatened" status under the existing guidelines of the Endangered Species Act of 1973; Aravaipa Creek is being considered as potential "critical habitat" for both fishes (Dr. Jim Johnson, USFWS, pers. comm.). In addition, the portion of Aravaipa Creek managed by the BLM will probably be officially designated as the Aravaipa Canyon Wilderness Area during 1983 by the U.S. Congress and become the first BLM-managed area to receive wilderness status.

I will not attempt to summarize most aspects of the excellent report on the physical, chemical and biological aspects of Aravaipa Creek (Minckley 1981) which was based on studies started in 1964 and intensified in 1976-1978 by Dr. W.L. Minckley and his colleagues. Minckley's (1981) report provides a thorough review of the available literature on the history, geology and hydrology of the Aravaipa Creek drainage and summarizes the results of an intensive survey of its flora and fauna in relation to their physical and chemical environment.

Minckley (1981) reviewed the discharge patterns in Aravaipa Creek based on USGS data for gaging stations located near the mouth of the drainage. He found that streamflow at the downstream gaging station generally reached its highest levels in the winter (December-March) and summer (July-September) with lowest discharges during April-June in most years. Winter discharge minima exceeded summer minima by 2-3 times and the frequency distribution of the mean daily discharges at the gaging station near Mammoth, Arizona exhibited a strong bimodality at 5 and 10 $ft.^3$/sec. Minckley (1981) considered the 5 $ft.^3$/sec. discharge as the base flow of the aquifer in the summer (less irrigation uses); the

higher mode was attributed to either periods when no irrigation was being practiced or when local spates (small floods) were occurring in the drainage because of localized thunderstorms. Discharges at the downstream USGS gaging station were less than 20 ft.^{3}/sec. about 90% of the time. This relatively low discharge provided "adequate stability for development and maintenance of a diverse biota"; flooding of more than 100 ft.^{3}/sec. occurred less than 3% of the time and had no long-lasting detrimental impacts on the native flora and fauna (Minckley 1981).

Since Minckley's (1981) review of the discharge patterns for the downstream gage, several significant events from a hydrological standpoint have occurred. The maximum discharge since 1931 occurred on December 18, 1978, when a flood peaked at 16,200 ft.^{3}/sec. at the downstream gage (USGS 1981). Although the impact of this flood was still evident in the floodplain, the stream and its aquatic biota had apparently recovered from any adverse impacts by the spring of 1980.

Of more significance to this study was the establishment in 1980 of two new BLM gaging stations near the upstream (East Aravaipa) and downstream (West Aravaipa) boundaries of the current wilderness area. The upper gaging station (East Aravaipa) now provides a daily record of the discharge entering the canyon and should allow careful monitoring of streamflow conditions. Although the East Aravaipa gaging station only provides complete data for the 1981 and 1982 water years, the discharge records indicate a relatively stable discharge pattern for the upper part of the drainage (Appendix A). Mean daily discharge for the East Aravaipa gage during the 1981 water year was 18.7 ft.^{3}/sec. (range of 13.7 to 30.9 ft.^{3}/sec.) compared to a provisional mean of 20.4 ft.^{3}/sec. (range of 6.0 to 276 ft.^{3}/sec.) at the USGS gaging station near Mammoth,

Arizona (Appendix A). Discharge at the East Aravaipa gage was slightly lower during the 1982 water year with a mean daily discharge of 14.7 $ft.^3$/sec. (range 7.3-34.3) $ft.^3$/sec.; mean monthly discharge ranged from 10.2-11.0 $ft.^3$/sec. during June, July, October and November of 1982 (Appendix A). Although the East Aravaipa gaging station has only been operational since August 1, 1980, a comparison of the streamflow records with the USGS gage near the mouth of the creek indicates considerable differences in the variability and magnitude of discharge between the upper and lower parts of the drainage. Insufficient data exists to make a thorough comparison in seasonal discharge patterns at this time, but monitoring the discharge at BLM's East Aravaipa gage should provide the best indicator of instream flow conditions both above the canyon and in the Aravaipa Canyon Primitive Area.

Because of the previously discussed reasons, our instream flow study of Aravaipa Creek concentrated on the instream flow requirements, particularly the physical habitat requirements, of the spikedace and loach minnow. We chose Meda and Tiaroga because we considered these species the most sensitive to instream flows and because we could obtain more reliable information on their habitat requirements than for other native fishes of Aravaipa Creek.

MATERIALS AND METHODS

Study Site (T.6S., R.19E., NE¼, Sec. 19)

The instream flow study site was selected after either walking or driving along the flowing portions of Aravaipa Creek upstream from the mouth of Turkey Creek. The study site, located about 3/4 mile upstream from Turkey Creek, was a 358-foot reach (T.6S., R.19E., NE¼, Sec. 19) of the creek in the George Whittell Wildlife Preserve which is owned and managed by the Defenders of Wildlife. Preliminary electrofishing efforts on May 14, 1980 at the proposed site, prior to surveying and placement of transects, yielded all seven of the native fishes found in Aravaipa Creek (Minckley 1973). We found both adult and juvenile roundtail chub in the small pool at the downstream portion (Transect 1) of the study site. Adult spikedace and adult loach minnows were found in the run and riffle habitat types characterized by Transects 2-6. Although other native fishes were also observed at the study site, no attempts were made to quantify our fish collections. Our sampling efforts for fish were specifically designed to obtain quantitative data on the physical habitats used by spikedace, loach minnow and roundtail chub in and adjacent to the study site.

Except for the pool at Transect 1 where depths reached nearly 2 feet, water depths throughout the study site rarely exceeded 1.1 ft. Bottom substrate was dominated by sand and gravel at all transects, but small amounts of cobble were present at Transects 2-4 and 6. Channel width at the time of field measurements ranged from 16 to 26 ft. except for the run at Transect 2 which was only 10 to 14 ft. wide. Mean column velocities generally ranged from 1.0 to 3.0 ft./sec. in the middle of the

stream channel except for Transect 2 and for our measurements at the highest discharge (24.4 $ft.^3$/sec. on March 4, 1981). Maximum mean column velocity during our field measurements was 4.6 ft./sec. at Transect 2.

The south bank of the creek at the study site was at the southern edge of the floodplain and was heavily wooded with deciduous species of the Mixed Broadleaf Community which includes cottonwood (Populus fremontii), willow (Salix spp.), sycamore (Platanus wrightii), velvet ash (Fraxinus pennsylvanica velutina), box elder (Acer negundo) and walnut (Juglans major) (Minckley 1981). Water cress (Rorippa Nasturtium-aquaticum) was present along the shallower margins of the study site during the summer of 1981, but was not apparent during May 14-15, 1980, presumably because of a series of floods in January, February and March of 1980 (USGS 1981). The north bank at the study site was considerably less steep and was less heavily vegetated by woody riparian species than the south bank.

Field Methods

Hydraulic Simulation. Techniques for placement of transects and collection of physical data on water depths, velocities and bottom substrate followed Bovee and Milhous (1978). Mean column water velocity was measured for each vertical during each sampling period with a pygmy flow meter which was attached to a top-setting wading rod. The wading rod was also used at each vertical to determine water depth to the nearest 0.1 foot.

The initial surveying and placement of the stakes for the transects and bench marks were accomplished on May 14-16, 1980. Because of obvious streambed movements over the winter, we took three additional sets of

field measurements at the study site on March 4, July 21 and August 26, 1981.

Collection of Habitat Data on Fish. Most fish were collected by dip nets after being immobilized by DC current produced by a Smith-Root, Inc., Type VI or Type VII (backpack) Electrofisher. Sufficient amperage was used to produce galvanonarcosis and special attempts were made to minimize sampling bias by following the recommendations given by Bovee and Cochnauer (1977). Electrofishing efforts generally proceeded either upstream or laterally to the current in stream sections suspected of supporting populations of the target species. In areas which were considered likely habitat for loach minnows, a small seine (1/4- or 3/16-inch mesh) was held in place a few feet downstream and then the area immediately upstream was electrofished. Because adult *Tiaroga* were carried along the bottom downstream to the seine by the current, it was necessary to either carefully note their original location when shocked or sample discrete sections with homogenous habitat characteristics.

The original location of each target species was marked by dropping color-coded markers at the site where the fish was first observed. The markers consisted of 3-inch sections of 1/2-inch wooden dowel rods which had been painted various colors and tied by nylon twine to a 3-inch piece of iron rebar. The twine was carefully rolled around the dowel rod and the weight of the rebar caused it to unroll immediately after being dropped. Because we only had sufficient color combinations to identify six different fish groups, it was possible to mark the locations for adults and juveniles of only three species. During most sampling runs, a single person was responsible for dropping the location markers which were carried in the various compartments of a carpenter's apron.

In Aravaipa Creek, we restricted the placement of location markers to spikedace, loach minnows and roundtail chubs. Fish habitat data from Aravaipa Creek were only collected from between the first upstream and first downstream stream crossings immediately above and below the instream flow study site. Although we concentrated our sampling efforts on spikedace and loach minnows in the Gila River in New Mexico, some habitat data was obtained for roundtail chubs, Sonora suckers and desert suckers; all of our sampling was done downstream from the Highway 180 bridge.

