EVALUATION OF INSTREAM FLOW METHODS AND DETERMINATION OF WATER QUANTITY NEEDS FOR STREAMS IN THE STATE OF COLORADO

EVALUATION OF INSTREAM FLOW METHODS AND DETERMINATION OF WATER QUANTITY NEEDS FOR STREAMS IN THE STATE OF COLORADO

by

R. Barry Nehring, Wildlife Researcher

Report to the U. S. Department of the Interior,
U. S. Fish and Wildlife Service,
Cooperative Instream Flow Service Group

Funded by the U. S. Fish and Wildlife Service
Under Contract No. 14-16-0006-78-909

Colorado Division of Wildlife
Jack R. Grieb, Director

Department of Natural Resources
Harris D. Sherman, Executive Director

Colorado Division of Wildlife
Fort Collins, Colorado

September, 1979

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (cont.)

LIST OF FIGURES

LIST OF APPENDICES

LIST OF APPENDICES (cont.)

ACKNOWLEDGEMENTS

To all those people (listed in the Appendix) who were a part of my stream survey crew during the 1978 field season, I extend my heart-felt thanks and appreciation for their assistance in the successful completion of this project. Without your help a project of this magnitude would have taken several years.

To the U.S. Fish and Wildlife Service I extend my appreciation for the financial support (Contract No. 14-16-996-78-909) without which this evaluation would not have been possible.

In addition I extend a special thanks to the following individuals: Marie Greubel, Kay Pankonin, and Lori Jiron for typing and retyping the many tables and drafts of the report. Mssrs. Wesley Nelson, Norwin Smith, and Bill Weiler for editing the original and polished rough drafts. Mr. Bruce Sanford for all of the excellent graphics and figures in the text and appendices. Dr. Clair Stalnaker, Ken Bovee, Bob Milhous, Mike Prewitt, Bob Judy, and Dave Wegner for their assistance and help in completion of all of the computer analysis with the IFG3 and IFG4 programs. Rex Taliaferro, Ed Kochman, Kathy Kribbs, and Elmer Luft in preparation and analysis of all of the computer work with the R-2 Cross Method.

For my wife and children, a very special thanks for the kindness and understanding they exhibited during my absence while collecting the field data in the summer of 1978.

INTRODUCTION

In 1973, the Colorado State Legislature passed a law, commonly referred to as Senate Bill 97, which established that the diversion of water from a stream was no longer a requirement for beneficial use. The law specifically provides that "beneficial use shall also include the appropriation by the State of Colorado in the manner prescribed by law of such minimum flows between specific points or levels for and on natural lakes and streams as are required to preserve the natural environment to a reasonable degree."[1]

This act established for the first time in the history of water law appropriation in the western United States that water left in a stream to sustain fish and wildlife is a beneficial use. This law was challenged in the courts of the State of Colorado and was recently upheld by the Colorado Supreme Court. The Colorado Water Conservation Board has instructed the Colorado Division of Wildlife (herein after referred to as DOW) to continue to evaluate streams throughout the State and recommend minimum stream flows for fisheries.

The Ecological Services Section of the DOW, in close cooperation with regional biologists, has already filed several hundred requests for minimum stream flows around the State. These requests have been based on a computer modeling method known as Sag Tape, U.S. Forest Service R-2 Cross, Colorado R-2 Cross, of IFG1 (Anonymous, 1974). All of these names refer to basically the same technique. This was the "state-of-the-art" method at the time of the passage of S.B. 97.

In the past 6 years the U.S. Fish and Wildlife Service has done intensive work in the field of instream flow assessment through the Instream Flow Service Group (IFSG) resulting in significant improvements in methodology (Bovee and Milhous, 1978). Currently the IFSG is sponsoring the "Phase II Program" under which selected instream flow methodologies are being evaluated under contracts with 14 western states, including Colorado.

The "Statement of Work" attached to the contract (No. 14-16-996-78-909, March 16, 1978) specifies methodologies to be used, criteria for selecting streams and reaches to be studied, and a schedule of tasks to be accomplished. This is the final report on the work accomplished under this contract.

---

[1] Senate Bill No. 97, Colorado State Senate, p.1, Enacted and approved April 23, 1973.

METHODS AND MATERIALS

Selection of Study Streams

Following consultation with DOW personnel and consideration of the availability of U.S. Geological Survey flow records a preliminary list of 30 Class I (critical) or Class II (high priority) streams was compiled. After consultation with personnel of the IFSG and further consideration, this list was reduced to 15 streams (Table 1). Carnero Creek, a Class III stream (U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, and Colorado Division of Wildlife, 1979) was included because DOW personnel discovered it contained an endemic population of Rio Grande cutthroat trout (*Salmo clarki viginalis*) and thus should be rated as Class I, not Class III.

One or two reaches of each stream were selected for survey according to selection criteria and techniques outlined by Bovee and Milhous (1978). Placement of the lower and upper cross sections was governed by the presence of a flow control point or a critical riffle. A flow control point is defined as a restriction or an obstruction in the stream channel across which the stream energy gradient reaches an inflection point (Bovee and Milhous, ibid.).

Field Data Collection Plan

An intensive evaluation of the annual discharge patterns of study streams was made using the Water Resources Data for Colorado (U.S. Geological Survey, 1961-1978). Using these data and estimating the anticipated maximum run-off time and volume based on the snow-pack data available for the various study areas, a prospective field schedule for 1978 was set up to maximize efficiency by minimizing travel time. In most instances, a field trip consisted of 3 to 5 days, and three to five study sites were evaluated each time. This worked out very well, since out of 168 man-days spent in the field over the 7 month field season, only 3 man-days were lost due to misjudgment of anticipated stream discharge. Every attempt was made to survey the study streams at levels near maximum run-off, median annual discharge, and minimum annual flow. However, on the larger study streams, the upper level of flow evaluation was set at a level double or triple the amount of water that would probably be recommended as an instream flow request.

In only two instances were we unable to meet the objectives of our plan for collection of field data. One was on the East River where the lower four cross sections were inundated by water backed up across the lower flow control point when DOW personnel set up a low diversion dam across the flow control point to divert a spawning run to kokanee salmon out of the East River into an irrigation canal for trapping and spawning operations. As a result, only the upper two cross sections were resurveyed and only twice instead of three times. The other problem occurred on the South Platte survey areas when the Denver Water Board refused to allow DOW personnel in to do cross section work without a court order. On the other 13 streams, the objectives of the field data collection program were realized (Table 2).

Table 1. Location, classification, and category of streams selected for study.

Stream name	Range	Township	Classification[a]	Category[b]
Cache la Poudre River, Little South Fork	73W	8N	I	1,4,8
Carnero Creek, South Fork	4E	43N	III	1,4,8
Cucharas River	69W	31S	I	1,4,9
Cunningham Creek	82W	8S	I	1,4,9
East River	85W	15S	I	1,6,7
Fryingpan River I (at Taylor Creek)	86W	8S	I	1,5,7
Fryingpan River, II (Castle View)	86W	8S	I	1,5,7
Fryingpan River, North Fork	82W	8S	I	1,4,7
Fryingpan River, South Fork	82W	9S	II	1,4,8
Gunnison River, Lake Fork	3W	48N	I	1,5,8
Huerfano River	72W	27S	I	1,4,9
Rio Grande River, South Fork	2E	39N	I	1,5,8
Sangre de Cristo Creek	71W	29S	I	2,4,8
South Platte River I (above Denver Water Board Diversion)	69W	7S	I	1,6,7
South Platte River II (below Marston Canal)	69W	7S	I	1,5,8
St. Louis Creek	76W	1S	I	1,4,9
Williams Fork River I (below Kinney Creek)	77W	2S	I	1,5,8
Williams Fork River II (at Ute Creek)	78W	2S	I	1,5,8

[a] I - critical; II - high priority; III - substantial

[b]
1) Cold water habitat
2) Cool water habitat
3) Warm water habitat
4) Small wadeable stream
5) Large wadeable stream
6) Unwadeable stream
7) Low gradient stream
8) Medium gradient stream
9) High gradient stream

Table 2. Cross sectional evaluations, dates completed, average flows and range of flows.

Date	Stream name	Number cross sections	Av. flow	Range of flow
6-8-78	Cache la Poudre River, Little South Fork	4	185.0	170 - 200
10-10-78	Cache la Poudre River, Little South Fork	4	15.7	12.3 - 18.3
5-22-78	Carnero Creek, South Fork	8	11.4	9.0 - 13.2
6-19-78	Carnero Creek, South Fork	7	6.4	5.4 - 7.1
7-26-78	Carnero Creek, South Fork	8	1.7	1.2 - 2.6
9-13-78	Carnero Creek, South Fork	8	1.0	0.4 - 2.1
5-25-78	Cucharas River	7	36.7	31.0 - 45.6
7-25-78	Cucharas River	7	19.6	17.8 - 23.1
9-7-78	Cucharas River	7	7.9	6.2 - 9.4
7-18-78	Cunningham Creek	7	18.0	15.1 - 20.0
8-22-78	Cunningham Creek	7	1.5	1.17 - 2.27
10-18-78	Cunningham Creek	7	0.9	0.64 - 0.98
8-16-78	East River	6	199.0	181 - 237
10-4-78	East River	2	76.6	76.3 - 76.8
4-11-78	Fryingpan River I (Taylor Creek)	4	250.0	241 - 255
8-21-78	Fryingpan River I (Taylor Creek)	4	139.4	121 - 151
9-18-78	Fryingpan River I (Taylor Creek)	4	75.2	69.2 - 83.5
4-11-78	Fryingpan River II (Castle View)	3	266.0	256 - 280
8-21-78	Fryingpan River II (Castle View)	3	138.0	135 - 146
9-18-78	Fryingpan River II (Castle View)	3	75.2	71.5 - 81.9
7-18-78	Fryingpan River, North Fork	6	65.3	61.1 - 70.5
8-22-78	Fryingpan River, North Fork	6	8.6	7.1 - 11.2
10-18-78	Fryingpan River, North Fork	6	1.5	1.07 - 1.75
7-19-78	Fryingpan River, South Fork	7	11.3	9.4 - 14.6
8-22-78	Fryingpan River, South Fork	7	16.6	13.6 - 21.1
8-15-78	Gunnison River, Lake Fork	6	171.0	158 - 186
9-5-78	Gunnison River, Lake Fork	6	96.6	81.5 - 106.2
10-2-78	Gunnison River, Lake Fork	6	68.3	62.5 - 79.8
5-24-78	Huerfano River	8	31.0	28.9 - 32.9
7-25-78	Huerfano River	8	21.6	16.6 - 24.0
9-7-78	Huerfano River	8	9.4	7.0 - 11.5
7-24-78	Rio Grande River, South Fork	6	34.4	31.2 - 40.0
9-12-78	Rio Grande River, South Fork	6	14.1	7.6 - 17.4
9-25-78	Rio Grande River, South Fork	6	26.9	19.9 - 34.0
5-23-78	Sangre de Cristo Creek	8	17.1	14.6 - 21.4
6-19-78	Sangre de Cristo Creek	8	3.4	2.6 - 3.9
9-7-78	Sangre de Cristo Creek	8	0.1	0 - 0.3
5-4-78	South Platte River I (above Denver Water Board Diversion)	4	211.0	202 - 219
5-4-78	South Platte River II (below Marston Canal)	3	85.9	83.5 - 88.4
6-6-78	St. Louis Creek	7	53.5	49.3 - 59.1
8-4-78	St. Louis Creek	7	26.2	21.5 - 29.2
10-9-78	St. Louis Creek	7	9.3	8.3 - 11.1
4-25-78	Williams Fork River I (below Kinney Creek)	7	40.9	37.2 - 44.8
6-5-78	Williams Fork River I (below Kinney Creek)	6	263.0	233 - 288
8-2-78	Williams Fork River I (below Kinney Creek)	7	111.0	101 - 131
4-26-78	Williams Fork River II (at Ute Creek)	3	49.5	47.6 - 51.4
8-2-78	Williams Fork River II (at Ute Creek)	3	100.9	92.5 - 117

Survey Methods Used

After considerable discussion with personnel of the Ecological Services Section of the DOW, it was decided to use the Colorado R-2 Cross Method as both the single cross section method and the multiple cross section method of analysis. Up until the present time, this model has been the only method utilized by the DOW to analyze field data in filing for water rights with the Colorado Water Conservation Board under Senate Bill 97. While the R-2 Cross and single cross section methodologies in general have received considerable criticism in the past (Bovee and Milhous, 1978), the DOW was not ready to scrap this method in favor of other more sophisticated methodologies requiring much greater time, manpower, and monetary expense without a comprehensive evaluation.

The IFG4 model was used for the Incremental Method of analysis. Results of this analysis were interfaced with the IFG3 model to provide a habitat analysis for target species (trout) occurring in the study reaches. The Tennant (1975) or Montana Method was a synthetic analysis of U.S.G.S. flow data and was completed in the office.

Field procedures and techniques of data collection are outlined in great detail by Bovee and Milhous (1978). These procedures were followed precisely as described.

Criteria For Minimum Flow Determination

Minimum levels for key determining parameters with the single transect R-2 Cross Method are presented in Table 3 below.

Criteria for the Multiple Transect R-2 Cross and the IFG4 methods on critical riffles were the same as those for the single transect R-2 Cross. But in run and pool type habitat, both water velocity and average depth respond differently when compared to critical riffle environments. Therefore, minimum average depth and velocity criteria in run and pool type transects were modified as shown in Table 3-A, below.

Table 3. Key flow parameters used to determine minimum flow requirements using the R-2 Cross Single Transect Method.[a]

Stream width (ft)	X Average depth (ft)	Y Average velocity (ft/sec)	Z Wetted perimeter (%)
1 - 20	0.2 or greater	1	50
21 - 40	0.2 - 0.4	1	50
41 - 60	0.4 - 0.6	1	50 to 60
61 - 100	0.6 - 1.0	1	70 or greater

[a] Colorado rivers in excess of 100 feet in wetted perimeter are judged on individual channel characteristics as related to key flow parameters. Parameters apply to instream flow recommendations for period May to September. October to April flow recommendations will be at the same level, or at the natural undepleted flow, whichever is less.

Instream flow recommendation in cfs are selected when minimum levels of two or more parameters are reached within the designated stream class. Average depth evaluation is based on maximum body depth of largest fish present and is considered one of the most important flow parameters. Body depth is defined as the distance from the tip of the extended dorsal fin to the lowest portion of the body cavity.

Table 3-A. Key flow parameters used to determine minimum flow requirements for the multiple transect R-2 Cross and IFG4 methods.

Stream width (ft)	Average depth (ft)	Average velocity (ft/sec)	Wetted perimeter[a] (%)
	Run Habitat Type		
1 - 21	0.2	0.5	50
21 - 40	0.2 - 0.4	0.5	50
41 - 60	0.4 - 0.6	0.5	50-60
61 - 100	0.6 - 1.0	0.5	70 or greater
	Pool Habitat Type		
1 - 20	0.4	0.1	50
21 - 40	0.4 - 0.8	0.1	50
41 - 60	0.8 - 1.2	0.1	50-60
61 - 100	1.2 - 2.0	0.1	70 or greater

[a] Wetted perimeter was not part of the computer printout with the IFG4 and was not used in determining minimum flow recommendations with this method.

Chronological Order of Data Analysis

The contract stated that each methodology should be evaluated individually, step by step and with as little bias as possible occurring between methods. The primary investigator and the field crew under his supervision collected all of the field data, thereby at least maintaining a constant source of error and hopefully as small an error as possible. The field data for the R-2 Cross analysis process was turned over to the Ecological Services Section of the DOW for computer analysis and determination of minimum flows by the Single Transect R-2 Cross Method. This was done without any assistance or input from the primary investigator.

After the single transect R-2 Cross minimum flow recommendations were made by Ecological Services, all R-2 Cross data were then turned over to the primary investigator for the multiple transect R-2 Cross analysis and minimum flow determination process, without the primary investigator's knowledge of what the single transect R-2 Cross minimum flow determination was.

Finally, these sets of data (single and multiple transect cross section R-2 Cross analysis) were set aside and the IFG4 analysis was completed using average velocity and average depth as the two criteria for making minimum flow recommendations.

The Tennant or Montana Method was the fourth method used and is a synthetic analysis based on mathematical manipulation of U.S.G.S. gaging data as described by Tennant (1975). Thirty percent of the average discharge, which Tennant classifies as an excellent flow for the needs of fish and aquatic invertebrates, was the level used in this study for comparative purposes between methods.

The last method of analysis was the IFG3 or "weighted usable area" model (Bovee and Cochnauer, 1977) which interfaces with both the IFG4 Incremental Method and the Wetted Surface Profile (WSP) or IFG2 Method. In this study, the IFG3 was interfaced with the IFG4 Method, but not in the traditional sense for setting minimum flow recommendations. Rather, weighted usable area for all life stages was analyzed to determine if the model predictions were reflected in the actual species composition of the fish population observed through electroshocking studies.

Population Estimation Methodologies

Trout population density and biomass estimates were completed using the standard Petersen Mark and Recapture method with two electroshocking runs through the stream. In most instances 24 hours of time elapsed between the first pass for marking and the second (recapture) pass. However, on the small streams with less than 10 cfs discharge the second pass was made the same day.

Electroshocking sections were from 500 to 1,000 feet of stream channel and contained at least two complete cycles of stream habitat, i.e., riffle-pool-riffle being one cycle. No attempt was made to prevent movement of fish into or out of the area during electroshocking. However, in two study sections shocking runs were made both above and below the study areas to evaluate the movement of marked fish out of the population estimation area. In one stream, no marked fish moved out and in the other only one marked trout of more than 200 captures had moved out of the study area, or less than 0.5%. Timmermans (1974) found this to be the case as well and concluded that screening of study areas was a superfluous exercise.

Trout captured on the first pass were marked by punching a 2 mm diameter hole in the caudal fin with a hand-operated paper punch. The hole heals up in 2 to 4 weeks and does not hinder the fish's swimming ability. Biometric data (length, weight, species, and scale samples) were collected after the second electroshocking and all fish were checked for marks. Only fish in excess of 13 cm in length were considered in the population estimation process. Data from the electroshocking surveys are summarized in Appendix A.

Instream Flow Service Group - Special Analysis Procedures

The IFSG prepared guidelines of suggested analysis procedures to be included as part of the final report. These analyses are presented in the appendix. The IFSG recommended method of stream by stream time and cost analysis is presented in Appendix D. Appendix E contains a brief curriculum vitae of all participants in this study and a stream by stream list of the functions the various individuals performed on the streams. Appendix F is a list of species occurring in each of the study areas as well as the target species.

RESULTS AND DISCUSSION

Single Transect (R-2 Cross) Method

All of the minimum flow recommendations in Table 4, except for the South Fork of the Fryingpan River, were based on data collected during the Phase II investigation. The Phase II recommendation of 30 cfs on the South Fork of the Fryingpan was based on a very atypical critical riffle and turned out to be excessively high when compared to the results of the other methodologies. This critical riffle was almost twice as wide as the rest of the stream channel due to the division of the stream into two channels a few feet below the transect. A minimum flow recommendation of 6 cfs has been in effect for a year or more on this stream, based on a previous critical riffle transect taken in the same general vicinity (within a few hundred yards).

Table 4. Minimum flow recommendations using the Single Transect (R-2 Cross) Method.

Stream name	Minimum flow recommendation (cfs)
1. Cache la Poudre River, Little South Fork	20
2. Carnero Creek, South Fork	2
3. Cucharas River	5
4. Cunningham Creek	4
5. East River	65
6. Fryingpan River I (Taylor Creek)	55
7. Fryingpan River II (Castle View)	65
8. Fryingpan River (North Fork)	8
9. Fryingpan River (South Fork)	6 (30)
10. Gunnison River, Lake Fork	45
11. Huerfano River	4
12. Rio Grande River, South Fork	40
13. St. Louis Creek	9
14. Sangre de Cristo Creek	2
15. South Platte River I - above Denver W.B. diversion	60
16. South Platte River II - below Marston Canal	18.5
17. Williams Fork River I - below Kinney Creek	37
18. Williams Fork River II - at Ute Creek	40

There were 33 transects on the 18 study reaches that were classified as critical riffle. Seventy-six percent of the time, average depth was considered first limiting or co-limiting according to the specified criteria (Table 3). Fifteen percent of the time, percent wetted perimeter was first limiting or co-limiting. Nineteen percent of the time, average velocity was first limiting or co-limiting. This indicates that average depth is the most important criterion in minimum flow recommendations as the parameters are set at the present time.

The primary assumptions made in using the critical riffle concept are that average depth, average velocity, and percent wetted perimeter change most rapidly across critical riffles. If these parameters are maintained at or above minimum acceptable levels across the riffle areas, they will be maintained in other habitat types such as pools and runs as well so that adequate habitat exists for maintenance of most life stages of fish and aquatic invertebrates. Examination of the data (Table 5) tends to bear out these assumptions. Observations made during electroshocking and cross section evaluations throughout the summer of 1978 also further substantiate these contentions. On Sangre de Cristo Creek early fall flows were reduced to less than 0.1 cfs and remained that way for approximately 60 days. Despite no opportunity for movement up or downstream to better refuge areas, this stream supported a standing crop of 27 lbs per surface acre biomass of Rio Grande cutthroat trout (*Salmo clarki virginalis*) during the extended period of near zero flow compared to 23 lb/acre in June 1978 at near optimum (17 cfs) flow conditions.

Average water velocities of 1 - 1 1/2 ft/sec have been shown by various investigators to produce both optimum numbers of aquatic invertebrates as well as good spawning conditions for most species of trout (Giger, 1973; Hooper, 1973; Hoppe and Finnell, 1970). These limits fall within the criteria range set for average velocity with the Colorado R-2 Cross Method. I found that 77% of the time the R-2 Cross overestimates the actual average velocity across the transect by almost 45%, i.e., a predicted average velocity of 1.45 ft/sec would only be 1 ft/sec. Under the proper set of circumstances this could result in a minimum flow recommendation that might not adequately sustain aquatic invertebrate populations or incubating trout eggs. Hoppe and Finnell (1970) found that incubating trout eggs suffocated when average water velocities dropped below 1 ft/sec.

Stalnaker and Arnette (1976), Hooper (1973), and the Wyoming Water Resources Research Institute (1978) have all presented excellent reviews of the literature concerning depth, velocity, and substrate preferences for the species of trout occurring in the stream reaches included in this study. The average depth and average velocity criteria used in setting the minimum flow recommendations for the R-2 Cross fall well within the accepted ranges as summarized by the above investigators.

Table 5. Minimum flow recommendation using the multiple transect (R-2 Cross) method.[a]

Stream name	Cal. flow (cfs)	Recom. flow (cfs)	X-Sec. no.	Av. velocity (ft/sec)	Av. depth (ft)	Percent wetted perimeter	Transect description
Cache la Poudre R., Little S. Fork	15.7	21.4	1	1.88	0.60	41	Critical riffle
	15.7	10.7	3	0.48	0.69	77	Pools
Av.	--	16.1	--	1.18	0.65	59	
Carnero Creek, South Fork	1.7	1.3	1	0.61	0.24	86	Pool & critical riffle
	1.7	1.2	2	0.30	0.69	57	Pool (standing)
	1.7	2.9	3	2.82	0.20	50	Critical riffle & run
Av.	--	1.8	--	1.20	0.38	64	
Cucharas River	7.9	4.4	1	1.79	0.21	55	Critical riffle
	7.9	2.8	4	0.99	0.26	61	Lip of rapids
	7.9	5.5	7	1.07	0.46	74	Deep fast pool
Av.	--	4.2	--	1.28	0.31	63	
Cunningham Creek	18.0	4.5	2	0.97	0.39	78	Deep pool
	0.9	5.6	4	3.76	0.16	58	Critical riffle
	18.0	2.3	4	1.54	0.16	61	Critical riffle
Av.	--	4.1	--	2.09	0.24	66	
East River	76.5	63.2	5	0.85	0.70	96	Critical riffle
	76.5	37.7	6	0.81	0.81	67	Critical riffle & run
Av.	--	50.5	--	0.83	0.76	82	
Fryingpan River I (Taylor Creek)	251.0	61.0	1	1.43	0.61	91	Critical riffle
	75.2	63.7	1	1.60	0.60	80	Critical riffle
	255.0	53.8	2	1.34	0.63	74	Deep riffle & run
	251.0	33.8	3	1.31	0.68	57	Shallow run & riffle
	241.0	51.1	4	1.72	1.00	50	Deep run
	75.2	56.3	4	1.07	1.20	70	Deep run
Av.	--	53.3	--	1.41	0.79	70	
Fryingpan River II (Seven Castles)	75.2	60.5	1	1.13	0.60	88	Critical riffle - spawning beds
	75.2	76.7	2	1.36	0.60	93	Spawning riffle
	75.2	49.9	3	0.77	0.90	86	Spawning riffle & deep run
Av.	--	62.4	--	1.09	0.70	89	
Fryingpan River, North Fork	8.6	3.6	3	0.34	0.40	85	Pool
	8.6	5.5	4	1.13	0.44	40	Deep run & riffle
	8.6	6.1	5	0.65	0.46	75	Slow run
	8.6	3.8	6	1.18	0.20	52	Critical riffle
Av.	--	4.8	--	0.83	0.38	63	(Atypical)
Fryingpan River, South Fork	11.3	5.0	1	1.03	0.10	61	Wide critical riffle
	11.3	5.4	2	0.36	0.67	68	Pool and run
	11.3	5.2	4	0.60	0.44	58	Deep pool and run
Av.	--	5.2	--	0.66	0.40	62	
Gunnison River, Lake Fork	68.3	45.4	1	1.21	0.60	95	Critical riffle
	68.3	39.3	3	1.47	0.77	54	Riffle & deep run
	68.3	72.4	5	2.40	0.66	70	Fast run
Av.	--	52.4	--	1.69	1.69	73	

[a] Underlined figure indicates the parameter that was considered the limiting factor.

Table 5. Minimum flow recommendation using the multiple transect (R-2 Cross) method (continued).[a]

Stream name	Cal. flow (cfs)	Recom. flow (cfs)	X-Sec. no.	Av. velocity (ft/sec)	Av. depth (ft)	Percent wetted perimeter	Transect description
Huerfano River	9.4	4.2	1	1.12	0.28	70	Critical riffle
	9.4	5.2	4	1.08	0.33	83	Fast run & pool
	9.4	5.6	6	1.22	0.60	50	Deep fast run & pool
Av.	--	5.0	--	1.14	0.40	68	
Rio Grande River, South Fork	34.4	34.6	1	1.03	0.60	75	Critical riffle & run
	34.4	58.8	2	1.68	0.60	87	Deep run & critical riffle
	34.4	35.2	4	1.50	0.46	83	Critical riffle
	14.1	42.2	1	0.92	0.70	95	Critical riffle
	14.1	29.2	2	1.19	0.50	80	Deep run & riffle
	14.1	45.8	4	1.32	0.60	94	Critical riffle
Av.	--	41.0	--	1.27	0.58	86	
Sangre de Cristo Creek	3.3	3.4	1	2.30	0.18	75	Critical riffle
	3.3	1.5	2	0.57	0.26	73	Shallow run & tail of pool
	3.3	0.5	4	0.31	0.22	55	Deep pool
	3.3	3.2	7	1.01	0.31	52	Shallow riffle & run
	3.3	2.0	8	0.42	0.26	90	Critical riffle & run
Av.	--	2.1	--	0.92	0.25	69	
South Platte River (above Denver Water Board Diversion)	214.0	90.4	1	1.81	0.56	82	Critical riffle
	219.0	63.9	2	1.41	0.53	83	Riffle & small pools
	202.0	70.0	3	1.30	0.60	86	Riffle & small pools
Av.	--	74.8	--	1.50	0.56	84	
South Platte River (below Marston Canal)	85.8	25.3	1	1.66	0.51	52	Deep fast run
	83.5	35.4	2	2.07	0.78	45	Deep fast run
	88.4	42.2	3	2.32	0.65	47	Deep fast run
Av.	--	34.3	--	2.02	0.65	48	
St. Louis Creek	9.4	6.3	2	0.65	0.71	58	Deep pool & run
	9.4	12.4	3	1.61	0.44	49	Deep pool & fast run
	9.4	9.4	4	1.46	0.44	36	Deep fast run
	9.4	6.5	7	0.72	0.40	71	Critical riffle & pool
Av.	--	8.7	--	1.11	0.50	54	
Williams Fork River I (below Kinney Creek)	39.3	39.4	1	1.52	0.35	76	Critical riffle
	42.1	42.4	6	1.58	0.43	72	Critical riffle
	39.9	25.6	7	0.72	0.63	86	Shallow run
Williams Fork River II (at Ute Creek)	51.4	37.2	1	3.21	0.39	54	Fast run & pools
	49.5	25.3	2	1.17	0.72	58	Deep fast run & pools
	47.6	18.8	3	0.87	0.72	54	Deep boulder pool
Av.	44.9	31.5	--	1.51	0.54	67	

---

[a] Underlined figure indicates the parameter that was considered the limiting factor.

Multiple Transect (R-2 Cross) Method

The minimum number of calibration flows (field discharge measurement) used was one and the minimum number of cross sections was two (Table 5). When only one calibration flow was used in the analysis, it was generally because the other calibration flows were too high or too low to be of any use in the analysis process, i.e., percent wetted perimeter, average depth, and average velocity at that particular flow never met the minimum levels established as the limiting factors. In all study areas at least one transect of three types of stream habitat (riffles, runs, pools) were selected to be included in the Multiple R-2 Cross Transect analysis. The reader is referred to Stalnaker and Arnette (1976) for concise definitions of these terms. Additional terms were added to more fully describe the particular stream transect being evaluated.

These transects were selected because they were considered representative of the actual stream configuration in the area being evaluated. Each transect was analyzed according to the criteria set forth in Table 3 for the "critical riffle" study transects together with the modifications in the criteria for run and pool habitats as set forth in Table 3-A.

Once the average velocities, average depths, percent wetted perimeters, and recommendations for instream flows were made for individual transects within a stream reach, the simple average was taken for each parameter, and the average recommended flow in cfs was used as the minimum flow for the Multiple Transect R-2 Cross analysis process (Table 5).

For each transect analyzed, the parameters that first became limiting by falling below the minimum criteria are underlined in Table 5. In 50 out of 77 instances or 65% of the time average depth became the limiting factor first. Average velocity became limiting or co-limiting 13 times or 17% of the time and percent wetted perimeter became limiting or co-limiting 14 times or 18% of the time.

The recommended flows developed using this multiple transect analysis were very similar to the flows obtained using the single transect method. These results indicate that the extra time expended on the multiple transect method is probably not worthwhile since there is no greater resolution or refinement in the minimum flow recommendation. The only advantage might be that the water courts may consider the recommendation more reliable since it was based on several different cross-sections over several types of stream habitat.

Incremental (IFG4) Method

The Incremental Method using the stage discharge approach was completed with the cooperation of and input from personnel of the Instream Flow Service Group. Average depth and average velocity were the only two parameters used in formulating minimum flow recommendations with the Incremental Method.

The average depth, average velocity, and recommended instream flows for each transect are given in Table 6. All three parameters for each transect were totalled and averaged. The average recommended flow in cfs was the discharge level used to compare with results of the other methodologies. As was the case with the multiple transect R-2 Cross, the parameter that first became limiting or co-limiting was average depth, 60 times out of 96, or 63% of the time.

In determining the flow level at which either average velocity or average depth became limiting, generally the flow was taken either just above or just below the point at which that factor became limiting. Possibly all values should have been interpolated to get the exact flow level at which one parameter became limiting. However, I felt this was unnecessary in most instances since the requested discharge levels (Q) were usually only a few cfs apart. In instances where the differences between adjacent discharge levels was 10 cfs or greater then exact values were interpolated. Where adjacent input Q requests were only 1 to 5 cfs apart, I felt the differences would average out, i.e., one flow was actually too high, the other too low, producing very nearly the same average flow as if all recommended flow levels had been interpolated exactly.

The Incremental Method produced minimum flow recommendations that closely approximated those from the Single and Multiple Transect R-2 Cross Method. Since average depth was the determining factor in the vast majority of instances for both methods it is perhaps not so strange that minimum flow recommendation from the two methods would agree quite well.

The Incremental Method offers great advantages over the R-2 Cross Methods because of its capability of interfacing with the IFG3 or Habitat Computer Model. This system allows for a detailed analysis of the stream habitat available to the trout at any flow regime desired. This facet of the study will be discussed in subsequent sections.

Table 6. Minimum flow determinations using the Incremental (IFG4) Method.[a]

Stream name	Transect no.	Av. depth (ft)	Av. velocity (ft/sec)	Recom. flow (cfs)	Transect descriptions
Cache la Poudre R., Little South Fork (21-40 ft width classification)	1	0.42	0.94	10.0	Critical riffle
	2	0.49	0.75	20.0	Fast run
	3	0.87	0.49	20.0	Slow riffle-pool
	4	0.74	0.50	15.0	Slow riffle-pool
Av.		0.63	0.67	16.3	
Carnero Creek, South Fork (1-20 ft width classification)	1	0.18	1.25	2.0	Critical riffle
	2	0.57	0.11	0.5	Deep pool
	3	0.31	1.21	2.0	Riffle and fast run
	4	0.22	1.45	3.0	Fast run
	5	0.42	0.45	5.0	Riffle and run
	6	0.26	0.90	2.0	Fast riffle
	7	0.27	0.80	2.0	Slow riffle
	8	0.42	0.31	2.0	Pool
Av.		0.33	0.81	2.3	
Cucharas River (1-20 ft width classification)	1	0.26	1.10	5.0	Critical riffle
	2	0.25	0.69	3.0	Riffle-run
	3	0.22	1.03	3.0	Critical riffle
	4	0.22	1.50	3.0	Lip of rapids
	5	0.27	1.34	5.0	Deep fast run
	6	0.40	0.64	3.0	Deep run
	7	0.41	0.47	2.0	Deep pool
Av.		0.31	1.03	3.6	
Cunningham Creek (1-20 ft width classification)	1	0.30	1.00	8.0	Riffle
	2	0.78	0.25	2.0	Deep pool
	3	0.33	0.38	2.0	Pool and run
	4	0.26	0.92	6.0	Critical riffle
	5	0.43	0.52	4.0	Riffle-run
	6	1.18	0.13	2.0	Deep pool
	7	0.40	0.17	2.0	Tail of pool - flow control point
Av.		0.52	0.43	3.7	
East River (60-100 ft width classification)		No incremental analysis			
Fryingpan River I, (Taylor Creek) (60-100 ft width classification)	1	0.57	1.39	60.0	Critical riffle
	2	0.63	1.13	60.0	Riffle and run
	3	0.68	0.65	30.0	Run and riffle
	4	1.24	0.56	40.0	Deep fast run
Av.		0.78	0.93	47.5	

---

[a] Underlined figure indicates the parameter that first became limiting or co-limiting.

Table 6. Minimum flow determinations using the Incremental (IFG4) Method (continued).[a]

Stream name	Transect no.	Av. depth (ft)	Av. velocity (ft/sec)	Recom. flow (cfs)	Transect descriptions
Fryingpan River II, (Castle View) (60-100 ft width classification)	1	0.88	0.92	100.0	Spawning riffle
	2	0.60	0.93	60.0	Riffle and run
	3	0.78	0.56	30.0	Run and riffle
Av.		0.75	0.80	63.3	
Fryingpan River, North Fork (21-40 ft width classification)	1	0.40	0.35	3.1	Pool + run (flow control point)
	2	0.42	0.94	10.0	Riffle and run
	3	0.79	0.46	10.0	Pool and run
	4	0.41	0.49	5.0	Run
	5	0.50	0.38	5.0	Run
	6	0.40	0.95	18.4	Critical riffle
Av.		0.49	0.60	8.5	
Fryingpan River, South Fork (21-40 ft width classification)	1	0.12	1.36	5.0	Critical riffle
	2	0.94	0.12	3.0	Pool
	3	0.65	0.40	5.0	Pool
	4	0.47	0.52	5.0	Run and pool
	5	0.48	0.94	10.0	Run and riffle
Av.		0.53	0.67	5.6	
Gunnison River, Lake Fork (41-60 ft width classification)	1	0.61	1.73	70.0	Critical riffle
	2	0.84	0.66	30.0	Run
	3	0.84	1.09	40.0	Deep run and riffle
	4	0.83	1.05	40.0	Pools and runs
	5	0.67	1.31	40.0	Fast run
	6	0.60	1.68	70.0	Riffle and run
Av.		0.73	1.25	48.3	
Huerfano River (1-20 ft width classification)	1	0.30	0.99	5.0	Critical riffle
	2	0.28	0.91	5.0	Riffle
	3	0.36	0.98	5.0	Riffle and run
	4	0.48	0.61	5.0	Pool and run
	5	0.54	0.64	5.0	Pool and run
	6	0.59	0.85	5.0	Pool and run
	7	0.58	0.67	5.0	Deep pool
	8	0.51	0.66	5.0	Deep pool
Av.		0.46	0.79	5.0	
Rio Grande River, South Fork (41-60 ft width classification)	1	0.60	0.75	40.0	Run and riffle
	2	0.60	1.06	42.2	Deep run and riffle
	3	0.65	0.99	40.0	Critical riffle
	4	0.59	1.08	40.0	Critical riffle
	5	0.60	1.09	56.7	Critical riffle
	6	0.76	0.58	30.0	Run and riffle
Av.		0.63	0.93	41.5	

---

[a] Underlined figure indicates the parameter that first became limiting or co-limiting.

Table 6. Minimum flow determinations using the Incremental (IFG4) Method (continued).[a]

Stream name	Transect no.	Av. depth (ft)	Av. velocity (ft/sec)	Recom. flow (cfs)	Transect descriptions
Sangre de Cristo Creek, (1-20 ft width classification)	1	0.20	0.98	2.0	Critical riffle
	2	0.39	0.35	2.0	Tail of pool and run
	3	0.46	0.30	2.0	Deep still pool
	4	0.64	0.16	1.0	Head of pool (deep)
	5	0.21	1.32	5.0	Critical riffle
	6	0.40	0.50	3.5	Riffle and run
	7	0.24	0.50	2.0	Shallow run
	8	0.21	0.98	5.0	Riffle and run
Av.		0.34	0.64	2.8	
South Platte River		No incremental analysis			
St. Louis Creek (21-40 ft width classification)	1	0.47	0.50	10.0	Run and riffle
	2	0.74	0.50	12.6	Deep pool and run
	3	0.40	1.18	12.3	Deep fast run and pool
	4	0.40	0.92	8.4	Deep fast run
	5	0.40	1.04	6.7	Deep fast run
	6	0.40	0.58	5.0	Pool and riffle
	7	0.41	0.50	7.9	Pool and riffle
Av.		0.46	0.75	9.0	
Williams Fork River I, (below Kinney Creek) (greater than 60-100 ft width classification)	1	0.56	1.34	80.0	Critical riffle
	2	0.67	0.93	40.0	Riffle and run
	3	1.17	0.69	30.0	Deep run and riffle
	4	0.60	1.53	57.0	Deep fast run and riffle
	5	0.60	1.30	54.0	Critical riffle and run
	6	0.60	1.29	38.0	Critical riffle
Av.		0.70	1.18	49.8	
Williams Fork River II, (Ute Creek confluence) (41-60 ft width classification)	1	0.81	0.75	30.0	Deep fast run and pools
	2	0.83	0.85	30.0	Deep fast run and pools
Av.		0.82	0.80	30.0	
Williams Fork River (Grand Av.) Av.		0.73	1.09	44.9	

[a] Underlined figure indicates the parameter that first became limiting or co-limiting.

Montana (Tennant) Method

In most instances the Montana Method gave a recommendation (Table 7) approximating the recommendations of the other three methods. The one notable disparity was on the Lake Fork of the Gunnison River where no plausible explanation existed for the difference between the Montana Method flow recommendation and the other three recommendations.

Flushing flows are defined by Stalnaker and Arnette (1976, p. 12) as "That discharge (natural or man-caused) of sufficient magnitude and duration to remove fines from the stream bottom gravel to maintain intragravel permeability." In trout streams this is necessary to maintain the viability of spawning beds. A survey of the gaging histories indicates that all of the streams included in this study have discharges that meet or exceed flushing flows during peak run-off in an average water year.

Minimum flow recommendations of 30% of the average flow are recommended by Tennant (1975) as flows that will maintain adequate habitat for most forms of aquatic life over a long (months) period of time. To establish how close the 30% value used in the Montana Method is to the other methods' recommendations, all minimum flows have been converted to percentage of average discharge (Table 8).

The most remarkable part of the data is how similar the single and multiple R-2 Cross and IFG4 recommendations for an individual stream are as compared to the Montana Method. Wesche (1974) found that available cover is reduced at its greatest rate in the range of 25% to 27% of the average discharge. Using this as one parameter, he recommended that for summer rearing flows the average discharge not be allowed to fall below 25%. The average percentage of average discharge for the 18 study reaches were 28.4, 26.4, and 27.9 for the Single Transect R-2 Cross, Multiple Transect R-2 Cross, and IFG4 Methods, respectively.

Based on the findings in this evaluation and the almost identical findings of Wesche (1974), when synthetic methods of analysis are used, 25% of the average flow should be the minimum acceptable level for summer rearing flows for trout. This level is regarded as a common denominator between methodologies. It was used to determine a synthetic minimum flow recommendation for all Class I (U.S. Fish and Wildlife Service classification) streams with adequate U.S.G.S. gaging histories in the State of Colorado. These recommendations are presented in Appendix B.

Table 7. Minimum flows (cfs) derived by the Montana Method.

Stream name	Av. flow 100%	Years of history	Flushing flow 200%	Minimum flows 30%
Cache la Poudre River, Little South Fork	62.6	21	125.0	18.8
Carnero Creek, South Fork	11.0	35	22.0	3.3
Cucharas River	22.4	43	44.8	6.7
Cunningham Creek	10.6	14	21.2	3.2
East River	334.0	55	668.0	100.0
Fryingpan River I & II	180.0	10	360.0	54.0
Fryingpan River, North Fork	19.8	14	39.6	5.9
Fryingpan River, South Fork	21.6	8	43.2	6.5
Gunnison River, Lake Fork	234.0	40	468.0	70.2
Huerfano River	31.4	53	62.8	9.4
Rio Grande River, South Fork	208.0	53	416.0	62.4
Sangre de Cristo Creek	18.1	33	36.2	5.4
South Platte River	175.0	51	350.0	52.5
St. Louis Creek	19.7	21	39.4	5.9
Williams Fork River I & II	101.0	44	202.0	30.3

Table 8. Minimum flow recommendations by four different methods expressed as percent average flow.

Stream name	Single R-2 Cross	Multiple R-2 Cross	IFG4	Montana Method
Cache la Poudre R.	31.9	25.7	26.0	30
Carnero Creek	18.2	20.0	20.9	30
Cucharas River	22.3	18.8	16.7	30
Cunningham Creek	37.7	38.6	34.9	30
East River	19.5	15.1	--	30
Fryingpan R. @ Seven Castles	36.1	34.7	35.2	30
Fryingpan R. @ Taylor Cr.	30.6	29.6	26.4	30
Fryingpan R., No. Fork	40.4	24.2	42.9	30
Fryingpan R., So. Fork	27.8	24.1	25.9	30
Gunnison R., Lake Fork	19.2	22.4	20.6	30
Huerfano River	12.7	15.9	15.9	30
Rio Grande R., So. Fork	19.2	19.7	20.0	30
Sangre de Cristo Creek	11.0	11.6	15.5	30
South Platte River I	34.3	42.7	--	30
South Platte River II[a]	--	--	--	--
St. Louis Creek	45.7	44.2	45.7	30
Williams Fork River I	36.6	35.4	44.5[b]	30
Williams Fork River II	39.6	26.8	--	--
Average	28.4	26.4	27.9	30

[a] Note: No. U.S.G.S. gaging data available at this transect location.

[b] Williams Fork River I and II combined.

Weighted Usable Area (IFG3) Method

I feel that any practical application of the IFG3 model must eventually manifest itself in some relationship between weighted usable area and fish biomass. Thus, although it was not specified as a part of the contract, I collected data on species composition, numbers, and biomass per acre by species for every study stream outlined in the contract in order to evaluate the reliability of the IFG3 model in assessing this relationship. Good data on wild rainbow trout populations were collected only on the Fryingpan River. In all the other streams the rainbow trout present were known to originate from plants of creel size fish. Brook, brown, and cutthroat trout populations were known to be from wild stocks.

The biomass (lbs/acre) of trout (by species) was plotted against the weighted usable area (hereafter WUA) measured at the average discharge (from U.S.G.S. gaging data). Regressions for brook trout and cutthroat trout showed no relationship between the two parameters at all. Problems with the reliability and applicability of the data used to generate probability curves for these two species may explain the lack of any correlation in the biomass-WUA relationship. Bovee (1978), on a classification scale of excellent, good, fair, or reconnaissance grade, rates the probability curves for adult cutthroat trout at only fair or reconnaissance grade. He also recognizes that the probability curves for cutthroat were a composite from several sources and that individual subspecies of cutthroat trout may show great variation from the curves as presently used. Likewise, the probability curves for brook trout (Bovee, ibid) are rated reconnaissance grade in three of four instances and fair in the fourth instance.

Bovee (1978) rates the curves for adult brown trout as presently used either good or excellent. A plot of WUA for adult brown trout against brown trout biomass indicates a very good correlation (r=0.87) exists between these two parameters (Figure 1). The data on biomass and WUA for the study streams are given in Appendix A.

The data in Table 9 below compares the species composition (percent) in the Colorado Phase II study streams and the ratios of WUA by species and life stage. In most cases the species with the greatest WUA advantage was the dominant species in the stream. The Fryingpan River is the best example of the comparison between wild rainbow and brown trout where the adult WUA showed no clear cut advantage for either species. However, the brown trout juvenile and fry WUA was significantly greater than for rainbow trout and population estimations have shown the brown trout to have a slight advantage in biomass at Fryingpan River, Station I and an enormous advantage in biomass at Fryingpan River, Station II.

The only real discrepancies that occurred in the WUA-biomass correlation were when brook trout curves were run in conjunction with any other species curves. In these cases brook trout invariably

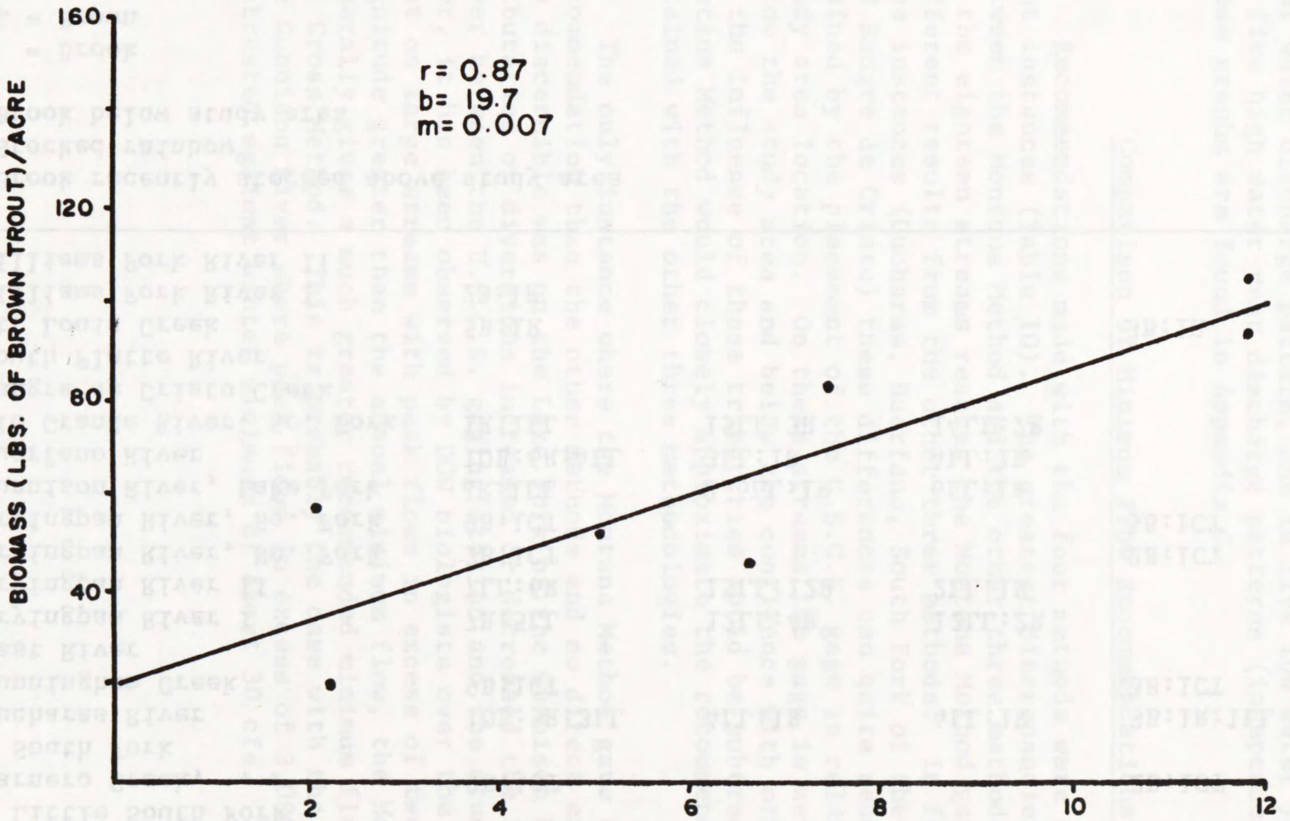


FIGURE 1: BROWN TROUT BIOMASS VS. WEIGHTED USABLE AREA FOR ADULT BROWN TROUT AT AVERAGE ANNUAL FLOW

Table 9. Predicted weighted usable area in ratios for individual species vs actual species composition (percent) in the stream.

