Development And Evaluation Of Weighted Criteria Probability-Of-Use Curves For Instream Flow Assessments: Fisheries

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INSTREAM FLOW
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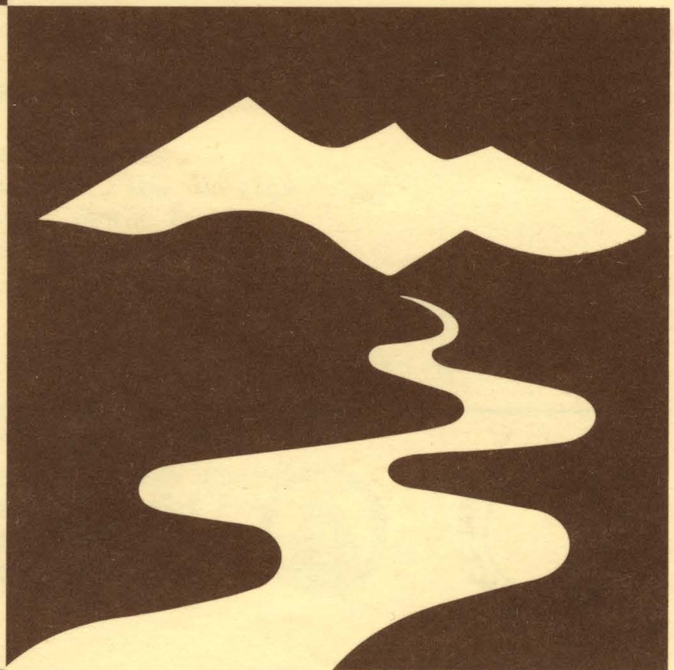

INSTREAM FLOW INFORMATION PAPER: NO. 3

FWS/OBS-77/63
DECEMBER 1977

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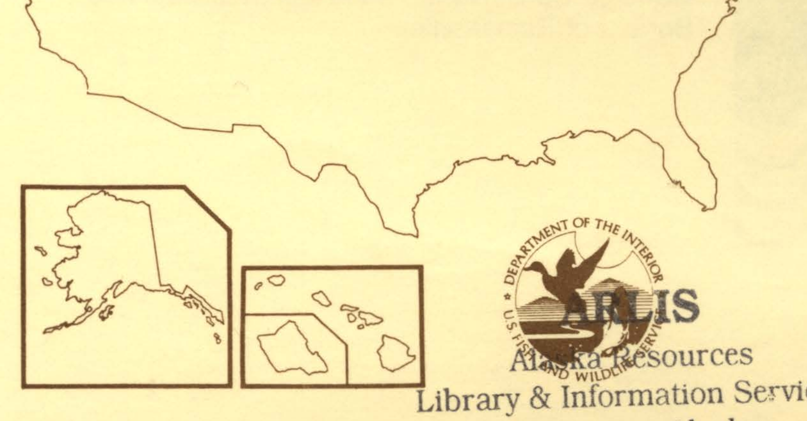

COOPERATIVE INSTREAM FLOW SERVICE GROUP

The Cooperative Instream Flow Service Group was formed in 1976 under the sponsorship of the U.S. Fish and Wildlife Service. Primary funding was provided by the U.S. Environmental Protection Agency. The group operates as a satellite of the Western Energy and Land Use Team. It is a part of the Western Water Allocation Project, Office of Biological Services.

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While the Fish and Wildlife Service is providing the initiative and leadership, the IFG is conceived as a multi-agency, multi-disciplinary program which is to become a "center of activity," providing a focus for the increasing importance of instream flow assessments.

The multi-agency, multi-disciplinary nature of the group is provided through the Intergovernmental Personnel Act transfer of state personnel, and details from other Federal agencies.