After a sampling run was completed, the crew would determine water depth and mean column water velocity with a top-setting wading rod and a pygmy flow meter at the site of the iron rebar anchor of the location marker. Bottom substrate within a 6-inch radius of the iron rebar was categorized to the nearest 10% into categories of the Modified Wentworth Particle Size Scale described by Bovee and Cochnauer (1977). When present, instream cover within 1 foot of a location marker and the presence of overhead cover (e.g. riparian vegetation) was noted.

Data Analysis

Hydraulic Simulation. The IFG4 analysis was done by Tim Hardin, a former CIFSG employee, using the computer facilities at Oregon State University in Corvallis, Oregon. The CIFSG computer programs used in this analysis were described by Milhous et al. (1981). Because of streambed movements between our March 4 and August 26, 1981, sampling dates, it was necessary to eliminate the data from the two upstream transects and make the IFG4 simulation with only four transects. The computer output includes the input data used in the computer analysis

and contains a plot of the bottom profile across each transect. Mr. Hardin made some minor adjustments in the input data to improve the IFG4 simulation; both the unmodified and adjusted input data are provided in the computer output.

Probability-of-use Curves. The habitat data that was collected from Aravaipa Creek and the Gila River, New Mexico was sent to the CIFSG in Fort Collins, Colorado for preliminary evaluation. Our data was coded into the computer and analyzed by a CIFSG computer program designed to evaluate probability-of-use data. The input data and computer output of this analysis is contained in the following appendices: Appendix B for Sonora sucker, desert sucker and roundtail chub; Appendix C for spikedace; and Appendix D for loach minnow. A written summary of this computer analysis by Ken Bovee, CIFSG, is contained in Appendix E.

We prepared probability-of-use curves for water velocity and water depth from the computer-drawn marginals for spikedace and loach minnow. For comparative purposes, probability-of-use curves were also prepared by frequency analysis (Bovee and Cochnauer 1977) of the raw habitat data for velocity and depth. For our analysis, the probability-of-use weighting factors were taken directly from the frequency-of-capture data which were clustered in different increments to produce weighting factors which had the least variance between adjacent clusters (Bovee and Cochauer 1977). The frequency-of-capture data from Aravaipa Creek and the Gila River were summarized separately, but were combined when preparing the probability-of-use curves. In a few cases, it was necessary to sum the frequency data from adjacent increments to reduce the variance of the larger increments which were used in the frequency analysis of either velocity or depth. When this was done, the weighting factors were given

the same value in both adjacent increments. In two cases where a school of spikedace had been collected together and assigned a single depth and velocity value, the school was counted as only a single observation in the frequency analysis. This method avoided excessive weighting of data which may have been influenced by schooling behavior associated with electrofishing efforts. Because the actual availability of different velocities and depths was unknown for most areas where fish habitat data was collected, we did not attempt to develop true habitat preference curves.

Weighted Usable Area

The weighted usable area (WUA) for all fish species was determined by using the CIFSG's HABTAT program (Milhous et al. 1981) with the IFG4 hydraulic simulation of the instream flow study site. For adult *Meda* and *Tiaroga*, the different sets of weighting factors developed from the computer-drawn curves and from our frequency analysis of the habitat data were both used in separate HABTAT runs to evaluate the impact of varying the probability-of-use weighting factors on weighted usable area over a range of discharges. The weighting factors used for the HABTAT analysis for Sonora sucker, desert sucker and roundtail chub were taken directly from the probability-of-use curves developed for these species in Burro and Francis creeks; the analysis of WUA for these three species was done mainly to evaluate how WUA varied for species which had substantially different probability-of-use curves from those of *Meda* and *Tiaroga*.

RESULTS AND DISCUSSION

Hydraulic Simulation

Hydraulic information was obtained for the Aravaipa Creek instream flow site at the following discharges (based on our estimate for transect 3): 14.7 ft.^{3}/sec. on May 15, 1980; 24.4 ft.^{3}/sec. on March 4, 1981; 16.5 ft.^{3}/sec. on July 21, 1981; and 11.1 ft.^{3}sec. on August 26, 1981. Our estimates at the instream flow station were consistently 2.5-3.1 ft.^{3}/sec. less than measured during 1981 at the BLM gaging station located downstream near the upstream boundary of the wilderness area. Thus, 3 ft.^{3}/sec. was added to our recommended instream flow values so that the BLM gaging station (East Aravaipa) could be used to monitor streamflow.

Because of extensive streambed movements between May 15, 1980 and March 4, 1981, we eliminated the measurements on May 15, 1980 from our hydraulic simulation; this was not a serious problem because the flow on July 21, 1981 was quite comparable. Although mean daily flow at the East Aravaipa gaging station only varied from 14.0 to 30.9 ft.^{3}/sec. between our March 4 and August 26 sampling dates in 1981, there was sufficient streambed changes at 2 of our 6 transects to cause problems with the assumption of no streambed movement which is required for the IFG4 hydraulic simulation. Thus, we were forced to eliminate transects 5 and 6 from our simulation.

Based on field observations, the sand and gravel substrates which predominate in the stream channel upstream from the primitive area move quite readily during even short periods of increased flow associated with afternoon thunderstorms. Based on this observation, it is

desirable to make field measurements within a 2-4 week period when discharge varies by only about 10 ft.^{3}/sec. in order to minimize streambed movement. In hindsight, the BLM streamflow records indicate that these criteria were best met from May 1-13, 1981.

The IFG4 simulation was based on three sets of data with a range of 11.1 to 24.4 ft.^{3}/sec. Using the accepted CIFSG guidelines for IFG4 simulation at 0.4 times the lowest flow to 2.5 times the highest flow (Milhous et al. 1981), our simulation of the instream flow site on Aravaipa Creek should have been acceptable within a range of flows from 4.4 to 61.0 ft.^{3}/sec. Because flows seldom exceed 40 ft.^{3}/sec. above the canyon except during floods, weighted usable area was only simulated over the range from 5 to 40 ft.^{3}/sec.

Although streambed movement was a problem in this study, the IFG4 simulation was considered preferable to a Water Surface Profile (WSP) simulation because it allowed evaluation over a wider range of flow conditions. After reviewing our results in Aravaipa Creek, it appears that a single set of hydraulic measurements taken at 12-15 ft.^{3}/sec. and a WSP simulation would have provided a sufficient range of simulated flows to adequately evaluate habitat conditions for Meda and Tiaroga.

Habitat Preferences of Key Species

Probability-of-use data were collected for spikedace and loach minnow on June 18-19, 1981, from the Gila River, New Mexico, and on July 19, August 27-28, and November 8-10, 1981, from Aravaipa Creek, Arizona (Appendices C and D). Limited data on Sonora and desert suckers were obtained on March 5-6, 1981, from the Gila River, New Mexico (Appendix B). However, the probability-of-use curves used for both suckers and the roundtail chub were developed from data collected from Burro and

Francis creeks, Arizona during the spring and summer of 1981 (Turner and Tafanelli 1983).

Spikedace. Probability-of-use data on *Meda fulgida* were obtained for 54 adults from the Gila River and 140 adults from Aravaipa Creek; data on juvenile spikedace were restricted to 7 fish collected on August 27-28, 1981 in Aravaipa Creek (Appendix C).

The probability-of-use curve derived from the computer-drawn marginal prepared by the CIFSG (Appendix C, Figure 1) indicated a probability-of-use for spikedace of 1.00 for velocities between 1.6 and 2.0 ft./sec.; probability-of-use dropped to 0.10 as velocity decreased to 0.4 ft./sec. and increased to 3.0 ft./sec. (Table 1). However, our analysis of the velocity data (Table 2) indicated that the probability-of-use curve for velocity should be more plateau-like with a probability-of-use of nearly 1.0 for velocities of 1.3 to 2.7 ft./sec. (Figure 1). Very few *Meda* were collected at velocities either less than 0.6 or greater than 3.0 ft./sec (Table 2). The probability-of-use weighting factors (Table 3) which were used for the alternate computer analysis of available habitat (Run 2) were determined directly from our analysis of data on capture frequencies at different mean column velocities. Our best estimate of the velocity preferences for spikedace is represented by the smoothed curve drawn for these probability-of-use factors (Figure 1). If a probability-of-use curve had been drawn for capture data from the Gila River, probabilities-of-use would have been slightly greater at mean column velocities less than 1.7 ft./sec. and lower at velocities greater than 1.9 ft./sec. However, the limited habitat data collected for *Meda* from the Gila River had little impact on the probability-of-use curve developed from the combined data (Figure 1, Table 3). Except for one

Table 1. Probability-of-use weighting factors for water velocity and depth used to determine weighted usable area for adult spikedace and loach minnow in Aravaipa Creek, Arizona. These factors were based on computer-drawn marginals prepared by CIFSG.

