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THE IMPACTS OF IRRIGATION WATER WITHDRAWALS ON BROWN TROUT (*Salmo trutta*) AND TWO SPECIES OF BENTHIC MACROINVERTEBRATES IN A TYPICAL SOUTHERN MICHIGAN STREAM

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Charles Gowan

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THE IMPACTS OF IRRIGATION WATER WITHDRAWALS ON BROWN TROUT (*Salmo trutta*) AND TWO SPECIES OF BENTHIC MACROINVERTEBRATES IN A TYPICAL SOUTHERN MICHIGAN STREAM

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Charles Gowan

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ABSTRACT

THE IMPACTS OF IRRIGATION WATER WITHDRAWALS
ON BROWN TROUT (Salmo trutta) AND TWO SPECIES
OF BENTHIC MACROINVERTEBRATES IN A TYPICAL
SOUTHERN MICHIGAN STREAM

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The Instream Flow Incremental Methodology (IFIM) was utilized for the first time in a Michigan stream. The objective was to test the method's applicability to the midwest, and to detail the impacts of irrigation withdrawals on a typical lower Michigan trout stream.

The IFIM was found to accurately simulate the hydraulic characteristics of a midwestern stream, and to predict brown trout (Salmo trutta) habitat locations within the stream.

Brown trout habitat losses were most critical in the month of July, with reductions up to 16 percent. It was demonstrated that these habitat reductions lead to a reduction in trout population levels. It was also shown that a greater percentage of the brown trout population remaining experienced negative growth rates as habitat availability was reduced.

Benthic macroinvertebrate habitat for Hydropsyche spp. and Ephemerella spp. was found to be less impacted by irrigation withdrawals. Habitat losses for Hydropsyche spp. reached a maximum of 11.05 percent during irrigation periods in July of 1983. Habitat losses for Ephemerella spp. reached a maximum of 6.35 percent during the same period.

Keywords: instream flow, habitat, brown trout, irrigation.

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INTRODUCTION

The lotic environment is characterized by variation. The intermittent or seasonal stream is an extreme example. However, even the largest river exhibits changes in temperature, velocity, depth, width and other physical characteristics by the hour, day, and season.

Natural flow variation can be considerable. In temperate zones the spring thaw can produce flow rates an order of magnitude greater than the flows occurring later in the summer. A heavy thunderstorm can change flow drastically in a short time. The attendant changes in velocity, depth, and width can be severe.

Despite these rapid changes in the physical environment, the biologic community can thrive. However, a stream's biota do have a finite amount of tolerance. Human influence can exceed even the harsh natural regime. In the Western United States tremendous demands are being placed on the available water resources (Powledge, 1982). The threatened extinction of some species can be directly related to reduced flow (Davis, 1979), and once productive fisheries are being lost due to streamflow regulation (Anon., 1977; Graham, 1980).

The midwestern U.S. has not had these water demand problems, and, in fact, is considered water rich (White, 1976). However, the situation is changing. Irrigation demands are rapidly increasing. Irrigation in Michigan counties (measured in acre-inches of water used) has increased an average of 268 percent from 1970 to 1977. Some of the most cultivated counties have had increases of over 11,000 percent. The prediction is for the trend to continue (Bedell, 1977).

Already the effects are being noticed. The Water Management Division of the Michigan Department of Natural Resources (DNR) in 1979 started a file to keep track of complaints made by riparian property owners concerning water use by their neighbors (Bedell, per. comm.). Some streams are completely dewatered by irrigation demands (Doyle, per. comm.).

Currently, no law limits the amount of water an irrigator can remove from a stream in Michigan. The courts can order withdrawals stopped if one riparian can demonstrate that another is making "unreasonable use" of the resource, or if the DNR can prove that "ecological damage" has resulted. "Unreasonable use" and "ecological damage" are not defined (Bedell, per. comm.).

Clearly, the stage is set for the midwest to start experienceing the same type of water use problems that the western states have faced. The midwest, however, is in a position to learn from its drier neighbors. Methods have been developed in the west to deal with the question of "ecological damage." The first application in Michigan of one of these methods, the U.S. Fish and Wildlife Service's Instream Flow Incremental Methodology (IFIM), is the topic of this report.

The IFIM is designed to estimate the amount of habitat available to a particular species at any flow. Thus, the amounts of habitat lost through water removal can be estimated.

There were two purposes in trying the IFIM in a Michigan stream. First, because the method was developed in the west, it was believed that this project would provide a test of the applicability of the method to midwestern streams. The second reason was to begin to establish an instream flow data base for the region in order to provide the information necessary for future water use policy. The objective of this study was to detail the possible impacts of irrigation water withdrawals in terms of fish and aquatic insect habitat loss, and fish population density and individual growth rate responses to habitat loss.

The stream chosen for study was Fish Creek, a small first order stream that runs along the eastern border of Montcalm Co., Michigan (Figure 1). The study section is located in section 11 of Evergreen Township. This stream was chosen on two criteria. The first was that, in many ways, it is typical of Michigan's marginal, managed trout streams. It is regularly stocked with brown trout (Salmo trutta) and has a native population of brook trout (Salvelinis fontinalis). The second reason for selecting Fish Creek was that it is surrounded for most of its length by farmland producing corn, potatoes, and soybeans. As a result, it is the major irrigation water source for at least eleven farms (Cooper, 1984). The section studied is located in section 11 of Evergreen Township. The section is just downstream from the heaviest irrigation withdrawals and is representative of the headwaters of Fish Creek.

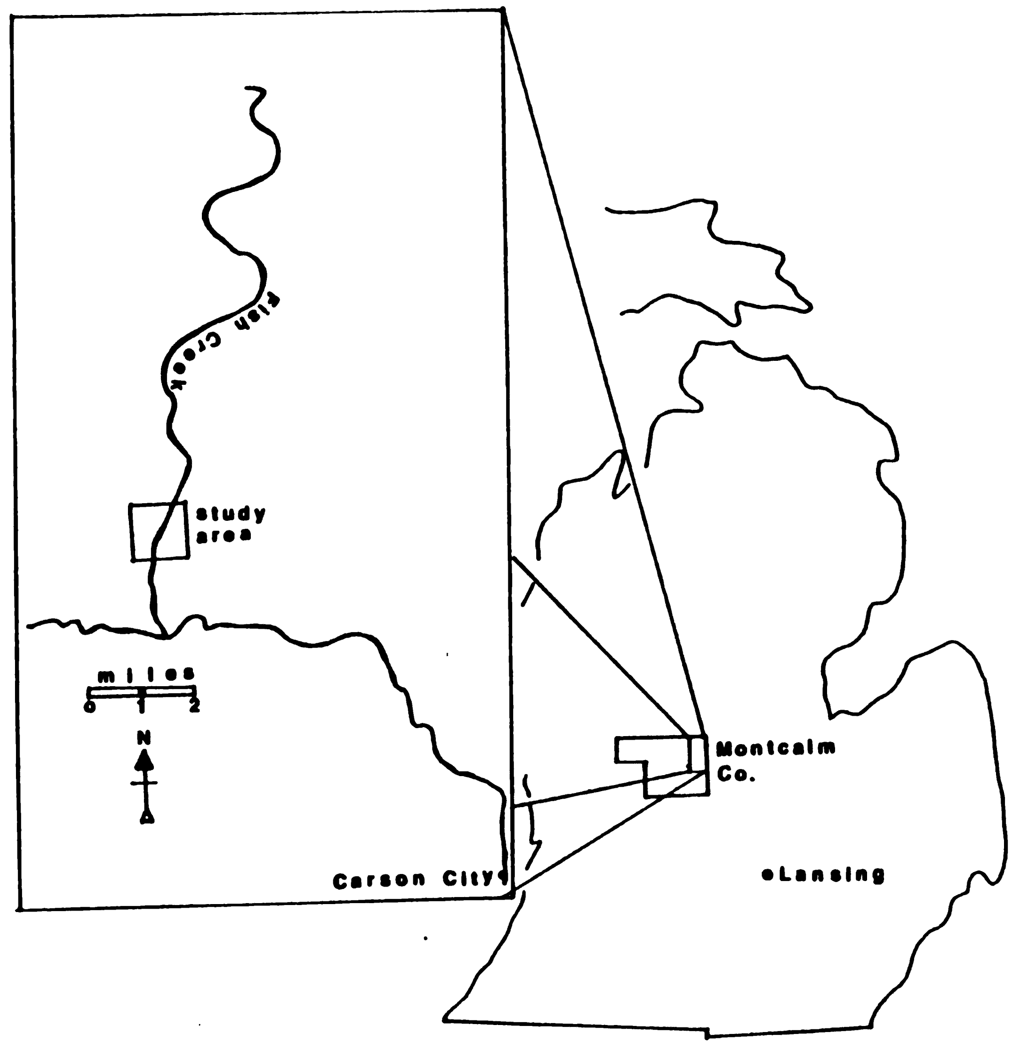


FIGURE 1: A map showing the location of Fish Creek and the study area.

METHODS AND MATERIALS

Habitat Estimation

The IFIM was used to determine the amount of brown trout habitat, measured in square feet of weighted usable area, present in the study section at flows ranging from six cubic feet per second (cfs) to thirty cfs. This constitutes the normal summer range of flows in Fish Creek. The amount of habitat available to two of the dominant benthic macroinvertabrates, Ephemerella spp. and Hydropshyche spp., was determined for the same flow range in order to estimate the effects of flow reduction on these two trout food organisms.

A brief summary of the theory behind the IFIM method is given here. A complete description is given by Bovee (1982).

The method involves four physical parameters: depth, velocity, substrate, and cover. In theory, if these variables could be measured at every location in a stream one would have a complete description of the physical characteristics of that stream. If this could be done at all flows of interest, one could say with certainty how that stream is affected by changes in discharge. The IFIM allows this with relatively little data.

Depth, velocity, substrate, and cover are measured at specific points along carefully chosen transects. This is done at the exact same locations at three different discharges. A series of computer programs perform a task known as Physical Habitat Simulation (PHABSIM), relating changes in discharge to changes in the availability of combinations of depth, velocity, substrate, and cover. The utility of these programs is that they interpolate data and give predictions of the availability of these physical parameters at discharges other than those at which the data were collected.

The estimate of fish habitat present is determined when the above predictions are combined with preference curves. Preference curves are probability density functions that describe the affinity a particular species has for various depths, velocities, substrates, and cover types. Preference ratings result from measurements detailing the availability of the physical characteristics and the utilization of these parameters by the species of interest (Figure 2a). Preference curves were constructed based on data collected on Fish Creek. A depth preference curve for brown trout is shown in Figure 2b. The construction of these curves will be addressed later in this section.

As seen from Figure 2b, all intervals of a given parameter are rated from 0 to 1. By multiplying the individual ratings for a given interval of each of the four physical parameters together, a composite rating for that particular combination of physical parameters is determined. This is the Joint Preference Function (JPF). For example, if the ratings for a depth of 1 ft., a velocity of 0.5 ft/sec., a substrate of course gravel, and a cover of down timber were 0.2, 1.0, 1.0, and 0.5 respectively, the JPF would be 0.1. This indicates that the combination of physical characteristics described would be rated as one-tenth as preferred as the optimum combination.

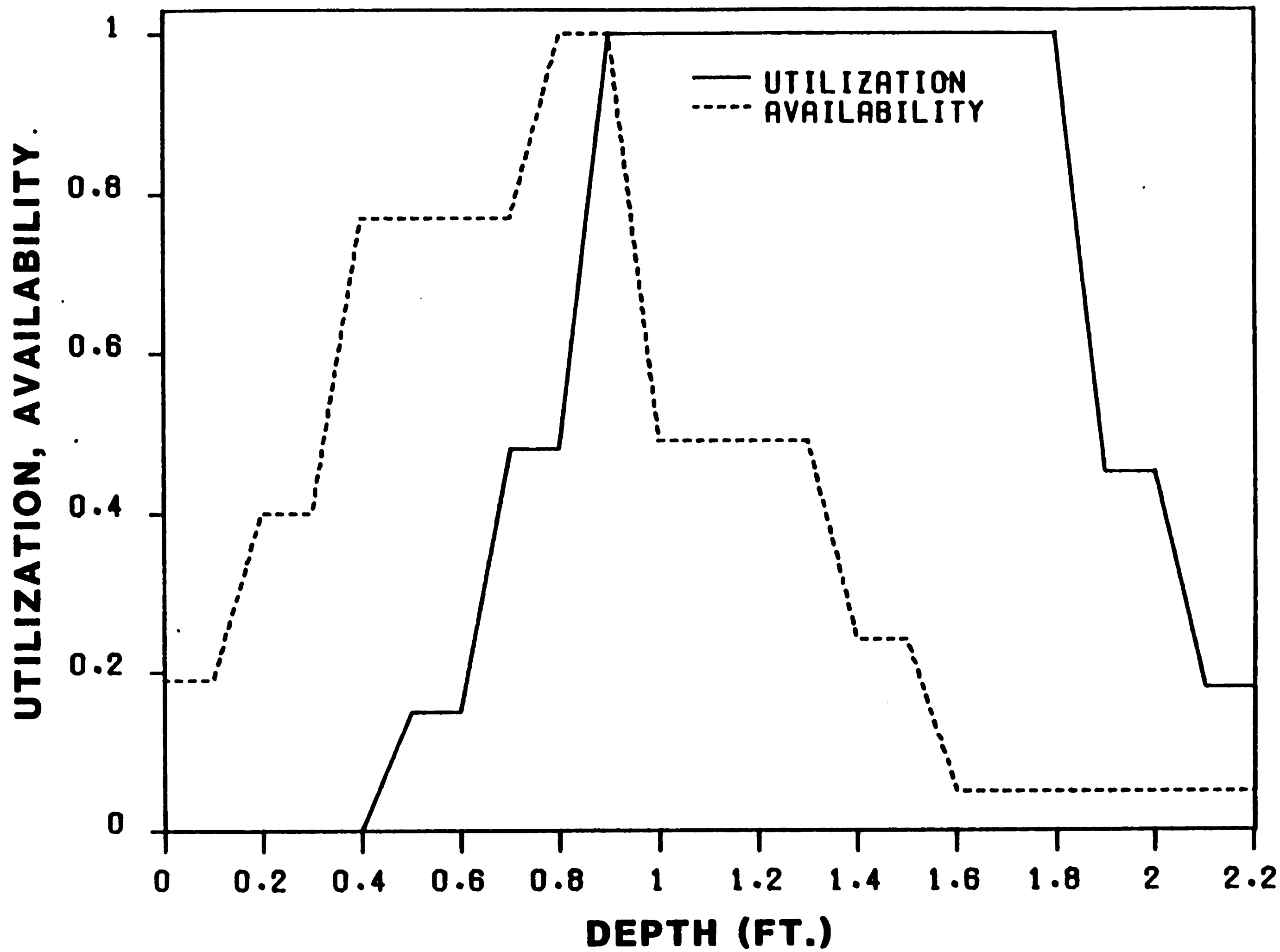


FIGURE 2a: Brown trout depth utilization and availability.

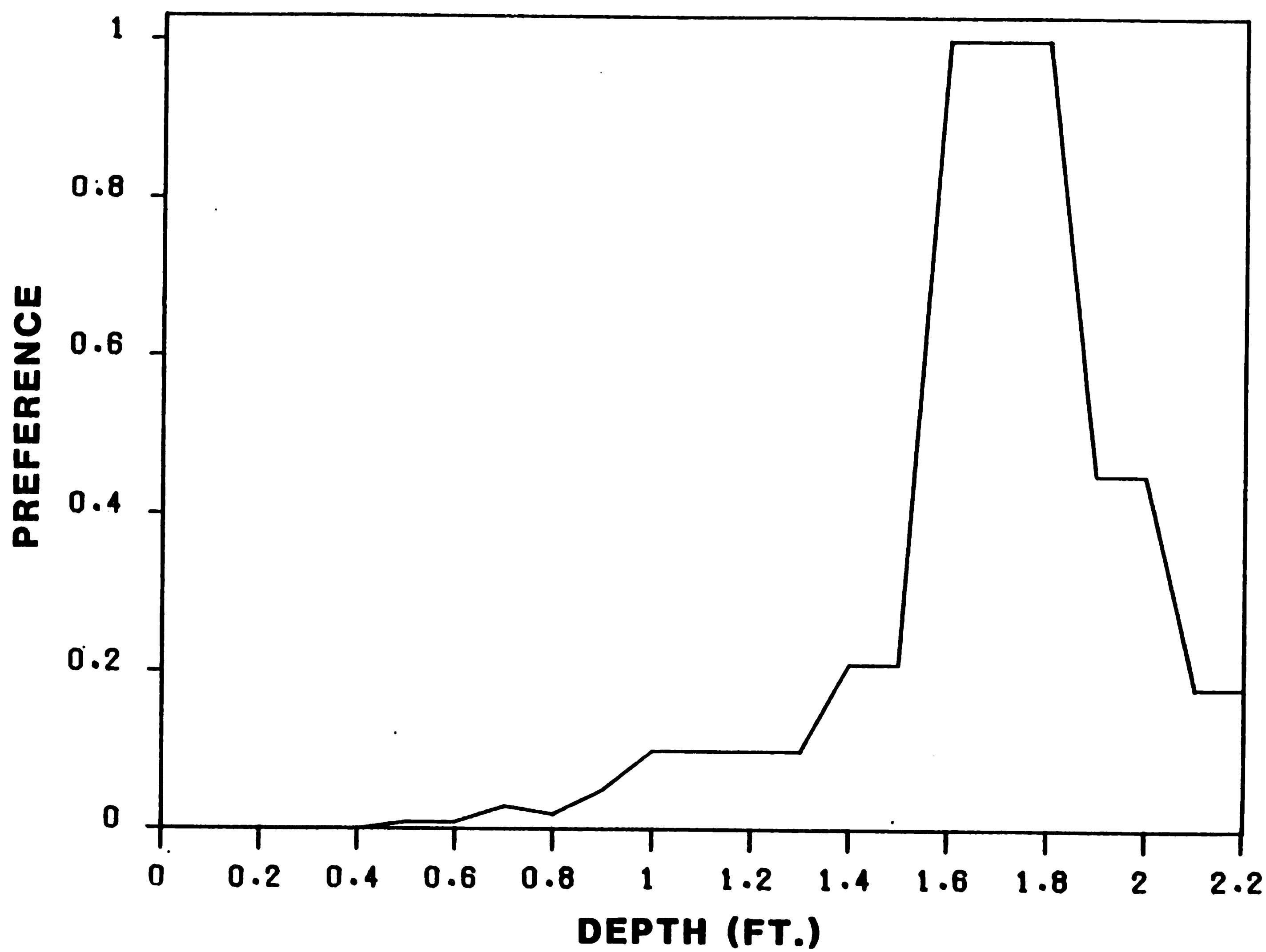


FIGURE 2b: Brown trout depth preference.

To determine fish or aquatic insect habitat the PHABSIM program multiplies the number of square feet of a particular combination of depth, velocity, substrate, and cover present by that combination's JPF. This results in Weighted Usable Area (WUA). Thus, if a particular combination of physical characteristics has a JPF rating of 0.1, and there are 100 square feet of that combination available, then the WUA would be 10 square feet. This indicates that 100 square feet of this type of habitat is equivalent to 10 square feet of optimum habitat. The WUAs for all the habitat types present are summed to give the total WUA. This is usually reported as WUA per 1000 linear feet of stream. The term "habitat area" will be used interchangably with WUA throughout the rest of this thesis.

Preference Curve Construction

The preference that an organism exhibits for a particular habitat component results from the interaction of two functions. The utilization function represents a frequency distribution of sites occupied by a population, given a certain variety of sites from which to select. The availability function describes the range of sites actually available to the population. The preference for any given interval of a physical parameter is defined by Bovee (1982) as:

$$\text{PREFERENCE} = \text{UTILIZATION}/\text{AVAILABILITY}. \qquad \text{(eq. 1)}$$

Thus, in order to accurately estimate preference, both utilization and availability must first be described.

The major concern in data collection is to avoid bias introduced by the sampling gear. The goal is to accurately assess the depth, velocity, substrate, and cover occupied by an individual of the species of interest. Visual observation of undisturbed individuals is the best method of data collection. However, this was impractical for brown trout due to the overgrown, inaccessable nature of Fish Creek. Observation of individual benthic macroinvertebrates would be equally as difficult. For these reasons, electroshocking was used to determine the locations of fish, and a pole mounted Eckman dredge was used to collect the invertebrates. A detailed description of each method is given below.

Brown Trout

A DC backpack electroshocker was used to make all of the brown trout observations. While moving upstream as quietly as possible, the probe was "poked" into the water ahead of the observer. This poking motion helped to prevent fish from being disturbed from their resting places by the advancing electric field. Fish obviously disturbed were ignored. When a fish was shocked, the depth, velocity, substrate, and cover was noted at the point of first observation. No attempts were made to guess where the fish "should have been." Depth and average velocity (measured at 0.6 of the depth) were measured with a wading rod and pygmy water velocity meter, respectively. Substrate and cover were estimated visually. The codes used for this are given in Table 1.

Table 1: Cover and substrate codes used during utilization and availability data collection.

Cover Code	Description
1	No cover
2	Undercut bank less than 1 ft. deep
3	Undercut bank greater than 1 ft. deep
4*	Overhanging vegetation greater than 1 ft. above surface
5	Overhanging vegetation within 1 ft. of the surface
6	Emergent or submerged overhanging vegetation
7	Down timber
8+	Half-log improvement structure
9	Large rock or boulder

Substrate Code	Description
1	Rooted aquatic vegetation
2	Fines (sand, silt)
3	Pebbles or fine gravel (up to 1")
4	Large gravel (1-3")
5	Cobble (3-12")
6*	Boulder (greater than 12")
7*	Bedrock
8**	Detritus
9	Down timber imbedded in the substrate

*eliminated due to impracticality or absence in the habitat
+considered as down timber
**considered as fines

These data constitute the information necessary to build the fish utilization curves. It should be noted that all of these data were collected on fish located out of the study section. This was necessary because a part of this study concerned testing the computer's ability to predict fish locations within the study section. Using data collected on fish found within the study section for construction of the preference curves would have precluded the use of this test. Essentially, using these data would have forced the computer to predict the correct fish locations.

In order to quantify the combinations of depth, velocity, substrate and cover available to the fish, random transects were run across the stream. Depth, velocity, substrate and cover were noted at 1.5 ft. intervals. Three random transects were measured for aproximately every 25 fish collected. The transects were run during fish collection so the availability data reflect the conditions present at the time of utilization data collection.

Data were analyzed using the procedure outlined by Bovee and Cochnauer (1977). The parameters of depth and velocity were divided into intervals of 0.1 ft. and ft. per second (fps), respectively. The number of observations in each interval was tallied. Right-hand and left-hand clustering was performed to reduce the natural variation present. One of the two clusters was chosen on the basis of having the smallest variance and the presence of a single peak. Chi square analysis was performed to discern significant differences between the totals of adjacent clusters. The average of the two clusters was used as the expected value. If two clusters were found to be not significantly different at the 0.1 level, the next adjacent cluster was included and significant differences tested for among the three.

Once significant differences between clusters were established, all clusters were scaled from 0 to 1. The cluster with the most observations was rated as 1 and the other clusters were rated relative to it. This process was followed for both utilization and availability.

Equation 1 was then used to determine preference. Preference curves were constructed by dividing the utilization rating (ranging from 0 to 1) of a given cluster by its availability rating. The values resulting from this division were then normalized from 0 to 1. The preference curve construction procedure is demonstrated, for depth, in Tables 2a-c.

The parameters of substrate and cover were handled differently for two reasons. First, unlike the continuous variables depth and velocity, they are discrete. Thus, the type of cluster analysis performed for depth and velocity would not be appropriate. Second, the computer simulation is set to handle only three physical variables (depth and velocity along with one of the user's choice). Since both substrate and cover can be important, they have been combined into one curve. The method used is adapted from Bovee (1982).

First, cover by substrate utilization and availability matrices were constructed. The cell containing the most observations was given a

Table 2a: Example of utilization curve construction from raw field data.

		Utilization		
Depth	Number observed	Left-hand cluster	Right-hand cluster	Rating
0.0-0.09	0			
0.1-0.19	0			
0.2-0.29	0			
0.3-0.39	0		0	0
0.4-0.49	0	5		
0.5-0.59	5		5	.15
0.6-0.69	0	6		
0.7-0.79	6		16	.48
0.8-0.89	10	23		
0.9-0.99	13		34	1.0
1.0-1.09	21	41		
1.1-1.19	20		38	1.0
1.2-1.29	18	37		
1.3-1.39	19		34	1.0
1.4-1.49	15	39		
1.5-1.59	24		33	1.0
1.6-1.69	9	27		
1.7-1.79	19		26	1.0
1.8-1.89	7	12		
1.9-1.99	5		15	.45
2.0-2.09	10	13		
2.1-2.19	3		6	.18
2.2-2.29	3	6		
2.3 +	3			.01

Table 2b: Example of availability curve construction from raw field data.

Depth	Number observed	Availability: Left-hand cluster	Availability: Right-hand cluster	Rating
0.0-0.09	not used			
0.1-0.19	18	18	36	.19
0.2-0.29	18	38		.40
0.3-0.39	20		50	
0.4-0.49	30	65		.77
0.5-0.59	35		77	
0.6-0.69	42	82		.77
0.7-0.79	40		99	
0.8-0.89	59	95		1.0
0.9-0.99	36		65	
1.0-1.09	29	47		.49
1.1-1.19	18		43	
1.2-1.29	25	46		.49
1.3-1.39	21		35	
1.4-1.49	14	23		.24
1.5-1.59	9		14	
1.6-1.69	5	8		.05
1.7-1.79	3		6	
1.8-1.89	3	3		.05
1.9-1.99	0		4	
2.0-2.09	4	5		.05
2.1-2.19	1		4	
2.2-2.29	3	3		.05
2.3 +	0			

Table 2c: Example of preference curve construction from raw field data.

Depth	Decimal equivalent of utilization/availability	Preference Rating
0.0-0.09	0.0	0
0.1-0.19	0.0	0
0.2-0.29	0.0	0
0.3-0.39	0.0	0
0.4-0.49	0.0	0
0.5-0.59	.19	.01
0.6-0.69	.19	.01
0.7-0.79	.62	.03
0.8-0.89	.48	.02
0.9-0.99	1.0	.05
1.0-1.09	2.04	.1
1.1-1.19	2.04	.1
1.2-1.29	2.04	.1
1.3-1.39	2.04	.1
1.4-1.49	4.17	.21
1.5-1.59	4.17	.21
1.6-1.69	20	1.0
1.7-1.79	20	1.0
1.8-1.89	20	1.0
1.9-1.99	9	.45
2.0-2.09	9	.45
2.1-2.19	3.6	.18
2.2-2.29	3.6	.18
2.3 +	---	---

rating of one, and all other cells were rated relative to it. From this procedure, a utilization and an availability matrix were constructed (as opposed to a curve). Equation (1) was used to construct the preference matrix in a manner similar to that used to construct the preference curves for depth and velocity.

Because the computer will not accept input in the form of a matrix, a curve had to be constructed. Each cell in the preference matrix was given a number, 1 through 42. This number describes a unique combination of substrate and cover and thus can be used as the abscissa in a preference curve. The curve construction is demonstrated in Tables 3a-c.

Benthic Macroinvertebrates

The construction of preference curves for the two species of benthic macroinvertebrates was done differently. As stated previously, utilization data were collected with a pole mounted Eckman dredge. Before going into the field a series of ten random numbers ranging from 1 to 100 was generated using a random number table. A second set of ten numbers ranging from 1 to 10 were similarly generated. These two sets of numbers were paired such that one number in the range 1 to 100 was matched with a number in the range 1 to 10. Once in the field a random point was selected as a starting spot. A number of steps equivalent to the lowest value in the 1 to 100 range were taken upstream from this point. The second number in the pair (in the range 1 to 10) determined

Table 3a: Brown trout utilization cover by substrate matrix.

Utilization

Cover

Substrate	1	2	3	5	6	7	9	
1	0 0	0 0	0 0	1 .01	0 0	0 0	0 0	1
2	0 0	4 .05	4 .05	0 0	7 .08	65 .74	0 0	80
3	1 .04	6 .07	15 .17	4 .05	2 .02	98 1.0	1 .01	117
4	0 0	0 0	0 0	0 0	0 0	3 .03	0 0	3
5	1 .01	1 .01	3 .03	1 .01	0 0	1 .01	2 .02	9
9	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
	2	11	22	6	9	157	3	210

Table 3b: Brown trout cover by substrate availability matrix.

Availability

Cover

Substrate	1	2	3	5	6	7	9	
1	9 .06	0 0	0 0	0 0	0 0	0 0	0 0	9
2	143 .88	4 .02	2 .01	23 .14	6 .04	57 .35	0 0	235
3	162 1.0	1 .01	1 .01	3 .02	2 .01	9 .06	0 0	178
4	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0
5	10 .06	0 0	0 0	C 0	0 0	0 0	0 0	10
9	1 .01	0 Q	0 0	0 0	0 0	0 0	0 0	1
	325	5	3	26	8	66	0	433

Table 3c: Brown trout cover by substrate preference matrix.

Preference

Cover

Substrate	1	2	3	5	6	7	9
1	0 0	0 0	0 0	.01 .01	0 0	0 0	0 0
2	0 0	2.5 .15	5 .29	0 0	2 .12	2.1 .12	0 0
3	.01 0	7 .41	17 1.0	2.5 .15	2 .12	16.67 .98	.01 .01
4	0 0	0 0	0 0	0 0	0 0	.03 .03	0 0
5	.17 .01	.01 .01	.01 .01	.01 .01	0 0	0 0	.02 .02
9	0 0	0 0	0 0	0 0	0 0	0 0	0 0

the number of steps to be taken from the right bank of the stream. A sample was taken at this point. This procedure was repeated using the remaining nine matched pairs of numbers. Thus, the stream was effectively divided into a grid with the matched pairs of random numbers determining the cell within the grid to be sampled. The samples were placed in plastic, sealable bags and taken back to the lab. Once there, the total numbers of Ephemerella spp. and Hydropshyche spp. in each sample were determined by hand-picking.

At the point where the sample was taken, a measurement of depth, velocity, and substrate was taken in the same manner as described for the fish observations. Cover was not noted, as it was felt that depth, velocity, and substrate would be sufficient to describe macroinvertebrate habitat. Because the points at which the samples were taken were determined randomly in the lab, the data collected could be used to determine utilization, availability and preference. The procedure is similar to that described for brown trout, with the exception that the species in question was considered "present" in a sample if more than 10 individuals were found in the sample. The number of samples found with the species of interest "present" was then used in the utilization curve construction. Total numbers of individuals found were not used because of the great variability this introduced into the calculations. The threshold limit of ten was used because it was judged that the few individuals found in some samples were artifacts of drift and not residents of the sampled area.

The data described above can now be used in the PHABSIM process to determine the amount of brown trout, *Ephemerella spp*., and *Hydropsyche spp*. habitat present in the study area at all flows of interest.

A Test of the IFIM

The applicability of the IFIM to midwestern streams was tested in three ways. First, the computer routines perform internal quality control checks as they are run. One of these checks is known as the Velocity Adjustment Factor (VAF). If the VAFs are within acceptable ranges, the computer should be estimating the hydraulic characteristics of the stream accurately. The second way to test the accuracy of the model is to determine if fish within the study section are occupying the sites predicted by the computer to be fish habitat. The final test was a check of the computer's ability to predict depths, velocities, substrates, and covers as they occurred throughout the stream. The three tests are described below.

Velocity Adjustment Factors

As stated earlier, the study section is mapped by taking depth, velocity, substrate, and cover data at specific points along carefully chosen transects. From these data a discharge estimate, (Q), can be made at each transect. All transects should have the same discharge at any one time. However, due to errors made in the field, the discharge estimates for each transect invariably differ slightly. The computer performs a mass balancing procedure in order to "force" all transects to have the same discharge. It does this by adjusting the velocities of each transect until all the discharges match (the user specifies what the actual discharge should be). The more adjusting necessary in order to reach the user specified Q, the less accurate the simulation. The VAFs give the user a measure of the amount of adjusting necessary.

The VAF for any one transect is defined by Milhous et. al. (1984) as:

$$VAF = Q\ computed / Q\ trial. \qquad (eq.\ 2)$$

where Q computed is the discharge specified by the user, and Q trial is the discharge that results from the unadjusted data. A VAF of 1.0 indicates that the field data need no adjustment. VAFs above or below 1.0 indicate increasingly unreliable data. The VAFs resulting from the Fish Creek data were analyzed and a determination of the accuracy of the simulation was made based on the guidelines specified by Milhous et. al. (1984).

Fish Locations

A second test of the accuracy of the simulation involved observation of brown trout in the study area. If the trout are occupying the areas described by the computer as habitat, the simulation must be accurate. Brown trout were collected by electroshocking and their location triangulated using permanent reference stakes set up in the study area. These locations were then noted on a map of the study section detailing the fish habitat locations as estimated by the computer. Comparison of actual fish locations to computer predicted habitat locations provides a qualitative test of the computer's ability to simulate brown trout habitat. A quantitative measure involves testing the relationship between habitat quality (as measured by WUA) and the number of fish found in that habitat. This was done on a transect by transect basis.

The average WUA found for each transect over the study period should correlate to the number of fish found at that transect over the same period. In other words, more fish should be found at transects the computer predicts to be high quality habitat compared to the number found at low quality transects. The average WUA for each transect was generated by computer simulation and a test of significance between this value and the number of fish captured during the study at each transect was made using the nonparametric statistic, Kendall's Tau (Lehner, 1979). A nonparametric statistic was necessary due to the non-homogeneous nature of the variances involved.

Depth, Velocity, Substrate, and Cover Predictions

As noted previously, fish locations within the study section were determined bi-monthly. At each spot a fish was captured, a depth, velocity, substrate, and cover measurement was taken. The computer was then used to predict the depth, velocity, substrate, and cover present at that spot based on the streamflow present at the time of fish collection. Thus, computer predicted depth, velocity, substrate, and cover could be directly compared to actual depth, velocity, substrate, and cover.

These three tests should be sufficient to determine the applicability of the model to the midwest. The VAFs and the depth, velocity, substrate, and cover checks will give an indication of the model's ability to simulate the hydraulics of midwestern streams. The fish locations will test the model's ability to actually describe trout habitat.

The Relationship of Habitat Availability to Population Density

The IFIM is only designed to estimate the amount of habitat present at different flows. It does not estimate the number of fish or aquatic insects that can be supported by these varying amounts of habitat. In order to determine the relationship between available habitat and brown trout population levels, bimonthy population estimates were made. However, due to inclement weather, not all sampling dates were exactly 14 days apart. These estimates could then be regressed against the average amount of habitat present in the study section over the previous two week period and a test of significance made.

Population estimates were made by making two shocking trials, without replacement, through the study section. Because of the small size of Fish Creek, these two trials were assumed to capture all of the trout present in the study area.

In order to estimate available habitat, a continuous water level recorder (Leupold and Stevens, Model F) was installed just above the study section. This recorder, once calibrated, supplied a continuous record of the discharges occurring in the study section. By taking the average daily flow in the study section over the two week interval between population estimates, and simulating this flow with the PHABSIM procedure, an estimate of average daily habitat over the interval was made. This could then be compared to the population estimate made at the end of that interval.

The Relationship of Habitat Availability and Growth Rates

Along with population levels, biologists and anglers are concerned with growth rates. In theory, the amount of habitat present in an area should have a direct influence on the growth rate of the fish in that area. To determine if this relationship existed, bimonthly estimates of individual growth rates were made.

Fish were collected by electroshocking (at the same time the population estimates were made). Each individual collected was identified with a small numbered tag (dimensions: 10mm * 3mm * 1mm) attached to the dorsal surface of the caudal peduncle by use of a lightweight nylon thread. These tags were fairly permanent, with fish tagged in June, 1983 retaining their tags until the completion of the study in August, 1984. Once tagged, the fish were weighed on a triple beam balance using a method of difference. A small bucket with approximately six inches of water in it was placed on the scale and weighed. The fish was then added and the total weight determined. Fish weight was determined by substraction. In this manner fish weight could be determined to the tenth of a gram.

Individual growth rates could be determined for fish caught on two successive sampling dates. Growth rate was defined as:

$$\text{Growth Rate} = W2-W1/W1/\text{days} \qquad \text{(eq. 3)}$$

where W1= fish weight at sample time t-1,

W2= fish weight at sample time t, and

days= the number of days between sampling times.

The resulting value is in units of grams/gram/day. The average growth rate of recaptured fish was then calculated. This value was regressed against the average habitat availability over the previous two week period.

RESULTS

Fish Preference Curves

A total of 210 individual fish utilization and 433 availability observations were made. The depth interval most utilized by brown trout was 1.5 to 1.59 ft., with 24 observations. The depth most available to fish was in the range 0.8 to 0.89 ft., with 59 observations. Combining depth utilization and availability results in the highest depth preference occurring between 1.6 and 1.79 ft. Because of the extremely low flows during the time of data collection, information about the preference for depths greater than 1.8 ft. is lacking. The assumption was made that depths greater than 1.8 ft. are as preferred as the interval 1.6 to 1.79 ft. Brown trout utilization, availability, and preference curves for depth are shown in Figures 2a and b.

The velocity most utilized by fish was in the range 0.6 to 0.69 fps with 32 observations. The most available velocity was in the range 0.3 to 0.39 fps with 37 observations. The preferred velocity is in the range 0.1 to 0.69 fps. Brown trout utilization, availability, and preference curves for velocity are shown in Figures 3a and b.

