FINAL REPORT
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FISHERY INVESTIGATION OF THE COLORADO RIVER FROM GLEN CANYON DAM TO THE CONFLUENCE OF THE PARIA RIVER:

ASSESSMENT OF THE IMPACT OF FLUCTUATING FLOWS ON THE LEE'S FERRY FISHERY

Federal Aid in Sport Fish Restoration
Dingell Johnson Project F-14-R-14

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INTRODUCTION

When Glen Canyon Dam was closed on the Colorado River in 1963, the Arizona Game and Fish Department (AGFD) recognized the potential for a cold-water tailwater fishery and began a stocking program with catchable-sized rainbow trout (*Salmo gairdneri*). Arizona Game and Fish Department has stocked the tailwater with trout since the closure of the dam (Appendix A1). Between 1964 and 1976 the fishery was managed as put-and-take and in 1976 the first all-fingerling stockings were made. The Glen Canyon or Lee's Ferry fishery developed rapidly, and following the introduction of freshwater shrimp (*Gammarus lacustris*) in 1968 has been one of Arizona's top trout waters. This 26 km stretch of river has yielded trophy-sized rainbow trout, some over 8.6 kg, and in 1980 produced a state record (2.3 kg) brook trout (*Salvelinus fontinalis*). In addition, the Grand Canyon, immediately downriver, supports an excellent rainbow trout fishery as a result of AGFD, National Park Service and U.S. Fish and Wildlife Service introductions (Appendix A2). Lake Powell, formed by closure of Glen Canyon Dam, is a deep, cold-water release reservoir built primarily for power production. In recent years, plans to increase power output of the dam raised concerns about the tailwater fishery. Proposed peaking power operations would cause a more rapid fluctuation in daily and seasonal releases and cause higher peak flows and longer duration low flows. Potential impacts of peaking flows on Glen and Grand canyons were evaluated by a Biological Resources Needs Subteam in 1978. Using a scale of low, moderate, high, or extreme, the subteam classified the biological impacts on the Colorado River as high. AGFD shared these concerns and pointed out that the altered flows could be detrimental to the Lee's Ferry trout fishery.

The impact of regulated flow on trout fisheries is one of the most widely studied subjects of tailwater streams. Low flows can reduce the quantity and quality of trout cover, increase overwintering mortality, and cause stranding (Parsons 1957, Weber 1959, Vincent 1969, Nelson 1977). High flows can be limiting to certain life stages of trout. Larger fish may be favored over small fish because of a lack of resting cover (Banks et al. 1974, Mullan et al. 1976). Rapid flow fluctuation can cause stranding of both trout and salmon (Anderson 1972, Kroger 1973, Fowler 1978). Fluctuating flows can also cause reduced trout reproduction by scouring and dewatering redds (Parsons 1957, Corning 1970). Dewatering can also reduce egg and larval survival (Corning 1970, Nelson 1977).

Cladophora beds frequently develop in cold tailwaters and can be an important food source for trout (Moffett 1942, Mullan et al. 1976). Trout graze on these algae and ingest the plant material and the isopods, amphipods, snails and other invertebrates associated with the Cladophora (Moffett 1942, Parsons 1957, Welch 1961, Mullan et al. 1976). Fluctuating flows and periodic dewatering may limit production of algae and associated fish food organisms by creating a zone of fluctuation where little production can occur.

Periodic dewatering of stream margins and current velocity fluctuations over submerged areas of the stream bed due to peaking flow fluctuation have reduced macroinvertebrate standing crops and community complexity in several streams (Radford and Hartland-Rowe 1971, Fisher and LaVoy 1972, Bruvsen et al. 1974, Trotsky and Gregory 1974). Because tailwater trout rely on invertebrates for food, fluctuating flows which impact plants and invertebrates can also affect trout.

The objective of this study was to determine the biological impact of fluctuating water levels on the fishery of the Colorado River from Glen Canyon Dam to just below the mouth of the Paria River (Lee's Ferry). Our primary objective was to determine the effect of fluctuating flows on salmonid spawning success and on the salmonid food base. Secondary objectives included: 1) evaluation of stocking procedures to enhance retention of maximum numbers of stocked trout above Lee's Ferry, 2) evaluation of the effect of various flow regimes and stocking procedures on harvest and year-class strength of Lee's Ferry trout, and 3) evaluation of the contribution of hatchery fish to the creel.

SITE DESCRIPTION

Glen Canyon Dam, one of the last major impoundments to be constructed on the Colorado River, was closed 19 km below the Arizona-Utah border in 1963. The tailwater is navigable to motorized watercraft for 26 km from the border of the Grand Canyon National Park to the dam with access at Lee's Ferry (Fig. 1). Below the Park boundary, the river is unsafe for

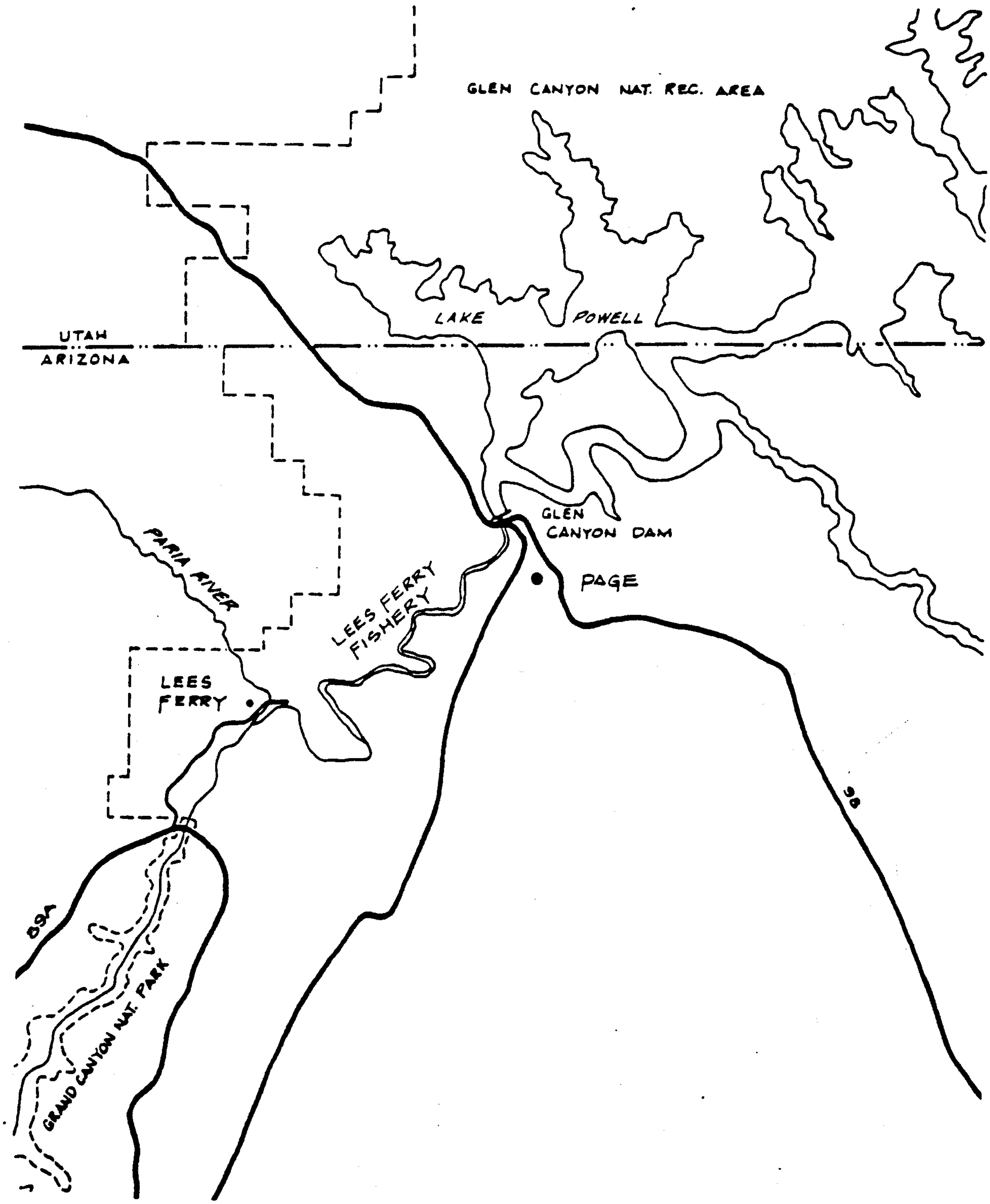


Figure 1. Map of Arizona and Utah showing location of Lee's Ferry fishery.

conventional boat travel. The National Park Service controls access below this point through issuance of permits for river travel.

Great variation in annual streamflow occurred prior to the construction of Glen Canyon Dam. The pre-dam seasonal flow pattern of the Colorado River was generally unimodal with maximum flows occurring during May and June. Peak flows now occur during the summer to accommodate power and irrigation demands as well as in mid-winter to meet power demand (Fig. 2). Discharge at Glen Canyon Dam also varies daily in response to periods of peak energy demand. Highest discharge occurs during the daylight hours and lowest discharge occurs from midnight to 8:00 AM to meet peak daily electrical demand (Fig. 3). Maximum and minimum discharges are attenuated by river storage, bank storage, channel geometry, and water velocities as they travel downriver.

Common discharge patterns are: 1) typical peaking discharges, 2) short-term low discharges and 3) extended high or low discharges. Peaking power operations produce short duration high and low flows. Short term low discharge results from low energy demand on weekends, holidays, or during maintenance activities at the dam. For example, on January 1 and January 13, 1981 the average daily discharge was below 1,500 cubic feet per second (cfs) and flow remained low for 9 to 12 hours.

An extended duration low discharge occurred in March 1979 when average daily flow remained below 2,000 cfs for 12 consecutive days. An extended duration high discharge occurred during this study when Lake Powell reached full capacity.

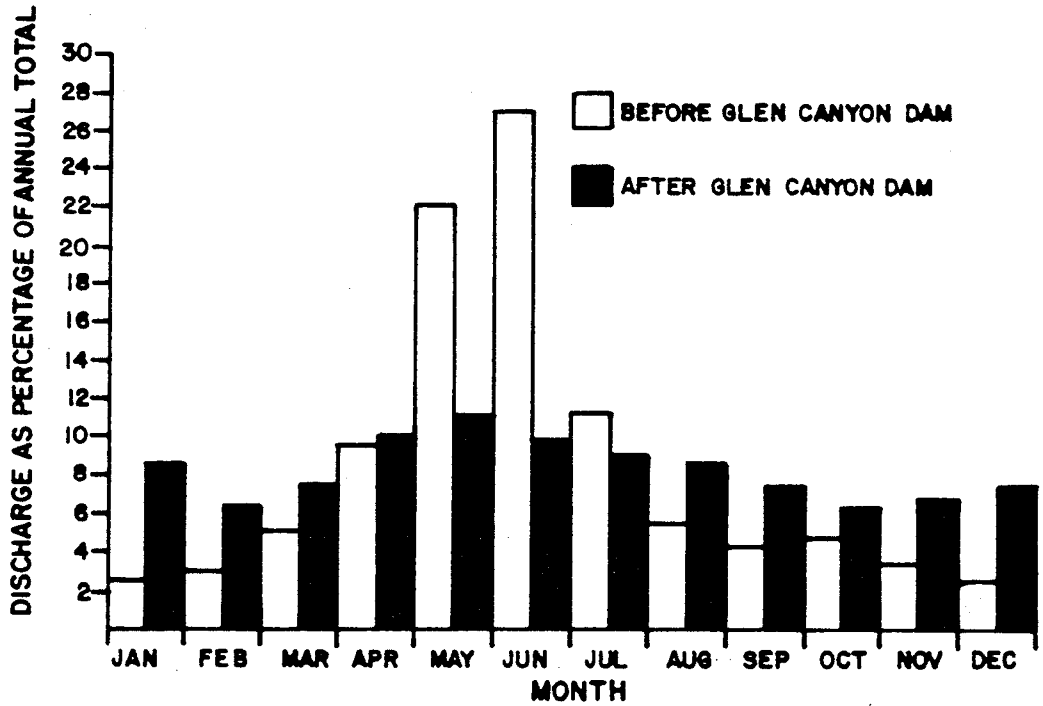


Figure 2. Monthly mean discharge as a percentage of total annual discharge, Colorado River, Lee's Ferry; open bars, period before Glen Canyon Dam (calendar year 1901 through calendar year 1962); solid bars, period after Glen Canyon Dam (April 1963 - March 1977) (Turner and Karpiscak 1980).

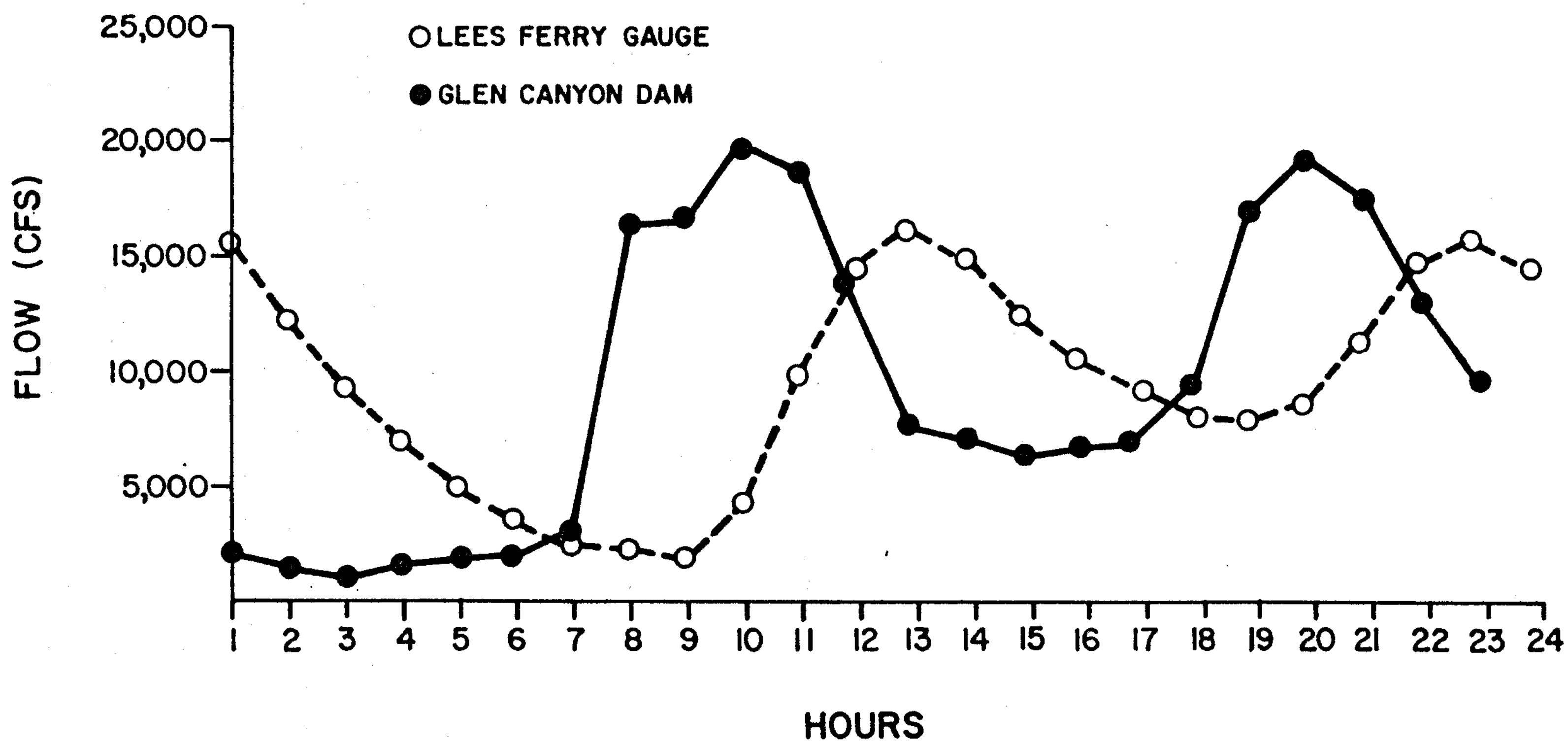


Figure 3. Typical daily Glen Canyon Dam releases and recorded flow at Lee's Ferry gauge (U.S. Bureau of Reclamation 1982).

Average daily flow remained above 25,000 cfs during July and August 1980.

METHODS

We randomly sampled the benthic macroinvertebrate community along the water fluctuation zone with a mini-ponar bottom dredge. In heavily armored areas, cobble was removed and the underlying substrate examined to a depth of 10 cm. Substrate and periphyton samples were washed through a 600 um screen and individually preserved in AFA (ethyl alcohol, formalin, acetic acid) for later analyses. Grab samples of *Cladophora* were also collected in the main channel by SCUBA divers.

Fish were collected at river km 6, 14, and 21 on the Colorado River. Sampling stations were selected with a non-uniform habitat including a riffle, run, reverse eddy, and deep water (>3m). Permanent sampling stations with variety of habitats were regularly sampled to compensate for errors associated with non-random movement or preferential habitat use. Fish nomenclature follows a list prepared by the American Fisheries Society (Bailey et al. 1980) (Appendix B). A list of common and scientific names of plants identified during the study is presented in Appendix C. Shallow backwaters that appeared to be potential trout nurseries were regularly examined and periodically seined for fry during the spring and early summer.

The lower Paria River was sampled with a hoop net (1.5 m diameter) modified with a 7 m trammel net extending from the throat. In the shallow reaches above the Paria River bridge, fish were seined with an 8 m beach seine (8 m by 1.5 m with 3.2 mm mesh) and a 1 m "kick" seine (1 m by 1 m, 3.2 mm mesh).

A winter survey of spawning habitat was conducted in 25 tributaries of the Grand Canyon (Fig. 4). Spawning trout were collected from the lower portion of the tributaries by seine, hook and line, or by hand.