Stream name	Advantage in weighted useable area by species: Adult	Juvenile	Fry	Spawning	Species ratio (by weight) in percent
Cache la Poudre River, Little South Fork	1R:1LL	5LL:1R	5LL:1R		96LL-2R-2B
Carnero Creek, South Fork	9B:4CT			2B:1CT	100CT[a]
Cucharas River	10B:5R:3LL	4LL:1R	4LL:1R	3B:1R:1LL	54R[b]-33L-13B
Cunningham Creek	9B:1CT			3B:1CT	100B
East River					88LL-12R-TB
Fryingpan River I	7R:5LL	12LL:4R	12LL:2R		42R-58LL
Fryingpan River II	7LL:6R	15LL:12R	2LL:1R		72LL-28R
Fryingpan River, No. Fork	3B:1CT			2B:1CT	100B
Fryingpan River, So. Fork	9B:1CT			5B:1CT	100CT[c]
Gunnison River, Lake Fork	1R:1LL	2.5LL:1R	6LL:1R		90LL-10R
Huerfano River	10B:6R:4LL	3LL:1R	4LL:1R		78LL-22R
Rio Grande River, So. Fork	1R:1LL	15LL:3R	14LL:2R		90LL-10R
Sangre de Cristo Creek					100CT
South Platte River					
St. Louis Creek	5B:1R			3B:1R	100B
Williams Fork River I	2B:1R				90B-10R
Williams Fork River II					

[a] Brook recently stocked above study area

[b] Stocked rainbow

[c] Brook below study area

B = Brook
LL = Brown
CT = Cutthroat
R = Rainbow

came out with greater WUA than rainbow, brown, or cutthroat. This indicates to me that something is inherently wrong with the brook trout probability curves and that a major review of brook trout curves is required. However, Bovee (personal communication) reports that if temperature probability curves are used in the matrix calculations for brook trout the correlation between WUA and biomass is much better for brook trout.

The percent weighted usable area (dependent variable) for various species, life stages, and streams was plotted against median year water discharge pattern, one in five low water year, and one in five high water year discharge patterns (independent variable). These graphs are found in Appendix C.

Comparison of Minimum Flow Recommendations

Recommendations made with the four methods were similar in most instances (Table 10). The greatest discrepancies occurred between the Montana Method and the other three methods. In five of the eighteen streams reaches the Montana Method gave quite different results from the other three methods. In four of the five instances (Cucharas, Huerfano, South Fork of the Rio Grande, and Sangre de Cristo) these differences can quite readily be explained by the placement of the U.S.G.S. gage in relation to the study area location. On these streams the gage is several miles below the study area and below the confluence with other tributaries. If the influence of these tributaries could be subtracted out, the Montana Method would closely approximate the recommended flows obtained with the other three methodologies.

The only instance where the Montana Method gave a higher recommendation than the other methods and no direct explanation was discernible was on the Lake Fork of the Gunnison River. No tributaries or diversions increased or decreased the flow of this river between the U.S.G.S. gaging station and the study reach. However, it has been observed by DOW biologists over the past few years that on large streams with peak flows in excess of two orders of magnitude greater than the annual minimum flow, the Montana Method generally gives a much greater recommended minimum flow than the R-2 Cross Method. This is probably the case with the Lake Fork of the Gunnison River where peak flows in excess of 3,000 cfs are contrasted against winter minimums of about 30 cfs.

Table 10. Comparison of the minimum flow recommendations generated using four different methodologies.

Stream name	Minimum flow recommendations (cfs)			
	Single R-2 Cross	Multiple R-2 Cross	IFG4	Montana Method
Cache la Poudre River, Little South Fork	20	16.1	16.3	18.8
Carnero Creek, South Fork	2	1.8	2.3	3.3
Cucharas River	5	4.2	3.6	6.7
Cunningham Creek	4	4.1	3.7	3.2
East River	65	--	--	--
Fryingpan River (Castle View)	65	62.4	63.3	54.0
Fryingpan River (Taylor Creek)	55	53.3	47.5	54.0
Fryingpan River, North Fork	8	4.8	8.5	5.9
Fryingpan River, South Fork	6	5.2	5.6	6.5
Gunnison River, Lake Fork	45	52.4	48.3	70.2
Huerfano River	4	5.0	5.0	9.4
Rio Grande River, South Fork	40	41.0	41.5	62.4
Sangre de Cristo Creek	2	2.1	2.8	5.4
South Platte I	60	74.8	--	--
South Platte II	18.5	34.3	--	--
St. Louis Creek	9	8.7	9.0	5.9
Williams Fork River I	37	31.5 (I & II)	44.9 (I & II)	30.3 (I & II)
Williams Fork River II	40	--	--	--

Comparison of Predictive Capabilities of the Multiple R-2 Cross and Incremental (IFG4) Methods

In addition to evaluating stream flow values, the capability of the R-2 Cross and the IFG4 models for predicting average depth and average velocity was evaluated. Predicted average velocity varied considerably between model outputs. Variations in average depth for a given transect were much less. In only five out of fourteen stream reaches (the IFG4 Method was not used on the South Platte and East Rivers) did the average depth output between the R-2 Cross and the IFG4 vary more than 0.1 feet and in 50 percent of the cases the variation was 0.05 feet or less (Table 11).

Table 11. Comparison of multiple R-2 Cross and IFG4 methodologies for average depth and average velocity predictions.

Stream name	Number of cross sections	Av. depth(ft)		Av. velocity(ft/sec)	
		R-2 Cross	IFG4	R-2 Cross	IFG4
Cache la Poudre River, Little South Fork	4	0.65	0.63	1.18	0.67
Carnero Creek, South Fork	8	0.33	0.33	1.21	0.81
Cucharas River	8	0.31	0.31	1.28	1.03
Cunningham River	7	0.24	0.52	2.09	0.43
Fryingpan River I (Taylor Creek)	4	0.79	0.78	1.41	0.93
Fryingpan River II (Castle View)	3	0.70	0.75	1.09	0.80
Fryingpan River, North Fork	6	0.38	0.49	0.83	0.60
Fryingpan River, South Fork	5	0.40	0.53	0.66	0.67
Gunnison River, Lake Fork	6	0.68	0.73	1.69	1.25
Huerfano River	8	0.40	0.46	1.14	0.79
Rio Grande River, South Fork	6	0.58	0.63	1.27	0.93
Sangre de Cristo Creek	8	0.25	0.34	0.92	0.65
St. Louis Creek	7	0.50	0.46	1.11	0.75
Williams Fork River I & II	8	0.54	0.73	1.51	1.09

Average velocity figures for the entire study reach were high for the R-2 Cross Method in 13 of 14 instances when compared against the output for the same parameter from the IFG4 Method. Many investigators have cited the importance of water velocities in streams in relation to the fish population, fish spawning, and aquatic invertebrate production (Baldes, 1968; Baldes and Vincent, 1969; Dodds and Hisaw, 1924; Hooper, 1973; Hoppe and Finnell, 1970; Lewis, 1969; McNeil, 1962; Orcutt, Pulliam, and Arp, 1968). It is of utmost importance to determine the relative reliability of the various computer models in predicting average velocities across a stream transect. If grave errors are inherently a part of the presently used computer models, then derived minimum flow recommendations could also be erroneous, not only in Colorado, but in other states as well.

To evaluate the differences in average velocity outputs between the R-2 Cross and the IFG4 methods, several tests and comparisons between the two methodologies were used. The first comparison was done using known average water velocities actually determined in the field. These average water velocities, determined on over 90 stream transects across a wide range and large number of calibration flows, were used as a standard against which predicted average water velocities from the R-2 Cross and IFG4 methods were compared. The results (Table 12) do not give a clear cut indication of any real differences in the magnitude of error between the IFG4 and the R-2 Cross methods. The findings of Elser (1976), Bovee and Milhous (1978), and Bovee, Gore, and Silverman (1977) do not agree with these results. They found the IFG4 stage discharge approach to be superior to the Manning equation one point approach used in the Single Transect R-2 Cross Method.

The next comparison involved separating out the direction (positive or negative) of the percentage of error between the IFG4 and R-2 Cross methods and comparing the results against known field measurements. The only clear cut distinction resulting from this comparison (Table 13) was that in more than 77% of the instances the R-2 Cross Method overestimated the known average velocity while the IFG4 Method underestimated the known average velocity 67% of the time.

A third test was made by comparing the absolute magnitude of error for a given average velocity at a given transect for both the R-2 Cross and the IFG4 methods and comparing each to the known average measured velocity at that transect to see which methodology produced a lower percentage error. In this comparison the IFG4 did slightly better than the R-2 Cross giving a lower percentage error when compared to measured field velocities 52.6% of the time (Table 14). Once again, there was no clear cut superiority demonstrated by the IFG4.

Table 12. Comparison of the reliability of the Single Transect R-2 Cross and IFG4 methods for predicting field velocity measurements.

	R-2 Cross		IFG4	
Range of error in percent	Number of predicted velocities in error bracket	Percent of predicted velocities in error bracket	Number of predicted velocities in error bracket	Percent of predicted velocities in error bracket
0.0 - 10	29	29.9	33	35.5
10.1 - 20	20	20.6	23	24.7
20.1 - 30	12	12.4	9	9.7
30.1 - 40	14	14.4	10	10.8
40.1 - 50	2	2.1	6	6.5
50.1 - 60	5	5.2	4	4.3
60.1 - 70	5	5.2	3	3.2
70.1 - 80	0	0.0	1	1.0
80.1 - 90	1	1.0	0	0.0
90.1 - 100	2	2.0	0	0.0
100.1 - 500	7	7.1	4	4.3
TOTAL	97	100.0	93	100.0

Table 13. Comparison of the R-2 Cross and IFG4 methods for relative accuracy in predicting field measured velocities.

	Number (%)	Mean % error	Range of error (%)
R-2 CROSS			
Overestimations	75 (77.3)	44.8%	0.7% - 500%
Underestimations	22 (22.7)	-17.8%	-0.5% - -34%
Perfect estimations	--	--	--
IFG4 (INCREMENTAL METHOD)			
Overestimations	29 (31.2)	36.4%	1.9% - 135%
Underestimations	62 (66.7)	-20.5%	-0.8% - -64%
Perfect estimations	2 (2.1)	0.0%	--

Table 14. Direct comparison of the R-2 Cross and IFG4 methods for best accuracy in predicting field velocity measurements.

Model	Number	Percentage
R-2 Cross Error < IFG4 Error	37	47.4
IFG4 Error < R-2 Cross Error	41	52.6
TOTALS	78	100.0

A fourth comparison involved the magnitude of error between predicted and measured velocities determined at high and low discharge calibration flows (Table 15). High (>100 cfs) and low (<10 cfs) calibration flows (Qs) refer to the highest and lowest discharges measured on an individual stream during the 1978 field season. In this comparison, the percentage of error between predicted and measured average velocities was the same at high and low calibration flows with the R-2 Cross Method. Fifty percent of the time the error in predicted average velocities was greater at a high rather than low discharge flow and vice versa. This could be interpreted to mean that the R-2 Cross Method worked equally well (or bad) at high and low discharges.

Table 15. Comparison of the R-2 Cross and IFG4 methods for the magnitude of error between average predicted velocities and field measured average velocities determined at high and low calibration flows.

Method	High Q error<low Q error N	percent	High Q error>low Q error N	percent
R-2 Cross	15	50.0	15	50.0
IFG4	26	72.2	10	27.8

With the IFG4 Method, 72% of the time the magnitude of error between average measured and predicted velocities was less when measured at high discharge calibration flow than at a low discharge calibration flow. This indicates that the results of the IFG4 Method are more reliable at high flows on larger streams than they are at lower flows on small streams.

In a final test the magnitude of error in predicted average velocities was compared to the known field values for average velocities with results of the R-2 Cross and the IFG4 methods being stratified into groups measured at high Q (>10 cfs) and low Q (<10 cfs) calibration flows (Table 16). Two significant departures from this classification were on the Fryingpan and the Lake Fork of the Gunnison rivers where low Q calibration flows were 75 and 68 cfs, respectively. In those two streams high Q flows were 250 and 170 cfs, respectively. The magnitude of error for the IFG4 Method was less than that of the R-2 Cross Method (Table 16). The differences in magnitude of error were smaller between the two methodologies when velocities determined at low Q calibration flows were used.

Table 16. Comparison of the R-2 Cross with the IFG4 methods for the magnitude of error in predicted velocities at high and low discharge (Q) calibration flows.

	High Q		Low Q		Total	
Error magnitude	N	percent	N	percent	N	percent
R-2 Cross >IFG4	26	60.5	17	53.1	43	57.3
R-2 Cross <IFG4	17	39.5	15	46.9	32	42.7
TOTAL	43	100.0	32	100.0	75	100.0

I conclude that the IFG4 Method gives more reliable results at higher discharge levels than does the R-2 Cross Method and still maintains a slight edge at low Q calibration flows.

Time and Cost Analysis

A total of 56 days over a 7-month period was needed to collect the field data. Out of a total of 930 man-hours expended for data collection, 447 man-hours were for travel time and 483 hours were for actual collection of data. This breaks out at 48% for travel time and 52% for data collection. Without a good analysis of gaging histories prior to collecting any field data the ratio could easily have been 60% to 40% in favor of travel time or even worse.

Table 17 presents labor costs (for travel time and data collection time only) for a single cross section for all 18 study areas. These data indicate that the cost per cross section increases in direct proportion to stream width up to approximately 30 feet. From 30 feet to about 60 feet in stream width the cost per transect is essentially constant with the cost again rising for streams up to 100 feet in width or more. This is solely the result of the type and amount of data needed for a cross section. The Instream Flow Service Group (IFSG) recommends a minimum of 20 to 30 data points (depth, velocity and substrate) be collected for each transect, but at no smaller intervals than 1-foot increments. Therefore, for streams up to 30 feet in width the time required for collection of field data is purely proportional to the transect width. Streams from 30 to 60 feet in width are evaluated in 2-foot increments; thus, the number of data points required remains at 20 to 30 per transect and the field time and costs are constant. The IFSG does not feel it is necessary to have more than 30 data points even for a stream of 200 feet in width as much additional data does not significantly improve the computer evaluation of the transect. However, this type of data collection requires a field crew well versed in the mechanics of stream hydrology to insure that the data collected is truly representative of the stream cross section. To eliminate this variable and potential serious sources of error resulting from subjective judgment, streams 40 feet in width and greater were always evaluated in 2-foot increments. While this may have resulted in some waste of time and effort in the eyes of the IFSG, it was a wise decision as insufficient data can greatly compromise the precision and accuracy of the computer output. Since almost 50% of the time is fixed as travel time, a doubling or even tripling of the number of data points does not add much to the total cost of the entire evaluation process.

To more accurately estimate costs for travel time, field data collection time, and per diem expenses, three of the 15 study streams were selected for a more detailed analysis. These three streams, the Lake Fork of the Gunnison, South Fork of the Rio Grande, and the Williams Fork rivers were chosen for the following reasons:

Table 17. Travel time and data collection costs[a] for Colorado Phase II Instream Flow Study versus stream width.

Stream name	Stream width (ft)	Travel (man-hours)	X-Sections (number)	X-Sections (man-hours)	Total hours expended	Total cost	X-Sections (cost)
Cache la Poudre River, Little South Fork	40.0	29.0	8	20.0	49.0	$285	$36
Carnero Creek, South Fork	9.3	41.0	32	36.0	77.0	447	14
Cucharas River	16.1	25.5	21	21.0	46.5	270	13
Cunningham Creek	13.8	17.0	21	30.0	47.0	273	13
East River	90.0	14.0	8	27.5	41.5	241	30
Fryingpan River I & II	72.7	35.0	21	79.0	114.0	662	32
Fryingpan River, No. Fork	23.6	34.0	18	33.5	67.5	392	22
Fryingpan River, So. Fork	27.2	34.0	14	21.0	55.0	320	23
Gunnison River, Lake Fork	47.6	23.5	18	33.0	56.5	328	18
Huerfano River	13.8	45.0	24	29.5	74.5	433	18
Rio Grande River, So. Fork	54.5	34.0	18	24.5	58.5	340	19
Sangre de Cristo Creek	8.2	19.0	24	18.0	37.0	215	9
St. Louis Creek	17.6	34.0	21	28.0	62.0	360	17
South Platte River I & II	93.5	22.0	7	29.0	51.0	296	42
Williams Fork River I & II	62.4	40.0	27	52.5	92.5	537	20

[a] Assumes an average hourly wage of $5.81/man-hour.

1. All three streams were of the same relative size.

2. Crew efficiency was constant on all three streams.

3. The three streams required approximately the same amount of field collection time.

4. The three streams chosen to assess the impact of non-data collection time costs (travel time and per diem) represent streams with the lowest, moderate, and highest non-data collection time costs of the study streams, respectively.

The data presented in Tables 18 and 19 show that travel time and per diem costs made up most of the cost for carrying out an instream flow evaluation. Specifically, on the Williams Fork River, $226 was the actual data collection cost, while $1,146 is the cost for travel time and per diem to collect data for an IFG4 evaluation. The fixed travel and per diem costs are more than five times the cost of the field data collection process. Similarly, on the South Fork of the Rio Grande River, the data collection cost was $146 while the travel and per diem costs were $687 which is a ratio of 1:4.5. Only on the Lake Fork of the Gunnison River did data collection costs approximate the travel and per diem costs, being $193 and $156, respectively.

Table 18. Travel time costs, cross section time costs, and total costs per visit for three similar rivers.[a]

Stream	Visit no.	Travel time cost	X-Section time cost	Per diem cost	Total cost
Lake Fork Gunnison	1	$ 52	$105	--	$ 157
Lake Fork Gunnison	2	52	44	--	96
Lake Fork Gunnison	3	52	44	--	96
Total		$156	$193	--	$ 349
South Fork Rio Grande	1	$139	$ 70	$ 90	$ 299
South Fork Rio Grande	2	139	41	90	270
South Fork Rio Grande	3	139	35	90	264
Total		$417	$146	$270	$ 833
Williams Fork	1	$232	$ 81	$180	$ 494
Williams Fork	2	232	75	180	488
Williams Fork	3	232	69	90	392
Total		$696	$225	$450	$1,374

[a] Hourly wage is $5.81 and average cost for per diem was $30.00 per day.

Table 19. Total costs per visit for three similar size study streams. Total cost per transect per method in parentheses.

Stream	Visit no.	R-2 Cross (IFG1)		Multiple R-2 Cross or IFG2		IFG4	
Lake Fork Gunnison	1	$ 52[a]		$157		$ 157	
Lake Fork Gunnison	2	--		--		96	
Lake Fork Gunnison	3	--		--		96	
Total		$ 52	($52)	$157	($26)	$ 349	($19)
South Fork Rio Grande	1	$165[a]		$299		$ 299	
South Fork Rio Grande	2	--		--		270	
South Fork Rio Grande	3	--		--		265	
Total		$165	($165)	$299	($50)	$ 834	($46)
Williams Fork	1	$264[a]		$494		$ 494	
Williams Fork	2	--		--		488	
Williams Fork	3	--		--		392	
Total		$264	($264)	$494	($81)	$1,374	($65)

[a] Assumes a crew size of two men instread of three.

Bovee and Milhous (1978) may be correct in insisting that the cost per cross section decreases drastically for the IFG4 Method as the parenthetical data in Table 19 clearly demonstrates. Nonetheless, the total cost still essentially doubles, triples, and quadruples with the second, third, and fourth visits to the stream.

It must also be reiterated that on virtually every field excursion during the summer of 1978, three to five stream study reaches were visited and the travel time from the home office (Montrose) was prorated and apportioned accordingly. Thus, the cost analysis presented in Tables 17, 18, and 19 is realistic for the State of Colorado.

Gasoline costs and vehicle maintenance costs were not included in the above portion of the cost evaluation. Approximately 15,000 vehicle miles were expended during the study. At a rate of reimbursement of 15¢/mile, the vehicle maintenance and mileage costs are approximately $2,250.

If costs for the actual collection of field data only are added up, the total is $11,850, broken out as $5,400 travel time and field time combined, $4,200 for per diem, and $2,250 for transportation expenses. A total of 282 cross sections were evaluated at a total cost of $11,850, or $42 per transect.

Data reduction costs have not yet been presented in this report. For comparative purposes, the data in Table 20 is presented below to get an actual cost for the various categories as well as on a percentage basis.

Field time, travel time and per diem costs combined made up almost 45% of the total cost of the project. Data formating and analysis costs approximately equal field and travel time. Non-disposable field equipment was all acquired through transfer to this project from other projects within the Colorado DOW and thus incurred no cost to the project. Non-disposable equipment included a surveyors transit, two pygmy type flow meters and two Price type AA flow meters, two flow meter staffs, two sets of earphones, and electroshocking equipment. Disposable field equipment included such items as rebar, hammers, 100 ft steel and fiberglass tapes and the like.

A stream by stream summary for the cost of this project for all phases of the study is presented in Appendix D.

Table 20. Actual costs and percentage of the total cost broken out by major category.

Category	Item cost	Percent of total cost
Data formating & analysis costs	$ 5,900	27.6
Disposable field equipment	616	2.9
Key punch data	150	0.7
Per diem cost	4,200	19.6
Photo & office supplies	510	2.4
Printout costs	398	1.9
Report reproduction costs	200	0.9
Surveyors equipment	203	0.9
Total computer time	250	1.2
Travel & field time	5,400	25.3
Typewriter rental	120	0.5
Vehicle mileage & maintenance	2,250	10.5
Write-up time	1,187	5.6
Total	$21,384	100.0

Requirements for Methodology Improvements - Single and Multiple Transect R-2 Cross Methods

The single and multiple transect R-2 Cross computer model has several probelms that should be corrected. The input parameter for slope as it is presently used by the Colorado Division of Wildlife can accept only three digits to the right of the decimal. On streams with a slope of less than 1% this only permits the input of one non-zero digit and rounding off errors can be significant. For example, the observed slope across transects 1, 2, 3, 5, and 6 on the East River was 0.00015. Since the lowest number that can be put into the Colorado R-2 Cross Program is 0.001, an input error of 259% results for the slope input value alone. The program should be modified to accept a minimum of five, or preferrably six digits to the right of the decimal so that when the slope is less than 1% (almost always the case in streams over 50 ft in width) three significant digits can be used. Bovee and Milhous (1978) alluded to this same problem in reference to single transect methods utilizing the Manning equation.

The tendency of the R-2 Cross model to overestimate the average velocity by an average of 45% from measured field values in this study indicates that some action should be taken to balance measured water stage levels and field velocity measurements, i.e., to better calibrate the model than is presently being done. This would require more manipulation of the data and greater data analysis expense but the improvement in the reliability and accuracy of the velocity component of the output should be worth the effort.

The possibility of increasing the minimum acceptable average velocity from 1 ft/sec to 1.5 ft/sec should be examined if no correction is made for the tendency to overestimate average velocity in the prediction of output parameters.

Finally, average depth should be the primary criterion on which minimum flow recommendations are determined since it is the first factor to become limiting in almost twice as many instances as average velocity and wetted perimeter combined.

Requirements for Methodology Improvement - IFG4

The IFG4 model worked very well on the majority of the study streams evaluated in this study. Two situations required data manipulation for a satisfactory response from the IFG4 model. First, in those instances where the calibration flows were very closely spaced, significant problems with the velocity adjustment factors were encountered which required manipulation of the data to "improve" the output. This occurred in only three instances and on relatively small mountain streams. Secondly, on larger streams (average discharge greater than 100 cfs) the only problems with the IFG4 model response to the data occurred where large boulders were strewn throughout the transect and the velocity profile varied greatly across the channel over very short distances. Modification of the program to handle large velocity variations across the transect(s) would greatly increase the range and capability of the IFG4 program.

The IFSG should modify the printout capability of the IFG4 program to give an average velocity, average depth, and total cross sectional area for each input Q at each transect. Then these parameters could be readily compared with the same output parameters of other methodologies. The lack of this capability required an additional 200 man-hours of hand calculations by the author in order to make direct comparison between the R-2 Cross and IFG4 methodologies.

Recalling that the average velocities predicted by the IFG4 Method were underestimated by 20%, 67% of the time, the question arises as to why this is the case. It is probably something inherent in the program and could very well have something to do with the velocity adjustment factor and the manipulation of the data inherent to that parameter. Some attempt should be made to correct this problem.

Requirements for Methodology Improvement - IFG3

I believe giving equal weight to all of the preference factors for each life stage when the IFG4 Model is interfaced with the IFG3 model is wrong, especially for brown trout. Several investigators have shown that overhead cover is the overriding factor in determining brown trout habitat, much more so than either depth or water velocity (Baldes and Vincent, 1969; Butler and Hawthorne, 1968; Elser, 1968; and Wesche, 1974). It is encouraging to know that a cover preference factor will soon be an input with the IFG3 model, but it should be given a heavier weighting in the calculation of weighted usable area.

Finally, preference factors for cutthroat trout may not be reliable for the species in the streams studied, especially the Rio Grande cutthroat trout, *Salmo clarki virginalis*. Streams where these cutthroat trout occurred had slow water velocities and silted beds. Despite problems with insufficient data for various life stage probability curves, the interfacing of the IFG3 Program with both the IFG2 (Water Surface Profile - WSP) and the IFG4 (Incremental) Methods gives it great potential for use in the natural stream environment.

Methodologies in Relation to Biological Conditions

The single and multiple Transect R-2 Cross methods are only indirectly related to the biological conditions of the stream through the parameters average depth, average velocity and percent wetted perimeter. While some work has been done to summarize the average depth and velocity preferences for fish and aquatic invertebrates (Stalnaker and Arnette, 1976; Hooper, 1973; Water Resources Research Institute, 1978), in most instances the tolerance ranges are so wide that any attempt to correlate fish numbers and/or biomass with the R-2 Cross output would be futile. Cover factors at present cannot be incorporated into this method. In short, the R-2 Cross probably has the least applicability of any tested method of stream flow assessment if correlation with the biological conditions in the stream is a necessity.

The IFG4 model by itself probably has no more potential than the R-2 Cross model in relation to biological conditions. But the capability of interfacing with the IFG3 for a WUA output versus flow makes the IFG4 a powerful tool in assessing the relationship between discharge and the habitat conditions of the stream.

With the IFG3 model now modified to accept input for stream cover, this program should become even more effective in assessing the relationship between weighted usable area and the actual biological conditions occurring in the stream. This model may have its greatest application in predicting changes in species composition resulting from drastic changes in flow patterns. It may also have application in predicting changes in WUA and trout standing crop that result from stream improvement projects.

Scrutiny of the curves of WUA plotted against the annual discharge patterns for median water years, one in five high water year, and one in five low water years, reveals a very consistent pattern (see Appendix C). That pattern is that WUA invariably decreases during the periods of peak runoff in May, June, and July or conversely, the WUA increases during lower flow periods.

Carrying this thought to its logical conclusion, the question arises, "Is too much water just as detrimental to a stream trout population as too little?" I feel the answer is most certainly affirmative. Evidence indicates that the stability of stream flow and the aquatic environment beneath it can actually be enhanced by topping off some of the peak run-off. Surveys of streams in the headwater areas of the Colorado River basin in 1964

(Burkhard, 1967; Weber, 1965) revealed that trout numbers and biomass statistics were from two to ten times higher below headwater diversions than on the same streams immediately above the diversions. These streams were resurveyed by the author again at the same sites in 1978, 14 years after the original investigations. The species composition and biomass ratios reconfirmed what was observed in 1964. Stable stream environments below the headwater diversions contained two to ten times the numbers and biomass of trout present in the same stream immediately above the diversions.

The fact that the IFG3 Habitat Program consistently indicates that the greatest WUA exists at moderate flow rather than at peak flow levels gives biologists a powerful tool in assessing the potential impacts of both high water and low water levels. The one problem that remains to be evaluated is, what time span is required for these excessive water levels to have a real impact on the trout population and be reflected in the standing crop?

Reliability and Comparability of Methodologies

Output of predicted parameters from the single and multiple transect R-2 Cross and the IFG4 methods showed the greatest disparity when the average predicted velocities were compared. However, the most important comparison was with the recommended minimum flows from the three methodologies. These differences were not great in most instances. Average depth showed great consistency among all methods tested and was the most often used parameter to delimit the minimum flow recommendation. Undoubtedly this was the primary reason for the similarities of the flow recommendations among the methods despite disparities between methodologies for average velocity.

The reader is reminded that average depth and average velocity criteria were essentially the same for all three computer methods. Other investigators might disagree with the levels of these criteria as being too high or too low to delimit the proper minimum flow recommendation. This evaluation has shown that if the criteria are common to all methodologies, then similar minimum flow recommendations are the result. Rose and Johnson (1976) found that to be the case in comparisons between the Montana, Forest Service, and Modified Sag-Tape methods on four streams in Utah.

Cost/Benefit Analysis

Bovee and Milhous (1978) concluded that the cost of three sets of data is small compared to the cost of one set which may prove unreliable. My results (Tables 17 - 19) show that the cost of data collection was almost directly proportional to the number of times the study reach was visited and the travel distance to the study area. Furthermore, travel time and per diem costs were as much as five times the cost of on-stream data collection time.

Recommendations for Methodology Application in Colorado

Since 1974, the Colorado DOW, working in close association with the Colorado Water Conservation Board (hereafter CWCB), has acquired 40 water decrees on streams throughout the State. Another 467 applications for water rights under S.B. 97 have been ruled upon favorably by the CWCB, and 100 applications are presently pending with no action taken to date. These filings are the result of the field efforts and office work of up to 20 employees of the Colorado DOW on either a part-time or full-time basis.

During the past year this investigator carried out an incremental method of analysis on 15 streams and 18 stream reaches. The recommendations for minimum flows on these 18 reaches would affect a maximum of 190 stream miles.

There are reportedly (Colorado Division of Game, Fish, and Parks, 1970) 14,700 miles of streams in Colorado. In light of the above stream mileage in Colorado, the absolute enormity of the task of completing even a single transect on the fishable streams (reported to be 8,000 miles) becomes overwhelming.

The contract states, "Monthly water quantity needs for fish and wildlife populations will be recommended for all "critical" stream reaches on which adequate historical discharge records are available plus those streams on which methodologies are tested. Water quantity needs will be presented for low and median water year conditions, and for high water year conditions (i.e., waterfowl nesting) if applicable." Making monthly recommendations would be no more than a mathematical exercise completed to fulfill to the letter the stipulations of this contract. The CWCB has worked closely with and has been generally sympathetic to the recommendations of the Colorado DOW in the past. In my opinion, if every stream flow recommendation was to be presented as a month by month flow request all progress henceforth would cease. Even if the CWCB ruled favorably on the month by month recommendation, the ruling would be unenforceable and totally ignored.

From a realistic standpoint, minimum flow recommendations have been made on the basis of an April through September flow request. The October through March flow is generally somewhat less than the April - September flow or the undepleted natural flow of the stream from October through March. This is the way minimum flow recommendations made in this report should be viewed.

Keeping the foregoing cost analysis in mind and considering the magnitude of the instream flow assessment program still ahead, Colorado cannot afford the luxury of an incremental method of analysis on each and every stream. Some criteria must be set forth to relate the level of importance of the stream to the level of intensity of instream flow analysis deemed necessary.

As a first level of evaluation, I recommend that the Single Transect R-2 Cross Method be used, but with the suggested changes in the program to improve its reliability and accuracy. This method could be used on the majority of streams where filings for water rights are to be made with the CWCB. It should be used only on those streams of little to perhaps moderate value as far as the fisheries resource is concerned. Examples might be headwater streams at high elevations that receive little or no use by the fishing public as well as streams on national resource lands where encroachment by diversion, pollution, and development is not anticipated as a serious problem.

The second level of evaluation might be on major streams of moderate to good recreational potential or streams selected for some sort of stream improvement program. Streams in this classification support moderate to heavy public use for fishing, kayaking, and other types of outdoor recreation. They are usually more subject to the encroachments of water development, diversion, and pollution. At this level some sort of multiple transect methodology should be used, perhaps the multiple R-2 Cross for least important streams in this category but the IFG2 or Wetted Surface Profile (WSP) interfaced with the IFG3 Habitat Program for the more important streams in this category.

The third and highest level of priority would be reserved for those streams of critical importance to either the state or federal natural resource agencies. At this level of intensity, the most sophisticated incremental analysis would be required, either the WSP or IFG4. Either would be interfaced with the IFG3 Habitat Program for a weighted usable area analysis. Streams in this classification would probably rank among the top 20 streams in the state from a fisheries standpoint. Examples might be the Fryingpan River below Ruedi Dam, the South Platte River below Cheesman Dam, the Gunnison River upstream from Hotchkiss, Rio Grande River from Del Norte upstream, the Cache la Poudre River, North Platte River, and the Blue River. From a rare and endangered species point of view this might include sections of the White and Yampa Rivers, the Colorado River below Grand Junction, and others. It might also include those important streams either undergoing or in serious danger of encroachment from pollution, energy development, water diversion, or impoundment.

With this sort of a scheme where the importance of the stream governs the level of intensity of evaluation for instream flow assessment, manpower and cost requirements can hopefully be kept within the limits and capabilities of the Colorado Division of Wildlife without greatly compromising the integrity of the fish resource in the State of Colorado.

SUMMARY

Data from 15 streams and 18 stream reaches were subjected to four different methods of computer analysis for assessing instream flow regimes. The four methods evaluated were the Single Transect R-2 Cross, the Multiple Transect R-2 Cross, the IFG4 Incremental, and the IFG3 Habitat. The output from the first three computer models was compared with the results from the Montana or Tennant Method.

The stream flow recommendations from the three computer methods more closely approximated each other than they did the results of the Montana Method. However, in many instances recommendations by the computer methods closely approximated those of the Montana Method. Results for individual streams, expressed as a percent of the average flow, ranged from 11% to 45.7% for minimum flow recommendations. However, when the results for 18 study streams are averaged by methodology, the single transect R-2 Cross percent average flow recommendation was 28.4%, the multiple transect R-2 Cross averaged 26.4% and the incremental minimum flow recommendations averaged 27.9% of the average flow.

For all three computer methodologies, average depth was the parameter (of average depth, average velocity, and percent wetted perimeter) that most often became first limiting or co-limiting in determining the minimum flow recommendation. With the Multiple Transect R-2 Cross Method the average depth was first limiting or co-limiting almost twice as often as average velocity and percent wetted perimeter combined.

The Incremental Method (IFG4) interfaced with the Habitat Method (IFG3) appears to have good potential for predicting changes in species composition and fish biomass carrying capacity as a result of impacts from agricultural, industrial, domestic, and water development projects.

Cost analyses made as a part of this study indicated that the Incremental Method of stream modeling is prohibitively expensive for general use on Colorado's trout streams in filing for water rights under S.B. 97. Rather, this investigator recommends a three level arrangement where the stream model to be used is determined by the importance of the stream being evaluated. For the majority of streams in the State of Colorado, the single transect R-2 Cross would continue as the standard computer model for assessing minimum flow recommendations under S.B. 97. This method would be used on high elevation headwater streams that receive a low level of use by the fishing public and are in little danger of impact from diversion, pollution, or encroachment by any development projects. The second level of analysis would entail the use of some multiple transect methodology, the multiple R-2 Cross or the WSP Program interfaced with the IFG3 Habitat Program. This level of intensity would be applied to streams of moderate to good recreational potential or streams selected for some sort of stream improvement program.

The third and highest level of intensity would entail the use of the Incremental Method, probably using the IFG4 in conjunction with the IFG3 Habitat Program. The streams in this category would be streams of greatest importance to the state as far as fisheries resources are concerned, probably ranking among the top 20 streams in the state. It would also include streams in grave danger of encroachment from pollution, energy development, water diversion, or impoundment.

Based on my results, the 30% of average flow used as the minimum flow recommendation by the Montana (Tennant) Method seems excessive. I concur with Wesche (1974) that 25% of average flow should be the standard minimum flow recommendation used in synthetic office analysis where adequate gaging data is available. However, I am opposed to wide use of synthetic methods for an instream flow recommendation program. The results of field analysis in this study show that minimum flow recommendations expressed as a percentage of average flow can vary from 11% to 46% among streams due to variations in channel configuration and/or cross section placement. This wide range of variation indicates that streams should not be subjected to an across the board percentage of average flow as a "first time through" minimum flow recommendation just to get something started. Too often these recommendations are readily accepted as law and cannot be changed without tremendous expenditures of time, money, and manpower.

There are times when no action at all can be the more prudent course. I feel that Colorado has time to do the job right without resorting to rush jobs based on synthetic office methodologies. But we must also work within the cost, time, and manpower constraints of the organizational structure within the Division of Wildlife. These constraints definitely require establishing priorities for streams based on their importance. With these concepts well in mind, we can get the job done and do it right.

LITERATURE CITED

Anonymous. 1974. R-2 Cross Program - Sage-Tape method of channel cross section measurement for use with minimum instream flow determinations. U.S.D.A., Forest Service, Region 2, Denver, Colorado.

Baldes, R. J. 1968. Microhabitat velocity occupied by trout. M.S. thesis. Colorado State University, Fort Collins. 33 p.

Baldes, R. J., and R. E. Vincent. 1969. Physical parameters of microhabitats occupied by brown trout in an experimental flume. Trans. Amer. Fish. Soc. 98(2):230-238.

Bovee, K. D. 1978. Probability-of-use criteria for the family Salmonidae. Cooperative Instream Flow Service Group. Western Energy and Land Use Team, Office of Biological Services, Fish and Wildlife Service, U.S.D.I. Instream Flow Information Paper No. 4.

Bovee, K. D., and T. Cochnauer. 1977. Development and evaluation of weighted criteria, probability-of-use curves for instream flow assessments: fisheries. Cooperative Instream Flow Service Group. Western Energy and Land Use Team, Office of Biological Services, Fish and Wildlife Service, U.S.D.I. Instream Flow Information Paper No. 3.

Bovee, K. D., J. Gore, and A. J. Silverman. 1977. Field testing and adaptation of a methodology to measure instream values in the Tongue River, Northern Great Plains Region. U.S. Environmental Protection Agency, Office of Energy Activities Contract 68-01-2653.

Bovee, K. D., and R. T. Milhous. 1978. Hydraulic simulation in instream flow studies: theory and techniques. Cooperative Instream Flow Service Group. Western Energy and Land Use Team, Office of Biological Services, Fish and Wildlife Service, U.S.D.I. Instream Flow Information Paper No. 5

Burkhard, W. T. 1967. Stream fishery studies. Statewide stream surveys. Colorado Dept. Game, Fish and Parks Job Compl. Rep., Fed. Aid Proj. F-25-R-4, Job 1. 39 p.

Butler, R. L., and V. M. Hawthorne. 1968. The reactions of dominant trout to changes in overhead artificial cover. Trans. Amer. Fish. Soc. 97(1):37-41.

Colorado Game, Fish and Parks Division. 1970. The fact finder: an almanac of information for use by personnel of the Colorado Game, Fish and Parks Division.

Dodds, G. S., and F. S. Hisaw. 1924. Ecological studies of aquatic insects. I. Adaptations of mayfly nymphs to swift streams. Ecology 5(2):137-148.

Elser, A. A. 1968. Fish populations of a trout stream in relation to major habitat zones and channel alterations. Trans. Amer. Fish. Soc. 97(4):389-397.

Elser, A. A. 1976. Use and reliability of water surface profile program data on a Montana prairie stream. pp 496-504. *In* J. F. Orsborn and C. H. Allman (ed.) Instream Flow Needs. Proc., Amer. Fish. Soc. Vol. II.

Giger, R. D. 1973. Stream flow requirements of salmonids. Oregon Wildlife Commission.

Hooper, D. R. 1973. Evaluation of the effects of flows on trout stream ecology. Dept. Eng. Res., Pacific Gas and Electric Co. 97 p.

Hoppe, R. A., and L. M. Finnell. 1970. Aquatic studies on the Fryingpan River, Colorado, 1969-1970. Bureau Sport Fish. and Wildlife, Division River Basin Studies, and Colo. Div. Game, Fish and Parks. Coop. Rep. 12 p.

Lewis, S. L. 1969. Physical factors influencing fish populations in pools of a trout stream. Trans. Amer. Fish. Soc. 98(1):14-19.

McNeil, W. J. 1962. Variations in the dissolved oxygen content of intra-gravel water in four spawning streams of southeastern Alaska. U.S.D.I., Fish and Wildlife Service, Spec. Sci. Rep.--Fish. No. 402. 15 p.

Orcutt, D. R., B. R. Pulliam, and A. Arp. 1968. Characteristics of steelhead trout redds in Idaho streams. Trans. Amer. Fish. Soc. 97(1):42-45.

Rose, K. L., and C. D. Johnson. 1976. The relative merits of the modified sag-tape method for determining instream flow requirements. U.S.D.I., Fish and Wildlife Service. Salt Lake City, Utah. 26 p.

Stalnaker, C. B., and J. L. Arnette. 1976. Methodologies for the determination of stream resource flow requirements: an assessment. Utah State University, Logan. 199 p.

Tennant, D. L. 1975. Instream flow regimes for fish, wildlife, recreation and related environmental resources. U.S.D.I., Fish and Wildlife Service.

Timmermans, J. A. 1974. Etude d'une population de truites (*Salmo trutta fario* L.) dans deux cours d'eau de l'Ardenne Belge. Ministere de l'Agriculture administration des Eaux et Forets. Station de Recherches de Eaux et Forets, Groenendall-Hoeilaart, Belgique. Travaux-Serie D, No. 43.

Univ. of Wyoming, Water Resources Research Institute. 1978. Determining instream flows for management of aquatic and riparian ecosystems. Vol. I. Manual. Report to U.S. Forest Service, Cooperative Agreement 16-556-CA. Laramie. v.p.

Weber, D. T. 1965. Stream fishery studies. Denver Water Board Projects. Colo. Dept. Game, Fish and Parks Job Compl. Rep., Fed. Aid Proj. F-26-R-3, Job 4. 84 p.

Wesche, T. A. 1974. Relationship of discharge reductions to available trout habitat for recommending suitable stream flows. Water Resources Series No. 53. Water Resources Research Institute, Univ. Wyo., Laramie. 71 p.