The most frequently utilized combination of cover and substrate was down timber and gravel with 88 observations. The most available combination was no cover and gravel with 162 observations. The most preferred combination was undercut banks greater than 1 ft. deep and gravel. The brown trout utilization, availability, and preference matrices are shown in Tables 3a,b, and c. The resulting preference curve is shown in Figure 4.

Fish Habitat Availability

The IFIM model used these preference curves along with the stream mapping data to arrive at estimates of brown trout habitat present at flows of 6 to 30 cfs.

The Weighted Usable Area vs. discharge plot for brown trout is shown in Figure 5. The average daily flows by month as recorded by the water level recorder are shown in Figures 6a-h. The estimate of average

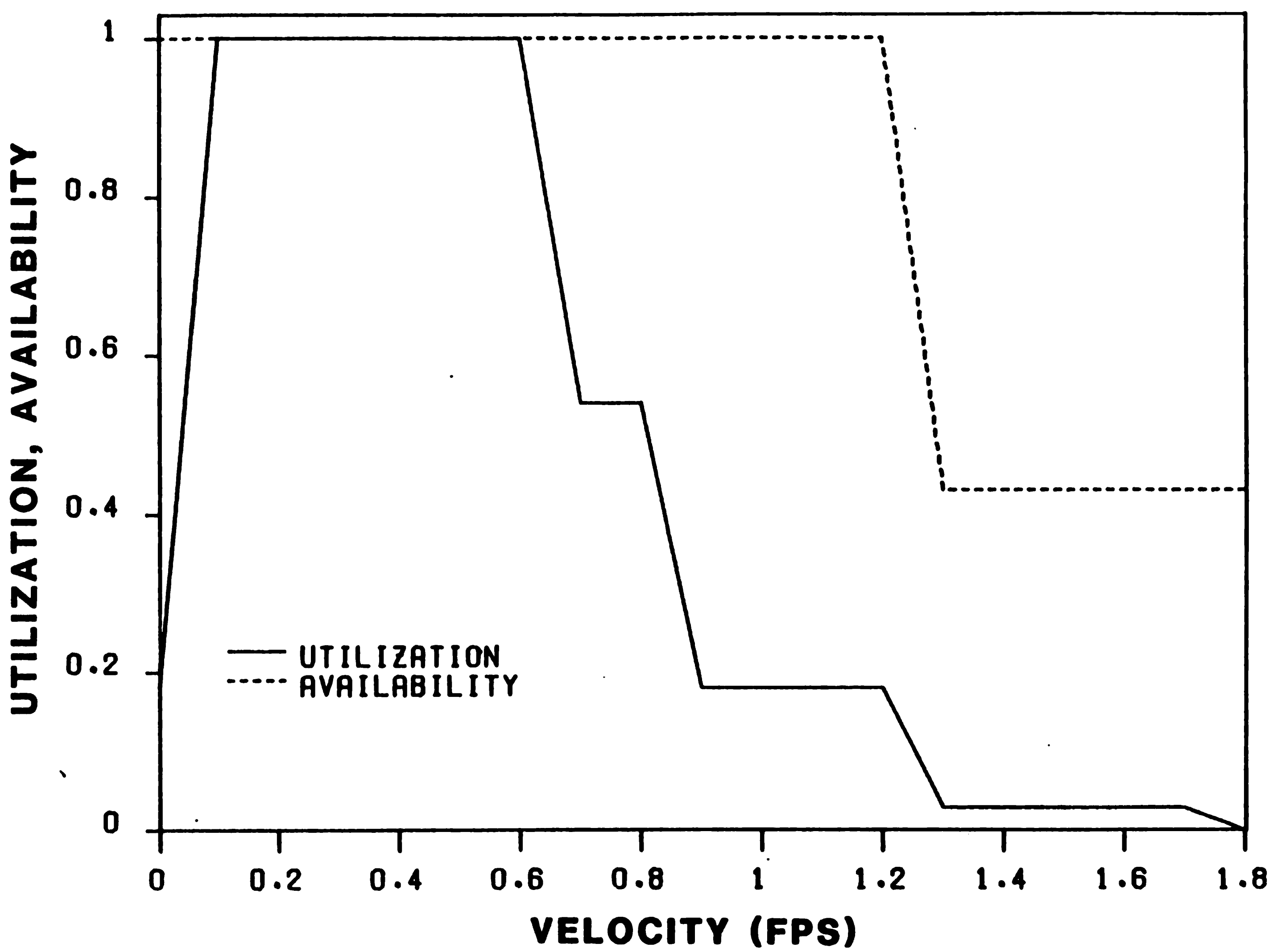


FIGURE 3a: Brown trout velocity utilization and availability.

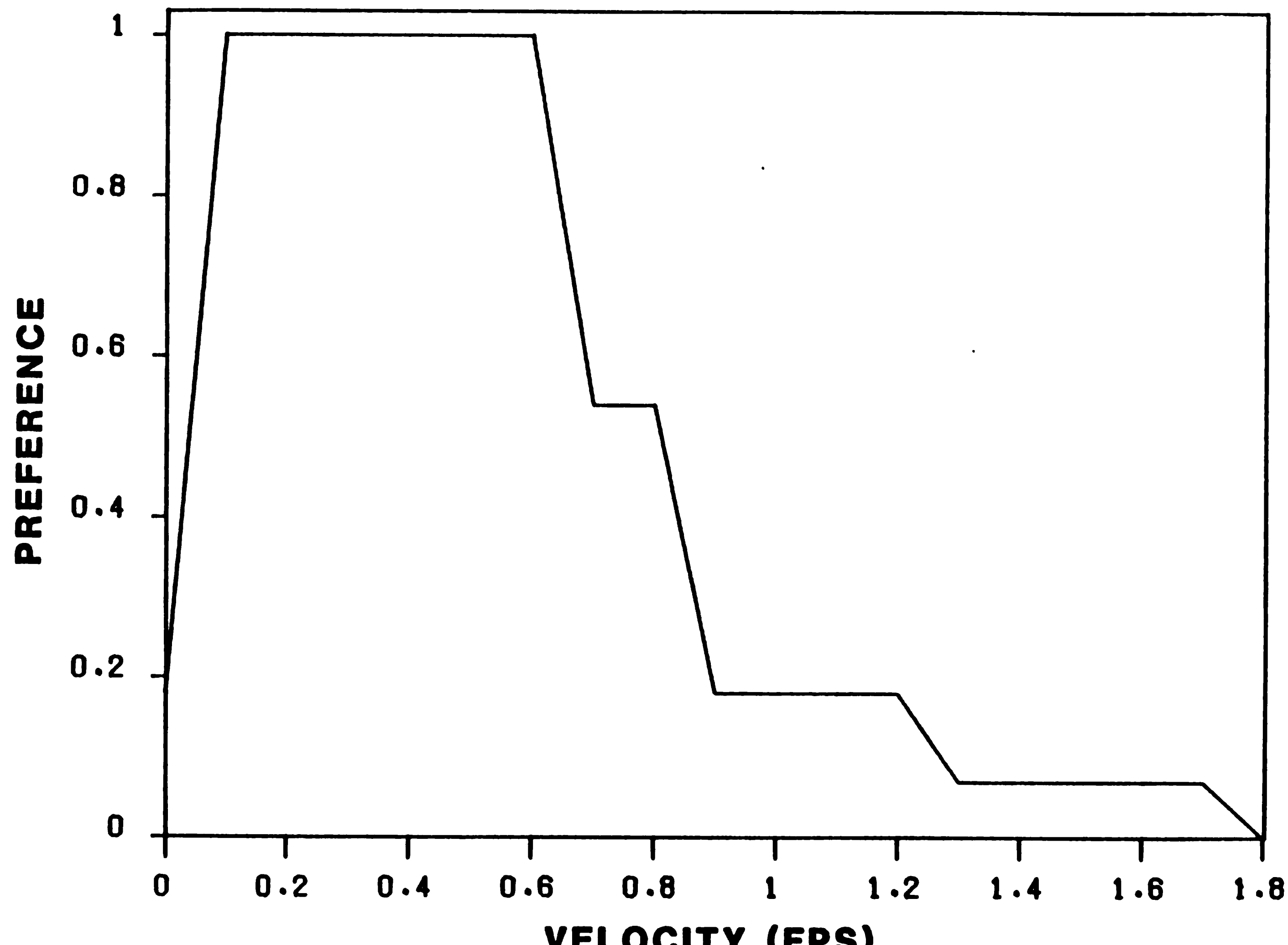


FIGURE 3b: Brown trout velocity preference.

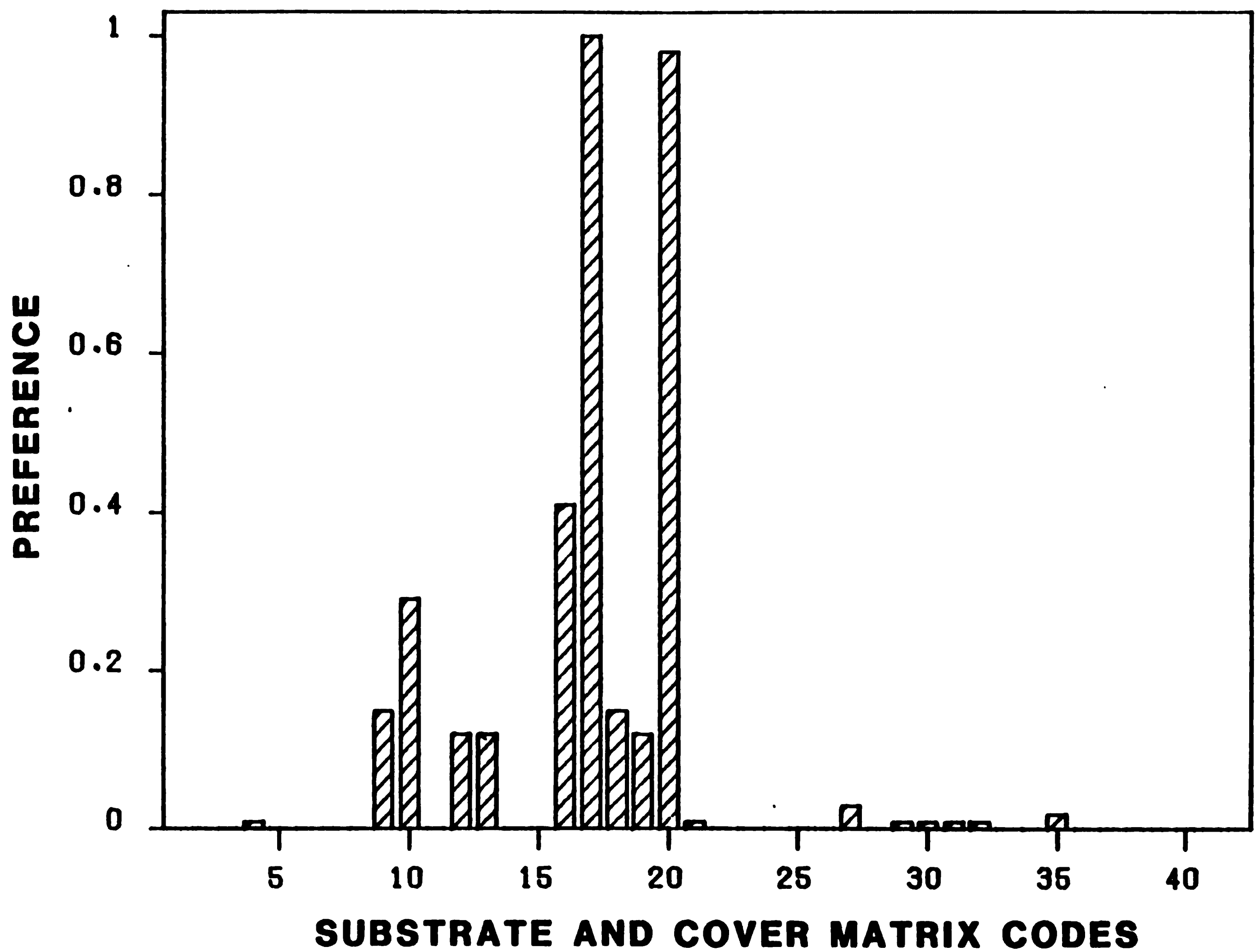


FIGURE 4: Brown trout cover by substrate preference curve developed from Table 3(c).

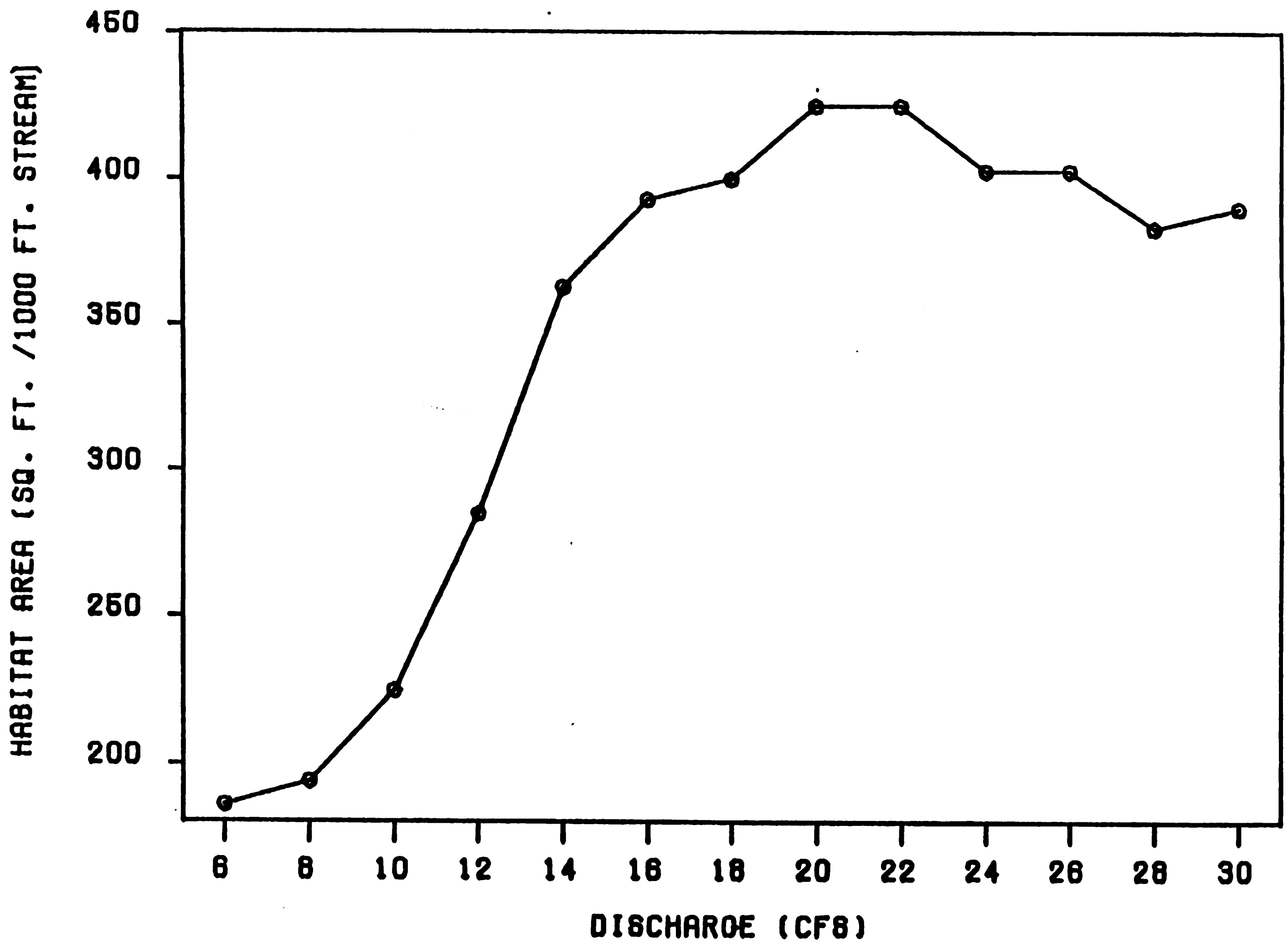


FIGURE 5: Brown trout habitat area versus discharge curve.

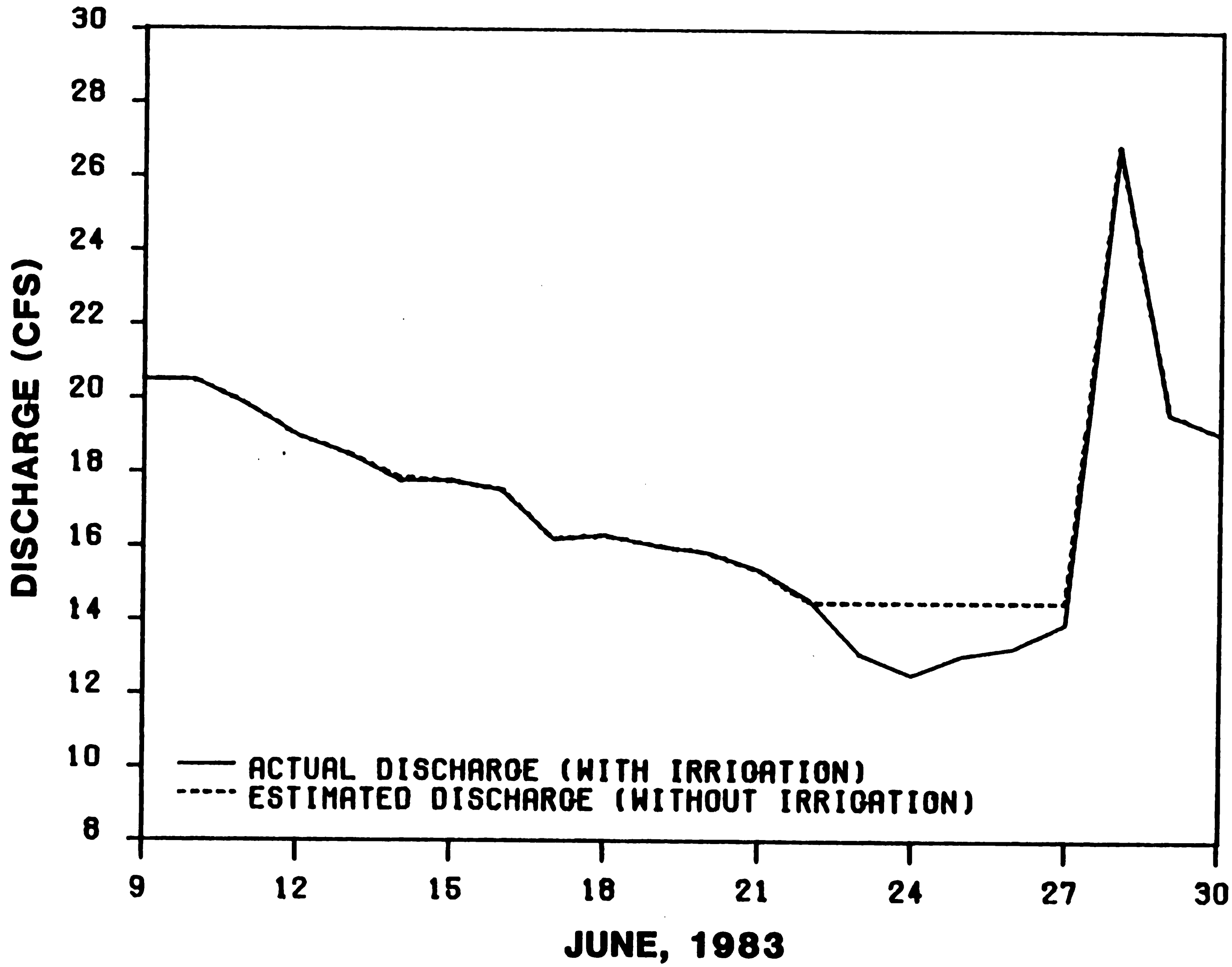


FIGURE 6a: Hydrograph for June, 1983.

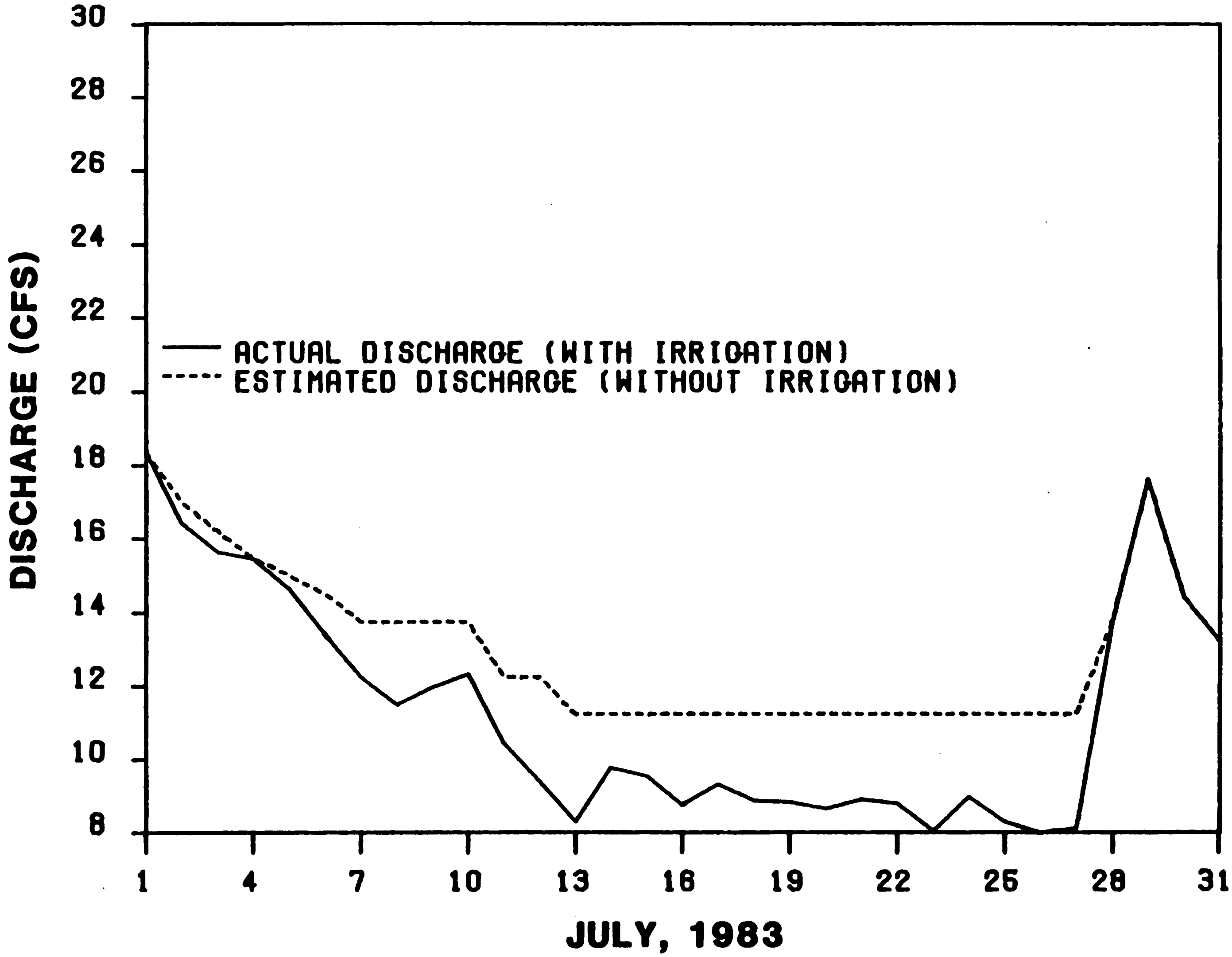


FIGURE 6b: Hydrograph for July, 1983.

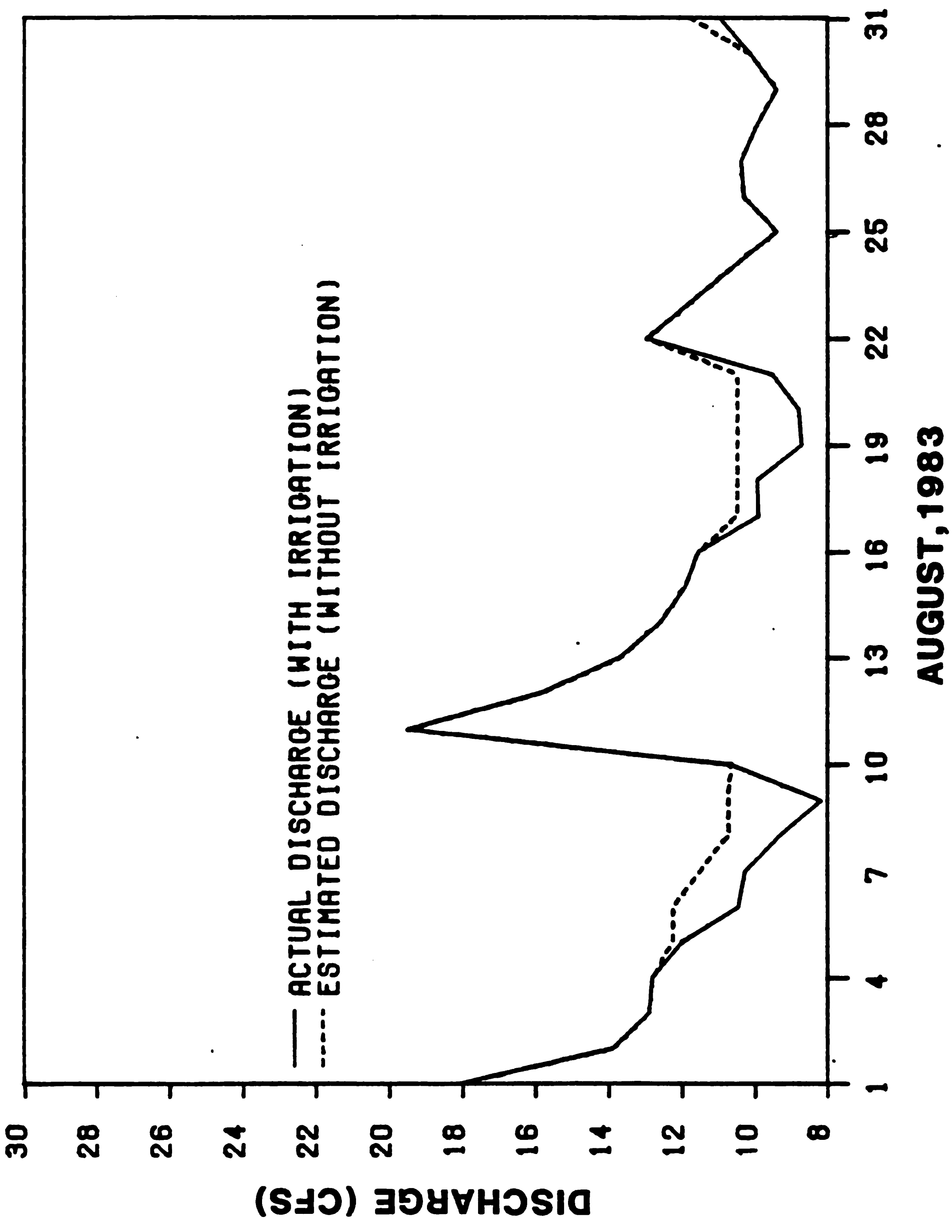


FIGURE 6c: Hydrograph for August, 1983.

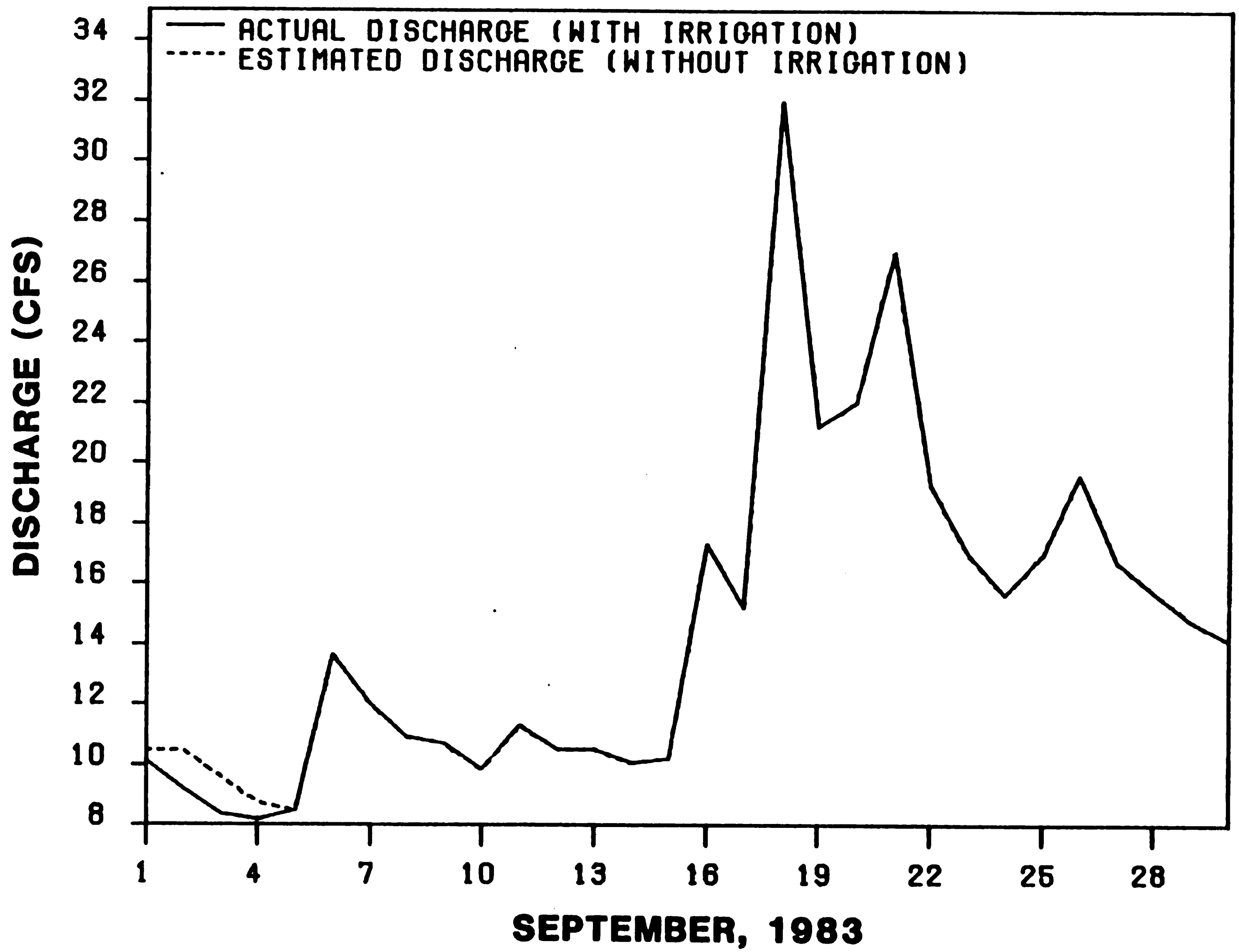


FIGURE 6d: Hydrograph for September, 1983.

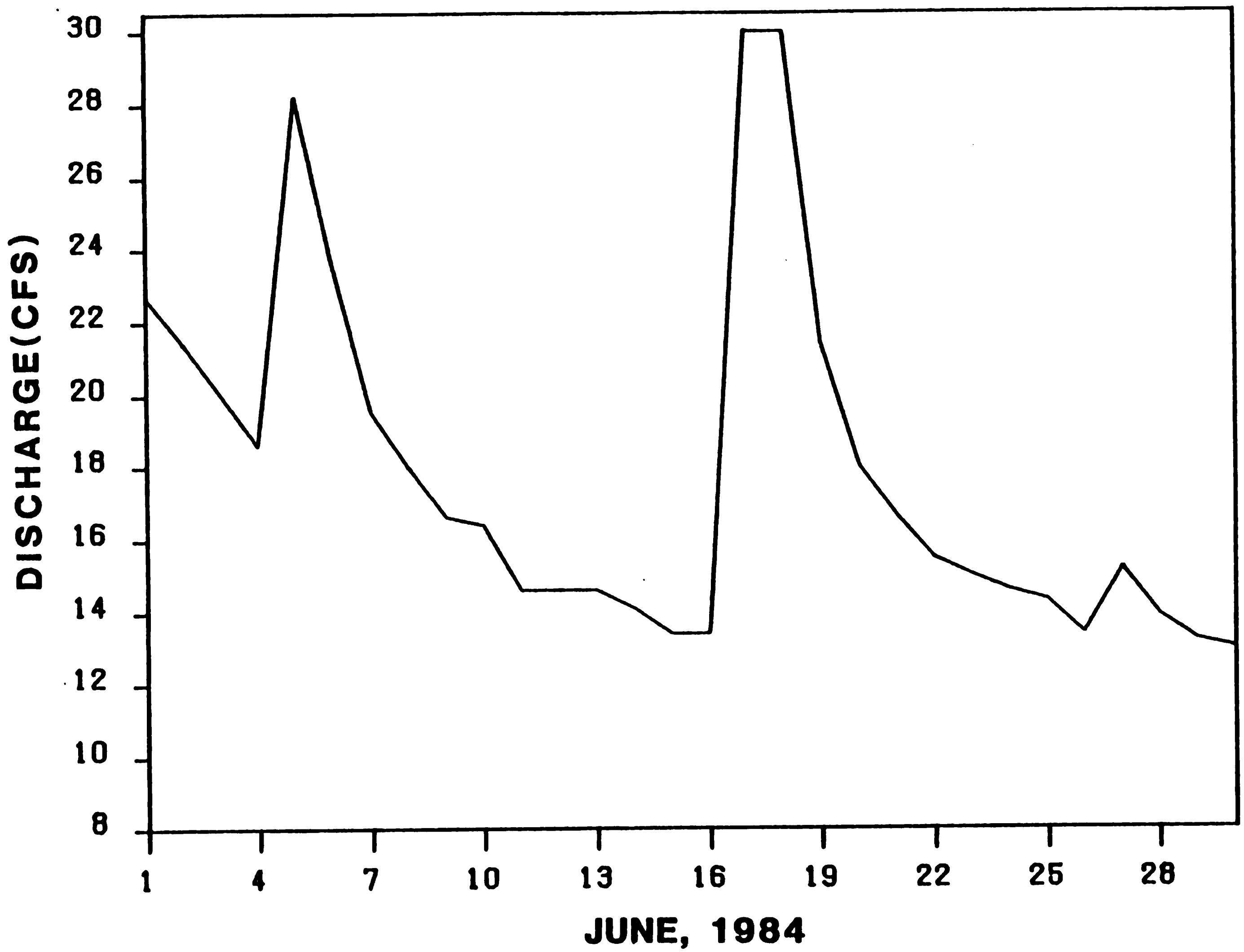


FIGURE 6e: Hydrograph for June, 1984.

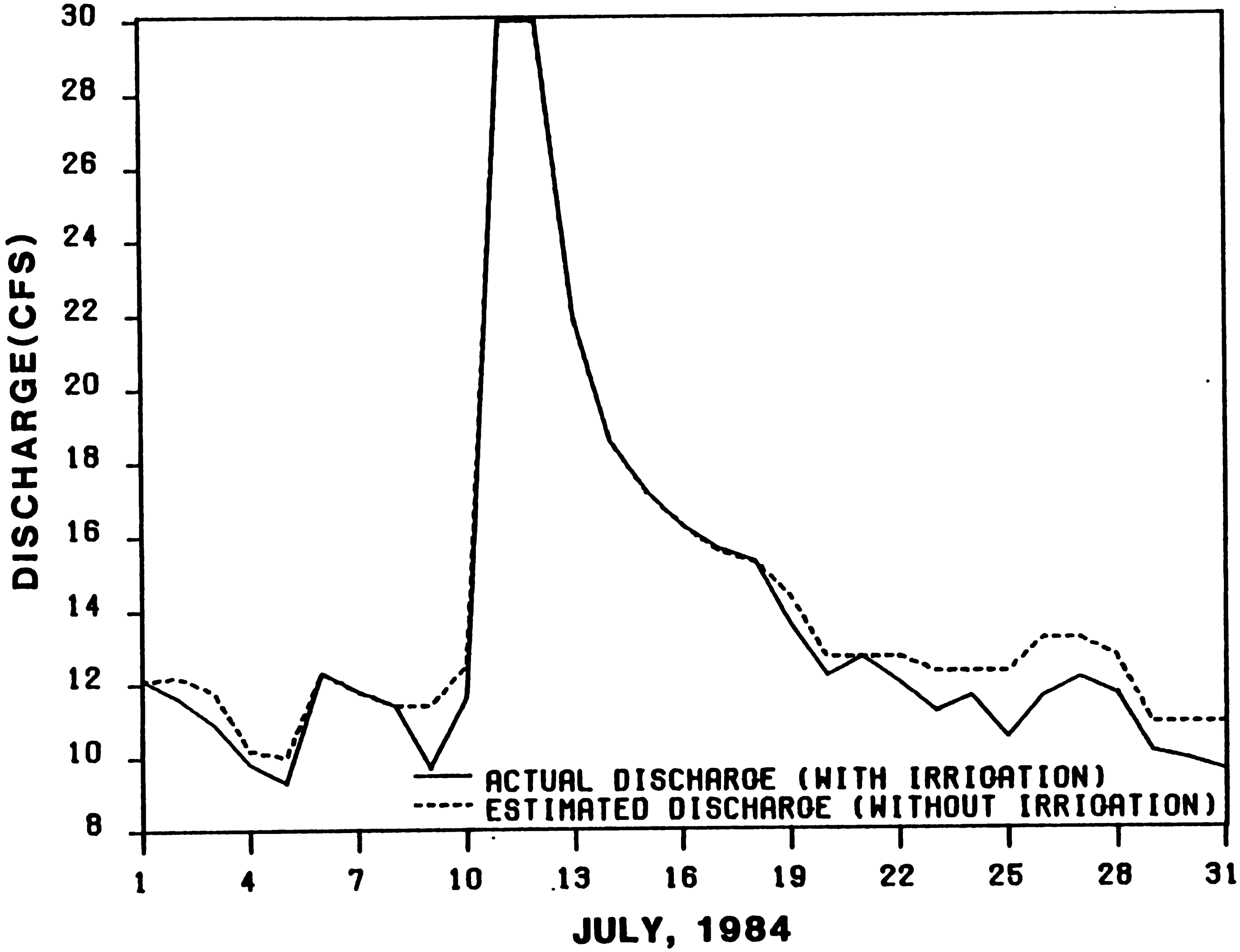


FIGURE 6f: Hydrograph for July, 1984.