Fish were collected from the Colorado River with an electrofisher and a weighted trammel net (100 x 1.8 m) with 35.5 cm bar mesh outside walls and 3.18 cm inside bar mesh. The net was drifted at low flows during the dark hours, usually between 3:00 and 5:00 A.M. Fish were held in a live box until dawn when they were placed in a mild solution of tricane methane sulfonate (MS222). When shallow opercular movements were observed, fish were weighed and measured and a color-coded tag was attached about 10 mm below the dorsal fin on the left side. Carp and suckers were tagged with plastic-coated spaghetti tags while trout were tagged with color coded disk tags sewn to the dorsum with 2.7 kg test monofilament fishing line. A tag return box and measuring board were placed near the launch ramp at Lee's Ferry where anglers were asked to return tags from creeled fish with catch and size information.

A subsample of each species was sacrificed and inspected for disease and endoparasitism. Ovaries were removed and weighed to evaluate reproductive condition and stomachs were preserved for later diet analyses. Trout stomach contents were identified and counted and the life stage of major aquatic insects in the diet was noted. Scales were removed from the left dorsum.

Coefficient of condition was calculated with the formula:

$$K_{tl} = W_g \times 10^5 / TL_{mm}^3$$

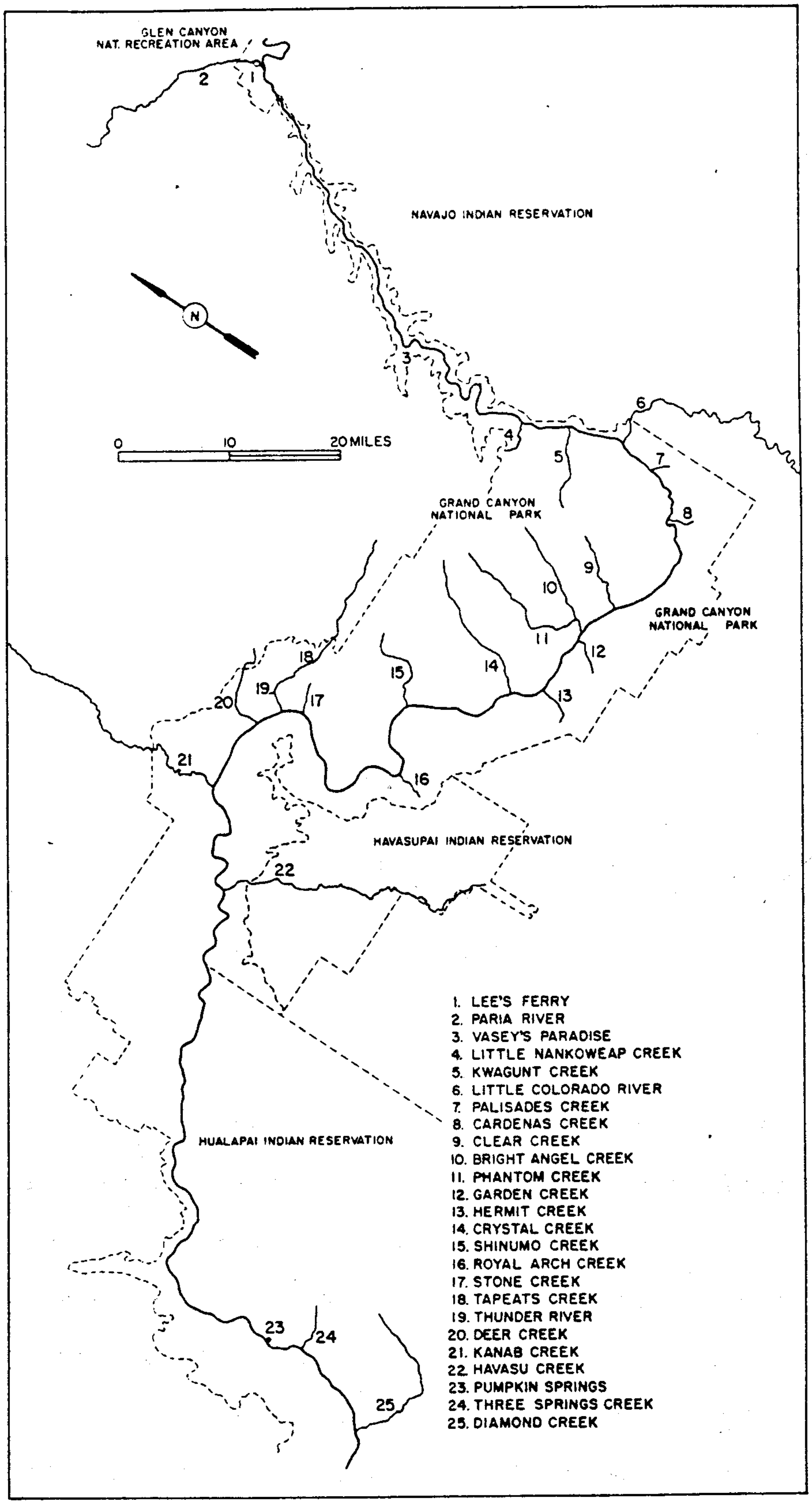


Figure 4. Map of the Colorado River in Grand Canyon showing locations of tributary sampling stations.

where W_g = weight in grams and TL_{mm} = total length in millimeters.

RESULTS

Water quality

Trout are found in most tailwaters throughout the United States where summer water temperatures normally do not exceed 21.1 °C (Walburg et al. 1981). Tailwaters below most deep release reservoirs have low turbidity, cold water, and stabilized seasonal flow that provide satisfactory trout habitat. Optimal oxygen levels for trout are not well documented but appear to be greater than 7 mg/l at temperatures less than 15 °C (Raleigh et al. 1984). Dissolved oxygen at Lee's Ferry was 8 -12 mg/l which is within the optimum range. Optimal temperature range is thought to be 12 to 18 °C and trout can probably tolerate a pH range of 5.5 to 9.0 (Raleigh et al. 1984).

The aquatic ecosystem of the Colorado River was markedly changed during the period when Glen Canyon Reservoir was filling. As a hypolimnion formed in Lake Powell, river temperatures that once ranged from 1 - 28 °C were restricted to 8 - 14 °C with a mean of approximately 9 °C. Water temperatures of the hypolimnetic releases have been relatively uniform in recent years with an annual mean slightly greater than 9 °C and seasonal variations usually less than 4 °C (Table 1). Clear water released from Glen Canyon Dam increased the sediment transport capacity of the river, and by 1975 about 9.87×10^6 m^3 of bottom

Table 1. Mean monthly water temperature (^{o}C) of the Colorado River at Lee's Ferry 1969 - 1982 (U.S.G.S. Water Resources data).

	Month												
Year	J	F	M	A	M	J	J	A	S	O	N	D	Mean
1969	8.6	7.6	8.5	9.1	10.5	12.8	14.5	16.0	17.5	14.0	-	-	11.9
1971	8.0	-	8.0	9.0	-	9.5	11.5	12.0	12.5	13.0	-	-	10.4
1972	8.0	8.5	9.5	10.0	11.0	12.0	12.5	11.5	11.5	11.0	9.5	8.5	10.3
1973	8.0	8.0	7.5	7.0	7.0	8.2	8.5	9.5	9.8	9.5	9.0	9.2	8.4
1974	8.5	7.5	8.0	8.5	9.0	8.5	8.0	8.0	8.0	7.5	8.0	9.5	8.2
1975	8.0	-	8.0	8.0	8.5	10.0	10.0	9.5	10.0	10.0	10.0	9.5	9.2
1976	8.0	8.0	8.0	8.5	9.0	10.0	9.5	10.0	10.0	10.0	9.0	10.0	9.1
1977	8.0	9.0	9.0	11.0	12.0	11.0	11.0	10.0	10.0	9.0	9.0	8.0	9.9
1978	9.0	9.5	8.0	9.5	9.0	10.0	10.0	10.0	12.0	11.4	11.5	10.6	10.0
1979	9.5	8.3	9.0	9.4	9.4	9.5	9.2	8.0	9.0	8.0	6.0	7.0	8.5
1980	8.0	10.0	8.5	8.5	7.0	9.0	13.0	9.5	10.0	-	9.5	9.5	9.3
1981	9.5	8.5	10.5	10.0	10.0	10.5	12.0	10.0	10.0	11.7	-	-	10.3
1982	-	7.8	8.5	9.0	9.7	9.8	9.6	9.5	9.4	-	-	-	9.1
Mean	8.5	8.4	8.5	9.0	9.3	10.1	10.7	10.3	10.8	10.5	9.1	9.1	9.5

sediment had been removed from the river channel within the reach between the dam and the mouth of the Paria River at Lee's Ferry (Turner and Karpiscak 1980). As this material was removed, coarser material was exposed, resulting in channel armoring and a pavement like channel bed dominated by large, coarse sediments. Water releases are clear year round and only occasionally does the river appear gray-colored from surface runoff over Manson Mesa. Secchi disc measurements were clear to the bottom (3-5 m) throughout the study period. Light penetration readings in February 1980 and August 1981 were 1 and 2 JTU's (Jackson Turbidity Units) respectively. Below Lee's Ferry, water clarity decreases due to sediment input from tributaries, particularly the Paria River, Little Colorado River, and Kanab Creek.

Aquatic and riparian flora

Before Glen Canyon Dam was constructed, the sandy river bottom of the Colorado was scoured by seasonal spates which prevented the growth of most aquatic vegetation. Regulated flows, decreased turbidity, and stabilization of the substrate aided development of the aquatic plant community. Filamentous algae, (*Cladophora glomerata*), quickly became established in this altered environment. Stimulated by increased light penetration, nutrient availability and substrate stability, *Cladophora* thrived and by 1969 large beds extended as far as 8 km below Glen Canyon Dam (Mullan et al. 1976). Large *Cladophora* beds are now found more than 98 km downstream to the mouth of the Little Colorado River.

Distribution and abundance of aquatic plants in tailwaters influences aquatic invertebrate productivity and ultimately the productivity of the fishery. Extended duration low flow periods can desiccate *Cladophora* beds, the most common aquatic plant at Lee's Ferry. Preliminary results of lab experiments indicated that 12 hours of dewatering will kill *Cladophora* (Dean Blinn, Northern Arizona University, personal communication). High flows can also affect *Cladophora* by detaching and scouring. Removal of vegetation by high flows in the Bull Shoals tailwater adversely affected trout growth the following year (Parsons 1957).

General observations by study personnel indicated that highest concentrations of *Cladophora* bordered the lower edge of the zone of water fluctuation. Uniform water temperature allowed continuous algal growth with no yellow or brown discoloration that is indicative of algal dieoff in waters with cyclic seasonal temperatures.

Poolmat was the most common macrophyte and often grew in complex with *Cladophora*. Stands of poolmat were most abundant along the extreme lower edge of the fluctuation zone, suggesting that it is less tolerant to dewatering than *Cladophora*. Water weed was collected from two sites: near the launch ramp at Lee's Ferry and approximately 14 km below the dam.

Emergent vegetation was primarily sedges. Bullrush and cattail were found in isolated stands along the river corridor. Common reed and horsetail grew from alluvial deposits at the edge of the high water line.

Aquatic invertebrates.

Post-impoundment studies indicated that the tailwater's depauperate benthic invertebrate fauna was typical of the erosive silt-laden Colorado River. Abundance estimates were low and limited to a small bloodworm (Chironomidae larvae) and a black snail (Helisoma sp.) (Stone 1964, 1972).

Arizona Game and Fish Department introduced a variety of invertebrates in 1968 to improve the forage base for trout. Introductions included crayfish, snails, mayfly larvae, freshwater shrimp (Gammarus), caddisfly larvae, leeches, dragon fly and damsel fly niads, water boatmen, backswimmers, water striders, beetle larvae, cranefly larvae, and midge larvae (Stone 1972). Gammarus and midges became established and were important trout food items.

We collected aquatic invertebrates to evaluate the quantity and quality of fish food organisms in the tailwater. Mini-ponar dredge samples contained primarily midges (64%) and Gammarus (32%) (Table 2). Chironomidae larvae composed 96% of the midges. Although dredge samples were primarily comprised of midges, grab samples of Cladophora contained mostly Gammarus (90%). Invertebrates were most abundant in Cladophora mats located at the lower edge of the water fluctuation zone. Estimates of number of Gammarus per gram of Cladophora collected by grab sample ranged from 0.4 to 1.8 and averaged 0.7/g wet weight.

Gosse (1981) also reported invertebrates to be most numerous in plant beds at Lee's Ferry, with highest numbers of Gammarus

Table 2. Number and percentage composition of organisms collected by mini-ponar and grab samples, Lee's Ferry, 1980-81.

	Mini Ponar Samples[a/]		Grab Samples[b/]	
Organism	Number	Percent	Number	Percent
Gammarus	213	32.4	1,190	89.7
Chironomid larvae	404	61.5		
Chironomid pupae	4	0.6		
Chironomid adult	15	2.3		
Total Chironomid	423	64.4	7	0.5
Oligochaets	21	3.2	33	2.5
Physa			96	7.2
Total	657		1326	

a/ Five samples collected January 12, 13, 1980.

b/ Eleven samples collected December 4-6, 1981.

collected from plant beds in lower water velocities. Gosse's (1981) invertebrate collections contained a substantially higher percentage of *Gammarus* and reflected higher invertebrate densities than our work. These differences are probably due to Gosse's use of more efficient sampling gear. Although relative abundance of *Gammarus* and midges varied widely within and between sampling methods, *Gammarus* and midges made up more than 90% of invertebrates collected by either method.

The benthic invertebrate community at Lee's Ferry developed a low diversity, high density pattern similar to other tailwaters with isothermal temperatures and fluctuating flows (Walburg et al. 1981). The benthos was dominated by invertebrates able to withstand constantly changing environmental conditions. The success of invertebrate introductions was probably aided by the development of *Cladophora* beds which provided an excellent substrate for *Gammarus* and midges.

Fishes

Six species of fish were collected by drifting trammel nets and electrofishing above Lee's Ferry. Rainbow trout and flannelmouth sucker combined made up 84.3% of the fish collected (Table 3). Rainbow trout averaged more than 50% of the catch at all stations whereas flannelmouth sucker made up 27% of the catch. Brook trout, first released in 1977, made up 8% of the catch. Eleven cutthroat trout representing 1% of the catch were collected during the study. These were probably remnants of a cohort of 43,000 fingerlings experimentally released in December

Table 3. Number and percentage composition of fishes collected at Lee's Ferry and Colorado River tributaries.

Species	Lee's Ferry						Paria River		Other Tributaries	
	Dam	I	II	III	Total	(%)	No.	(%)	No.	(%)
Rainbow trout	83	177	195	112	567	(56.8)			368	(96.1)
Brook trout	17	1	47	14	79	(7.9)			9	(2.3)
Brown trout									4	(1.0)
Cutthroat trout		2	5	4	11	(1.1)	3	(0.6)		
Flannelmouth sucker	35	76	83	80	274	(27.5)	103	(19.7)		
Bluehead sucker		3	21	11	35	(3.5)	1	(0.2)	1	(0.3)
Carp	18	3	11	0	32	(3.2)				
Speckled dace							416	(79.5)	1	(0.3)
Total	153	262	362	221	998		523		383	

1978. Brown trout are infrequently reported from the Lee's Ferry fishery and were not collected or reported in the creel during the study. Bluehead mountain sucker were collected from 3 stations and represented 4% of the catch. Carp were collected at every station and composed 3% of the catch. Speckled dace were common in the shallow reaches of the Paria River and were occasionally taken from the cold water interface near the mouth of the Paria River. Flannelmouth sucker were also common in the Paria River.

Other species have entered the fishery from Lake Powell through penstocks and turbines at Glen Canyon Dam. In January 1980, a 250 mm striped bass was found stranded on a gravel bar 12 km below the dam. Threadfin shad and channel catfish were reported from the tailwater in the late 1970's (Dennis Darr, Arizona Game and Fish Department, personal communication). When the reservoir reached full capacity in June 1980, striped bass and walleye entered the river through the spillway. Anglers reported striped bass and walleye near the dam for two weeks following the surface releases. Two striped bass and one walleye were recorded in the creel in the summer of 1980.

Fish were also collected in tributaries of the Colorado River downriver from Lee's Ferry during January and February 1982 to evaluate the use of Grand Canyon National Park tributaries by spawning trout. Rainbow trout was the most common species found in all tributaries examined (Table 3). Eleven tributary creeks including Bright Angel, Clear, Crystal, Phantom, Shinumo, Tapeats, and Havasu Creeks were used as spawning areas by rainbow trout (Appendix D). Brook trout and brown trout were also occasionally collected.

Fish tagging

Hatchery fish and fish collected in the field were tagged to determine their movement in the tailwater. Hatchery rainbow trout (245 mm), brook trout (224 mm), and cutthroat trout were tagged and released at Glen Canyon Dam, Nine-mile bar, and Lee's Ferry boat ramp (Table 4).

Approximately 3% of hatchery rainbow trout, and 1% of brook trout were returned. Only 1 cutthroat trout was returned. Low rate of return of marked fish may have been due to extensive tag loss (Don Randall, Arizona Game and Fish Department, personal communication) and by movement out of the study area. Although rate of return was low, a higher percentage of fish released at Nine-mile bar were returned than those released at other locations.

Within the study area rainbow trout were recaptured an average distance of 4.2 km from the release site, brook trout an average of 5.4 km, and cutthroat trout an average of 8.7 km. Some of these fish were tagged in the field (Table 5). In general, hatchery fish were recaptured upstream from their release point and fish marked in the field were recaptured downstream from their release point. Reasons for this trend are unclear.

Although there was little effort to collect fish below Lee's Ferry, movement out of the study area was confirmed by the

Table 4. Summary of recapture of hatchery reared rainbow, brook, and cutthroat trout by release location, Lee's Ferry, 1980-81. Percentage recaptured in parentheses.