APPENDIX A

Biomass of Wild Trout Versus Adult Trout Weighted Usable Area/Acre[a] in Colorado's Phase II Study Streams

Stream name	Date	Brook lb/acre	Brook WUA/acre av. flow	Brown lb/acre	Brown WUA/acre av. flow	Cutthroat lb/acre	Cutthroat WUA/acre av. flow	Rainbow[b] lb/acre	Rainbow[b] WUA/acre av. flow	Av. flow in cfs
Cache la Poudre R., Little South Fork	10/78	0.4	10,980	46.7[c]	6,630	--	--	0.8	5,057	62.6
Carnero Creek, South Fork	5/78	--	2,580	--	--	55.5	1,490	--	--	11.0
	6/78	--	--	--	--	57.8	--	--	--	--
	8/78	--	--	--	--	52.9	--	--	--	--
Cucharas River	9/78	21.6	3,750	56.3	2,038	--	--	92.3	3,354	22.4
Cunningham Creek	8/78	39.7	14,130	--	--	--	--	--	--	10.6
East River	10/78	0.3	--	90.3	--	--	--	9.5	--	334.0
Fryingpan River	10/78	--	--	82.9	7,400	61.3	9,300	61.3	9,300	180.0
Fryingpan R., No. Fork	8/78	6.9	12,976	--	--	--	6,891	--	--	19.8
Fryingpan R., So. Fork	8/78	--	9,900	--	--	9.2[d]	2,510	--	--	21.6
Gunnison R., Lake Fork	10/78	--	4,650	53.2	5,066	18.7[e]	--	10.0	6,900	234.0
Huerfano River	9/78	5.7	3,855	20.7	2,343	--	--	29.0	3,390	31.4
Rio Grande R., So. Fork	9/78	--	--	94.3	11,800	--	--	7.6	9,138	208.0
	9/77	--	--	116.0	--	--	--	--	--	--
Sangre de Cristo Creek	6/78	--	--	--	--	23.3	462	--	--	18.1
	9/78	--	--	--	--	27.3	--	--	--	--
St. Louis Creek	4/78	13.7	12,200	--	--	--	--	--	4,643	--
	8/78	13.5	--	--	--	--	--	14.4	4,463	22.0
Williams Fork River I	4/78	0.5	7,470	--	--	--	--	0.0	3,930	101.0
Williams Fork River II	4/78	1.0	7,470	--	--	--	--	8.0	3,930	101.0

[a] WUA/acre expressed as square feet at average flow

[b] Rainbow trout in all study streams are the result of domestic artificial stock except on the Fryingpan River

[c] Pounds per acre netted - not a population estimate

[d] Above Fry/Ark diversion point

[e] Below Fry/Ark diversion point

APPENDIX B

Montana Method Minimum Flow Recommendation for All U.S.G.S. Gaged Class I Streams in Colorado

Stream name & gaging area	Flow - cfs Average 100%	 Flushing 200%	 Minimum 25%
ARKANSAS RIVER BASIN			
Apishapa River (source to intermittent sections)	30.7	61.4	7.7
Arkansas R. #7 (Brown's Canyon to S. Arkansas River)	630.0	1,260.0	157.0
Arkansas R. #8 (Chalk Cr. to Brown's Canyon)	493.0	986.0	123.0
Arkansas R. #9 (Clear Cr. to Chalk Cr.)	366.0	732.0	91.5
Cottonwood Cr. (source to Arkansas R.)	56.3	112.0	14.1
Huerfano R., S. Fork (Cascade Cr. to Huerfano R.)	34.1	68.2	8.5
COLORADO RIVER BASIN			
Beaver Cr. (source to Colorado R.)	4.4	8.8	1.1
Colorado R. #1 (Gunnison R. to State Line)	5,627.0	11,254.0	1,407.0
Colorado R. #2 (Rifle to Gunnison R.)	--	--	--
Colorado R. #7 (Troublesome R. to Gore Canyon)	--	--	--
Colorado R. #9 (Hot Sulphur Springs to Troublesome)	--	--	--
Colorado R. #10 (Lake Granby to Hot Sulphur Springs)	--	--	--
Colorado River, No. Fork (Source to Shadow Mountain Res.)	90.3	180.6	22.6
Crystal R. #2 (Yule Cr. to Redstone)	280.0	560.0	70.0
Crystal R. #3 (Crystal to Yule Cr.)	206.0	412.0	51.5
Dolores R. #1 (City of Dolores to State Line)	422.0	844.0	105.0
Dolores R. #2 (W. Fk. Dolores to City of Dolores)	406.0	812.0	101.0
Elk R. #1 (Middle Fk. of Elk to Yampa R.)	333.0	666.0	833.0
Fryingpan R. #1 (Ruedi to Basalt)	180.0	360.0	45.0
Fryingpan R. #2 (Nast to Ruedi Res.)	123.0	246.0	30.8
Fryingpan R. #3 (source to Nast)	34.2	68.4	8.5
Fraser R. #2 (Jim Cr. to Tabernash)	--	--	--
Fraser R. #3 (source to Jim Cr.)	--	--	--
Gunnison R. #1 (Uncompahgre R. to Colorado R.)	2,526.0	5,052.0	631.0
Gunnison R. #3 (Crystal Dam to No. Fork confluence)	1,380.0	2,760.0	345.0
Gore Cr. (upper station near Minturn)	27.7	55.4	6.9
Gore Cr. (at Vail)	--	--	--
Homestake Cr. (Gold Park)	63.4	127.0	15.9
Homestake Cr. (Red Cliff)	86.6	173.0	21.7
Parachute Cr. East Middle Fork (source to Parachute Cr.)	17.5	35.0	4.4

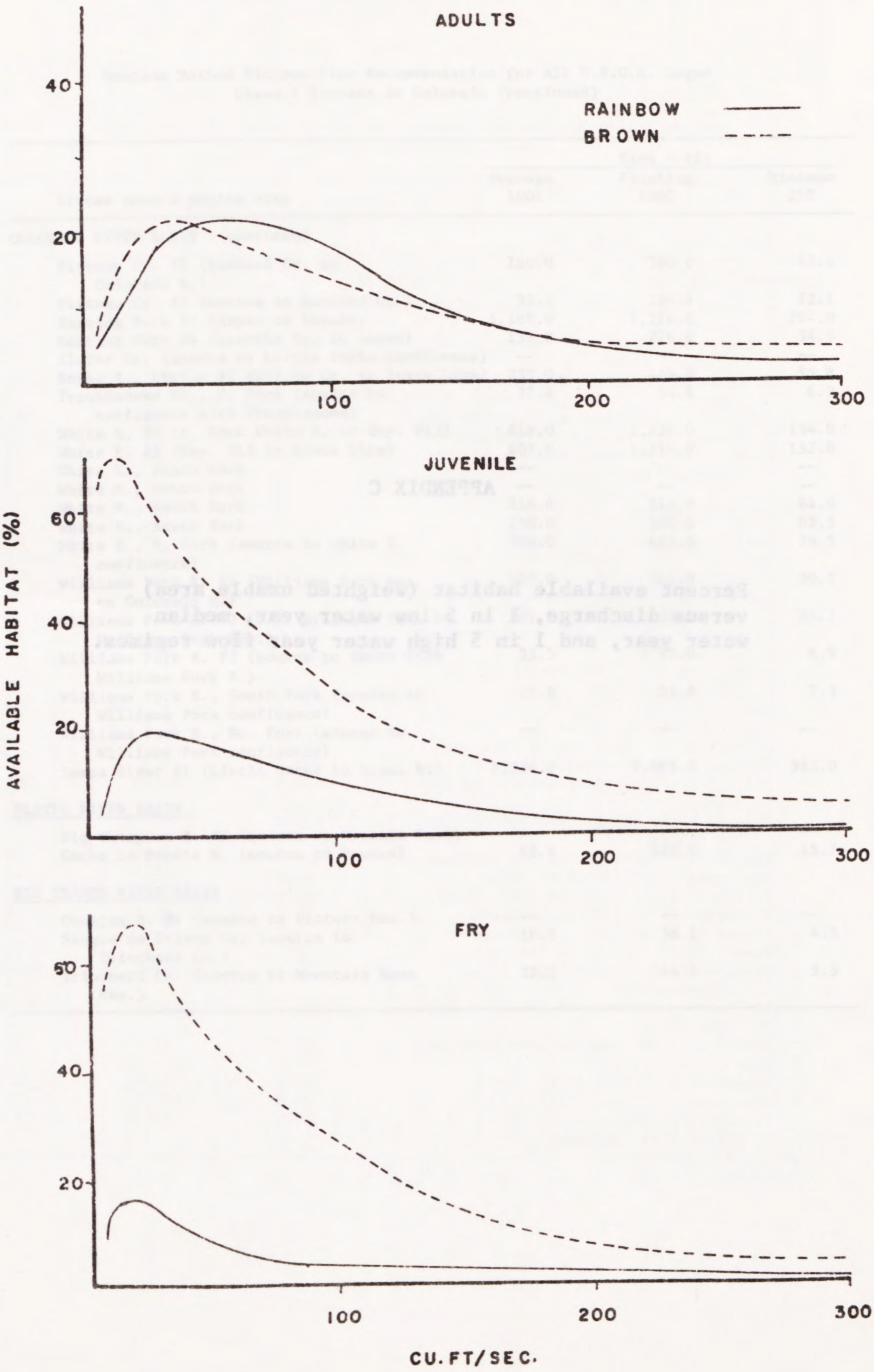
Montana Method Minimum Flow Recommendation for All U.S.G.S. Gaged Class I Streams in Colorado (continued)

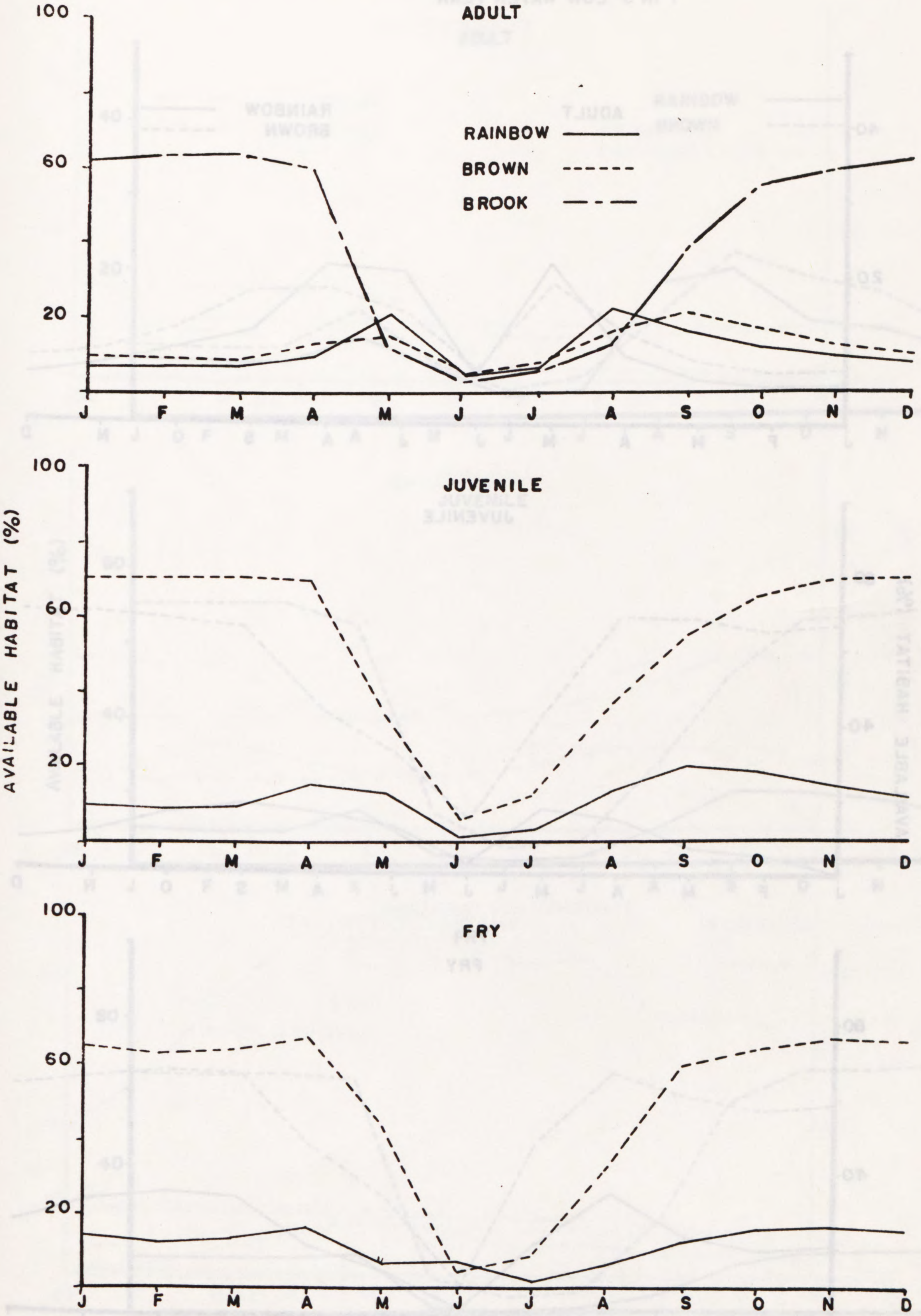
	Flow - cfs		
Stream name & gaging area	Average 100%	Flushing 200%	Minimum 25%
COLORADO RIVER BASIN - continued			
Plateau Cr. #1 (Buzzard Cr. to Colorado R.)	180.0	360.0	45.0
Plateau Cr. #2 (source to Buzzard Cr.)	92.2	184.4	23.1
Roaring Fork #3 (Aspen to Basalt)	1,188.0	2,376.0	297.0
Roaring Fork #4 (Lincoln Cr. to Aspen)	138.0	276.0	34.5
Slater Cr. (source to Little Snake confluence)	--	--	--
Snake R., Little #7 (Willow Cr. to State Line)	233.0	446.0	55.8
Troublesome Cr., E. Fork (source to confluence with Troublesome)	27.4	54.8	6.9
White R. #2 (S. Fork White R. to Hwy. #13)	618.0	1,236.0	154.0
White R. #1 (Hwy. #13 to State Line)	607.0	1,214.0	152.0
White R., South Fork	--	--	--
White R., South Fork	--	--	--
White R., South Fork	256.0	512.0	64.0
White R., South Fork	250.0	500.0	62.5
White R., N. Fork (source to White R. confluence)	306.0	612.0	76.5
Williams Fork R. #1 (Williams Fork Res. to Colorado R.)	122.0	244.0	30.5
Williams Fork R. #2 (S.F. Williams Fork to Williams Fork Res.)	101.0	202.0	25.3
Williams Fork R. #3 (source to South Fork Williams Fork R.)	35.5	71.0	8.9
Williams Fork R., South Fork (source to Williams Fork confluence)	29.8	59.6	7.5
Williams Fork R., No. Fork (source to Williams Fork confluence)	--	--	--
Yampa River #1 (Little Snake to Green R.)	1,534.0	3,068.0	383.0
PLATTE RIVER BASIN			
Big Thompson R. #5 (source to Morrain Peak)	--	--	--
Cache la Poudre R. (source to Poudre)	62.6	125.0	15.7
RIO GRANDE RIVER BASIN			
Conejos R. #4 (source to Platoro Res.)	--	--	--
Sangre de Cristo Cr. (source to Trinchera Cr.)	18.1	36.2	4.5
Trinchera Cr. (source to Mountain Home Res.)	22.3	44.6	5.5

APPENDIX C

Percent available habitat (weighted usable area) versus discharge, 1 in 5 low water year, median water year, and 1 in 5 high water year flow regimes.

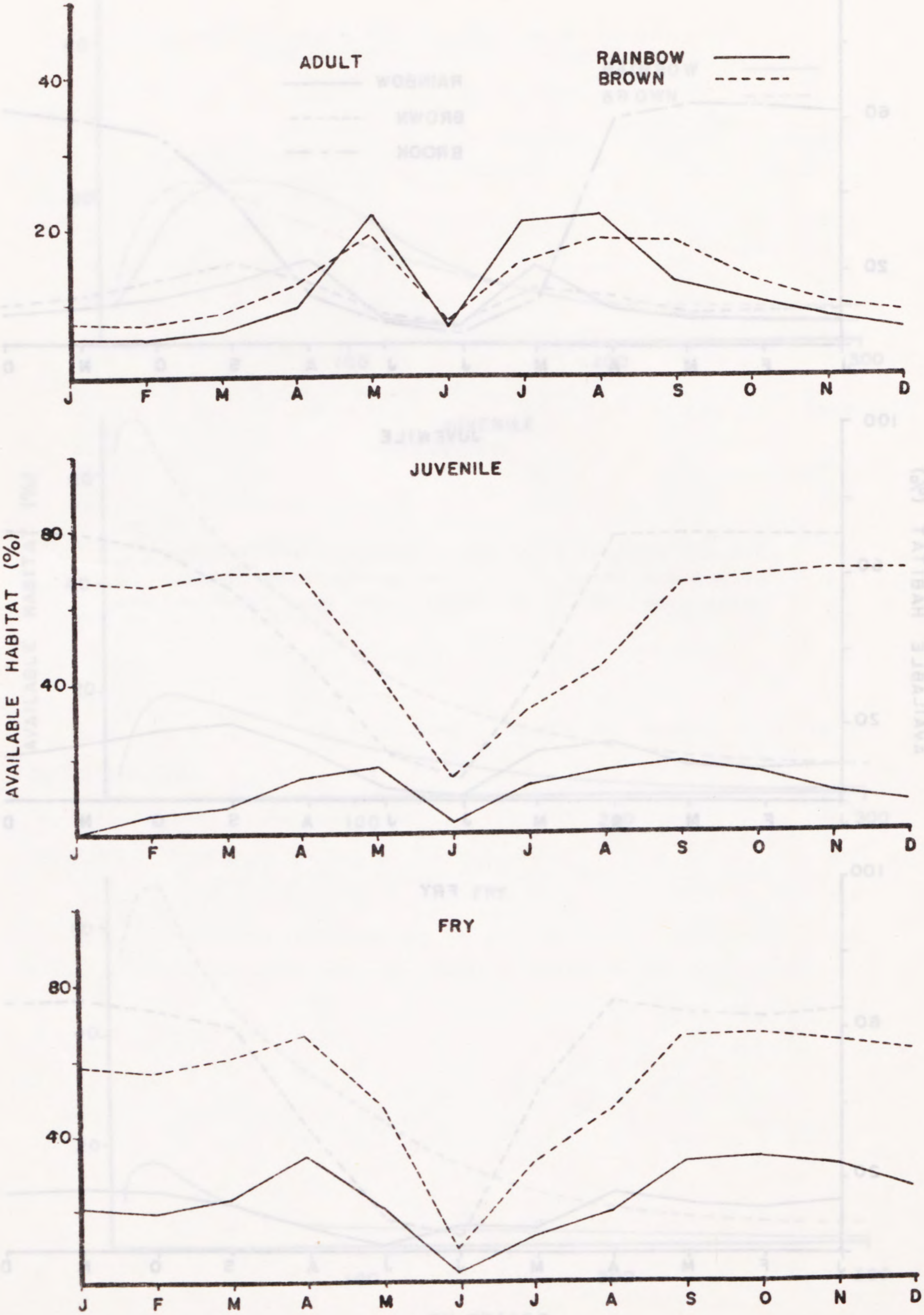
LITTLE SOUTH FORK CACHE LA POUDRE RIVER



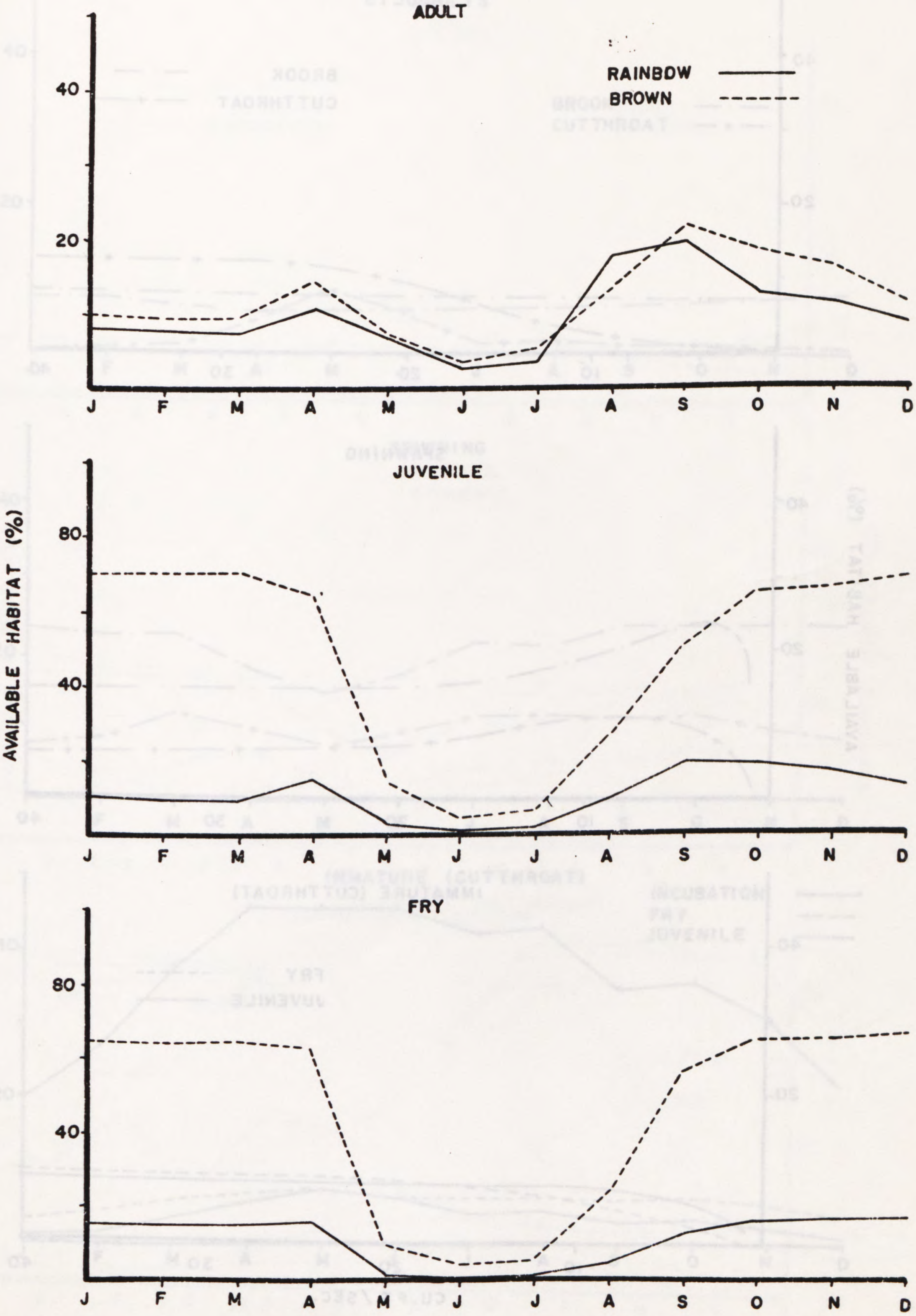


LITTLE SOUTH FORK : CACHE LA POUDRE RIVER
MEDIAN WATER YEAR

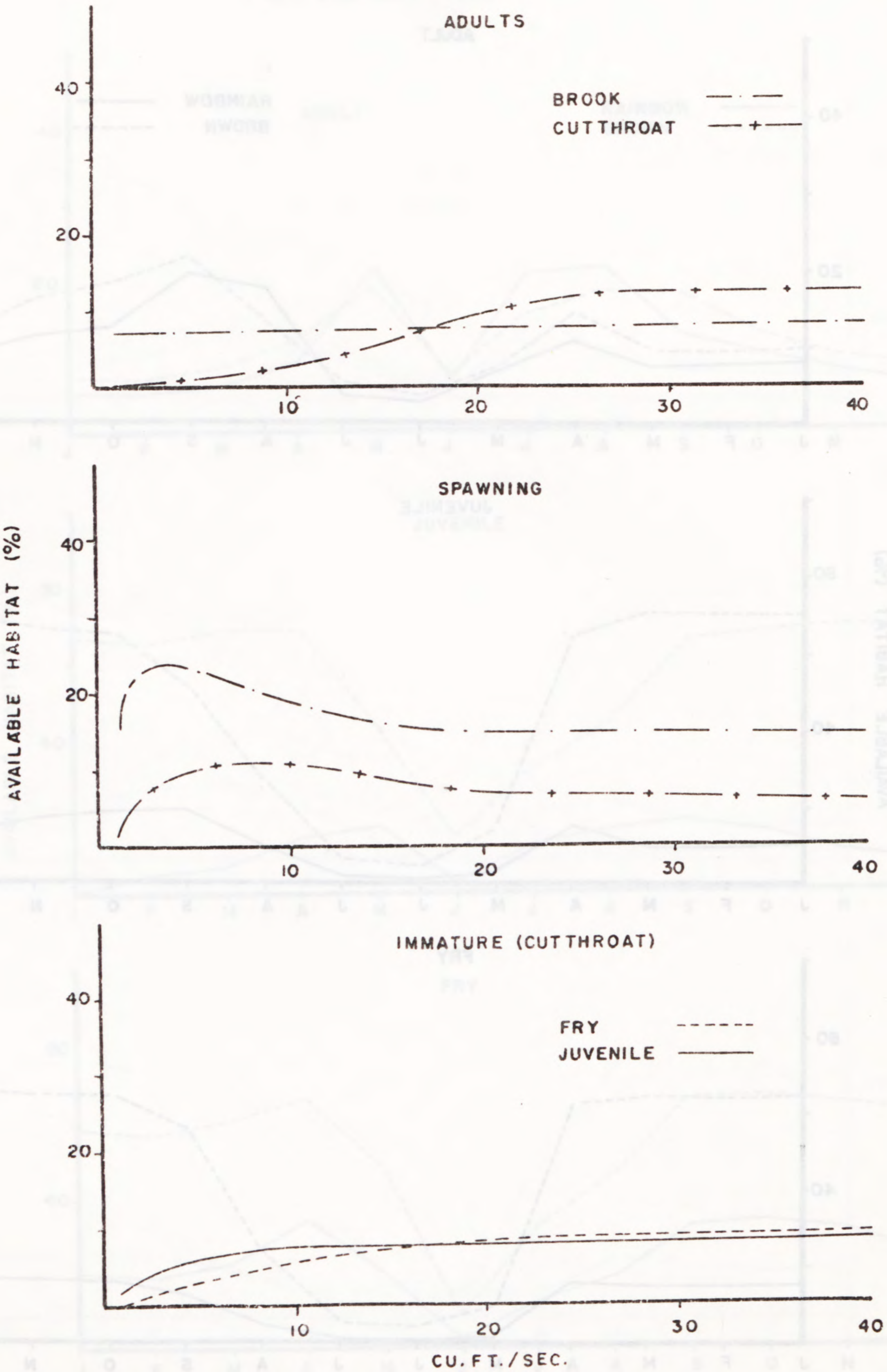
SOUTH FORK OF CACHE LA POUDRE RIVER
1 IN 5 LOW WATER YEAR



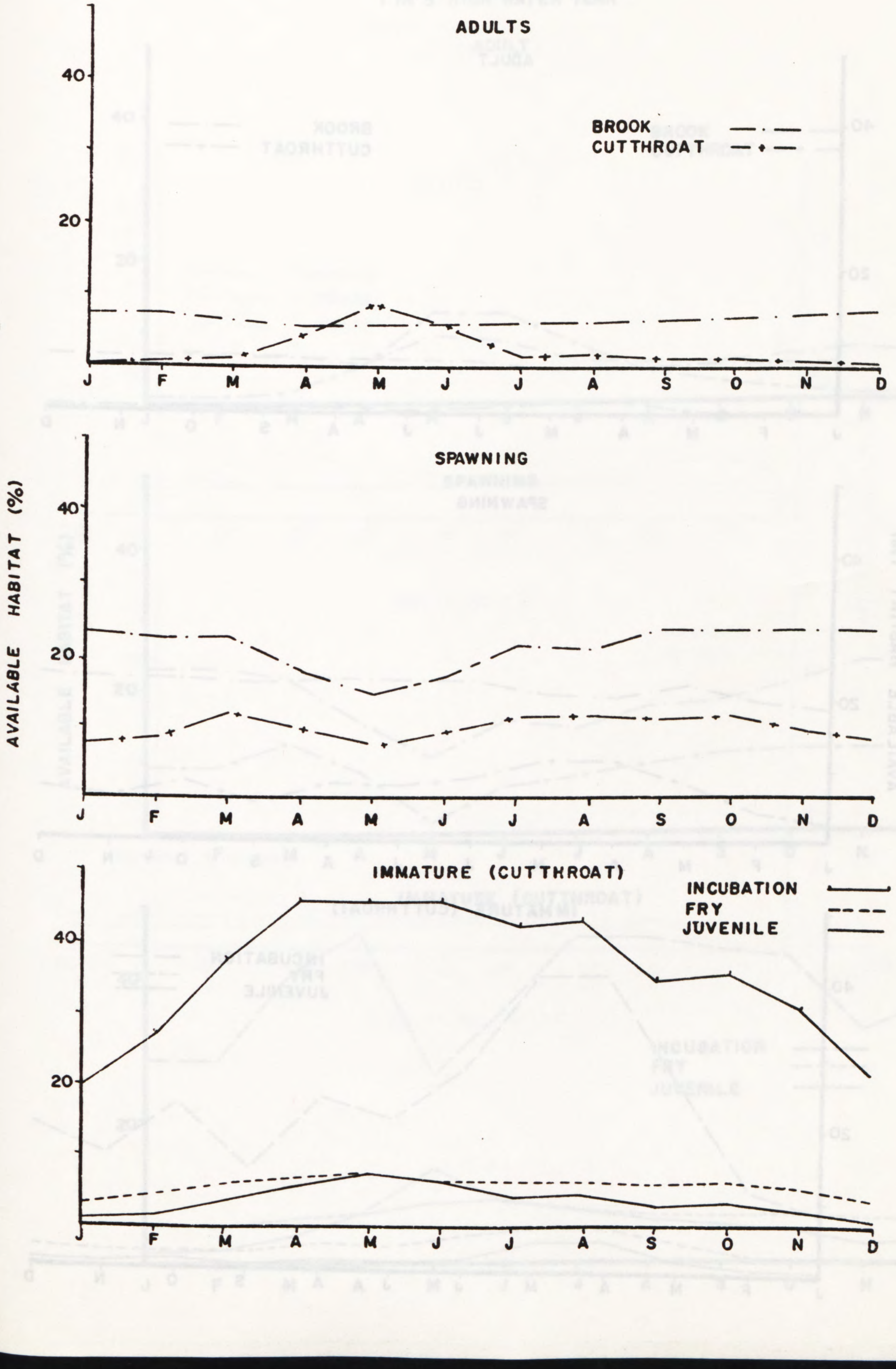
LITTLE SOUTH FORK CACHE LA POUDRE RIVER
1 IN 5 HIGH WATER YEAR



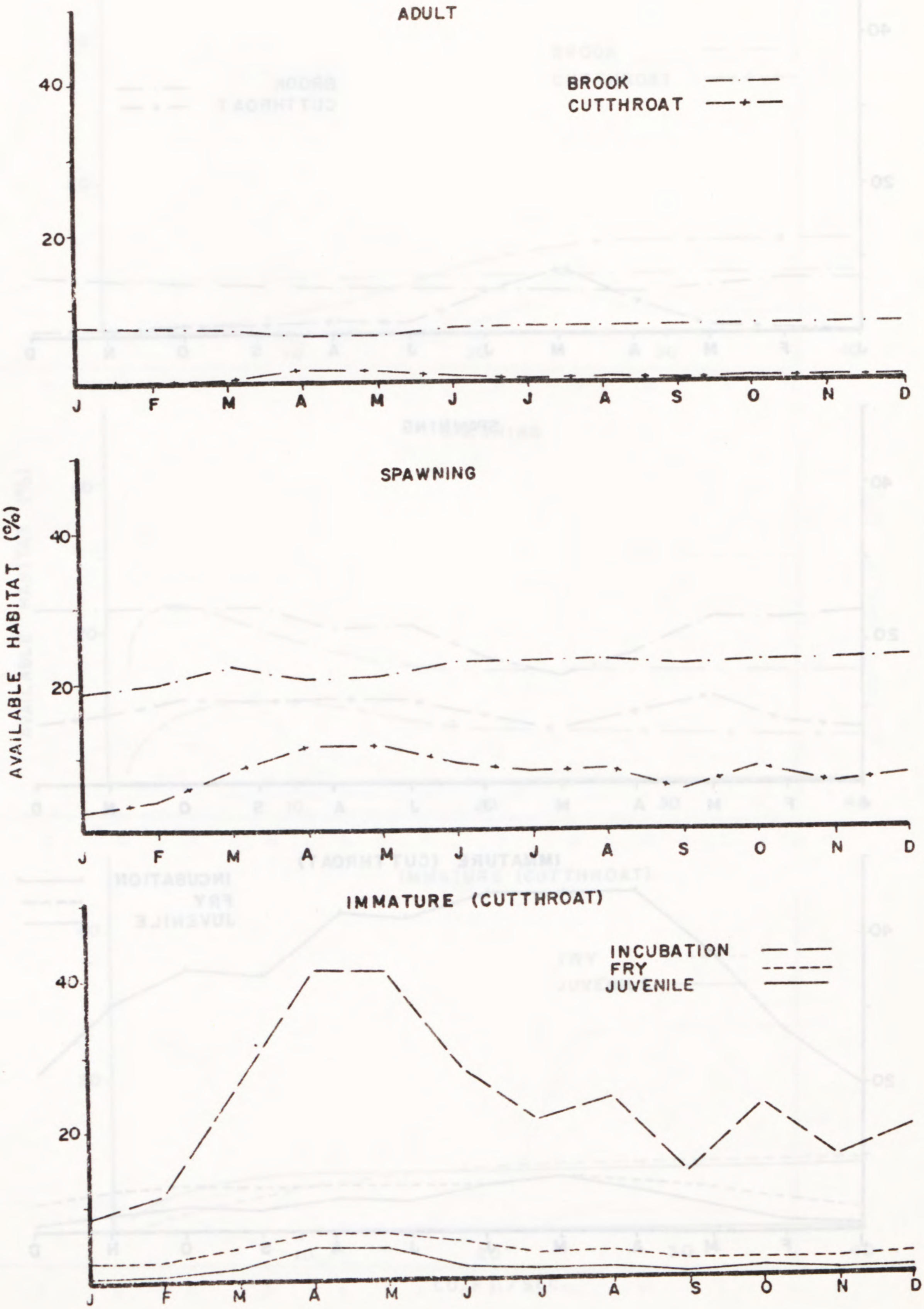
SOUTH FORK OF CARNERO CREEK



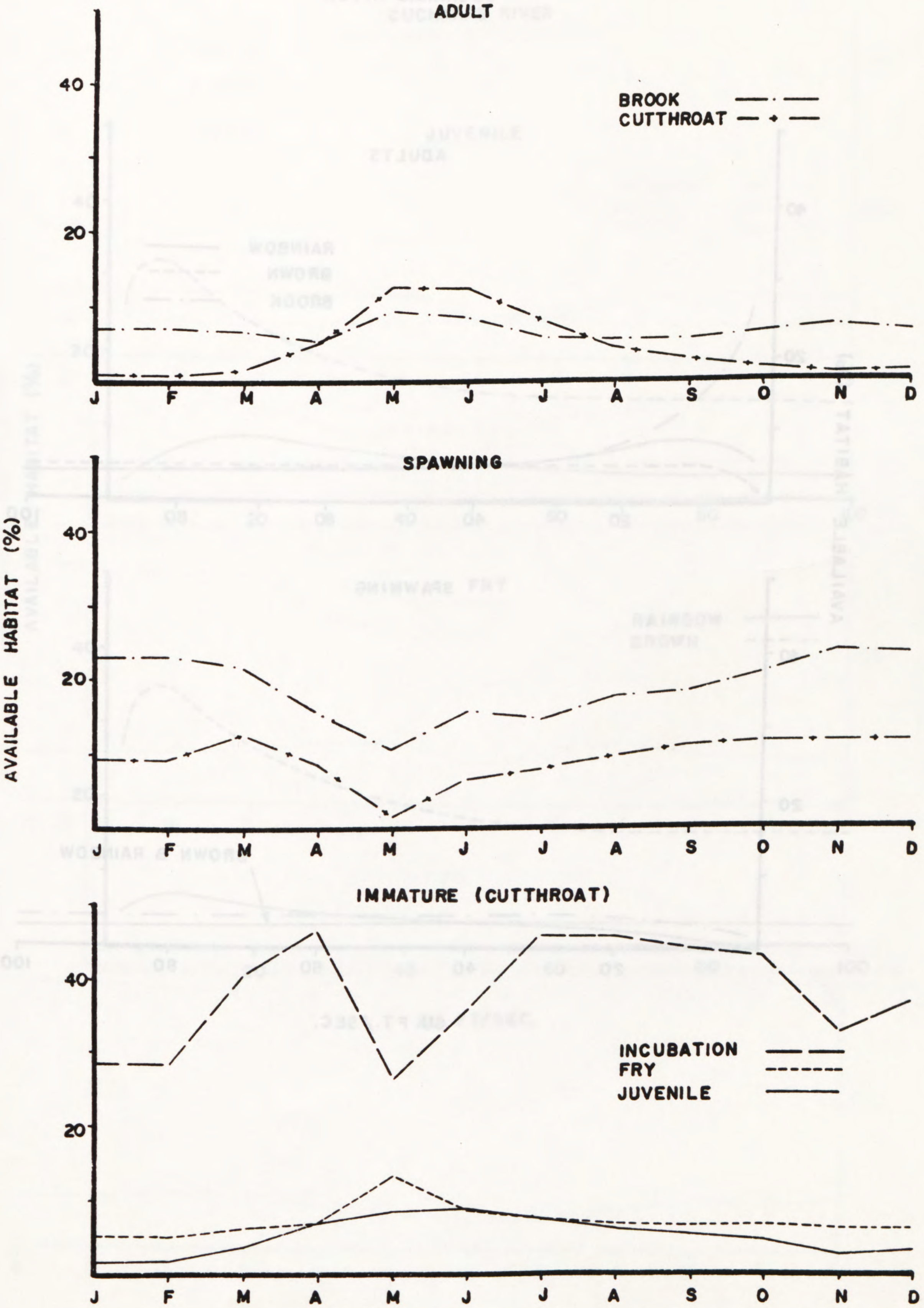
SOUTH FORK OF CARNERO CREEK
MEDIAN WATER YEAR

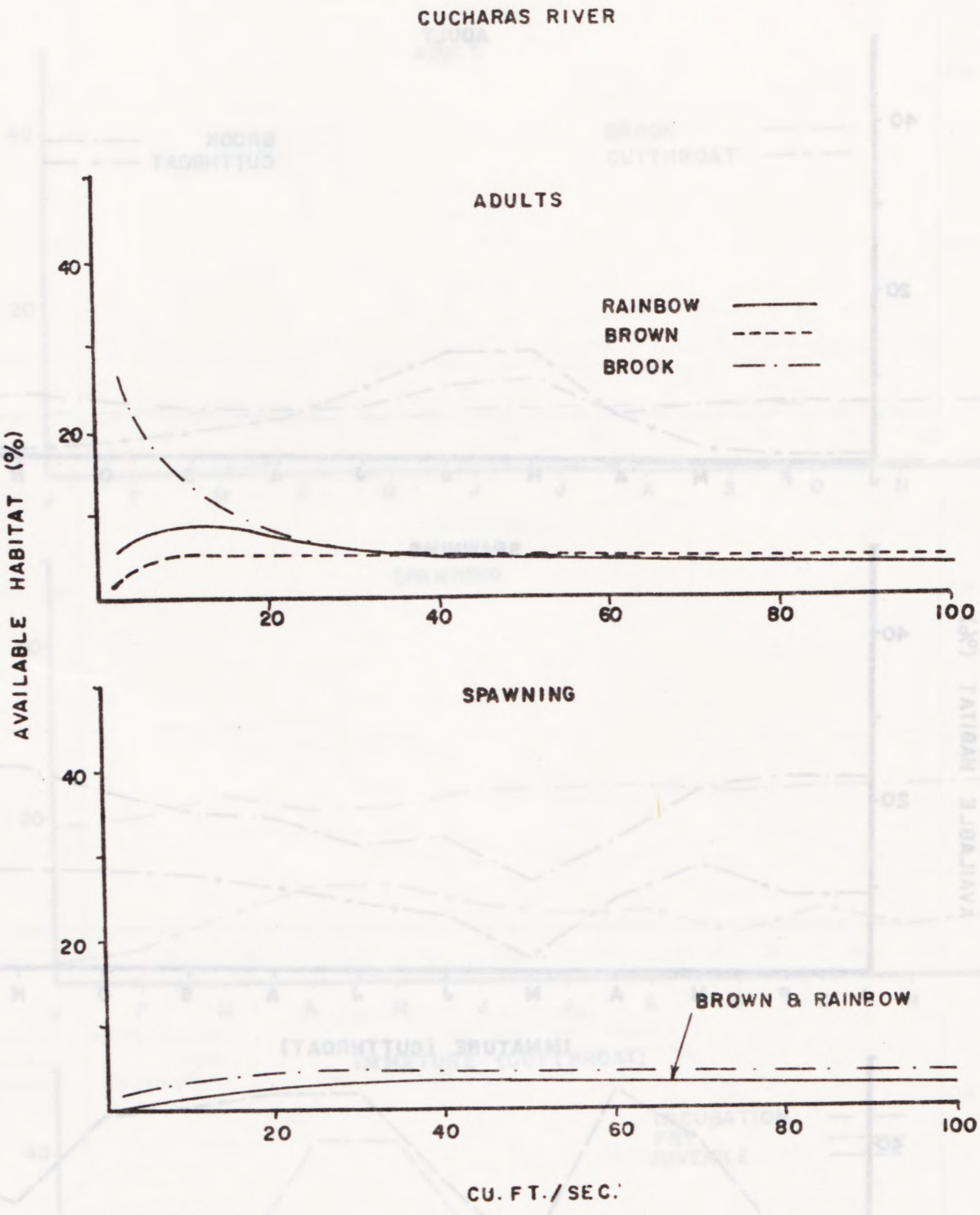


SOUTH FORK CARNERO CREEK
I IN 5 LOW WATER YEAR

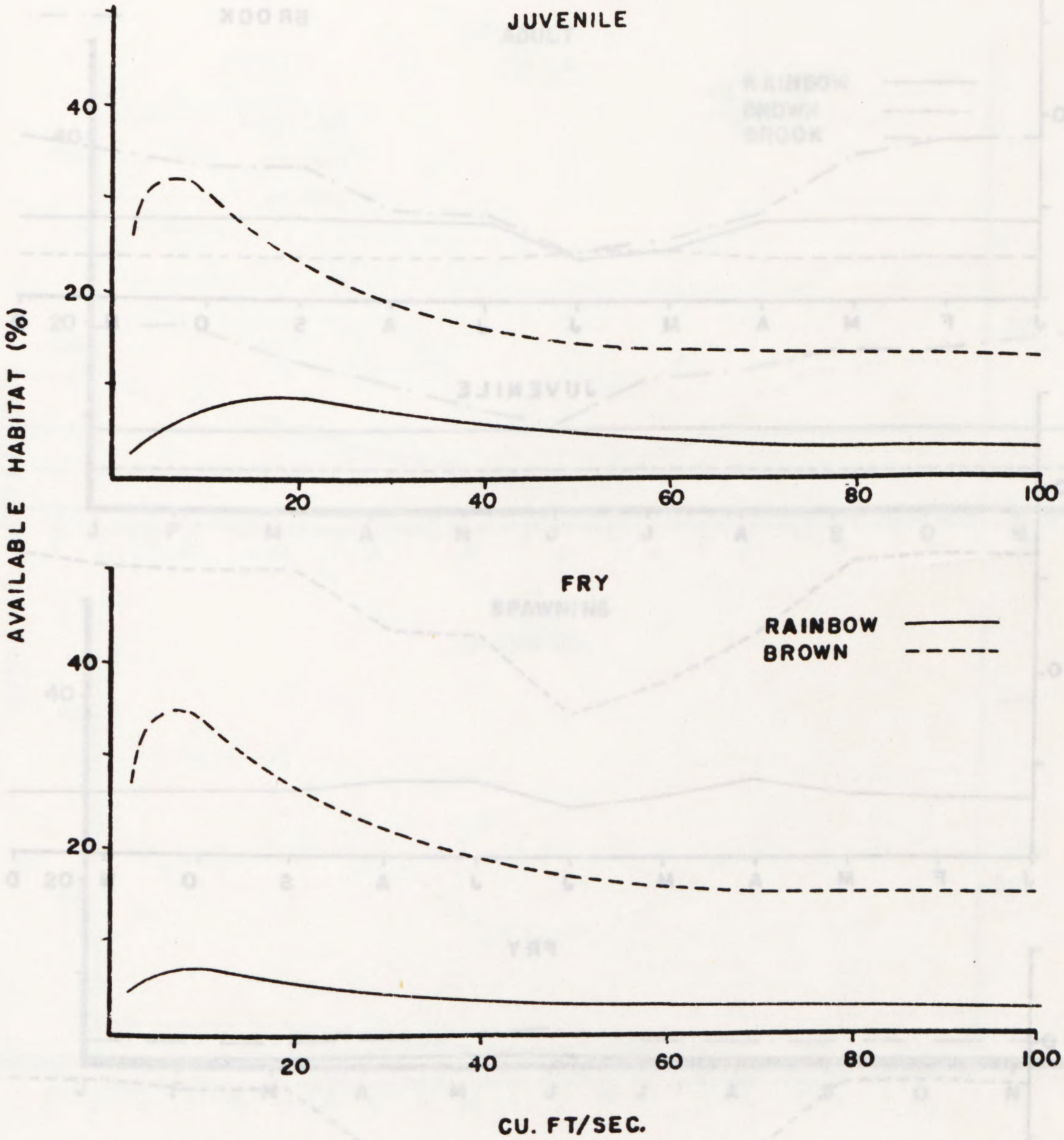


SOUTH FORK CARNERO CREEK
I IN 5 HIGH WATER YEAR



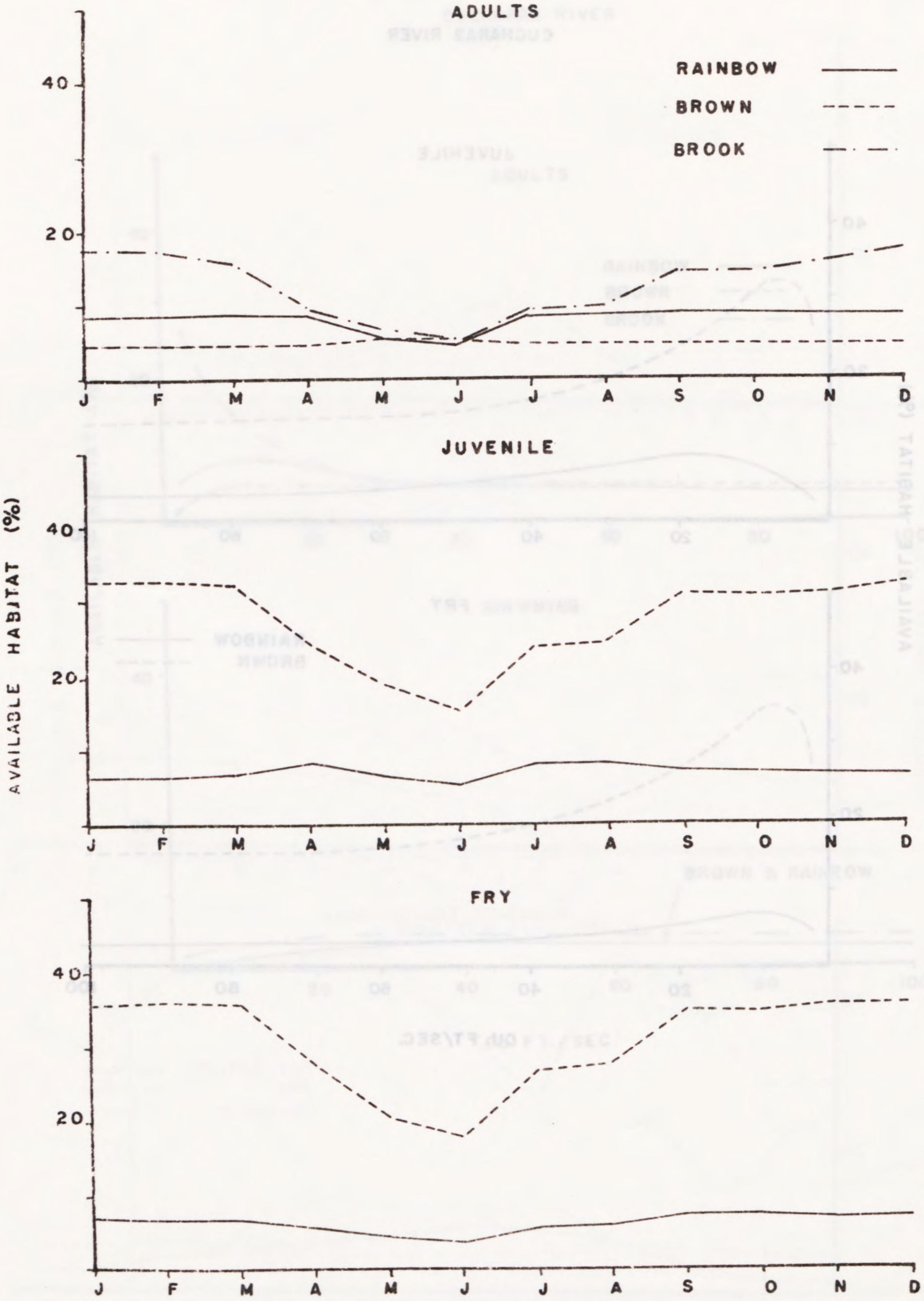

CUCHARAS RIVER
ADULTS
RAINBOW
BROWN
BROOK
40
20
20
40
60
80
100
AVAILABLE HABITAT (%)
SPAWNING
40
20
BROWN & RAINBOW
20
40
60
80
100
CU. FT./SEC.