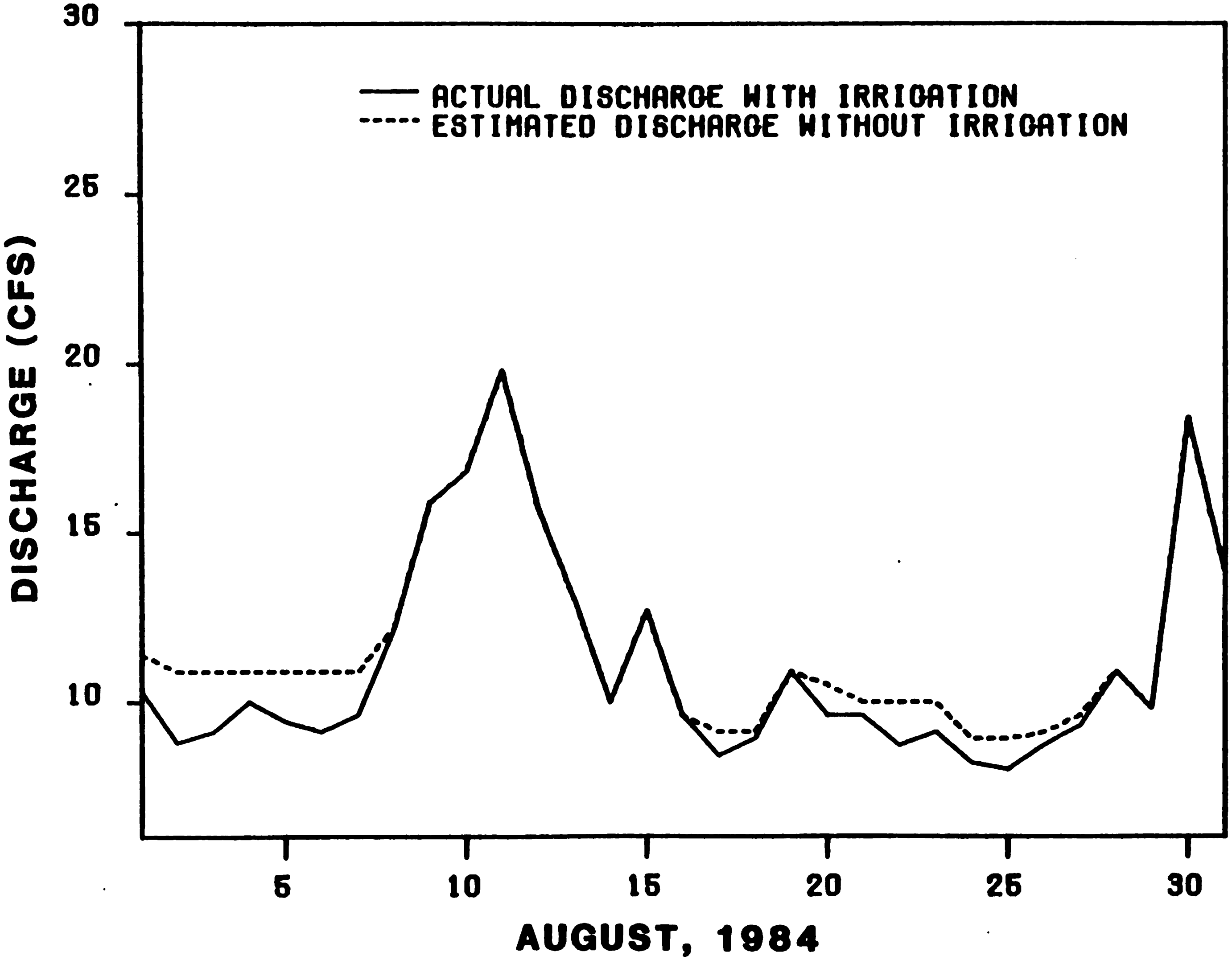


FIGURE 6g: Hydrograph for August, 1984.

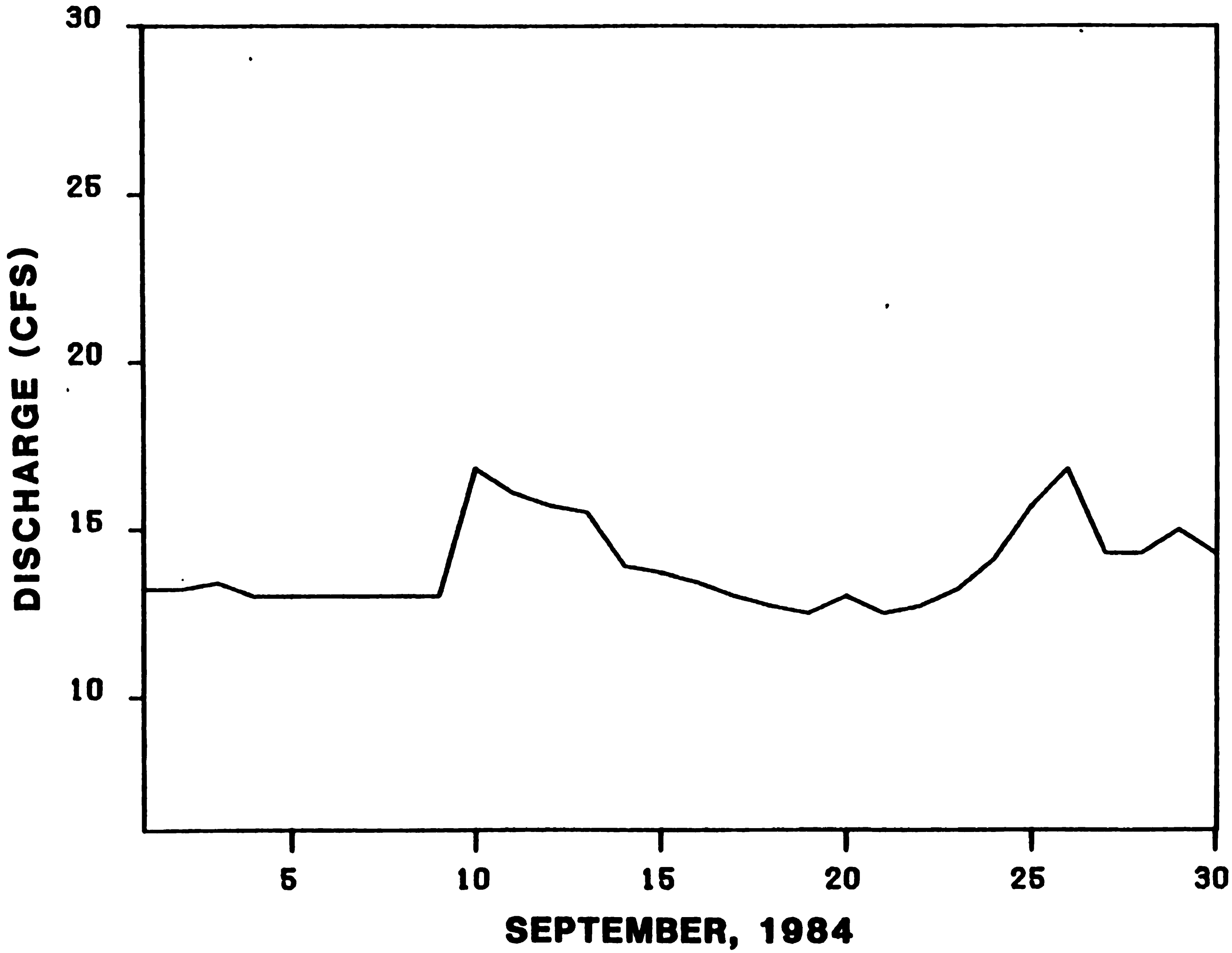


FIGURE 6h: Hydrograph for September, 1984.

daily flow that would have existed without irrigation was made based on flows recorded when little or no irrigation was occurring). The combination of these curves yields the brown trout habitat time series (Figures 7a-h).

Insect Preference Curves

A total of 209 insect samples were taken. The resulting depth, velocity, and substrate availability curves are given in Figures 8a-c. Depth utilization and preference curves for both species are given in Figures 9a and b. Velocity utilization and preference curves are given in Figures 10a and b. The depth preference curve for *Hydropsyche spp.* shows three peaks. This was a result of insufficient data to accurately detail this species depth preference. It was judged that all depths in the range 0.01 to 2.0 should be rated as 1.0. The resulting curve (not shown) was used in all computer simulations. Substrate utilization and preference curves are given in Figures 11a and b. It should be noted that the insect utilization and preference curves may contain significant errors. The reason for this will be treated in the discussion section.

Insect Habitat Availability

The IFIM model used these preference curves along with the stream mapping data to arrive at estimates of Ephemerella spp. and Hydropsyche spp. habitat present at flows of 6 to 30 cfs.

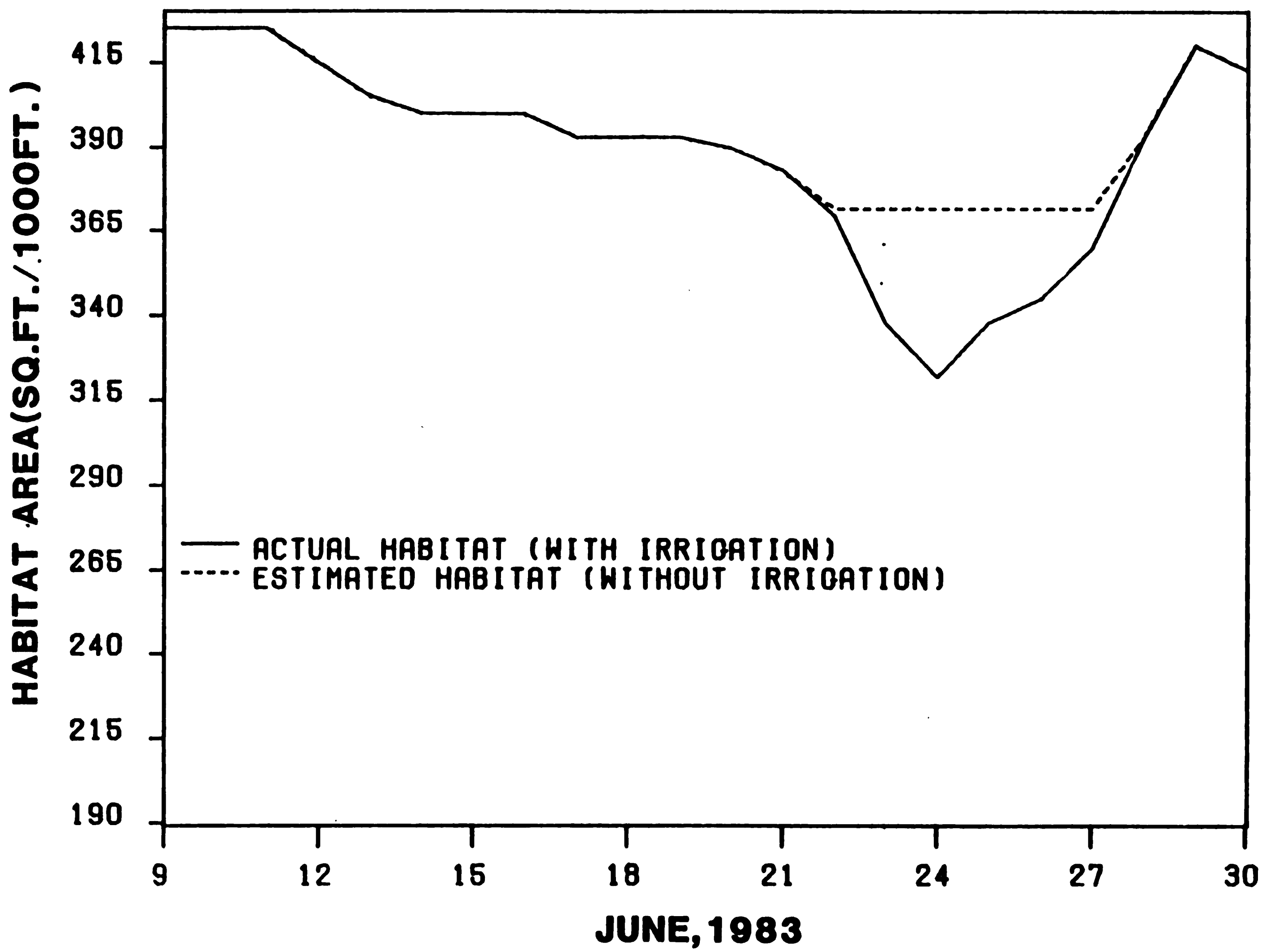


FIGURE 7a: Brown trout habitat time series for June, 1983.

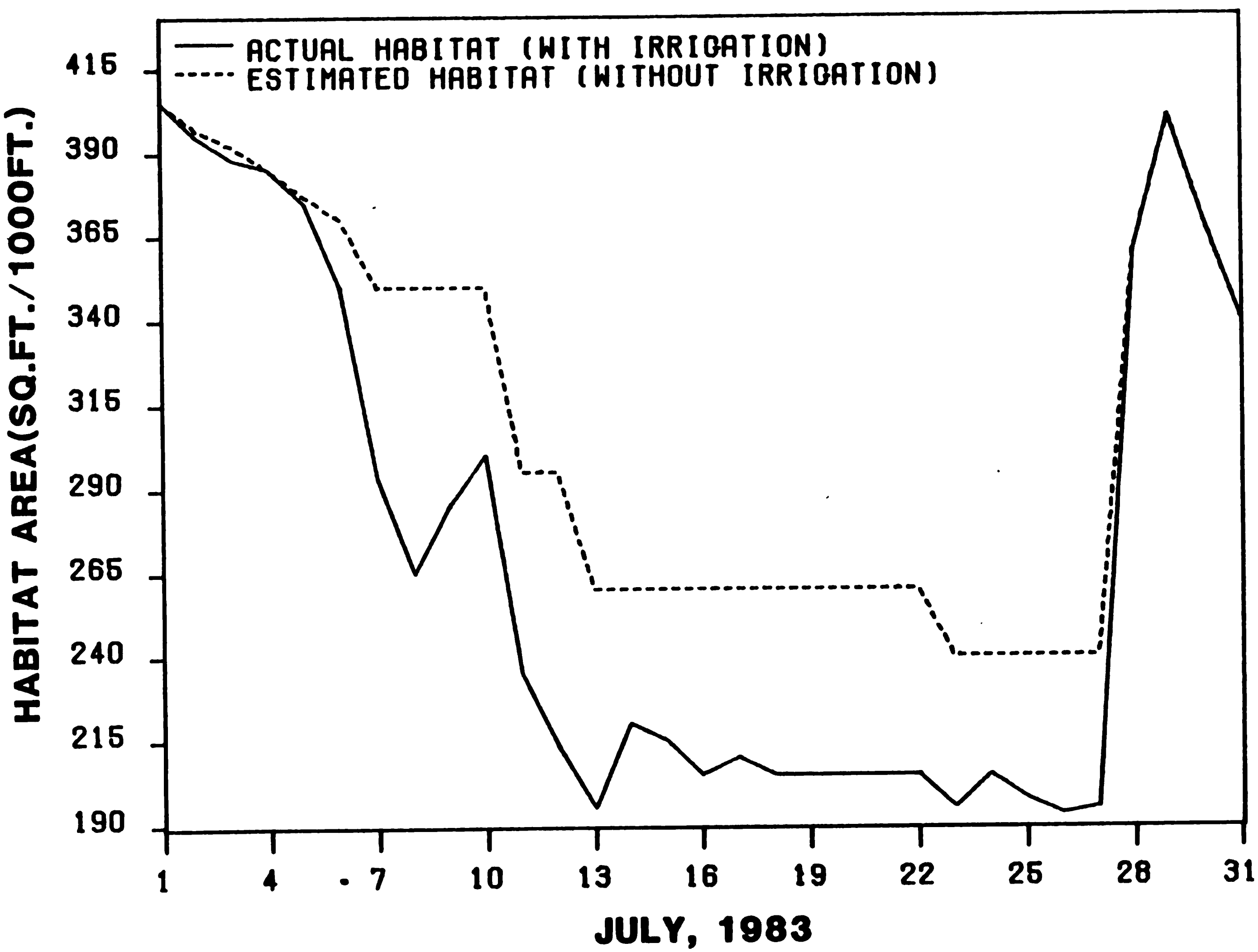


FIGURE 7b: Brown trout habitat time series for July, 1983.

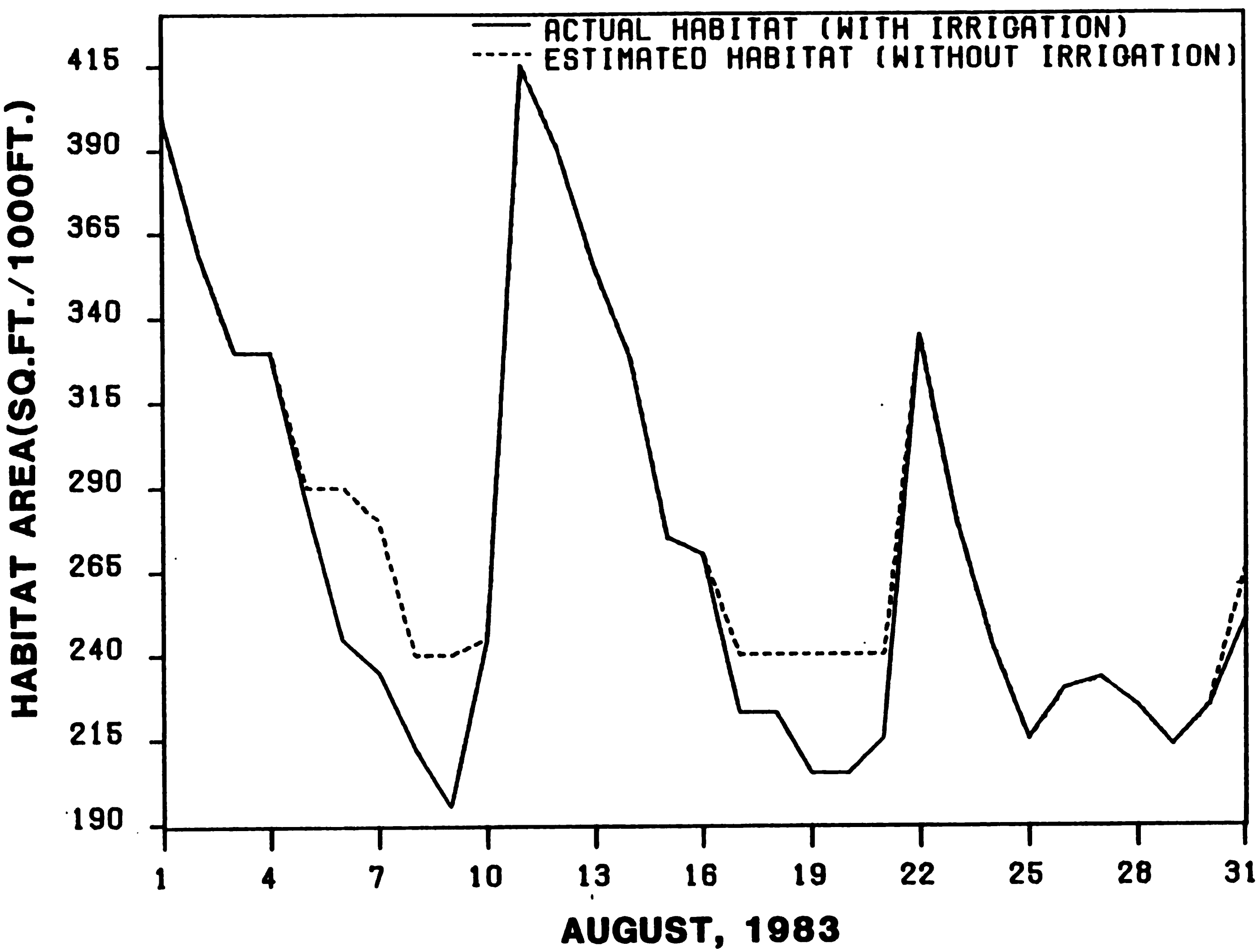


FIGURE 7c: Brown trout habitat time series for August, 1983.

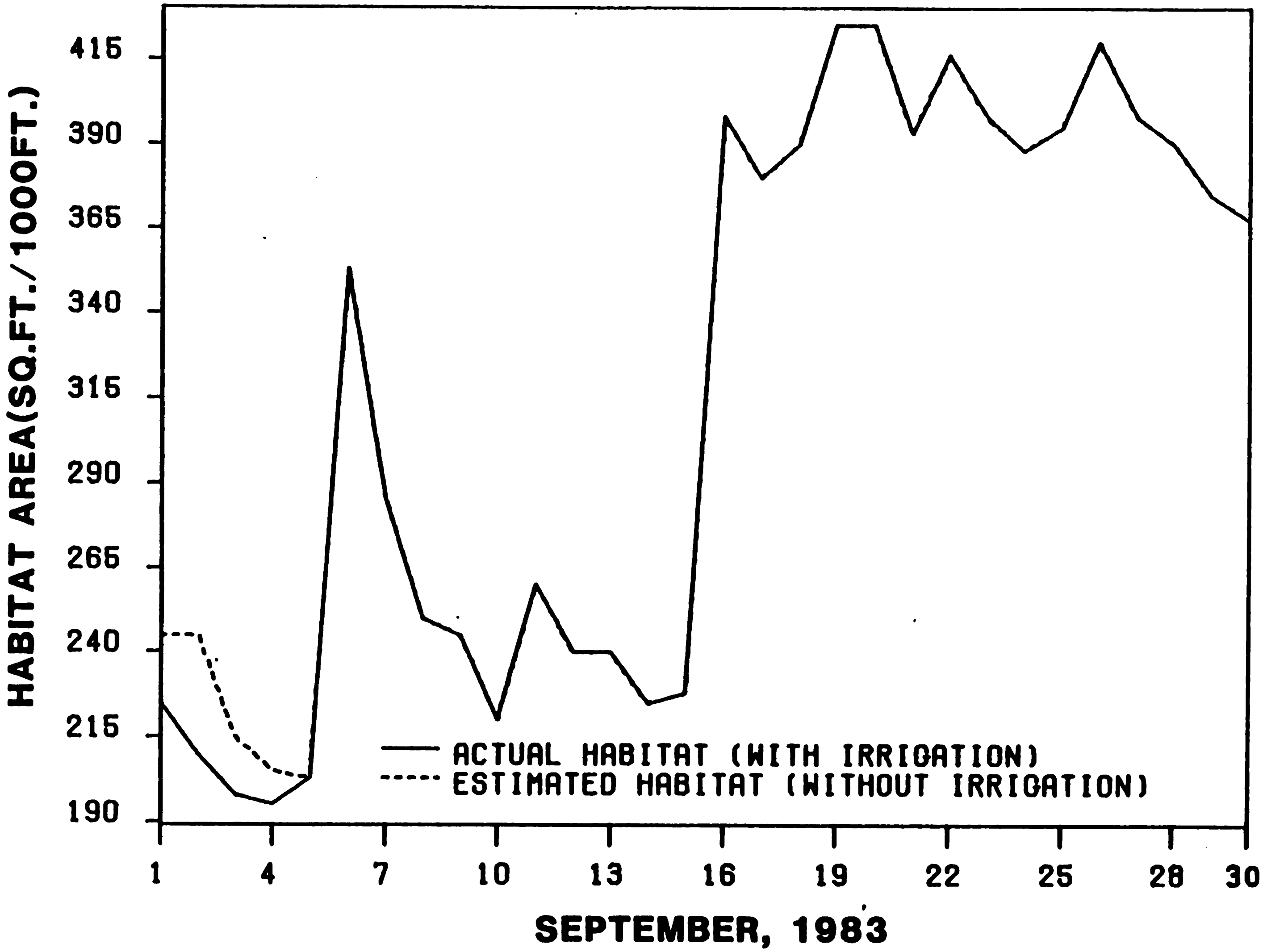


FIGURE 7d: Brown trout habitat time series for September, 1983.

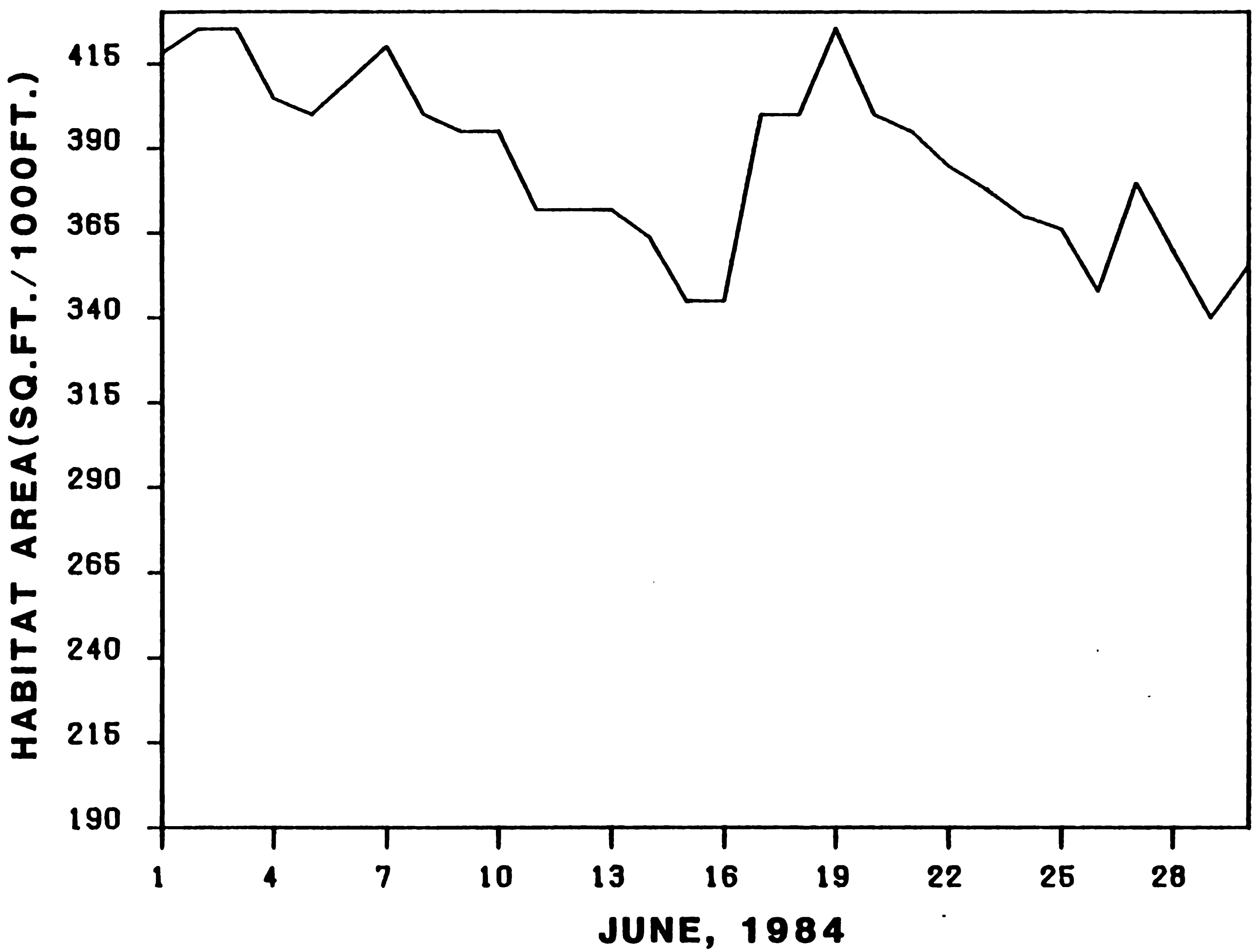


FIGURE 7e: Brown trout habitat time series for June, 1984.

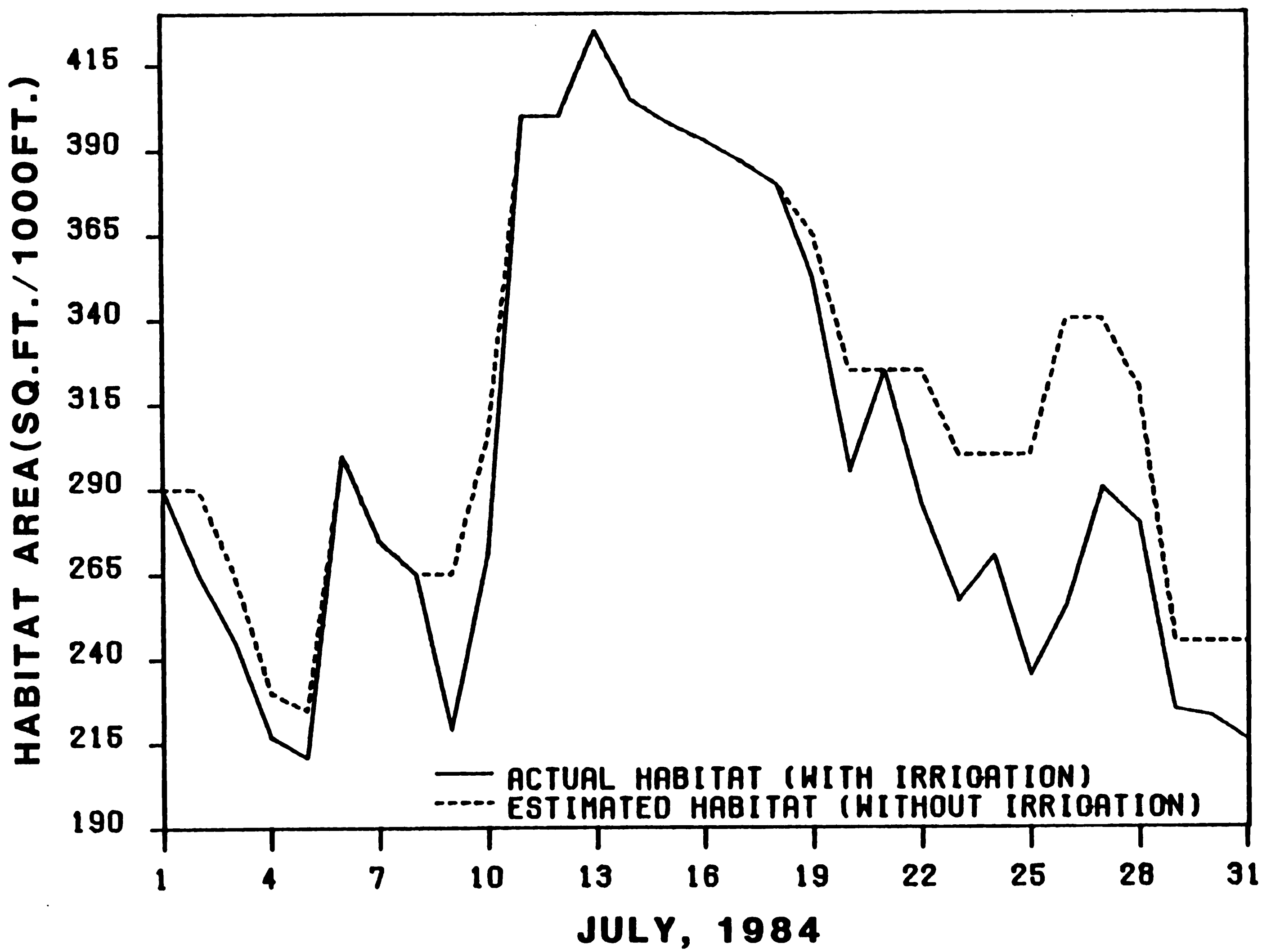


FIGURE 7f: Brown trout habitat time series for July, 1984.

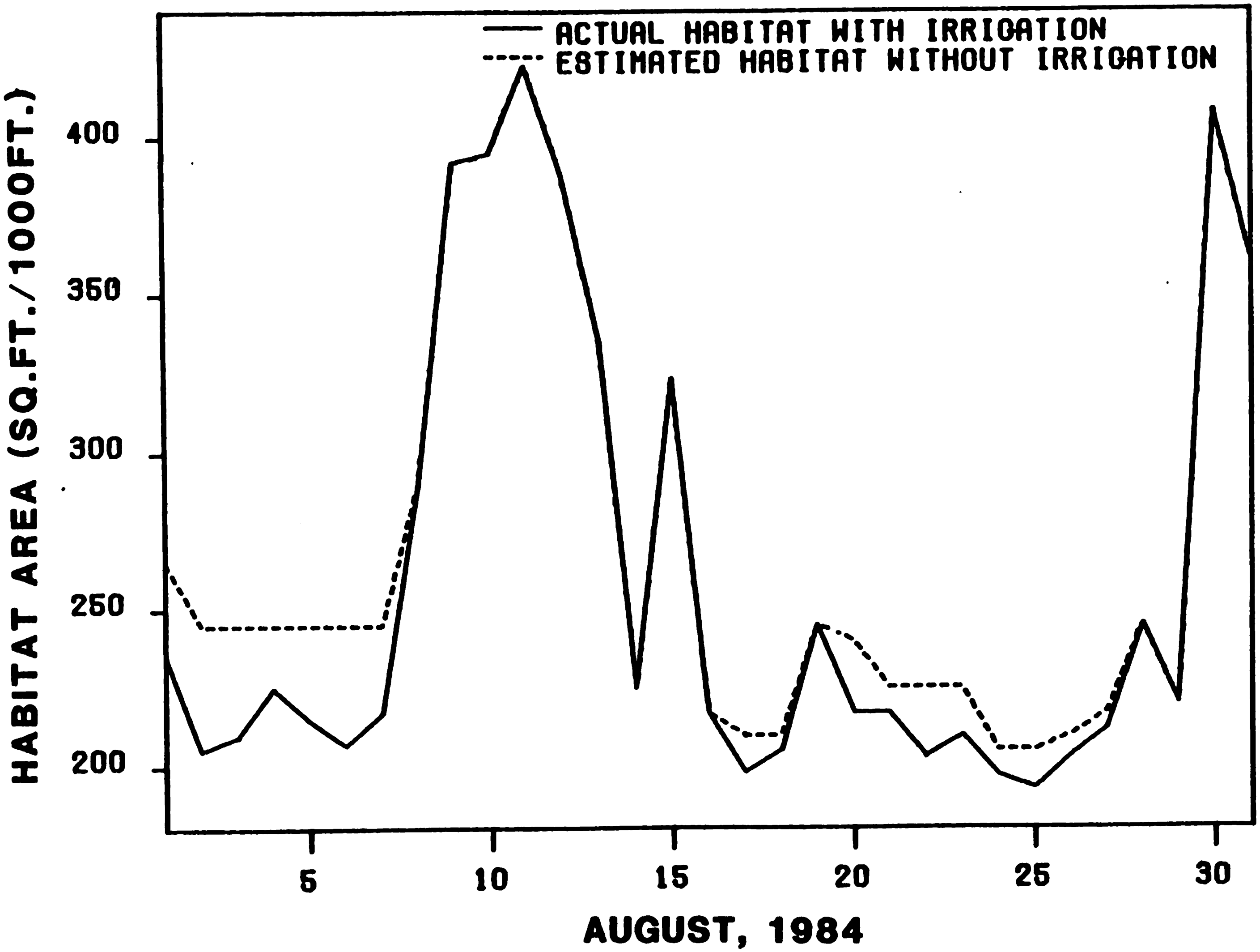


FIGURE 7g: Brown trout habitat time series for August, 1984.