Species	Release location	Number Released	Number Recaptured
Rainbow trout	Glen Canyon Dam	323	7 (2.2)
	Nine-Mile Bar	297	12 (4.0)
	Lee's Ferry Ramp	266	10 (3.8)
	Total	886	29 (3.3)
Brook trout	Glen Canyon Dam	305	2 (0.7)
	Nine-Mile Bar	298	8 (2.7)
	Lee's Ferry Ramp	283	3 (1.1)
	Total	886	13 (1.5)
Cutthroat trout	Glen Canyon Dam	310	1 (0.3)
	Nine-Mile Bar	331	0
	Lee's Ferry Ramp	216	0
	Total	857	1 (0.1)

Table 5. Number of fish tagged in the field and recaptured in Glen Canyon tailwater, 1980-81. Percentage in parentheses.

Species	Number Tagged	Net Recaptures	Angler Returns	Percentage Recaptured
Rainbow trout	405	7	51	(12.6)
Brook trout	69	1	4	(5.8)
Cutthroat trout	10	1	2	(20.0)
Flannelmouth sucker	374	6	1	(0.2)
Bluehead sucker	34	0	0	
Carp	36	2	0	

recapture of three brook trout in Grand Canyon National Park. Fish were recaptured 13, 19, and 99 km downriver from Lee's Ferry. Stone (1966) reported the recapture of three 400-430 mm fin-clipped rainbow trout 5 km below Lee's Ferry at the head of Cathedral Rapids. Stone (1968) also recaptured a marked fish 27 km below Lee's Ferry, 9 days after it was stocked in March 1968.

Movement into the study area from downriver was confirmed by the collection of five flannelmouth sucker tagged in 1978 by Carothers and Minckley (1981) in the Paria and Little Colorado Rivers (Appendix E). However, none of the 141 rainbow trout tagged in Grand Canyon National Park during 1978 were recaptured in the Lee's Ferry fishery.

Information on movement of rainbow trout within the Park comes from the capture of a single trout at Pipe Creek (River Mile 89) on January 30, 1982. This fish had been tagged at River Mile 59, 48 km upstream, on October 27, 1981 (Lynn Kaeding, U.S. Fish and Wildlife Service, personal communication).

During the period 1963 -1970 catchable and sub-catchable (200 - 300 mm) rainbow trout were marked by fin clip and streamer tags before release at Lee's Ferry (Stone 1964 - 1971). Stone estimated the percent return to the creel, or number captured with the formula:

$$\frac{\text{Number of marked fish checked}}{\text{Number of fish checked}} = \frac{\text{Estimate of total recaptures}}{\text{Estimated harvest}}$$

The average exploitation rate for the period 1963-1968 when good data were available was 0.26; using the same procedure for 886 marked hatchery rainbow trout released in 1980, we estimated an exploitation rate of 0.38 for the period 1980-1981 (Table 6). The exploitation rate has evidently increased since the early days of the fishery.

Stomach contents

Stomach contents of rainbow trout were examined to determine the quantity and quality of food consumed. Freshwater shrimp (*Gammarus lacustris*) and midges (Chironomidae) were the most numerous items found in trout stomachs, and occurred in more than 60% of stomachs containing food items (Table 7). *Cladophora glomerata* was found in more than 55% of stomachs examined and composed a relatively large percentage of stomach content volume. Other food habit studies in Colorado River tailwaters have shown that plant material may represent as much as 90% of trout stomach contents (Moffett 1942, Stone 1964, Binns 1967, Pearson 1967). Trout in the Lee's Ferry area were observed consuming drifting *Cladophora*, but its nutritional value is unknown. Trout may be feeding primarily on *Gammarus* associated with the *Cladophora*, but may derive coincidental nutritional benefit from diatoms ingested along with the *Cladophora* (L. Montgomery, Northern Arizona University, personal communication).

Age and Growth

We were unable to age fish by conventional scale and otolith methods, probably because of the relatively constant water

Table 6. Number marked (M), estimated first year recaptures (R1), estimated second year recaptures (R2), annual survival rate (S), and exploitation rate (u) for Lee's Ferry rainbow trout, 1963-68 and 1980-81.[a]

Date marked	M	R1	R2	S	u
11/18/63	2000	150	62	0.41	0.08
12/16/63	2000	360	82	0.23	0.18
5/ 4/64	1500	102	62	0.61	0.07
12/ /65	750	82	43	0.52	0.11
4/15/66	750	624	180	0.29	0.83
9/12/66	750	97	7	0.04	0.26
3/24/67	1200	322	156	0.49	0.27
1/18/68	2500	726	79	0.11	0.29
Mean 1963-68				0.34	0.26
1980-81	886	337	-		0.38

a/ Stone 1964 - 1968, Arizona Game and Fish Department Section 8 reports.

Table 7. Mean number per stomach and frequency of occurrence of organisms in stomachs of rainbow trout collected by trammel net, April 1980 - March 1981 (n=102).

Food item	Mean Number per Stomach[a/]	Frequency of Occurrence
Invertebrates		
Gammarus lacustris	26.9	69.0
Physella spp	1.3	24.1
Chironomidae		
Adult	15.0	20.7
Pupae	93.1	60.9
Larvae	38.5	56.3
Hirudinea	0.1	1.1
Orthoptera	0.1	3.4
Odonata	t[b/]	2.3
Unidentified insect	0.2	5.7
Plants		
Cladophora glomerata	-	55.2
Unidentified plants	-	5.7
Other		
Stones	-	9.2
Twigs	-	9.2
Feathers	-	1.1
Fish eggs	-	1.1
Unidentified organic matter	-	3.4
Bait worms	0.2	8.0
Empty[c/]		14.7

a/ Mean number per stomach of stomachs containing food

b/ t <= 0.5

c/ Fifteen empty stomachs

temperature at Lee's Ferry. Growth of rainbow trout was estimated from return of marked fish in the creel and growth of brook trout and cutthroat trout was estimated by following the first stocked cohort of each species through the creel. Growth rates of all three trout species were good compared to other areas (Table 8). The relatively good growth of trout in Lee's Ferry may be due to a variety of factors including relatively constant water temperature near the optimum for trout growth, good food supply, and possibly strain vigor.

Mean monthly condition factor of 571 rainbow trout creeled at Lee's Ferry from April 1980 to March 1981 was 1.41, indicating that rainbow trout were in relatively good condition. Rainbow trout collected in the Grand Canyon during the winter of 1982, on the other hand, had a mean condition factor of 0.81. No seasonal trends in condition factors were evident.

Reproduction

Lee's Ferry rainbow trout spawn primarily during late fall and winter. Ripe male trout were encountered from September through March and spent females were observed from October through April. Monthly mean gonadal somatic indices [(Ovary weight/total weight) x (100)] of females were highest during fall and winter. Most redd construction and spawning was observed during the fall and winter months. Depending on the strain, rainbow trout can spawn at almost any month of the year. Some spawning may occur throughout the year because of the number of different strains stocked at Lee's Ferry (R. Sorensen,

Table 8. Estimated total length of rainbow, brook, and cutthroat trout at Ages I - III, Lee's Ferry and other waters.

Species	Location	I	II	III	Source
Rainbow trout	Lee's Ferry	378	470	564	Length frequency of creel (1977-84)
	Lee's Ferry		437	540	Fin clip recaptures (1980-81)
	Western lakes	236	325	388	Carlander (1969)
	Western streams	173	231	287	Carlander (1969)
	Midwestern streams	160	213	343	Carlander (1969)
Cutthroat trout	Lee's Ferry		374	448	Marked fish recaptures (1980-81)
	Lee's Ferry		254	457	Length frequency of creel (1980-81)
	U. S. Mean	86	145	211	Carlander (1969)
Brook trout	Lee's Ferry	189	404		Length frequency of creel (1977-84)
	U. S. Mean	155	196	241	Carlander (1969)

Arizona Game and Fish Department, personal communication). Lack of a precisely timed spawn could account for the lack of change in rainbow trout condition factors at Lee's Ferry.

Spawning activity was observed on eighteen cobble bars during the study period, and all of these spawning areas were located within the zone of water fluctuation. Seining of potential nursery areas and SCUBA surveys collected and observed few fry. During the two year study period, trout fry were observed on only three occasions (Don Randall, Arizona Game and Fish Department, personal communication). Six fry were collected just above Nine-mile bar from approximately six inches of water (Jim Burton, Arizona Game and Fish Department, personal communication).

Substrate in the Lee's Ferry area appears to be larger than optimum for rainbow trout spawning. Hooper (1973) and Orcutt et al. (1968) reported preferred spawning gravel diameter to be 13 - 38 mm. Most particles in the river bed below Glen Canyon dam ranged from 76 - 126 mm (Pemberton 1976). Armoring of prime spawning areas in the Lee's Ferry area may also limit use of cobble bars as spawning areas by trout.

Stranding

Rainbow trout are reluctant to abandon established territories, or their mates, until the redds are complete and ova fertilized. Arizona Game and Fish Department wildlife managers have received reports of fish kills of up to 200 fish from concerned anglers, usually during the fall and winter. An investigation of one of these reports in January 1980 collected 23 dead adult trout stranded in a shallow backwater pool. When the area was re-examined at low flow the following day all the dead trout had been flushed into the river by high nighttime flows. Mortalities were attributed to fluctuating water levels that left spawning trout stranded. Dead and stranded trout were also observed in backwater pools and on a boulder bar near the Lee's Ferry boat ramp during low flow periods in October 1984. Most trout stranded for more than 36 hours died (Henry Maddux, Arizona Game and Fish Department, personal communication). However, not all stranded fish die. Depending on the season, permeability of the substrate, and elevation of the pool in relation to the main channel water level, some fish are able to survive until they are freed by rising water levels.

Instream flow

An instream flow study was conducted by the U.S. Bureau of Reclamation, Durango Projects Office, at Lee's Ferry to quantify changes in trout and periphyton (attached, submerged vegetation) habitat at various flows. The Instream Flow Incremental Methodology (IFIM) (Bovee 1982) was used as a representative reach application on 11 transects about 8 km below Glen Canyon Dam in March, April, and July, 1980. Depth, substrate, and velocity were measured at flows of approximately 2,000, 16,000, and 26,000 cfs. The IFG-4 hydraulic simulation model used these measurements to predict depth and velocity at flows from 1,000 to 40,000 cfs. Predicted available habitat for various trout lifestages was estimated using the Physical Habitat Simulation System (PHABSIM) described by Milhous et al. (1981).

Probability-of-use curves developed by Bovee (1978) were used as a base in developing habitat criteria for Lee's Ferry (Table 9). Additional habitat data were collected by Gosse (1981) at Lee's Ferry to refine probability-of-use curves for the Glen Canyon tailwater. The IFIM analysis considered all substrates as optimal, therefore habitat suitability was based entirely on depth and velocity criteria. Fish habitat analyses were run using bottom velocities because they were considered most representative of actual trout habitat. Probability-of-use curves were integrated with PHABSIM to estimate weighted usable area (WUA) for a given lifestage of trout.

Maximum WUA for adult trout was at flows of 7,000 - 10,000 cfs (Fig. 5) The decline in WUA at flows below 7,000 cfs was due to dewatering large sections of the river channel. WUA peaked at 4,000 - 6,000 cfs for juvenile trout and peaked sharply at 4,000 cfs for fry. The sharp peak in fry habitat is due to the predicted inundation of a large area of river channel bottom.

Habitat analysis for mature periphyton considered all velocities, substrates, and depths to 9 m as optimum as a function of light availability. This established a direct relationship between the filling of the river channel and an increase in periphyton habitat. Approximately 70% of the loss in periphyton habitat occurs below 10,000 cfs as cobble bars and benches are dewatered.

Transect contours were plotted and three distinct contour

Table 9. Habitat suitability criteria developed for Lee's Ferry rainbow trout.

Lifestage	Velocity (fps)	Depth (ft)	Source
Fry	0-0.1	0.1-4.0	Bovee (1978)
Fingerling (<16 cm)	0.1-1.4	1.5-8.2	Gosse (1981)
Sub-adult (17-28 cm)	0.2-2.2	1.5-16.4	Gosse (1981)

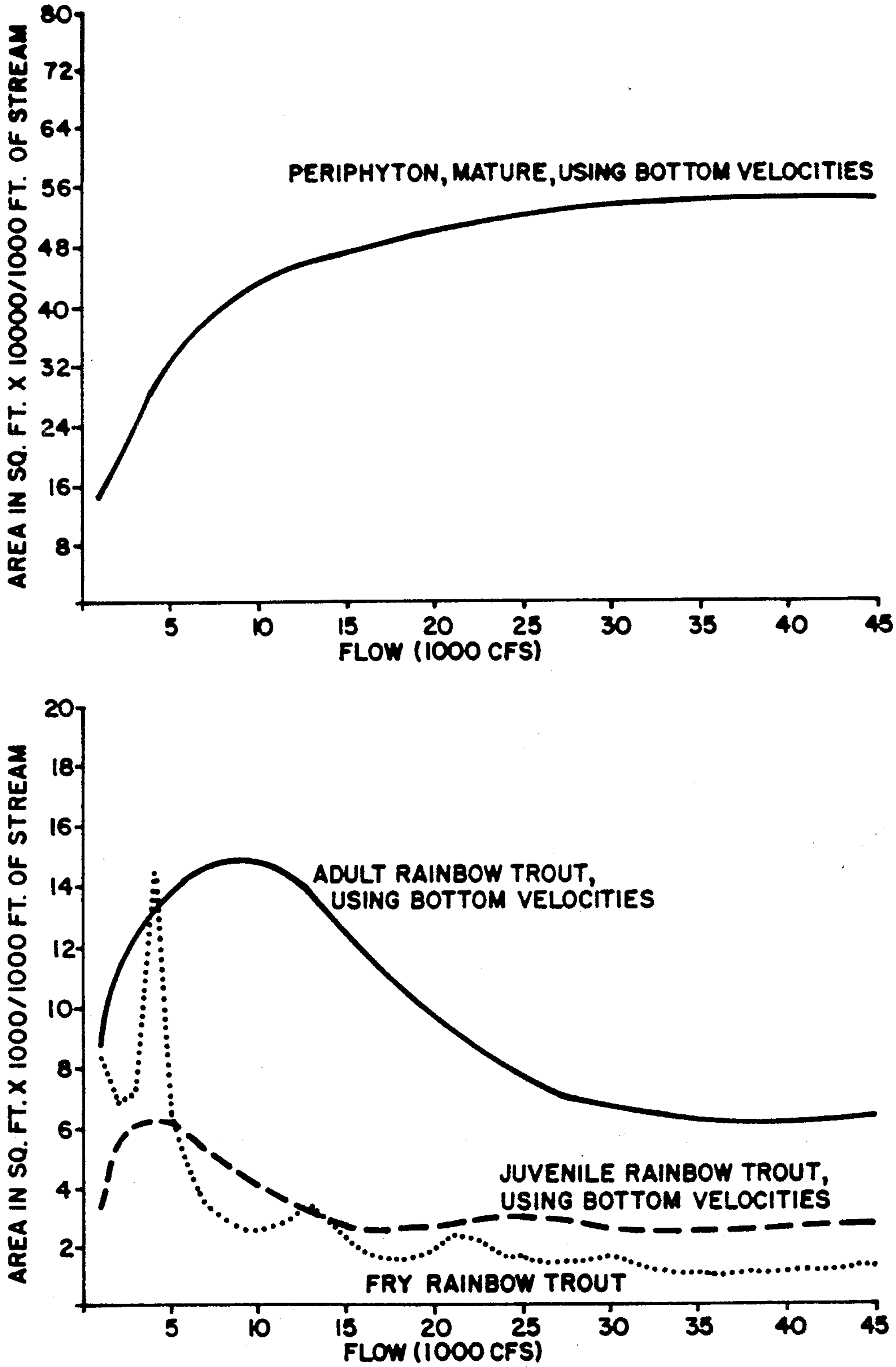


Figure 5. Weighted usable area for fry, juvenile, and adult rainbow trout; and for mature periphyton (U.S. Bureau of Reclamation 1984).

types identified: 1) low bar, 2) high bench, and 3) canyon (Fig. 6). Low bar contours had large areas that were predicted to be dewatered at flows below 5,000 cfs. These transects cross a bar commonly referred to as Nine-mile bar. High bench contours had areas dewatered at flows between 5,000 and 15,000 cfs depending on elevation of the bench. Canyon contours had relatively steep sloping contours and had the smallest amount of area dewatered at low flows.

A procedure was developed to determine the amount and location of available habitat at each transect at a variety of flows to gain a better understanding of changes in suitable habitat at each transect. Habitat at each station was judged suitable or unsuitable based on depth and velocity criteria for each lifestage of rainbow trout. Each cross-sectional transect was made up of stations spaced at 10 ft intervals, therefore each station with suitable habitat was assumed to represent 10 linear feet of available habitat. Distance, or linear feet of available habitat (LFAH) was summed for each transect and locations of suitable habitat were mapped. For example, at a hypothetical transect with 11 stations spaced at 10 ft intervals, there were four stations with suitable depth and velocity for fingerling trout. These four stations were assumed to represent 4 x 10 or 40 ft of available habitat within the entire transect (Fig. 7). Locations of LFAH were determined at flows ranging from 1,000 to 40,000 cfs.