CUCHARAS RIVER

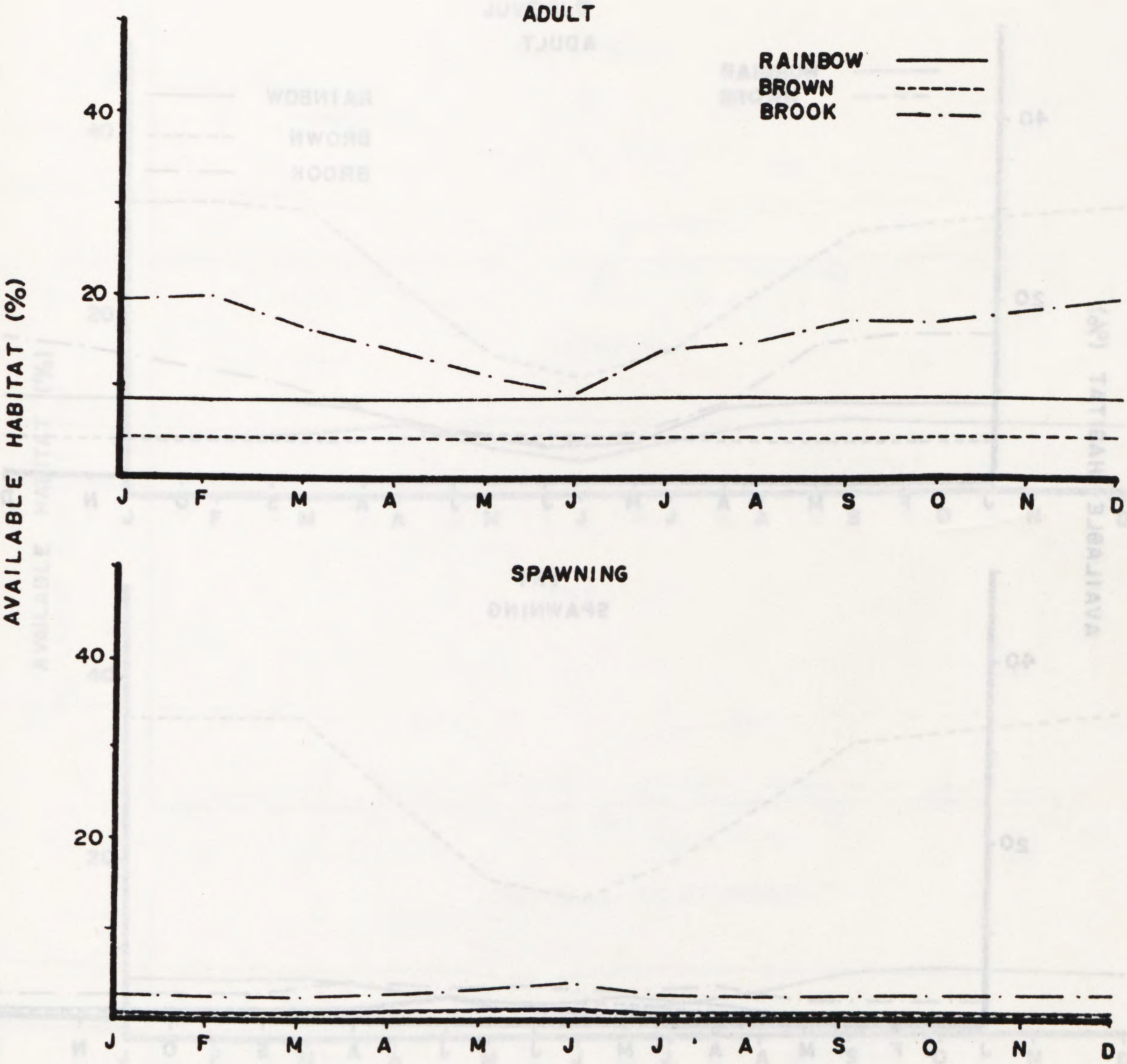


CUCHARAS RIVER

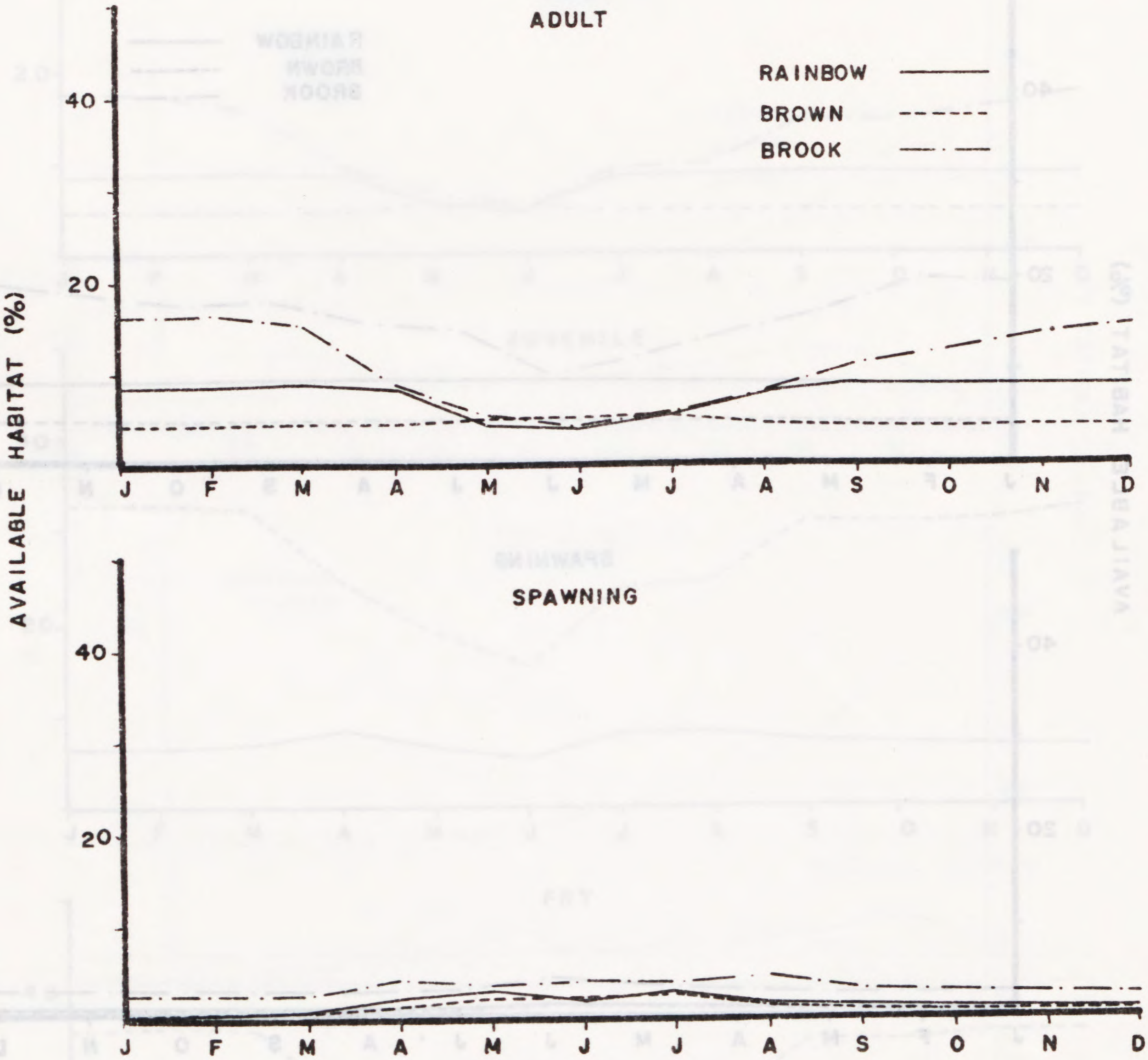
MEDIAN WATER YEAR



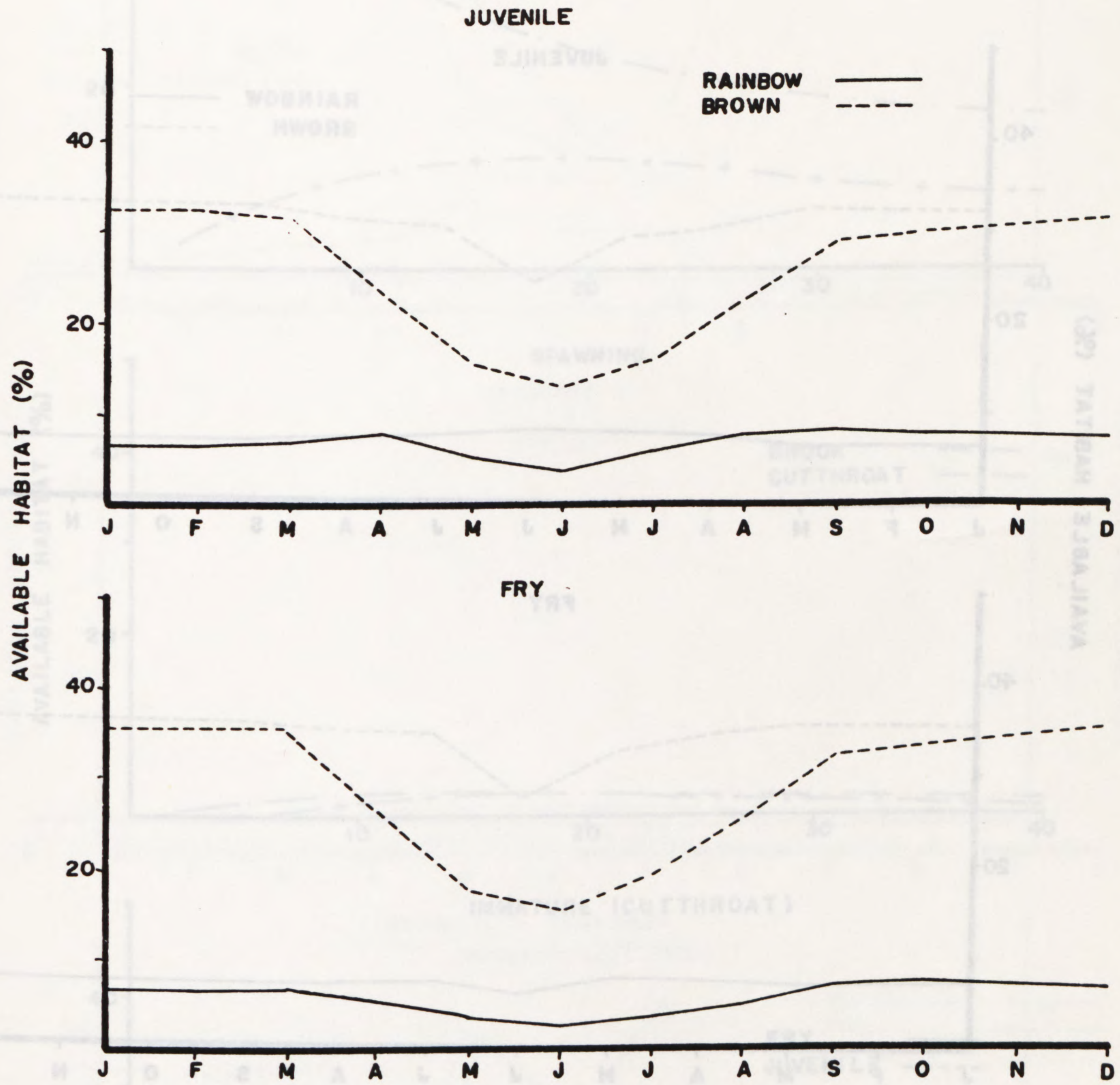
CUCHARAS RIVER
1 IN 5 LOW WATER YEAR



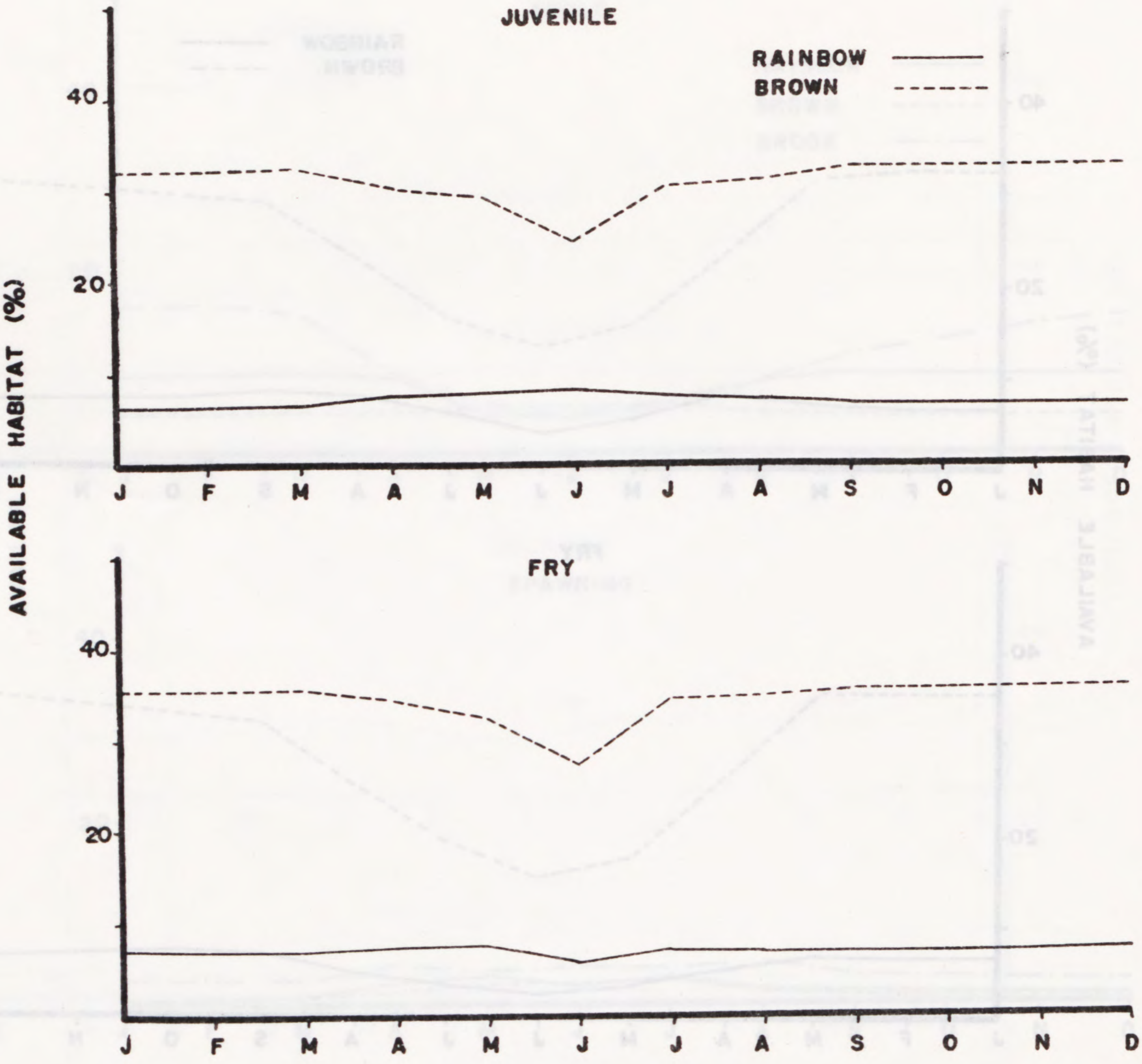
CUCHARAS RIVER
1 IN 5 HIGH WATER YEAR

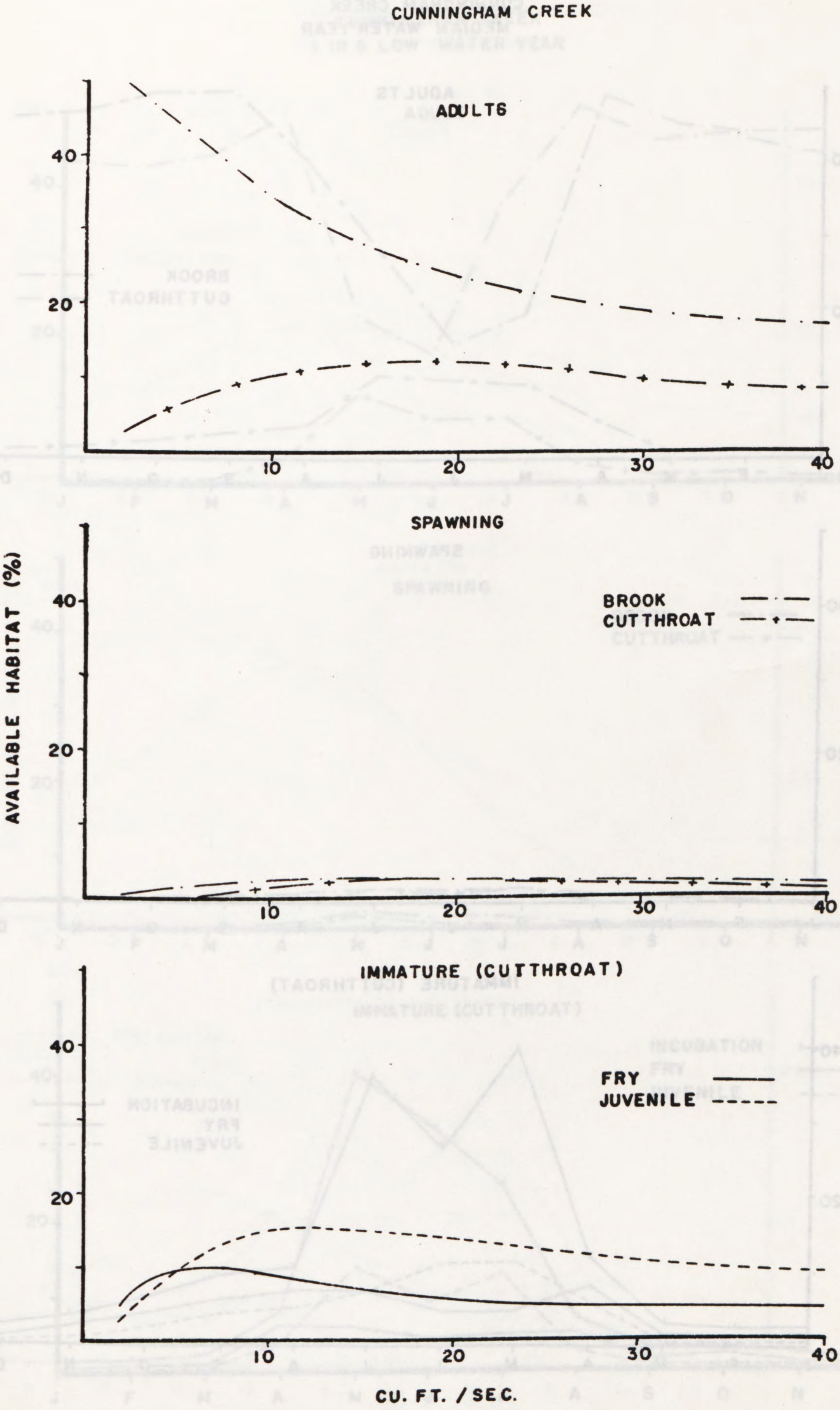


CUCHARAS RIVER
I IN 5 HIGH WATERYEAR

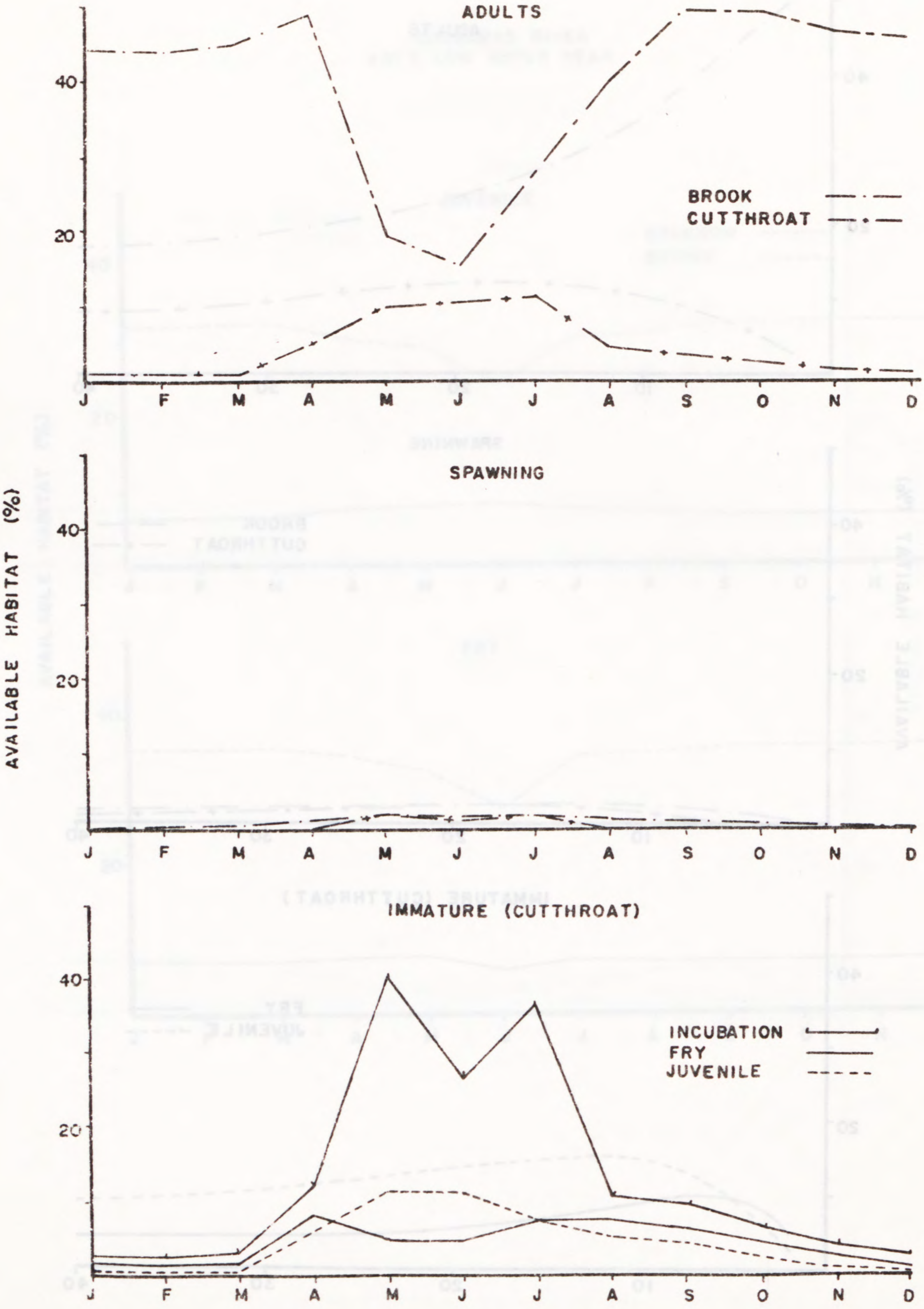


CUCHARAS RIVER
1 IN 5 LOW WATER YEAR

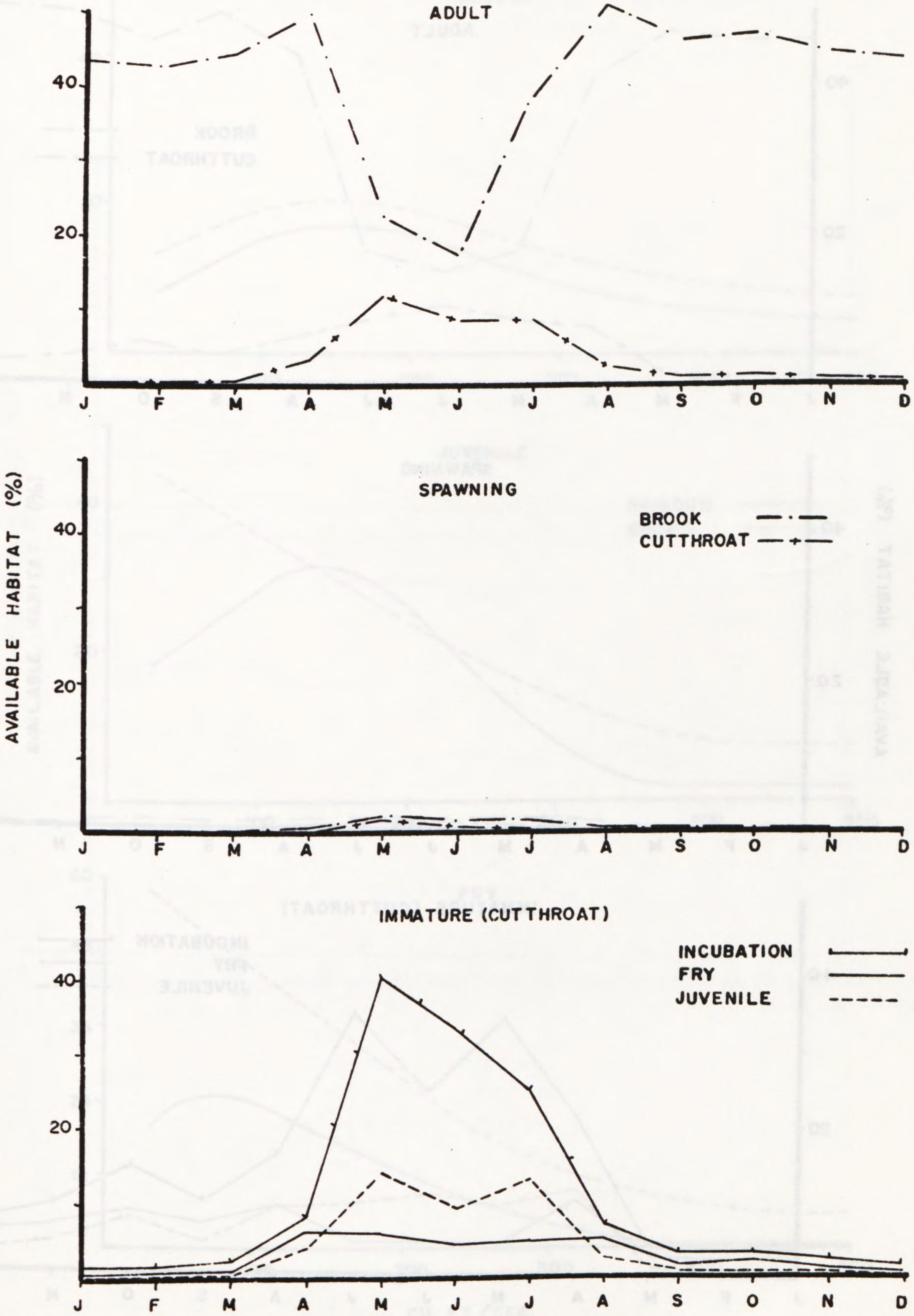



CUNNINGHAM CREEK
ADULTS
40
20
10
20
30
40
SPAWNING
BROOK
CUTTHROAT
AVAILABLE HABITAT (%)
40
20
10
20
30
40
IMMATURE (CUTTHROAT)
FRY
JUVENILE
40
20
10
20
30
40
CU. FT. / SEC.