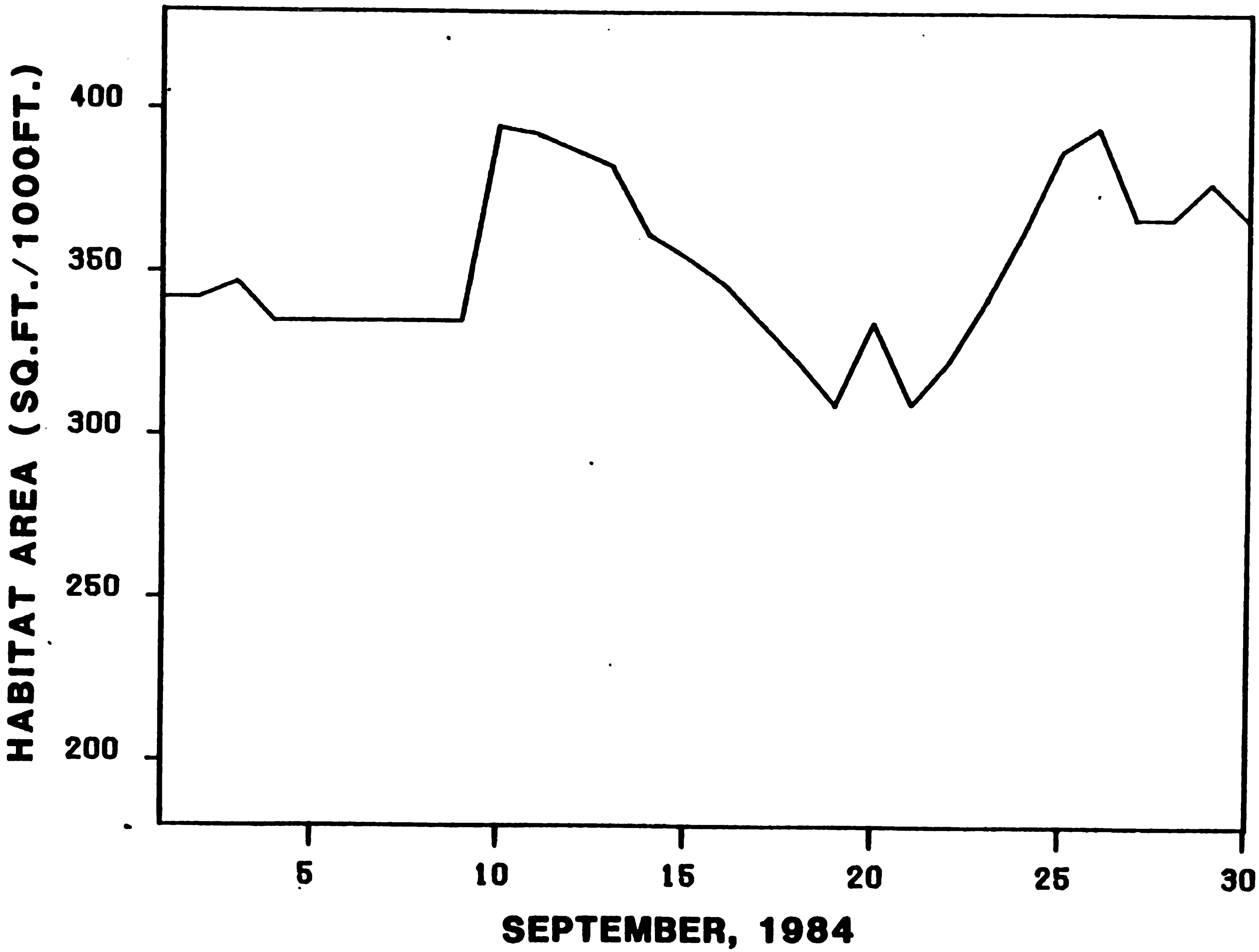


FIGURE 7h: Brown trout habitat time series for September, 1984.

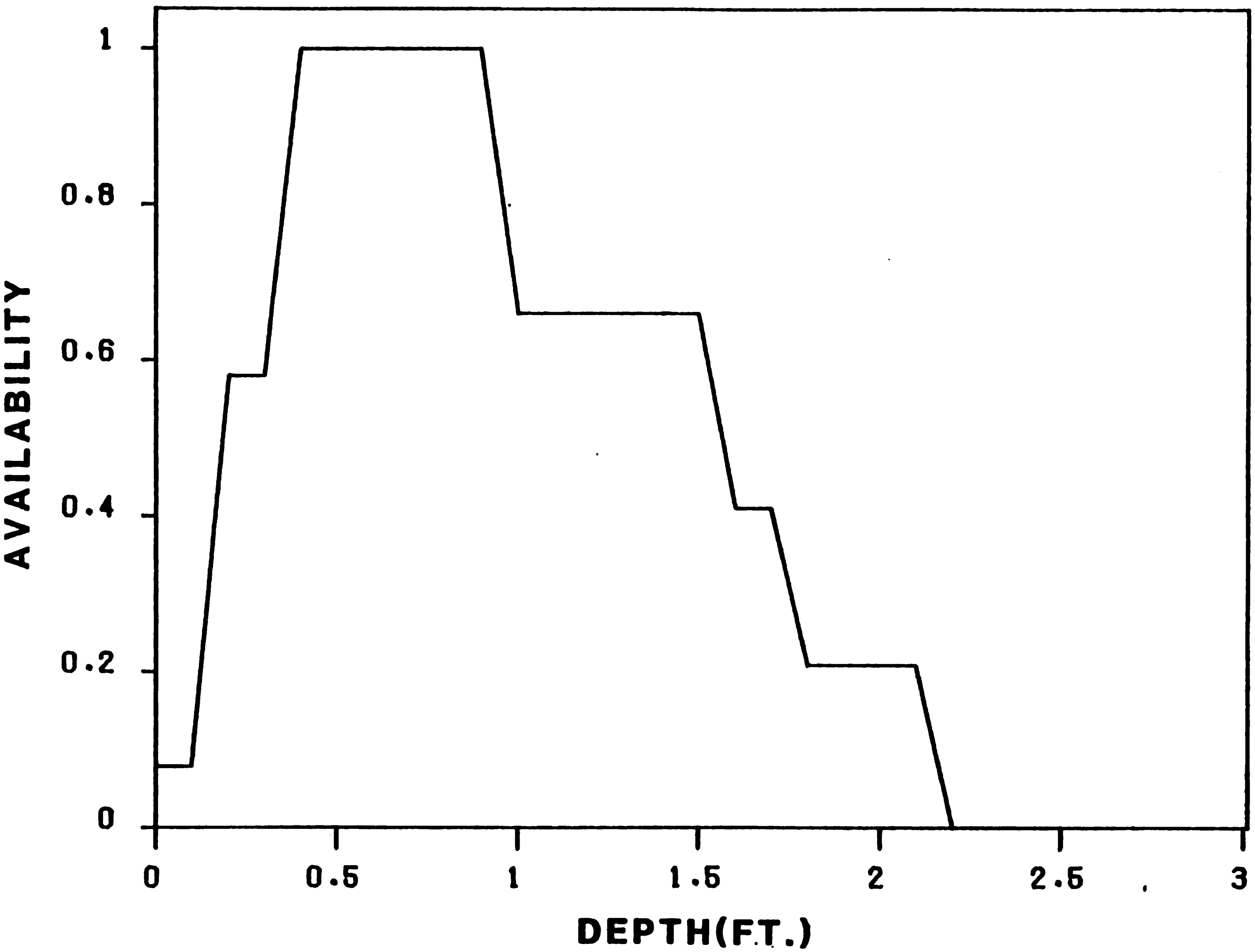


FIGURE 8a: Aquatic insect depth availability curve.

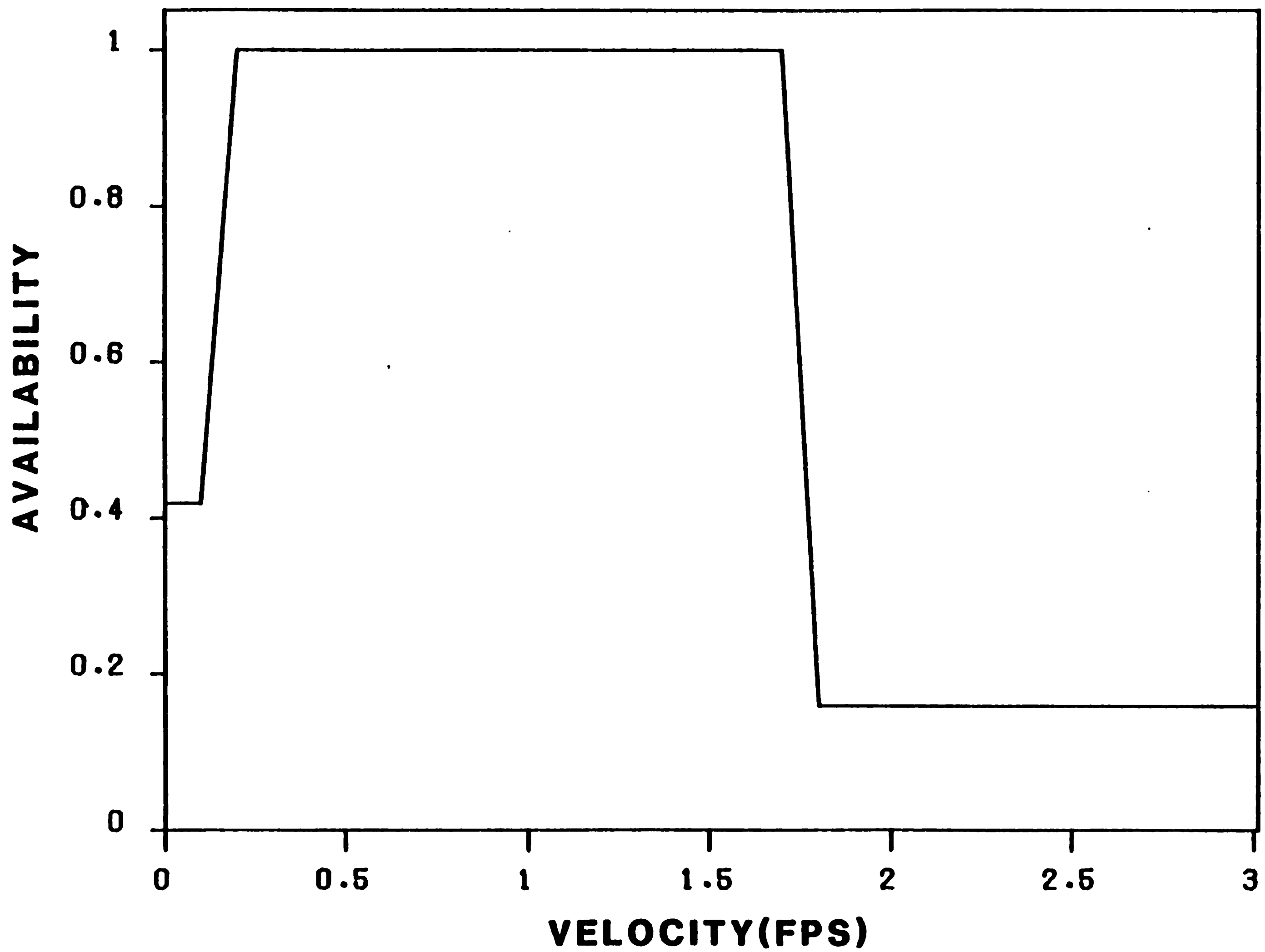


FIGURE 8b: Aquatic insect velocity availability curve.

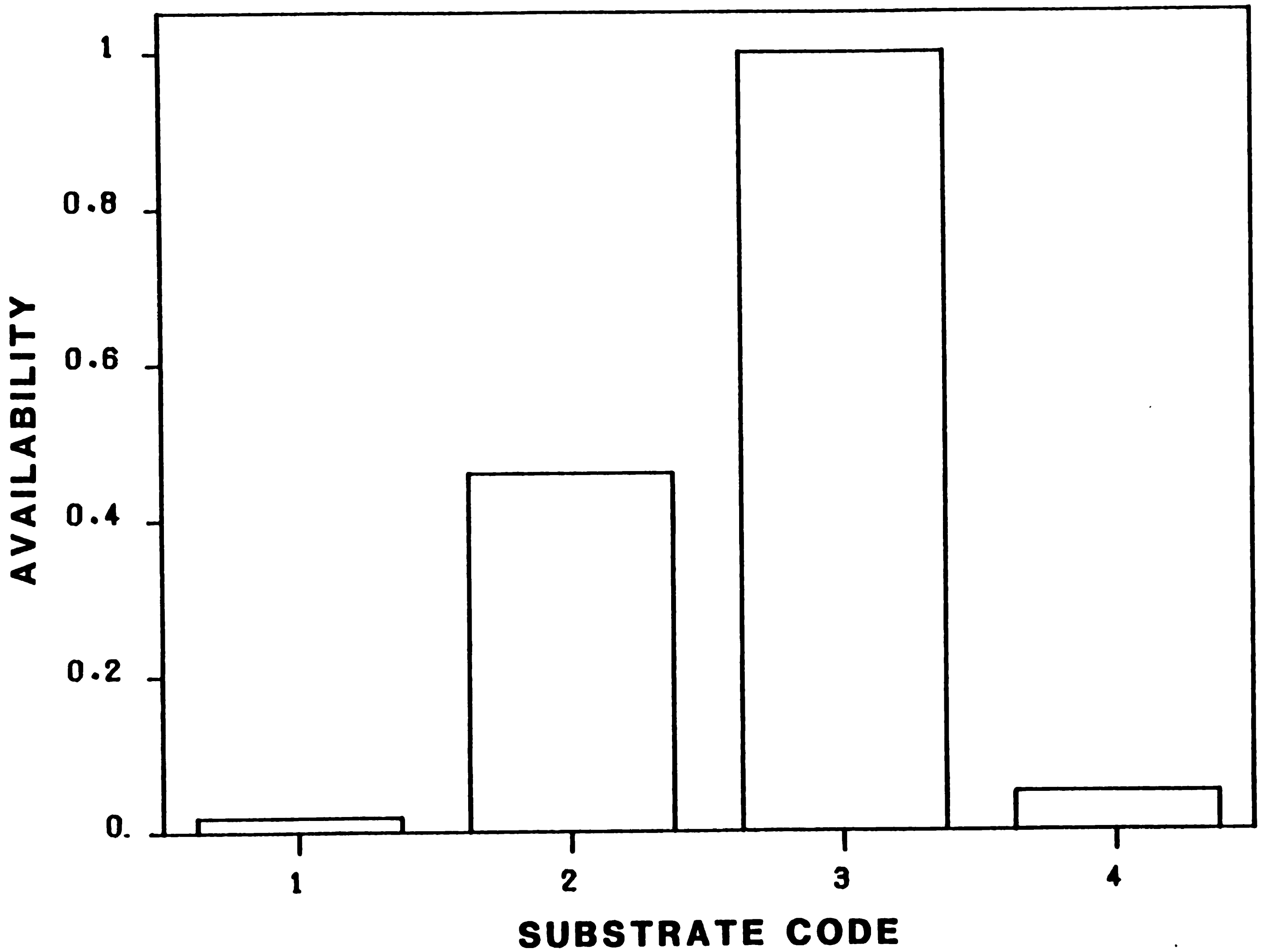


FIGURE 8c: Aquatic insect substrate availability curve.

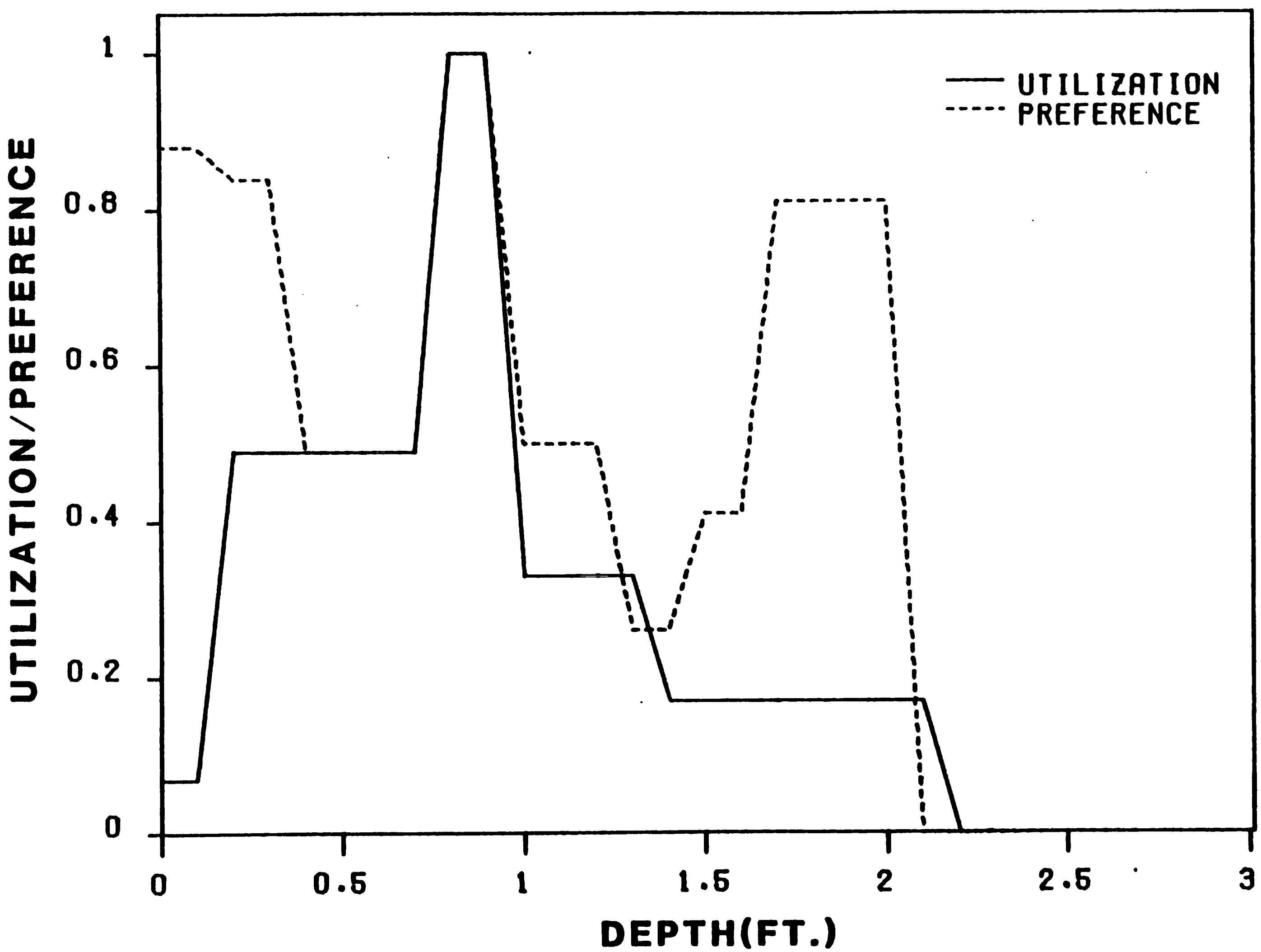


FIGURE 9a: Depth utilization and preference for <u>Hydropsyche</u> <u>sp</u>.

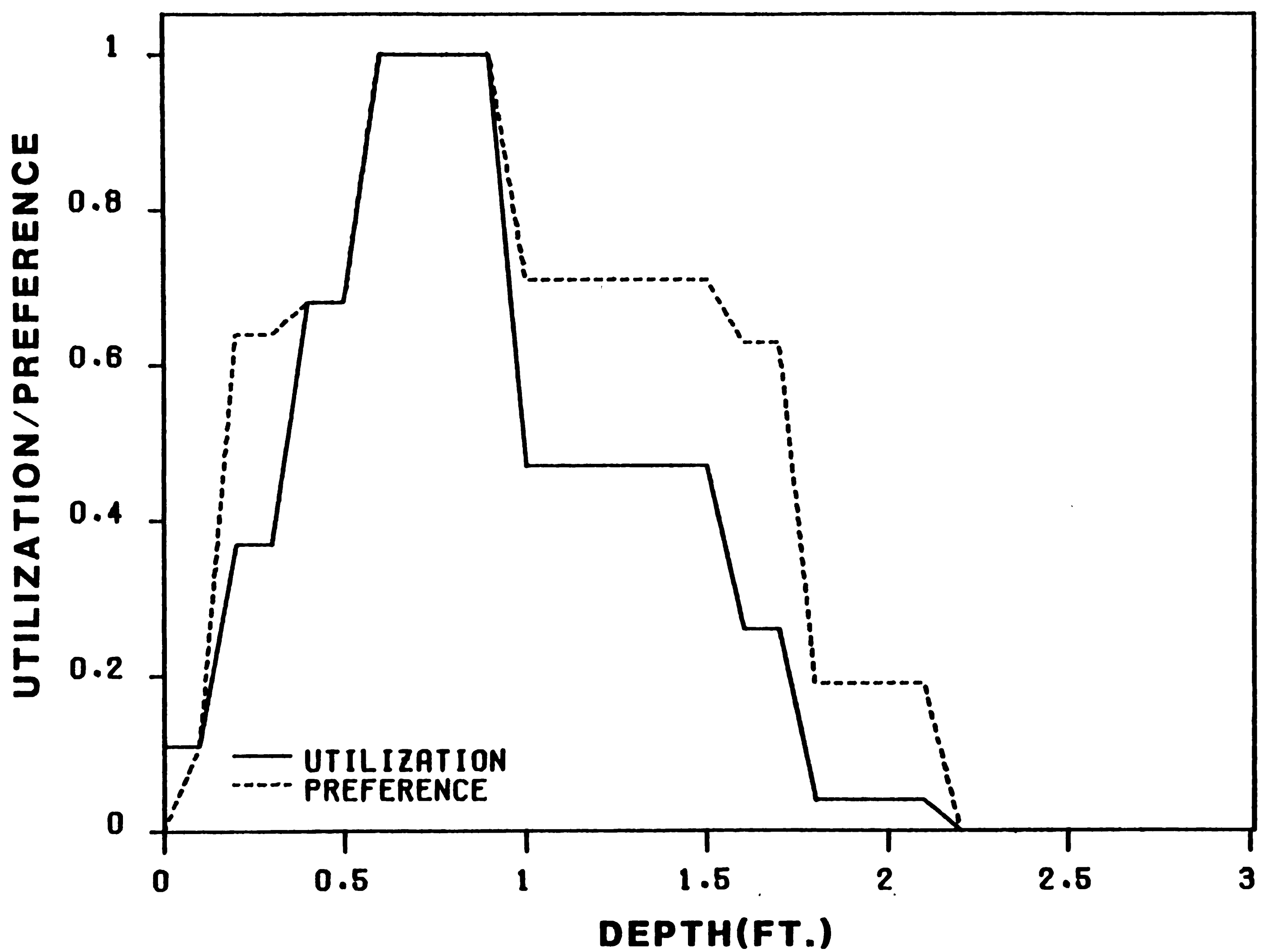


FIGURE 9b: Depth utilization and preference for <u>Ephemerella</u> <u>sp</u>.

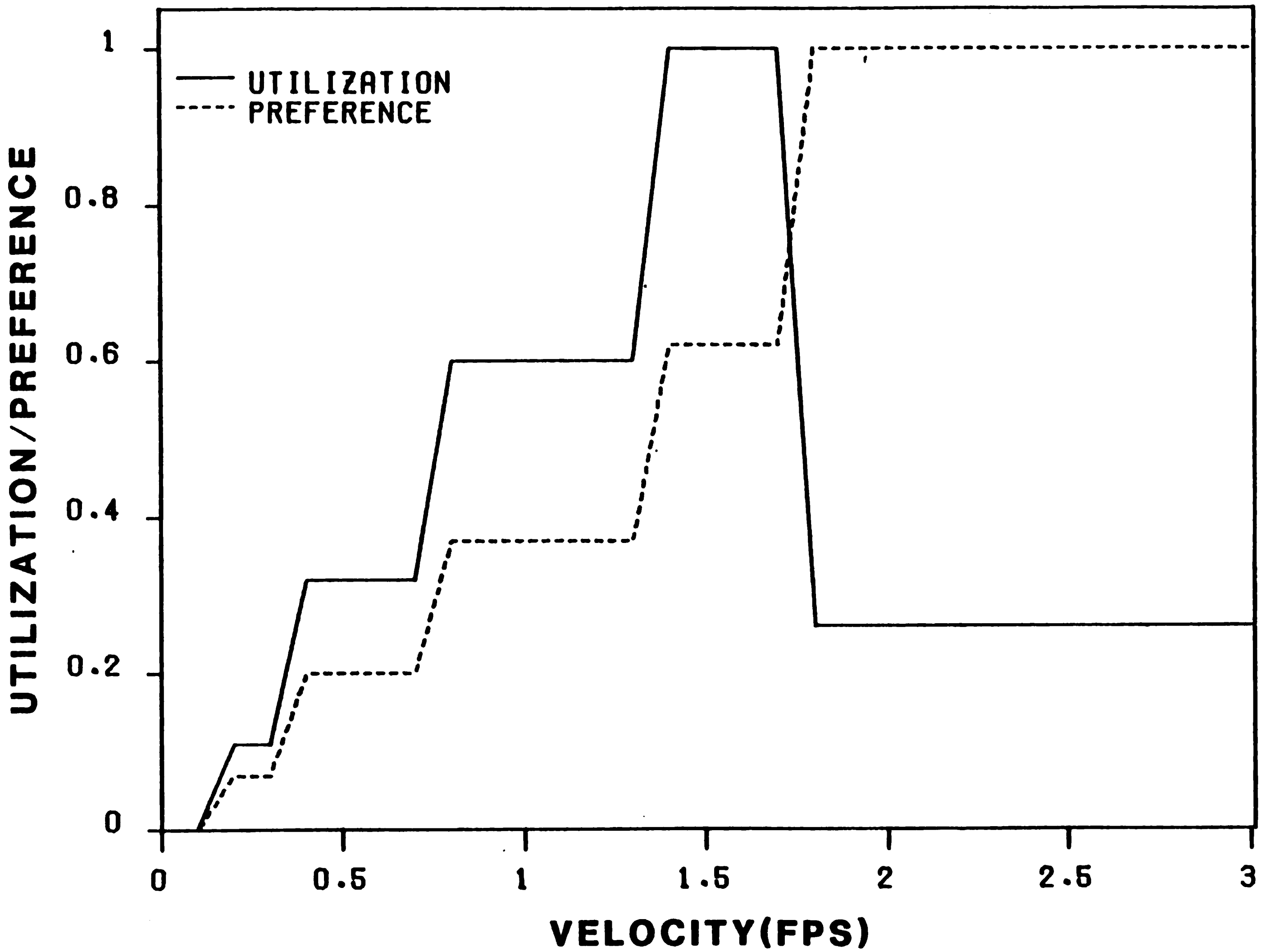


FIGURE 10a: Velocity utilization and preference for _Hydropsyche sp._

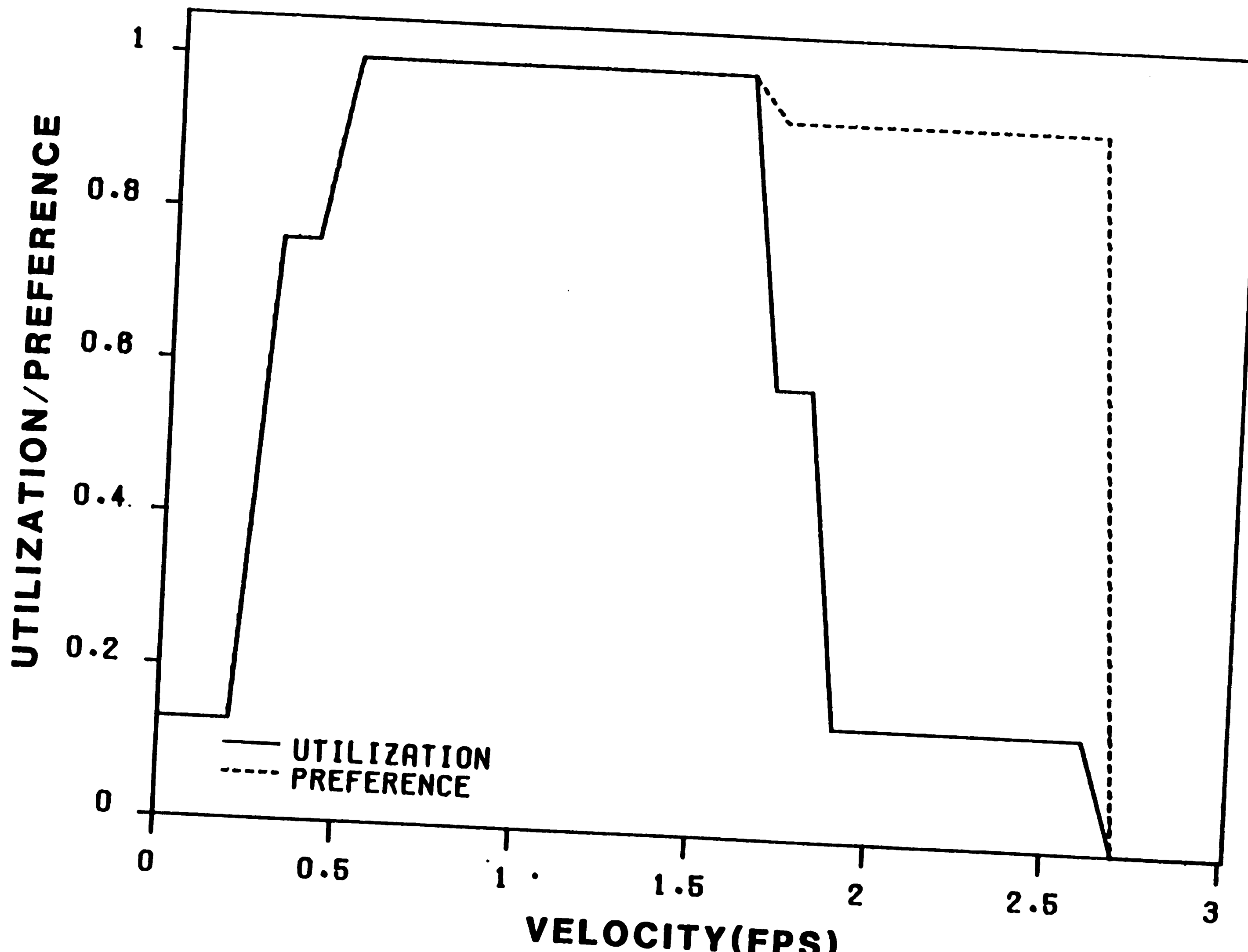


FIGURE 10b: Velocity utilization and preference for _Ephemerella sp._

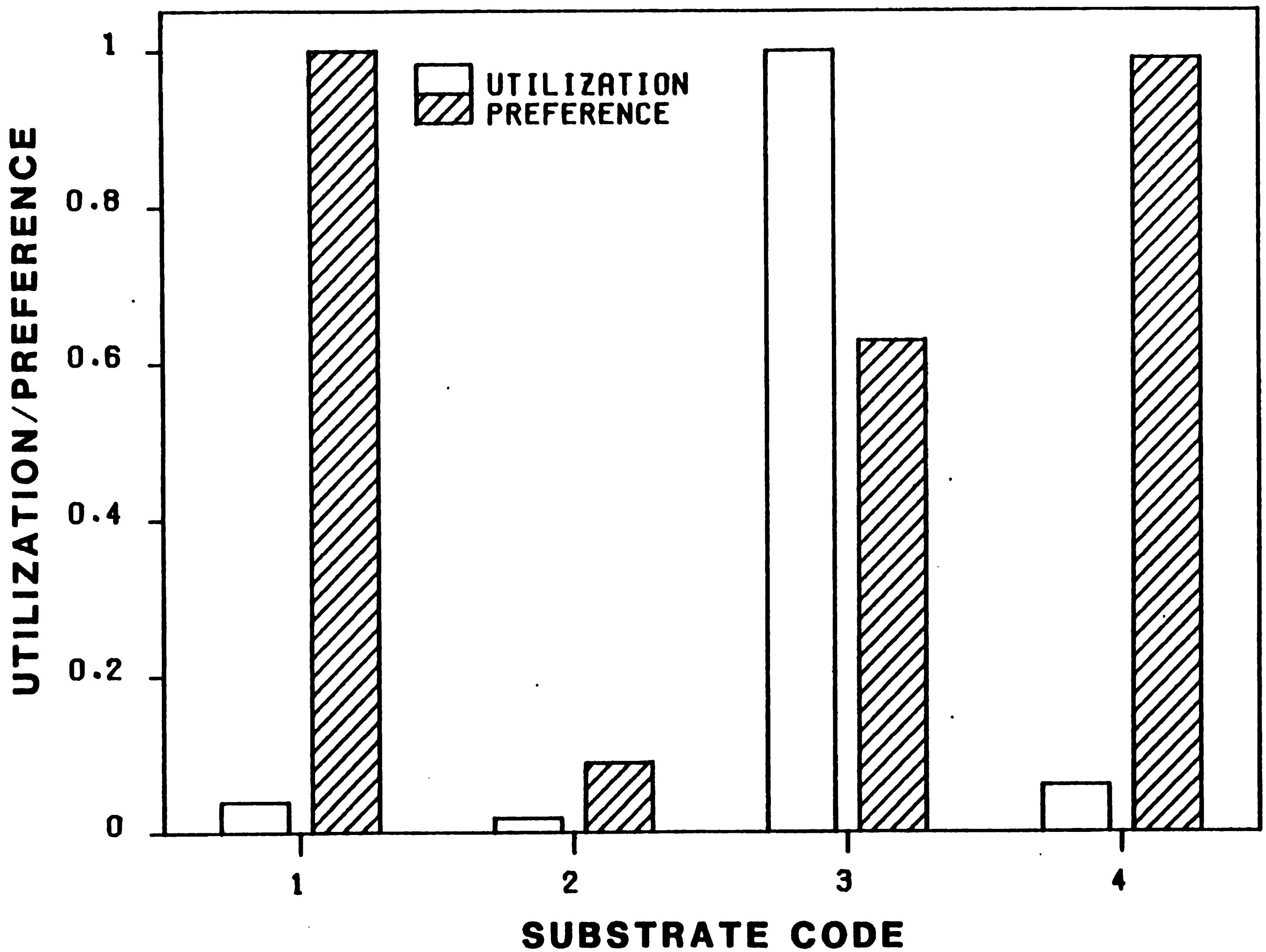


FIGURE 11a: Substrate utilization and preference for *Hydropsyche sp.*

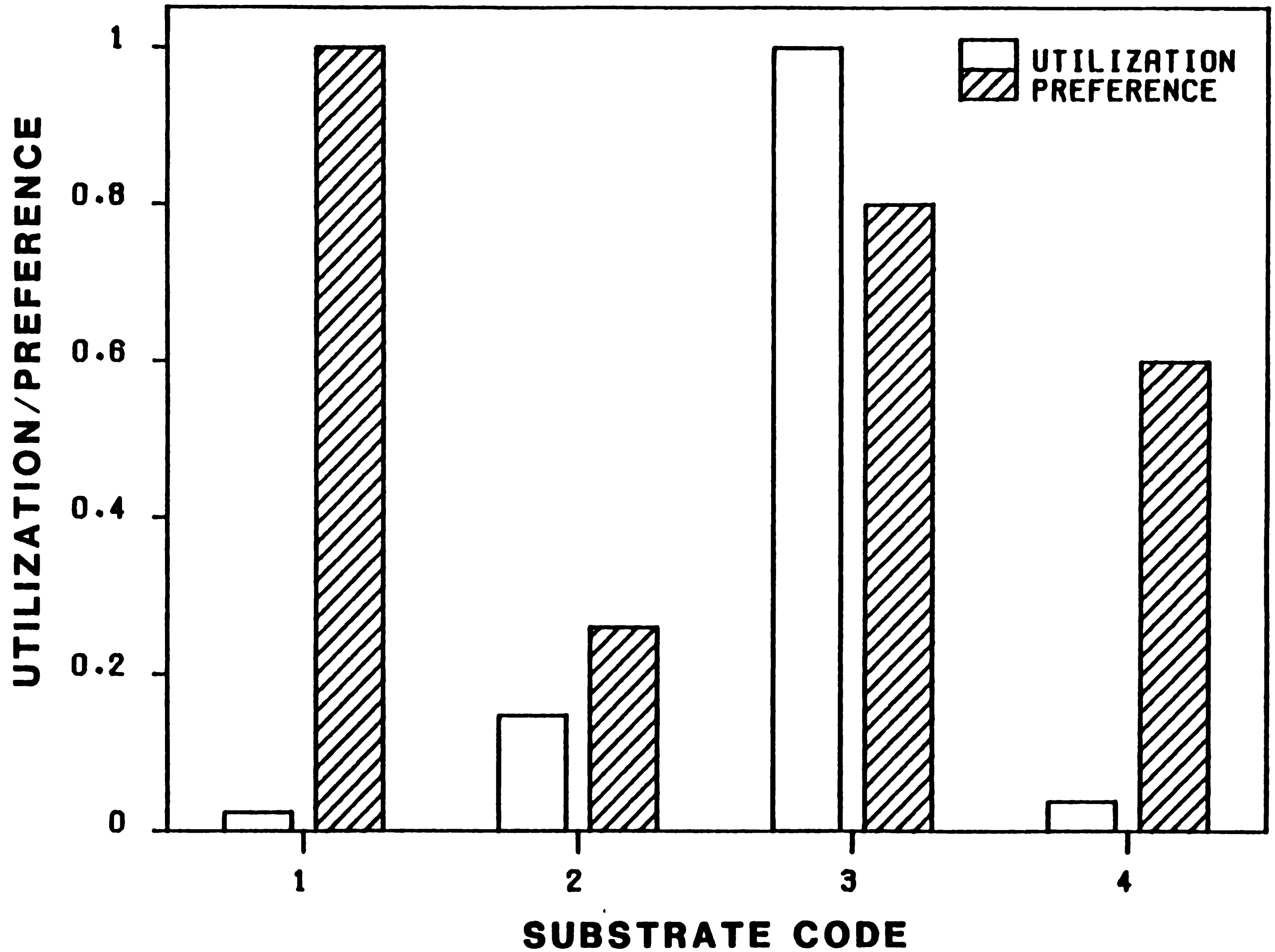


FIGURE 11b: Substrate utilization and preference for *Ephemerella sp.*

The Weighted Usable Area vs. discharge plot for *Ephemerella spp.* and *Hydropsyche spp.* is given in Figure 12. These data were combined with the data given in Figure 6 to produce the *Ephemerella spp.* and *Hydropsyche spp.* habitat time series shown in Figures 13a-h, and 14a-h, respectively.

Test of the IFIM

Velocity Adjustment Factors were generated for each transect for flows 6 through 30 cfs (in increments of 2 cfs). This yielded a total of 243 VAFs. Each VAF was then compared to the ratings given by Milhous et. al. (1984) (Table 4). Two hundred and thirteen or 87.7 percent of the VAFs fell into the "good" rating. Seventeen or 7.0 percent fell into the "fair" catagory, 9 or 3.7 percent were "marginal", and 4 or 1.6 percent were rated as "poor."