Species	Velocity (ft./sec.)	Probability-of-use	Depth (feet)	Probability-of-use
Spikedace	0.0	0.0	0.00	0.00
(*Meda fulgida*)	0.4	0.1	0.15	0.00
	1.0	0.6	0.30	0.40
	1.6	1.0	0.45	0.60
	2.0	1.0	0.60	1.00
	2.4	0.6	0.75	1.00
	3.2	0.0	0.90	0.45
	100.0	0.0	1.05	0.10
			1.20	0.00
Loach Minnow	0.0	0.2	0.00	0.00
(*Tiaroga*	0.8	0.6	0.10	0.00
cobitis)	1.3	1.0	0.24	0.38
	1.7	1.0	0.30	0.65
	2.4	0.7	0.36	0.85
	3.2	0.2	0.40	1.00
	4.0	0.0	0.50	1.00
	100.0	0.0	0.58	0.80
			0.72	0.20
			0.85	0.05
			1.00	0.00
			100.00	0.00

Table 2. Frequency-of-capture data for loach minnow and spikedace collected at different water velocities in Aravaipa Creek, Arizona and the Gila River, New Mexico.

Velocity (ft./sec.)	Loach Minnow			Spikedace		
	Aravaipa Creek	Gila River	Total	Aravaipa Creek	Gila River	Total
0.0	--	1	1	--	--	--
0.1	--	3	3	--	1	1
0.2	1	5	6	--	--	--
0.3	--	6	6	--	--	--
0.4	2	4	6	--	1	1
0.5	--	7	7	--	--	--
0.6	1	4	5	--	2[a]	2[a]
0.7	4	5	9	1	1	2
0.8	1	2	3	1	2	3
0.9	2	3	5	1	2	3
1.0	1	4	5	6	1	7
1.1	9	7	16	1	--	1
1.2	5	5	10	1	--	1
1.3	5	--	5	7	5	12
1.4	2	2	4	6	3	9
1.5	10	3	13	4	1	5
1.6	8	4	12	6	1	7
1.7	7	1	8	6	5	11
1.8	10	--	10	6[b]	2	8[b]
1.9	10	5	15	4	1	5
2.0	9	4	13	12	1	13
2.1	12	5	17	7	2	9
2.2	8	2	10	10	2	12
2.3	3	2	5	9	--	9
2.4	11	2	13	4	1	5
2.5	4	1	5	7	4	11
2.6	3	3	6	7	1	8
2.7	3	--	3	5	1	6
2.8	4	6	10	3	--	3
2.9	4	1	5	2	--	2
3.0	--	1	1	1	--	1
3.1	--	1	1	--	--	--
3.2	--	6	6	--	--	--
3.3	1	--	1	--	--	--
3.4	--	3	3	--	--	-
3.5	--	3	3	1	--	1
3.6	--	2	2	--	--	--

[a]A school of 15 spikedace which were first observed at a location with this velocity was counted as a single observation.

[b]A school of 23 spikedace which were first observed at a location with this velocity was counted as a single observation.

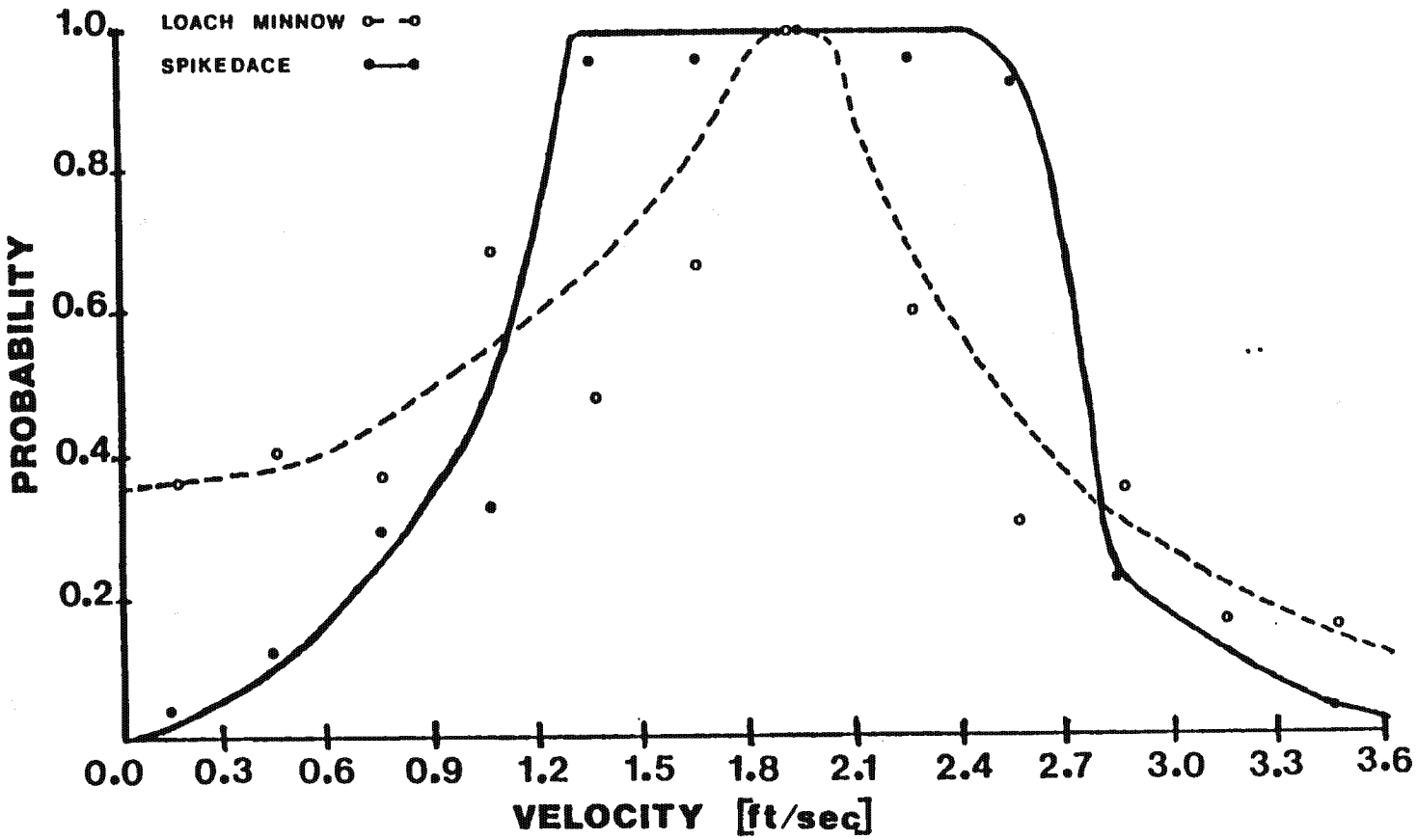

Figure 1. Probability-of-use curves for water velocity for loach minnow (--) and spikedace (—). Probability points for loach minnow (∘) and spikedace (·) were based on frequency-of-capture data for fish collected in Aravaipa Creek, Arizona and the Gila River, New Mexico.

Table 3. Probability-of-use weighting factors for velocity and depth for spikedace and loach minnow developed by frequency analysis of capture data from Aravaipa Creek, Arizona and Gila River, New Mexico.

Velocity (ft./sec.)	Probability-of-use		Depth (feet)	Probability-of-use	
	Meda	Tiaroga		Meda	Tiaroga
0.0	0.00	0.20	0.00	0.00	0.00
0.2	0.04	0.36	0.15	0.00	0.06
0.5	0.12	0.40	0.25	0.06	0.29
0.8	0.30	0.40	0.35	0.17	0.61
1.1	0.33	0.60	0.45	0.23	0.87
1.4	0.96	0.60	0.55	1.00	1.00
1.7	1.00	0.70	0.65	0.79	0.58
2.0	1.00	1.00	0.75	0.35	0.17
2.3	0.96	0.62	0.85	0.35	0.06
2.6	0.93	0.34	0.95	0.15	0.01
2.9	0.22	0.34	1.05	0.09	0.01
3.2	0.04	0.18	1.15	0.06	0.00
3.5	0.04	0.18	1.25	0.02	0.00
4.0	0.00	0.00	1.50	0.00	0.00
10.0	0.00	0.00	10.00	0.00	0.00

fish collected at a mean column velocity of 0.1 ft./sec. from the Gila River, adult spikedace were not collected at velocities less than 0.4 ft./sec. Mean column velocities at capture locations ranged from 0.85 to 3.0 ft./sec. in Aravaipa Creek, but ranged from 0.1 to 2.7 ft./sec. in the Gila River (Appendix C).