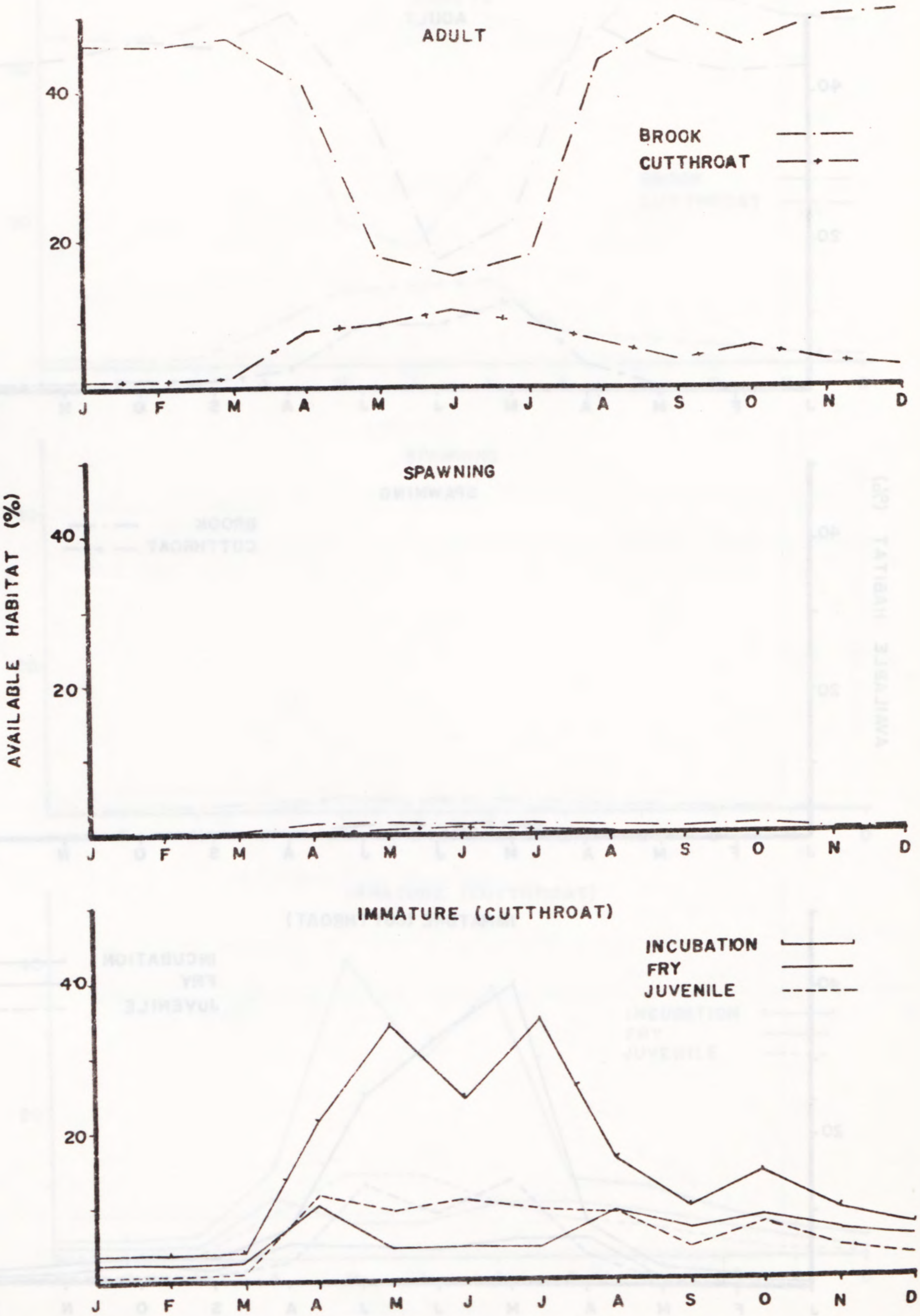
CUNNINGHAM CREEK
MEDIAN WATER YEAR



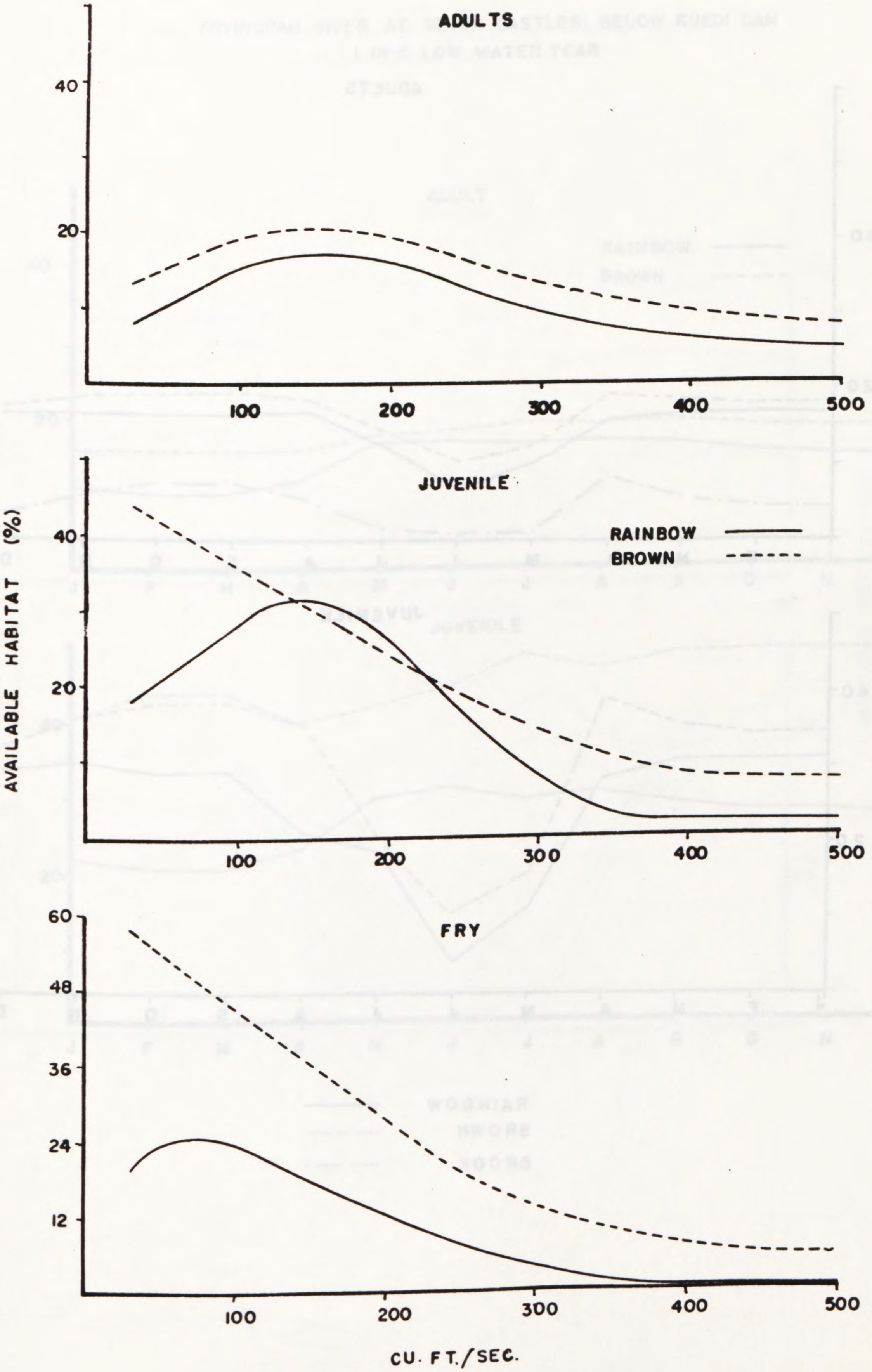
CUNNINGHAM CREEK
I IN 5 LOW WATER YEAR



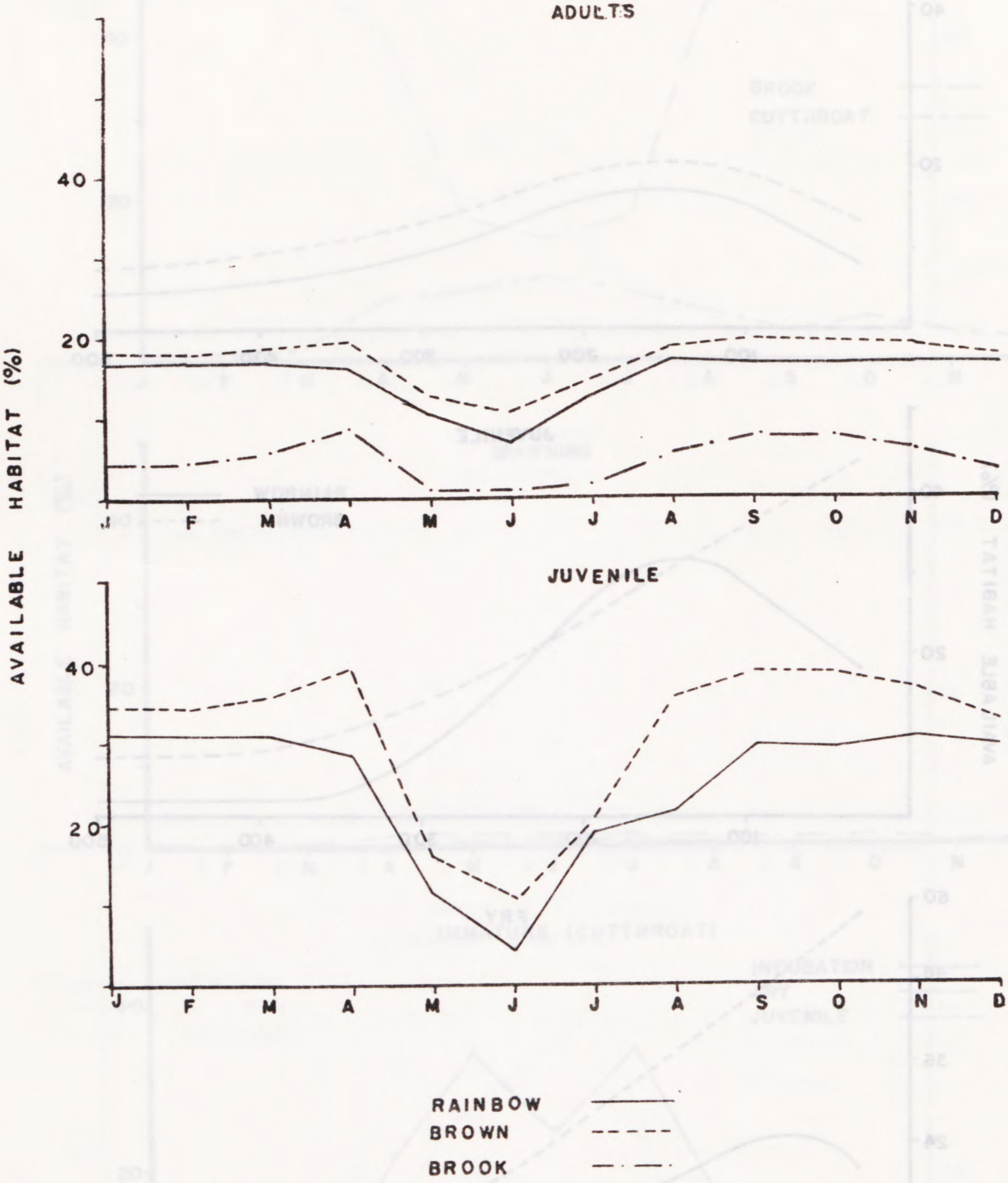
CUNNINGHAM CREEK
I IN 5 HIGH WATER YEAR



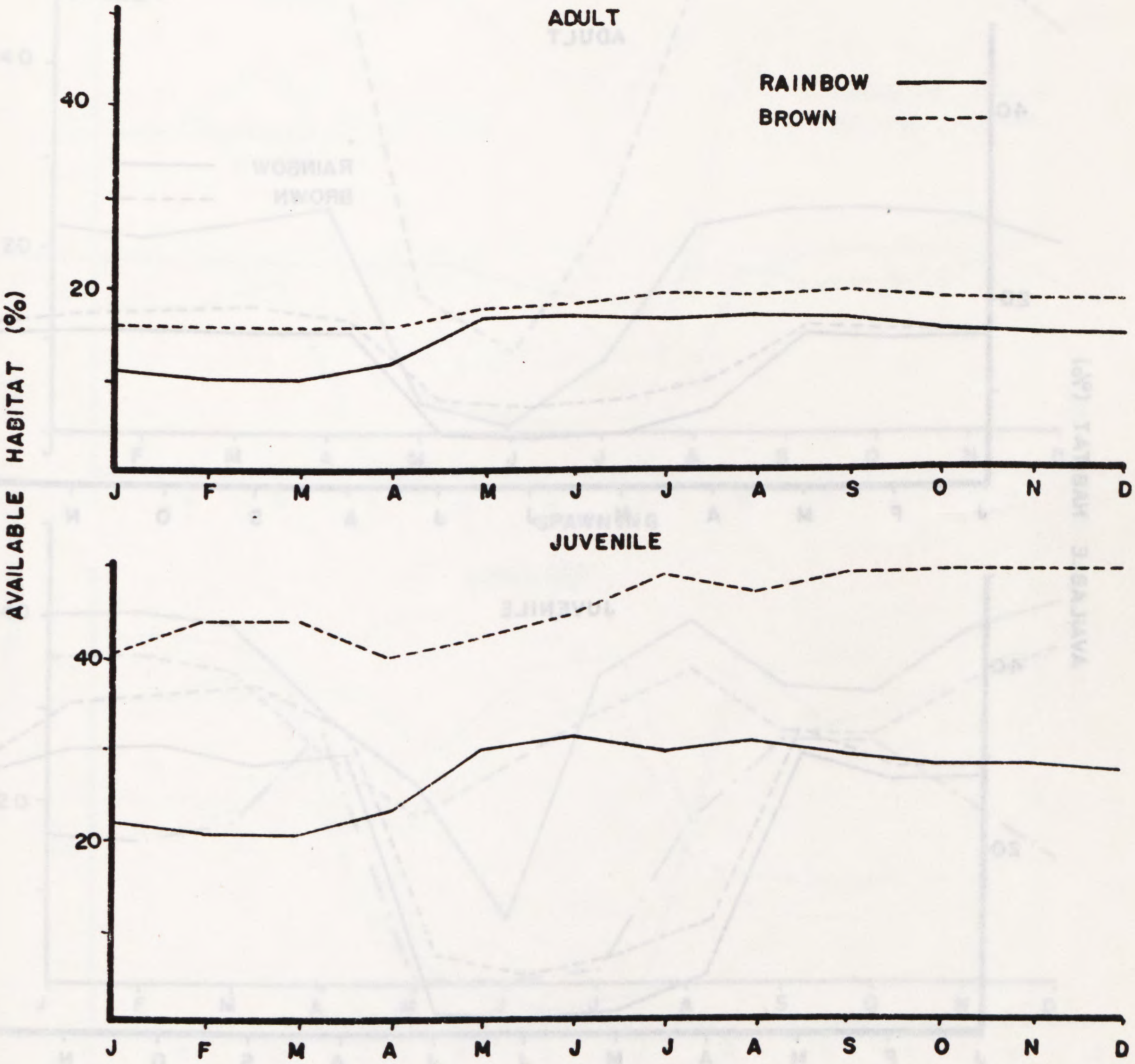
FRYINGPAN RIVER AT SEVEN CASTLES



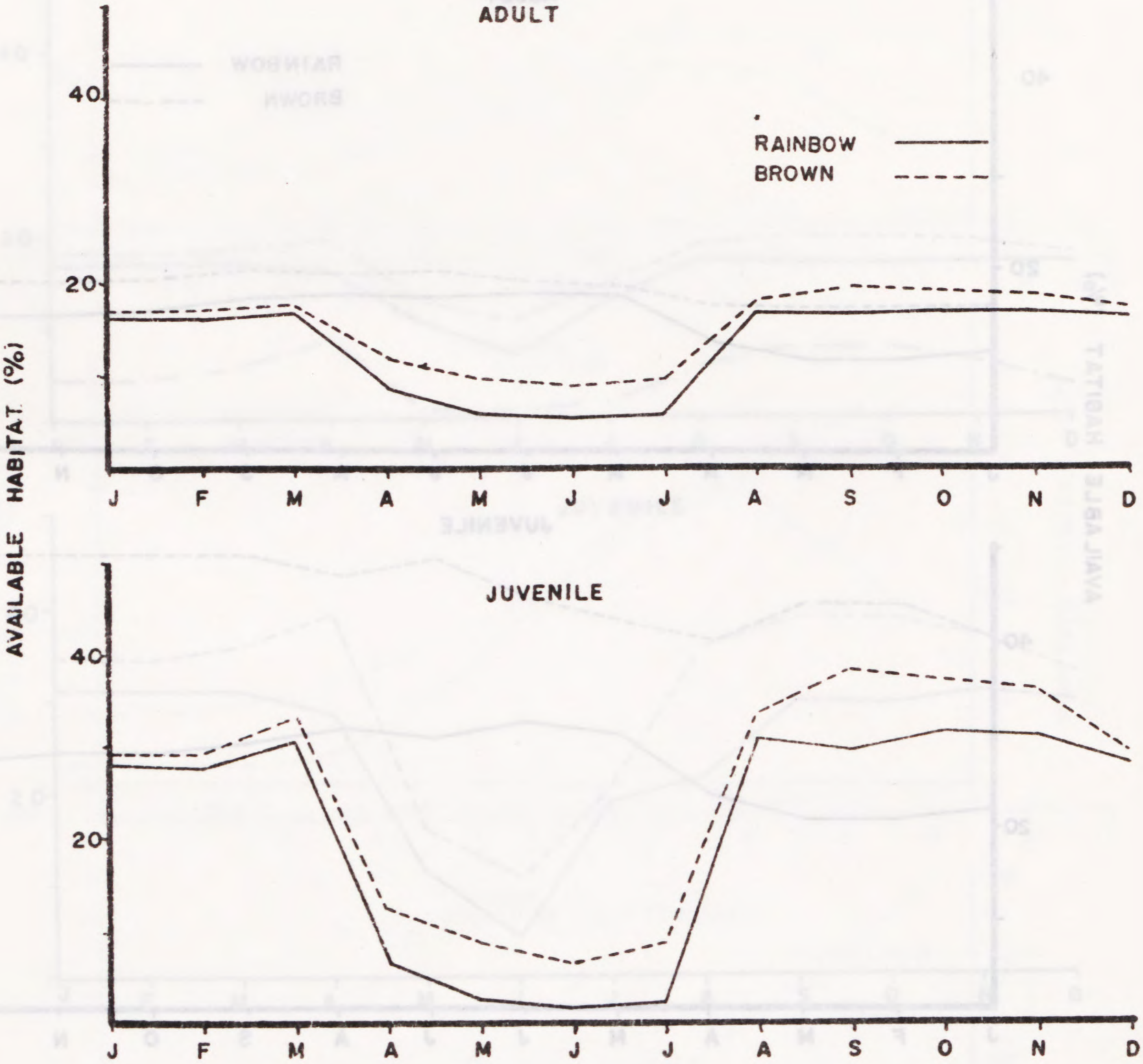
FRYINGPAN RIVER AT SEVEN CASTLES: AFTER RUEDI DAM OPERATION
MEDIAN WATER YEAR



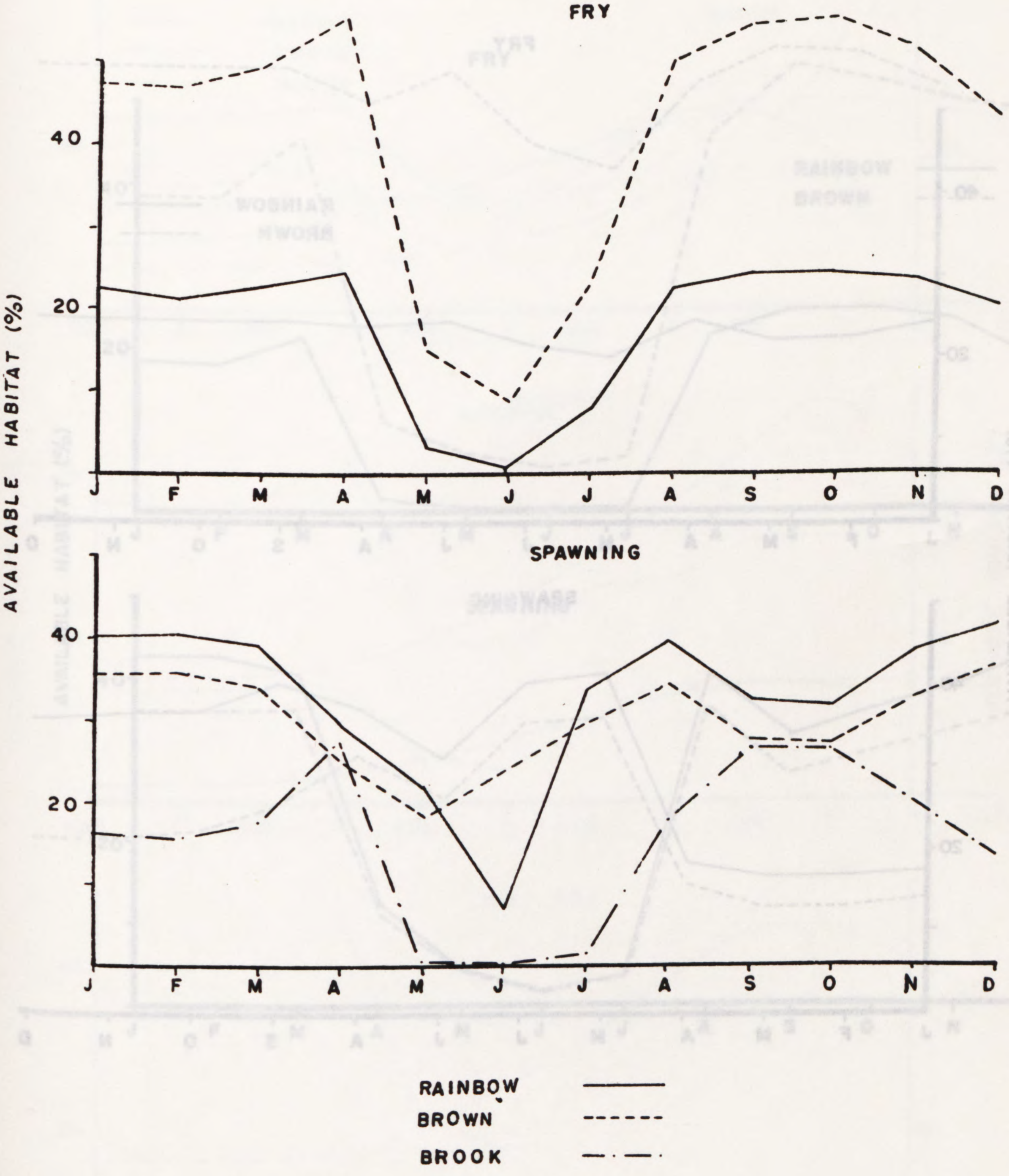
FRYINGPAN RIVER AT SEVEN CASTLES: BELOW RUEDI DAM
I IN 5 LOW WATER YEAR



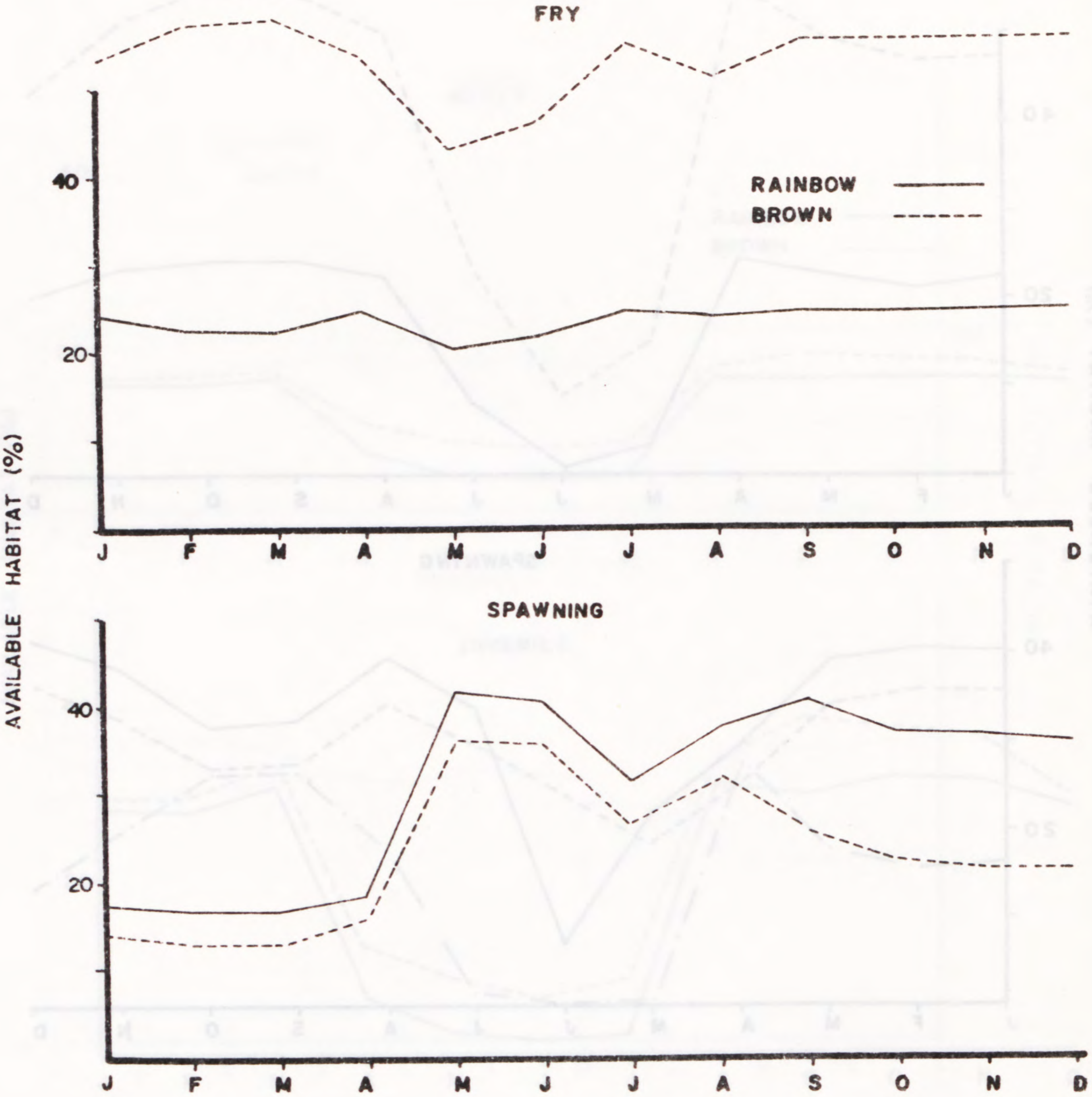
FRYINGPAN RIVER AT SEVEN CASTLES: BELOW RUEDI DAM
1 IN 5 HIGH WATER YEAR



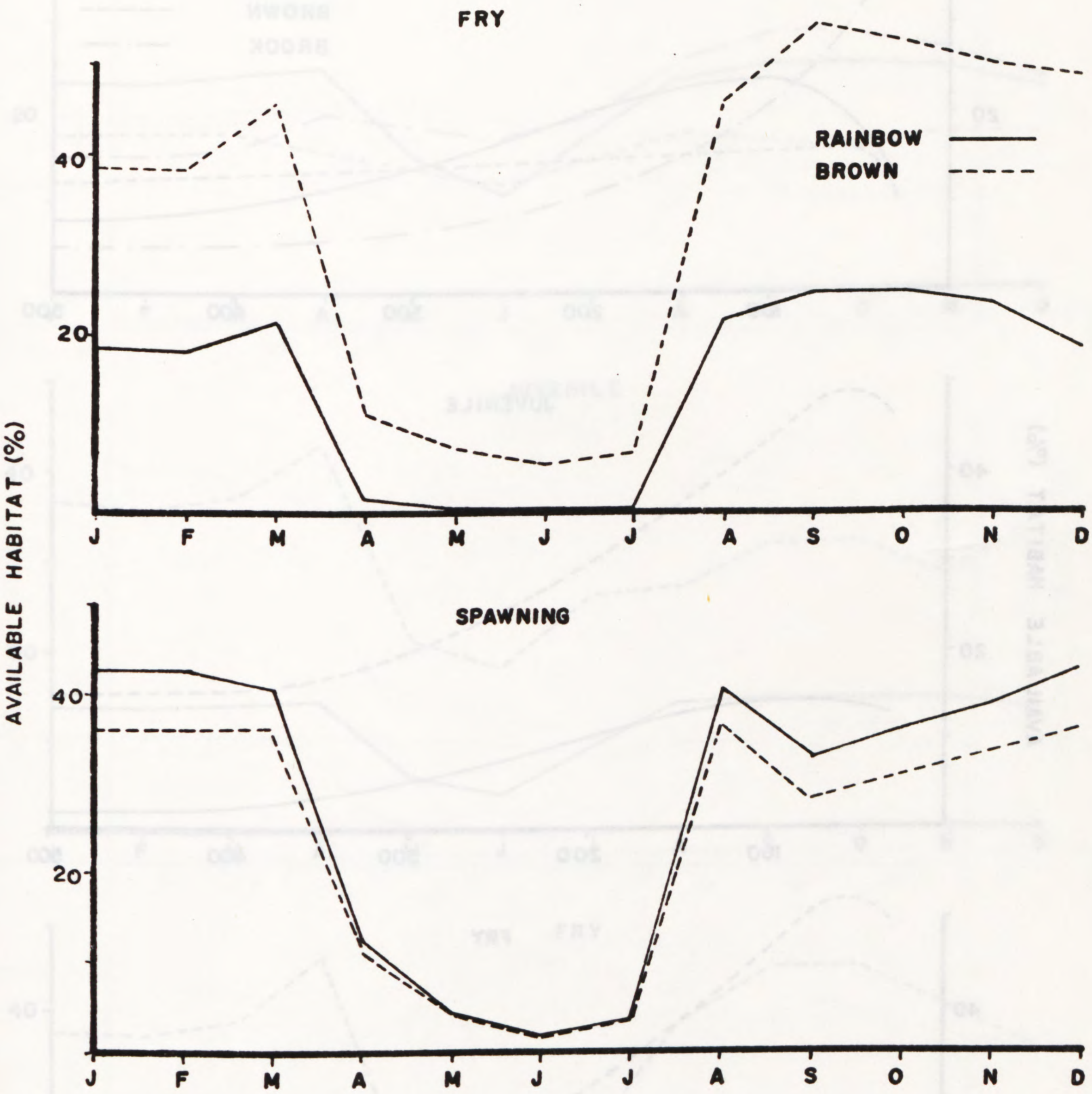
FRYINGPAN RIVER AT SEVEN CASTLES: AFTER RUEDI DAM OPERATION
MEDIAN WATER YEAR



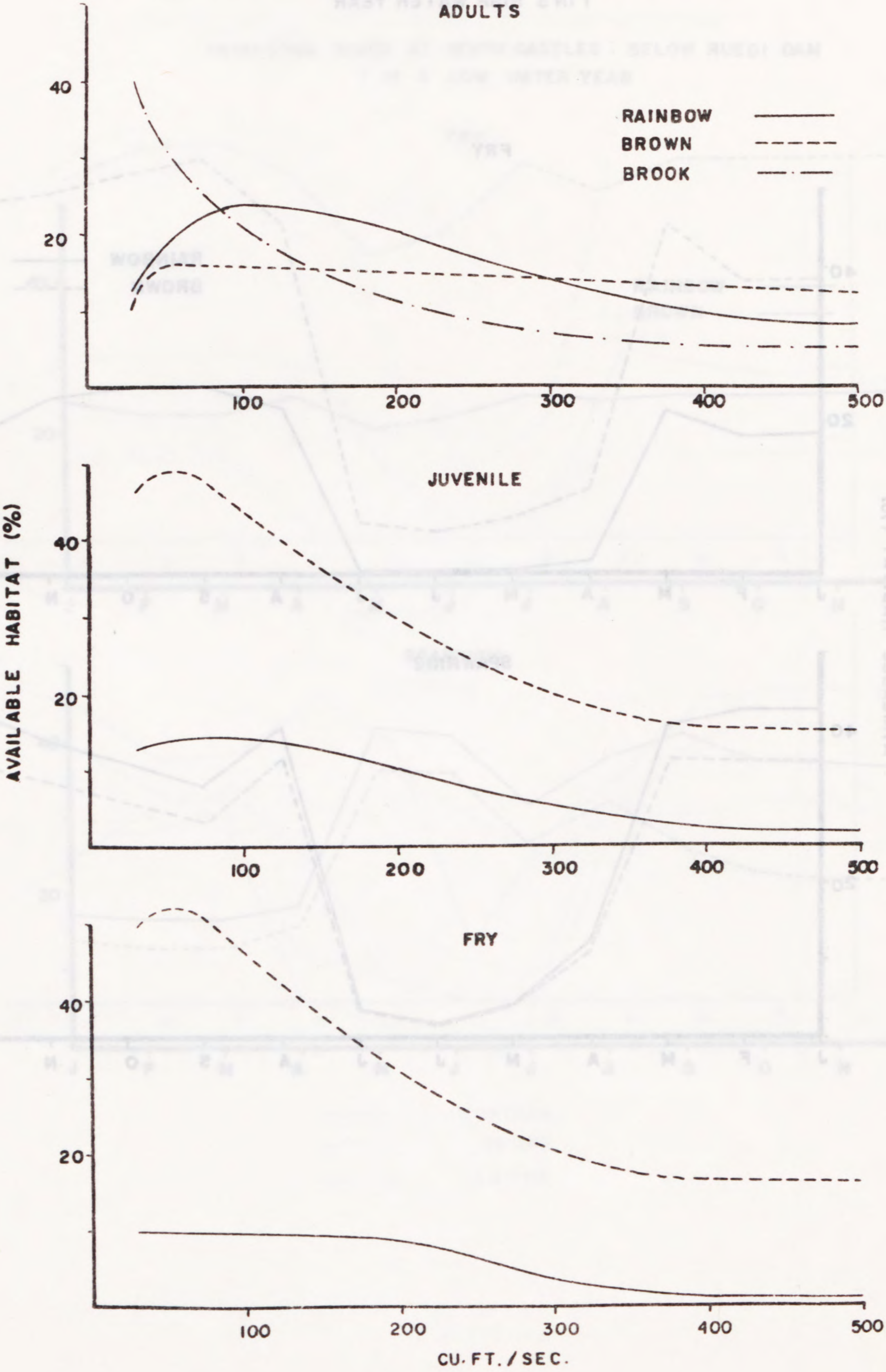
FRYINGPAN RIVER AT SEVEN CASTLES : BELOW RUEDI DAM
I IN 5 LOW WATER YEAR



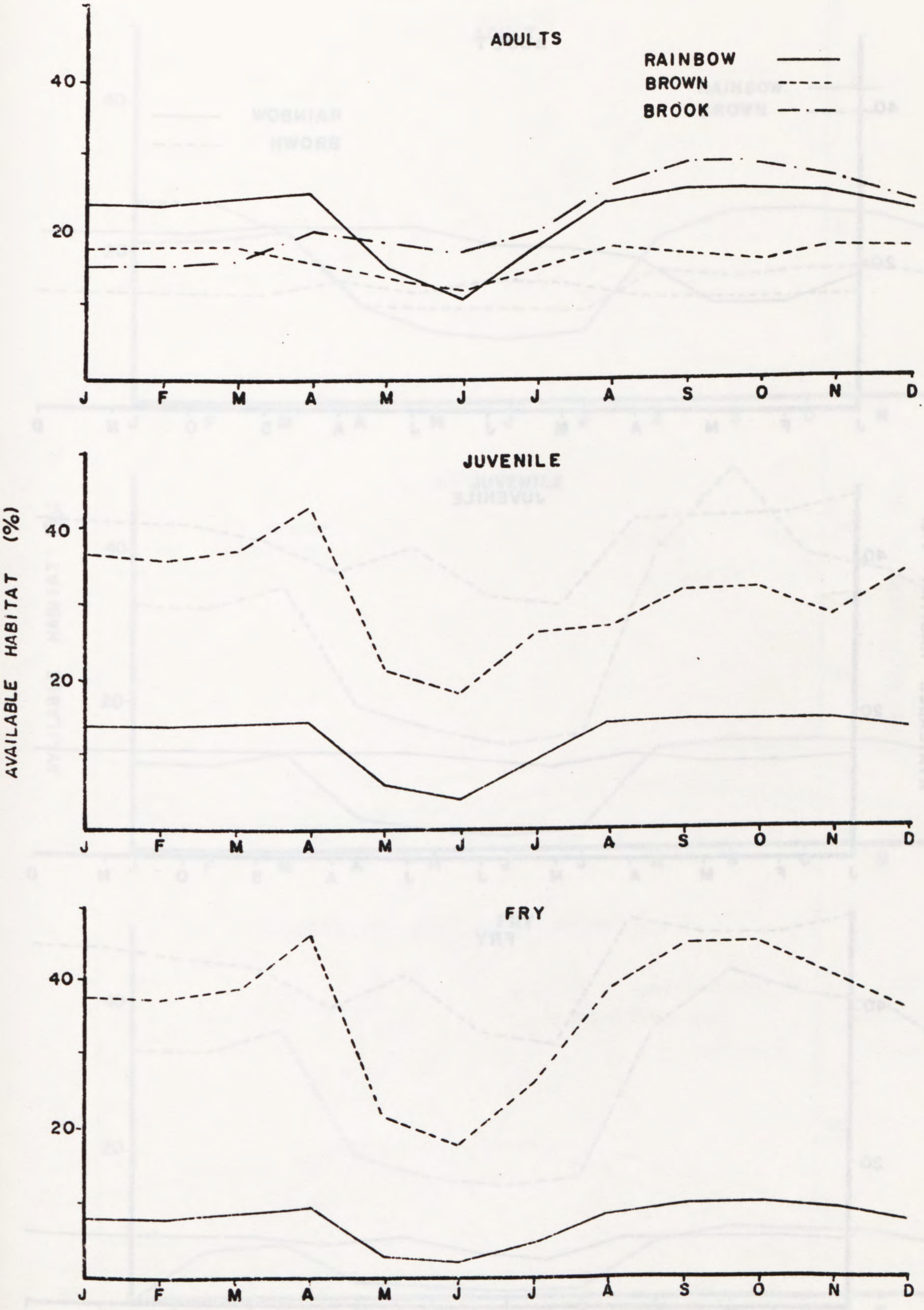
FRYINGPAN RIVER AT SEVEN CASTLES: BELOW RUEDI DAM
1 IN 5 HIGH WATER YEAR



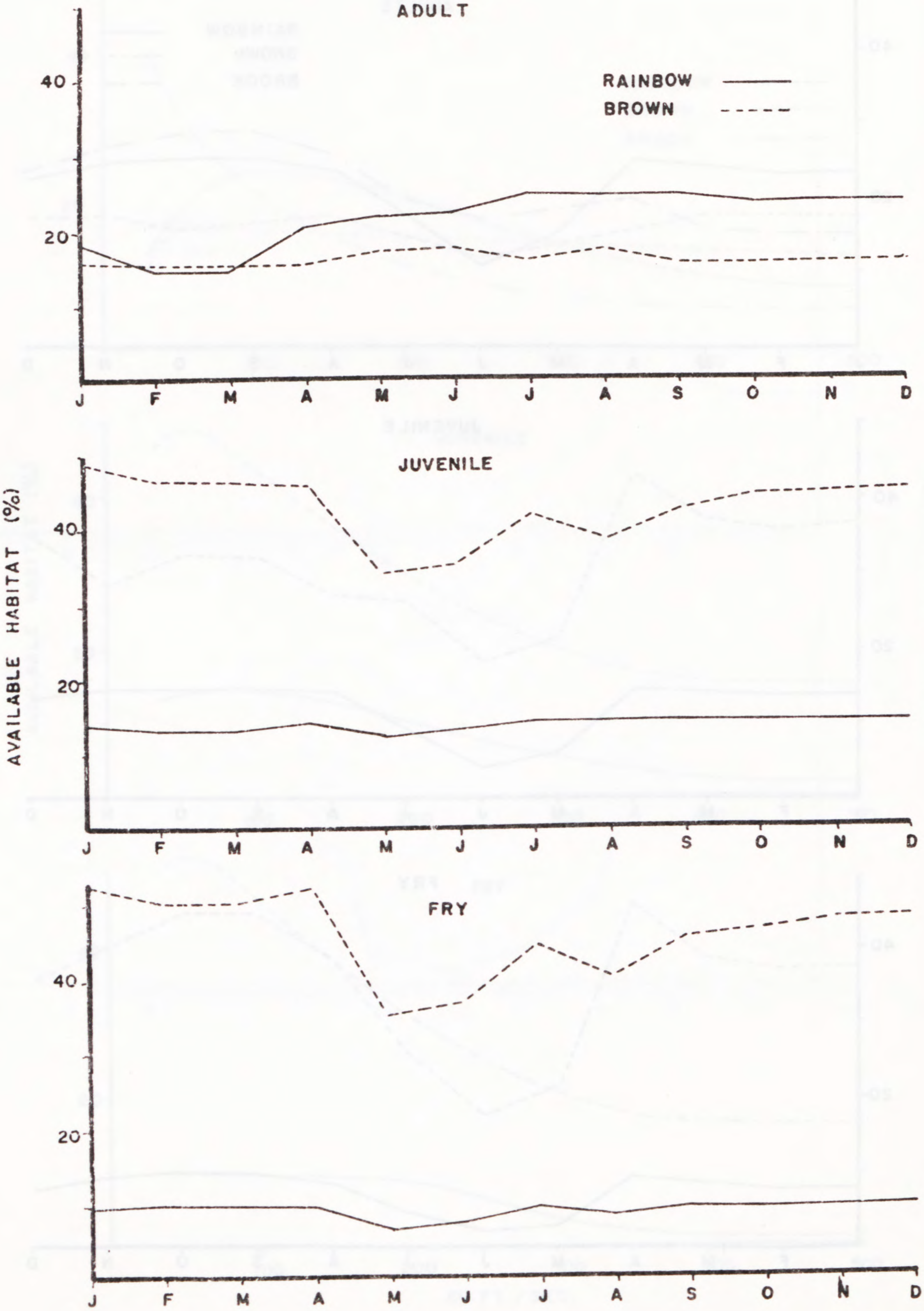
FRYINGPAN RIVER AT TAYLOR CREEK



FRYINGPAN AT TAYLOR CK: AFTER RUEDI DAM OPERATION
MEDIAN WATER YEAR

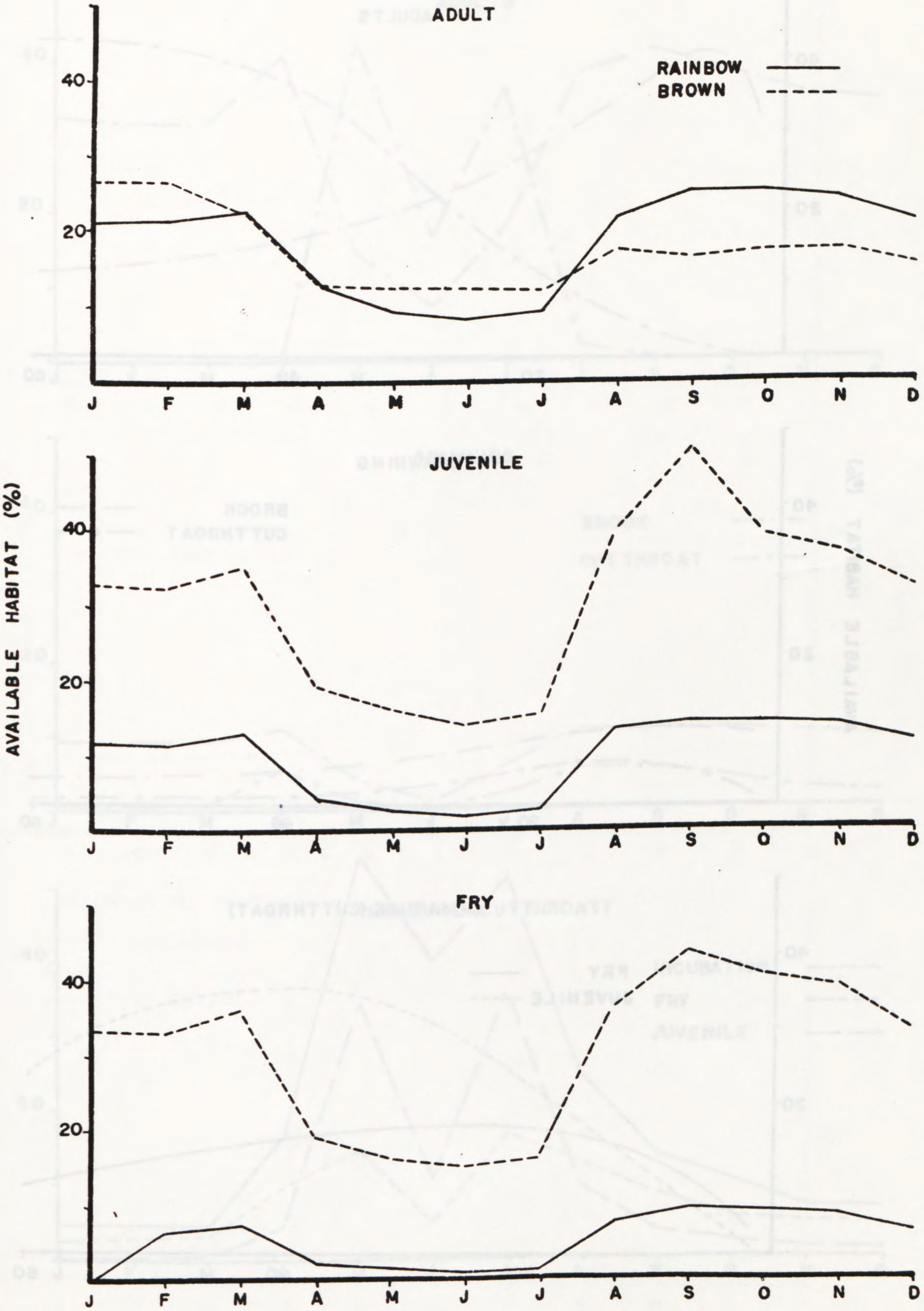