<u>Fry lifestage</u>. Linear feet of available habitat for rainbow

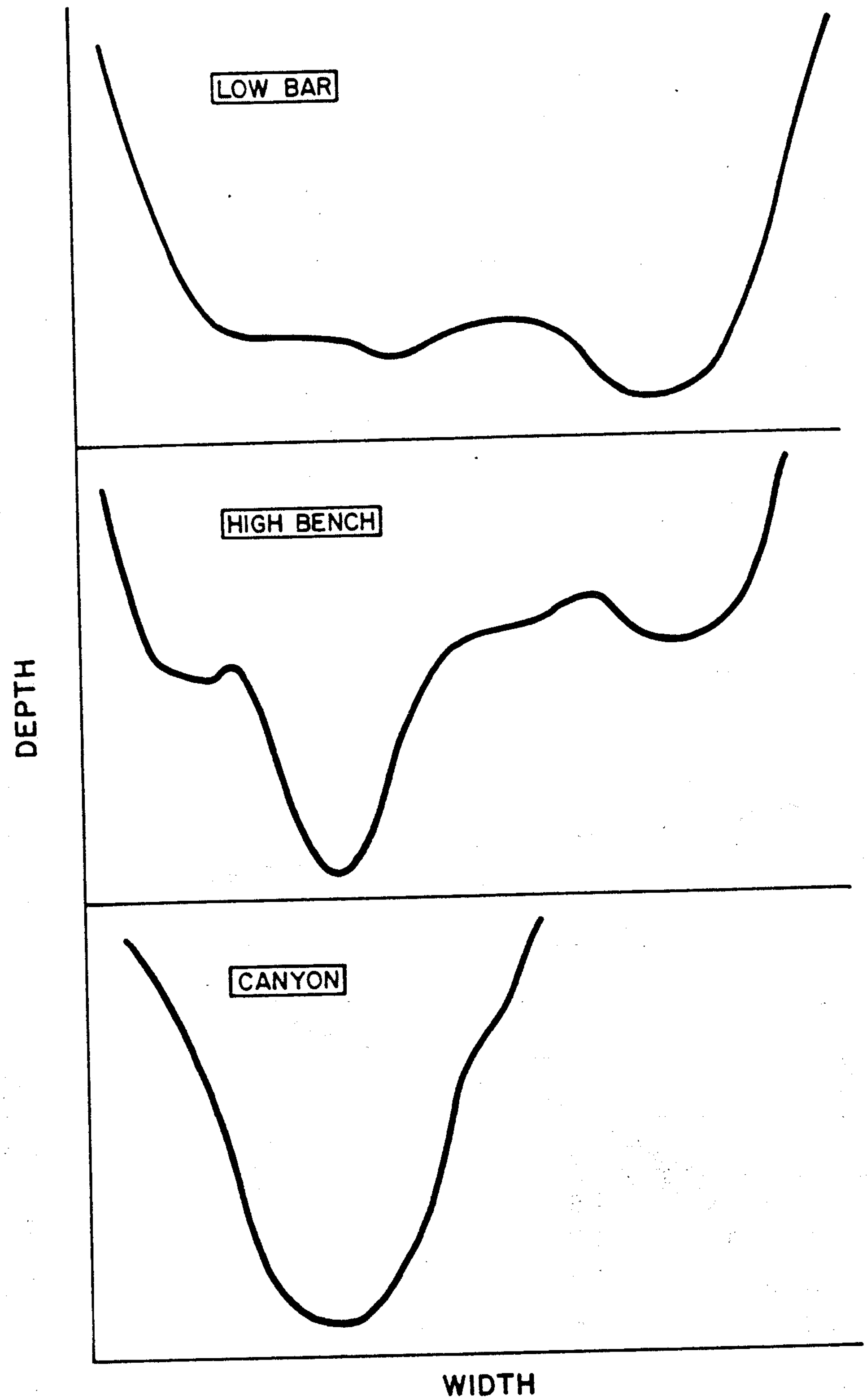
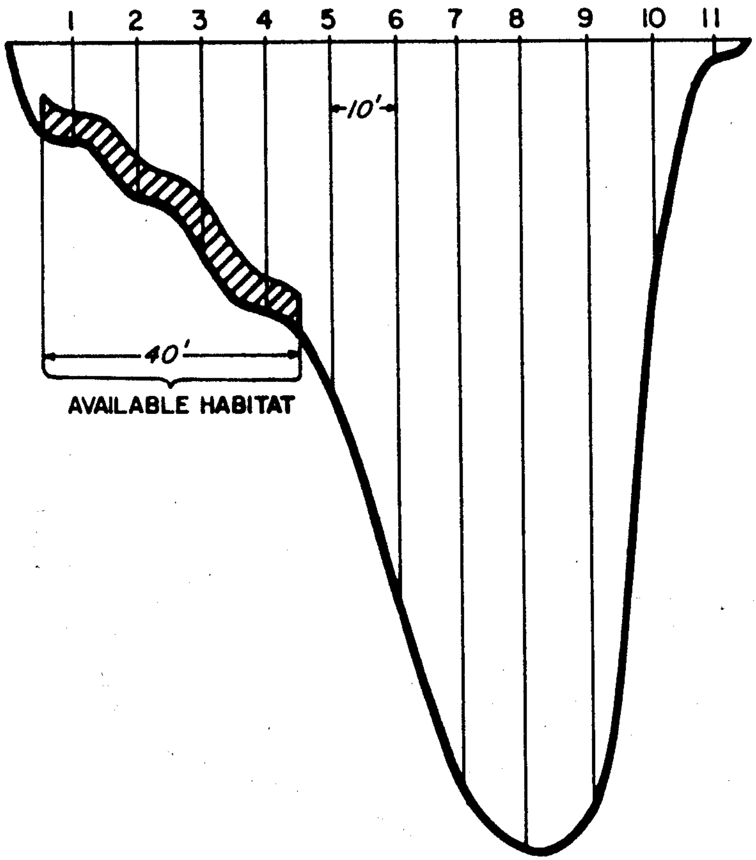


Figure 6. Diagramatic representation of channel contour types, Lee's Ferry.



STATION	DEPTH (ft.)	VELOCITY (FPS)	SUITABLE HABITAT ?
1	2.5	0.3	Y
2	4.0	0.3	Y
3	5.5	1.0	Y
4	7.0	1.2	Y
5	9.2	2.1	N
6	14.5	2.7	N
7	19.5	3.0	N
8	21.0	3.0	N
9	19.6	3.1	N
10	6.3	3.2	N
11	0.5	0.7	N

Figure 7. Diagramatic representation of computation of linear feet of available habitat for fingerling rainbow trout, based on suitable depth from 1.5 to 8.2 ft and suitable velocity from 0.1 to 1.4 feet per second.

trout fry in the Lee's Ferry area was similar to WUA predicted by the IFIM model. Both modeling techniques indicated a peak in habitat between 2,000 and 5,000 cfs. However, the LFAH curve had a much lower peak than the WUA curve, perhaps because habitat was not estimated with the LFAH technique at 3,000-4,000 cfs (Fig. 8). Low bar transects had substantially more available habitat for trout fry at low flows than other contour types. Contours with low bars made up more than 50% of the estimated fry habitat for 11 transects at 5,000 cfs.

Maps of habitat locations show that a large movement would be required for fry to stay in suitable habitat under fluctuating flows. At transect 1, as flow increased from 1,000 to 25,000 cfs the locations of suitable fry habitat shift approximately 100 and 400 ft for the left and right bank, respectively. A similar movement would be required to stay in suitable habitat as flows are reduced during a typical diel peaking cycle. Similar changes in habitat locations occurred at transect 7, a low bar contour. Fry on the left bank would be required to move approximately 600 ft on the left bank under peaking power operations (Fig. 9). Dewatering of high benches and low bars at flows below 8,000 cfs caused the greatest movement in suitable habitat locations for trout fry. These changes in suitable habitat locations are probably too great for trout fry to make twice a day under peaking flows. Fry stranding and mortality can be expected to occur with decreasing flow as areas of suitable habitat are dewatered. Post-emergent fry located in this zone of fluctuation would be most susceptible due to their low mobility.

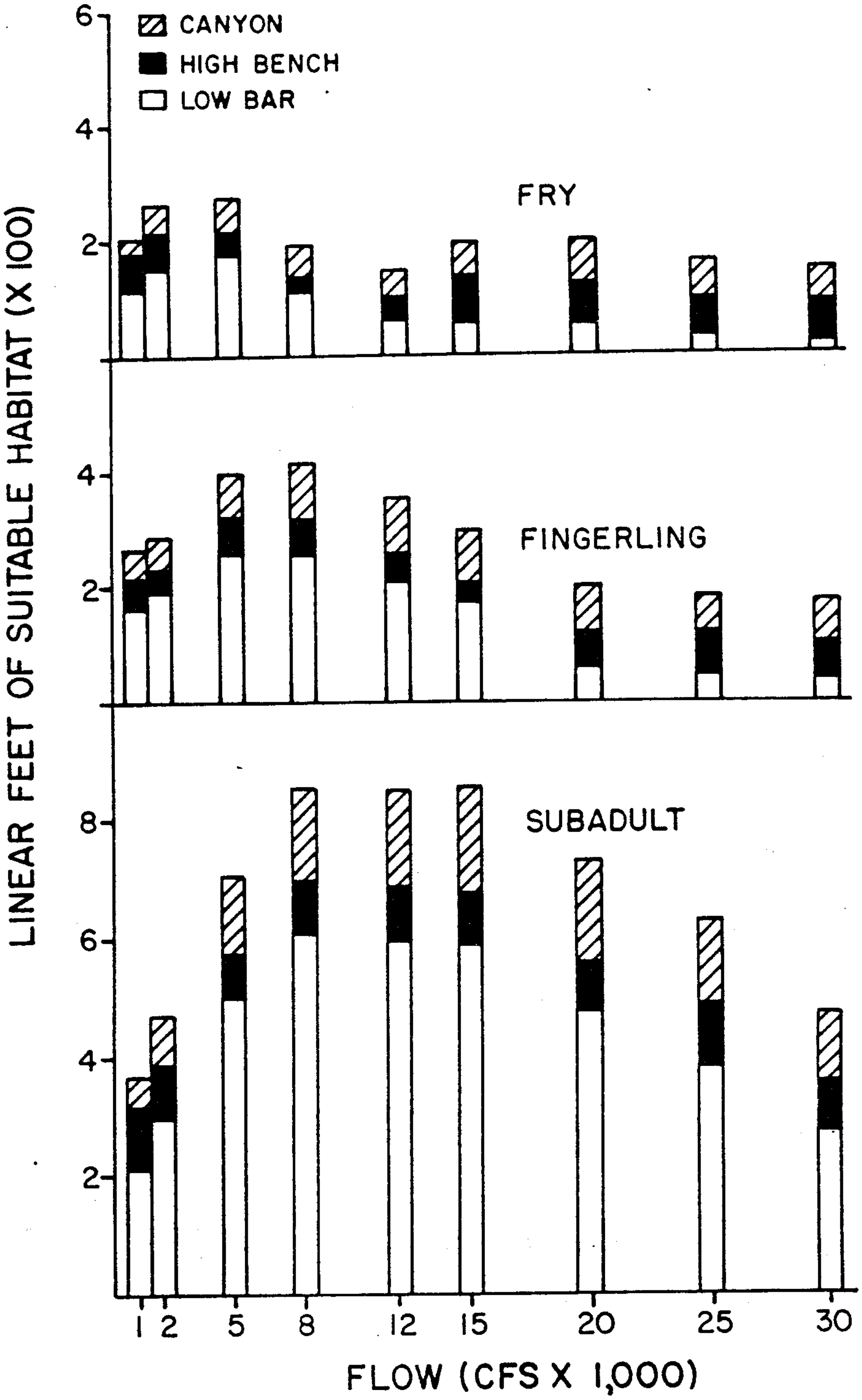


Figure 8. Mean linear feet of available habitat for fry, fingerling, and subadult rainbow trout at low bar, high bench, and canyon contour types, Lee's Ferry.

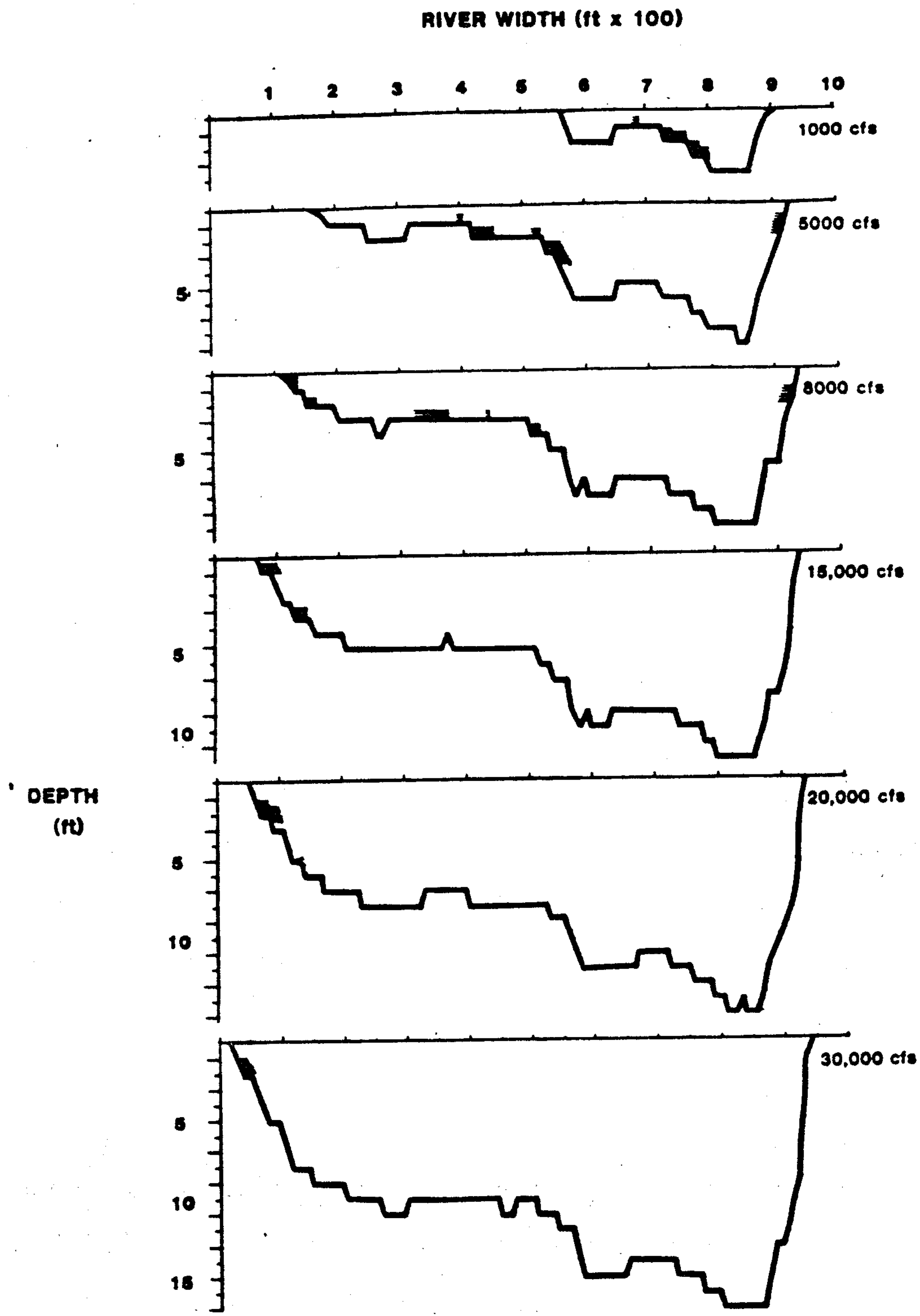


Figure 9. Location of suitable habitat for rainbow trout fry at flows from 1,000 to 30,000 cfs, IFIM transect 7, Lee's Ferry, 1981.

Fingerling and subadult trout. Fingerling (<16 cm) and subadult (17-28 cm) trout habitat was also evaluated with the IFG-4 and LFAH methods. Results of both habitat evaluation techniques were similar for fingerlings with peak habitat available at approximately 8,000 cfs (Figs. 5, 8). Substantially more habitat was estimated for subadult lifestages than for fingerlings.

Low bar contours had the greatest amount of suitable habitat of all contour types and composed more than 50% of the estimated habitat for both size classes at flows between 5,000 and 30,000 cfs (Fig. 8). More than 70% of the subadult habitat lost below 8,000 cfs was caused by low bar contours being dewatered.

Suitable habitat for fingerling and subadult trout was plotted at transect 7 to illustrate habitat changes caused by the inundation or dewatering of low bars. The sharp increase in LFAH for subadult trout at low flows was the result of inundation of low bars between 2,000 and 5,000 cfs (Fig. 10). The increase in fingerling habitat is less dramatic; as the inundated bench becomes suitable, main channel habitat at lower flows becomes unsuitable.