The computer-drawn marginal for probability-of-use for depth of adult spikedace (Appendix C, Figure 2) indicated that probability-of-use was 1.00 for water depths of 0.60 to 0.75 ft. and then dropped to 0.00 when depths either decreased to 0.15 ft. or increased to 1.20 ft. (Table 1). Our analysis of the frequency-of-capture data for depth (Table 4) indicated more restrictive depth preferences for adult spikedace with a strong preference for depths of 0.5 to 0.6 ft. (Figure 2). The probability-of-use weighting factors which we determined from our frequency analysis (Table 3) were lower at depths from 0.20 to 0.45 ft. and from 0.60 to 1.05 ft. than the weighting factors generated from the computer-drawn marginal (Table 1). Both sets of weighting factors were used in separate computer runs (HABTAT program) to evaluate the sensitivity of the habitat analysis to modifications in the probability-of-use curves.

Depths of capture for adult spikedace were slightly greater in Aravaipa Creek (mean of 0.65 ft., range of 0.3 to 1.2 ft.) than in the Gila River (mean of 0.52 ft., range of 0.2 to 0.8 ft.) (Table 4). Probability-of-use weighting factors (Table 3) would have been 0.04-0.15 greater at depths from 0.6 to 1.1 ft. if the data for spikedace from the Gila River had been eliminated from our analysis.

The axes of the depth-velocity scattergram (Appendix C, Figure 3), are quite skewed and indicate that there is a high degree of correlation

Table 4. Frequency-of-capture data for loach minnow and spikedace collected at different depths in Aravaipa Creek, Arizona and the Gila River, New Mexico.

Depth (feet)	Loach Minnow			Spikedace		
	Aravaipa Creek	Gila River	Total	Aravaipa Creek	Gila River	Total
0.10	--	1	1	--	--	--
0.15	--	3	3	--	--	--
0.20	2	7	9	--	1	1
0.25	2	9	11	--	2	2
0.30	19	17	36	4	--	4
0.35	4	2	6	2	2	4
0.40	35	9	44	6	2	8
0.45	8	8	16	2	1	3
0.50	31	22	53	22	14	36
0.55	9	7	16	8	3	11
0.60	20	13	33	24	9	33
0.65	3	4	7	3	1	4
0.70	6	4	10	12	2	14
0.75	--	2	2	1	--	1
0.80	1	3	4	15[a]	2	17
0.85	--	--	--	--	--	--
0.90	--	1	1	5	--	5
0.95	--	--	--	2	--	2
1.00	1	--	1	3	--	3
1.05	--	--	--	1	--	1
1.10	--	--	--	1	--	1
1.15	--	--	--	3	--	2
1.20	--	--	--	1[b]	--	1

[a] A school of 15 spikedace which were first observed at a location with this depth and captured later was counted as only a single observation in the frequency analysis.

[b] A school of 23 spikedace which were first observed at a location with this depth and captured later was counted as only a single observation in the frequency analysis.

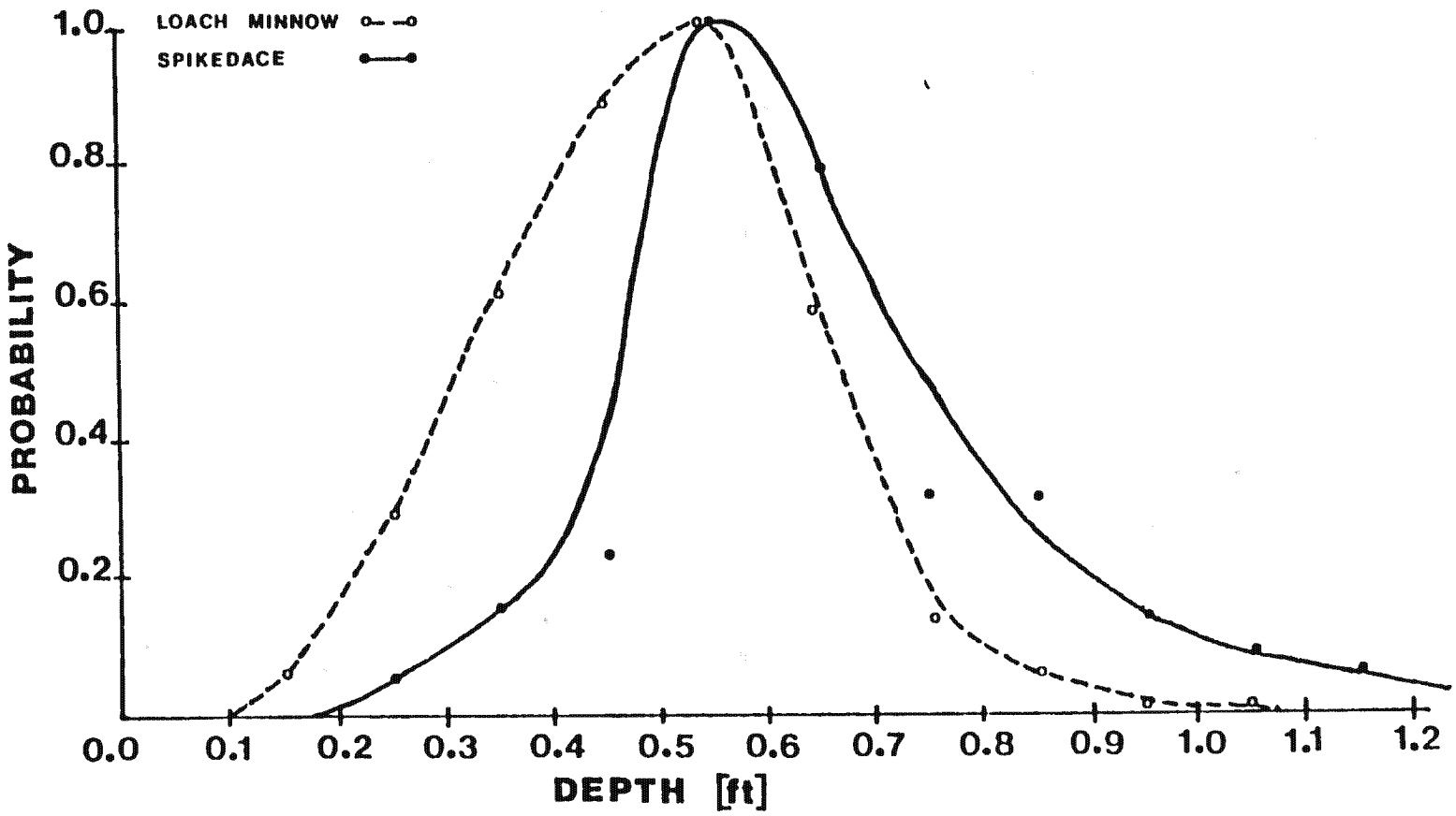

Figure 2. Probability-of-use curves for water depth for loach minnow (--) and spikedace (—). Probability points for loach minnow (∘) and spikedace (·) were based on frequency-of-capture data for fish collected in Aravaipa Creek, Arizona and the Gila River, New Mexico.

between depth and velocity in the two streams. This "environmental bias" in our data causes our curves for Meda and Tiaroga to really describe the range of tolerances for a restricted range of environmental conditions where both suitable velocity and depth occur together rather than the fish's actual preferences for these parameters (Ken Bovee, CIFSG, pers. comm.). Because we did not have time to collect the PHABSIM type data needed to simulate the availability of microhabitats at each site where habitat preference data was obtained, it was impossible to correct for the environmental bias in our preference data. The summary of habitat data by Ken Bovee indicated that our curves "are as good as most curves on FISHFIL," but the curves on Meda and Tiaroga should not be used on streams that are much different from where we collected the habitat data (Appendix E).

The CIFSG was unable to get computer-drawn preference curves for substrate for Meda and Tiaroga. A good deal of their difficulties probably resulted from the differences in how substrate information was recorded between our June sample from the Gila River and later collections of habitat preference data from Aravaipa Creek. Our data on adult Meda indicate an apparent preference for substrates containing smaller gravel sizes and sand (Appendix C, Figures 4 and 5).

Although we did not observe spawning activities, observations on habitat preferences in Arizona waters are quite consistent with observations made by the senior author in the Gila River and its tributaries in New Mexico. The following information refers to habitat preferences in Arizona waters:

> Meda fulgida appears to prefer moving water less than a meter in depth during most of the year, concentrating near the downstream ends of riffles, or in eddies. In larger habitats, such as in the

Salt River Canyon, spikedace have been taken only below the mouths of creeks, and as young along the margins of large pools over muddy bottoms. In spring, the fish often frequents fairly shallow areas, especially over sand and finer gravels in places of swift, relatively laminar flow (Minckley 1973).

Spawning habitat in Aravaipa Creek was described as shallow sand-bottomed areas with moderate water velocities (Barber et al. 1970). The presence of shallow riffles (less than 1 ft.) with sand and fine gravel substrate and relatively moderate, laminar flows coincided with large aggregations of adult spikedace prior to 1979 in the East Fork of the Gila River just upstream from its confluence with the West Fork. However, the elimination of this habitat type and its replacement by narrower, more rapidly-flowing runs by floods in 1978 has resulted in Meda becoming uncommon in the lower portions of the East Fork in recent years. In the Gila River downstream from Cliff, New Mexico, spikedace have been observed to patrol the edges of rapidly-flowing runs within a relatively narrow range of water depths and velocities. They also utilized eddies on the downstream portions of runs and shallower (less than 1 ft.) riffles with moderate flows where braided channels provided a variety of habitat types.