The IFIM predicts not only the total amount of habitat available to a particular species, but also where that habitat is found in the stream. If the model is working well, fish should be located in the places the computer predicts there is habitat. Figure 15a-c is a map of the study section detailing fish locations as they occurred throughout the summer and computer predicted habitat. This is a qualitative test of the computer's ability to predict brown trout habitat.

A quantitative test between habitat quality at each transect and the number of fish found at that transect was made using the nonparametric statistic, Kendall's Tau. Table 5 details the test and

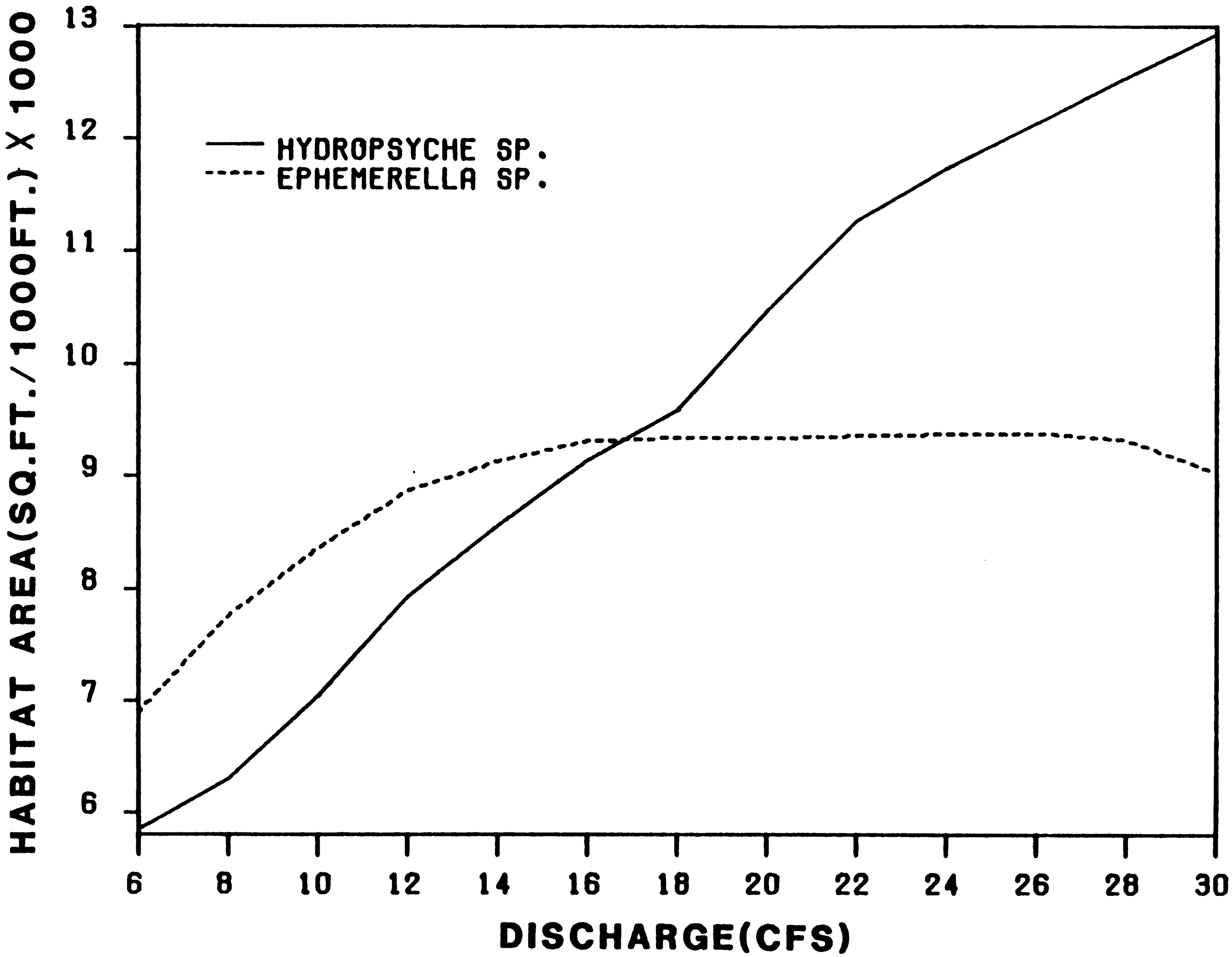


FIGURE 12: Aquatic insect habitat versus discharge curve.

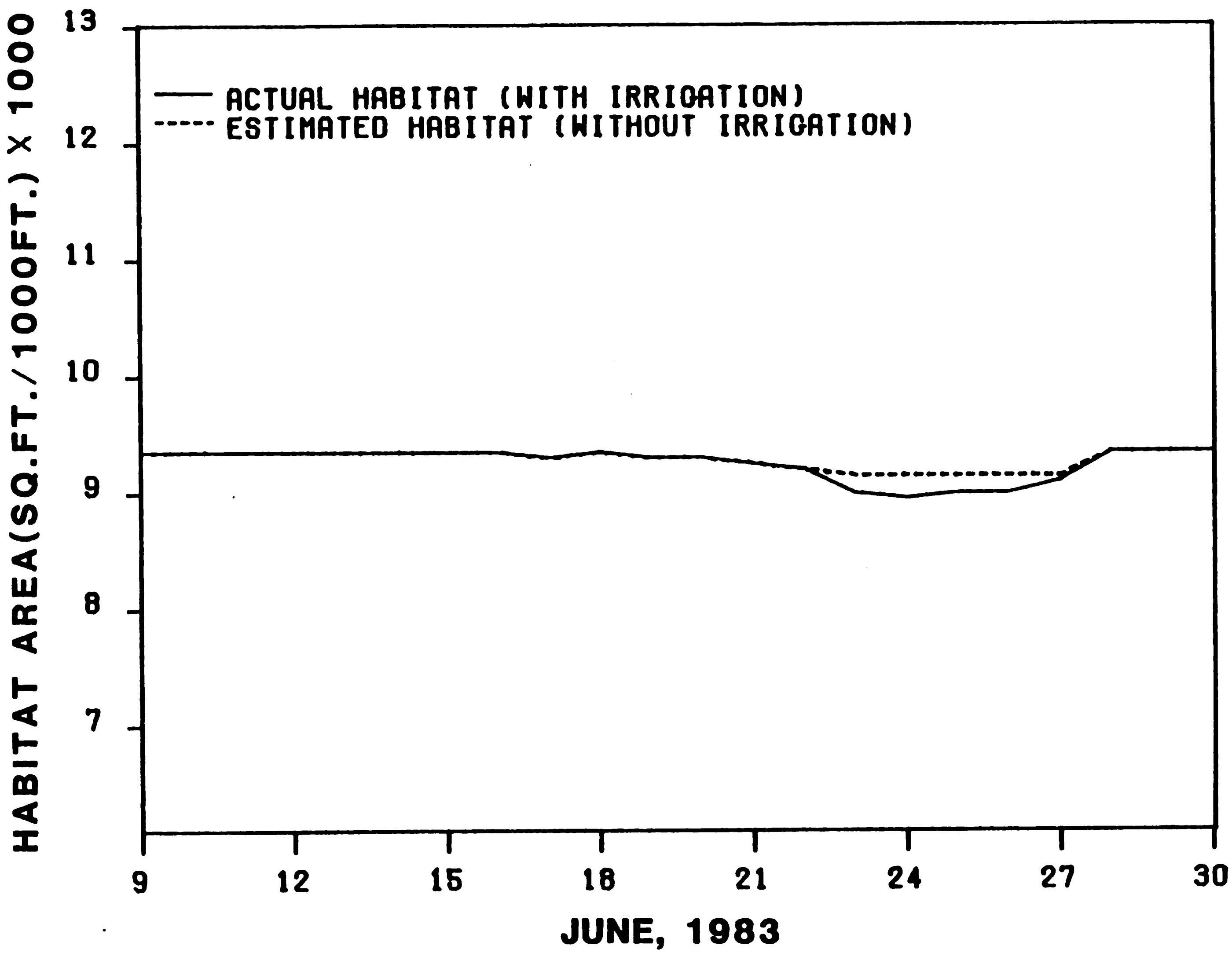


FIGURE 13a: <u>Ephemerella</u> <u>sp</u>. habitat time series for June, 1983.

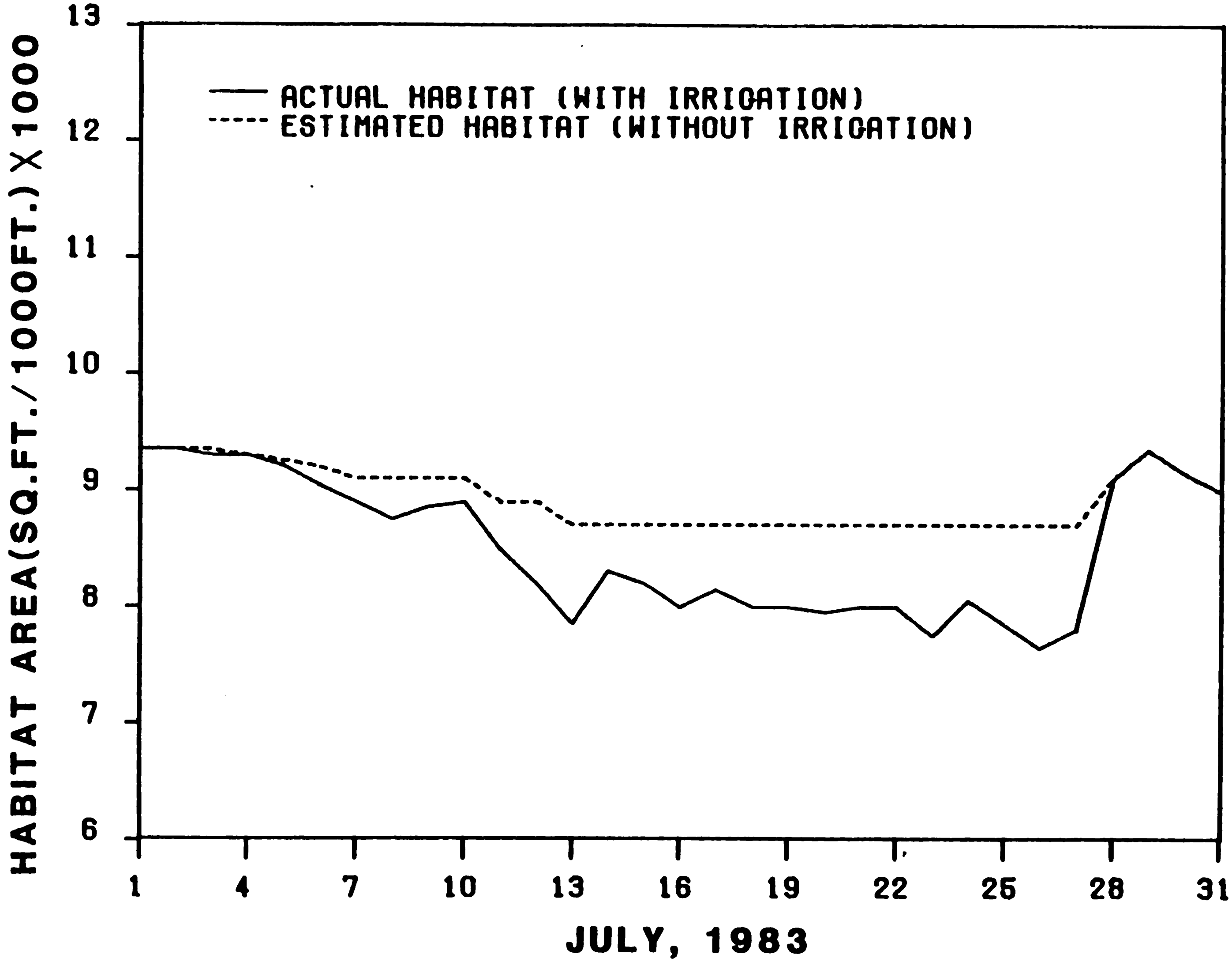


FIGURE 13b: Ephemerella sp. habitat time series for July, 1983.

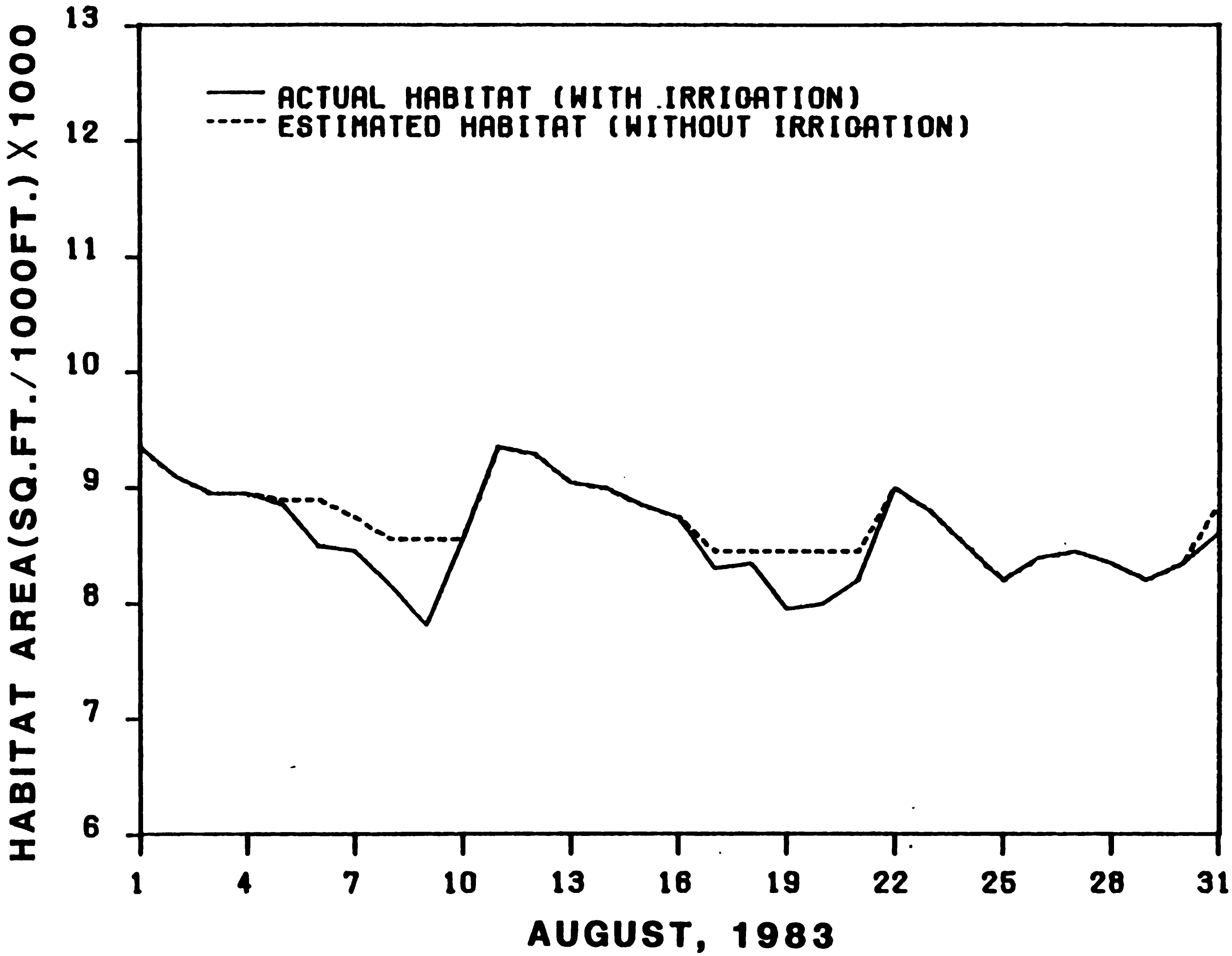


FIGURE 13c: Ephemerella sp. habitat time series for August, 1983.

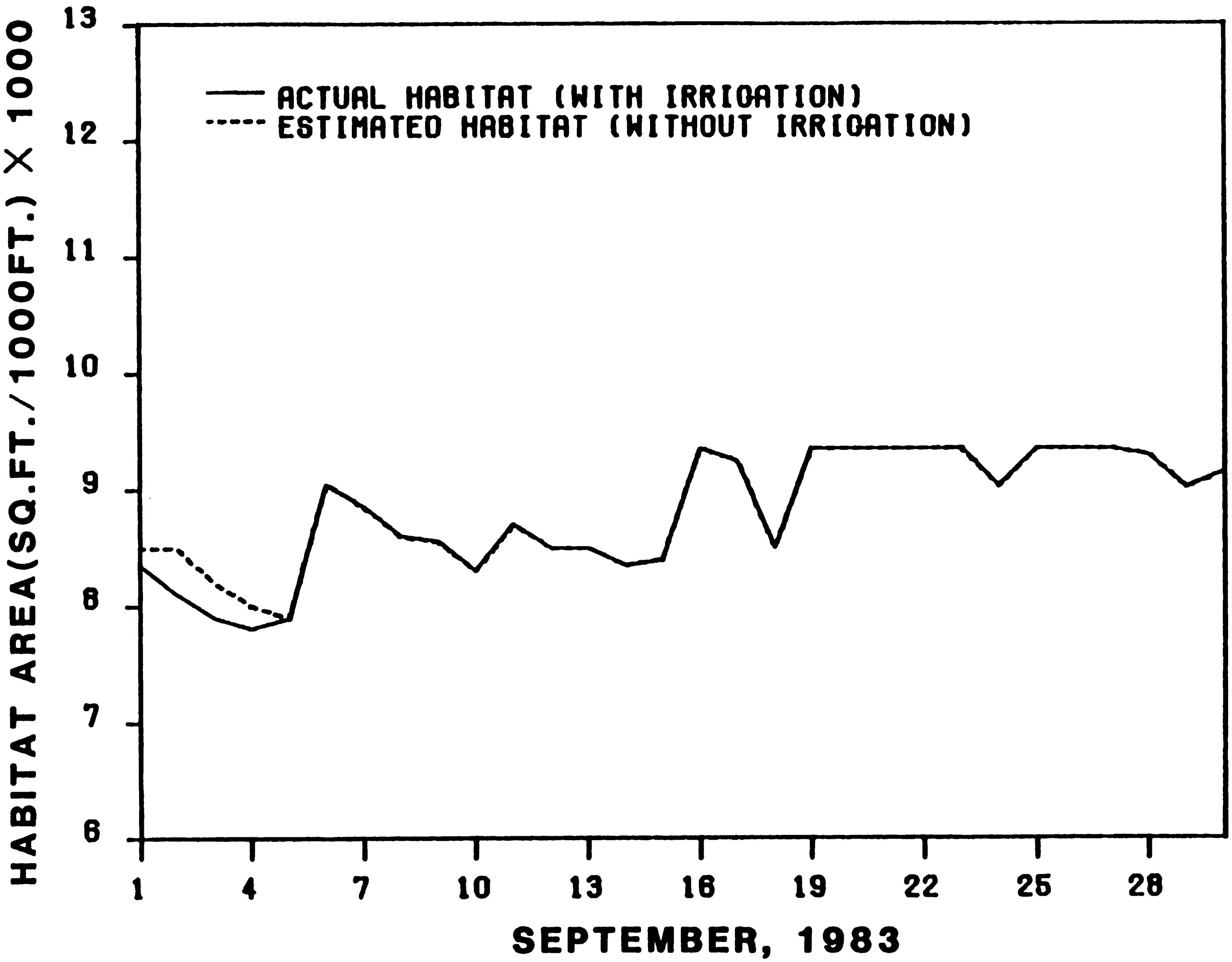


FIGURE 13d: <u>Ephemerella</u> <u>sp</u>. habitat time series for September, 1983.

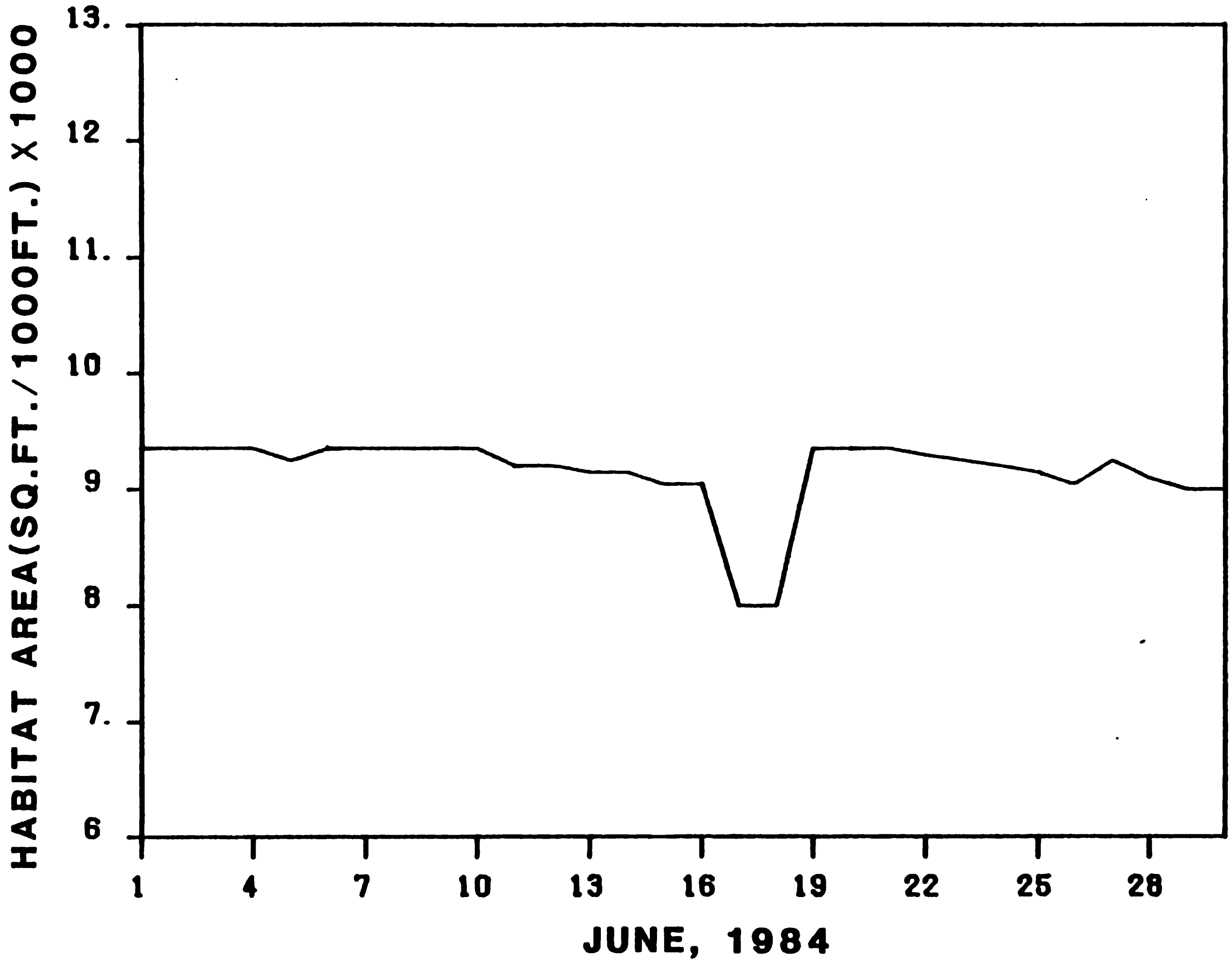


FIGURE 13e: Ephemerella sp. habitat time series for June, 1984.

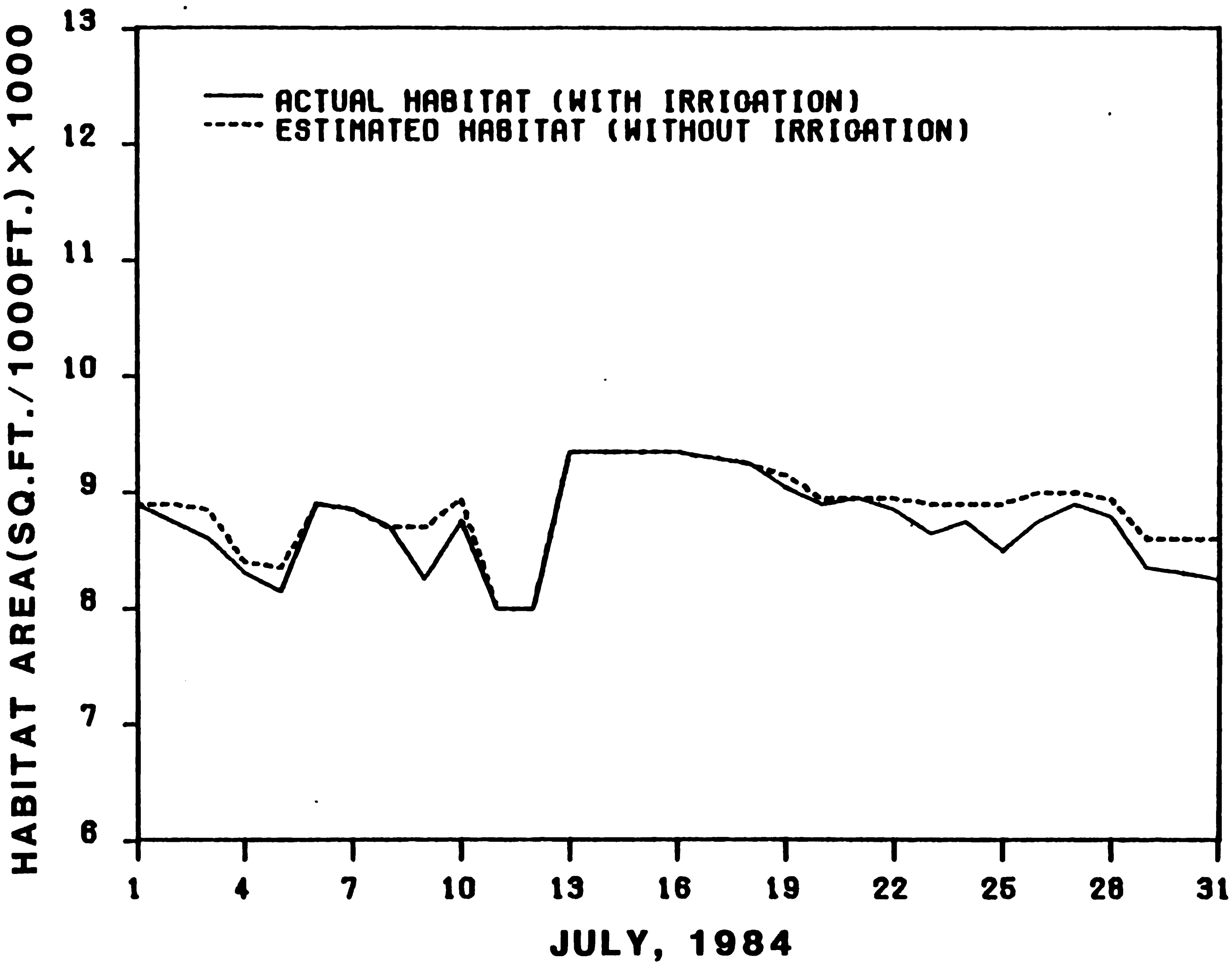


FIGURE 13f: Ephemerella sp. habitat time series for July, 1984.

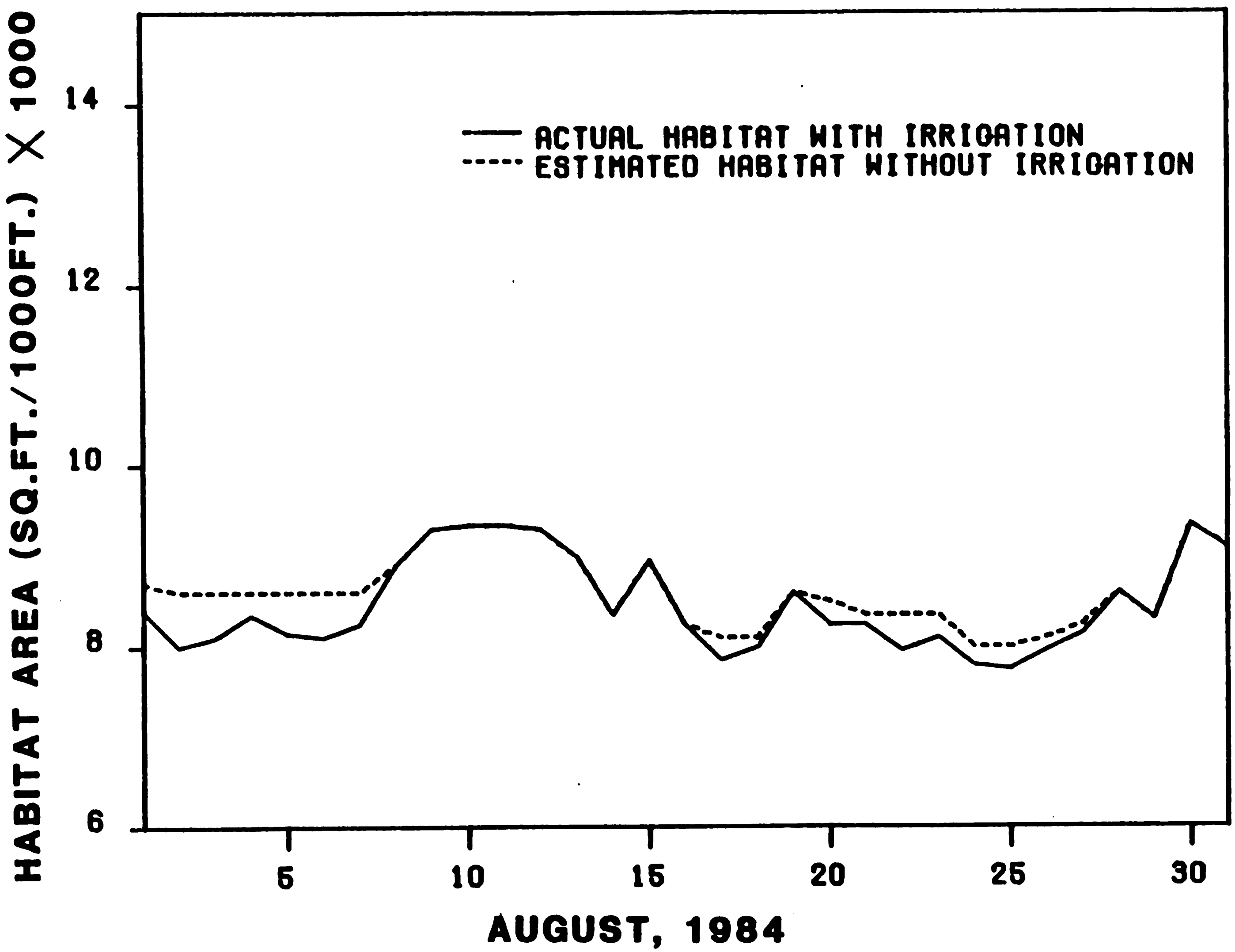


FIGURE 13g: <u>Ephemerella sp</u>. habitat time series for August, 1984.

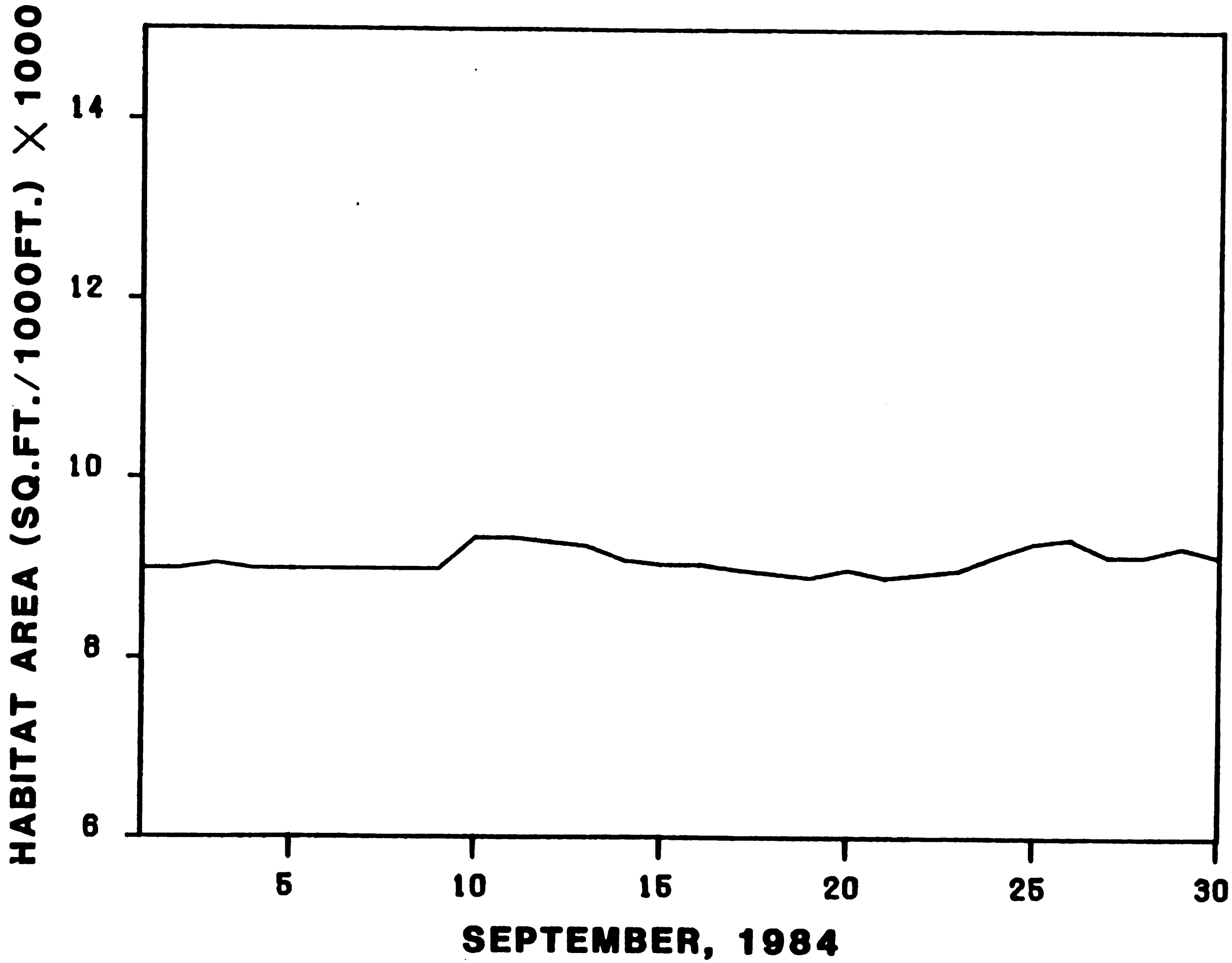


FIGURE 13h: *Ephemerella sp.* habitat time series for September, 1984.

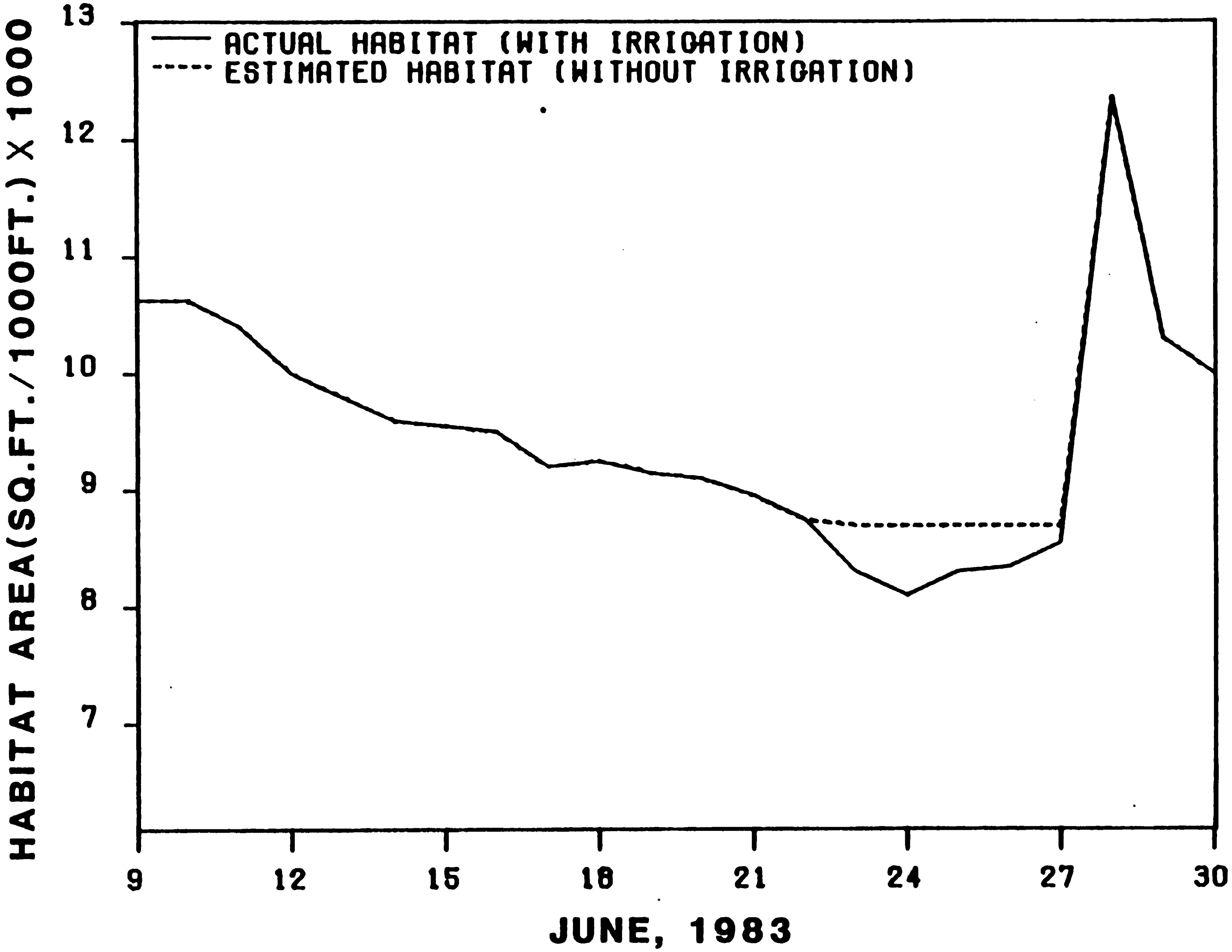


FIGURE 14a: Hydropsyche sp. habitat time series for June, 1983.