Problems with habitat evaluation methods. Instream flow analyses must be interpreted with caution because of limited knowledge of specific lifestage habitat requirements for trout at Lee's Ferry and problems in the stage-discharge relationship used to calibrate the models. The IFG-4 model consistently

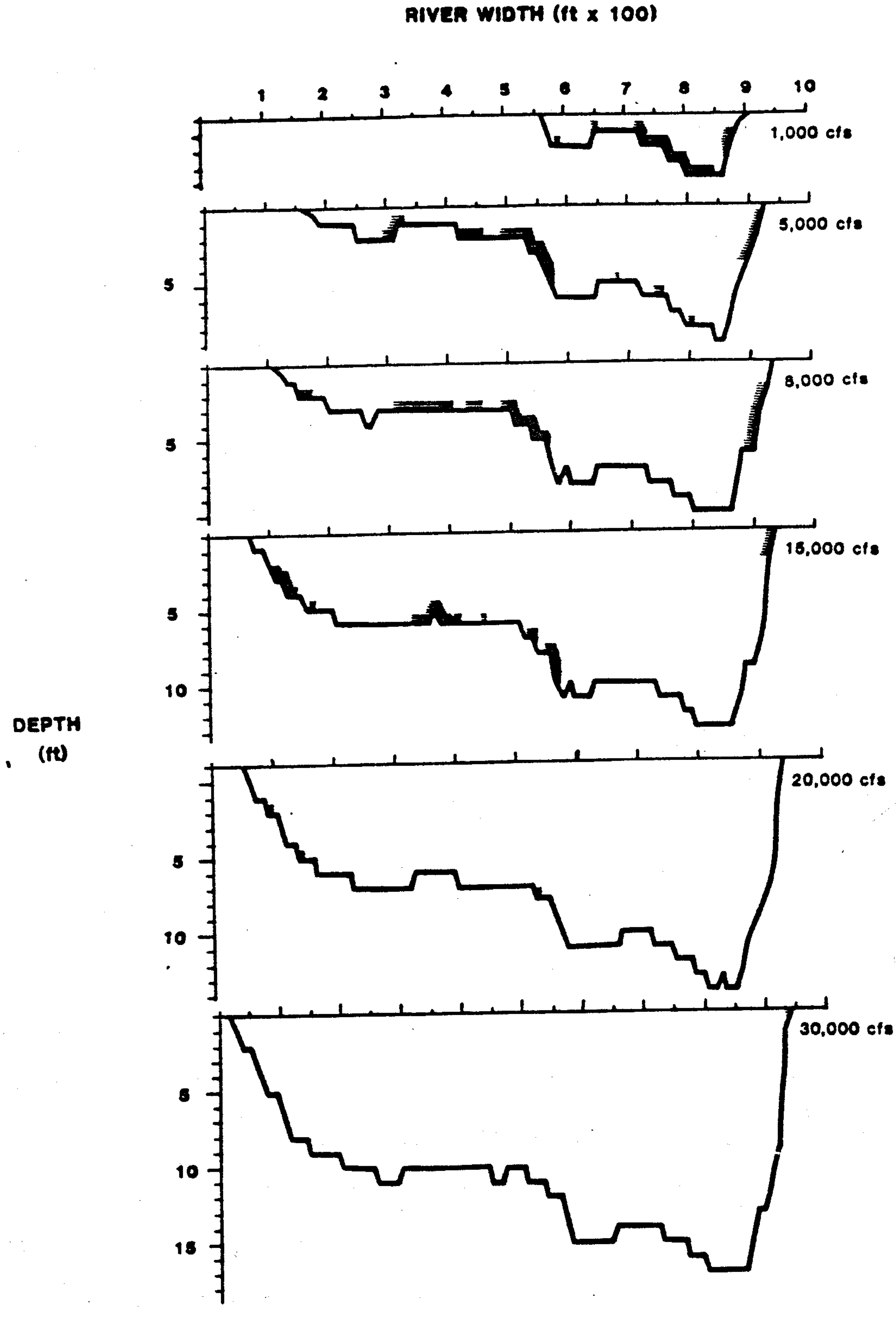


Figure 10. Location of suitable habitat for rainbow trout juveniles at flows from 1,000 to 30,000 cfs, IFIM transect 7, Lee's Ferry, 1981.

overestimated river width. For example, the measured width of the river at 2,800 cfs was 270 feet whereas the predicted width at 2,000 cfs was 550 ft (Fig. 11). River widths computed by IFIM at 1,000 cfs equaled or exceeded river widths measured at 2,000-3,000 cfs at five of the eleven transects. These errors in model calibration mean that low bars are exposed at flows predicted to inundate the bars. The hydraulic simulation model is being refined, and additional microhabitat data are being collected at Lee's Ferry to improve the model applications (D. Wegner, U.S. Bureau of Reclamation, personal communication).

Sport fish harvest 1980-81

Lee's Ferry is essentially a single access fishery, therefore a single check point creel survey was conducted from April 1980 to March 1981. Creel data, including length, weight, tag information, and scale samples were collected by a clerk stationed at the launch ramp during four 24 hour sampling periods each month. The sampling schedule was stratified to include two weekdays and two weekend days each month. A third sampling stratum was developed to represent the extended trip anglers that spent more than one day camped upriver.

Anglers were counted and interviewed as they finished their fishing day or fishing trip. Fish were identified, weighed to the nearest 10 g, and measured to the nearest mm. Anglers were questioned about method of fishing, actual catch, and length of fishing day.

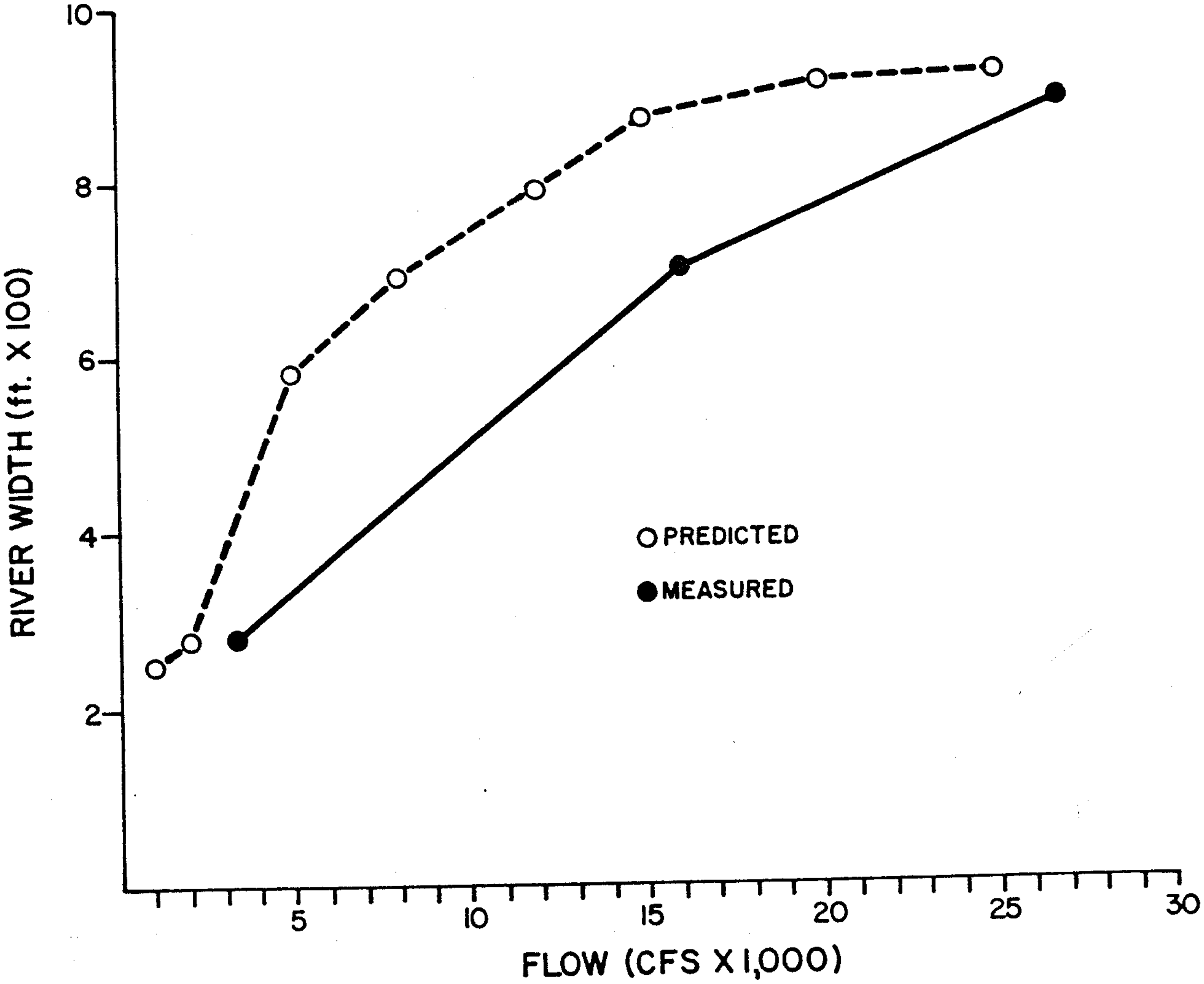


Figure 11. Measured and predicted river widths, transect 8, Lee's Ferry, 1981.

Catch and harvest data collected from anglers were combined with our survey estimates of angler pressure to provide a monthly estimate of total harvest by species. Alternatively, we used National Park Service estimates of numbers of anglers from daily trailer and shore angler counts to predict total harvest by species.

A total of 2,107 anglers were interviewed and biological data obtained from 871 trout harvested at Lee's Ferry from April 1980 through March 1981. During this period, the National Park Service reported that 19,571 visitors fished at Lee's Ferry. Using estimates of the length of a fishing day from angler interviews this would account for 121,394 angler hours at Lee's Ferry (Table 10). Our estimate of angling pressure based upon angler contacts at the creel station was 112,413 angler hours, or about 8% less than the Park Service estimate. When these estimates of effort were combined with monthly estimates of harvest rate the Park Service estimated 11,336 rainbow trout removed from the river, while our survey estimated only 10,284 harvested during the period April 1980 - March 1981. Inflation of the harvest estimate based upon Park Service angler use data may be attributed, in part, to shore anglers below the Lee's Ferry boat ramp. Bank anglers probably would not pass the creel station at the boat ramp and would not have been counted or checked by the creel clerk.

Harvest from Lee's Ferry was dominated by rainbow trout which made up 87% of the creel. Fewer brook trout (8%) and cutthroat trout (5%) were caught. Rainbow trout larger than

Table 10. Estimated angler hours, catch rates, creel rates, and harvest of rainbow, brook, and cutthroat trout, Lee's Ferry, April 1980 - March 1981.

	Month												
	A	M	J	J	A	S	O	N	D	J	F	M	Total
Angler counts													
National Park Service	1,529	1,901	826	786	925	1,885	2,099	1,945	1,773	1,860	1,879	2,163	19,571
Angler hours													
National Park Service	9,633	11,216	5,204	4,716	7,400	11,687	13,224	11,087	10,638	11,904	11,274	13,411	121,394
AGFD	8,287	8,014	3,847	4,782	8,835	12,679	17,803	10,415	6,857	9,830	8,948	12,116	112,413
Angler hours/day	6.3	5.9	6.3	6.0	8.0	6.2	6.3	5.7	6.0	6.4	6.0	6.2	
Estimated Catch per hour	0.16	0.12	0.13	0.14	0.15	0.12	0.09	0.13	0.17	0.21	0.16	0.18	0.15
Estimated harvest per hour	0.08	0.10	0.08	0.12	0.11	0.10	0.08	0.10	0.08	0.15	0.12	0.15	0.11
					Estimated Harvest								
NPS													
Rainbow trout	733	819	382	459	716	994	836	987	757	1,652	1,231	1,770	11,336
Brook trout	38	135	26	73	65	82	127	100	68	89	95	121	1,019
Cutthroat trout	0	168	8	34	33	93	95	22	26	72	27	121	699
Total	771	1,122	416	566	814	1,169	1,058	1,109	851	1,813	1,353	2,012	13,054
AGFD													
Rainbow trout	630	585	283	465	778	1,078	1,125	927	489	1,342	977	1,605	10,284
Brook trout	33	96	19	75	71	89	171	94	44	74	75	110	951
Cutthroat trout	0	120	6	34	35	101	128	21	16	59	22	110	652
Total	663	801	308	574	884	1,268	1,424	1,042	549	1,475	1,074	1,825	11,887

500 mm were more common in the creel during the months of August through February, and less common from March through July (Table 11).

Approximately 58% of the anglers at Lee's Ferry used a boat during some part of their trip (Table 12). Shore angling was probably discouraged by limited area available near the boat ramp. It is likely that our survey underestimated number of shore anglers because they could not be counted or checked by the boat ramp clerk. Therefore, further analysis of harvest data from 1980-81 uses harvest estimates derived from Park Service angler counts.

On the average, an angler could expect to spend 6.8 hours fishing to catch a trout (mean catch rate of 0.147 fish/hour), and 9.3 hours to harvest a trout (mean harvest rate of 0.107). Forty-six percent of the anglers at Lee's Ferry were successful in catching at least one trout, and the average trout creeled was relatively large (466 mm) (Table 13).

There was some concern that fluctuating flows may influence the catchability of trout at Lee's Ferry. To address this question, we attempted to correlate average monthly catch rate with mean monthly flow, mean monthly range in flow (daily average of maximum - minimum flow), and the coefficient of variation of mean flow. In no case could a significant correlation be found that would influence catch rate. There are obvious exceptions to this situation at the extremes of flow. Extremely low flows would impede upstream navigation and limit anglers to the lower segment of the river. Extremely high flows would make boating

Table 11. Monthly length frequencies of rainbow trout checked at Lee's Ferry creel station, April 1980 - March 1981.

Length (inches)	Month												Total
	4	5	6	7	8	9	10	11	12	1	2	3	
7													0
8				1						1	1	1	4
9				2			1				1	6	10
10				3		1	2		1	7	4	4	22
11	1			2	1	1		1	1	7	6	7	27
12	6	2	1			6	4	1	1	2		7	30
13	5	2	4	2	1	5		3	2	1	3	4	32
14	3	2	1		4	7	6	5	3	1	4	5	41
15	1		2	2	8	5	9	4	3	2	4	4	44
16	3	2	1	4	4	14	11	9	4	6	3	2	63
17	7	9	9	5		9	4	4	5	3	7	4	66
18	4	4	4	7	3	3	13	6	3	8	9	4	68
19	2	2	6	12	12	11	11	6	2	11	5	5	85
20	2	2	3	7	13	16	14	9	4	2	11	7	90
21	2	4	2	4	12	14	9	9	12	9	11	4	92
22		1	1	1	12	13	12	8	3	14	6	10	81
23		2	2		6	5	13	4	3	19	10	2	66
24				1	1	3	3	2	2	10	4	3	29
25					1	2	5			3		2	13
26						1				1			2
27					1					1	1	1	4
28	1										1		2
29													0
30													0
31													0
32													0
33													0
Total	37	32	36	53	79	116	117	71	49	108	91	82	871

Table 12. Summary of angler use and preference, Lee's Ferry April 1980 - March 1981.

	Month													
	A	M	J	J	A	S	O	N	D	J	F	M	Total	Mean
Anglers checked	110	154	83	98	149	208	300	185	129	178	239	274	2,107	176
% Residents	49	67	83	61	83	84	70	68	78	83	72	56		71
Angling method														
% Boat	38	47	61	64	75	58	56	57	55	62	61	62		58
% Bank	29	29	33	27	16	36	36	40	31	34	32	22		30
% Both	33	24	6	6	9	6	8	27	14	4	8	16		13
Gear preference														
% Bait	46	33	52	39	55	59	46	53	41	59	71	73		52
% Lure	3	16	6	12	5	1	6	3	16	9	3	2		7
% Fly	0	0	0	0	4	1	5	4	6	2	0	1		2
% Combination	51	51	42	49	36	39	43	40	37	31	27	24		39
Percent successful	47	39	30	44	48	51	33	44	48	61	46	55		46
Bait	95	51	91	74	88	90	52	77	60	76	90	88		78
Lure	5	44	9	26	6	10	37	18	25	20	9	11		18
Fly	0	50	0	0	6	0	11	5	15	4	1	1		8

Table 13. Monthly mean length (mm) and weight (kg) of rainbow, brook, and cutthroat trout creeled at Lee's Ferry, April 1980 - March 1981.

	Month												
	A	M	J	J	A	S	O	N	D	J	F	M	Mean
Mean length (mm)													
Rainbow trout	412	437	455	446	518	477	483	456	473	510	465	455	466
Brook trout	340	437	455	325	396	362	314	373	351	375	363	330	368
Cutthroat trout	-	302	-	348	390	398	403	416	465	445	448	466	408
Mean weight (kg)													
Rainbow trout	1.37	1.46	1.50	1.26	1.62	1.46	1.53	1.30	1.38	1.37	1.40	1.43	1.42
Brook trout	0.57	0.63	0.66	0.41	0.92	0.75	0.69	0.75	0.61	1.72	0.72	0.50	0.74
Cutthroat trout	-	0.50	0.30	0.45	0.65	0.59	0.73	0.55	0.95	0.26	1.02	0.81	0.62

unsafe and make it impossible for boat anglers to fish the river. However, between these extremes, there was no apparent relationship between catch rate and rate of release from the dam.

Creel data from the Lee's Ferry fishery collected during 1980-81 was compared with data from other tailwaters. Angling pressure was similar at Lee's Ferry, Flaming Gorge (1969-80), and Navajo tailwater (1965-68) and averaged about 270 hours/ha/year (Table 14). Catch rate and number harvested at Navajo and Flaming Gorge was about 4 times greater than that at Lee's Ferry. However, yield (kg/ha) was similar at all three tailwaters, reflecting the greater average weight of fish harvested at Lee's Ferry.

Using the exploitation rate (u) of 0.38 from tag returns for 1980-81 and estimated yield (C) of 16,097 kg we calculated standing stock (B) with the formula $B=C/u$ (Ricker 1975). The Lee's Ferry standing stock of 42,320 kg or 102 kg/ha was much higher than the 22 - 33 kg/ha calculated from data for 1965-68 (Stone 1965-68). The large increase in standing stock of trout at Lee's Ferry since the late 1960's is probably due to increased stocking rates, the introduction of freshwater shrimp in 1968 and the subsequent rapid growth of the fish. Although standing crop during 1980-81 was relatively high, the potential carrying capacity of the tailwater may be higher than estimated because few fish were stocked in 1979 and 1980.

Table 14. Harvest and yield of rainbow trout at Glen Canyon (1980-81), Flaming Gorge, Utah (1969-80), and Navajo, New Mexico (1965-68) tailwaters.

	Glen Canyon (1980-81)	Flaming Gorge (1969-80)[a]	Navajo (1965-68)[b]
Angler hours per year	121,394	75,697	93,815
Angler hours per ha	292	254	262
Creel per hour	0.11	0.46	0.50
Number harvested	11,336	34,437	46,865
Number harvested per ha	27.3	116	131
Kg harvested	16,097	12,079	14,481
Kg per ha	38.8	41	40

a/ Larson et al. 1980

b/ Mullan et al. 1976

Sport fish harvest 1977-1984

Creel survey statistics for the period 1977-1984 from Lee's Ferry were calculated for an annual rather than fiscal year basis (AGFD F-7 reports) to examine effects of various flow regimes and stocking rates on year-class strength, harvest, and yield of trout. Ages were assigned to fish creeled from 1977 through 1984 based on monthly length frequencies (Appendix F). Ages 0-II were relatively easy to discern but size of fish ages III and over tended to overlap. Year-class strength indices, based on percentage of fish assigned ages 0-II in the creel, were calculated for the 1977-83 year-classes to compare year-class strength with numbers of fish stocked and flow variables (Hile 1941) (Appendix G, Appendix H).

Pressure increased greatly from about 174 to 864 angler hours/ha from 1977 to 1983 (Table 15). Yield increased from about 31 to 120 kg/ha over the same period (Fig. 12). Harvest decreased substantially in 1984 (0.08 fish/hr, 52.7 fish/ha) from 1982 and 1983. Yield showed a more marked decrease as average size of fish decreased in 1984. The 1980 harvest was also unusually low (28 fish/ha, 0.09 fish/hr) following a year with no stocking.