Loach minnow. Habitat preference data were collected for 141 adults in Aravaipa Creek and 112 adults in the Gila River. Comparable data for 14 juveniles was collected from Aravaipa Creek on August 27, 1981.

In contrast to our data on spikedace, adult loach minnows appear to have a strong preference for a cobble and gravel substrates and avoid substrates dominated by sand and finer gravel (Appendix D, Figures 4 and 5). The apparent requirement for cobble and large gravel substrates is probably related to the tendency for Tiaroga to maintain a relatively

stationary position on the bottom in flowing water. An irregular bottom caused by the presence of cobble and larger gravels should create microhabitats near the bottom with low velocities. These microhabitats should allow Tiaroga to maintain a stationary position with less energy expenditure.

The presence of cobble substrate appears to be necessary for spawning and satisfactory egg incubation in the Gila River and its tributaries in New Mexico; fertilized eggs were only found attached to the underside of flattened cobble (average dimensions of 5.3 x 7.1 inches) (Britt 1982). This cobble substrate apparently must provide a protected location, which lacks periphytic growth because of the shading caused by the cobble. Thus, it appears important that the cobble is not imbedded in finer substrate particles which may eliminate shaded cavities for egg deposition.

In New Mexico, spawning sites were typically found along the head and margins of riffles and runs at depths of 1.2 to 29.9 inches with a mean of 5.1 inches (Britt 1982; Appendix D); bottom velocities taken with a pygmy meter immediately downstream from the cobble spawning site (after the cobble was carefully repositioned) averaged 0.6 ft./sec. Eggs of loach minnows were also found attached to the underneath sides of cobble in Aravaipa Creek in May of 1980, but the size of the cobble was considerably smaller; the reduced abundance of larger unimbedded cobble in Aravaipa Creek was probably a factor in the use of smaller spawning substrate.

Minckley (1973) indicates that Tiaroga is "restricted to gravelly riffles" and is "most often taken in association with beds of filamentous algae such as Pithophora or Cladophora, either in the main channels of shallow swift reaches, or along the margins of more torrential rapids"

of small to moderately-large creeks and rivers. Because algal beds are typically absent in the Gila River and its larger tributaries in New Mexico, Tiaroga does not seem to require the presence of aquatic vegetation. However, it has been collected from submerged beds of vascular macrophytes in New Mexico streams when this type of vegetation was present. Beds of submerged algae or macrophytes may serve the same purpose as cobble substrate, which is to reduce bottom water velocities. In the absence of cobble, the availability of submerged vegetation may become a more important habitat feature; however, it is unknown whether submerged vegetation can provide suitable sites for attachment of the loach minnow's adhesive eggs.

Collections of young-of-the-year loach minnows in New Mexico streams prior to 1981 indicate that juveniles have greater preferences for smaller substrate sizes (e.g. sand), shallower depths and slower velocities than adult Tiaroga. Although our observations prior to this study were not quantified, juvenile loach minnows have been commonly encountered near the edges of riffles and runs and in shallow (less than 6 inches) portions of braided riffles which have been created by temporary diversion structures or dropping water after high winter and spring flows. The 14 juvenile Tiaroga which were captured in Aravaipa Creek in 1981 were at depths of 4.0 to 8.4 inches and at mean column velocities of 0.9 to 2.5 ft./sec. (Appendix D).

Adult loach minnows have a somewhat wider range of tolerance for water velocity than adult spikedace, especially for lower mean column velocities (Tables 1-3, Figure 1). When the computer-drawn marginal (Appendix D, Figure 1) was used as a guide, probability-of-use was 1.00 between 1.3 and 1.7 ft./sec. and dropped linearly to a probability of

0.20 at 0.0 and 3.2 ft./sec. (Table 1). When our capture frequencies were compared, it was obvious that Tiaroga preferred slower mean column velocities in the Gila River than in Aravaipa Creek (Table 2). In the Gila River, probability-of-use was essentially 1.0 at velocities of 0.1-1.2 ft./sec. and decreased to about 0.5 at 1.3-3.6 ft./sec. In contrast, loach minnows preferred velocities of 1.5-2.4 ft./sec. in Aravaipa Creek with progressively lower probabilities-of-use at velocities less than 1.5 ft./sec. and greater than 2.4 ft./sec. The major differences in velocity preferences between streams could have been caused by one or more of the following factors: loach minnows were collected only in early June in the Gila River and habitat preferences may have still been influenced by spawning activities which continue into June in the Gila River (Britt 1982); water transparency was lower in the Gila River than in Aravaipa Creek in the summer and fall when Tiaroga were collected; the presence of more and larger cobble substrate in the Gila River may have influenced the use of slower velocities and shallower water; and considerably more water with slower velocities was available for Tiaroga use in the Gila River than in Aravaipa Creek which had a higher proportion of runs and rapidly-flowing riffles in a single well-established channel in the areas where we collected habitat data.

The use of slower velocities by Tiaroga in the Gila River suggested a higher preference for this type of water than indicated by the capture data in Aravaipa Creek (Table 4). Thus, the frequency-of-capture data for both streams were combined to produce more generalized probability-of-use weighting factors (Table 3) for use in the computer analysis. The combination of capture data resulted in the probability-of-use factors being considerably greater at mean column velocities less

than 1.3 ft./sec. and slightly greater at velocities greater than 2.8 ft./sec. than would have occurred if only capture data from Aravaipa Creek were used. The weighting factors which we developed by frequency analysis (Table 3) indicated lower probability-of-use values for Tiaroga between 1.0 and 2.0 ft./sec. than predicted by the computer-drawn marginal (Table 1; Appendix D, Figure 1).

Although adult Tiaroga apparently have a wider range of tolerance for velocity than Meda, the probability-of-use curve for mean column velocity has a much sharper peak for Tiaroga than the plateau-like curve for Meda (Figure 1). Our habitat data for the loach minnow indicate greater preferences for higher velocities in streams where cobble substrate provides the preferred microhabitats on the bottom. In the Gila River, adult loach minnows were not collected at mean column velocities of 2.5-3.6 ft./sec. unless cobble substrate was present (Appendix D). Adult Tiaroga were rarely collected at velocities greater than 2.0 ft./sec. in Aravaipa Creek (Table 2) unless very coarse gravel or cobble was present.

Adult loach minnows preferred slightly shallower water than adult spikedace in our streams (Figure 2). Based on the computer-drawn marginal (Appendix D, Figure 2), probability-of-use was 1.00 at a depth of 0.4-0.5 feet and dropped rapidly to 0.20 when depth increased to 0.7 ft. (Table 1). When the frequency-of-capture data were analyzed (Table 4), we found that the probability-of-use peaked at 0.50-0.55 ft. (Table 3, Figure 1). When the capture data were compared between streams, the preferences appeared similar at depths greater than 0.25 ft., but loach minnows used water less than 0.3 ft. more in the Gila River than in Aravaipa Creek (Table 4).

Although adult Tiaroga were not collected at depths greater than 1.0 ft. during 1981 (Appendix D), they must occasionally occur at greater depths during spawning because Britt (1982) found eggs in water as deep as 29.9 inches. This may indicate either sampling bias or environmental bias in our data collection in 1981; however, the preferred depths for the species was probably accurately described for the summer and fall. It is likely that habitat preferences may be somewhat different during winter and spring and during the spawning period.

Other species. Because of time limitations and our belief that Meda and Tiaroga were more sensitive to changes in instream flow, we collected little data on habitat preferences on other species in Aravaipa Creek. Although habitat data were obtained for 62 roundtail chub from Aravaipa Creek, the probability-of-use curves which were prepared from data collected in Burro and Francis creeks (Turner and Tafanelli 1983) for roundtail chub (Gila robusta robusta), Sonora sucker (Catostomus insignis) and desert sucker (Catostomus clarki) (Table 5) were used to estimate how available habitat (weighted usable area) for these species would be influenced by changing discharge in Aravaipa Creek. Changes in weighted usable area for these three species should be considered less reliable than for Meda and Tiaroga for the following reasons: roundtail chub from Aravaipa Creek belong to a different subspecies (Gila robusta grahami) which is generally found in smaller tributaries and at higher elevations than Gila r. robusta which occurs in Burro Creek (Minckley 1973); Catostomus clarki may differ genetically between Aravaipa and Burro creeks (Minckley 1973); stream habitat conditions in upper parts of Aravaipa Creek and where we collected habitat data in the Burro Creek drainage were quite different, thus our probability-of-use

Table 5. Probability-of-use weighting factors for water velocity and depth used to estimate weighted usable area for roundtail chub, Sonora sucker and desert sucker. These weighting factors were based on habitat data collected in Burro Creek, Arizona for the size ranges indicated for each species.