FRYINGPAN RIVER AT TAYLOR CK. BELOW RUEDI DAM
I IN 5 LOW WATER YEAR

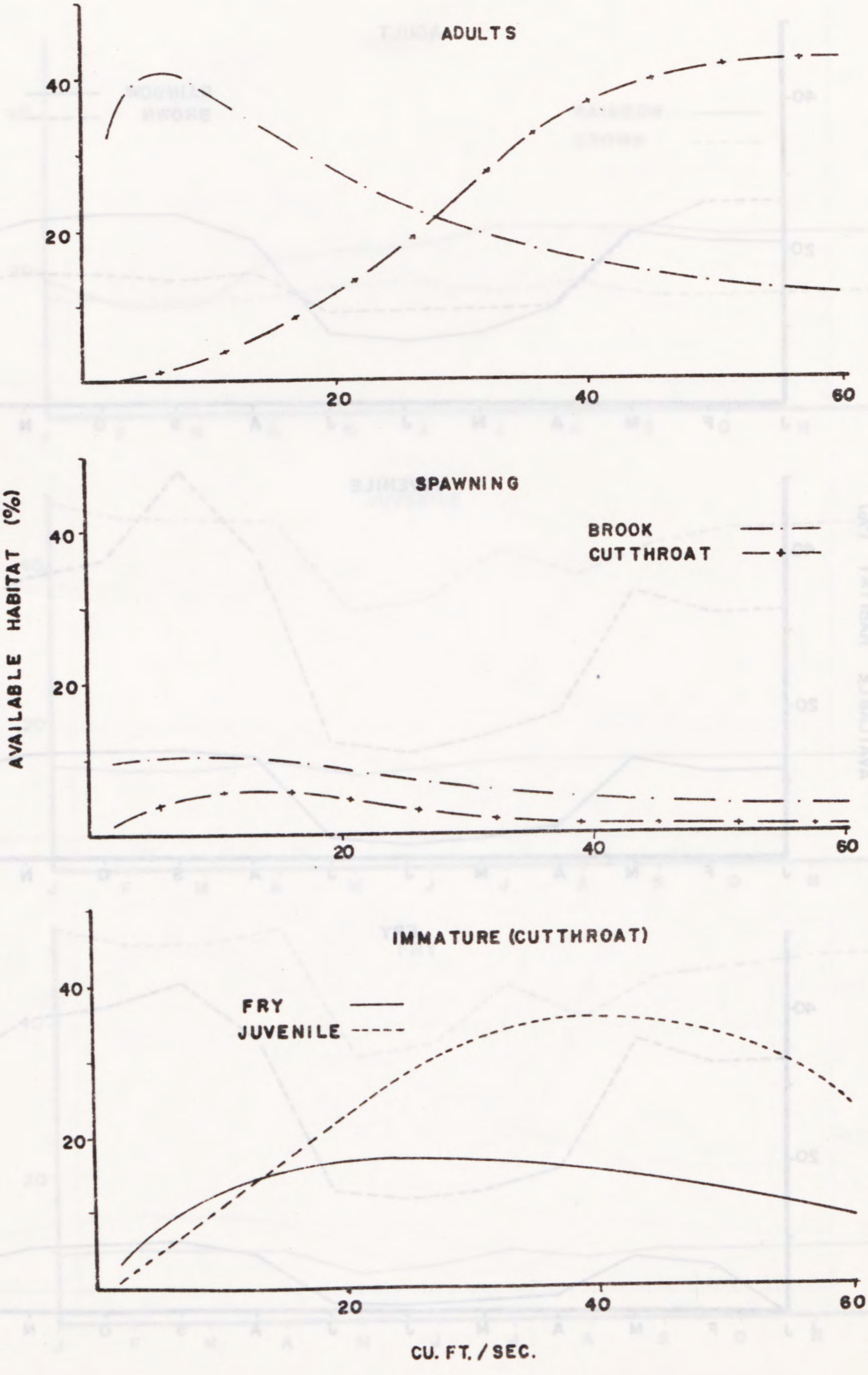


FRYINGPAN RIVER AT TAYLOR CK. BELOW RUEDI DAM

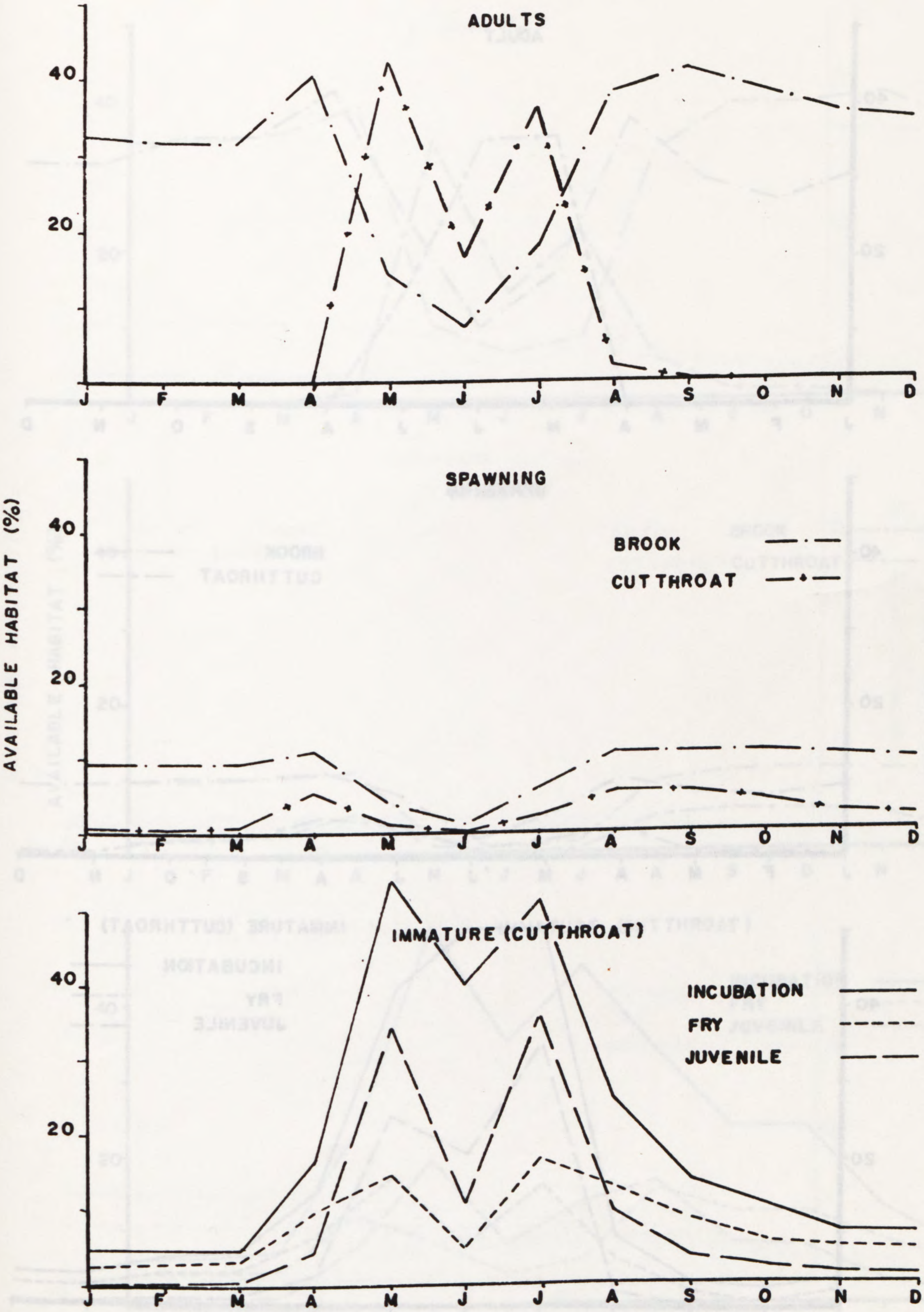
I IN 5 HIGH WATER



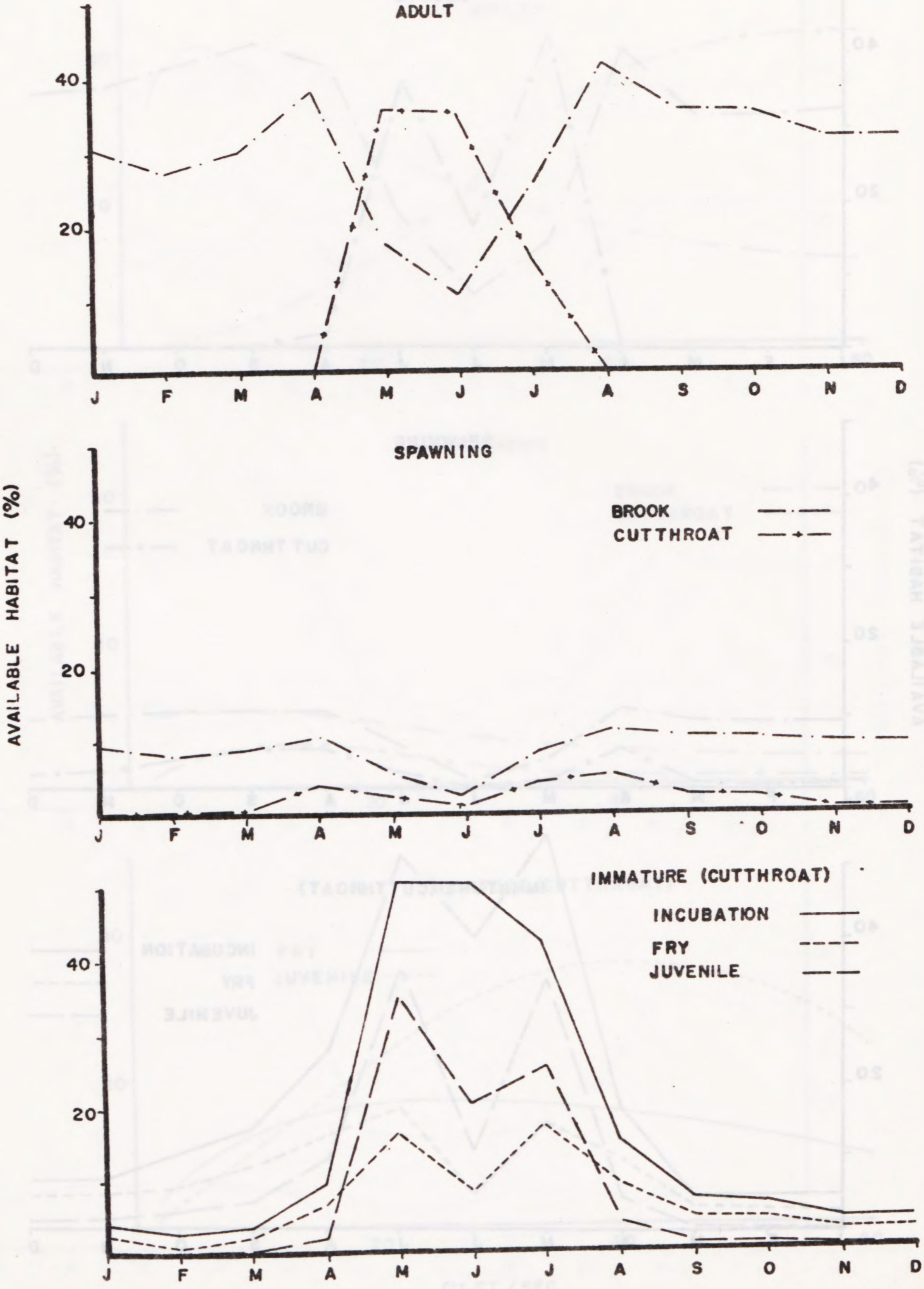
NORTH FORK OF FRYINGPAN RIVER ABOVE
CUNNINGHAM CREEK



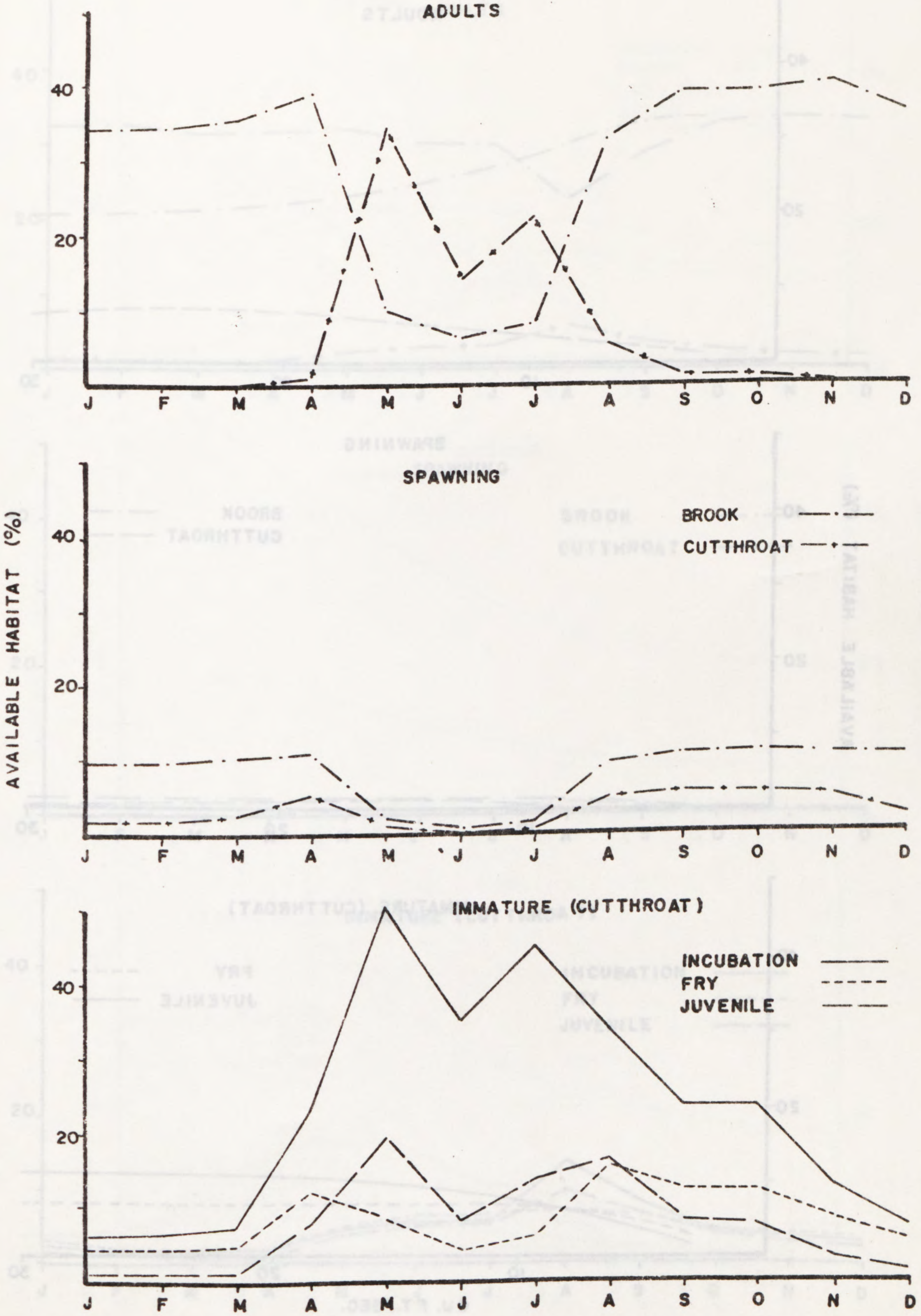
NORTH FORK OF THE FRYINGPAN
MEDIAN WATER YEAR



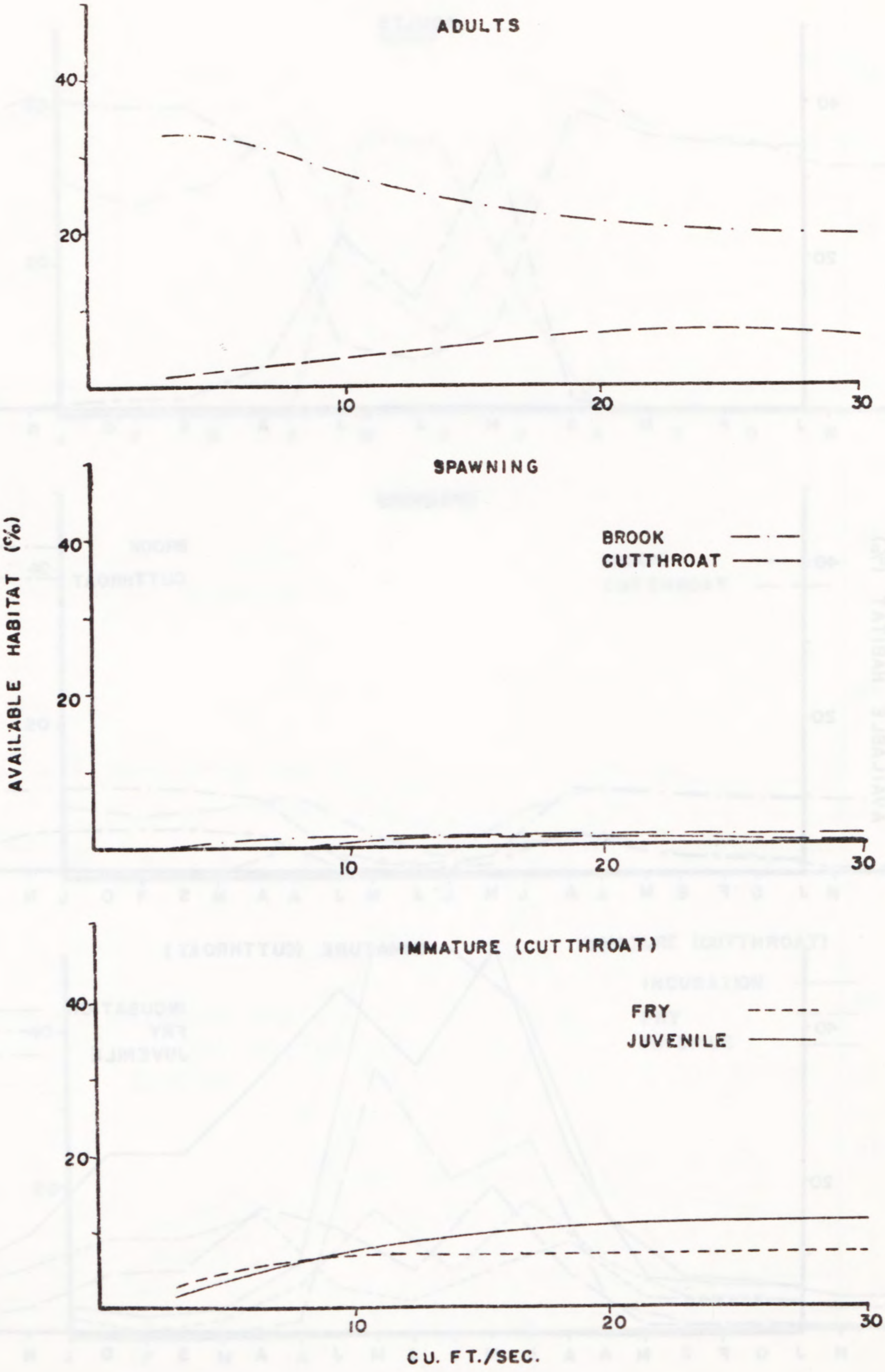
NORTH FORK FRYINGPAN RIVER
1 IN 5 LOW WATER YEAR



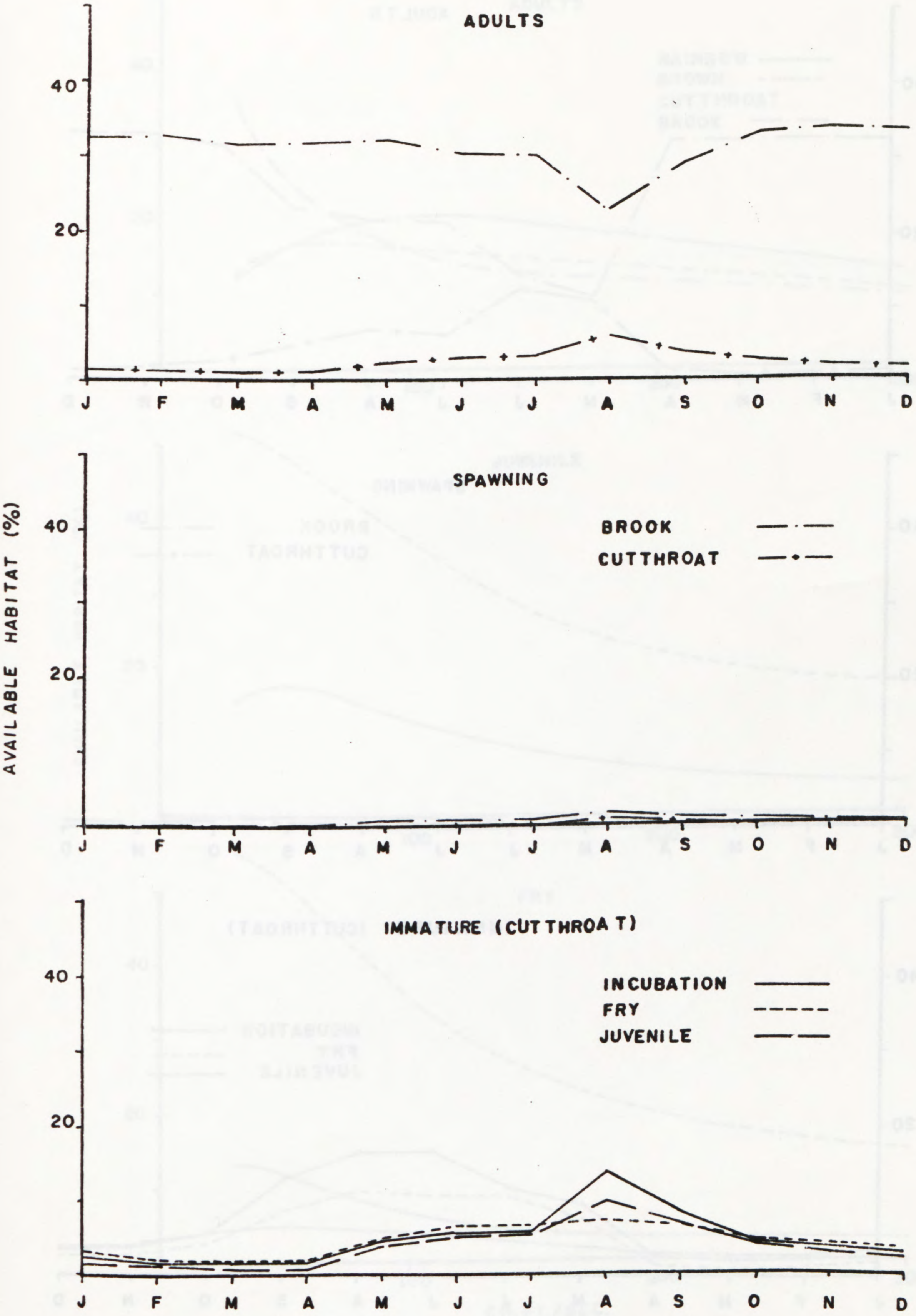
NORTH FORK FRYINGPAN RIVER
I IN 5 HIGH WATER YEAR



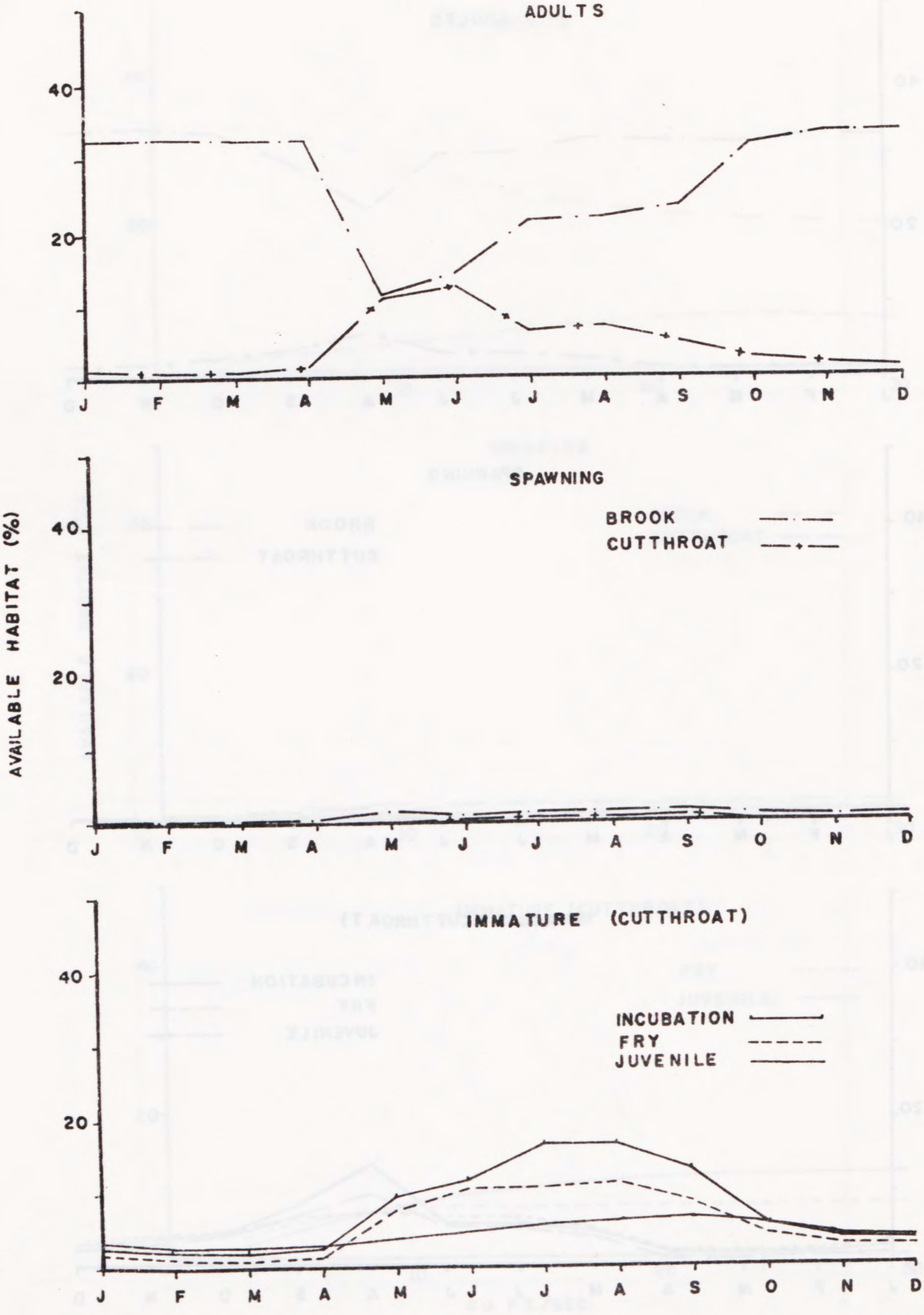
SOUTH FORK OF FRYINGPAN RIVER



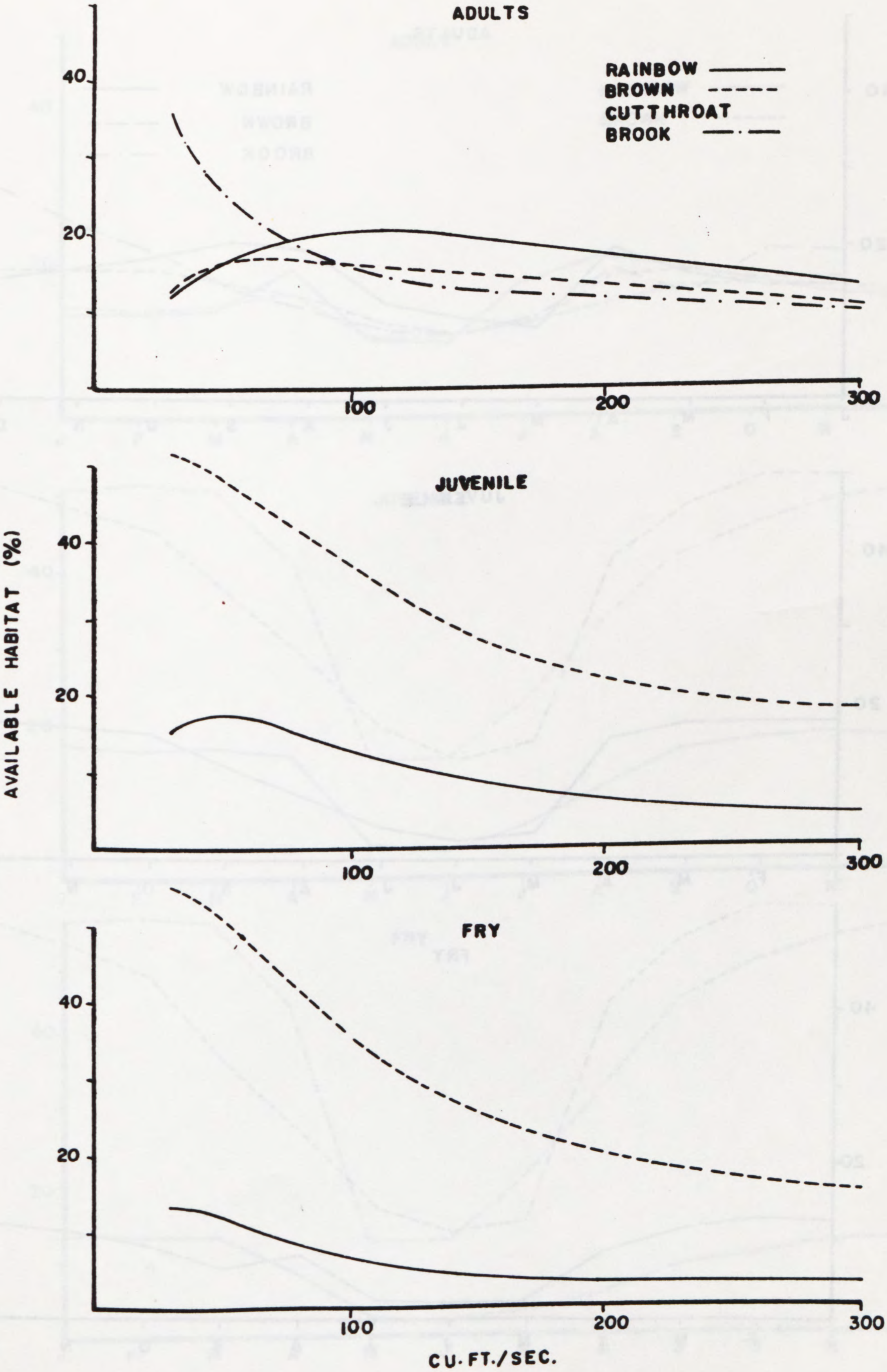
SOUTH FORK FRYINGPAN RIVER: AFTER FRYARK DIVERSION
MEDIAN WATER YEAR



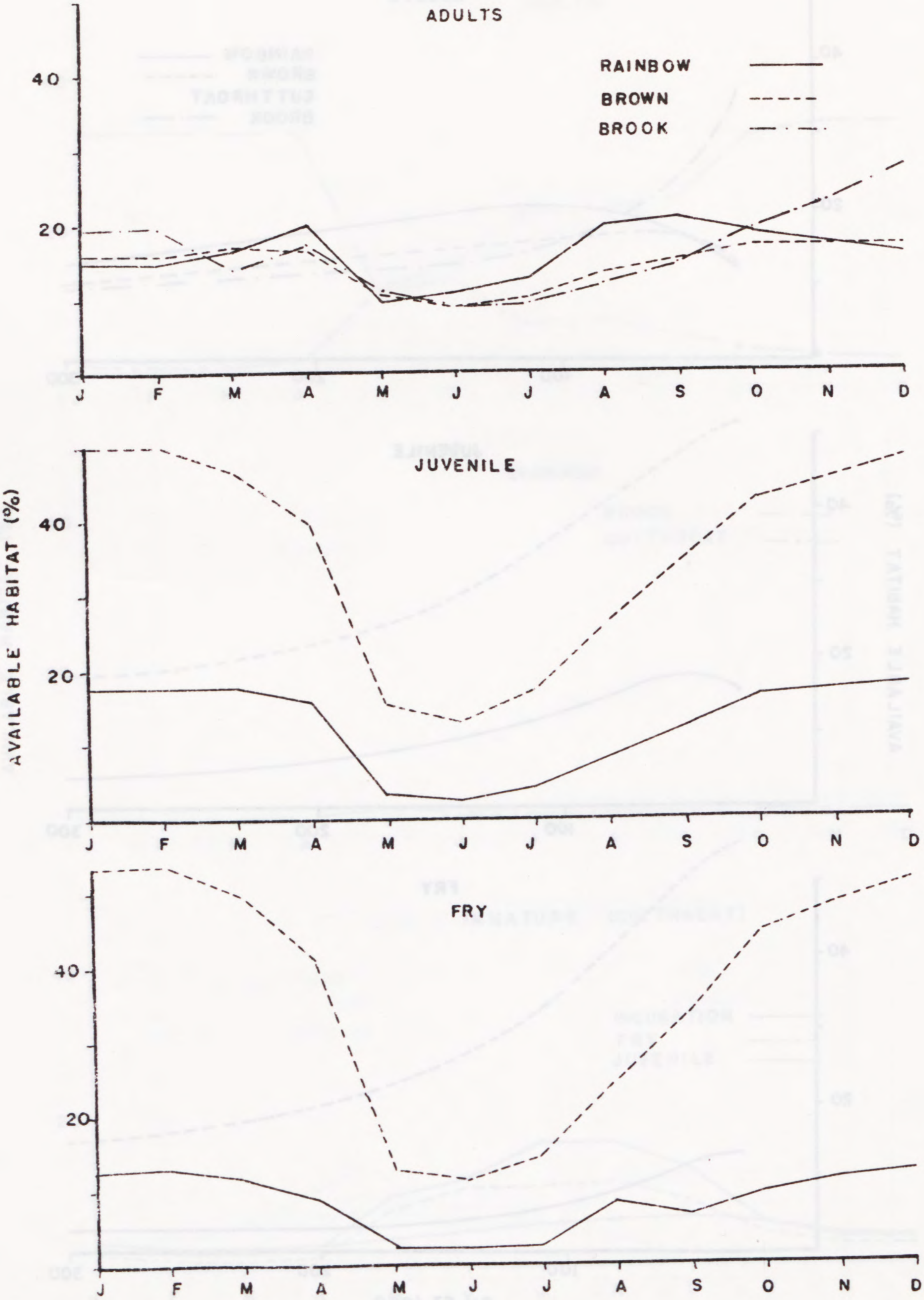
SOUTH FORK FRYINGPAN RIVER: BEFORE FRYARK DIVERSION
MEDIAN WATER YEAR



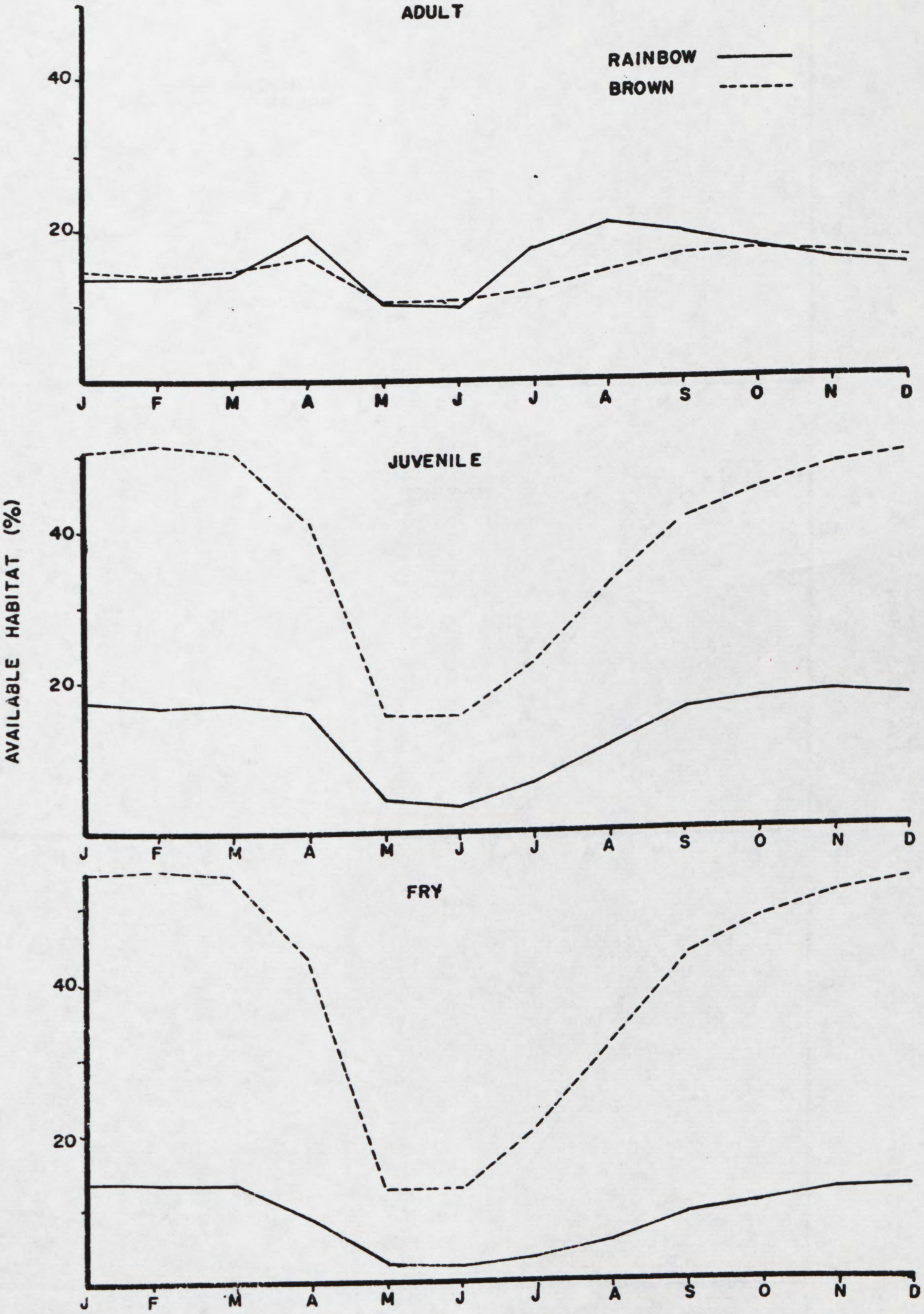
LAKE FORK OF THE GUNNISON RIVER



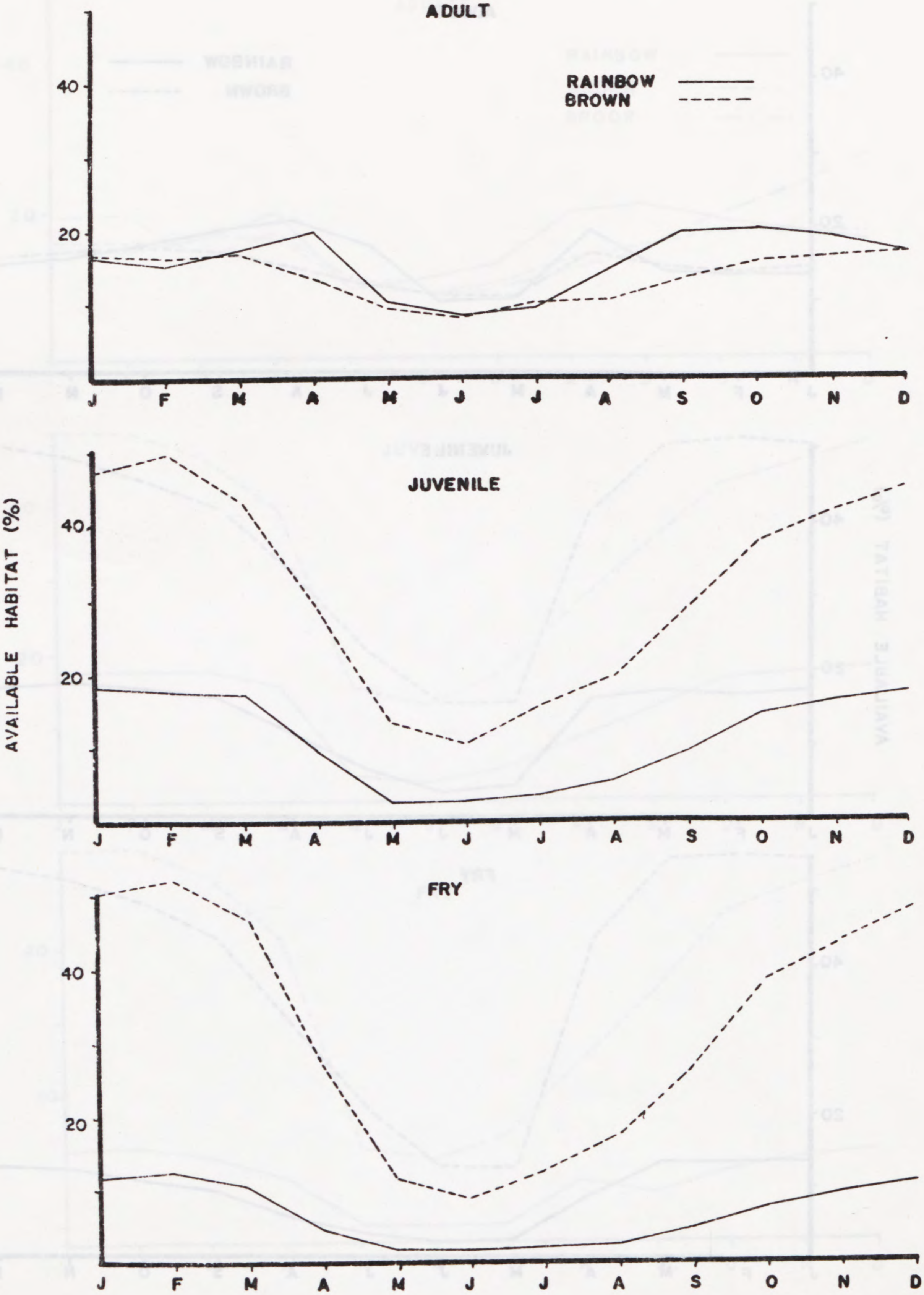
LAKE FORK OF THE GUNNISON
MEDIAN WATER YEAR



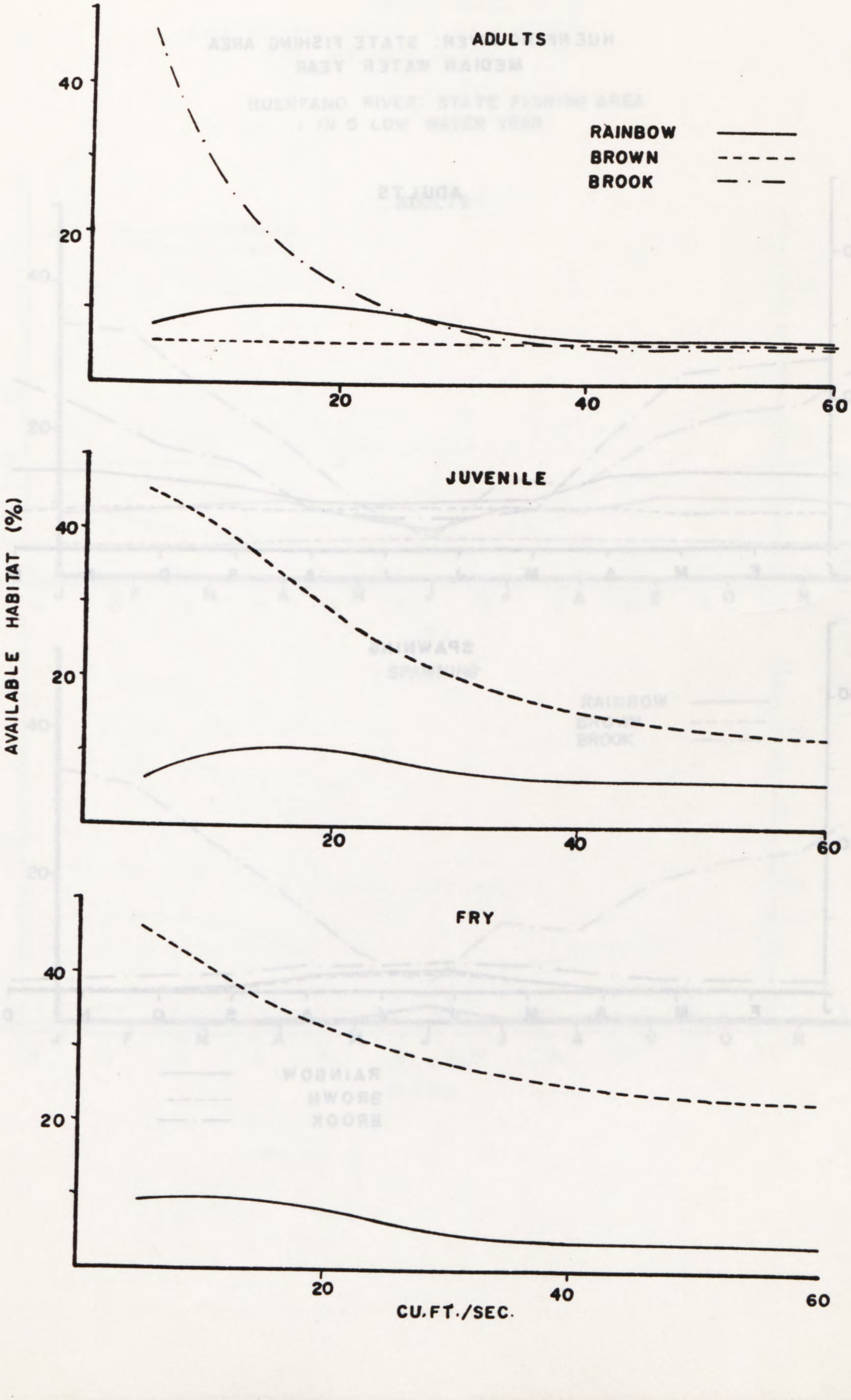
LAKE FORK GUNNISON RIVER
I IN 5 LOW WATER YEAR



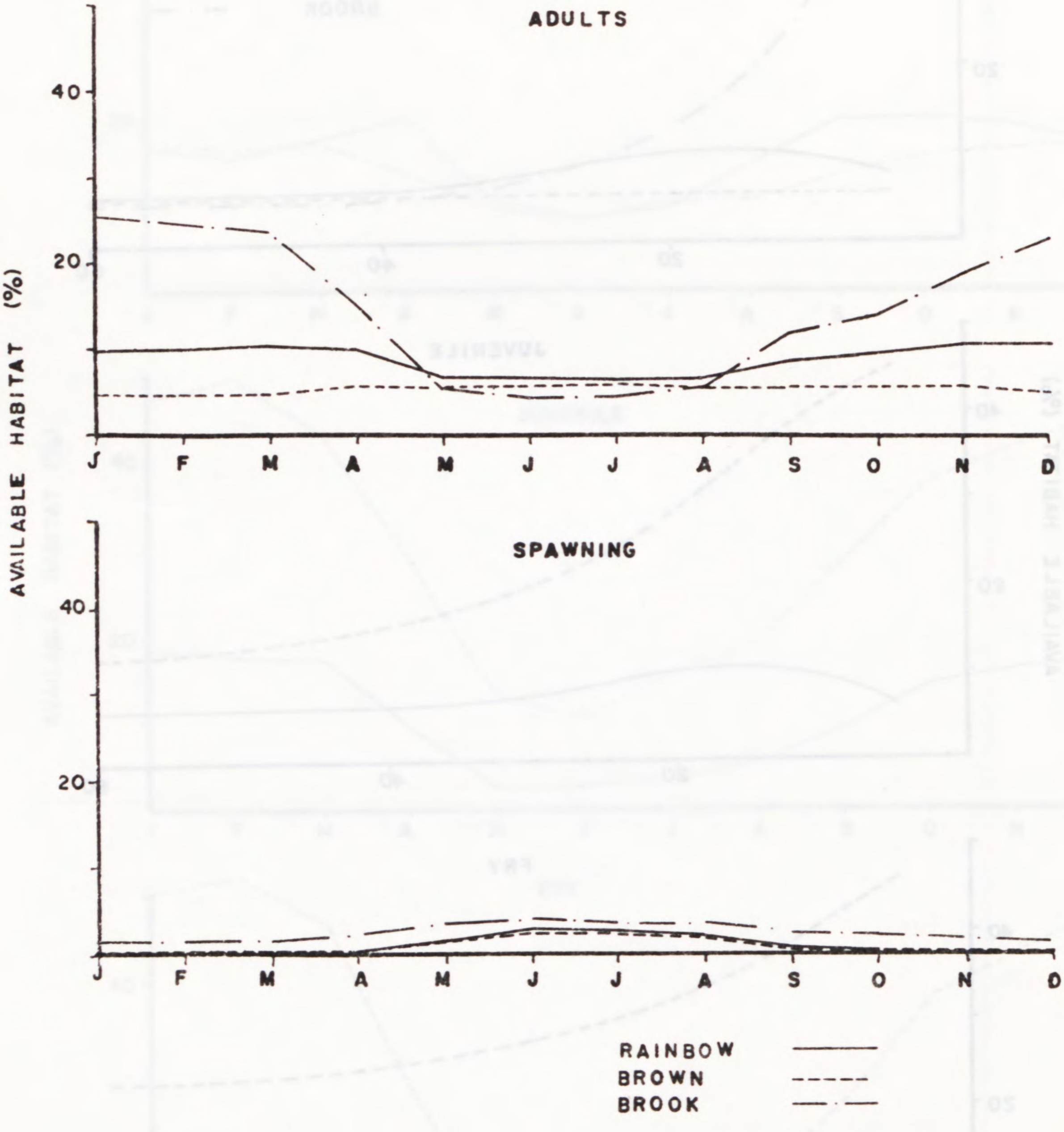
LAKE FORK OF GUNNISON RIVER
I IN 5 HIGH WATER YEAR