Table 15. Summary of creel survey statistics from Lee's Ferry, 1977 - 1984.

Year	Anglers	Angler Hours	Hours per ha	Creel per Hour	Catch per Hour	Mean Length (mm)	Mean Weight (g)	Number Harvested	Harvest per ha	Yield (kg)	Yield per ha
1977	10,613	72,202	174.0	0.24	n/a	398	735	17,320	41.7	12,730	30.7
1978	9,990	67,932	260.6	0.20	n/a	445	1,015	13,586	32.7	13,790	33.2
1979	22,085	150,178	361.9	0.15	n/a	431	926	22,527	54.3	20,860	50.3
1980	18,986	129,105	311.1	0.09	0.13	465	1,153	11,619	28.0	13,397	32.3
1981	28,784	195,731	471.6	0.14	0.22	436	957	27,402	66.0	26,224	63.2
1982	49,000	333,200	802.9	0.13	0.19	449	1,042	43,316	104.4	45,135	108.8
1983	52,725	358,530	863.9	0.15	0.27	431	926	53,780	129.6	49,800	120.0
1984	40,174	273,183	658.3	0.08	0.18	370	595	21,855	52.7	13,033	31.3

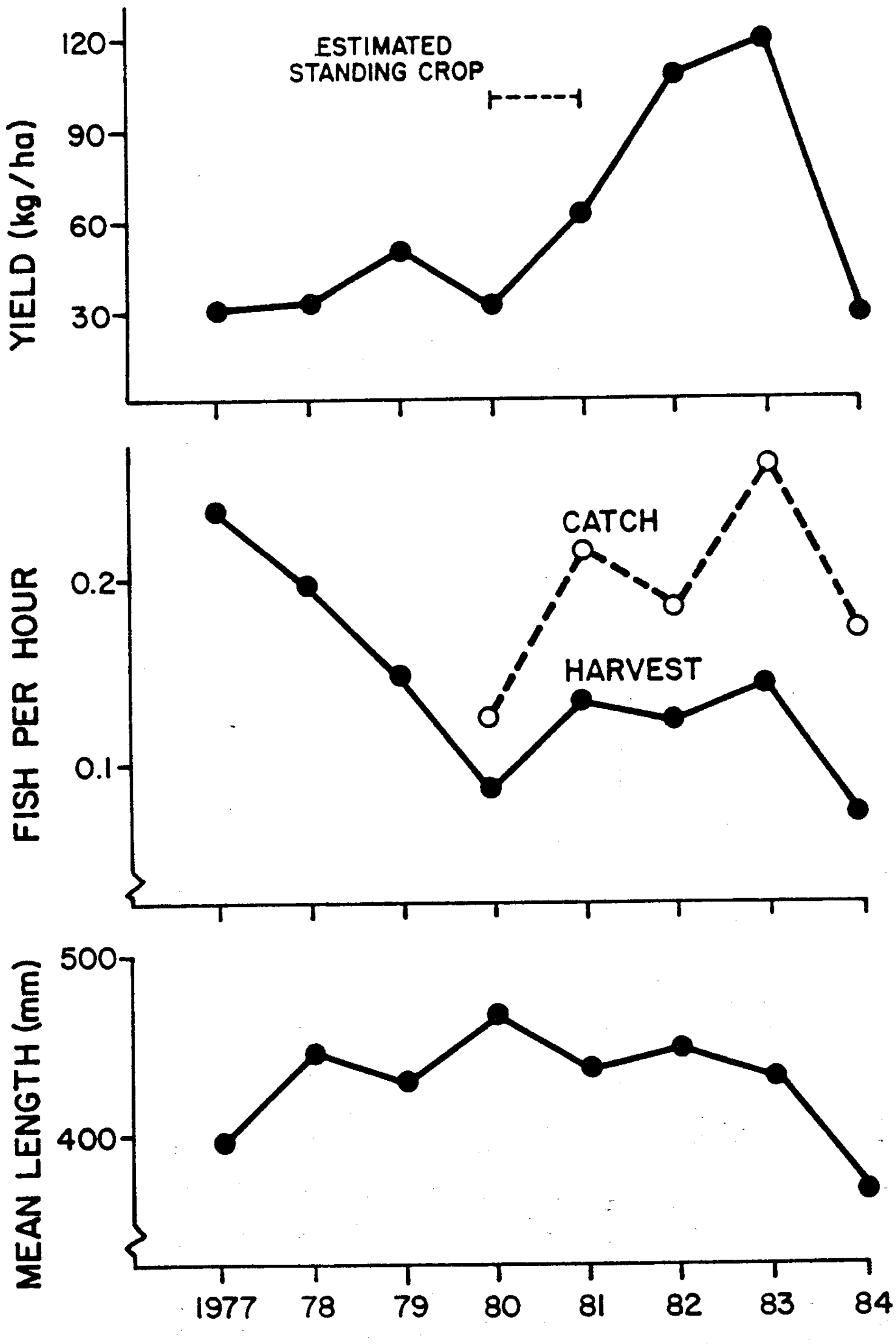


Figure 12. Yield (kg/ha), catch per hour, harvest per hour, and mean length (mm) of rainbow trout, Lee's Ferry 1977-84.

MANAGEMENT IMPLICATIONS

Sport fishery management

Yield of fish at Lee's Ferry increased four-fold from 1977 to 1983, then decreased about 75% in 1984. The decrease in yield in 1984 may be partly due to: 1) lack of stocking in 1979, 2) low stocking in 1980, 3) relatively low stocking in 1982 (50,000 fish), and 4) an increase in percentage of small fish retained in the creel in 1984. However, low yield in 1984 may also indicate overfishing during 1982 and 1983. Decreases in catch rate and size of fish creeled often indicate overfishing. Harvest rate during 1984 was quite low (0.08 fish/hr) and average length of fish creeled was lower than in previous years (Fig. 12). High harvest of fish in 1982 and 1983 probably contributed to lower catches in 1984.

Bag limits. Harvest of fish can be decreased by several methods including establishing bag and size limits. Lee's Ferry has a 4 fish immediate-kill bag limit with no length limit. To examine the theoretical effect of bag limits on the Lee's Ferry harvest we calculated the percent reduction in harvest that would have occurred in 1984 with various bag limits. A bag limit of 1 fish would have affected 32% of the anglers and reduced harvest by 42.5% (Fig. 13). A bag limit of 2 fish would have affected only 18% of anglers and would have reduced harvest by 14.8%.

Size limits. Length frequencies of rainbow trout creeled at Lee's Ferry from the period 1977-83 were used to estimate the

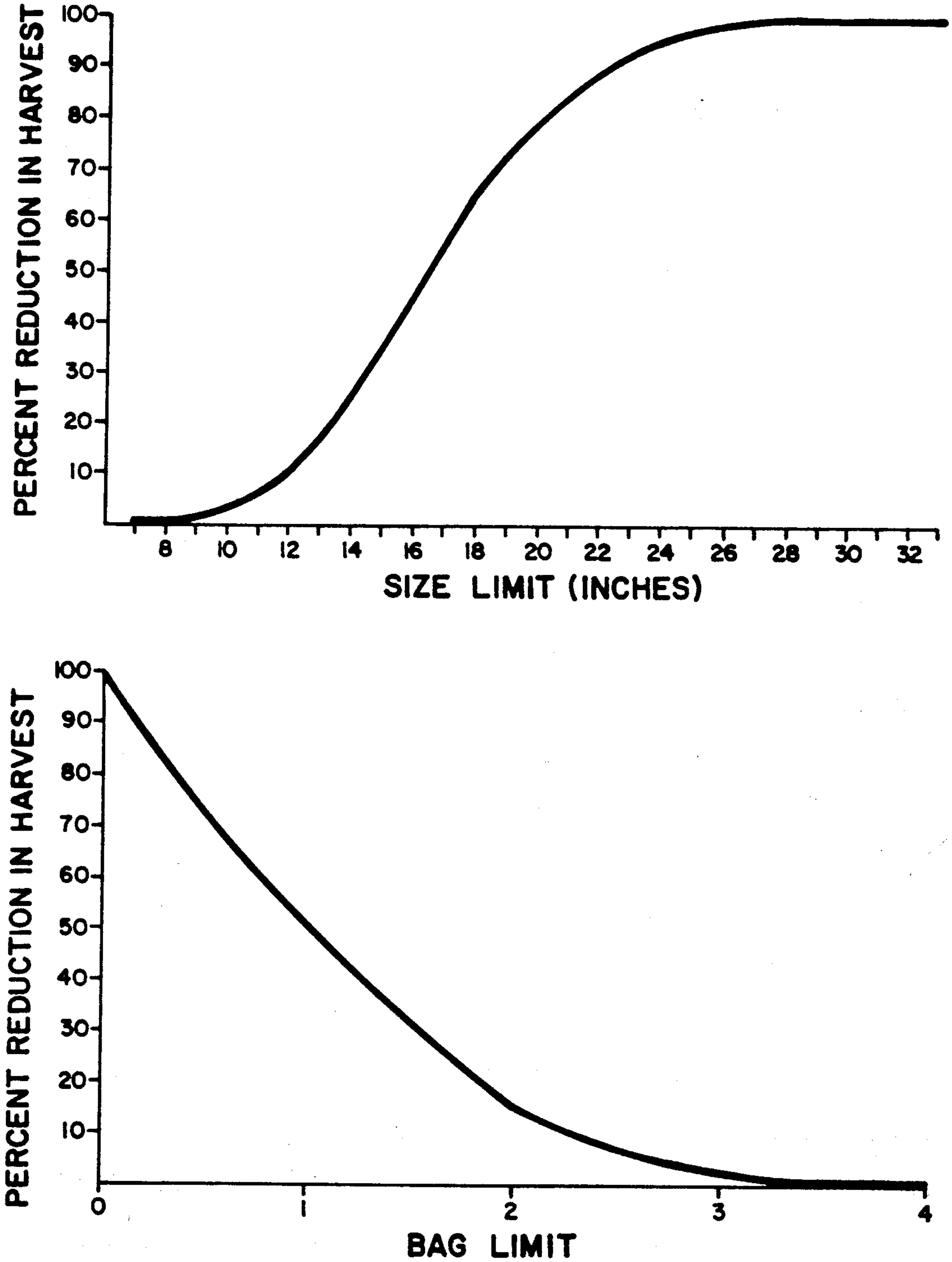


Figure 13. Hypothetical effect of various length and bag limits on harvest of rainbow trout at Lee's Ferry.

effect of minimum length limits on harvest. For example, 26.6 percent of trout examined in the creel were less than 15 inches long. Theoretically then, a fourteen inch length limit would have reduced the harvest by approximately 27% (Fig. 13).

Slot size limits have been proposed as a method to increase the catch of large fish without drastically reducing total harvest of fish (Jensen 1981). Slot limits protect a size group of fish from anglers and allow the fish to grow to a larger size when they can again be harvested. Slot limits have been used successfully to increase catch of trophy-sized fish without reducing total catch (Hunt et al. 1962). A slot limit whereby 15-20 inch fish are released would theoretically increase the catch of fish greater than 20 inches by about 60% while decreasing total harvest by only about 14% (Table 16). However, slot size limits are generally not effective except on fisheries where artificial-lure regulations are in effect. Hooking mortality of bait caught rainbow trout (30%) would counteract beneficial effects on the population made by releasing fish.

Gear restrictions. Gear restrictions can also be used to reduce fishing mortality. A review of data on rainbow trout hooking mortality indicated that fish caught and released on bait suffered about 30% hooking mortality (Mongillo 1984). Artificial-lures on the other hand, caused only 5-10% hooking mortality. In recent years greater numbers of fish have been hooked and released at Lee's Ferry (Table 17). Assuming a 30% hooking mortality, total fishing mortality increased from about 13,100 fish in 1980 to about 67,000 fish in 1983. Had

Table 16. Hypothetical effect of various slot size limits on harvest of rainbow trout at Lee's Ferry based upon 1980-81 estimates of fishing mortality (0.387) and instantaneous total mortality (0.5).

	Harvest per 1,000 recruits		
	Fish > Slot	Fish < Slot	Total
None (20 in)	46[a/]	458	504
None (22 in)	27[b/]	477	504
15 - 20 in	74	370	444
15 - 22 in	55	370	425
16 - 20 in	68	392	460
16 - 22 in	51	392	443

a/ Fish larger than 20 in

b/ Fish larger than 22 in

Table 17. Total deaths attributable to hooking, based upon an assumed mortality rate of 0.3 for bait and 0.1 for lures, Lees Ferry, 1980-84.

	Year				
	1980	1981	1982	1983	1984
Number harvested	11,619	27,402	43,316	53,780	21,855
Number released	5,165	15,658	19,992	43,024	27,318
Percent released	30.8	36.4	31.6	44.4	55.6
Estimated total deaths					
Bait	13,169	32,099	49,314	66,687	30,050
Lure	12,136	28,968	45,315	58,082	24,587

artificial-lure regulations been in effect during 1983 and 1984, and catch rates remained the same, total fishing mortality would probably have decreased by 16-18%. However, because lure and fly anglers may be less successful than bait anglers (only 22% successful in 1980-81), catch rates may decrease until anglers learn new fishing techniques. Therefore harvest might decrease more than the estimated 16-18%.

Stocking rates

The influence of stocking on harvest was examined by comparing number of fish stocked to harvest of age 0 fish. Catch of age 0 fish was significantly correlated with number of fish stocked during the same year ($r^2=0.7212$, $p<0.05$) (Fig. 14). Lack of stocking during 1979 was evident in both the 1979 and 1980 harvests (Fig. 15). Few age 0 fish were creeled in 1979 and few age I fish were harvested in 1980. The Lee's Ferry fishery has been very dependent on stocking.

In order to determine stocking rates at Lee's Ferry to sustain a harvest rate of 0.15 fish per angler hour (Stephenson 1985) we attempted to determine yield per 1,000 recruits. Using the method of Jensen (1981) with an estimated fishing mortality of 0.387 and natural mortality of 0.5 from 1980-81 data we calculated an expected yield of 504 fish per 1,000 recruits. We also estimated yield of fish ages 0 - II per 1,000 recruits from angler harvest data for 1977-1982. Yield ranged from 217 to 596 and averaged 363 per 1,000 recruits. Adjusted for total catch of all age groups the average yield was 444 fish per 1,000

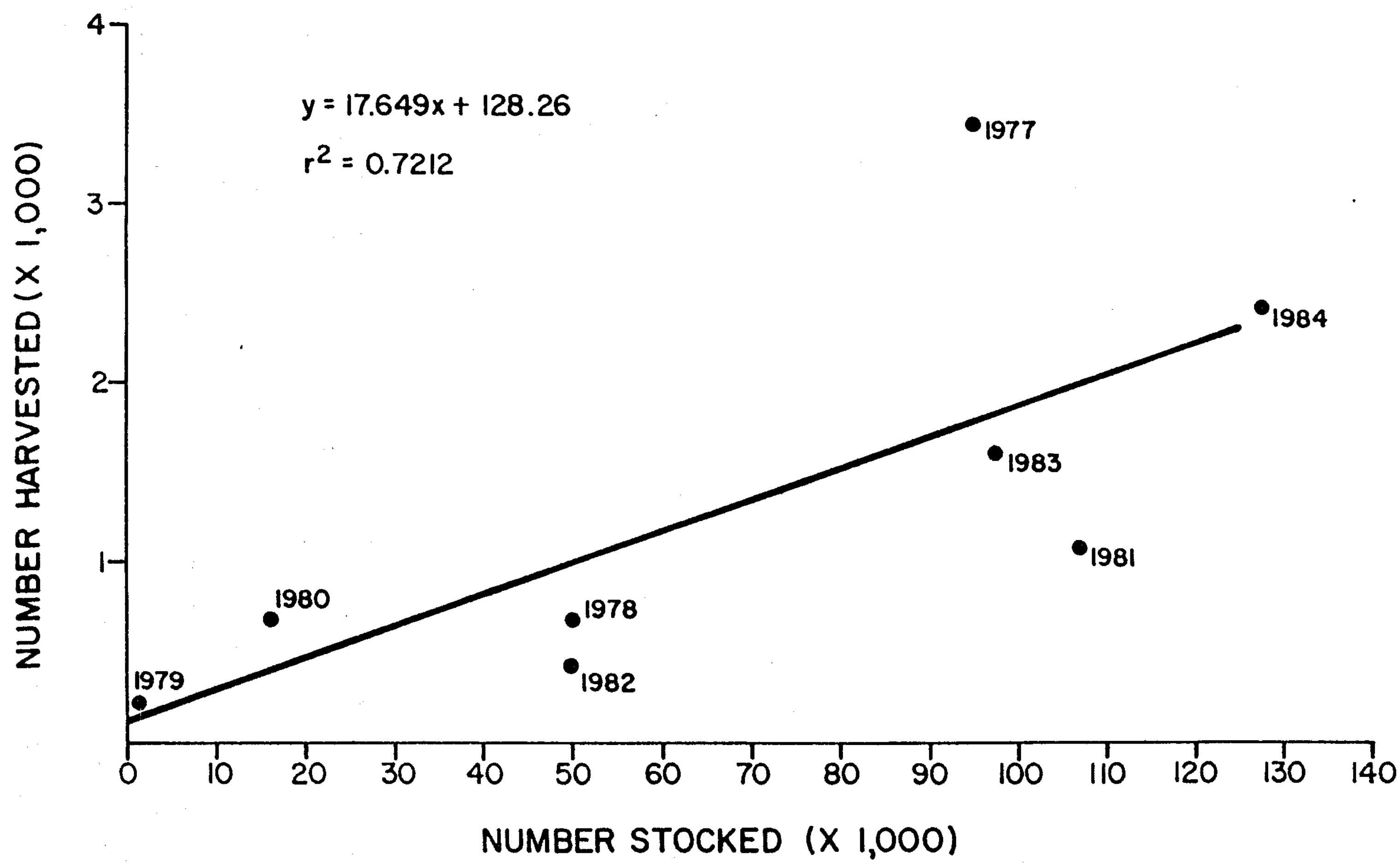


Figure 14. Relationship between harvest of age 0 rainbow trout and number stocked, Lee's Ferry, 1977-1984.