	Velocity (ft./sec.)	Probability-of-use	Depth (feet)	Probability-of-use
Roundtail chub (3-7 inches, TL)	0.00	1.00	0.00	0.00
	0.30	1.00	0.08	0.00
	0.50	0.50	0.15	0.30
	0.70	0.25	0.20	0.40
	1.30	0.15	0.30	0.80
	2.00	0.10	0.40	0.90
	2.50	0.00	0.50	0.97
	100.00	0.00	0.60	1.00
			100.00	1.00
Sonora sucker (5-12 inches, TL)	0.00	0.90	0.00	0.00
	0.05	0.96	0.10	0.00
	0.20	1.00	0.30	0.15
	0.40	0.95	0.50	0.30
	0.50	0.34	0.60	0.50
	0.60	0.25	0.64	0.85
	1.00	0.12	0.80	0.98
	1.60	0.09	0.90	1.00
	2.00	0.07	100.00	1.00
	100.00	0.00		
Desert sucker (3-9 inches, TL)	0.00	0.85	0.00	0.00
	0.20	0.95	0.09	0.00
	0.30	1.00	0.30	0.30
	0.60	0.70	0.50	0.65
	0.80	0.34	0.80	0.93
	1.30	0.15	1.00	1.00
	2.00	0.07	100.00	1.00
	100.00	0.00		

curves were probably influenced by environmental bias which reduce their comparability between different types of streams; and sampling biases associated with collecting fish by electrofishing probably has a greater impact on probability-of-use curves for both suckers and roundtail chub than for Meda and Tiaroga.

Because of the limited amount of pool habitat available in the sections of Aravaipa Creek that we sampled, we only collected roundtail chub at depths of 0.4 to 1.5 feet. Although this data should be considered biased because we seldom sampled water over 1.5 feet in Aravaipa Creek, our data on depth preferences of roundtail chub compared well with the probability-of-use curve prepared with data from Burro and Francis creeks (Table 5). In contrast, our data suggested higher preferences for mean column water velocities greater than 0.5 ft./sec. in Aravaipa Creek than in the Burro Creek drainage. When instream cover was absent, roundtail chub were collected in similar numbers at mean column velocities from 0.75 to 2.5 ft./sec.; when instream cover (e.g. undercut banks, submerged logs) was present, roundtail chub were collected more commonly at velocities less than 1.0 ft./sec. These data were considered to be biased because relatively few pools or areas with lower water velocities were sampled in Aravaipa Creek except at the shallow margins of riffles and runs where depth probably limited the likelihood of roundtail chub being collected. Our data do suggest a strong preference for instream cover for Gila robusta grahami in Aravaipa Creek during the daytime when water transparencies were high.

Because of previously discussed reasons, estimates of weighted usable area (WUA) for both suckers and the roundtail chub in Aravaipa Creek should only be used for comparative purposes to the more reliable

WUA values obtained for Meda and Tiaroga. A more complete discussion of habitat preferences of both suckers and roundtail chub was given by Turner and Tafanelli (1983).

Weighted Usable Area Versus Discharge

Spikedace. When the weighting factors developed from the computer-drawn preference curves were used (Run 1), weighted usable area (WUA) was greatest for adult spikedace at discharges of 20-25 ft.^{3}/sec., but varied relatively little at flows of 10 to 40 ft^3/sec. (Table 6). The use of our alternate probability-of-use factors (Table 3) caused a 30-70% reduction in WUA, but WUA still peaked at 20 ft.^{3}/sec. (Run 2, Table 6). In both computer runs, WUA varied by less than 25% as discharge was simulated over a range from 10 to 40 ft^3/sec. WUA decreased rapidly for both computer runs when discharge was reduced from 10 to 5 ft.^{3}/sec. (Table 6). For Run 2, WUA decreased from 4400 to 900 ft.^{2} per 1000 feet of stream when discharge dropped from 10 to 5 ft.^{3}/sec. Although the use of different probability-of-use weighting factors changed the absolute amount of WUA, the peak in WUA for adult spikedace still occurred at 20 ft.^{3}/sec.

Loach minnow. WUA for adult Tiaroga peaked at 15-20 ft.^{3}/sec. for both computer runs, but was relatively similar at discharges of 10 to 25 ft.^{3}/sec. (Table 6). Although WUA decreased by 45% for adult loach minnows when discharge was reduced from 10 to 5 ft.^{3}/sec. (Run 2), the magnitude of this decrease was not as great as noted for adult spikedace. As noted with spikedace, WUA was 30 to 45% less for Tiaroga in Run 2 than estimated in Run 1 for the same discharges (Table 6). WUA was greater for adult Tiaroga than adult Meda at all flows from 5 to 35 ft.^{3}/sec.

Table 6. Weighted usable area and percentage of gross area for spikedace and loach minnow at the Aravaipa Creek, Arizona Study Site which was located on Defenders of Wildlife property upstream from the Aravaipa Canyon Wilderness Area.

Discharge ($ft.^3/sec.$)	Area in Square Feet (x1000) per 1000 Feet of Stream				
	Gross Area	Weighted Usable Area			
		Spikedace		Loach Minnow	
		Run 1[a]	Run 2[b]	Run 1[a]	Run 2[b]
5	14.4	2.5 (18)[c]	0.9 (6)[c]	5.5 (38)	3.0 (21)
7	15.5	3.9 (25)	1.9 (12)	6.9 (41)	4.4 (28)
10	16.7	5.6 (34)	4.4 (26)	7.9 (47)	5.5 (33)
12	17.2	6.3 (36)	4.6 (27)	8.1 (47)	5.7 (33)
15	19.0	6.7 (35)	4.8 (25)	8.3 (44)	5.9 (31)
20	20.4	7.1 (35)	5.6 (27)	8.5 (41)	5.7 (28)
25	21.3	7.1 (34)	5.1 (24)	8.1 (38)	5.6 (26)
30	22.0	6.7 (30)	4.8 (22)	7.4 (34)	5.1 (23)
35	26.1	6.0 (23)	4.3 (16)	6.3 (24)	4.4 (17)
40	27.8	5.6 (20)	4.5 (16)	5.5 (19)	4.1 (15)

[a]Probability-of-use weighting factors for Run 1 were based on computer-drawn preference curves prepared by the CIFSG from our capture data (Table 1).

[b]Probability-of-use weighting factors for Run 2 were based on preference curves prepared by frequency analysis from our capture data (Table 3).

[c]Number in parentheses is the percentage of the gross area.

Other Species. WUA varied by less than 10% for both Sonora and desert suckers over the range of discharge from 7 to 25 $ft.^3$/sec. and then increased slowly with increasing discharge up to 40 $ft.^3$/sec. (Table 7). In contrast to both suckers where WUA was lowest at 5 $ft.^3$/sec., WUA for roundtail chub was greater at 5-12 $ft.^3$/sec. than at higher discharges. The relative insensitivity of WUA to varying discharge for both suckers and roundtail chub was related to their preference for low water velocities and tolerance for shallow depths (Table 5).

Instream Flow Recommendations for Aravaipa Creek

Because of their apparent tolerance of a wide range of discharges and low-flow conditions, WUA values for both suckers and the roundtail chub were not as useful as WUA values for *Meda* and *Tiaroga* in making instream flow recommendations for Aravaipa Creek above the Aravaipa Canyon Primitive Area. The current distribution of the spikedace and loach minnow is more restricted than for the other native cyprinids and catostomids of Aravaipa Creek and the upper portions of the Gila River drainage. In addition, proposed water developments on the Gila and San Francisco rivers may have serious impacts on the status of native fishes, especially the spikedace. Listing packages for both *Meda* and *Tiaroga* are currently being prepared by the Office of Endangered Species, U.S. Fish and Wildlife Service. Both species are likely to be recommended for "threatened" status and Aravaipa Creek is being considered as "critical habitat" for both species (Jim Johnson, USFWS, pers. comm.).

Based on changes in WUA, it appears that a discharge of 20 $ft.^3$/sec. at our instream flow study site would provide the most usable habitat

Table 7. Weighted usable area and percentage of gross area for roundtail chub, Sonora sucker and desert sucker at the Aravaipa Creek Study Site which was located on Defenders of Wildlife property upstream from the Aravaipa Canyon Wilderness Area.