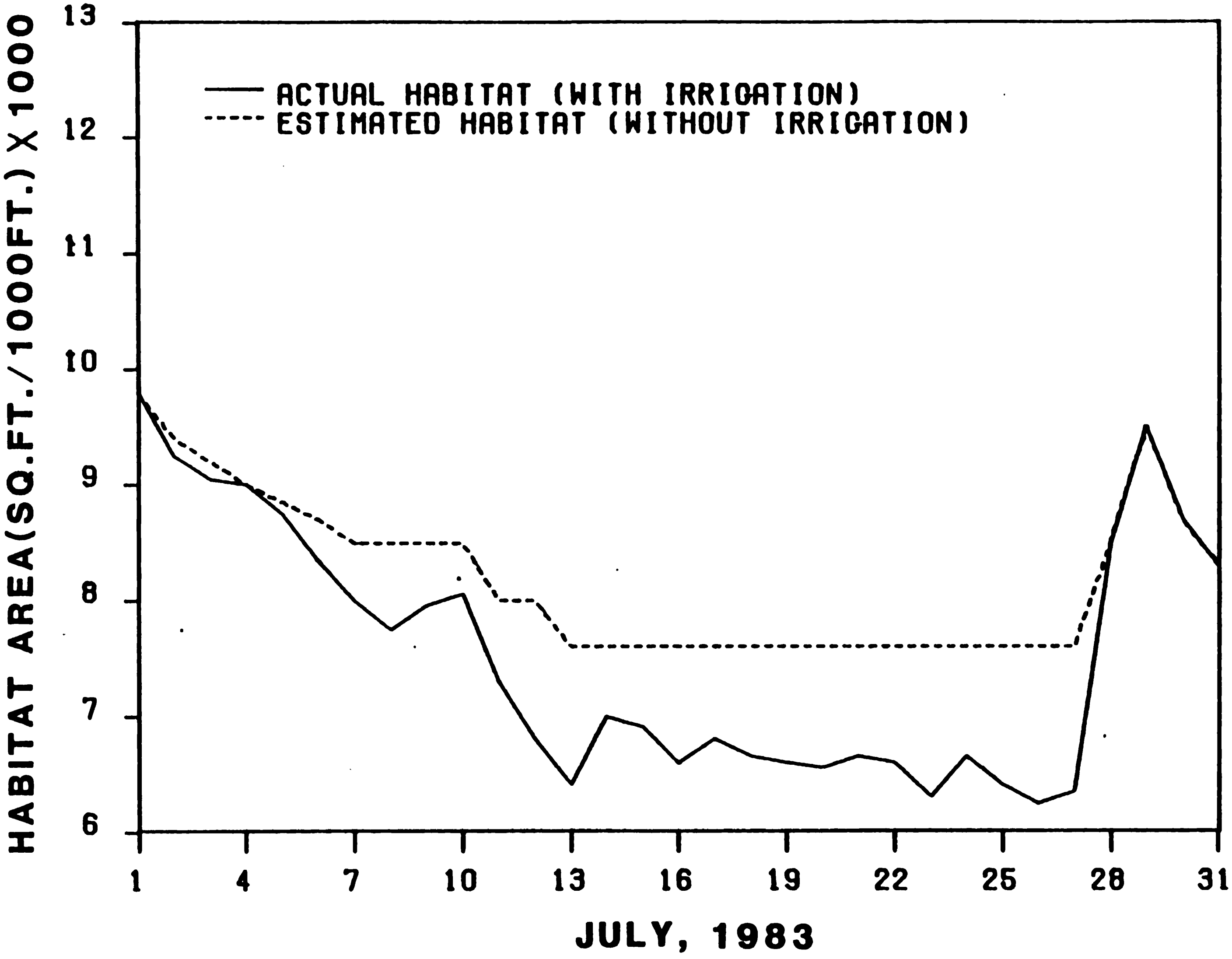


FIGURE 14b: Hydropsyche sp. habitat time series for July, 1983.

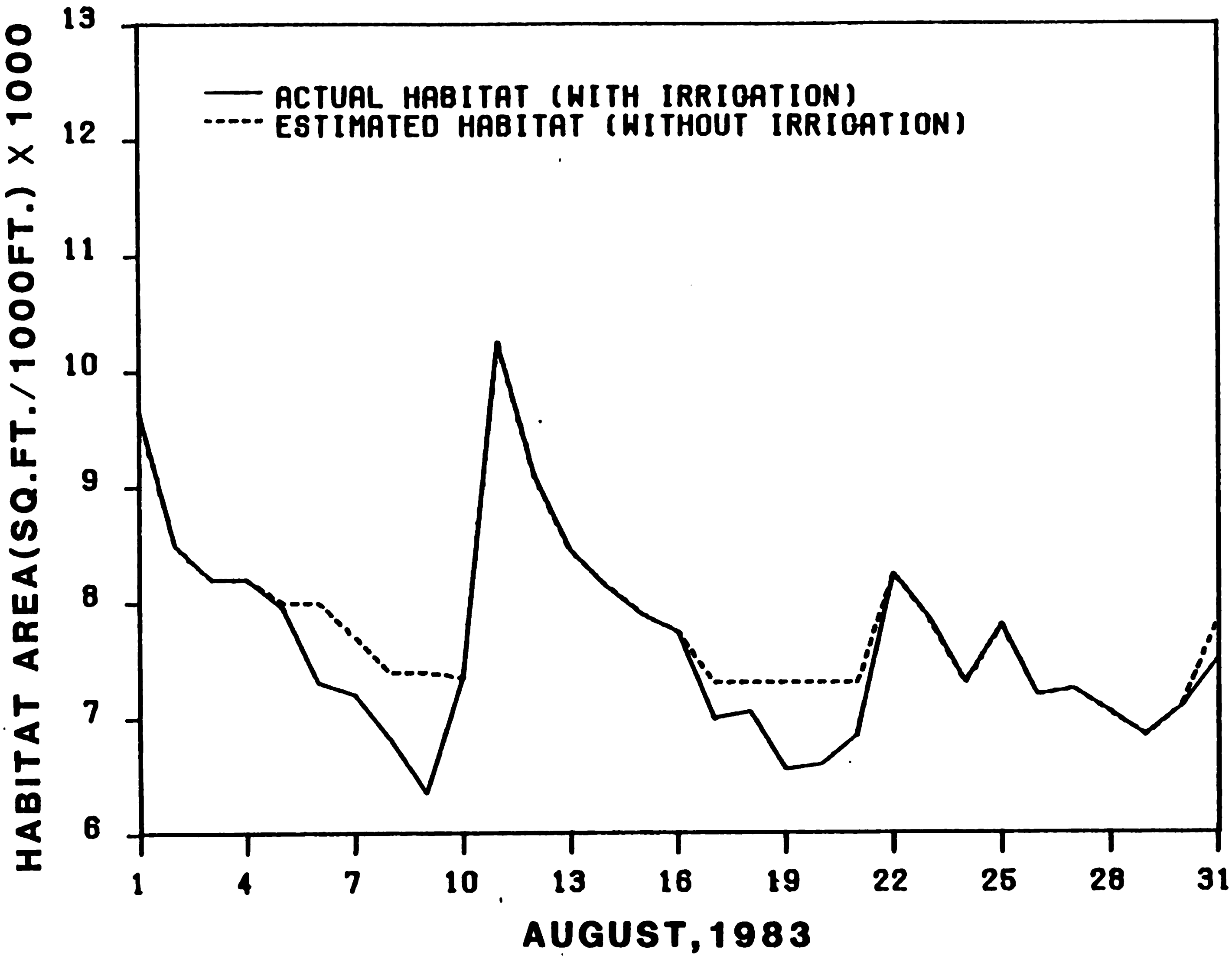


FIGURE 14c: *Hydropsyche sp.* habitat time series for August, 1983.

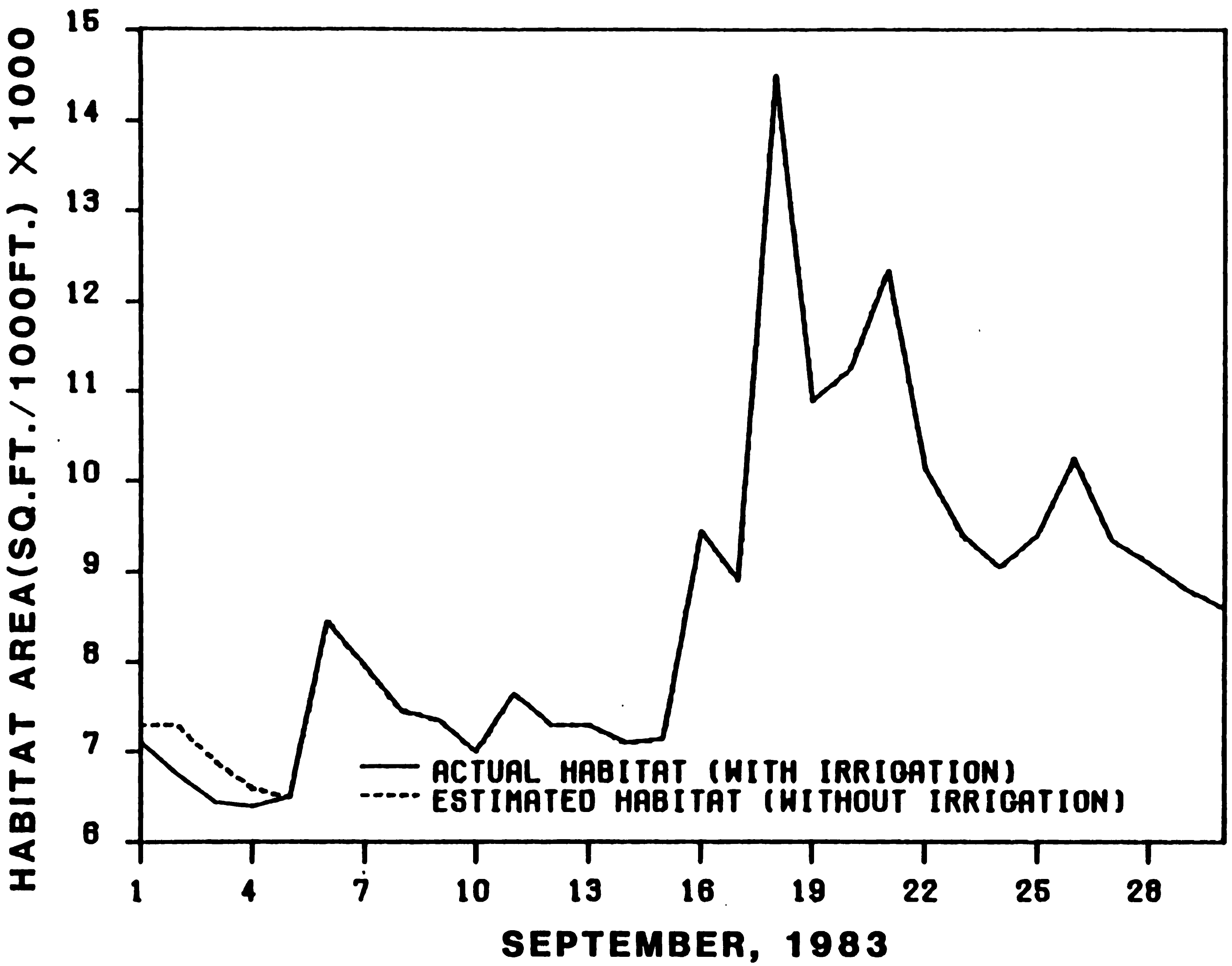


FIGURE 14d: Hydropsyche sp. habitat time series for September, 1983.

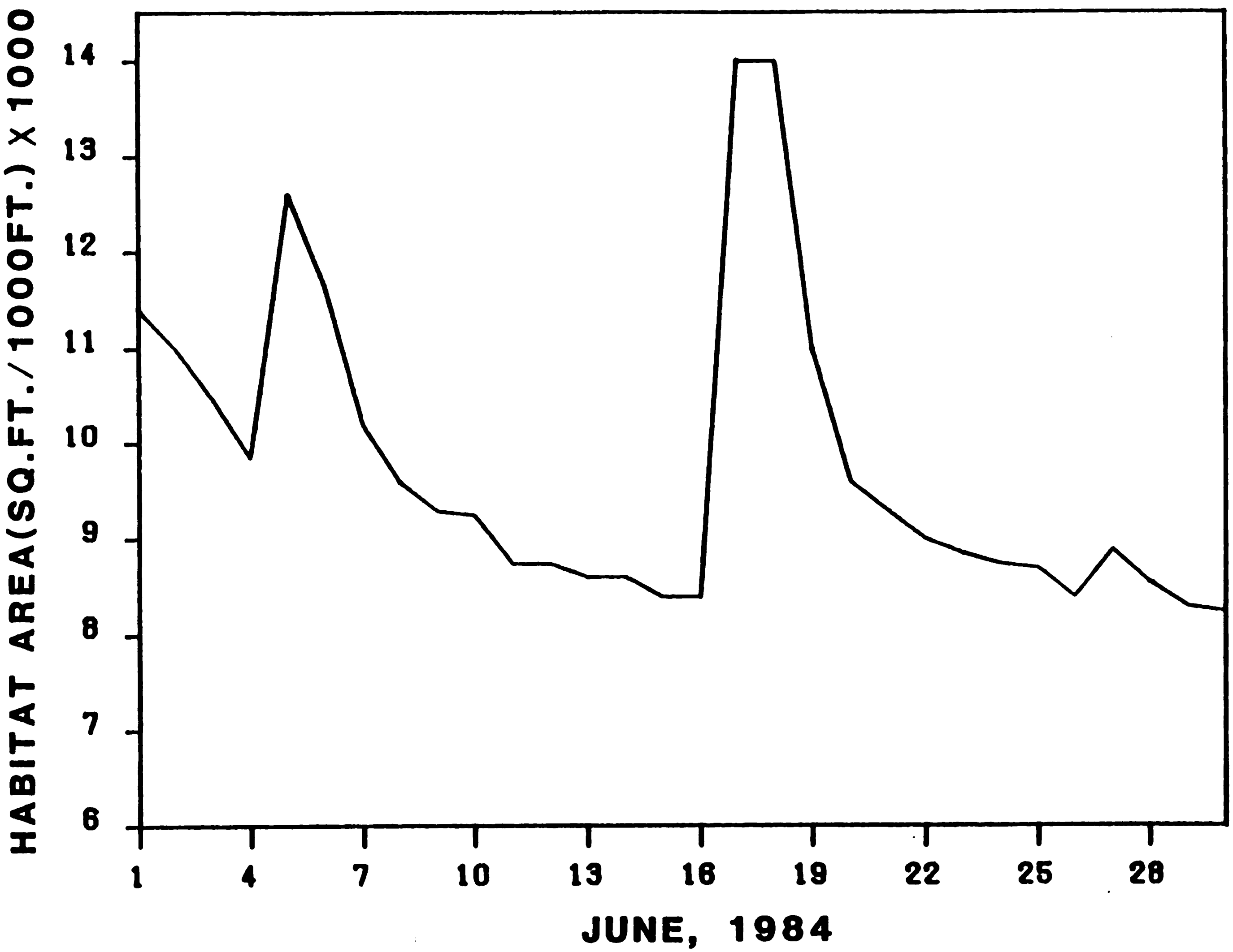


FIGURE 14e: <u>Hydropsyche</u> <u>sp</u>. habitat time series for June, 1984.

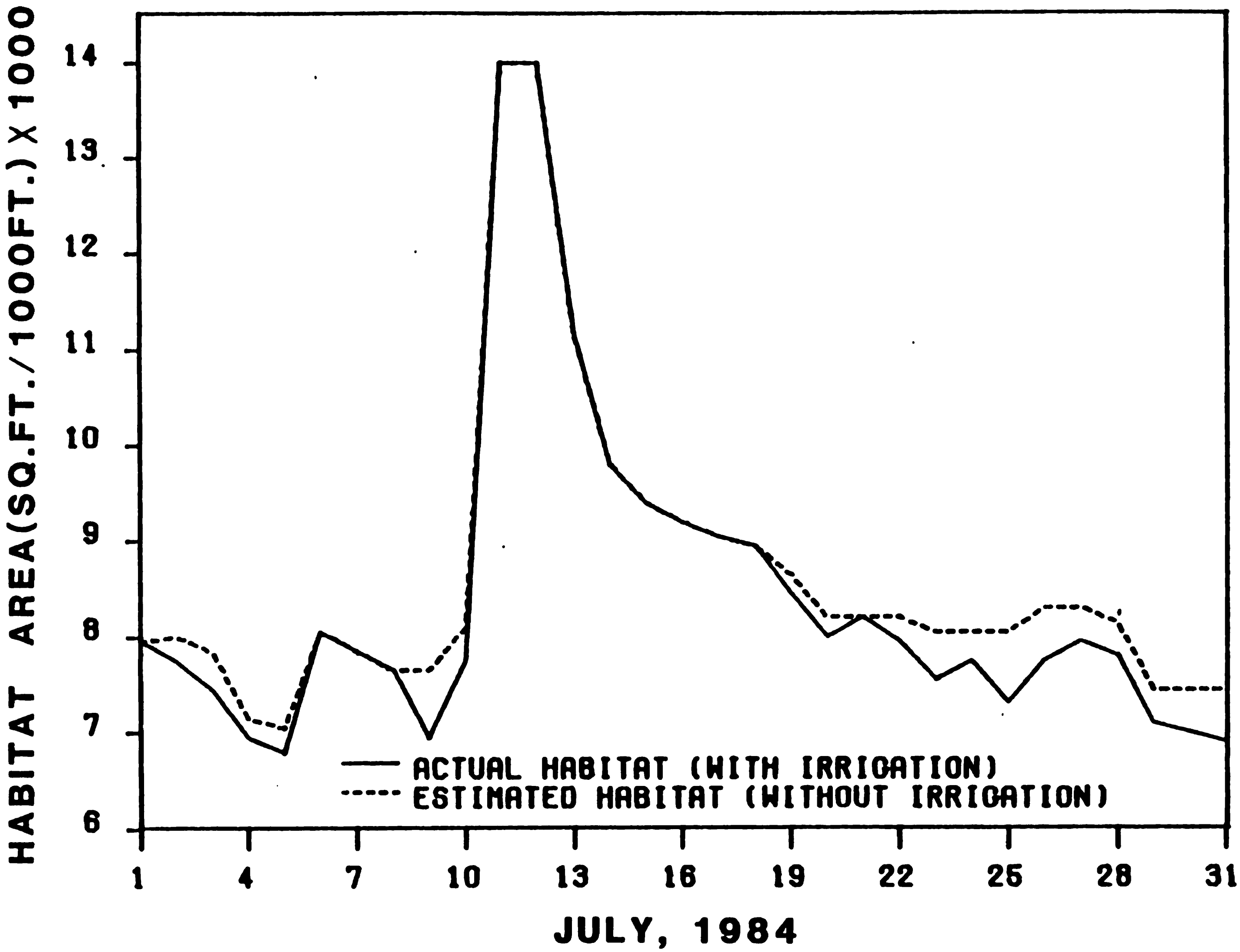


FIGURE 14f: Hydropsyche sp. habitat time series for July, 1984.

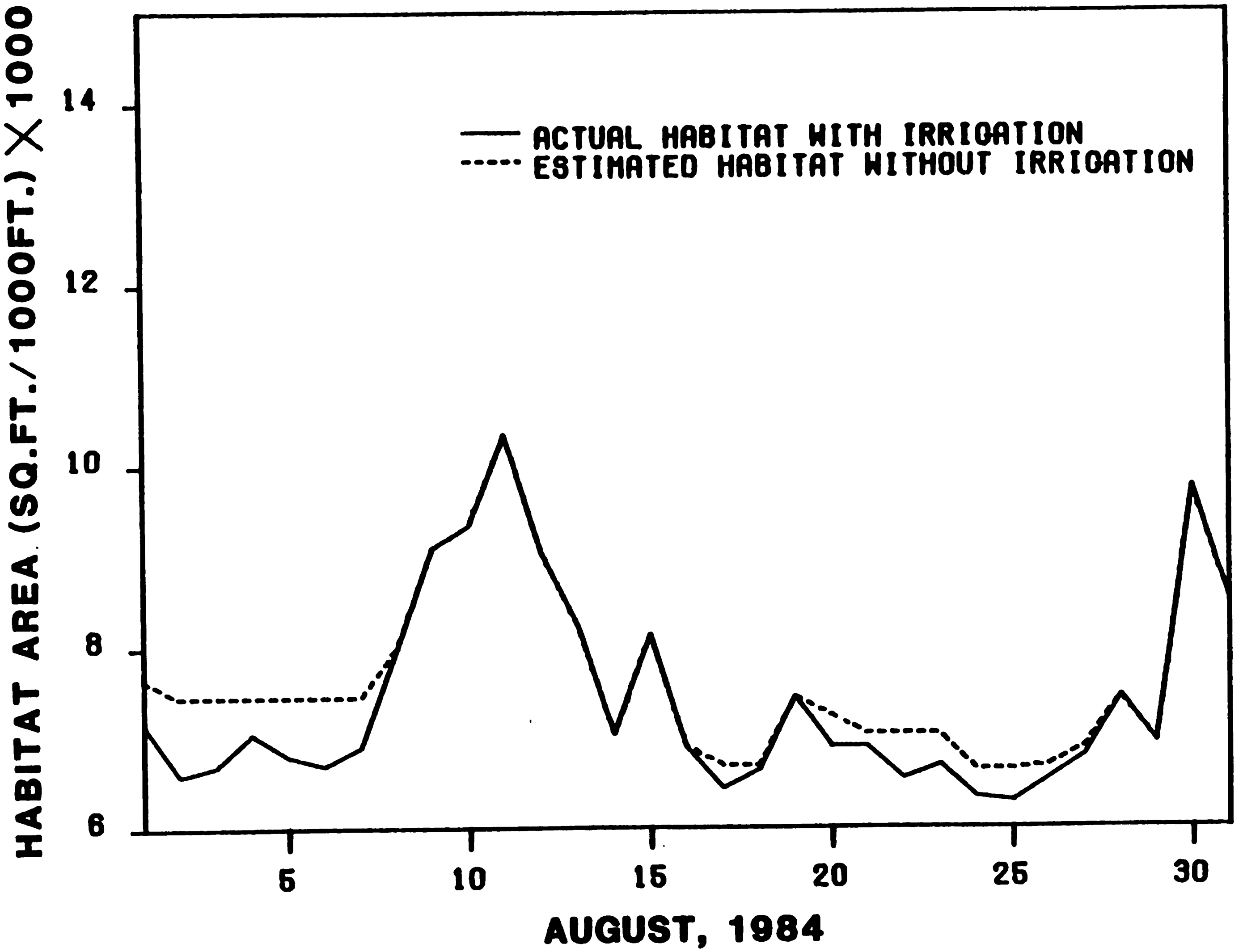


FIGURE 14g: Hydropsyche sp. habitat time series for August, 1984.

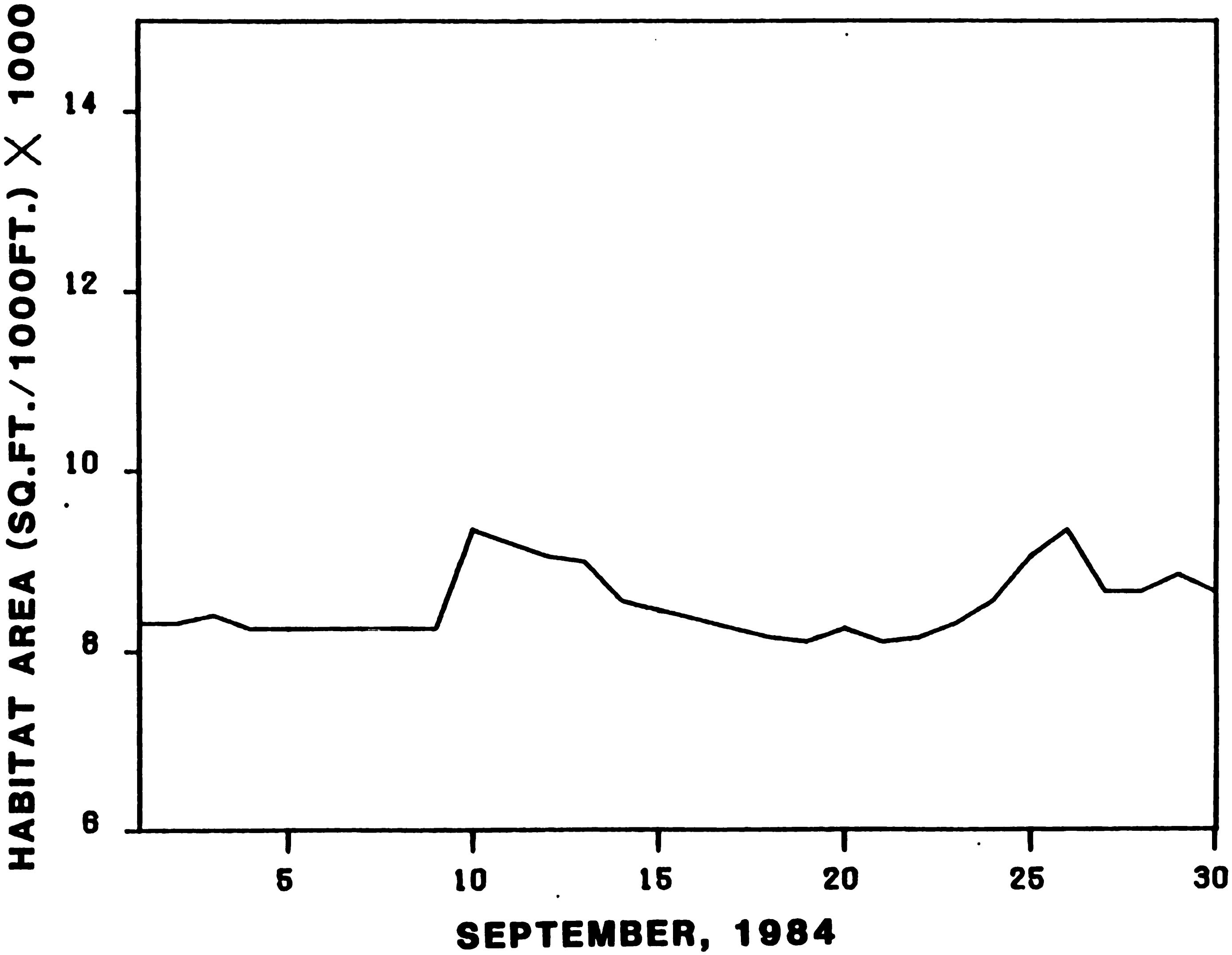


FIGURE 14h: *Hydropsyche sp*. habitat time series for September, 1984.

Table 4: Velocity Adjustment Factor ratings as given by Milhous et. al. (1984).

Velocity Adjustment Factor	Rating
0.9-1.1	good
0.85-0.9, 1.1-1.15	fair
0.80-0.85, 1.15-1.20	marginal
0.70-0.80, 1.20-1.30	poor
less than 0.70, greater than 1.30	very poor

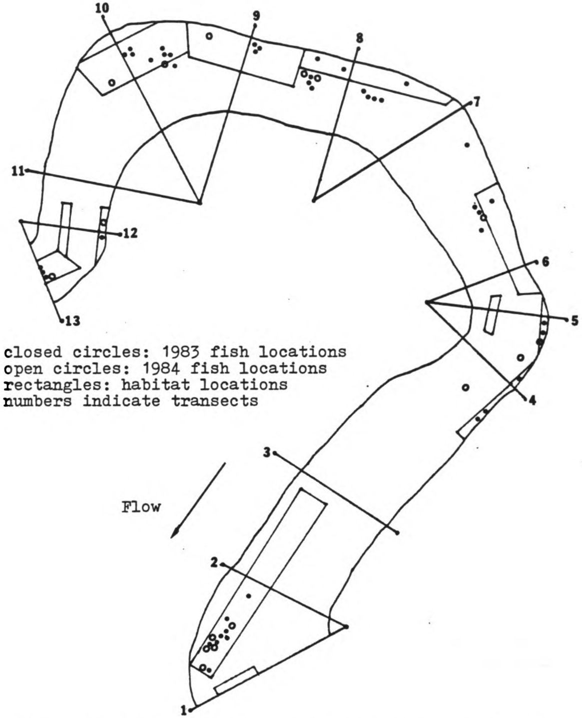
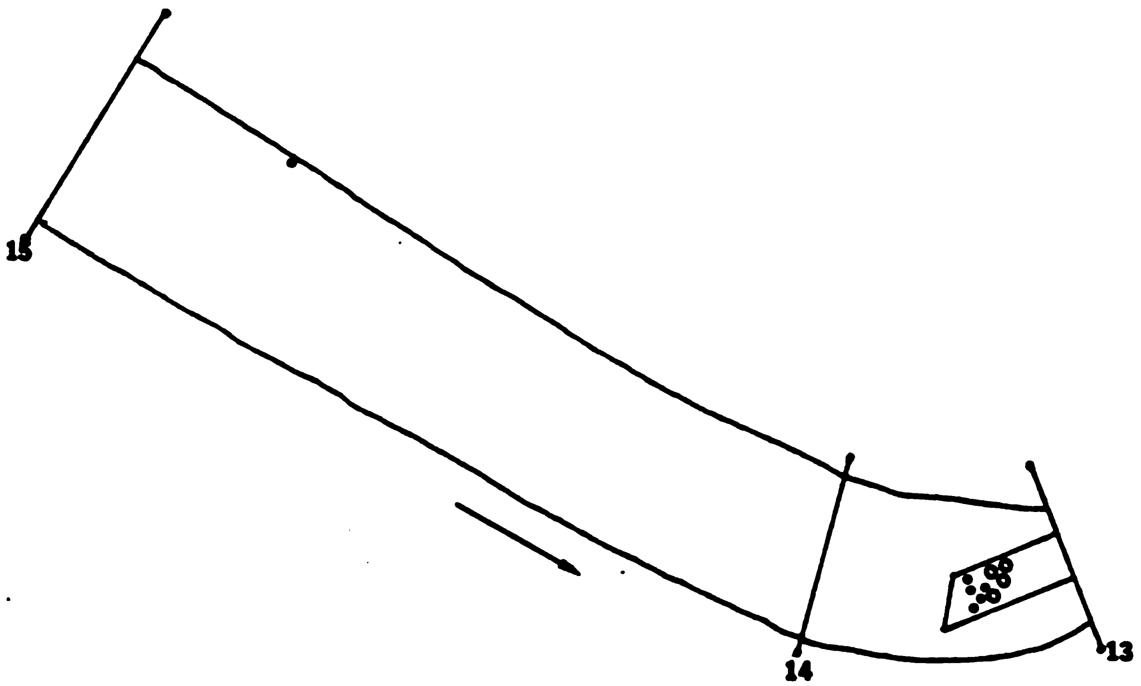


FIGURE 15a: Map detailing downstream computer predicted habitat locations and actual fish locations.



closed circles: 1983 fish locations
open circles: 1984 fish locations
rectangles: habitat locations
numbers indicate transects.

FIGURE 15b: Map detailing midstream computer predicted habitat locations and actual fish locations.

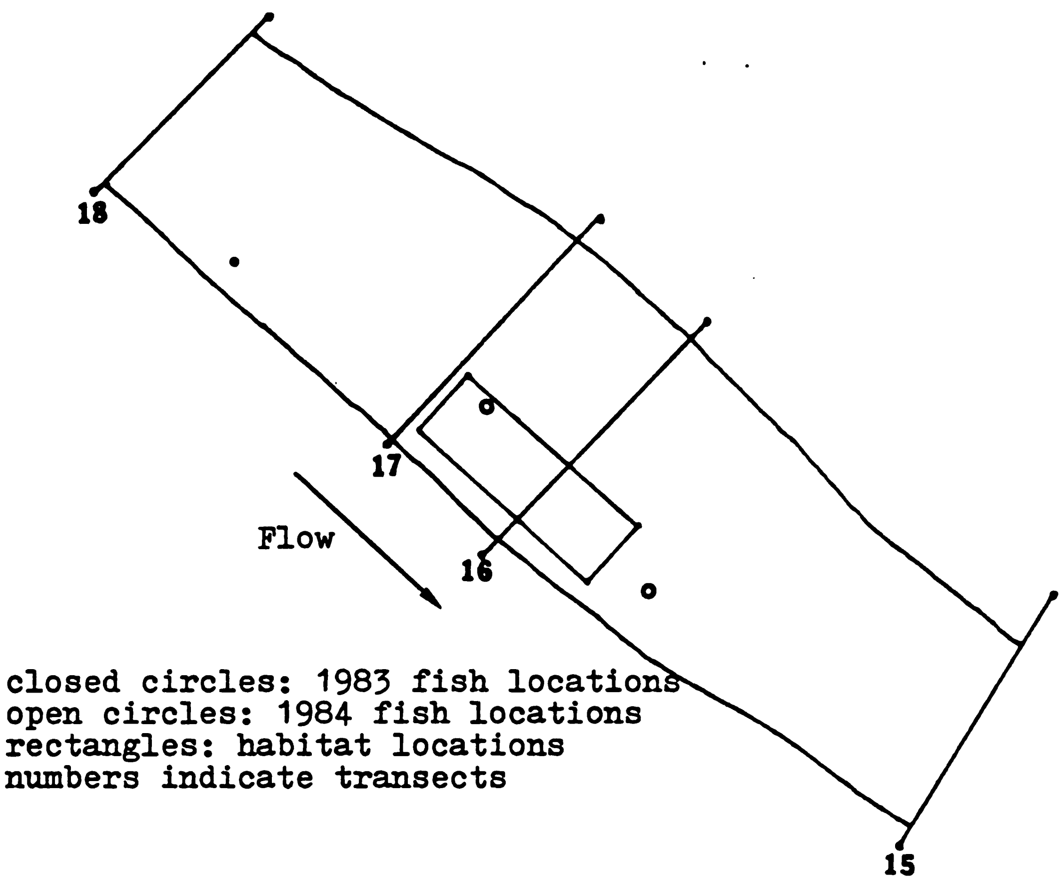


FIGURE 15c: Map detailing upstream computer predicted habitat locations and actual fish locations.

TABLE 5: A test for significance between the average WUA found at a transect and the number of fish captured in that transect. The test used is the correlation coefficient Kendall's Tau.

transect	WUA ranked in increasing order	number of fish observed	number of subsequent transects with a greater number of observed fish
11	0.09	0	9
4	0.096	5	5
1	0.11	0	8
3	0.123	0	8
5	0.398	3	6
6	0.432	0	7
12	1.05	3	6
10	3.02	10	3
9	3.38	4	4
2	6.80	13	1
13	11.20	12	1
7	19.70	6	1
8	42.91	15	0
			total=59= S^+

$S=2S^+-(\frac{N(N-1)}{2})$, where N=the number of paired observations

$S=118-78=40$; $Tau=\frac{S}{\frac{N(N-1)}{2}} = \frac{40}{78} = 0.513$; Tabular Tau at alpha= 0.05= 0.41

results. As given in Table 5, there was a statistically significant relationship between average WUA and the number of fish (Tau= 0.513, N=13, alpha= 0.05).

Table 6 details the computer's ability to simulate the depths, velocities, substrates, and covers as they occur throughout the study section. As given in this table, the computer was not always able to accurately predict these parameters.

The Relationship of Habitat Availabilty to Population Density

A simple linear regression was used to relate the average daily amount of habitat present over the number of days prior to the sampling time and the population estimate made at the sampling time. The resulting plots for the 1983 and 1984 data are shown in Figure 16a and b. As seen from this figure, no statistically significant relationship could be demonstrated for the 1983 data ($r2= 0.09$, n.s. at alpha=.05, d.f.=6). A very highly significant relationship did occur during 1984 ($r2= 0.837$, alpha=.01, d.f.=6).

The Relationship of Habitat Availabilty and Growth Rate.

A linear regression was used to relate the average amount of habitat available over the number of days prior to the sampling time and the average growth rate of the fish captured at the sampling time. This could only be done for the 1983 data because insufficient recaptures were made during 1984 (Figure 17). No statistically significant

Table 6: Summary of the computer's ability to simulate the depths, velocities, substrates and covers actually occurring in Fish Creek. Values in the far left column represent the difference between the computer predicted depth or velocity and the actual depth or velocity measured in ft. and fps.