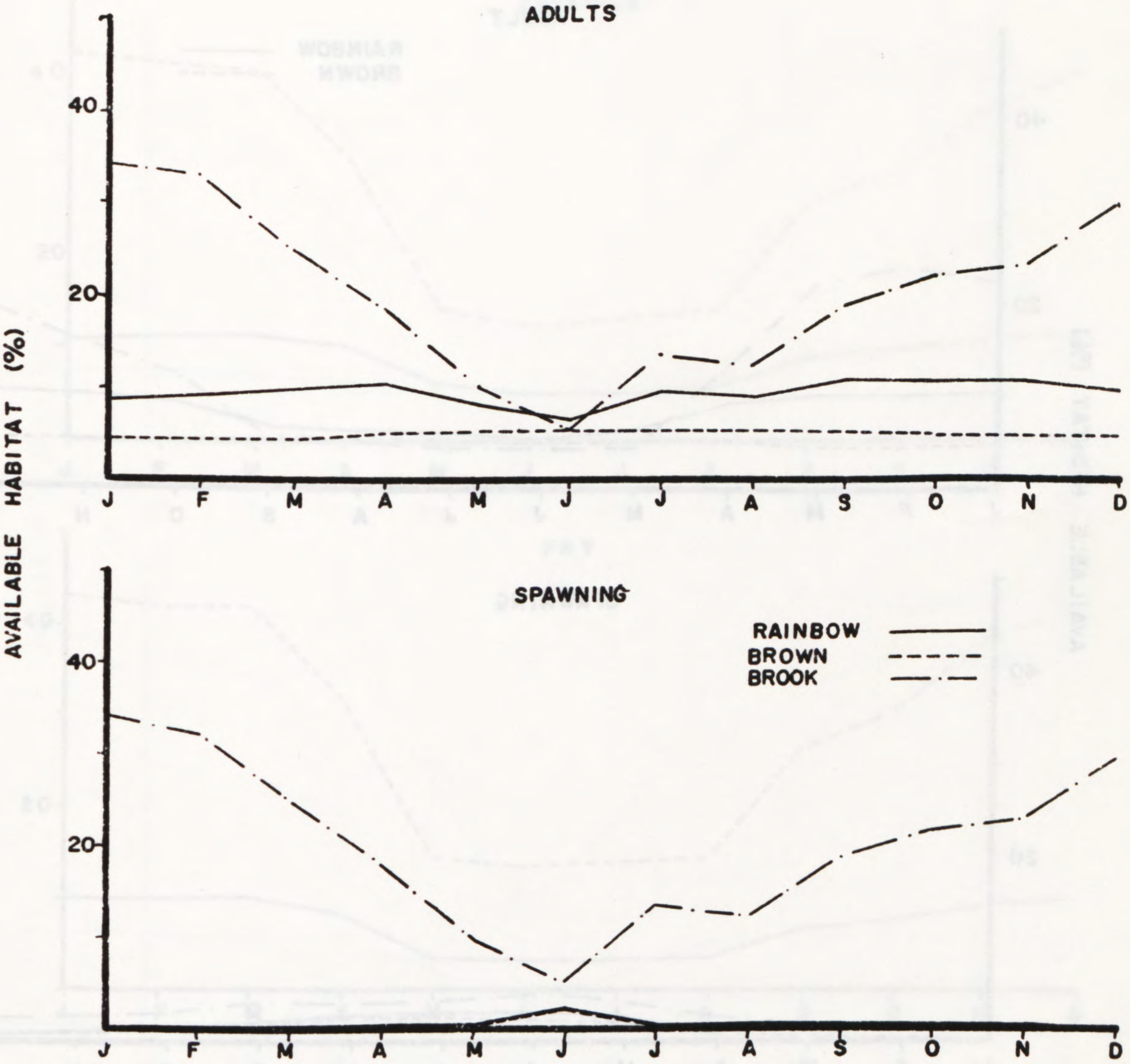
HUERFANO RIVER: STATE FISHING PROPERTY



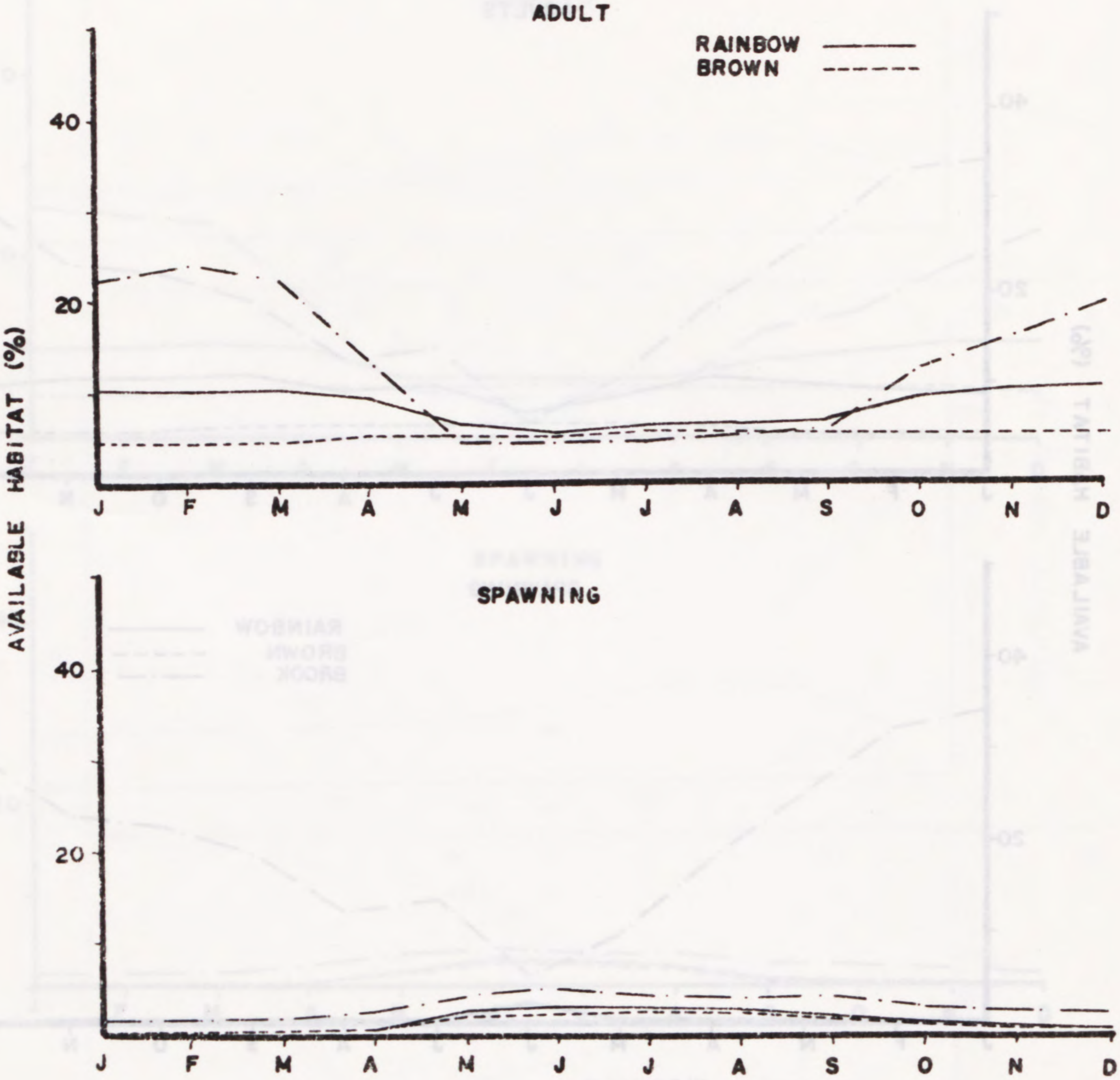
HUERFANO RIVER: STATE FISHING AREA
MEDIAN WATER YEAR



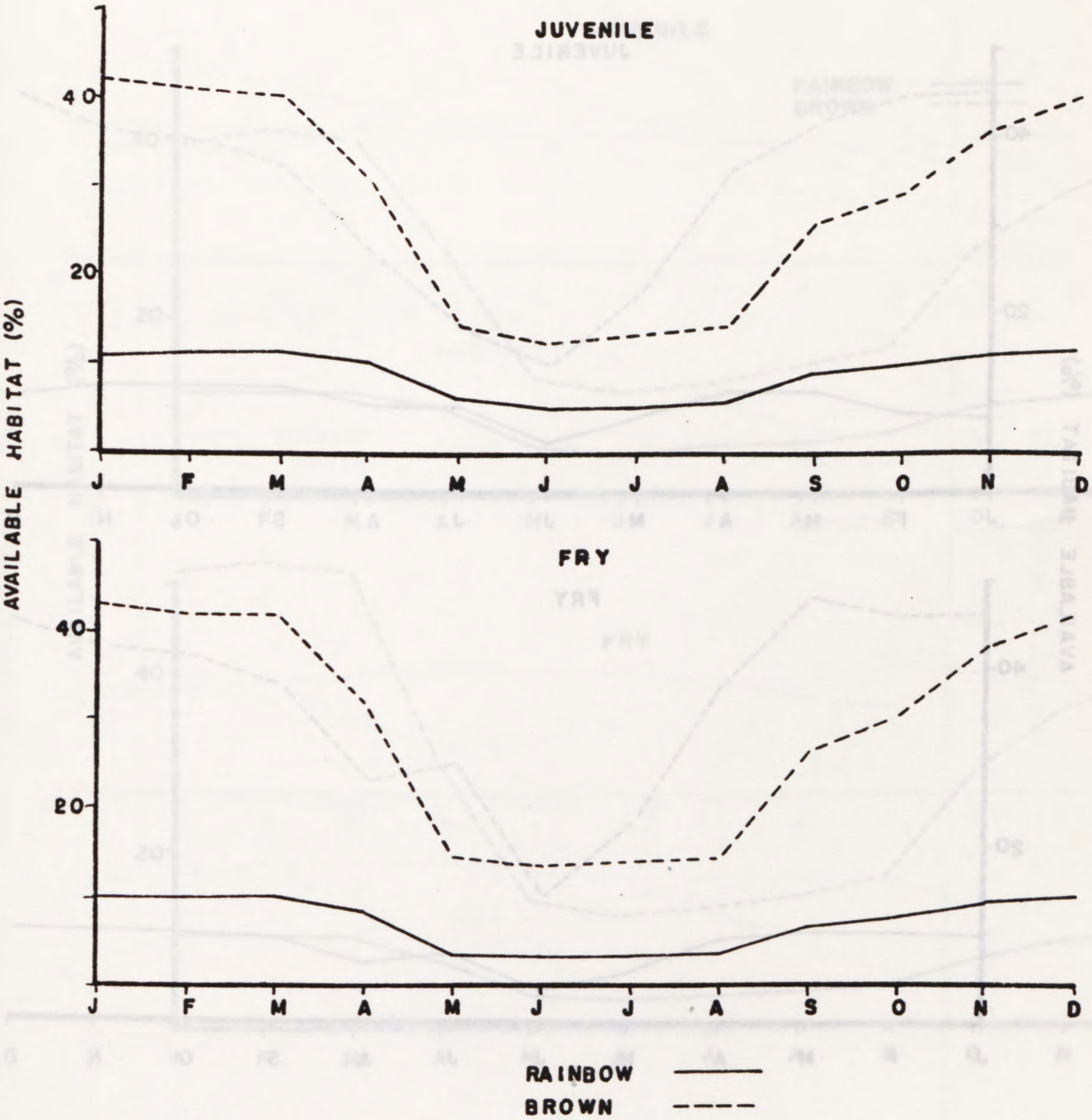
HUERFANO RIVER: STATE FISHING AREA
I IN 5 LOW WATER YEAR



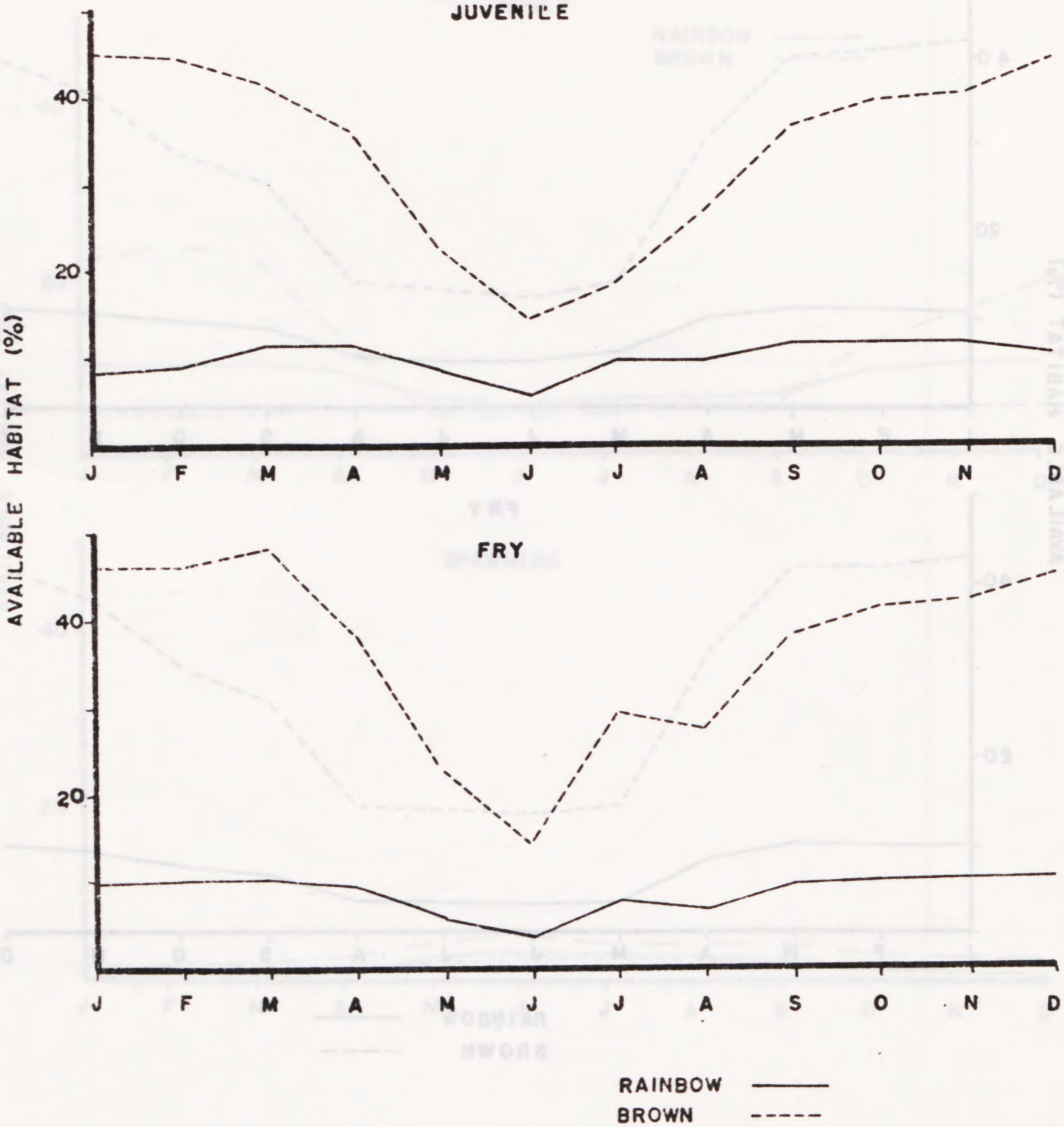
HUERFANO RIVER: STATE FISHING AREA
I IN 5 HIGH WATER YEAR



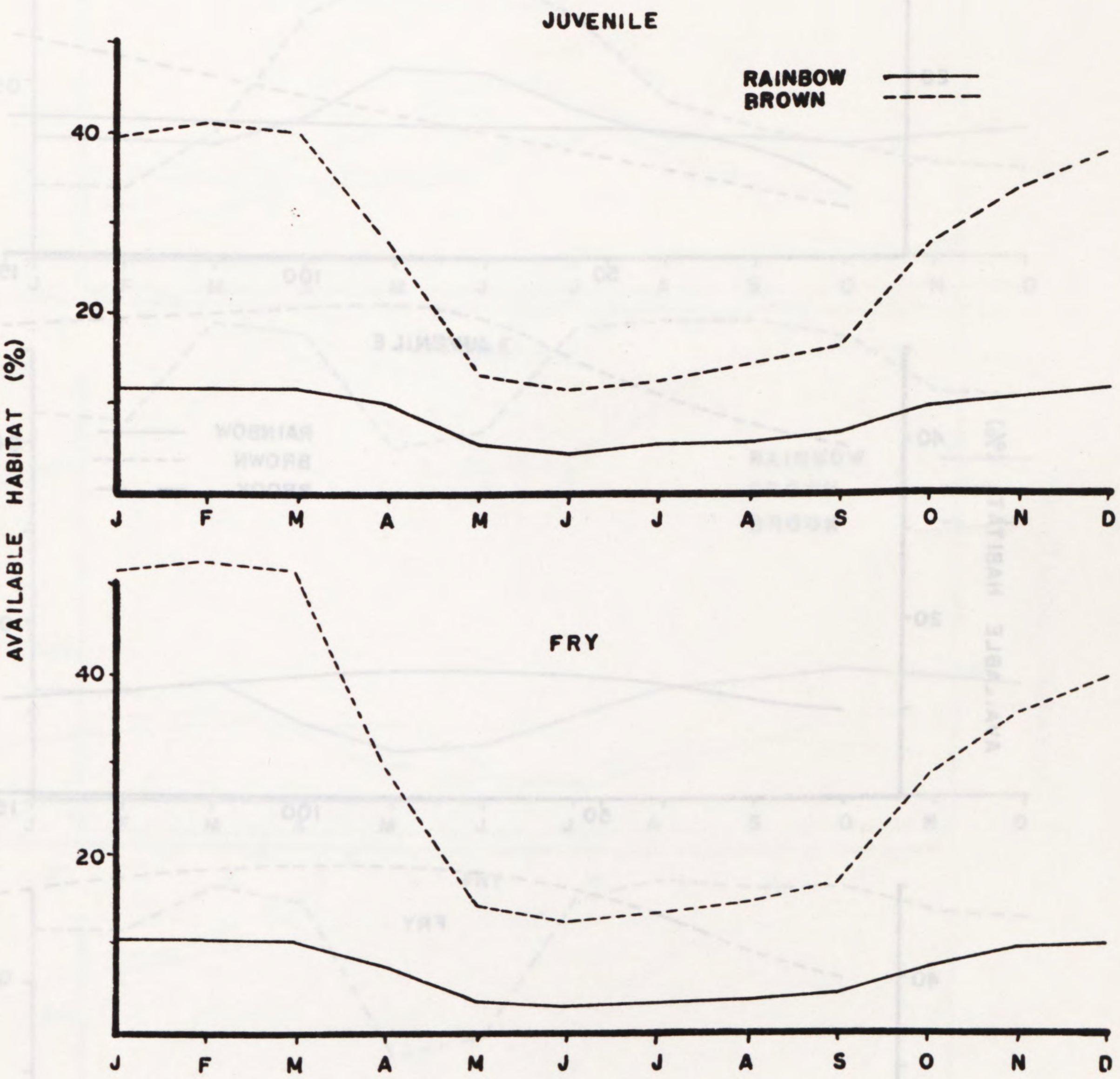
HUERFANO RIVER: STATE FISHING AREA
MEDIAN WATER YEAR



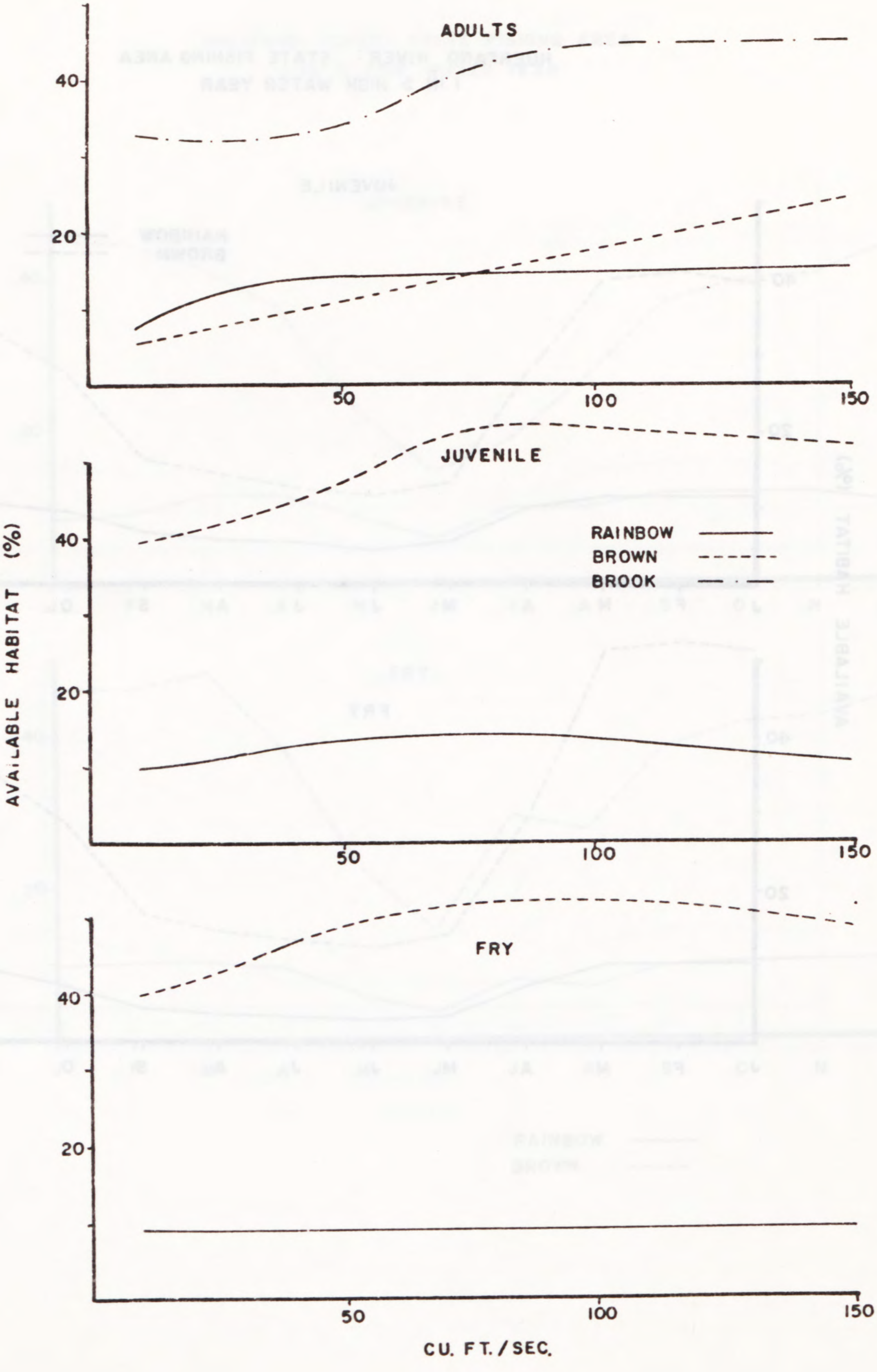
HUERFANO RIVER: STATE FISHING AREA
1 IN 5 LOW WATER YEAR



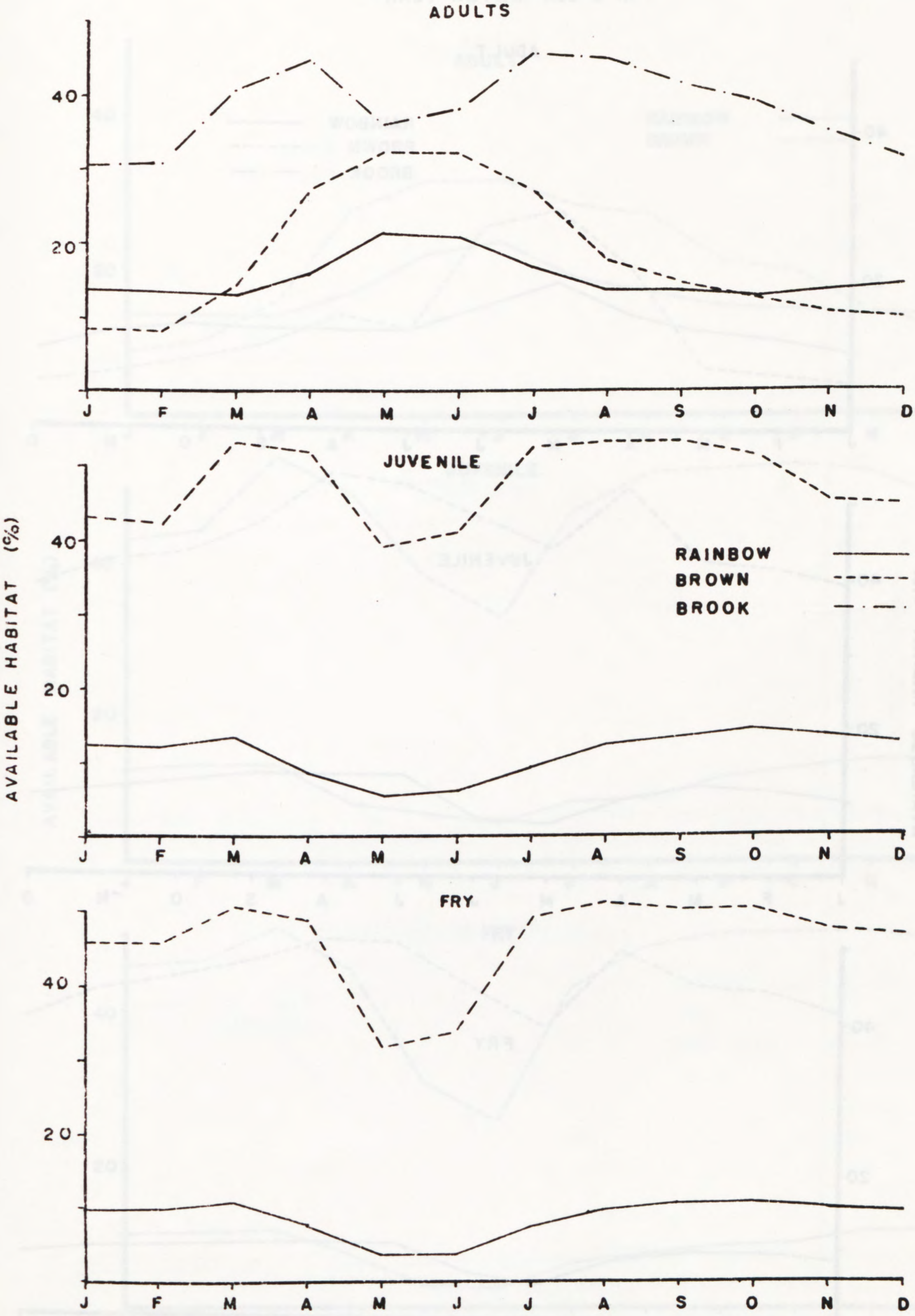
HUERFANO RIVER: STATE FISHING AREA
I IN 5 HIGH WATER YEAR



SOUTH FORK RIO GRANDE



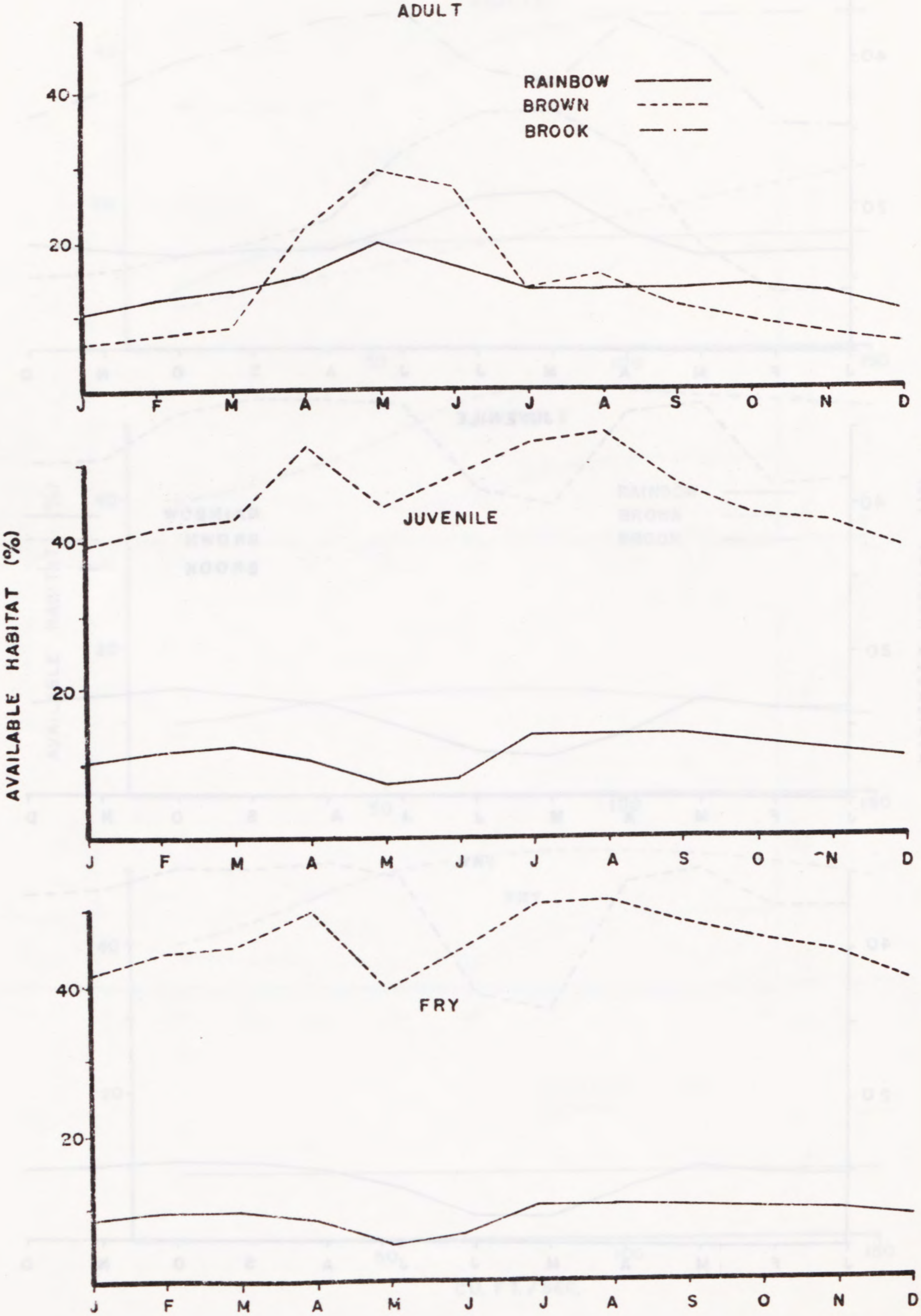
SOUTH FORK OF THE RIO GRANDE
MEDIAN WATER YEAR


ADULTS

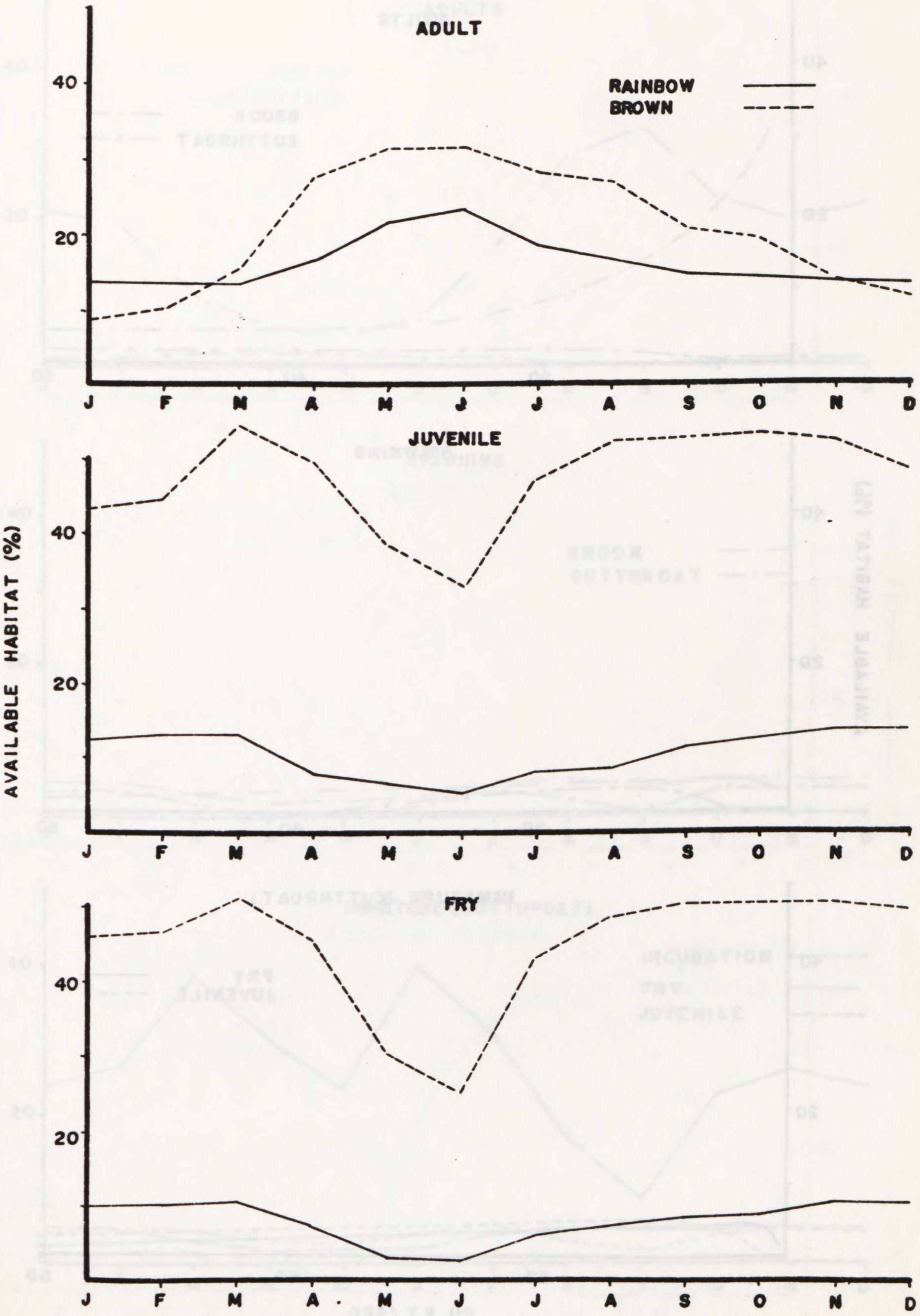
JUVENILE

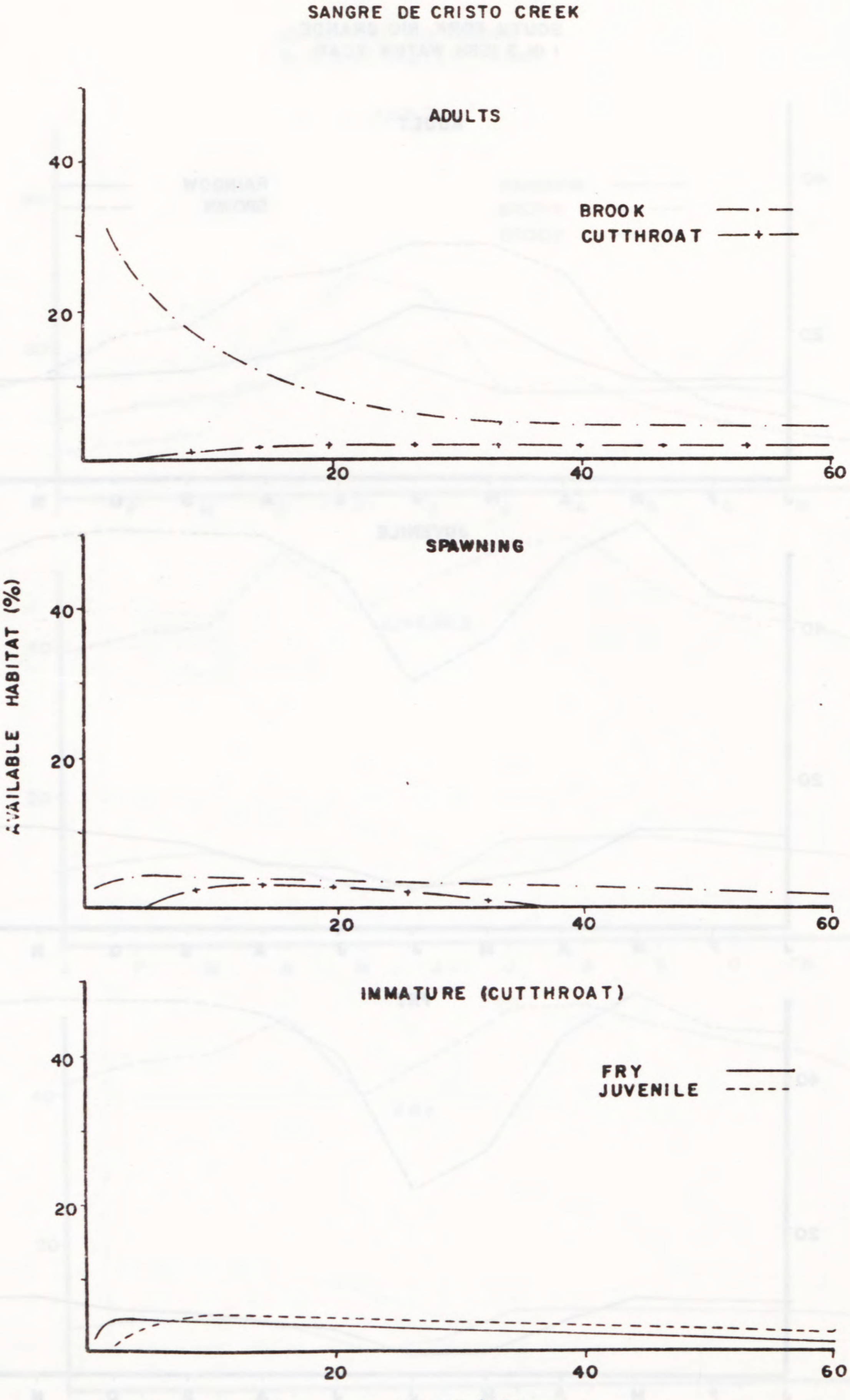
FRY

SOUTH FORK RIO GRANDE
I IN 5 LOW WATER YEAR

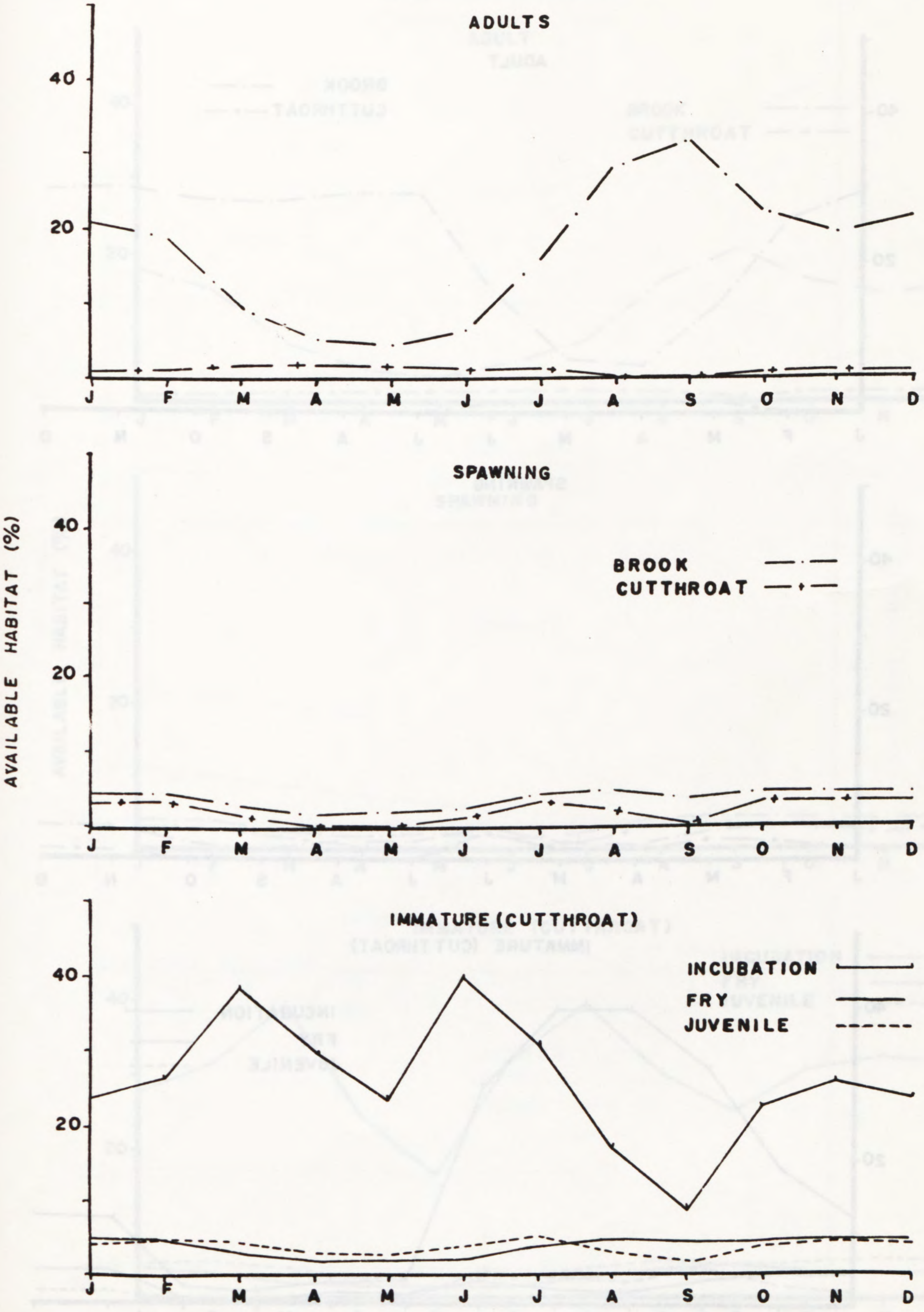


SOUTH FORK RIO GRANDE
I IN 5 HIGH WATER YEAR

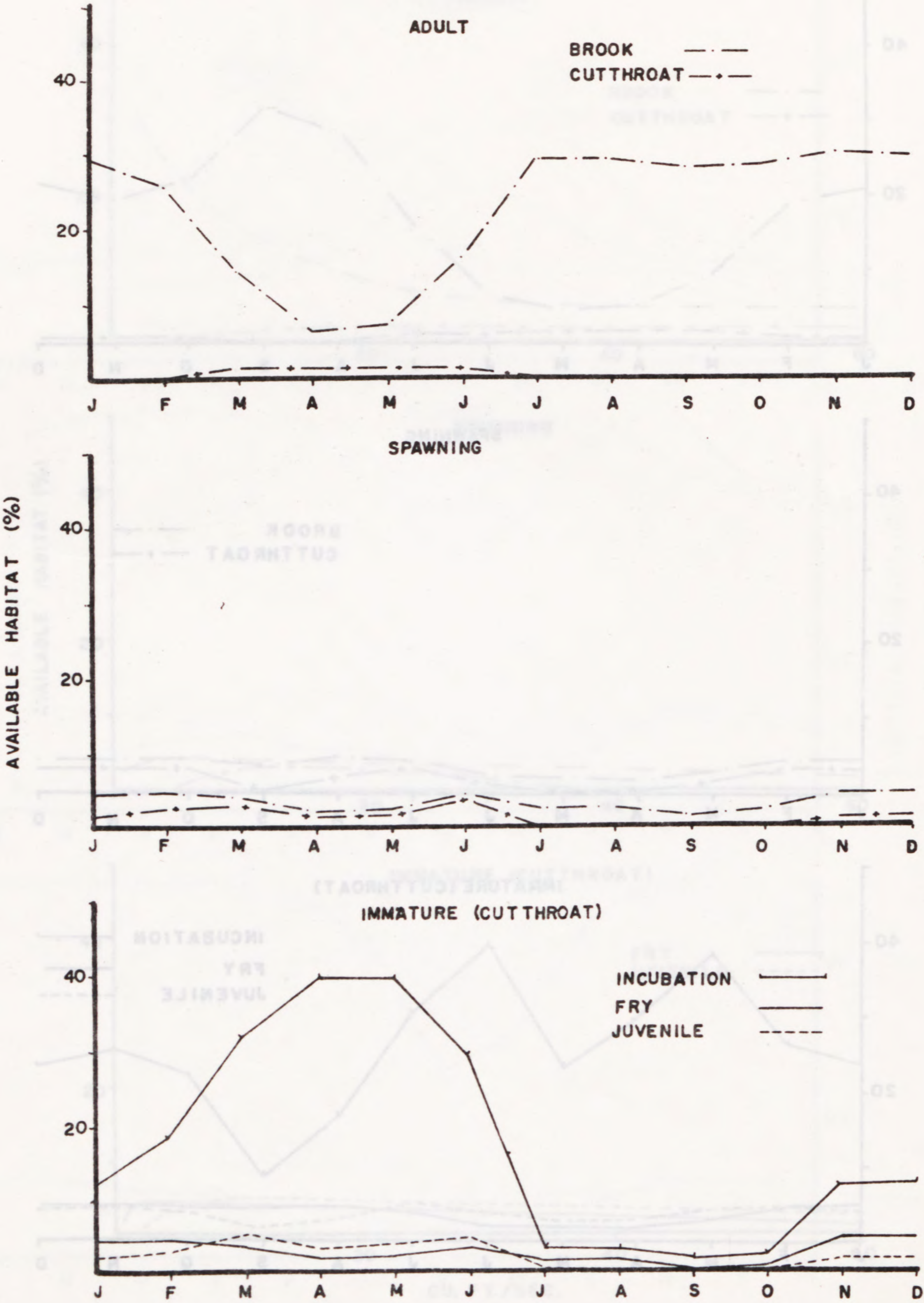



SANGRE DE CRISTO CREEK
ADULTS
40
20
BROOK
CUTTHROAT
20
40
60
SPAWNING
AVAILABLE HABITAT (%)
40
20
20
40
60
IMMATURE (CUTTHROAT)
40
20
FRY
JUVENILE
20
40
60
CU. FT./SEC.

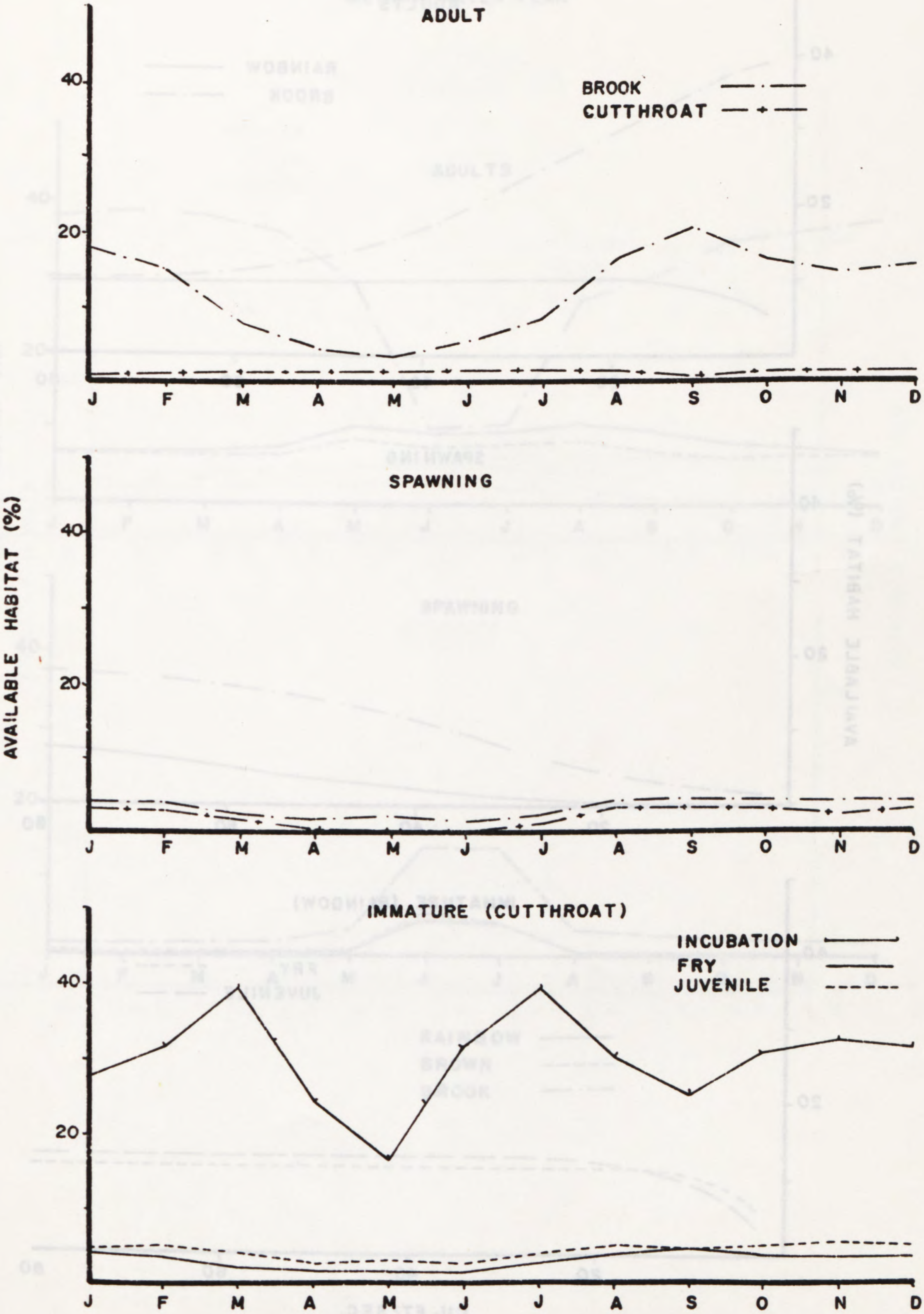
SANGREDE CRISTO CREEK
MEDIAN WATER YEAR



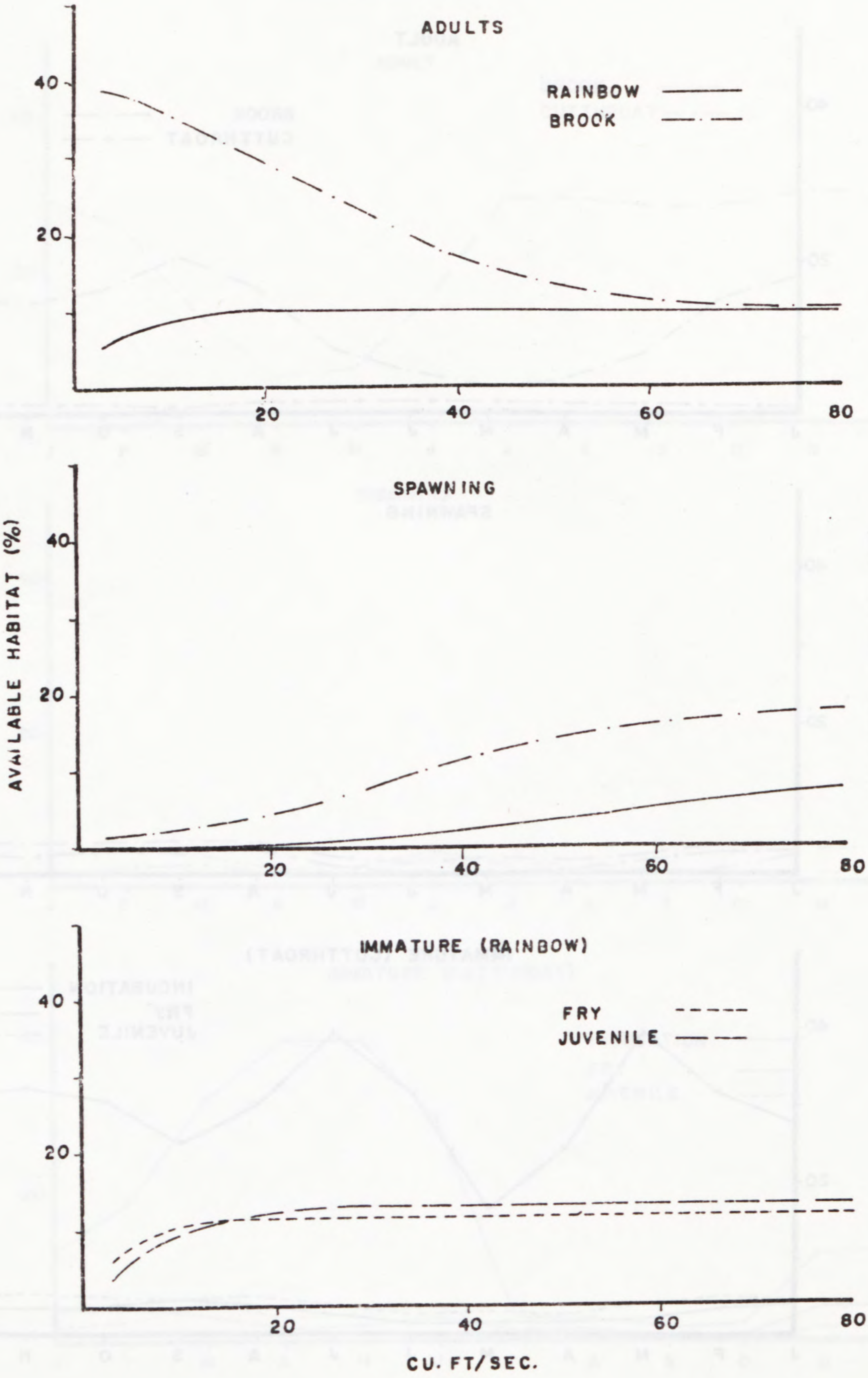
SANGRE DE CRISTO CREEK
I IN 5 LOW WATER YEAR



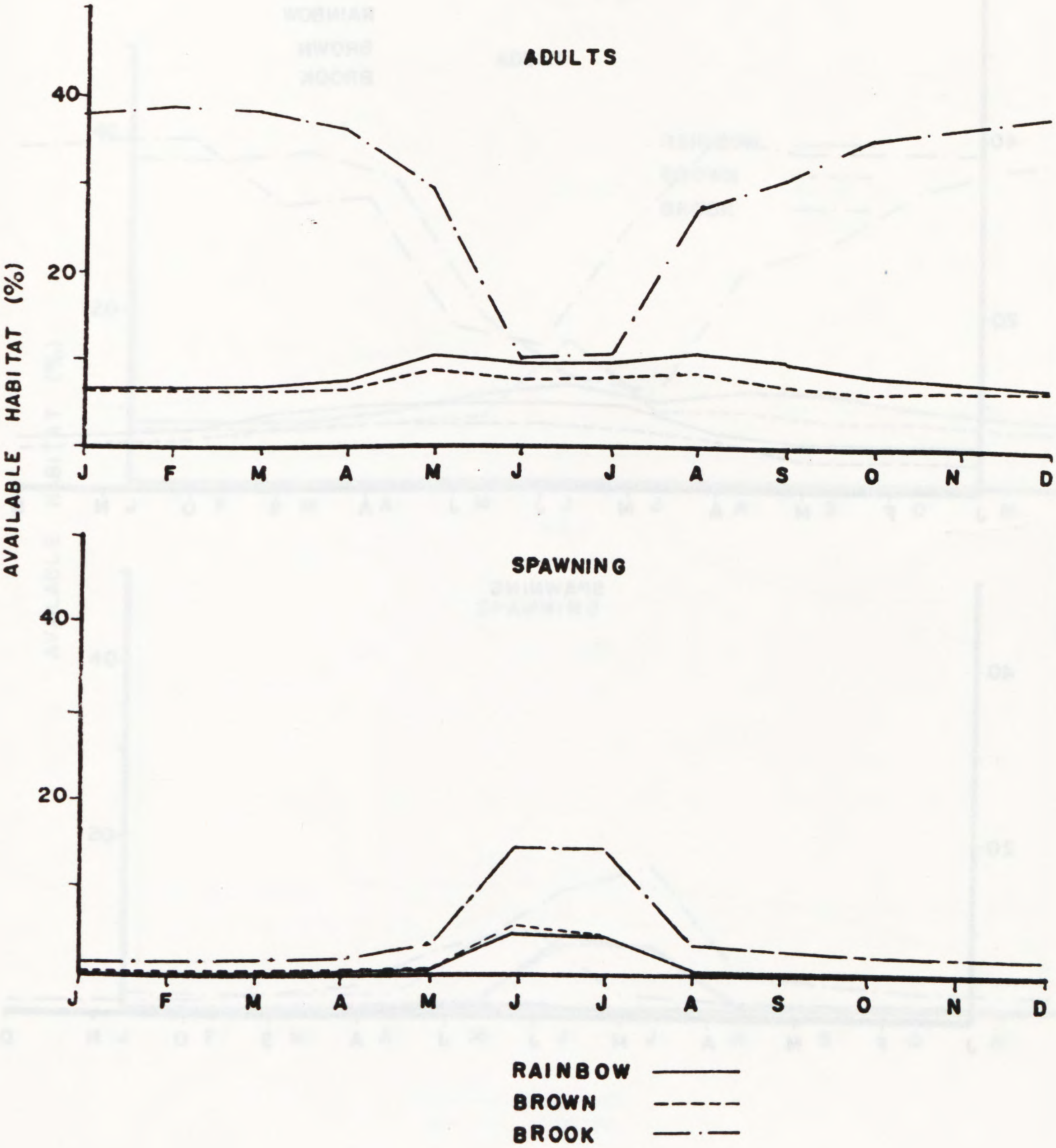
SANGRE DE CRISTO CREEK
1 IN 5 HIGH WATER YEAR