Discharge ($ft.^3/sec.$)	Area in Square Feet (x1000) per 1000 Feet of Stream			
		Weighted Usable Area		
	Gross Area	Roundtail Chub	Sonora Sucker	Desert Sucker
5	14.4	3.0 (21)[a]	0.8 (6)[a]	1.6 (11)[a]
7	15.5	3.2 (20)	1.0 (6)	1.8 (12)
10	16.7	3.2 (19)	1.0 (6)	1.9 (12)
12	17.2	3.1 (18)	1.1 (7)	2.0 (12)
15	19.0	2.8 (15)	1.0 (6)	2.0 (11)
20	20.4	2.2 (11)	1.0 (5)	1.9 (9)
25	21.3	2.3 (11)	1.1 (5)	1.9 (9)
30	22.0	2.2 (10)	1.2 (6)	2.0 (9)
35	26.1	2.1 (8)	1.4 (5)	2.1 (8)
40	27.8	2.6 (9)	1.5 (5)	2.4 (9)

[a]Number in parentheses is the percentage of the gross area.

for adult spikedace and loach minnow in Aravaipa Creek during the summer and fall. A minimum flow of 10 ft.^{3}/sec. would not result in much reduction in usable habitat, but lower flows would have more detrimental impacts, especially for Meda. Streamflow data for the BLM gaging station upstream from the wilderness area (East Aravaipa) indicates that June and July are low-flow periods and flows of 7.5-13.6 ft.^{3}/sec. occurred in those months in 1982, discharge was less than 10 ft.^{3}/sec. on 18 days. When using the BLM gaging station (East Aravaipa) for monitoring purposes, 3 ft.^{3}/sec. should be added to our flow recommendations. Thus, an optimum flow of about 23 ft.^{3}/sec. would be desirable during the late spring through early fall; below about 13 ft.^{3}/sec., the amount of WUA would decrease rapidly for Meda and Tiaroga.

Although we did not include substrate preferences in our analysis of weighted usable area, it appears that cobble substrate which is not imbedded in the bottom by accumulations of fines and gravel is an important habitat requirement of adult loach minnows and may be an absolute requirement for successful spawning and egg incubation. This information indicates that the control of soil erosion and accumulations of silt and sand in the streambed is desirable. It appears that the substrate-cleaning effects of scouring flows which occur during the winter may be a desirable part of the annual flow regime in Aravaipa Creek.

Any additional water withdrawals from Aravaipa Creek above the primitive area by either surface diversions during low-flow periods or groundwater pumping in low-water years should be opposed. A nonconsumptive water right which guaranteed a minimum flow of 13 ft.^{3}/sec. at BLM's East Aravaipa gaging station should be obtained for Aravaipa

Creek upstream from the primitive area. It may be desirable to purchase sufficient water rights from private land owners who currently irrigate limited amounts of agricultural land upstream from the primitive area to insure instream flows do not drop below 13 $ft.^3$/sec. during summer and early fall low-flow periods.

Recommendations for Additional Study

Based on our IFG4 simulation, a range of simulated discharges from 5 to 40 $ft.^3$/sec. provided sufficient data for making instream flow recommendations in Aravaipa Creek for adult Meda and Tiaroga. However, it would be worthwhile to compare our IFG4 simulation to a WSP simulation using the hydraulic information that we collected on May 15, 1980 at a discharge of 14.7 $ft.^3$/sec. Likewise, it would be desirable to include substrate preferences for both adult Meda and Tiaroga into an analysis (using the WSP simulation) of available habitat using the CIFSG's HABTAT program. It might be possible to obtain acceptable probability-of-use curves for substrate by either eliminating the data we collected from the Gila River from the data set or by combining the various gravel sizes (e.g. course, medium, pea) into a single coding for all gravel size for the analysis of dominant particle size (see Bovee's comments in Appendix E). However, it may be desirable to wait until more extensive habitat data for Meda and Tiaroga from the Gila and San Francisco River drainages in New Mexico are analyzed before including substrate preferences in the HABTAT analysis. The main problems with our habitat data are the restricted range of substrates available in Aravaipa Creek and our inability to determine the actual availability of different substrates, velocities and depths in the specific stream sections where we

obtained habitat data on Meda and Tiaroga. Because of the latter problem, we were restricted to developing probability-of-use curves with our data and could not determine actual preference curves for the habitat parameters.

It would be worthwhile for future investigators to prepare habitat preference curves for other life stages of Meda and Tiaroga. In particular, preference curves for spawning, egg incubation and fry may be quite valuable in future instream flow studies. It appears that the spawning requirements for Tiaroga are quite restricted and future studies should concentrate on substrate size and degree of imbeddedness. Because eggs are attached to the underside of cobble substrates, it will require tedious and careful fieldwork to document the actual habitat preferences. The fieldwork will require the researchers to check potential spawning sites by removing each possible substrate (e.g. cobble) from the bottom and examining the underneath side for eggs. An alternative approach would be studies in a laboratory stream where substrate sizes and degree of imbeddedness can be controlled. In either case, the disturbance created by checking the substrate for eggs may alter either the degree of imbeddedness or the behavior of potential spawners.

Considerations for Desert Streams

Hydraulic Simulation. The methodology (e.g. WSP or IFG4) chosen to simulate the hydraulic conditions in desert streams should be determined after a review of annual streamflow regime, streambed morphology and accessibility of study sites. If the accessibility of the study sites during higher flow periods is poor (e.g. Burro and Francis creeks) because of road conditions and stream fords, it is desirable to either plan fieldwork during low-flow periods or make arrangements for reaching

the study sites by helicopter. When low-flow conditions are likely to be the limiting aspect for fishes or higher flows are uncontrollable because of no upstream dams, it is not necessary to simulate hydraulic conditions at higher flows. Thus, a WSP simulation may be quite adequate for simulating the hydraulic conditions that occur over a restricted range of discharges about the median flow during low-flow periods.

A WSP simulation would also be desirable when the stability of the streambed and predictability of storm events are low. The sand and finer gravel substrates in the Arizona streams we studied were easily moved by relatively minor increases in discharge. Thus, the potential for simulating a wide range of flows by an IFG4 simulation is relatively low unless the field measurements can be made during a relatively short time interval when discharge can be expected to decrease in a predictable fashion. The first set of field measurements should be made at the upper end of the expected range in discharges and successive field measurements should be taken when discharge decreases by 20-30% from the previously measured discharge. If streambed movement is excessive between the first and second set of field measurements, the first set of measurements can be eliminated from the data set for the IFG4 simulation and an additional set of field measurements can be taken as flow continues to drop.

In the case of lower elevation (less than 4,000 feet) Arizona streams where there is a wintertime peak in streamflow, it appears that the optimum time to take a set of field measurements for IFG4 simulation is from mid-March through mid-June. At higher elevation streams in Arizona and New Mexico which are influenced by snowmelt runoff, it would

be desirable to wait until the snowmelt runoff has started to decrease (i.e. April-June, depending on elevation and snowpack) before beginning any fieldwork. Field measurements made during the months of July-September are subject to rapid hour-to-hour or day-to-day changes in discharge because of the unpredictability of summer thunderstorms.

Our WSP simulations in Burro and Francis creeks were complicated because of the relatively high gradient and presence of large boulders in the riffle sections. When gradient is high enough to cause stairstep-type drops in the riffles, it becomes very difficult to adequately calibrate a WSP simulation (Tim Hardin, pers. comm.). Likewise, the occurrence of braided flow through boulder-strewn riffles (e.g. Burro and Francis creeks) during low-flow periods causes problems with WSP simulation.

Sampling Bias Associated with Fish Capture. These comments are based on fish captured during spring, summer and fall sampling trips to Aravaipa, Burro and Francis creeks, Arizona, and the Gila River downstream from the Highway 180 bridge in New Mexico. Electrofishing was used to capture all fish, but the sampling bias associated with this method was quite variable between species. Large boulders, cobble and algal mats prohibited the use of seines in Burro Creek. Although seines could have been used more easily in Aravaipa Creek, the exact location of each fish could not be determined by seining unless the seine hauls were made only in water where the bottom could be observed. Visual observations were used mainly for deeper pools and also worked quite well in slow-moving water for those species that could be readily identified with just a brief sighting. Visual observations were useful as a supplement to electrofishing data, but did not provide satisfactory

data in either rapidly-flowing riffles and runs or areas where instream cover (e.g. logs, undercut banks, boulders, cobble) concealed the fish until they were either shocked or flushed from cover. Visual observations of the movements of fish in relation to electrofishing efforts provided much of the basis for the following discussion of sampling bias.

Because the loach minnow is a small (less than 3½ inches, TL), sedentary bottom dweller that apparently remains in place in shallow flowing water (often near cobble substrate), electrofishing was an effective method for obtaining data on habitat preferences. This species did not appear to be disturbed and apparently stayed relatively stationary as the electrofishing crew approached. When shocked, individuals usually simply rolled over in place and either began rolling downstream along the bottom or became lodged in crevices between gravel and cobble. Their original location was relatively easy to establish and they were usually captured quickly by either dip nets or a seine set a few feet downstream after being shocked.

The spikedace is a small (less than 3½ inches, TL) fish that usually stays in the lower half of the water column in flowing water. It prefers moving water less than 1.5 feet in depth and is often found in small schools near the edge of runs and in shallow riffles with sand and gravel substrate. It was more affected by the approach of the electrofishing crew and sometimes would flee; however, they were relatively easy to identify in the water and could usually be captured within a few feet of where they were first seen. With some care the species could be shocked without undue effects on their behavior and a reasonably good determination made of their original location.