	DEPTH number of observations	%	cum. %	VELOCITY number of observations	%	cum. %
<0.1	17	25.4	25.4	9	13.4	13.4
<0.2	13	19.4	44.8	14	20.9	34.3
<0.3	8	11.9	56.7	13	19.4	53.7
<0.4	11	16.4	73.1	9	13.4	67.1
<0.5	13	19.4	92.5	10	14.9	82.0
<0.6	2	3.0	95.5	5	7.5	89.5
<0.7	2	3.0	98.5	2	3.0	92.5
<0.8	1	1.5	100.0	1	1.5	94.0
<0.9	0	0.0	--	2	3.0	97.0
<1.0	0	0.0	--	0	0.0	97.0
>1.0	0	0.0	--	2	3.0	100.0

SUBSTRATE AND COVER SUMMARY

	number of observations correct	%	number of observations incorrect	%
substrate	54	80.6	13	19.4
cover	35	52.2	32	47.8

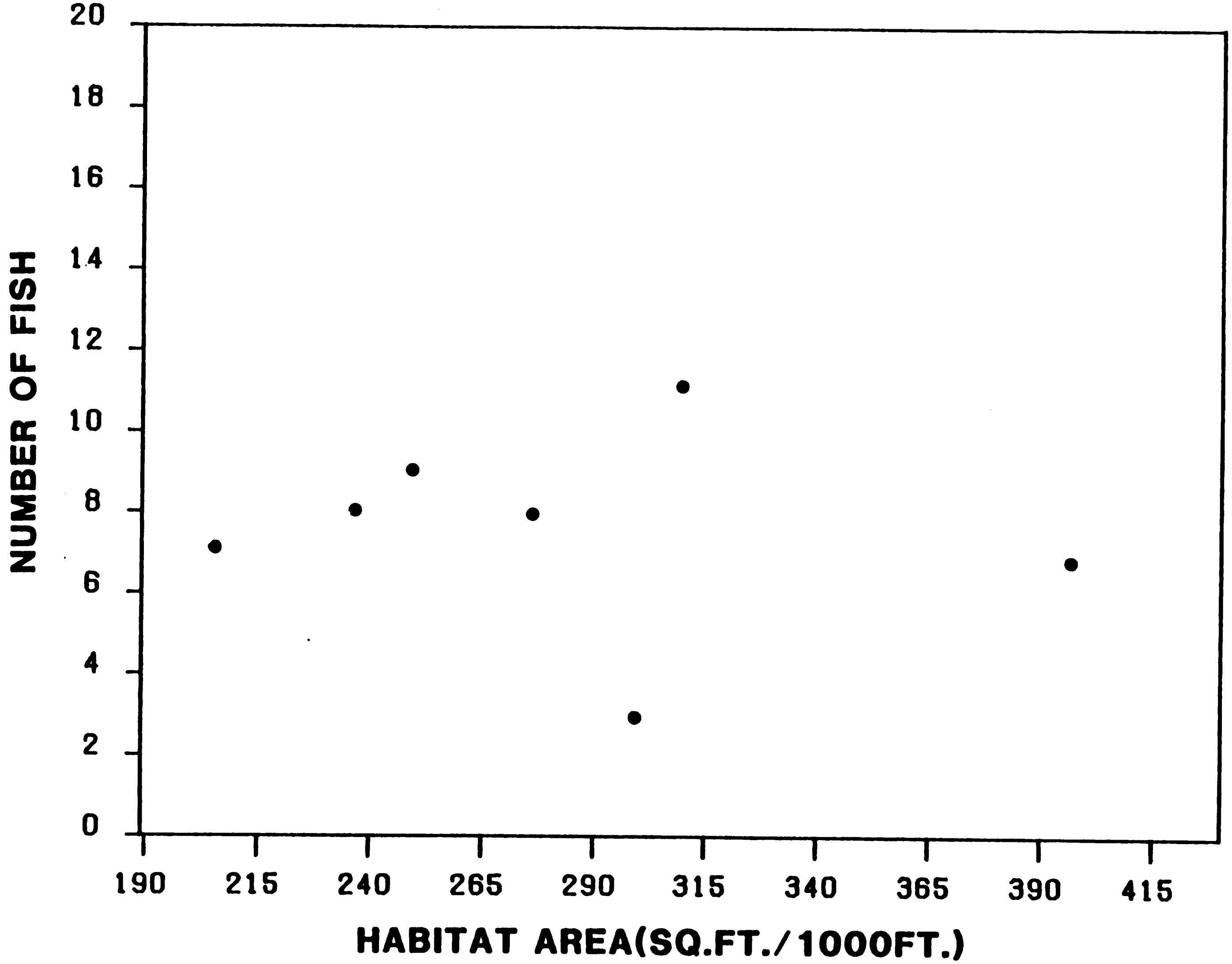


FIGURE 16a: Regression of habitat availability versus population density for 1983.

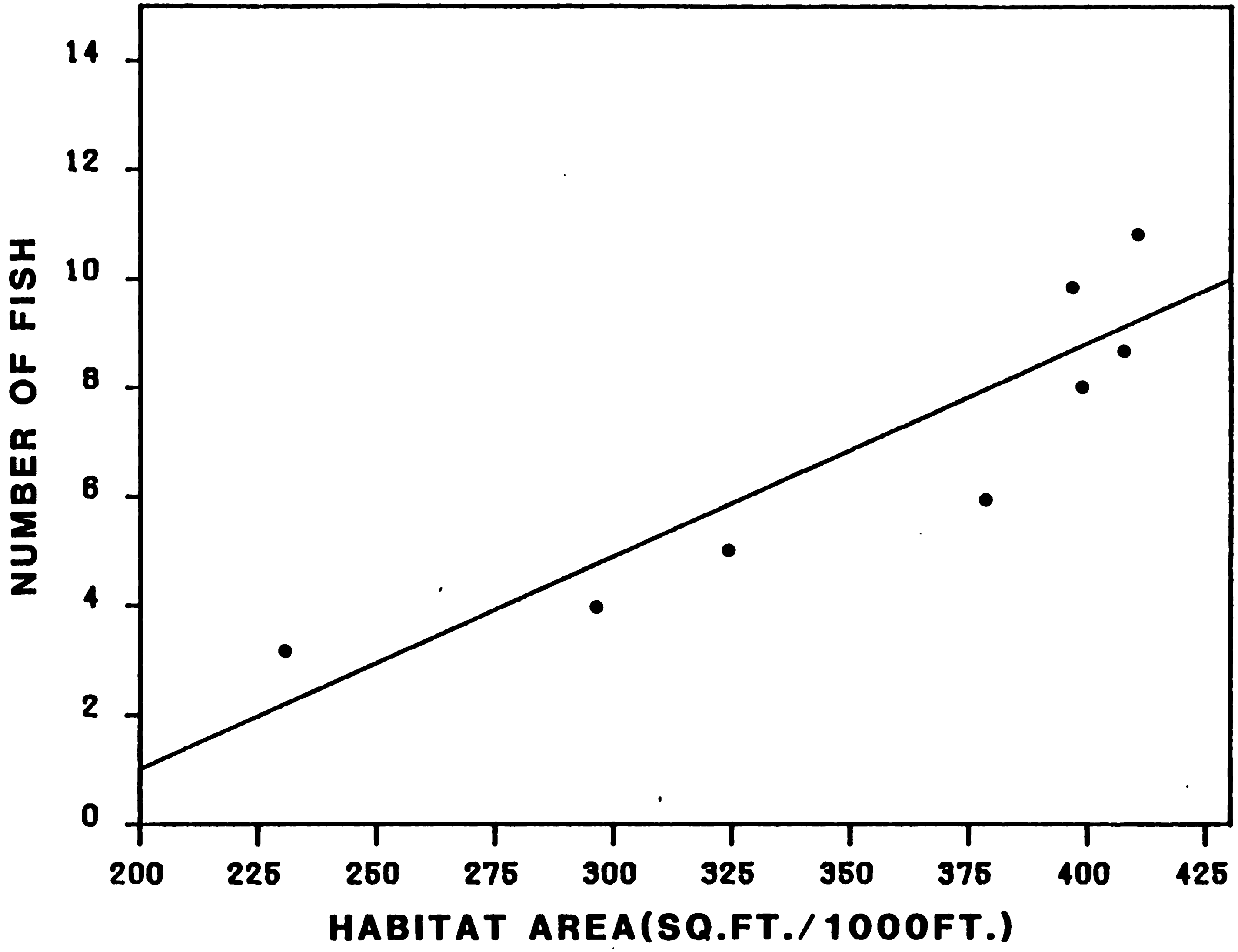


FIGURE 16b: Regression of habitat availability versus population density for 1984.

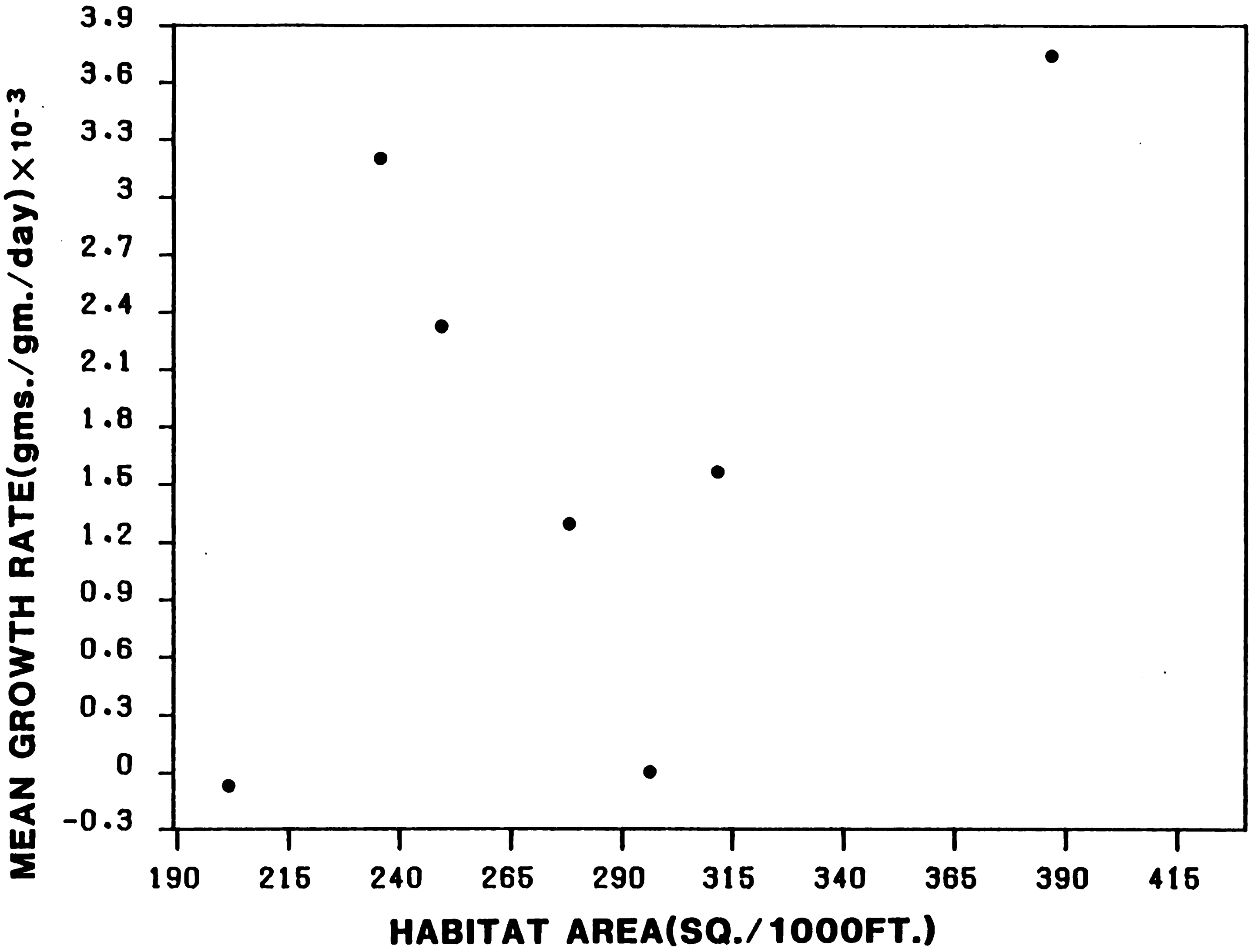


FIGURE 17: Regression of habitat availability versus mean growth rate (1983 data only).

relationship could be demonstrated. Use of the median or mode of habitat availabilty did not improve the relationship.

DISCUSSION

Fish Preference Curves

Preference curves, while only one part of the IFIM process, contain much interesting information by themselves. There also are theoretical evaluations to be made before the curves can be used with reliability. For these reasons a discussion of preference curves is warranted.

In most past applications of the IFIM method the curves developed for use in the computer simulation process were actually utilization curves. Generally, no attempt was made to determine the availability of the physical factors. The disadvantage of this is that utilization curves are fairly site specific unless the site had all possible combinations of depth, velocity, substrate and cover present in equal proportions. The advantage of true preference curves is that they are much less site specific, i.e., local environmental influences encountered during data collection have largely been removed (Bovee, 1982). This transferability from site to site reduces the cost of doing an instream flow study by eliminating the need to build separate preference curves for each stream.

Utilization curves are simply probability density functions of the type $P(E|F)$, the probability of observing a combination of stream attributes given the presence of a fish. Availability curves are also probability functions. P(E) is the relative abundance of various combinations of physical parameters available to the population. Thus, as shown in equation (1), preference can be defined as the ratio of the two probability functions (Bovee, 1982):

$$\text{Preference} = P(E|F)/P(E) \qquad \text{(eq. 2)}$$

As discussed earlier, preference curves are used in the PHABSIM process. Each point in a stream has a certain combination of depth, velocity, substrate, and cover. These combinations are simulated by the computer. The preference that a fish will have for the predicted combination of conditions is estimated by the Joint Prefernce Function. The JPF is simply the product of the individual preference functions (Bovee, 1982):

$$\text{JPF} = f(v) * f(d) * f(\text{user's option}) \qquad \text{(eq. 3)}$$

where v=velocity, and

d=depth.

Accounting for the nature of the user's option that was described earlier, equation (3) would read:

$$\text{JPF} = f(v) * f(d) * f(s,c) \qquad \text{(eq. 4)}$$

where s=substrate, and

c=cover.

It can be seen that no interaction term is present in either equation (3) or (4). A major assumption is that there is no interaction between the variables. This leads to an interesting question: Do fish actually choose depth, velocity, substrate, and cover independently of each other?

The intuitive answer would seem to be that there is some type of interaction, i.e. by choosing a certain depth, the fish gets "locked into" certain velocities, substrates and covers. In fact Orth and Maughan (1980) have found that for certain species, at certain times of the year, there is an interaction involved. There is disagreement as to the extent of the effect of these interactions on the final habitat prediction.

However, for the method to be reliable without adding interaction terms to equation (3), the interaction cannot be too great. One of the best tests to identify interactions would involve testing for interactions among all four variables at the same time. However, nineteen velocity classes, twenty-three depth classes, seven cover classes and six substrate classes would yield a matrix with well over 10,000 cells. The collection of enough data to run such a test would be a monumental task. Therefore, a Chi square test designed to detect interactions between two variables was used (Cress, per. comm.). Pairwise tests were made between depth and velocity, depth and substrate, depth and cover, velocity and cover, velocity and substrate and finally, substrate and cover. A simplified example and the actual test results are given in Table 7.

Three of the six utilization tests show that there is no significant interaction between the variables involved. Significant

Table 7: Chi square interaction tests showing (a) an example, and (b) the actual test results.

(a)

Depth

Velocity		shallow	deep	
	fast	35 27.5	15 22.2	50
	slow	20 27.5	30 22.5	50
		55	45	100

The upper numbers are the observed totals. The lower numbers are the expected values.

Expected values are obtained by multiplying the row total by the column total for each cell and dividing by the grand total.

$$X^2 = \frac{(\text{Observed-Expected})^2}{\text{Expected}}$$

, where i is the number of cells in the matrix.

$$X^2 = \frac{(35-27.5)^2}{27.5} + \frac{(15-22.5)^2}{22.5} + \frac{(20-27.5)^2}{27.5} + \frac{(30-22.5)^2}{22.5} = 9.1$$

Degrees of freedom = (#depth intervals-1) (# velocity intervals-1)=2

$X^2{}_{.05(2)} = 5.99$

9.1 is greater than 5.99. Therefore, there is a significant interaction between depth and velocity. Shallow depths and slow velocities occur together more often than would be expected due to chance alone.

(b)

	Utilization	Availability
d by v	N.S.	***
d by c	N.S.	N.S.
d by s	** see text	***
v by s	*	****
v by c	N.S.	N.S.
s by c	*** see text	***

interactions are only shown for comparisons involving substrate. However, for two of those tests (depth by substrate and substrate by cover) it seems that the calculated Chi square is not reliable and that no significant interaction exists. The problem develops when small expected values (those less that 1) occur. For instance, in the depth by substrate test one cell has an observed value of 3 (out of 208 total observations). The expected value is calculated to be 0.42. This leads to a Chi square value for that cell of 15.85. This is over one-half of the total Chi square value (30.83) for the test. Thus, one cell with only a few data points is determining the outcome of the test. Cells with large numbers of data points have expected and observed values that are very similar. The same situation occurs in the substrate by cover test. Two cells with expected values less than one and only a few observations contribute well over one-half the total Chi square for the test. For these reasons I feel that the only significant interaction on the utilization level occurs between velocity and substrate. Because five of the six combinations do conform to the assumption of the JPF model, I feel that the simulation can be run with no significant error.

The interesting point in the fish's ability to deal with its environment as a series of independant variables is the strong dependence of those variables in the natural stream setting. From Table 7 it can be seen that four of the six availability combinations have very strong interactions. For instance, depth and velocity are strongly interactive. Greater depths are associated with faster velocities, while lesser depths are associated with slower velocities. While the fish prefers large depths and small velocities, the environment is more often available as large depths and large velocities. Thus, in order for these variables to appear as non-interacting in regards to fish utilization, the fish must uncouple these availability interactions. While we would view the natural physical environment of the stream as a complex web of highly dependent variables, the fish's view must be one of discrete entities that can be "restacked" into the microhabitat that it prefers.

Insect Preference Curves

The previous discussion of fish preference curves was possible because of the quality of the data used to generate the curves. Unfortunately, the insect preference curves are much less reliable. The reason for this is the nature of the organisms themselves.

The small size of aquatic macroinvertebrates precludes the collection of depth, velocity, and substrate utilization and availability data for single individuals. Thus, it becomes necessary to collect groups of individuals, and to note the average depth, velocity, and substrate present in the sampled area. This leads to great variability in the numbers of insects collected at any particular combination of physical characteristics, and, in turn, makes it very difficult to distinquish significant differences in preference. A great many samples would be needed before any accurate discription of preference could be made. Because of time constraints, it was not possible in this study to collect as many samples as would be needed. Thus, these curves should be considered "reconnaissance grade"(Bovee and Cochnauer, 1977). Estimates of aquatic insect habitat availabilities are subject to error and will only be used to detect the possible impacts of irrigation.

A Test of the IFIM

The Velocity Adjustment Factors provide strong evidence that the IFIM model is completely applicable to the midwest. Nearly ninety percent of the VAFs were in the "good" range. The VAFs that were only "fair" or "marginal" nearly all occurred at flow volumes below 10 cfs. This means that flows lower than this were not simulated as well as the higher flows. This is a reflection of the quality of the data supplied to the computer, not the computers ability to simulate low discharges.

More evidence of the IFIM's applicability to the midwest is found in Figure 15. Virtually all the brown trout captured throughout the summer were found in, or directly next to, spots predicted by the computer to be trout habitat. Descrepencies at transect 8 resulted from an error in stream mapping. A piece of down timber was missed and this misinformation fed to the computer. This resulted in many fish being captured in seemingly non-habitat areas. In actuality, if the stream mapping had been accurate, the computer would have indicated habitat to be present where those fish were caught.

The Kendall's Tau test provides quantitative evidence of the computer's ability to predict trout habitat. As given in Table 5, a statistically significant relationship did occur between the computer's measure of habitat quality (WUA) and fish numbers. This indicates that the computer can predict with some accuracy not only the location of fish habitat, but that habitat's quality as well.

The computer's ability to accurately predict depths, velocities, substrates, and covers is called into question from the data in Table 6. As given in this table, the computer's predictions are substantially inaccurate in some cases. However, in the majority of cases, the computer was able to estimate depth and velocity to within three-tenths of a foot and foot per second, respectively. The computer was also correct in predictions of substrate and cover in the majority of cases. The errors that do occur are from two sources.

The first source of error is human. It is difficult to accurately measure depth and velocity in log jams and under undercut banks. Thus, the information used by the computer to simulate flow conditions was, in some cases, inaccurate. Better data will result in more accurate simulations.

The second reason the predicted and actual values do not always match has to do with the way the data were collected. The depth, velocity, substrate, and cover data were collected where a fish was located. Thus, this was not a random sampling. The fish are going to actively search for the best conditions possible. Thus, small variations in the stream channel morphology (too small to warrant detailed mapping) will influence where the fish is found. This point is demonstrated by the fact that computer predicted depths were, on the average, less than the actual depths the fish chose (1.08 ft versus 1.22 ft). Predicted velocities were, on the average, faster than the velocities the fish were able to find (0.703 fps versus 0.689 fps). The fish were also able to find small areas of undercut bank or down timber that were not mapped. A similar situation existed with substrate. Thus, the fish are able to key in on small variations in the physical conditions present which would require an excessive amount of time to map. This results in a systematic disagreement between predicted and actual depths, velocities, substrates, and covers. Given these errors, the computer is doing an adequate job of simulating the physical characteristics of Fish Creek.

Aside from testing the computer's predictive reliability, the data in Table 6 provide insight into which physical parameters are the most important determiners of brown trout habitat. The parameters which the fish key on most strongly when selecting a resting area must be those the computer simulates the least accurately. The reasoning for this is as follows. It is impossible to accurately map every small variation in any of the physical parameters. However, the fish can very easily find these small areas of suitable habitat. The more strongly the fish are searching for, as an example, a certain depth, the more likely it will be able to find a small area of suitable depth not mapped during data collection. Thus, the computer prediction will not match the actual depth where the fish was found.

Using this logic, it is clear from Table 6 that fish are keying in on cover very strongly. Depth and velocity seem to be of somewhat lesser importance. Substrate does not appear to be an important parameter. In future applications of the method, it may be worthwhile to use only depth, velocity, and cover in the simulations. Naturally, if a different life stage is being considered (spawning habitat, as an example), substrate may become a very important parameter and should be included in the simulation.

There is no theoretical discrepancy in the IFIM model precluding its use in the midwest. The above evidence provides empirical support of the applicability of the method to the region. Indeed, Carlson (1979) reported that the computer's predictive reliabilty is a reflection of the reliability of the data it is supplied. As long as well trained people are responsible for the data collection, the model is applicable to virtually any region.

Fish Habitat Estimations

Given that the model is working well on Fish Creek, it is now possible to make estimates of fish habitat loss due to irrigation withdrawals. The following discussion of habitat losses is designed to present the type of analysis possible given the data described in the Results section. The first step is the examination of the WUA vs. discharge plot (Figure 5).

As given in Figure 5, brown trout habitat in Fish Creek changes rapidly in the range 10 to 14 cfs. Relatively small changes in discharge will result in large changes in available habitat. Discharge records from a U.S.G.S. gaging station located in Carson City, downstream from the study section, were regressed against discharges measured with the water level recorder installed in the study section. From this regression and the discharge records made at Carson City in previous years, it is possible to estimate the summer base flow in the study section over the years 1974 to 1980. This estimate is 12.1 cfs.

This estimate falls in the range of discharges most critical in terms of habitat (Figure 5). Thus, in a normal year, any irrigation withdrawals will have a significant impact on available habitat. The slope of the line between 10 and 14 cfs is roughly 34 square ft./cfs. Irrigation rigs on Fish Creek have a capacity of 600 gallons per minute (gpm) or 1.3 cfs. Thus, each rig on Fish Creek removes not only 600 gpm but also 44 square ft. of habitat/1000 ft. of stream during an average summer base flow period.

The study section, while only approximately 950 ft. long, was chosen because it is representative of the headwaters of Fish Creek. The habitat estimates made in this section should represent a stream length of approximately 37,000 ft. of Fish Creek. Thus, it is possible to estimate the total number of square ft. of brown trout habitat present in the headwater section of the stream at the various flows of interest. Using this logic, the 44 square ft./1000 ft.of stream removed by a single irrigation rig operating at full capacity, translates into a total habitat loss of 1,628 square feet.

The above discussion is largely theoretical. The actual habitat losses will depend on how many rigs are running at any one time, at what percentage of full capacity the rigs are operating, and what the actual discharges would be without irrigation. While the discharge recorder will not give detailed information on the number of rigs operating or at what capacity they are running, it does provide a composite estimate of water withdrawals. Actual streamflow is measured by the recorder, and it is possible to estimate the discharge that would have occurred without irrigation. This estimate is based on discharges recorded during those times of the day when little or no irrigation is occurring. Both estimates can then be converted into a habitat estimate. From these estimates a habitat time series with, and without, irrigation can be generated. This was done by month for the summers of 1983 and 1984 (Figure 7a-h).

Using these figures a fairly complete analysis of habitat loss can be made. To quantify habitat loss over time, the concept of a habitat-day will be used. A habitat-day will be defined as 1 square foot of habitat available for a period of one day. Thus, if streamflow conditions are such that an average of 400 square ft./1000 ft. of stream of habitat are present on each of two consectutive days, it can be said that a total of 800 habitat-days were present. If irrigation withdrawals accounted for a loss of 200 square ft./1000 ft. of stream of habitat on each day, a total of 400 habitat-days were lost. This type of analysis was performed with the data contained in Figure 7a-h.

Fish Habitat Losses in 1983

Irrigation began on June 22 of 1983. From this time until the end of the month, a total of 159 habitat-days were lost. Averaged over the month, this is a 1.7 percent reduction in habitat-days. This loss does not seem excessive. However, the average habitat loss that occurred at the time of irrigation withdrawals was 7.1 percent. In other words, during those times that irrigation was occurring, habitat availability was reduced an average of over 7 percent. This value may be the more important one if fish are responding to short-term, low habitat availability events, rather than longer-term, average habitat availabilities.

July was an extremely dry month. Irrigation occurred on all but six days during the period. The total habitat loss was 1,171 habitat-days. Averaged over the month, this is a 12.2 percent reduction in available habitat. Taking into account only those times when irrigation was occurring, a 16.0 percent reduction in habitat occurred.

August was also fairly dry, and irrigation occurred on 11 days of the month. The total habitat loss was 312 habitat-days. The monthly average habitat loss was 3.6 percent. The loss during actual irrigation times was 11.1 percent.

Irrigation ended for the season on September 4. The habitat loss due to irrigation was 82 habitat-days. This is a 0.9 percent reduction averaged over the month, and a 9.0 percent reduction during actual irrigation events.

A convenient way to summarize the effects of irrigation in 1983 is the habitat duration curve (Figure 18a). The habitat duration curve describes the amount of time that a particular amount of habitat availability was equalled or exceeded. For example, the actual amount of habitat that was equalled or exceeded 50 percent of the time during the summer of 1983 was 303 square ft./1000 ft. of stream. The estimated 50 percent value without irrigation was 346 square ft./1000 ft. of stream. As given in Figure 18a, irrigation substantially increased the occurrence of low habitat availability events. It is probable that low habitat availability events are an important determiner of carrying capacity. If this is true, irrigation must be lowering the brown trout carrying capacity of Fish Creek. This will be examined in detail later in this discussion.

The type of data given in Figure 18a can also be valuable if a certain "critical habitat availability" is known. The habitat duration curve will describe how often this habitat availability will not be present both with and without irrigation. A discussion of this follows later.

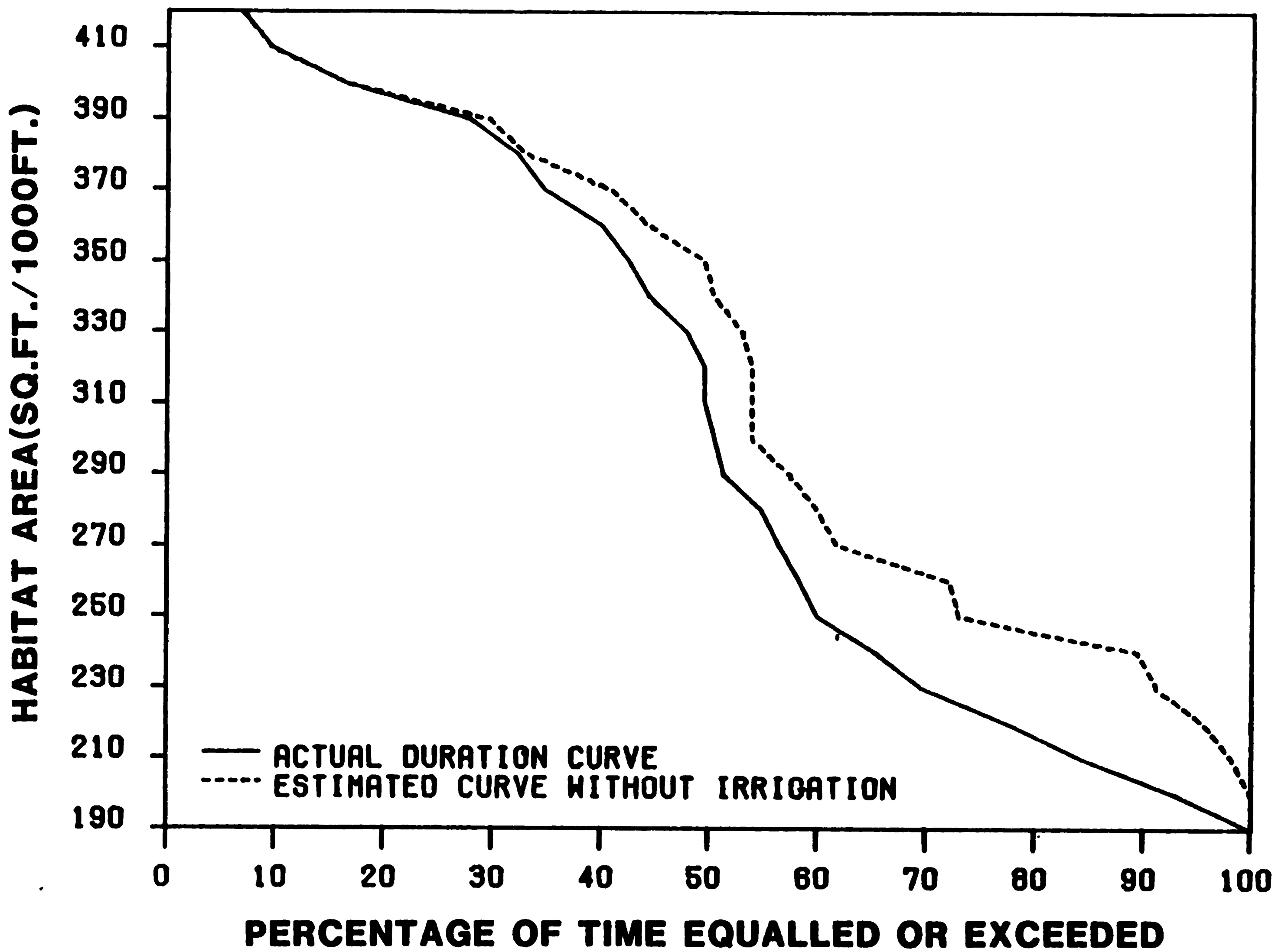


FIGURE 18a: Habitat duration curve for the period June 9, 1983 to September, 1983.

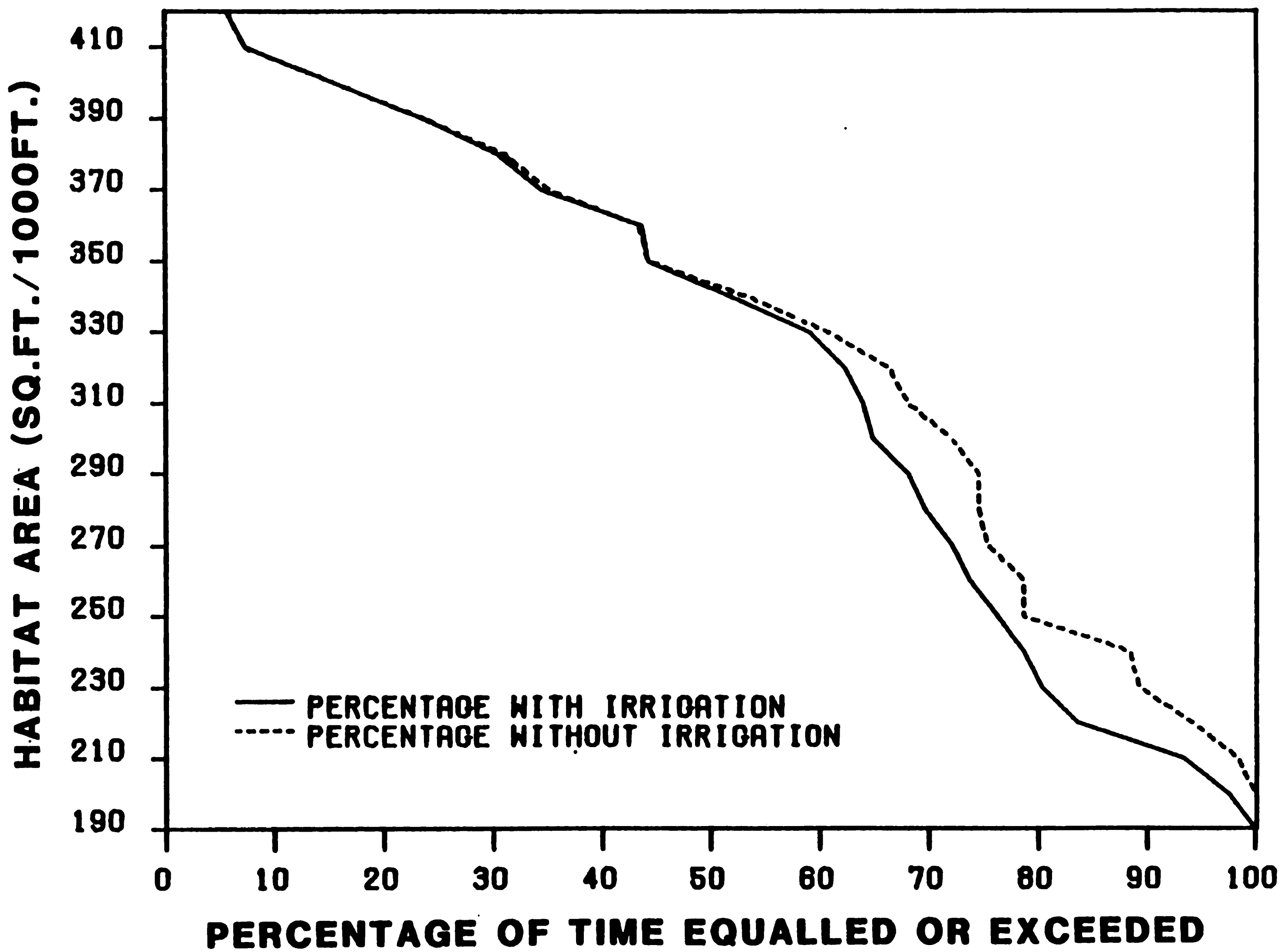


FIGURE 18b: Habitat duration curve for the period June 1, 1984 to September 30, 1984.

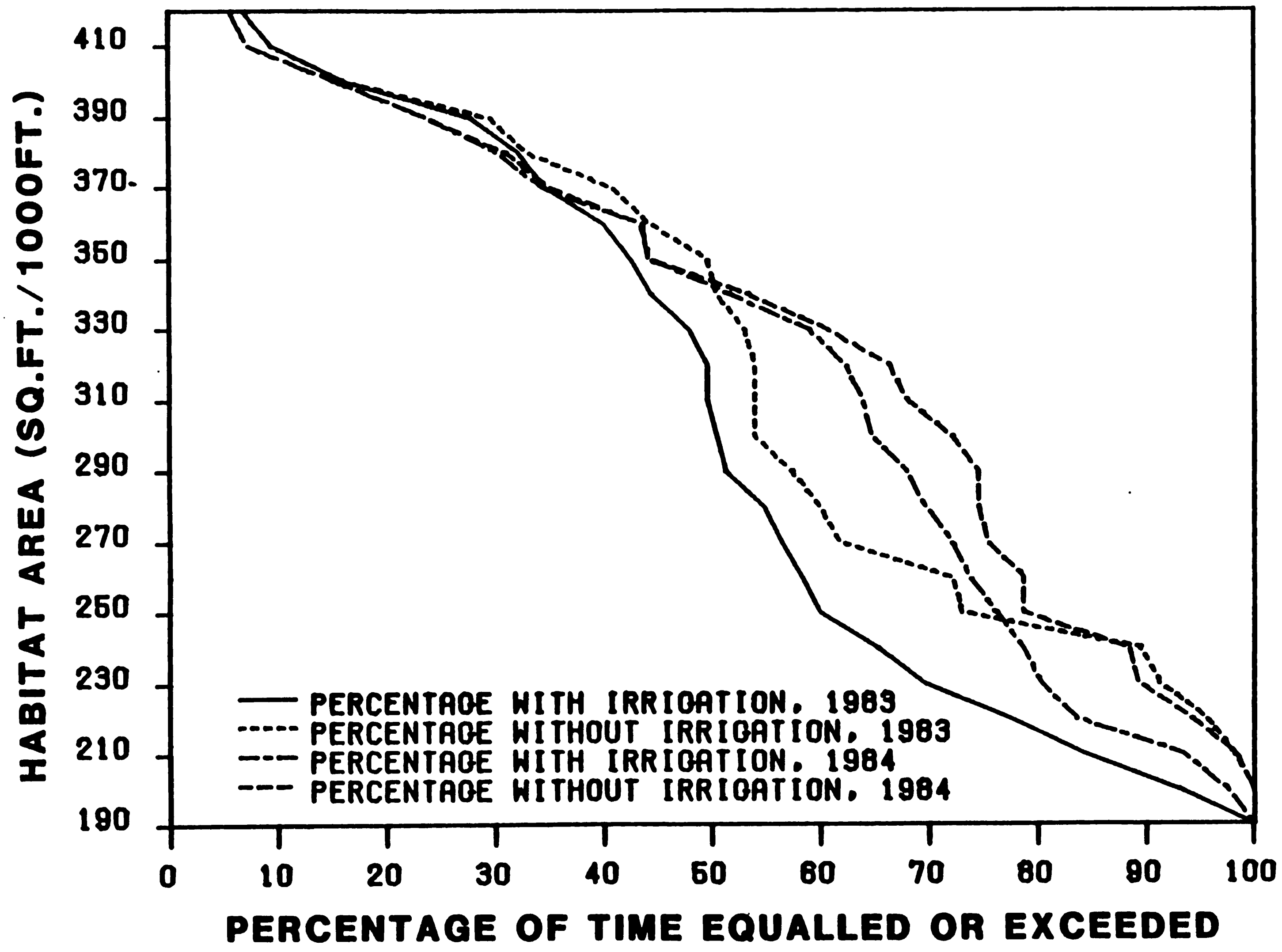


FIGURE 18c: Habitat duration curves for the summers of 1983 and 1984.