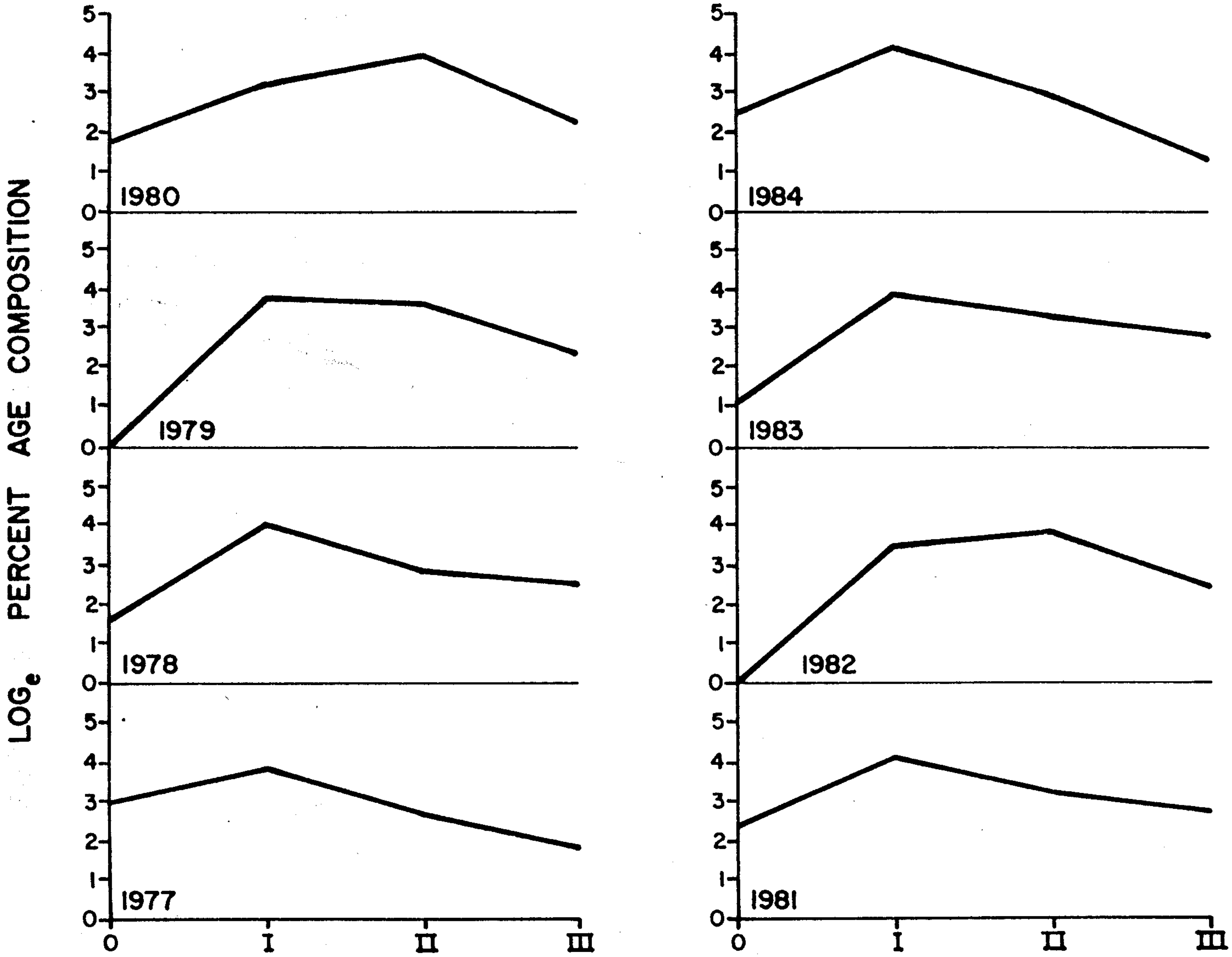


Figure 15. Catch curves for the 1977 through 1984 rainbow trout harvests, Lee's Ferry.

recruits. We used the average of both techniques of 474 fish per 1,000 recruits to estimate the number of fish to be stocked to sustain a catch rate of 0.15 fish per hour with the formula:

$$\text{Recruits} = \frac{\text{Angler hours x 0.15 fish/hour}}{\text{474 fish / 1,000 recruits}} .$$

Therefore, in order to sustain a harvest rate of 0.15 fish per angler hour with pressure of 350,000 angler hours (1982), we recommend stocking a minimum of 111,000 fish. These are not definite numbers, but should serve as guidelines to maintain the catch rate objectives for blue-ribbon trout fisheries outlined in the AGFD Coldwater Strategic Plan (Stephenson 1985). These stocking estimates assume that natural and fishing mortality will remain similar to those from 1977-1982.

Water management

To more closely examine effects of flow variables on year-class strength of rainbow trout at Lee's Ferry, we compared Hile year-class indices to various flow measurements (Hile 1941). Although no fish were stocked during 1979, approximately eight hundred 230 mm fish were stocked during the spring of 1980. These fish were of a size more representative of the 1979 cohort, therefore the 800 fish were assigned to the 1979 year-class for analysis of the influence of flow on year-class strength.

Results of Spearman rank correlations (Snedecor and Cochran 1967) suggest that year-class strength was inversely related to number of days during the year with flow less than 3,000 cfs;

number of days during the year with flow less than 8,000 cfs; and number of days during the year with a daily range in flow greater than 15,000 cfs (Table 18).

Yield of trout increased greatly at Lee's Ferry following the introduction of freshwater shrimp in 1968. Gammarus has probably been largely responsible for the excellent growth of trout in the tailwater. Effects of fluctuating flows on Gammarus production and drift are unclear at this time, although the distribution of Cladophora probably limits standing crop of Gammarus. Cladophora is most abundant below the zone of water fluctuation. Low flows for more than 12 hours will probably kill Cladophora and have detrimental impacts on standing crop of Gammarus. Effects of diurnal fluctuations in flow on Gammarus drift and availability as food for trout are unknown. In light of the good growth of trout at Lee's Ferry during the late 1970's under periods of peaking power operation, fluctuating flows may stimulate drift of Gammarus and increase availability of food for trout. Other workers have also found that fluctuating flows can increase invertebrate drift (Minshall and Winger 1968).

Table 18. Spearman rank correlation coefficients between year-class strength, harvest of age 0 fish, number stocked, and various flow measurements.

Variable	Year Class Strength	Number of Age 0 Harvested
Number stocked[a/]	0.3000	0.6307
Number of days during year with flow less than:		
1,000 cfs	-0.4037	-0.1455
3,000 cfs	-0.7568*	0
5,000 cfs	-0.6487	-0.2857
8,000 cfs	-0.6847*	-0.2857
Number of days during year with flow greater than 30,000 cfs	0.3063	0.2857
Number of days during year with range in flow greater than 15,000 cfs	-0.7388*	-0.3214

* $p<=0.05$

a/ Adjusted to 866 for 1979 year class of 230 mm fish stocked in 1980. Unadjusted correlation coefficient for age 0 harvested was 0.8264, $p<=0.05$.

RECOMMENDATIONS

Based on the results of the present study, various factors were identified that affect the Glen Canyon tailwater. Water and fishery management techniques can be manipulated within certain limits to protect and enhance the sport fishery. After briefly reviewing each identified problem area, we recommend methods to minimize or alleviate effects of these situations on the biota of the Glen Canyon tailwater, realizing that some methods would severely impact power production and therefore may not be economically feasible.

Stocking. Harvest and year-class strength of rainbow trout were dependent upon stocking of hatchery fish. Stocking rates and schedules have been erratic in the past. In order to make flow recommendations to protect hatchery stocked trout, AGFD needs to adopt a stocking schedule to coincide with water management periods for protection of fingerling trout. In addition, numbers stocked must be sufficient to meet the demand by anglers.

1 We recommended that AGFD stock fingerling rainbow trout from March through July. This schedule should meet hatchery production constraints and coincide with periods when the Bureau of Reclamation has the most latitude in providing adequate flows.

2 Stock a minimum of 110,000 fingerling rainbow trout to maintain catch rates of 0.15 fish per hour with pressure of 350,000 angler hours per year.

3 Stock fish at sites upstream from the boat ramp to decrease densities of fingerlings at specific locations.

4 Continue periodic stockings of brook trout and cutthroat trout because they grow well and provide anglers the opportunity to catch species other than rainbow trout.

5 Evaluate growth rates and return to the creel of various strains of trout. If possible, stock strains that show good growth and survival to the creel.

Sport fishery regulation

Low stocking rates; increased pressure, harvest, and percent of fish released by bait anglers in 1982 and 1983 appear to have hurt the sport fishery in 1984. Decreases in catch rates and average length of fish creeled suggest that high fishing mortality has decreased the quality of the fishery below standards set for Arizona blue-ribbon fisheries. A variety of options are available to reduce fishing mortality and improve the quality of the fishery, including decreased bag limits, minimum and slot size limits, and terminal gear restrictions. Most management techniques would probably be ineffective if a high percentage of fish were hooked and released on bait.

6 In order to keep regulations as simple as possible, yet have the greatest positive potential impact on the fishery, we

recommend that Lee's Ferry be made an artificial-lure only fishery.

7 If after the additional stocking program, size of fish does not increase to Arizona blue-ribbon fishery objectives, we recommend that a 15-20 inch slot size limit be instituted to improve survival of fish larger than 20 inches to the creel.

8 To effectively manage the fishery it is crucial that AGFD have reliable estimates of trout standing crop. Stocked trout should be marked and creeled fish should be monitored for mark returns to obtain population estimates and growth rates.

<u>Water management</u>

Flows less than 5,000 to 8,000 cfs dewater cobble and boulder bars that are used by trout as spawning and rearing areas. Flows less than 8,000 and greater than 20,000 cfs reduce the amount of habitat available for planted fingerling trout; and low flows may cause stranding mortalities. Year-class strength of trout was lower during years with low flows and high ranges in flows. Although natural recruitment may be limited by poor spawning substrate, steps can be taken to protect hatchery stocked fingerling trout.

9 Maintain flows above 8,000 cfs to inundate cobble and

boulder bars for fingerling trout from March through July when most hatchery fish are stocked.

10 Reduce daily flow fluctuations during the period from March through July. We recommend a minimum flow of 8,000 cfs and a maximum daily flow of 20,000 cfs to protect and enhance habitat for fingerling trout.

11 Ramp flows so that changes in flow take place over several hours, thereby allowing fish a greater opportunity to avoid strandings.

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APPENDICES

Table A1. Record of fish stocked by Arizona Game and Fish Department at Lee's Ferry, 1964-84.

Species	Date	Number Stocked	Size (Inches)
Rainbow trout	3/64	10,200	5.5
	5/64	5,000	8.5
	6/64	5,000	10.0
	7/64	5,000	10.5
	10/64	5,000	11.0
	11/64	5,000	11.0
	1/65	4,366	11.5
	3/64	4,464	11.5
	6/65	2,000	10.0
	7/65	10,000	3.0
	9/65	2,000	8.5
	10/65	2,000	8.5
	1/66	1,500	9.8
	4/66	10,000	3.0
	4/66	1,500	11.5
	9/66	1,500	9.0
	3/67	5,000	4.5
	3/67	1,600	12.5
	5/67	2,500	7-10
	6/67	1,500	9.5
	12/67	10,000	4.0
	1/68	2,800	11.0
	3/68	1,000	9.0
	3/68	20,000	5.0
	8/68	4,500	8.0
	9/68	10,000	5.5
	5/69	945	9.5
	5/69	16,000	5.0
	5/69	24,000	4.5
	6/69	1,500	9.0
	6/69	1,225	9.5
	7/69	20,000	7.0
	8/69	1,225	8.5
	4/70	20,000	6.0
	5/70	1,050	9.0
	6/70	1,050	9.0
	7/70	1,225	9.0
	8/70	1,050	9.0
	5/71	1,225	9.0
	5/71	1,225	9.0
	7/71	1,400	9.0
	8/71	1,260	9.5
	5/72	875	10.0
	6/72	1,225	10.5
	7/72	1,225	10.5
	8/72	1,260	9.5
	6/73	1,225	8.5
Rainbow trout	7/73	1,225	8.5
	8/73	1,225	9.5
	7/74	3,990	8.5
	5/75	30,000	3.0
	6/75	4,500	9.0
	3/76	50,000	2.0
	10/76	40,000	3.0
	10/76	10,000	3.0
	4/77	45,000	3.0
	4/77	50,000	3.0
	3/78	50,000	4.0
	7/80	846	9.0
	8/80	7,522	5.5
	9/80	7,581	5.5
	2/81	20,208	4.0
	2/81	19,298	4.0
	3/81	18,298	4.0
	8/81	50,000	4.0
	7/82	50,000	4.0
	10/83	59,296	4.0
	10/83	39,287	4.5
	6/84	24,952	4.0
	8/84	25,000	3.0
	8/84	28,000	3.0
	9/84	50,000	3.0
Brook trout			
	6/77	47,880	2.5
	8/78	100,000	2.5
	11/78	42,7000	Fingerling
	7/80	886	9.0
	9/80	40,000	3.0
	9/81	50,000	4.0
	12/81	10,096	5.0
	6/82	50,000	3.0
	10/83	50,000	3.5
Cutthroat trout			
	12/78	60,000	3.0
	11/80	857	Advanced Fingerling
Coho salmon			
	6/71	20,000	3.0

Table A2. Record of fish stocked by National Park Service (NPS) and U. S. Fish and Wildlife Service (USFWS), Colorado River tributaries.

Species	Date	Location	Number	Size	Agency
Rainbow trout	5/1923	Tapeats Creek	5,000	Eyed eggs	NPS
	9/1923	Bright Angel Creek	20,000	Fingerlings	NPS
	9/1924	Bright Angel Creek	6,000	Fingerlings	NPS
	2/1931	Havasu Creek	18,000	Eyed eggs	NPS
	1/1932	Bright Angel Creek	21,000	Eyed eggs	NPS
	12/1934	Bright Angel Creek	31,000	Eyed eggs	NPS
	9/1935	Bright Angel Creek	21,000	Eyed eggs	NPS
	5/1939	Bright Angel Creek	13,800	Fingerlings	NPS
	6/1940	Bright Angel Creek	18,000	Fingerlings	NPS
	6/1940	Tapeats Creek	2,000	Fingerlings	NPS
	7/1940	Clear Creek	18,000	Fry	NPS
	11/1941	Bright Angel Creek	32,000	Fingerlings	NPS
	7/1942	Bright Angel Creek	28,000	Fingerlings	NPS
	7/1942	Phantom Creek	14,000	Fingerlings	NPS
	9/1944	Havasu Creek	4,500	Fry	NPS
	6/1947	Bright Angel Creek	10,394	Fingerlings	NPS
	4/1948	Havasu Creek	13,000	Fingerlings	NPS
	3/1950	Bright Angel Creek	45,240	Fingerlings	NPS
	4/1954	Havasu Creek	20,000	Fingerlings	NPS
	7/1958	Bright Angel Creek	45,000	Fingerlings	NPS
	6/1964	Bright Angel Creek	23,900	Fingerlings	NPS
	1970	Diamond Creek	6,173	Fingerlings	USFWS
	1971	Diamond Creek	11,000	Fingerlings	USFWS
Brown trout	7/1926	Shinumo Creek	50,000	Eyed eggs	NPS
	8/1930	Shinumo Creek	50,000	Eyed eggs	NPS
	12/1930	Garden Creek	4,000	Eyed eggs	NPS
	1/1930	Bright Angel Creek	100,000	Eyed eggs	NPS
	12/1930	Bright Angel Creek	45,000	Eyed eggs	NPS
	12/1934	Bright Angel Creek	50,000	Eyed eggs	NPS
Brook trout	8/1920	Bright Angel Creek	5,000	Fingerlings	NPS
	6/1927	Havasu Creek	10,000	Fingerlings	NPS
	12/1928	Clear Creek	50,000	Eyed eggs	NPS
	1/1931	Clear Creek	25,000	Eyed eggs	NPS
	12/1934	Clear Creek	18,000	Eyed eggs	NPS

Appendix B. List of common and scientific names of fishes collected from the Colorado River below Glen Canyon Dam[a/].

Common name	Scientific name
Threadfin shad	Dorosoma petenense
Cutthroat trout	Salmo clarkii
Rainbow trout	Salmo gairdneri
Brown trout	Salmo trutta
Brook trout	Salvelinus fontinalis
Common carp	Cyprinus carpio
Speckled dace	Rhinichthys osculus
Bluehead sucker	Catostomus discobolus
Flannelmouth sucker	Catostomus latipinnis
Striped bass	Morone saxatilis
Walleye	Stizostedion vitreum

[a/]Nomenclature according to Bailey et al. (1980)

Appendix C. List of common and scientific names of aquatic and riparian plants along the Colorado River from Glen Canyon Dam to the confluence of the Paria River.

Scientific name	Common name
Equisctaceae	Horsetail
Equicetum laevigatum	
Hydrocharitaceae	
Elodea canadensis	Water weed
Juncaceae	
Juncus balticus	Wire rush
Juncus torreyi	Rush
Potamogetonaceae	
Potamogeton sp.	
Zannichelliaceae	
Zannichellia palustris	Common poolmat
Typhaceae	
Typha domingensis	Southern cattail
Typha angustifolia	Narrow leaved cattail
Gramineae	
Phragmites communis	Common reed
Cyperaceae	
Carex lanuginosa	Sedge
Carex nebraskensis	Sedge
Carex aquatilis	Sedge
Eleocharis macrostachya	Spike rush
Scirpus americanus	Bullrush
Scirpus acutus	Great bullrush
Scirpus sp.	
Cruciferae	
Rorippa nasturtium-aquatum	Watercress
Salicaceae	
Populus fremontii	Fremont cottonwood
Salix exiqua	Coyote willow
Salix goodingii	Godding willow
Tamaricaceae	
Tamarix chinesis	Tamarisk
Tamarix gallica	Tamarisk
Tamarix pentandra	Desert tamarisk
Scrophulariaceae	
Veronica anagallis-aquatica	Speedwell

Appendix D. Location, dimensions, temperature, and number of redds observed at 20 Colorado River tributaries in the Grand Canyon, January 23 - February 1, 1982.