The desert sucker and Sonora sucker are both basically bottom dwellers that are relatively mobile, but often use boulders, debris, undercut banks and overhanging vegetation as shelter. These two species were much more affected by the approach of the electrofishing crew than Meda and Tiaroga and would often flee making it difficult or even impossible to determine their original position. Sometimes the fish would flee before they could be identified only to be herded a short distance ahead (5-10 feet) and shocked as a group, outside of their original microhabitat. In small, shallow pools this was even more of a problem than in boulder-strewn riffles and runs. More turbid water made fleeing and herding less of a problem but made seeing the fish more difficult.

The roundtail chub is a relatively mobile mid-water species that was highly sensitive to disturbances such as the approach of an electrofishing crew. They would usually flee for cover if available or swim rapidly away from the area; thus, it was often difficult to determine the original location of roundtail chubs. This was virtually impossible in shallow pools unless the observers either approached very carefully and slowly or could first observe their behavior from out of the stream from a distance of at least 15-20 feet.

If electrofishing were rated on a scale of 1-10 (poor to excellent) as the only method for obtaining unbiased data on habitat preferences, we would give the following ratings for the species we studied: loach minnow, 9.5; spikedace, 8.0; Sonora sucker and desert sucker, 3.5-4.0; and roundtail chub, 1.0. The presence of cover and intermediate water transparencies which permit observation of fish, but reduce water clarity could be expected to decrease sampling bias associated with

electrofishing for the latter three species by reducing their tendency to flee from the sampling crew.

Because of the difficulties encountered in obtaining unbiased habitat on desert suckers, Sonora suckers and roundtail chubs in Burro and Francis creeks, an alternative method of collecting data on habitat preferences would be desirable for supplementing visual observation and capture data by electrofishing. Although Burro Creek consisted of a variety of substrates, velocities, and depths, these differences in habitat features often occurred within a few feet of each other in a mosaic along any given stretch of run or riffle habitat. The fish moved freely between these microhabitats, especially when pursued by a sampling crew. Thus it was difficult to obtain unbiased estimates of their habitat preferences in shallow, moving waters by sampling with backpack electrofishing gear. Although this sampling bias was noted by visual observations and considered when preparing the probability-of-use curves, the difficulty in quantifying observations made during electrofishing efforts make it desirable to develop a more quantifiable approach to characterizing habitat preferences for fishes like suckers and chubs in small, clear desert streams.

Since suckers and roundtail chub use a larger area within a short time interval than less mobile species like the loach minnow, it would seem reasonable to characterize their habitat preferences by characterizing the habitat parameters within a larger cell. For the latter three species, it might be better to evaluate a large cell (of 10-30 square feet, in either a rectangular or circular configuration) and then determine the relative abundance of each species in that cell. This could be

then compared with ratios for other cells of similar size, but with different substrate-velocity-depth characteristics.

This approach could be facilitated by selecting sections of stream that differ significantly in velocity, substrate, and depth characteristics. These areas should be characterized by using conventional instream flow methods by placing transects and verticals as close together as is practically possible at the boundaries of stream sections with more homogeneous habitat parameters. After areas that are quantifiably different have been located, block off as small a stream section of a particular habitat type that can be effectively blocked by seines without affecting the relative abundance of different fishes in that section and then thoroughly sample each section by repeated electrofishing passes (i.e. depletion sampling). Record the relative number of each species as well as the relative number of juveniles versus adults. If habitat preferences differ between species or between juveniles and adults of a species, the relative numbers collected in different types of habitats should show significant differences and could be used to supplement habitat data collected by visual observations and electrofishing. It would be desirable to conduct this sampling either with permanent instream flow study reaches or in reaches which could be characterized by WSP simulation in order to know the relative availability of different combinations of habitat types available for use by the fish species. In either case, the blocking off of sections for fish sampling would have to be based on the observed differences in habitat parameters at the time of sampling.

It would be desirable to set the block seines both at night and during the day to determine diurnal differences in habitat preferences;

the actual collection of fish could be done during the daytime. Although difficulties in assuring an effective blockage of fish movements is recognized, we feel this approach may be useful when determining the habitat preferences of species which cannot be observed easily or modify their location in the stream because of sampling efforts. It would also be desirable to evaluate potential seasonal differences in habitat preferences by sampling throughout the year. In particular, the habitat needs of a species may differ greatly between winter and summer, depending on the magnitude of the seasonal or diurnal shifts in water temperature and flow. Likewise, the presence of other aquatic organisms (e.g. fishes, invertebrate prey species) which affect the behavior of the species in question by either competition, predation or serving as a food source could have substantial impacts on the habitat preferences of fishes and should be considered when analyzing data on habitat preferences between different areas or waters.

General Recommendations

When considering the initiation of an instream flow study using the Incremental Methodology, the researcher should carefully read Bovee (1982) for recommended procedures. The need for close contact with CIFSG personnel throughout an instream flow study becomes increasingly important if the researcher has only limited familiarity with the methodology. The development and modification of the Incremental Methodology in the last few years has resulted in the availability of a versatile and valuable tool which can provide a rational and sophisticated approach to instream flow analysis. However, the ability to use this methodology properly is largely dependent on the user becoming thoroughly familiar with the methodology through short courses and direct contact with personnel who are

intimately knowledgeable of the intracacies and pitfalls associated with the method. Unless the researcher has considerable experience with the methodology in similar streams, we recommend involving a member of the CIFSG in the early phases of all instream flow studies. This involvement may require the on-site presence of a knowledgeable person to assist in scoping, site selection and placement of transects (especially if a WSP simulation is desirable) for types of streams which have not been evaluated previously with the Incremental Methodology (e.g. desert streams with unpredictable flow regimes).

In the case of undammed streams with unstable substrates and either unpredictable or poorly documented flow patterns, it is important to make the field measurements over as short a time interval as possible for an IFG4 hydraulic simulation. As stated previously, a 2- to 4-week period when discharge can be expected to decrease (e.g. near end of snowmelt runoff or rainy season) is a good time to make measurements; this is especially true if it is difficult to reach the stream on short notice or if the instream flow study team either cannot be maintained intact or be available when the streamflow conditions require fieldwork. For an IFG4 simulation of Burro Creek with a desirable range of discharges (e.g. 5 to 25 $ft.^3/sec.$), the necessary field measurements could have been taken only in the latter half of March and again in late April during the 1981 water year. For undammed desert streams, it would always be good insurance to take the appropriate field measurements for a WSP simulation at a discharge near the median flow during low-water periods.

When collecting habitat data to develop probability-of-use or habitat preference curves, the researcher should typically discuss the most

desirable methods with individuals who have personal sampling experience with the target species in the waters to be sampled. Prior to data collection, the recommendations and methods in Bovee (1981) should be reviewed to minimize sampling and environmental biases when collecting habitat data; this may require obtaining the data with innovative methods tailored to the particular species and streams. Consultations with CIFSG personnel and other experts should be mandatory. If electrofishing or other active sampling methods are used to collect data on habitat preferences, the researcher should provide space on the data forms to describe and rank the degree of avoidance and behaviorial modification associated with the collection of each fish or group of fishes; a coded ranking or descriptive system may be helpful. Data forms should also provide space to record water temperature and transparency, cover, associated species and general comments.

Our experience with sampling in clear desert streams suggests that it would be a good idea to periodically utilize a pre-positioned, stationary observer who can watch the reaction of the fish to the approach of the sampling team. When possible, direct observations of fish movements in areas where a grid system can be set up in advance probably offers the best opportunity to obtain unbiased data on fish habitat preferences. This approach may require the use of binoculars, polaroid glasses and elevated platforms, but should always be included with other methods for obtaining habitat data when feasible. As discussed earlier, it is obvious that habitat preferences of the same species will vary from one type of stream to another because of differences in the types and combinations of physical habitat parameters (e.g. substrate, cover, water depth) and probably because of the presence

or abundance of other aquatic and semi-aquatic species. Likewise, seasonal and diurnal differences in habitat preferences are probably significant in most streams and should be evaluated whenever appropriate and economically feasible. For some of the smaller fishes (e.g. cyprinids) and for fry and juveniles of larger fishes it appears that habitat preference data may be obtained by the use of observations in laboratory streams or specifically modified reaches of natural streams.

In all cases, it would be highly desirable to document the actual availability of different combinations of habitat parameters for the specific areas where the habitat preference data are collected. When feasible, the inclusion of sufficient field measurements to allow either an IFG4 or WSP simulation of the sampling sites would be appropriate; a grid map which describes habitat parameters such as instream cover, streambank conditions, and aquatic and riparian vegetation should be included. In some cases, it may be practical and necessary to sample a range of relatively homogenous stream sections (e.g. equivalent to specific cells in a hydraulic simulation) to augment other habitat preference data. The ability to effectively segregate these cells may be difficult with block seines, but some habitats and fishes may lend themselves to this approach. Although many of the previous recommendations are difficult to put into effect and often time-consuming, the availability of meaningful habitat preference curves are critical to the use of the Incremental Methodology. Our experience with modifying the probability-of-use curves for adult Meda and Tiaroga indicate the major impact of even relatively minor changes in the weighting factors on the predicted weighted usable area at various discharges.

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