Fish Habitat Losses in 1984

The summer of 1984 was not nearly as dry as that of 1983. Irrigation did not begin until July 2. From this time until the end of the month a total of 619 habitat-days were lost. This represents a loss in habitat of 6.3 percent averaged over the month. The average loss during irrigation was 11.8 percent. In August, an average of 4.0 percent of the available habitat was lost. During irrigation periods an average of 8.7 percent was lost. These data reflect a reduced impact compared to the much drier summer of 1983, but show that even in more normal years, irrigation can remove a substantial percentage of brown trout habitat.

The 1984 habitat duration curve, Figure 18b reflects the reduced impact reported above. However, irrigation is still increasing the occurrence of low habitat availability events. In order to contrast the effects of irrigation during 1983 and 1984, both habitat duration curves have been superimposed in Figure 18c. As given in this Figure, more habitat was available in 1984 even with irrigation compared to the amount available without irrigation in 1983. This indicates that natural low flow conditions can reduce habitat more than some artificially derived flow conditions. More importantly, however, Figure 18c indicates that irrigation reduces habitat relatively more in those years which are dry already. Thus, it is in naturally dry years that irrigation has it's most detrimental impact on habitat availability.

Insect Habitat Estimations

Many authors have demonstrated that benthic macroinvertebrates do respond to alterations in the natural flow regime (Briggs, 1948; Phillipson, 1954; Minshall, 1968; Phillips, 1969; Phillipson, 1969; Spence and Hynes, 1971; Fisher and LaVoy, 1972; Trotzky, 1974; Kroger, 1974; Ward, 1976a; Ward, 1976b; Covich, 1978; Kovalak, 1978; Armitage, 1978; Ward, 1979; Gislason, 1980). This study focused on insect habitat availability and its relation to discharge.

The two insect species studied respond to flow reductions differently (Figure 12). *Hydropsyche spp*. habitat is related to discharge in a linear fashion. Flow reductions at any point on the curve result in loss of habitat for this insect. *Ephemerella spp*. habitat, in contrast, only shows a reduction when flow is reduced below about 16 cfs. However, because summer base flow is below 14 cfs, and the slopes of the two curves below this value are similar (357.5 and 287.5 square ft. per cfs for *Hydrospyche spp*. and *Ephemerella spp*., respectively), flow reductions due to irrigation should effect these two species similarly. Based on the above slopes, each irrigation rig has the capacity to remove 475.5 and 382.4 square ft./1000 ft. of stream of *Hydrospyche spp*. and *Ephemerella spp*. habitat, respectively.

Insect Habitat Losses in 1983 and 1984

Due to the shape of the habitat-discharge curve for both species, habitat losses for the insects were less substantial than the losses reported for brown trout. All losses for both species are summarized in Table 8, and for the most part were well below 10 percent. Thus, it appears that the two most abundant macroinvertebrate species present in Fish Creek are not being severely impacted by irrigation withdrawals. Based on this information, it can tentatively be stated that irrigation is not limiting possible brown trout food resources in this stream. However, other species of benthic macroinvertebrates (those with narrower preference ranges than the two species studied here) may be impacted by reduced discharge conditions..

Fish Habitat Availability and its Relation to Population Density

Many studies have indicated various species of fish respond to streamflow and streamflow regulation (Schuck, 1945; Smoker, 1953; Parsons, 1955; Kalleberg, 1958; Hourston, 1958; Von Heinz, 1959; Delisle, 1964; Gordon, 1965; Corning, 1969; Phillips, 1969; Zalumi, 1971; Fraser, 1971; Spence and Hynes, 1971; Kraft, 1972; Hooper, 1973; Giger, 1973; Havey, 1974; White, 1975; White et. al., 1976; Mullan, 1976; Holcik, 1976; Blahm, 1976; Finnigan, 1978; Anon., 1979; Young and Maughan, 1980; Holden, 1980; Solomon and Paterson, 1980; Lambert, 1980; Avery, 1980; Holcik, 1981; Scarnecchia, 1981; Ottaway and Clarke, 1981;

Table 8: Summary of aquatic insect habitat losses for 1983 and 1984.

	Percent loss over the month		Percent loss at irrigation	
Month	*Hydropsyche sp.*	*Ephemerella sp.*	*Hydropsyche sp.*	*Ephemerella sp.*
June, 1983	0.91	0.34	4.57	1.55
July, 1983	8.51	5.02	11.05	6.35
August, 1983	2.40	1.35	7.39	3.95
September, 1983	0.54	0.40	5.24	3.27
June, 1984	0.00	0.00	0.00	0.00
July, 1984	2.67	1.40	5.14	2.45
August, 1984	3.09	1.91	6.23	3.64
September, 1984	0.00	0.00	0.00	0.00

Trapicyna, 1981; Eley et. al., 1981). At least two others have specifically attempted to relate the availability of certain physical characteristics to trout populations (Lewis, 1969; Wesche, 1974). This study is one of the first to attempt to verify the IFIM model based on trout population responses to fluctuating habitat availabilities as predicted by the method.

As stated in Results, a significant relationship was found to exist between habitat availability and population levels for 1984. Why then did this relationship not show up in 1983? I believe the reason was rapidly fluctuating habitat availabilities during the summer of 1983. This resulted in a lag period between the time a certain habitat availability was present, and the time the fish responded to this habitat availability. This is demonstrated in Figure 19, which traces both habitat availabilities and population levels through time. The lag period described becomes evident when the data are arranged in this manner. If this lag period is incorporated into the regression, the resulting r2 value falls just short of being significant at the 95 percent level (the calculated and test values are .555 and .570, respectively, with d.f.=5). There is a significant relationship at the 90 percent level. This lends support to the contention that it was rapidly fluctuating habitat availabilities that obscurred the relationship between habitat and population levels in 1983.

Brook trout were also present in the study area at times. Assuming that this species has habitat requirements similar to brown trout, it

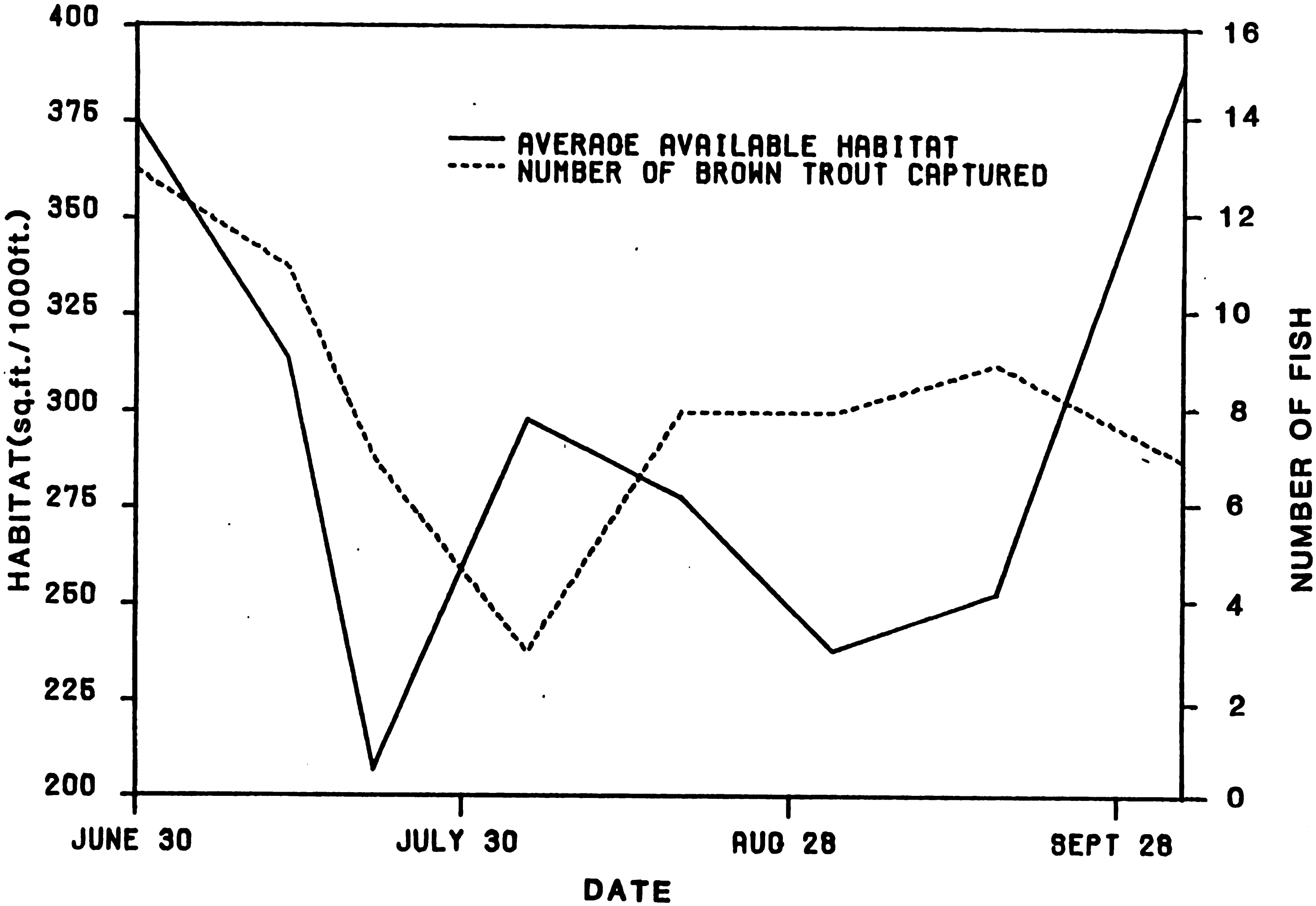


FIGURE 19: Chronological sequence of habitat availabilities and population levels of brown trout, 1983.

may be that total trout population levels are more closely related to habitat availability than are brown trout population levels. In order to test this, total trout populations present at the sampling date were regressed against average habitat availability over the two week period prior to the sampling date. It was found that this significantly improved the habitat availability-population level relationship found for brown trout alone. In 1983 (with the lag period included) the r2 value increased from the previously reported .555 up to .834. This value is highly significant (alpha=.01, d.f.=5). The 1984 r2 value increases from .837 up to .904. This value is very highly significant (alpha=.001, d.f.=5). These data verify that the IFIM generated habitat estimations do have biological significance. A reduction in habitat as estimated by the method will result in a reduction in trout population levels. While the habitat reductions reported were temporary, I believe that a permantent reduction would lead to a similarly permanent reduction in trout population levels. This has probably already occurred to the extent that past irrigation withdrawals have increased the occurrence of low habitat availability events.

While it seems that the fish are responding to habitat availability in part, temperature must also be exerting an influence. Low habitat availabilities result from reduced discharge, and this leads to a more rapid warming of the stream. During the lowest discharge periods in July of 1983, water temperatures reached 70 degrees. It is at this temperature that brown trout will begin to actively search for cooler water. This may result in an upstream migration which could reduce population levels in the study section. However, during the summer of 1984 water temperatures never rose above 63 degrees. Most temperatures were below 60 degrees. Thus, the influence of temperature was probably not substantial. Without the influence of temperature, the relationship of habitat availability to population levels was even stronger. Irrigation then, can impact fish in at least two ways: first, by reducing the amount of habitat available and second, by promoting a warming of the stream.

Fish Habitat Availability and its Relationship to Growth Rates

Average growth rate over the period between sampling times was regressed against mean habitat availability over the same period. This could only be done for the 1983 data due to insufficient numbers of recaptures during 1984. No significant correlation existed (Figure 17). I feel the lack of a significant correlation resulted from the inability to obtain an accurate estimate of average growth rate. There were sometimes as little as three fish from which to make growth rate estimates. This small sample size, while virtually the entire population, allowed the growth rate estimates to be heavily influenced by single individuals. It appears that individual fish did not respond to the same average habitat conditions in the same manner. Some individuals experienced positive growth throughout the season, some simply maintained their weight, and others had negative growth rates

(Figure 20). This type of highly variable growth rate has long been recognized, and is probably a result of high water temperatures (Brown, 1946). Thus, the problems caused by small sample size were magnified by the highly variable nature of the fish themselves. This resulted in average growth rate estimates having little biological significance.

This is unfortunate because, during the data collection, it seemed obvious that extended low flow conditions were causing reduced growth rates. During these low flow periods, a majority of the fish were experiencing negative growth rates. During times of greater habitat availability most or all of the fish experienced positive growth. To demonstrate this point, the percentage of fish experiencing positive growth was regressed against average habitat availability (Figure 21). This regression was very highly significant (r2 =.874, alpha> 0.001, d.f.=7). Thus, it appears that reduced habitat availabilities result in a greater proportion of the population being unable to maintain positive growth rates. This is certainly of biologic importance.

The "break even" point for the population is approximately 260 square ft./1000 ft. of stream (Figure 21). Below this habitat availability greater than 50 percent of the population will lose weight, while above it the majority of fish will grow positively. This is where the habitat duration curve (Figure 18a and b) becomes extremely useful. The 1983 data (Figure 18a) will be used to demonstrate this point.

As given in Figure 18a, irrigation was responsible for greatly increasing the number of low habitat availability events in Fish Creek.

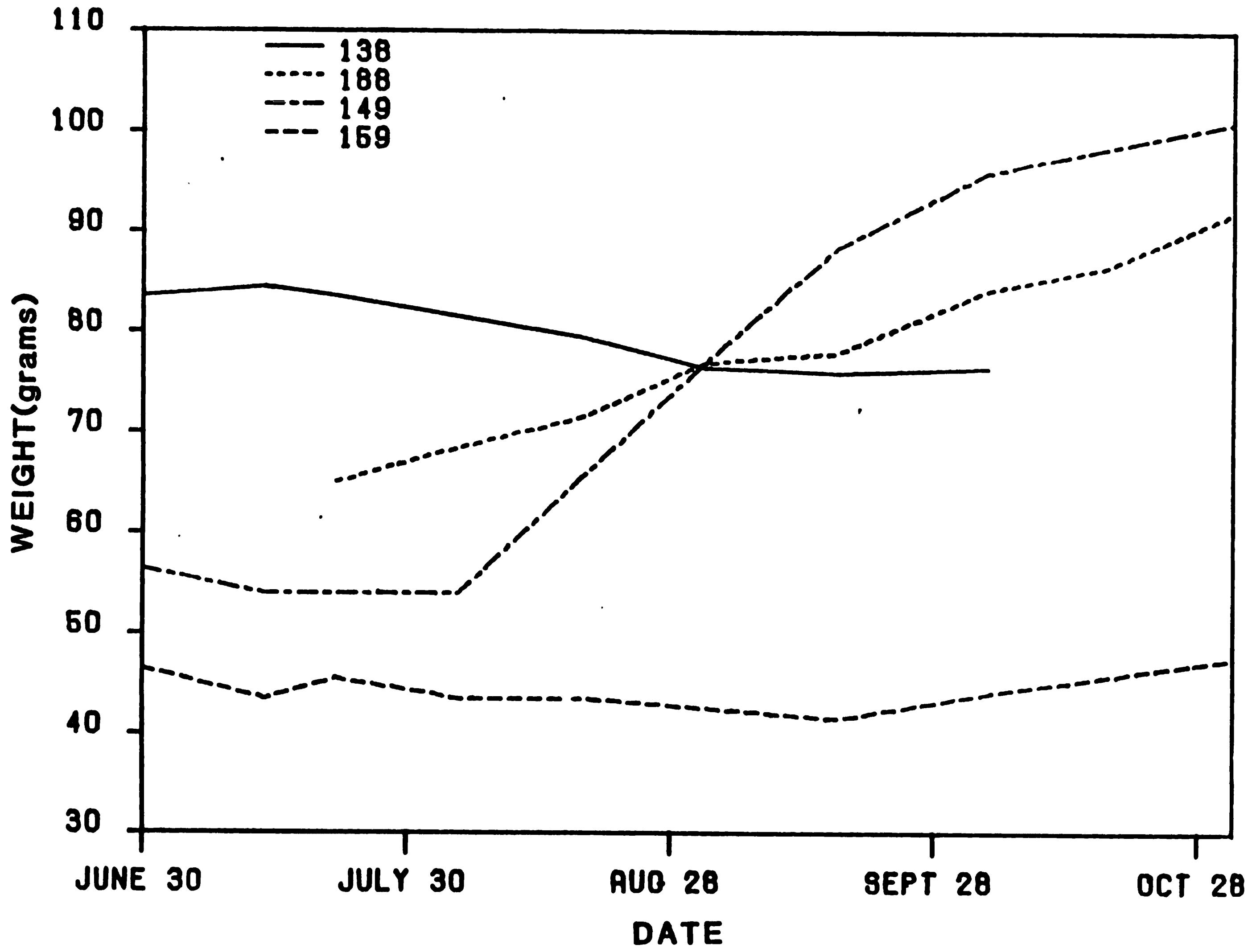


FIGURE 20: Change in weight through time of four "typical" brown trout in 1983.

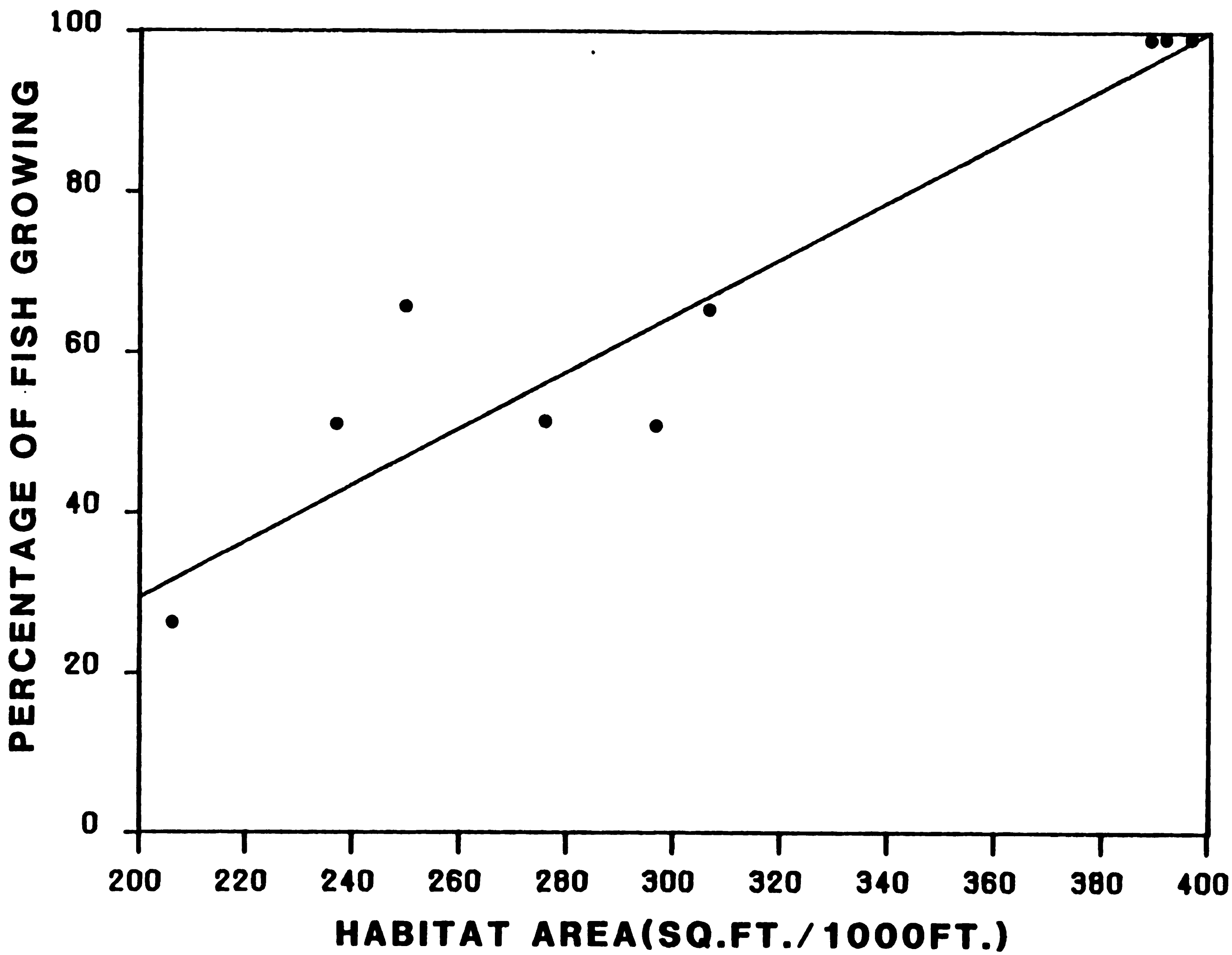


FIGURE 21: Percentage of the brown trout population gaining weight versus habitat availability in the summer of 1983.

As a result of irrigation, habitat availabilities equal to, or less than, the critical value of 260 square ft./1000 ft. of stream occurred on 41.7 percent of the days in the summer of 1983. Without irrigation, habitat availabilities this low or lower would have occurred on only 27.83 percent of the days. Thus, irrigation caused a 13.87 percent increase in the amount of time that a majority of the fish population experienced negative growth.

The Future

The habitat duration curve details the frequency of habitat availabilities as they occurred over a specific period of record. A similar curve, the probability of occurrence curve, can detail the probability that a specific habitat availability will occur over a given time span. Figure 22a-c is a habitat probability of occurrence curve constructed on data generated by Dr. Roger Wallace of the Department of Civil Engineering, Michigan State University. This figure describes the probability of occurrence of mean monthly habitat availabilities for any twenty year period.

Figure 22a-c can be useful in detailing the long term impacts of irrigation on fish habitat. Irrigation increases the probability of occurrence of low mean monthly habitat availabilities. For example, in July (Figure 22b), the probability of occurrence of a mean monthly habitat availability below the critical value of 260 sq. ft./1000 ft.

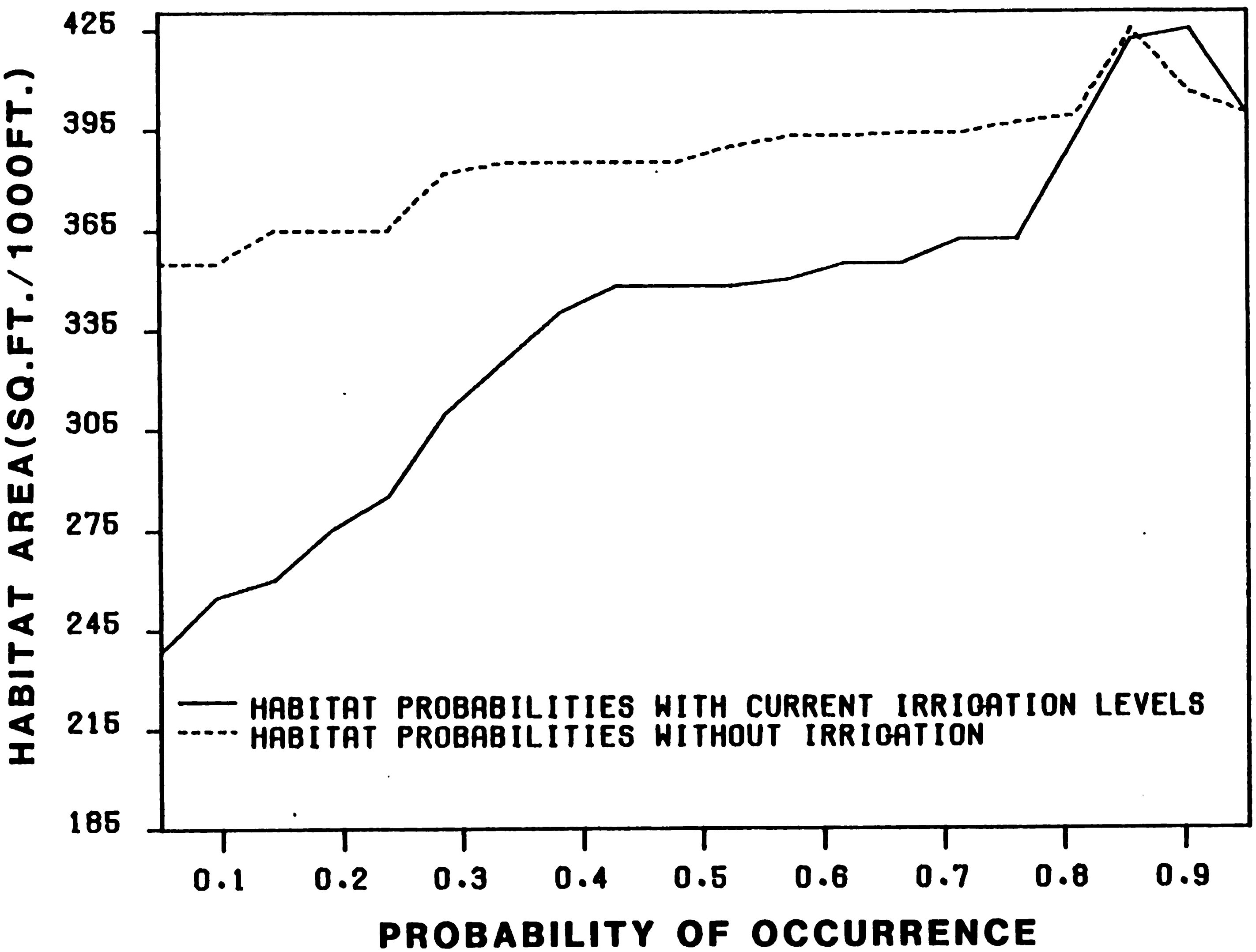


FIGURE 22a: Mean monthly habitat availability in June versus probability of occurrence curve. The time span considered is twenty years.

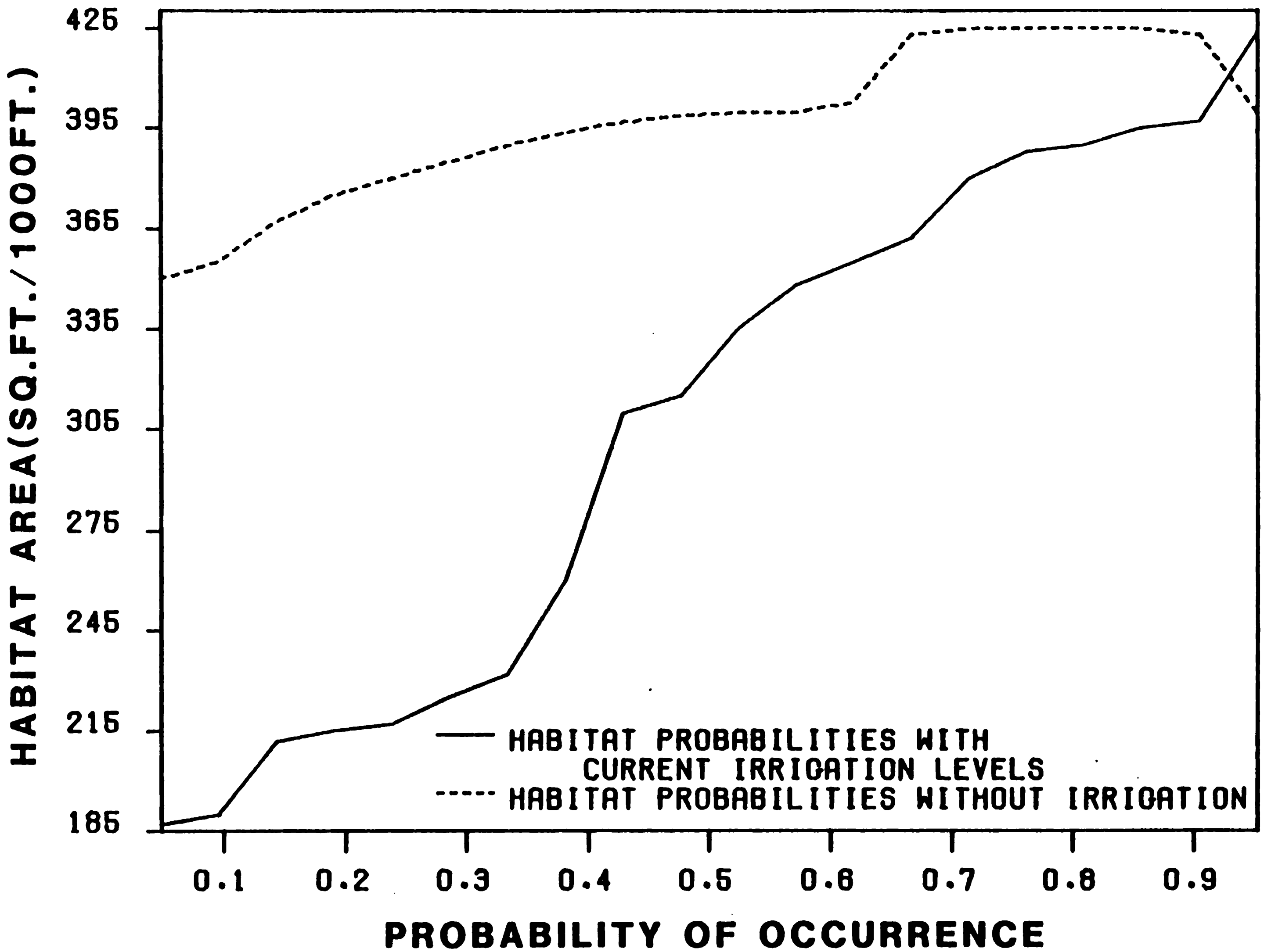


FIGURE 22b: Mean monthly habitat availability in July versus probability of occurrence curve. The time span considered is twenty years.

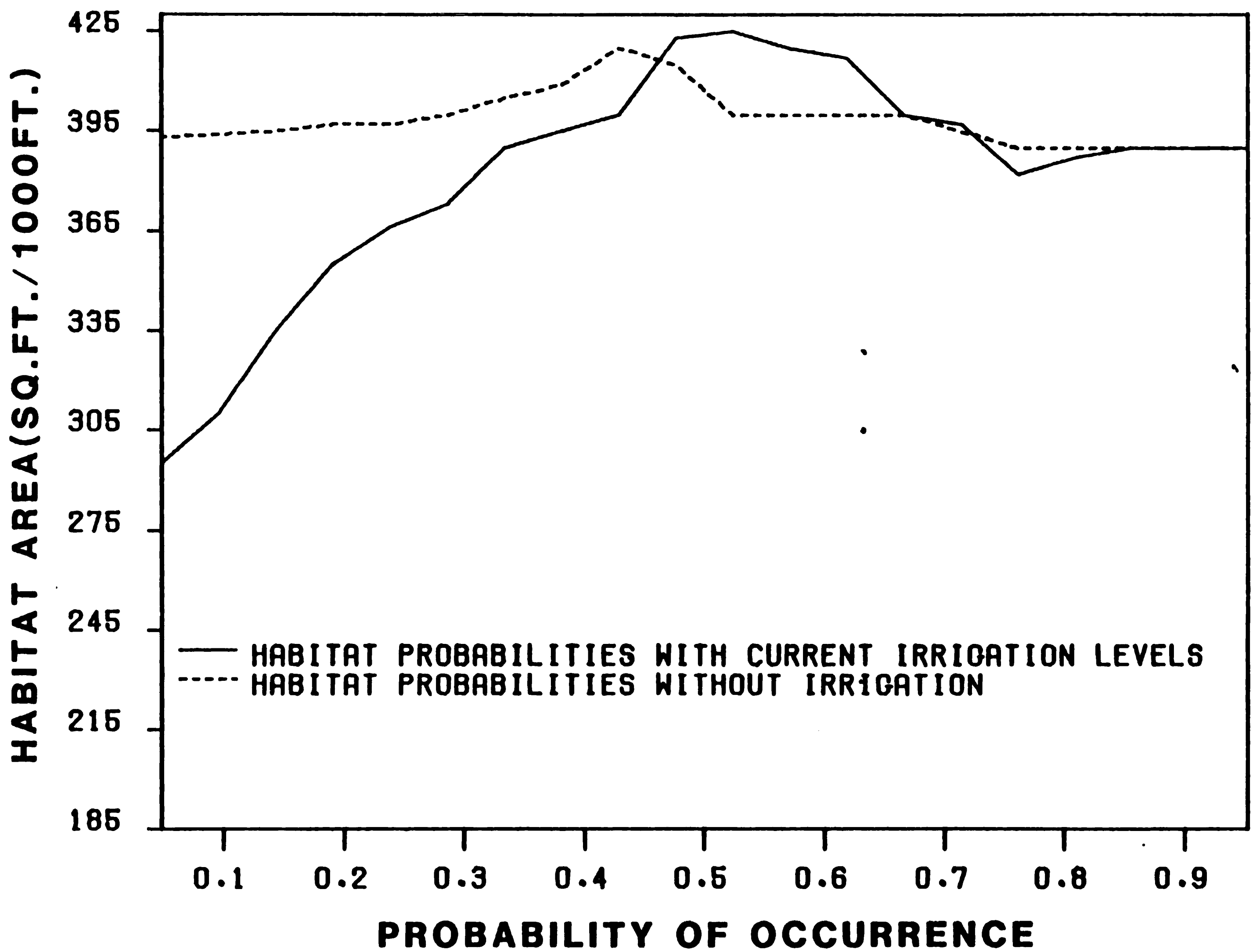


FIGURE 22c: Mean monthly habitat availability in August versus probability of occurrence curve. The time span considered is twenty years.

without irrigation is nonexistent. In contrast, with irrigation, the probability of occurrence of this habitat availability is 0.381.

As more and more acres are put into irrigation, the probability of occurrence of very low habitat availabilities will continue to increase. As this happens, the low habitat availabilities previously present only in an extremely dry year will occur nearly every year. Fish populations will respond in the manner described earlier, and a once productive fishery will be lost.

CONCLUSIONS

The Instream Flow Incremental Methodology proved to be applicable to a typical Lower Michigan stream. Internal quality control checks referred to as Velocity Adjustment Factors indicated that the IFIM could accurately simulate the hydraulic characteristics of a Michigan stream. Comparisons made between computer predicted habitat locations and actual brown trout locations demonstrated the methodology's ability to accurately simulate brown trout habitat. The accuracy of the method in any instance is a reflection of the quality of the data supplied to it.

Simulations performed by the IFIM indicate that, below 16 cfs, small reductions in discharge will result in substantial reductions in available brown trout habitat. A one cfs reduction in discharge was shown to result in a 34 square ft./1000 ft. of stream reduction in habitat. Actual mean monthly habitat losses ranged from 0.85 percent up to 12.2 percent. Habitat reductions during periods of irrigation ranged from 4.0 percent to 16.0 percent. In general, irrigation was found to substantially increase the frequency of low habitat availability events as demonstrated by the flow duration curve. July was found to be the most critical month both in terms of naturally low habitat availabilities, and irrigation demands.

A statistically significant relationship was found to exist between habitat availabilities and brown trout population levels. Rapidly fluctuating habitat availabilities introduced a lag period, but did not alter the nature of the relationship. Total trout populations (i.e. brook and brown trout) were found to be even more significantly related to habitat availabilities. Thus, habitat reductions resulting from water withdrawals for any purpose will reduce trout populations.

The relationship between average brown trout growth rate and habitat availability was found to be not statistically significant. The reason may have been lack of sufficient data to accurately determine average trout growth rates. However, the percentage of the population experiencing a positive growth rate was found to be statistically significantly related to habitat availability. Thus, based on this preliminary data, it appears that reduced habitat availabilities will lead to reduced brown trout growth rates.

Aquatic insect habitat losses were estimated utilizing a limited preference data base. The simulations show that irrigation withdrawals will have less of an impact on this portion of the stream community, compared to fish populations. Mean monthly habitat losses for Hydropsyche spp. ranged from 0.54 to 8.51 percent. Losses during irrigation periods ranged from 4.57 to 11.05 percent. Mean monthly habitat losses for Ephemerella spp. ranged from 0.34 to 5.02 percent. Losses during irrigation periods ranged from 1.55 to 6.35 percent.

The most important conclusion to be drawn from this study is this: current levels of irrigation in Michigan are having a detrimental impact on inland trout fisheries in terms of habitat, population levels, and growth rate. As irrigation water withdrawals increase, the magnitude of the impact will also increase. If left unchecked, irrigation will result in the degredation or loss of a significant portion of our fishery resource. Only through documentation of these potential losses, followed by strong legislation designed to protect the fishery resource, can we hope to reduce the problem to acceptable levels. The Instream Flow Incremental Methodology provides a useful tool by which these losses can be quantified before they actually occur. Would it not be preferable to avert the losses before they occur, rather than mitigate them afterwards?

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