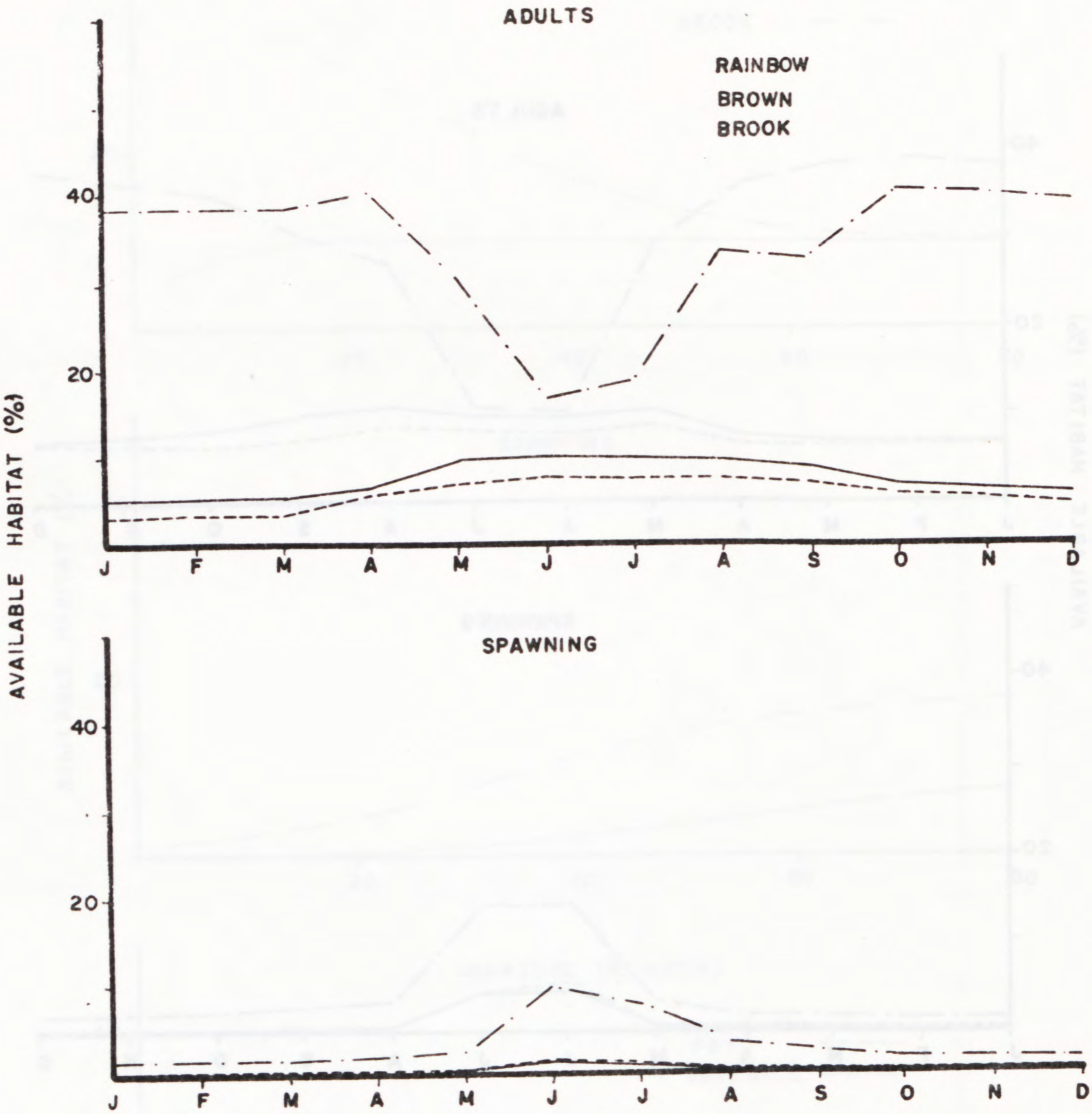
ST. LOUIS CREEK



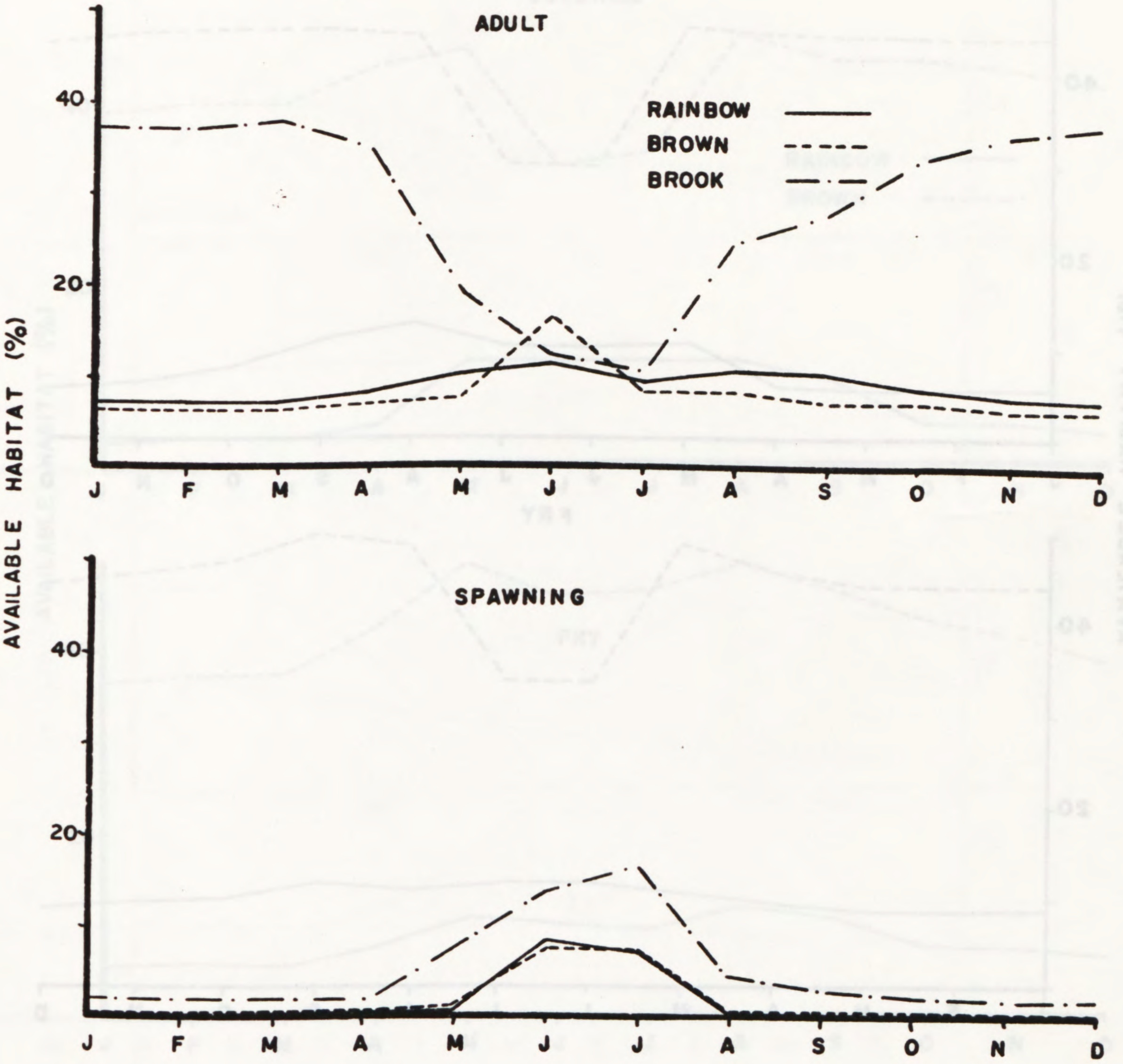
ST. LOUIS CREEK
MEDIAN WATER YEAR



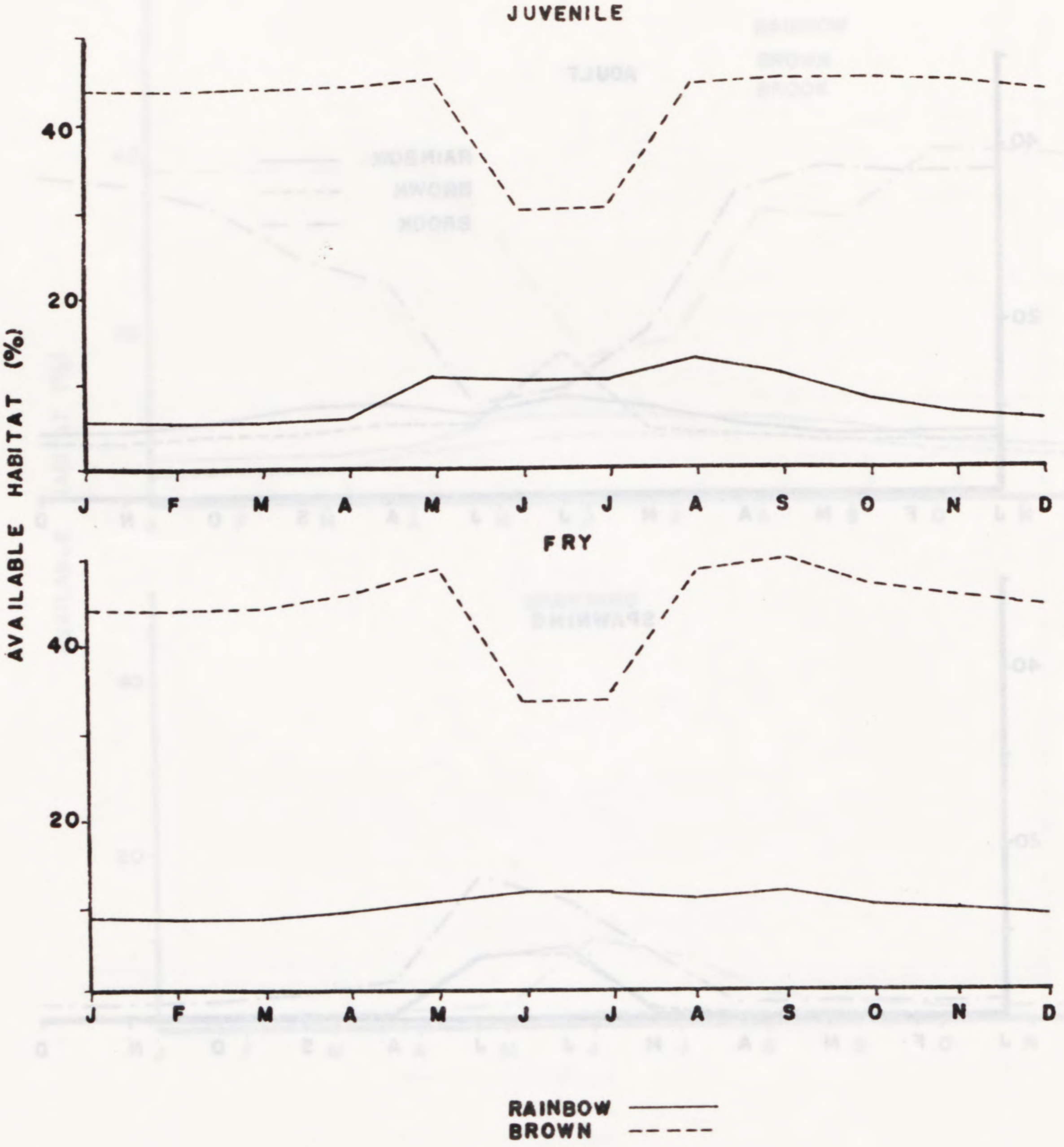
ST. LOUIS CREEK
I IN 5 LOW WATER YEAR



ST. LOUIS CREEK
1 IN 5 HIGH WATER YEAR

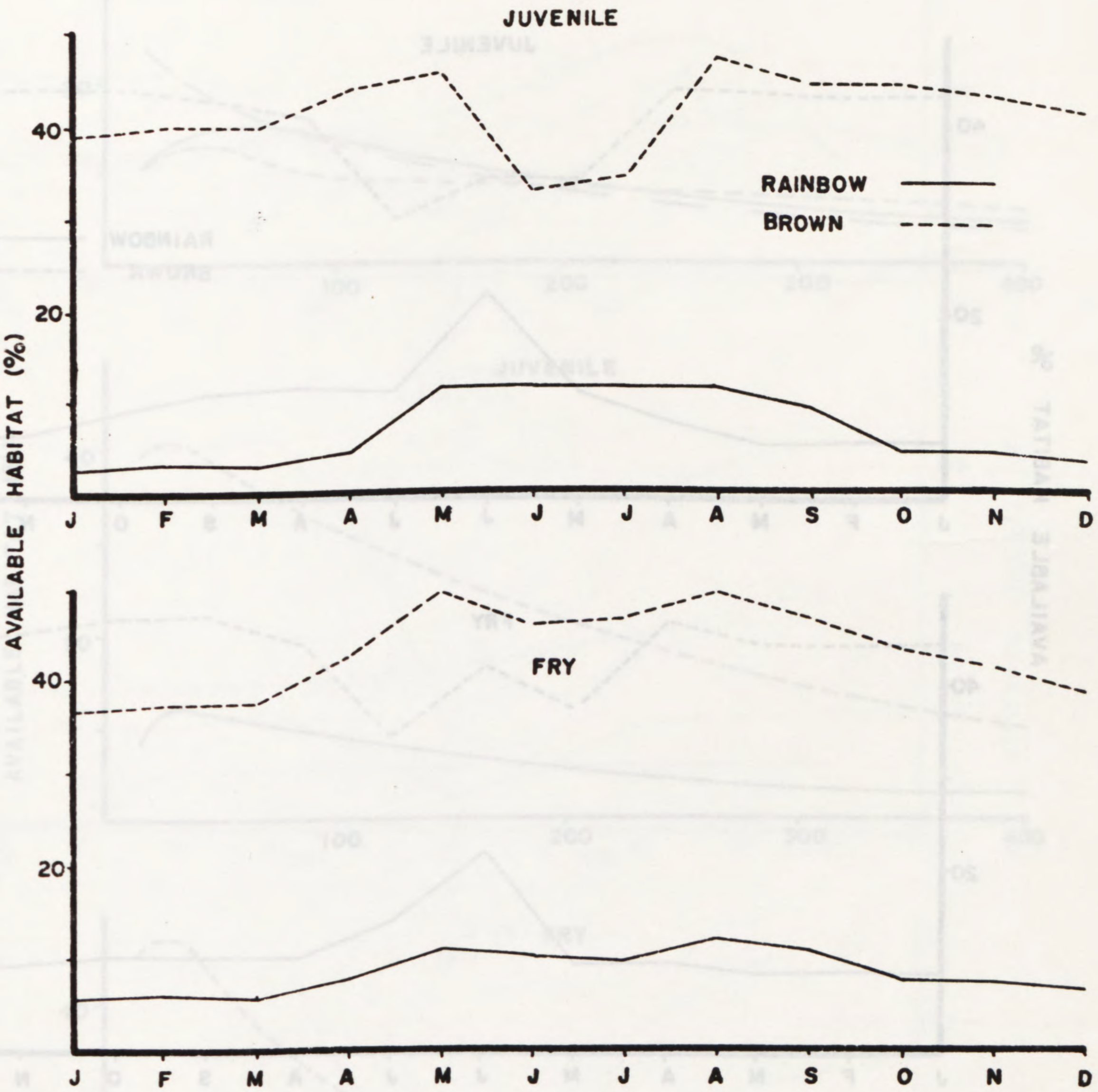


ST. LOUIS CREEK
MEDIAN WATER YEAR

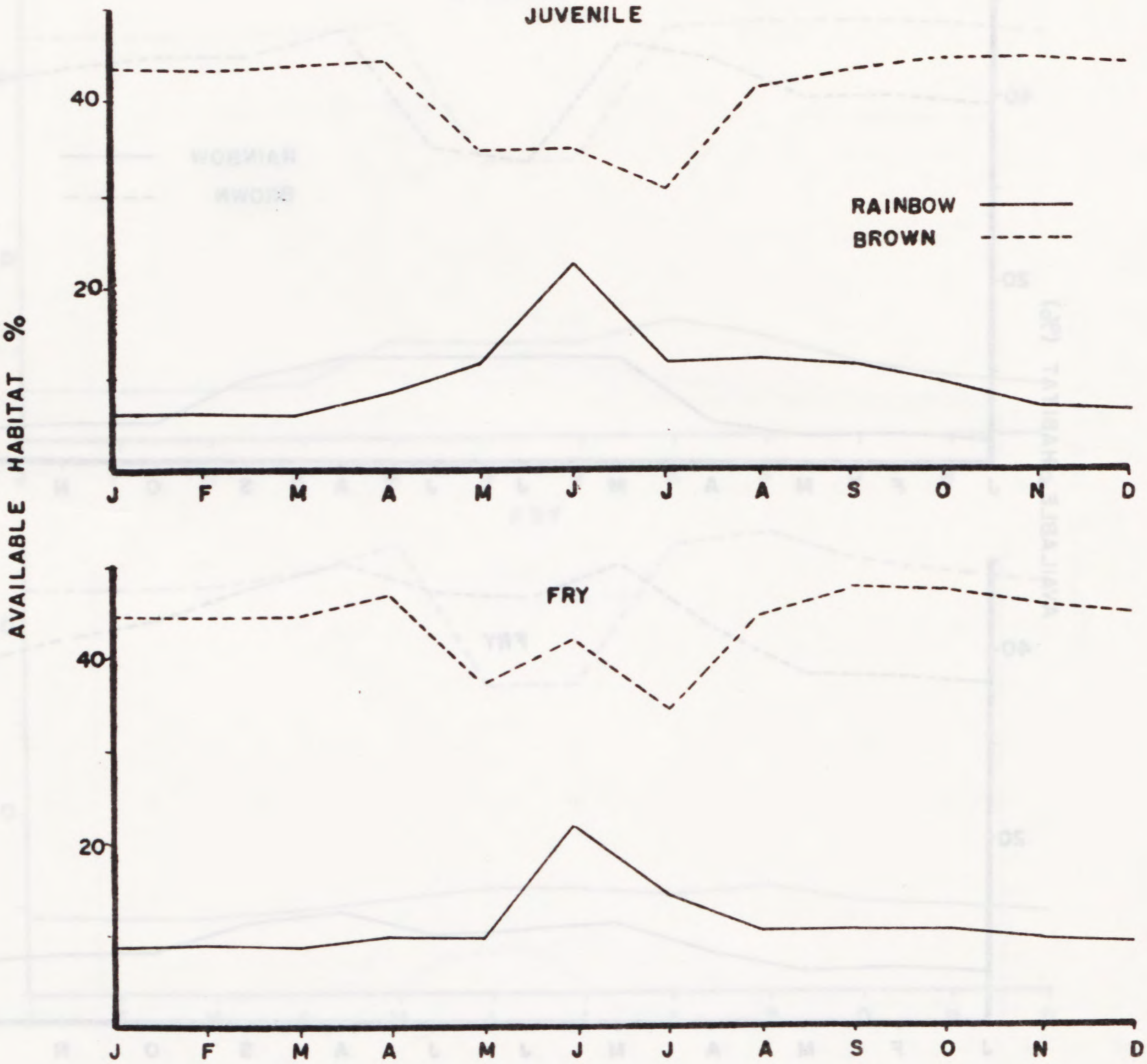


ST. LOUIS CREEK

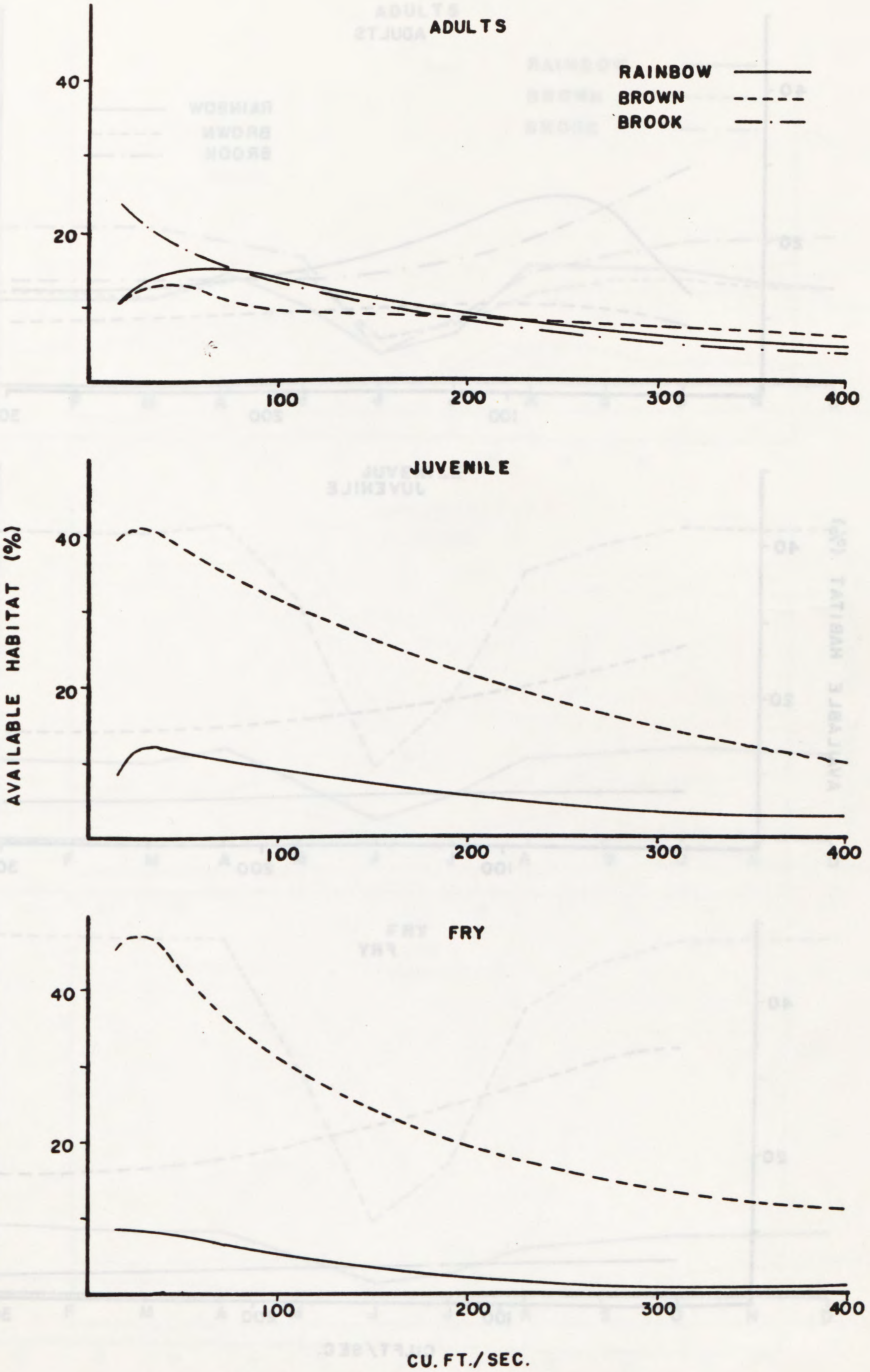
1 IN 5 LOW WATER YEAR



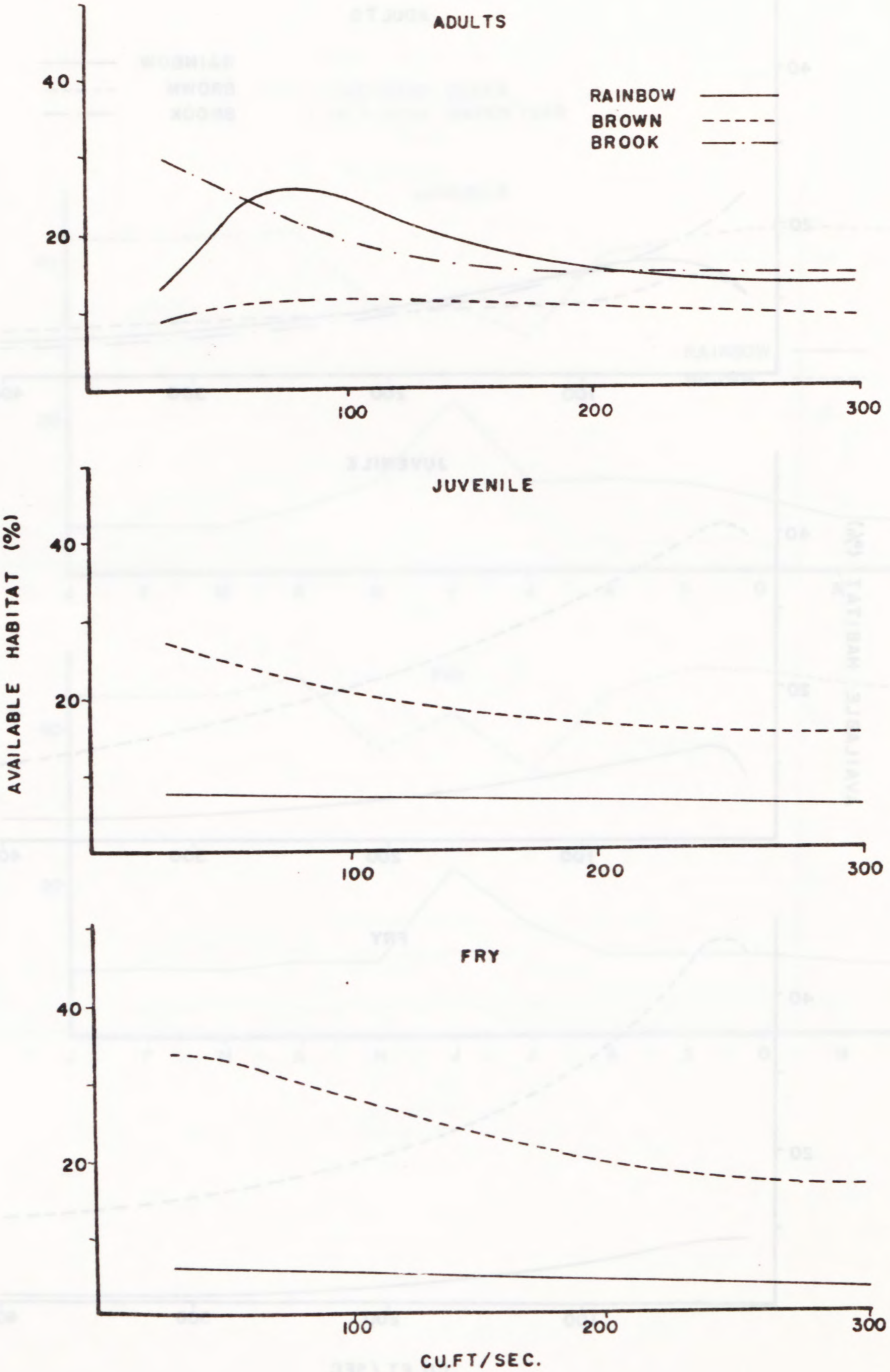
ST. LOUIS CREEK
1 IN 5 HIGH WATER YEAR



WILLIAMS FORK: I MI. BELOW KINNEY CREEK

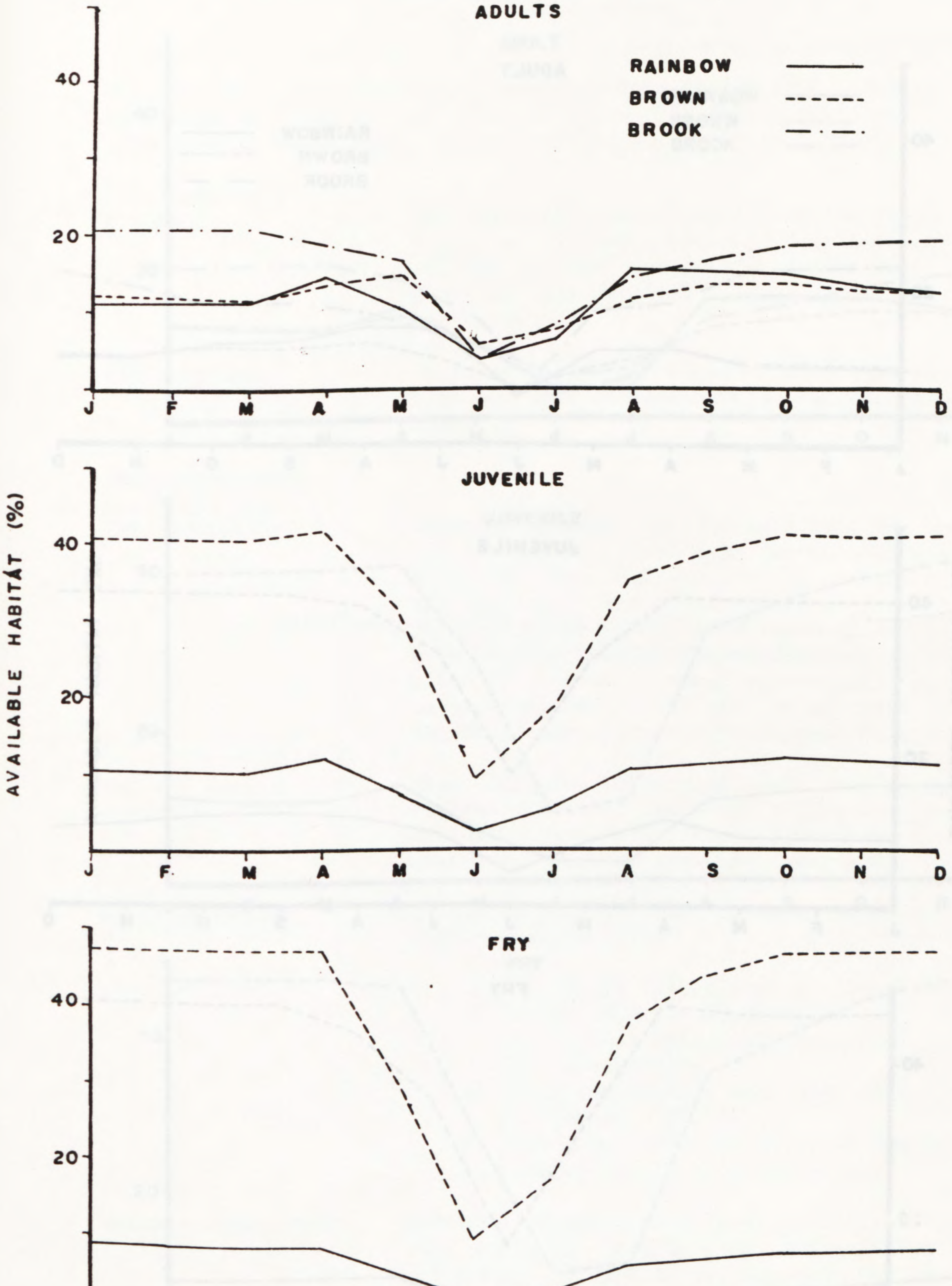


WILLIAMS FORK AT UTE CREEK CONFLUENCE

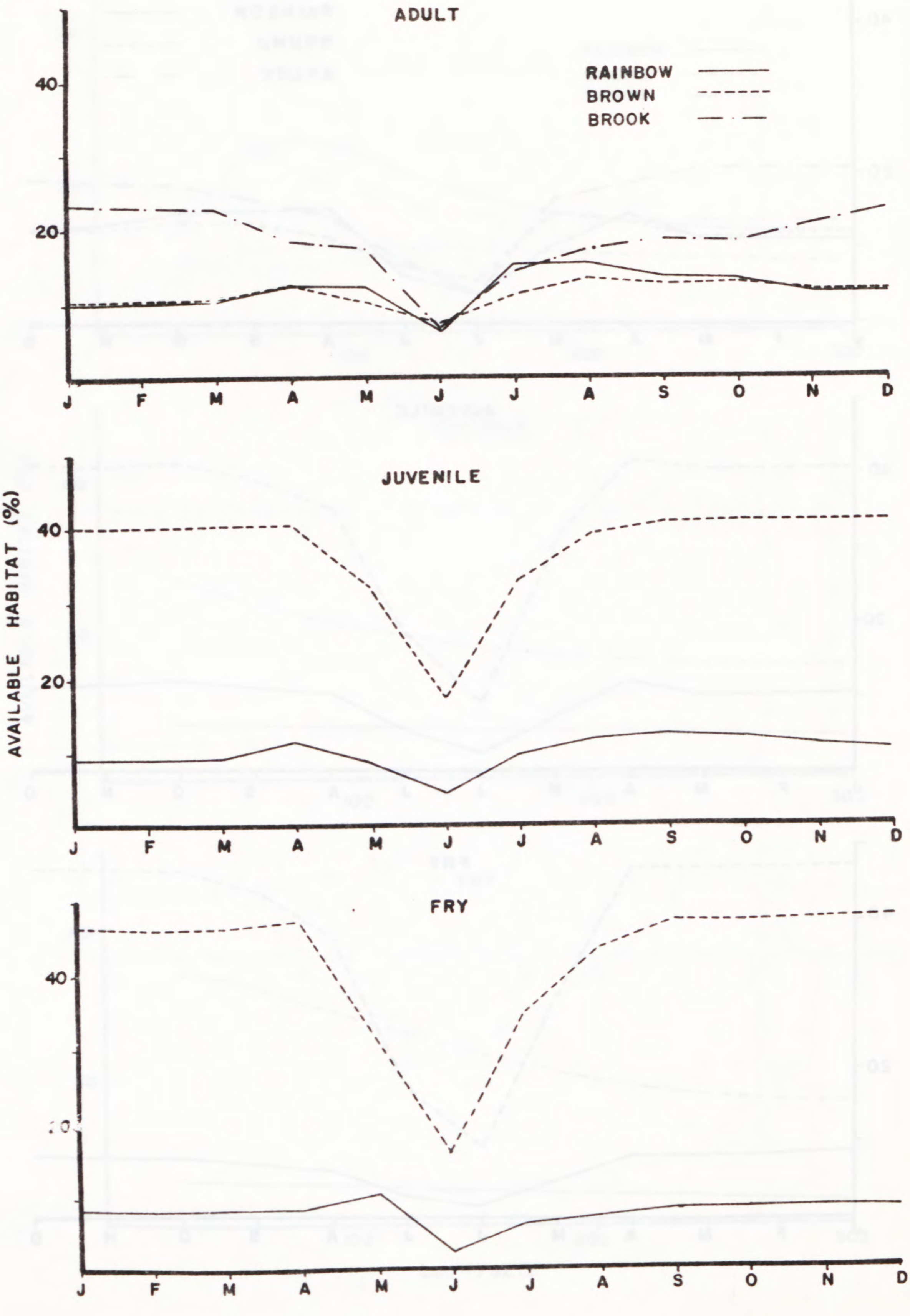


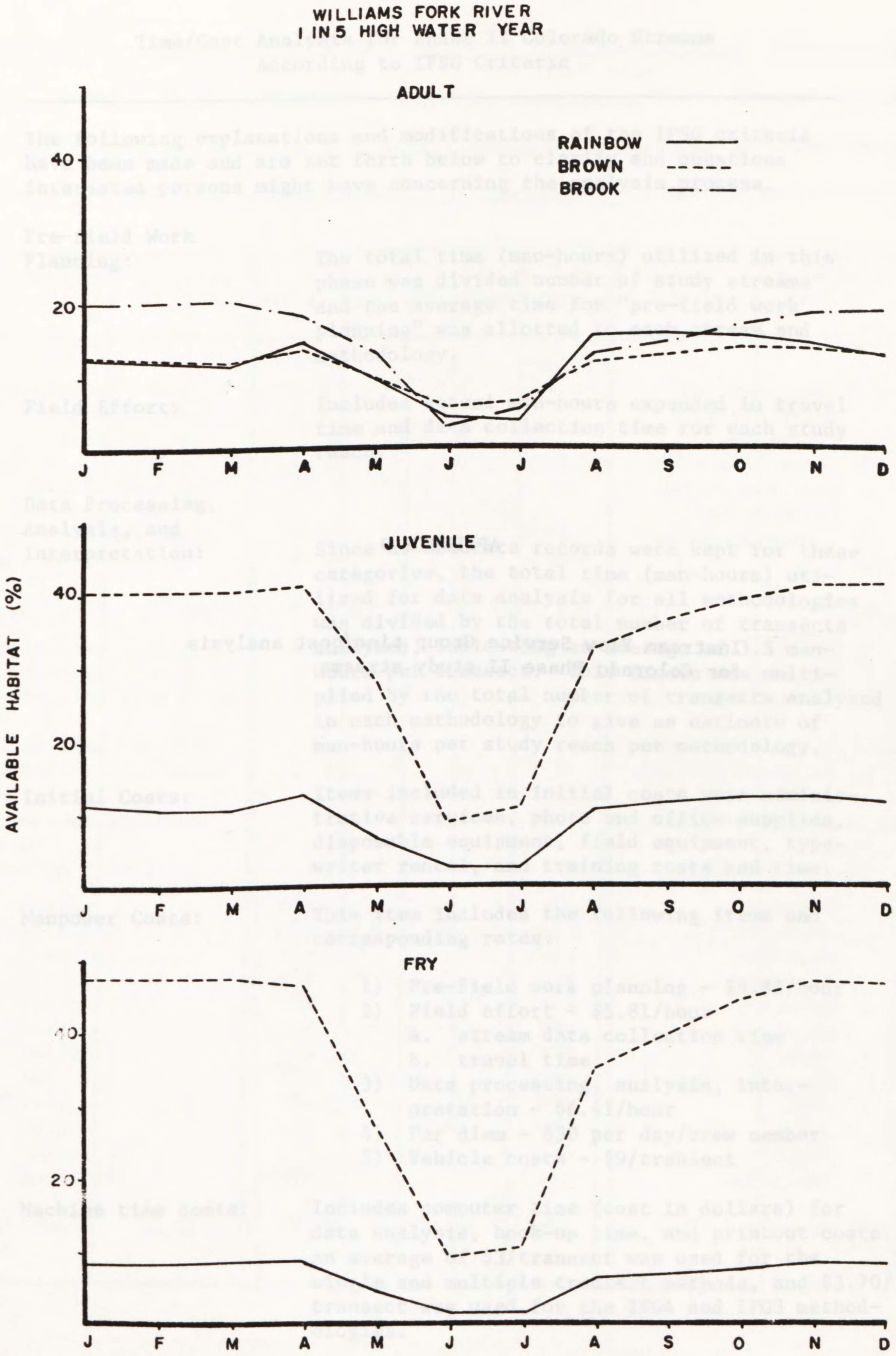
WILLIAMS FORK RIVER

MEDIAN WATER YEAR



WILLIAMS FORK RIVER
1 IN 5 LOW WATER YEAR




WILLIAMS FORK RIVER
1 IN 5 HIGH WATER YEAR
ADULT
RAINBOW
BROWN ----
BROOK _._._
40
20
J F M A M J J A S O N D
JUVENILE
AVAILABLE HABITAT (%)
40
20
J F M A M J J A S O N D
FRY
40
20
J F M A M J J A S O N D

APPENDIX D

Instream Flow Service Group time/cost analysis for Colorado Phase II study streams

Time/Cost Analysis for Phase II Colorado Streams According to IFSG Criteria

The following explanations and modifications of the IFSG criteria have been made and are set forth below to clarify and questions interested persons might have concerning the analysis process.

Pre-field Work Planning:	The total time (man-hours) utilized in this phase was divided number of study streams and the average time for "pre-field work planning" was allotted to each stream and methodology.
Field Effort:	Includes actual man-hours expended in travel time and data collection time for each study reach.
Data Processing, Analysis, and Interpretation:	Since no accurate records were kept for these categories, the total time (man-hours) utilized for data analysis for all methodologies was divided by the total number of transects analyzed, indicating an average of 3.5 man-hours per transect. This figure was multiplied by the total number of transects analyzed in each methodology to give an estimate of man-hours per study reach per methodology.
Initial Costs:	Items included in initial costs were administrative services, photo and office supplies, disposable equipment, field equipment, typewriter rental, and training costs and time.
Manpower Costs:	This item includes the following items and corresponding rates: 1) Pre-field work planning - $5.81/hour 2) Field effort - $5.81/hour a. stream data collection time b. travel time 3) Data processing, analysis, interpretation - $6.41/hour 4) Per diem - $30 per day/crew member 5) Vehicle costs - $9/transect
Machine time costs:	Includes computer time (cost in dollars) for data analysis, hook-up time, and printout costs. An average of $3/transect was used for the single and multiple transect methods, and $3.70/transect was used for the IFG4 and IFG3 methodologies.

Stream Name: Cache la Poudre – Little South Fork State: Colorado

Stream Segment: From Little Beaver Creek

Downstream to: Confluence w/Cache la Poudre

Coldwater or Warmwater Coldwater Wadable Yes X No ____

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	34	51	111
Pre-Field Work Planning	%	0	47	31	14
Field Effort	%	0	35	41	48
Data Processing Analysis and Interpretation	%	1	18	28	38
Crew Size	#	1	3	3	3
Costs	$	6	610	780	$1,325
Initial Costs	%	0	55	43	26
Manpower Costs	%	100	44	55	72
Machine Time Costs	%	0	T	2	2
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs	Undepleted		natural	flow
December	cfs				
January	cfs				
February	cfs				
March	cfs				
April	cfs				
May	cfs				
June	cfs	18.8	20	16.1	16.3
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	62.6	62.6	62.6	62.6

Stream Name: Carnero Creek - South Fork State: Colorado

Stream Segment: From Headwaters

Downstream to: U. S. G. S. gage near La Garita

Coldwater or Warmwater Coldwater Wadable Yes X No

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	35	70	163
Pre-Field Work	%				
Planning		0	46	23	10
Field Effort	%	0	37	37	39
Data Processing	%				
Analysis and Interpretation	%	1	17	40	51
Crew Size	#	1	3	3	3
Costs	$	$ 6	$646	$857	$1,639
Initial Costs	%	0	52	39	21
Manpower Costs	%	100	47	58	74
Machine Time Costs	%	0	1	3	5
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs	Undepleted natural flow			
December	cfs				
January	cfs				
February	cfs				
March	cfs				
April	cfs				
May	cfs	3.3	2.0	1.8	2.3
June	cfs				
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	11.0	11.0	11.0	11.0

Stream Name: Cucharas River State: Colorado

Stream Segment: From Cuchara, Colorado

Downstream to: Three Bridges, Colorado

Coldwater or Warmwater Coldwater Wadable Yes X No ___

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	29	59	130
Pre-Field Work Planning	%	0	55	27	12
Field Effort	%	0	24	31	31
Data Processing	%				
Analysis and Interpretation	%	1	21	42	57
Crew Size	#	1	3	3	3
Costs	$	6	641	899	$1,764
Initial Costs	%	0	53	38	19
Manpower Costs	%	100	47	60	77
Machine Time Costs	%	0	T	2	4
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs	Undepleted natural flow			
November	cfs				
December	cfs				
January	cfs				
February	cfs				
March	cfs				
April	cfs				
May	cfs				
June	cfs	6.7	5.0	4.2	3.6
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	22.4	22.4	22.4	22.4

Stream Name: Cunningham Creek State: Colorado

Stream Segment: From Source

Downstream to: Confluence w/N. Fork Fryingpan

Coldwater or Warmwater Coldwater Wadable Yes X No

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	39	76	154
Pre-Field Work Planning	%	0	41	21	10
Field Effort	%	0	44	46	42
Data Processing Analysis and Interpretation	%	1	15	33	48
Crew Size	#	1	3	3	3
Costs	$	6	$669	$968	$1,813
Initial Costs	%	0	50	35	19
Manpower Costs	%	100	49	63	77
Machine Time Costs	%	0	1	2	4
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs				
December	cfs	Udepleted natural flow			
January	cfs				
February	cfs				
March	cfs				
April	cfs				
May.	cfs				
June	cfs	3.2	4.0	4.1	3.7
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	10.6	10.6	10.6	10.6

Stream Name: East River State: Colorado

Stream Segment: From Cement Creek Confluence

Downstream to: Taylor River Confluence

Coldwater or Warmwater Coldwater Wadable Yes X No ____

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	44	68	---
Pre-Field Work	%				
Planning		0	36	24	---
Field Effort	%	0	27	40	
Data Processing	%				
Analysis and Interpretation	%	1	37	36	---
Crew Size	#	1	3	3	---
Costs	$	6	$614	$837	---
Initial Costs	%	0	55	40	---
Manpower Costs	%	100	45	58	---
Machine Time Costs	%	0	T	2	---
Applications Required to Become Proficient	#	1	4	4	---
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs				
December	cfs	Udepleted natural flow			
January	cfs				
February	cfs				
March	cfs				
April	cfs				
May.	cfs				
June	cfs	100	65	50.5	---
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	334	334	334	334

Stream Name: Fryingpan River at Seven Castles State: Colorado

Stream Segment: From Ruedi Dam Outflow

Downstream to: Confluence w/Roaring Fork River

Coldwater or Warmwater Coldwater Wadable Yes X No ___

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	37	59	104
Pre-Field Work Planning	%	0	43	27	15
Field Effort	%	0	41	54	54
Data Processing	%				
Analysis and Interpretation	%	1	16	19	31
Crew Size	#	1	3	3	3
Costs	$	$ 6	$658	$812	$1,355
Initial Costs	%	0	52	42	25
Manpower Costs	%	100	48	57	72
Machine Time Costs	%	0	T	1	3
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs				
December	cfs				
January	cfs				
February	cfs	54	65	62.4	63.3
March	cfs				
April	cfs				
May	cfs				
June	cfs	54	65	62.4	63.3
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	180	180	180	180

Stream Name: Fryingpan River at Taylor Creek State: Colorado

Stream Segment: From Ruedi Dam Outflow

Downstream to: Confluence w/Roaring Fork River

Coldwater or Warmwater Coldwater Wadable Yes X No

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	38	74	129
Pre-Field Work	%				
Planning		0	42	22	12
Field Effort	%	0	42	59	55
Data Processing	%				
Analysis and Interpretation	%	1	16	19	33
Crew Size	#	1	3	3	3
Costs	$	$ 6	$663	$913	$1,548
Initial Costs	%	0	51	37	22
Manpower Costs	%	100	49	62	74
Machine Time Costs	%	0	T	1	4
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs				
December	cfs				
January	cfs				
February	cfs	54	55	55.3	47.5
March	cfs				
April	cfs				
May	cfs				
June	cfs	54	55	55.3	47.5
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	180	180	180	180

Stream Name: Fryingpan River - North Fork State: Colorado

Stream Segment: From Crater Creek Confluence

Downstream to: Cunningham Creek Confluence

Coldwater or Warmwater Coldwater Wadable Yes X No

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	39	69	135
Pre-Field Work	%				
Planning		0	41	23	12
Field Effort	%	0	44	46	41
Data Processing	%				
Analysis and Interpretation	%	1	15	31	47
Crew Size	#	1	3	3	3
Costs	$	$ 6	$669	$912	$1,658
Initial Costs	%	0	51	37	20
Manpower Costs	%	100	49	61	76
Machine Time Costs	%	0	T	2	4
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs	Undepleted natural flow			
December	cfs				
January	cfs				
February	cfs				
March	cfs				
April	cfs				
May.	cfs				
June	cfs	5.9	8.0	4.8	8.5
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	19.8	19.8	19.8	19.8

Stream Name: Fryingpan River, South Fork State: Colorado

Stream Segment: From U.S.G.S. gage at Fry-Ark Diversion

Downstream to: Coldwater

Coldwater or Warmwater ________ Wadable Yes X No ____

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	39	71	154
Pre-Field Work Planning	%	0	41	23	10
Field Effort	%	0	44	42	42
Data Processing	%				
Analysis and Interpretation	%	1	15	35	48
Crew Size	#	1	3	3	3
Costs	$	$6	$669	$930	$1,813
Initial Costs	%	0	51	36	19
Manpower Costs	%	100	49	62	77
Machine Time Costs	%	0	T	2	4
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs				
December	cfs	Undepleted natural flow			
January	cfs				
February	cfs				
March	cfs				
April	cfs				
May	cfs				
June	cfs	6.5	6.0	5.2	5.6
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	21.6	21.6	21.6	21.6

Stream Name: Gunnison River, Lake Fork State: Colorado

Stream Segment: From Henson Creek Confluence

Downstream to: Blue Mesa Reservoir

Coldwater or Warmwater Coldwater Wadable Yes X No

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	34	64	139
Pre-Field Work Planning	%	0	47	25	12
Field Effort	%	0	35	42	43
Data Processing	%				
Analysis and Interpretation	%	1	18	33	45
Crew Size	#	1	3	3	3
Costs	$	$ 6	$640	$793	$1,411
Initial Costs	%	0	53	43	24
Manpower Costs	%	100	47	55	71
Machine Time Costs	%	0	T	2	5
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs				
December	cfs	Undepleted		natural	flow
January	cfs				
February	cfs				
March	cfs				
April	cfs				
May.	cfs				
June	cfs	70.2	45	52.4	48.3
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	234	234	234	234

Stream Name: Huerfano River State: Colorado

Stream Segment: From Deer Creek Confluence

Downstream to: Manzanares Creek Confluence

Coldwater or Warmwater Coldwater Wadable Yes X No

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	36	70	166
Pre-Field Work	%				
Planning		0	44	23	10
Field Effort	%	0	39	37	40
Data Processing	%				
Analysis and Interpretation	%	1	17	40	50
Crew Size	#	1	3	3	3
Costs	$	$6	$652	$947	$1,927
Initial Costs	%	0	52	36	17
Manpower Costs	%	100	48	62	78
Machine Time Costs	%	0	T	2	5
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs				
December	cfs	Undepleted		natural	flow
January	cfs				
February	cfs				
March	cfs				
April	cfs				
May	cfs				
June	cfs	9.4	4.0	5.0	5.0
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	31.4	31.4	31.4	31.4

Stream Name: Rio Grande, South Fork State: Colorado

Stream Segment: From Lake Creek Confluence

Downstream to: Park Creek Confluence

Coldwater or Warmwater Coldwater Wadable Yes X No

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	44	69	164
Pre-Field Work	%				
Planning		0	36	23	10
Field Effort	%	0	50	46	52
Data Processing	%				
Analysis and Interpretation	%	1	14	31	38
Crew Size	#	1	3	3	3
Costs	$	$ 6	$698	$912	$1,827
Initial Costs	%	0	48	37	18
Manpower Costs	%	100	52	61	78
Machine Time Costs	%	0	T	2	4
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs				
December	cfs	Udepleted natural flow			
January	cfs				
February	cfs				
March	cfs				
April	cfs				
May.	cfs				
June	cfs		40	41.0	41.5
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	2	2	2	2

Stream Name: Sangre de Cristo Creek State: Colorado

Stream Segment: From Placer Creek Confluence

Downstream to: Ute Creek Confluence

Coldwater or Warmwater Coldwater Wadable Yes X No ____

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	34	59	145
Pre-Field Work Planning	%	0	47	27	11
Field Effort	%	0	35	25	31
Data Processing	%				
Analysis and Interpretation	%	1	18	48	58
Crew Size	#	1	3	3	3
Costs	$	$6	$670	$883	$1,805
Initial Costs	%	0	51	38	19
Manpower Costs	%	100	49	59	76
Machine Time Costs	%	0	T	3	5
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs				
December	cfs	Undepleted natural flow			
January	cfs				
February	cfs				
March	cfs				
April	cfs				
May	cfs				
June	cfs	5.4	2.0	2.1	2.8
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	18.1	18.1	18.1	18.1

Stream Name: South Platte State: Colorado

Stream Segment: From North Fork-South Fork Confluence

Downstream to: Marston Canal Diversion

Coldwater or Warmwater Coldwater Wadable Yes X No

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	28	54	---
Pre-Field Work Planning	%	0	29	14	---
Field Effort	%	0	50	59	---
Data Processing	%				
Analysis and Interpretation	%	1	21	26	---
Crew Size	#	1	3	3	---
Costs	$	$ 6	$605	$827	---
Initial Costs	%	0	56	41	---
Manpower Costs	%	100	44	58	---
Machine Time Costs	%	0	T	1	---
Applications Required to Become Proficient	#	1	4	4	---
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs				
December	cfs				
January	cfs	52.5	60.0	74.8	---
February	cfs				
March	cfs				
April	cfs				
May.	cfs				
June	cfs	52.5	60.0	74.8	---
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	175	175	175	---

Stream Name: South Platte State: Colorado

Stream Segment: From Marston Outlet

Downstream to: Highline Canal Outlet

Coldwater or Warmwater ________ Wadable Yes X No ____

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	---	28	38	---
Pre-Field Work	%				
Planning			29	21	---
Field Effort	%		50	50	---
Data Processing	%				
Analysis and Interpretation	%	---	21	29	---
Crew Size	#	---	3	3	---
Costs	$	---	$605	$713	---
Initial Costs	%	---	56	47	---
Manpower Costs	%	---	44	52	---
Machine Time Costs	%	---	T	1	---
Applications Required to Become Proficient	#	---	4	4	---
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs				
December	cfs				
January	cfs	---	18.5	34.3	---
February	cfs				
March	cfs				
April	cfs				
May	cfs				
June	cfs				
July	cfs	---	18.5	34.3	---
August	cfs				
September	cfs				
Ave. Annual	cfs	---	18.5	34.3	

Stream Name: St. Louis Creek State: Colorado

Stream Segment: From West St. Louis Creek Confluence

Downstream to: Fraser River Confluence

Coldwater or Warmwater Coldwater Wadable Yes X No

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	42	74	172
Pre-Field Work					
Planning		0	38	21	9
Field Effort	%	0	48	46	48
Data Processing	%				
Analysis and Interpretation	%	1	14	33	43
Crew Size	#	1	3	3	3
Costs	$	$ 6	$687	$956	$1,917
Initial Costs	%	0	49	35	18
Manpower Costs	%	100	51	63	78
Machine Time Costs	%	0	T	2	4
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs				
December	cfs	Undepleted natural flow			
January	cfs				
February	cfs				
March	cfs				
April	cfs				
May	cfs				
June	cfs				
July	cfs	5.9	9.0	8.7	9.0
August	cfs				
September	cfs				
Ave. Annual	cfs	19.7	19.7	19.7	19.7

Stream Name: Williams Fork River State: Colorado

Stream Segment: From Kinney Creek Confluence

Downstream to: Williams Fork Reservoir

Coldwater or Warmwater Coldwater Wadable Yes X No ____

	UNITS	MONTANA	Single R 2 Cross	Multiple R 2 Cross	Incremental IFG 4
Total Manpower Req.	Person-Hours	1	43	95	224
Pre-Field Work Planning	%	0	37	17	7
Field Effort	%	0	49	46	50
Data Processing Analysis and Interpretation	%	1	14	37	43
Crew Size	#	1	3	3	3
Costs	$	$ 6	$710	$1,137	$2,616
Initial Costs	%	0	48	30	13
Manpower Costs	%	100	52	68	83
Machine Time Costs	%	0	T	2	4
Applications Required to Become Proficient	#	1	4	4	4
Recommended Instream Flows (median condition)					
October	cfs				
November	cfs				
December	cfs	Undepleted natural flow			
January	cfs				
February	cfs				
March	cfs				
April	cfs				
May	cfs				
June	cfs	30.3	40	31.5	44.9
July	cfs				
August	cfs				
September	cfs				
Ave. Annual	cfs	101	101	101	101

APPENDIX E

Brief resume of educational background, experience, and job descriptions for field crew personnel on Colorado Phase II study streams.

NAME	BACKGROUND AND EXPERIENCE
Bennett, Jerry	B.S. Colorado State University 1971, Fishery Biology; M.S. Colorado State University 1972, Fishery Biology; Fishery Research and Fishery Biologist with Colorado Division of Wildlife 1972-1979. Four years experience with velocity meters, R-2 Cross model.
Brunjak, Greg	B.S. Colorado State University circa 1977. Summer temporary 1976-1978 under J. Bennett. Three summers experience in collecting field data with Sag-Tape (R-2 Cross) system.
Burrell, Mike	B.S. Colorado State University 1978. Summer Temporary employee for Colorado Division of Wildlife 1977-78. Two summers experience in collecting field data with Sag-Tape methodology under Colorado's S.B. 97 program.
Craig, Jerry	High school diploma, summer temporary under J. Bennett summer 1978.
Craig, Mike	Three years Western State University, Gunnison, Colorado. Summer temporary 1978. Primary crew member on Colorado's Phase II stream flow analysis program. Trained and supervised by Barry Nehring.
Daber, Jim	B.S. degree in hydrology. Hydrologist for Colorado Water Conservation Board.
Harridge, Bill	B.S. Colorado College, 1973. Four years summer temporary with Colorado Division of Wildlife.
Hebein, Sherman	B.S. Colorado State University, 1979, Fishery Biology. Two summers experience with Colorado Division of Wildlife.
Ida, Mike	B.S. Colorado State University 1979, Fishery Biology. One summer experience with Colorado Division of Wildlife.
Kochman, Eddie	B.S. and M.S. Colorado State University, Fishery Biology, circa 1965, 1967. In charge of Colorado Division of Wildlife S.B. 97 stream flow program 1974-1978.
Martinez, Pat	Two years in biology major at Mesa College. Two summers experience as summer temporary for Colorado Division of Wildlife working on Sag-Tape 97 stream flow program.

NAME	BACKGROUND AND EXPERIENCE
Nehring, Barry	B.S. and M.S. 1971 and 1973 at Colorado State University in Fishery Biology. Four years as advisor to Iran Department of Environment in fisheries research and management. Four summers experience as summer temporary employee for Colorado Division of Wildlife. Fishery researcher with Colorado Division of Wildlife 1978-1979. Primary investigator on Colorado's Phase II stream evaluation program.
Smith, Dick	Fish salvage crew member with Colorado Division of Wildlife and four years experience with Sag-Tape methodology under S.B. 97 stream flow program for Colorado.
Taliaferro, Rex	B.S. and M.S. Colorado State University. Twenty-five years as fish biologist and environmentalist with Colorado Division of Wildlife. Presently in charge of S.B. 97 program for Colorado Division of Wildlife. Carried out all single transect R-2 Cross analysis and flow recommendations on the Phase II contract for Colorado Division of Wildlife.
Thornton, Bill	Fish salvage crew member with Colorado Division of Wildlife and four years experience with Sag-Tape methodology under S.B. 97 stream flow program for Colorado.
Weiler, Bill	B.S. Colorado State University 1964, Fishery Biology. Fifteen years experience as fish biologist with Colorado Division of Wildlife and four years experience on S.B. 97 stream flow evaluation program for SW Colorado.
Whittaker, Jerry	B.S. Colorado State University in Fishery Biology circa 1978. Eleven years experience as fish culturist and biologist with Colorado Division of Wildlife. Four years experience with Sag-Tape stream flow program.

Job Functions of Various Crew Members by Stream

	Cache la Poudre R., Little South Fork	Carnero Creek, South Fork	Cucharas River	Cunningham Creek	East River	Fryingpan River	Fryingpan River, North Fork	Fryingpan River, South Fork	Gunnison River, Lake Fork	Huerfano River	Rio Grande River, South Fork	Sangre de Cristo Creek	South Platte River	St. Louis Creek	Williams Fork River
Bennett				13		13	13	13						13	13
Brunjak				13		13	13	13						13	13
Burrell				1	13	13	1		13		13				
Craig, J.														123	123
Craig, M.	1234 ALL STREAMS														
Daber						126							126		
Harridge				1	13	13	1	1	13		13				
Hebein		1234	1234	1234	1234	1234	1234	1234	1234	1234	1234	1234			
Ida	123														
Kochman						1									
Martinez						13								13	
Nehring	123456 ALL STREAMS														
Smith													13		
Taliaferro	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
Thornton													13		
Weiler															
Whittaker	123														

Categories of Contribution

1 - Velocity measurements and data recording
2 - Level rod man
3 - Assist in biomass data collection
4 - Data formating and reduction
5 - Data interpretation and analysis
6 - Transit man and cross section profiling

APPENDIX F

List of Species Occurring in Phase II Study Stream
(starred species are the target species)

Stream name	Colorado speckled dace *Rhinichthys osculus yarrowi*	Western longnose sucker *Catostomus catostomus griseus*	Western white sucker *Catostomus commersoni suckleyi*	*Rio Grande cutthroat *Salmo clarki virginalis*	*Rainbow trout *Salmo gairdneri*	*Cutthroat trout *Salmo clarki*	*Brook trout *Salvelinus fontinalis*	*Brown trout *Salmo truta*	Kokanee salmon *Oncorhynchus nerka*	Mountain whitefish *Prosopium williamsoni*	Mottled sculpin *Cottus bairdi*
Cache la Poudre R., Little South Fork					X		X	X			
Carnero Creek, South Fork			X	X	X						
Cucharas River					X		X	X			
Cunningham Creek							X				
East River			X		X		X	X	X		
Fryingpan R. I & II					X	X	X	X		X	
Fryingpan R., North Fork							X	X			
Fryingpan R., South Fork						X	X				
Gunnison R., Lake Fork	X	X	X		X		X	X			
Huerfano R.					X		X	X			
Rio Grande R., South Fork	X		X		X	X	X	X			
Sangre de Cristo Creek	X		X	X							
South Platte R. I & II	X	X	X		X			X			
St. Louis Creek					X		X				
Williams Fork R. I & II					X		X				