Tributary	River Mile (Belknap 1969)	Width (m)	Depth (mm)	Temp. (^{o}C)	Number of Redds
Vaseys Paradise	32	3.0	5	15	
Nankoweap Creek	52	1.8	52	9	18
Kwagunt Creek	56	0.8	50	8	
Little Colorado River	62			12	
Palisades Creek	66	0.6	234	13	
Bright Angel Creek	88	5.2	444	5	17
Phantom Creek[a]	88	2.2	178	4.4	7
Pipe Creek	89	1.0	114	2.2	7
Hermit Creek	95	1.1	144	8	3
Crystal Creek	98	5.0	82	4	65
Shinumo Creek	108	4.6	332	5	3
Royal Arch Creek	112	7.0	673	7	15
Stone Creek	132	2.3	486	9	
Tapeats Creek	134	4.2		9.5	9
Deer Creek	136				2
Kanab Creek	143	11.0	196	3	
Havasu Creek	157	15.0		10	3
Pumpkin Springs	212	4.0		22	
Three Springs	216	1.3	45	15	
Diamond Creek	225	3.0	166	10	

[a] Tributary of Bright Angel Creek

Appendix E. Mark-recapture summary for five Colorado River flannelmouth suckers.

Release[a]			Recapture						
Tag	Date	Location	Location	Date	Gear[b]	Length (mm)	Weight (kg)	AGFD tag	Travel Distance (km)
Green 02051	Spring 1978	Little Colorado River (River mile 62)	Glen Canyon Dam (River mile 15.5)	1/22/80	EF	502	1.23	009	75
Yellow 01536	Summer 1978	Paria River	Lee's Ferry (River mile 13.6)	1/28/80	TN	448	0.36	016	12.1
Yellow 01616	Summer 1978	Paria River	Lee's Ferry (River mile 10.9)	5/16/80	TN	453	0.92	050	9.4
Blue 04515	Fall 1978	Little Colorado River (River mile 62)	Glen Canyon Dam (River mile 15.5)	11/27/80	TN	546	1.4	152	75
Blue 01011	Fall 1978	Little Colorado River (River mile 62)	Paria River	4/10/81	HN	390	0.7	---	61

a/ Carothers and Minckley (1981)

b/ EF = Electrofisher
TN = Trammel net
HN = Hoop net

Table F-1 . Monthly length frequencies and assigned ages of rainbow trout check at Lee's Ferry creel station, 1977.

Length (Inches)	Month													Age						
	1	2	3	4	5	6	7	8	9	10	11	12	Total	0	1	2	3	4	5	>5
7													0							
8													0							
9										16	3	7	26	26						
10						5	4			9		10	28	9						
11							7			2	11	8	28	21	7					
12						1	27	3			4	9	44	13	31					
13						2	13	2		3	6	6	32	6	26					
14						2	9			14	4	6	35		35					
15						6	7				8	1	22		16	6				
16						1	5	1		17		17	41		34	7				
17						3	8	1		13	6	13	44		32	12				
18						1	6			8	5	11	31		17	14				
19						2	5			2			9			5	4			
20						8	2	1		2		6	19			11	8			
21						5	3	1		1		6	16			6	10			
22							1				1		2				2			
23						4	6			2			12				2	10		
24						3	5			1		2	11					11		
25							1			1		3	5					5		
26						1	3			1		2	7					3	4	
27						2	1				1	1	5						5	
28													0							
29							1				1	1	3							3
30													0							
31													0							
32												2	2							2
33													0							
Total	0	0	0	0	0	46	114	9	0	92	50	111	422	85	207	61	26	29	9	5
Percent by age														20	49	14	6	7	2	1

Table F-2. Monthly length frequencies and assigned ages of rainbow trout checked at Lee's Ferry creel station, 1978.

Length (Inches)	Month 1	2	3	4	5	6	7	8	9	10	11	12	Total	Age 0	1	2	3	4	5	>5
7													0							
8	2		2					1	1				6	2	4					
9	5		6					1	3	2			17	6	11					
10	3	3	3	2					11	5			27	15	12					
11	2	2	8	2	1			2	2	3	1		23	8	15					
12	1	3	7	12	1	3	1	1	3	3		3	38	10	28					
13	1		8	13	12	1		3	5	5	1	7	56	8	48					
14	1		10	17	16	4	2	1	6	12	2	7	78	7	71					
15	2	3	15	23	30	8	2	3	8	11	3	6	114		114					
16	4		8	36	26	14	7	7	10	22	19	17	170		158	12				
17	3	1	14	24	7	6	4	6	12	22	19	20	138		88	50				
18	2	2	7	15	20	3	3	13	4	13	14	15	111		59	52				
19	3		8	14	8	2	6	11	9	20	15	19	115		58	54	3			
20	1		6	23	17	3	1	1	10	5	4	8	79		12	20	47			
21	1		4	15	14	2	9	7	6	8	3	7	76		7	17	51	1		
22	4		3	4		2	8	6	10	11	7	6	61			13	44	4		
23	1	1	2	6	1	1	4	2	6	6	3	5	38				8	30		
24			1	4	1	2	4	3	10	2		1	28				1	27		
25			4	6	5		4	2	5	4		2	32				1	16	15	
26					3	2	3		5	1		1	15				1	6	8	
27							2		4	1			7						7	
28					4	1	1		1				7						1	6
29											2		2							2
30											1		1							1
31											1		1							1
32													0							
33													0							
Total	36	15	116	216	166	54	61	70	131	156	95	124	1240	56	685	218	156	84	31	10
Percent by age														5	55	18	13	7	3	1

Table F-3. Monthly length frequencies and assigned ages of rainbow trout checked at Lee's Ferry creel station, 1979.

Length (Inches)	Month 1	2	3	4	5	6	7	8	9	10	11	12	Total	Age 0	1	2	3	4	5	>5
7								1					1	1						
8				1									1	1						
9				1									1	1						
10		2	1	8									11	1	10					
11		2	9	16				1					28	1	27					
12	1	2	5	25									33		33					
13	4	4	12	19	3			2					44		44					
14	3	6	21	17	3		1	2					53		53					
15	2	8	7	6	1		1						25		25					
16	7	17	27	8	6		6	5					76		25	51				
17	8	17	27	7	9		4	7					79		11	68				
18	8	15	13	3	4		4	12					59		16	43				
19	10	9	9	1	8		7	12					56		19	37				
20	4	3	1	1	4		1	2					16			16				
21		8	2	3	6		4	8					31			23	8			
22	3	7	3	1	2			6					22			13	9			
23	2	1	1		2		8	1					15			1	14			
24	1	3		1	2		5	4					16				16			
25			3	1	1		3	2					10				10			
26		1		1	2		3						7				6	1		
27			1		1		1						3				1	2		
28							1						1					1		
29					1		1						2						2	
30													0							
31													0							
32	1												1							1
33													0							
Total	54	105	142	120	55	0	50	65	0	0	0	0	591	5	263	252	64	4	2	1
Percent by age														1	45	43	11	1	0	0

Table F-4. Monthly length frequencies and assigned ages of rainbow trout checked at Lee's Ferry creel station, 1980.

Length (Inches)	Month																			
	1	2	3	4	5	6	7	8	9	10	11	12	Total	0	1	2	3	4	5	>5
7													0							
8							1						1	1						
9							2			1			3	3						
10							3		1	2		1	7	7						
11				1			2	1	1		1	1	7	7						
12				6	2	1			6	4	1	1	21	12	9					
13				5	2	4	2	1	5		3	2	24	5	19					
14				3	2	1		4	7	6	5	3	31	3	28					
15				1		2	2	8	5	9	4	3	34		34					
16				3	2	1	4	4	14	11	9	4	52		46	6				
17				7	9	9	5		9	4	4	5	52		22	30				
18				4	4	4	7	3	3	13	6	3	47		9	38				
19				2	2	6	12	12	11	11	6	2	64			64				
20				2	2	3	7	13	16	14	9	4	70			70				
21				2	4	2	4	12	14	9	9	12	68			60	8			
22					1	1	1	12	13	12	8	3	51			42	9			
23					2	2		6	5	13	4	3	35			13	22			
24							1	1	3	3	2	2	12				12			
25								1	2	5			8				8			
26									1				1					1		
27								1					1					1		
28				1									1						1	
29													0							
30													0							
31													0							
32													0							
33													0							
Total	0	0	0	37	32	36	53	79	116	117	71	49	590	38	167	323	59	2	1	0
											Percent by age			6	28	55	10	0	0	0

Table F-5. Monthly length frequencies and assigned ages of rainbow trout checked at Lee's Ferry creel station, 1981.

Length (Inches)	Month 1	2	3	4	5	6	7	8	9	10	11	12	Total	Age 0	1	2	3	4	5	>5
7									1				1	1						
8	1	1	1					5	3				11	8	3					
9		1	6					6	1				14	7	7					
10	7	4	4					2	2				19	4	15					
11	7	6	7					9	16	8	10	8	71	20	51					
12	2		7					3	20	11	10	8	61		61					
13	1	3	4					4	16	9	10	7	54		54					
14	1	4	5					33	13	23	13	16	108		108					
15	2	4	4					13	7	16	11	9	66		66					
16	6	3	2					7	10	15	20	8	71		62	9				
17	3	7	4					9	10	4	13	4	54		40	14				
18	8	9	4					8	18	11	20	8	86		45	41				
19	11	5	5					3	5	6	15	8	58		37	21				
20	2	11	7					3	7	7	5	12	54		4	50				
21	9	11	4					3	1	11	9	5	53			43	10			
22	14	6	10					4	3	4	3	10	54			24	30			
23	19	10	2					8	3	6	6	7	61			20	41			
24	10	4	3					2	2	6	5	5	37			10	27			
25	3		2					3		5	1	4	18				18			
26	1							1	2	5	1	3	13				10	3		
27	1	1	1							2	6	2	13				2	11		
28		1								2	2		5					5		
29									1	2			3					1	2	
30									1				1						1	
31													0							
32													0							
33										1			1							1
Total	108	91	82	0	0	0	0	126	142	154	160	124	987	40	553	232	138	20	3	1
													Percent by age	4	56	24	14	2	0	0

Table F-6. Monthly length frequencies and assigned ages of rainbow trout checked at Lee's Ferry creel station, 1982.

Length (Inches)	Month 1	2	3	4	5	6	7	8	9	10	11	12	Total	Age 0	1	2	3	4	5	>5
7							1				1		2	2						
8												1	1	1						
9			1									1	2	1	1					
10	1		4	1	2	1	1	1		1		1	13	3	10					
11	9	1	5		3	1	6		2	2	2	1	32	1	31					
12	6	7	3	2	4		8	9	9	2	2	1	53		53					
13	9	3	7		3	1	6	12	15	7	5	1	69		69					
14	14	16	6		5	3	8	12	10	7	6	4	91		61	30				
15	15	7	12	2	6	3	3	14	10	12	15	2	101		51	50				
16	25	11	8	1	6	2	7	16	9	13	9	6	113		55	58				
17	10	17	7		11	1	9	13	7	13	20	1	109		45	64				
18	13	17	2	1	6	3	5	18	13	12	18	5	113		23	90				
19	13	8	7		3	1	7	3	8	6	24	7	87			87				
20	6	13	2		3		6	7	4	9	19	6	75			56	19			
21	9	9			2	2	3	12	5	4	12	9	67			47	20			
22	10	8	3	1	2		4	4	6	3	10	6	57			30	27			
23	7	7				1	3	6	3	4	6	3	40			13	27			
24	5	7			1	1	2	1	2	1	2	3	25				25			
25	4	3	1		2		2	2	5	3	6	4	32				24	8		
26	4	1			1		1	1	1	1	3	2	15				7	8		
27	3	1	1	1	2			2	1		3		14				1	13		
28	3	1					1	1			1	1	8					8		
29	2										1	1	4					2	2	
30	1	1									1	1	4						4	
31											1		1						1	
32													0							
33													0							
Total	169	138	69	9	62	20	83	134	110	100	167	67	1128	8	399	525	150	39	7	0
Percent by age														1	35	47	13	3	1	0

Table F-7. Monthly length frequencies and assigned ages of rainbow trout checked at Lee's Ferry creel station, 1983.

Length (Inches)	Month 1	2	3	4	5	6	7	8	9	10	11	12	Total	Age 0	1	2	3	4	5	>5
7			1					2		1			4	3	1					
8										1			1	1						
9	3		5								4	1	13	5	8					
10	4	4			1			2		3	4	7	25	14	11					
11	4	9		2			2	2		4	3	12	38	15	23					
12	8	3		1	2		16	12	5	14	10	5	76	5	71					
13	4	3		2			24	25	8	26	13	8	113		113					
14	6	8	1	2			41	18	10	39	27	14	166		166					
15	10	9	1		2		34	26	8	47	27	17	181		159	22				
16	3	4	2	1			39	30	8	41	44	18	190		110	80				
17	7	14	1	4	1		19	21	2	43	48	19	179		87	92				
18	8	7	1	1	4		21	12	4	23	27	11	119			119				
19	8	3	3		2		10	11	1	18	15	11	82			72	10			
20	9	7		3	1		15	14	4	12	21	8	94			44	50			
21	4	5	2	4	3		21	7	5	11	13	7	82			31	51			
22	9	2	2	1	2		27	7	4	9	10	8	81				81			
23	2	4		1	3		20	12	1	5	6	2	56				50	6		
24	4		1	1	3		9	3	4	10	6	2	43				34	9		
25	3	1		1			11	4		2	2	1	25				2	23		
26	2		1	1	2-		6			2	2	3	19					19		
27					1		1						2					2		
28	1				1			2					4						3	1
29	1			1						1			3						2	1
30													0							
31													0							
32													0							
33													0							
Total	100	83	21	26	28	0	316	210	64	312	282	154	1596	43	749	460	278	59	5	2
Percent by age														3	47	29	17	4	0	0

Table F-8. Monthly length frequencies and assigned ages of rainbow trout checked at Lee's Ferry creel station, 1984.

Length (Inches)	Month 1	2	3	4	5	6	7	8	9	10	11	12	Total	Age 0	1	2	3	4	5	>5
7			1	1			1	1					4	3	1					
8	3	2	8	8	5	1	4	4	4	4	1		44	29	15					
9	1	4	4	16	12	14	19	13	5	4	6		98	63	35					
10	8	9	10	12	8	24	33	37	20	6	10		177	86	91					
11	5	11	14	9	12	18	37	37	50	26	10	3	232	75	157					
12	7	11	12	9	23	16	43	57	58	46	26	6	314	39	275					
13	8	6	4	5	10	9	34	40	46	48	40	5	255	12	243					
14	10	2	4	7	11	13	28	36	51	52	52	12	278	5	258	15				
15	9	16	8	9	14	7	9	32	37	33	26	13	213		182	31				
16	15	8	11	6	8	10	13	19	24	25	20	14	173		119	54				
17	25	10	5	12	13	12	12	12	24	20	12	8	165		82	83				
18	9	7	10	8	11	3	15	19	19	19	9	5	134		40	94				
19	9	5	8	4	12	4	7	12	23	18	8	11	121		29	87	5			
20	5	2	3	6	11	3	17	7	21	16	5	3	99		4	65	25	5		
21	5	7	2	6	4	5	5	10	10	8	4	6	72		1	42	19	10		
22	4	5	4	5	1	4	5	2	7	8	10		55			21	16	18		
23	2	4		2		6	2	3	2	4	1	1	27			6	13	8		
24	4	1	2	4		4	1	3	4	4			27			2	11	14		
25		1	1	3	3	2		1				1	12				2	10		
26	1	1							1	1	1	1	6				4	2		
27								1					1				1			
28							1			1	1		3					3		
29													0							
30									1				1						1	
31													0							
32													0							
33													0							
Total	130	112	111	132	158	155	286	346	407	343	242	89	2511	312	1532	500	96	70	1	
Percent by age														12	61	20	4	3	0	

Appendix G. Year class strength indices for rainbow trout, Lee's Ferry, 1977-83.

Table G-1. Percent age composition of fish in the creel by year class.

	Year Class									
Year Creeled	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
1977	14	49	20							
1978		18	55	5						
1979			43	45	1					
1980				55	28	6				
1981					24	56	4			
1982						47	35	1		
1983							29	47	3	
1984								20	61	12

Table G-2. Hile year class index computations, Lee's Ferry rainbow trout, 1977-83.

Years of Comparison	First Year	Second Year	Percent Change	Cumulative Percent	Year	Hile Index
					1977	-1.4
1977-78	118	105	-11.0	-11.0	1978	-12.4
1978-79	105	53	-49.5	-60.5	1979	-61.9
1979-80	53	109	105.7	45.2	1980	43.8
1980-81	109	68	-37.6	7.6	1981	6.2
1981-82	68	68	0	7.6	1982	6.2
1982-83	58	64	10.3	17.9	1983	16.5

Appendix H. Number stocked, harvest, yield (kg), year-class strength indices, and flow variables, Lee's Ferry 1977-84.

Variable	Year							
	1977	1978	1979	1980	1981	1982	1983	1984
Number stocked (x1,000)	95	50	0	16.8	107.8	50	98.5	128
Number harvested	17,320	13,586	22,527	11,619	27,402	43,316	53,780	21,855
Number of Age 0 harvested	3,464	679	225	687	1,096	433	1,613	2,623
Yield (kg)	12,730	13,790	20,860	13,397	26,224	45,135	49,800	13,033
Year class strength index	-1.4	-12.4	-61.9	43.8	6.2	6.2	16.5	-
Days with flow:								
Less than 1,000 cfs	25	1	10	2	1	2	0	-
Less than 3,000 cfs	206	119	178	91	161	99	20	-
Less than 5,000 cfs	259	250	272	156	275	208	53	-
Less than 8,000 cfs	306	320	325	226	343	278	96	-
Greater than 30,000 cfs	6	5	7	20	1	0	71	-
Days with range in flow:								
Greater than 15,000 cfs	172	234	209	158	137	136	77	-