Interagency Energy-Environment
Research and Development Program
Office of Research and Development
U.S. Environmental Protection Agency

FWS/OBS-77/63
December 1977

DEVELOPMENT AND EVALUATION OF WEIGHTED CRITERIA, PROBABILITY-OF-USE CURVES FOR INSTREAM FLOW ASSESSMENTS: FISHERIES

Instream Flow Information Paper No. 3

by

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This study was conducted
as part of the Federal
Interagency Energy/Environment
Research and Development Program
Office of Research and Development
U.S. Environmental Protection Agency

Cooperative Instream Flow Service Group
Western Energy and Land Use Team
Office of Biological Services
Fish and Wildlife Service
U.S. Department of the Interior

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ABSTRACT

Weighted criteria are used to assess the impacts of altered streamflow regimes on a stream habitat. They are developed primarily for those habitat parameters most closely related to stream hydraulics: depth, velocity, substrate, and temperature.

Species for which criteria are developed may be classified into five groups: economic objective species, indicator species, endangered or threatened species, nongame species, and forage species. For each species, criteria are developed for spawning, adult, juvenile, fry, and egg incubation. Passage criteria may also be developed for certain species.

Probability-of-use curves are based on the assumption that individuals of a species will tend to select areas within the stream having the most favorable combinations of hydraulic conditions. It is further assumed that they will also utilize less favorable conditions, with the probability-of-use decreasing with diminishing favorability of one or several hydraulic conditions. Finally, it is assumed that individuals will elect to leave an area before conditions become lethal.

Weighted criteria are presented in the form of probability-of-use curves, the peak of which represents the optimum condition for a given hydraulic parameter. These curves are developed through four data analysis techniques, either singly or in concert: (1) frequency

analysis, (2) range and optimum analysis, (3) parameter overlap, and (4) indirect parameter analysis.

Accompanying each set of probability curves is an outline describing: (1) source material used in the construction of the curves, (2) analysis technique(s) used, (3) an Instream Flow Group (IFG) evaluation rating for each curve, (4) comments concerning specific curves, and (5) references cited.

The IFG evaluation for each curve was developed by adherence to certain guidelines. An excellent rating was given to those curves for which frequency analysis was used on a large number of observations from a wide variety of conditions. In addition, for this rating a chi-square test was required that showed no significant difference in the frequency of observations within the optimum ($p<0.10$).

A rating of good was assigned when frequency analysis could be used, but either the number of observations or the variety of conditions observed, was limited. Additionally, if a chi-square test of the optimum showed no significant difference in frequency at $p <0.25$, but >0.10, the curve was rated good regardless of the number of observations.

The rating of fair was given if frequency analysis could be used, with a severely limited number of observations (< 50), or if range and optimum, parameter overlap, or indirect analyses were the only analysis techniques capable of constructing the curve. Additionally, if a chi-square test showed significant ($p>0.25$) variance within the optimum, the curve was rated fair regardless of the number of observations.

Curves were rated as reconnaissance grade if frequency analysis could not be used, and if some or all of the hydraulic parameters were not measured but were calculated, based on a description of the stream reach.

Guidelines are given for field and data analysis techniques for individuals desiring to construct their own curve sets. Potential errors in curves due to sampling bias and possible corrective measures are also discussed.

PREFACE

This information paper was prepared to document the methods and procedures used in the construction of probability criteria curves. These curves are an integral part of the IFG incremental method, which will be described in detail under a separate title.

This report accompanies information papers about the various families of fish for which probability criteria have been documented. The user is urged to keep this document for reference with each collection of species curves. In any advocacy proceeding, such as an adjudication hearing, the validity of the curves may come into question. Therefore, the user should understand the assumptions and potential limitations to any given curve set, before he/she is required to defend the use of that curve in court.

In many cases the user will want to develop curves, based upon field investigations. Guidelines for data collection, analysis, and curve development are discussed.

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INTRODUCTION

Criteria are necessary for interpretation of any information base developed for a species, group of species, or recreational activity used to assess the impacts of altered streamflow regimes on instream habitats. As such, biological criteria are primarily aimed at those parameters affecting fish distribution which are most directly related to streamflow: namely depth, velocity, temperature, and substrate. Cover, a habitat parameter of paramount importance to many species, is also indirectly related to streamflow. Cover may be incorporated into an instream flow assessment by evaluating the utility of available cover objects in reference to the flow parameters around them.

The application of a methodology is dictated by the critera available for the target species. Criteria are as much a constraint on streamflow assessments as are time, expense, manpower, and accuracy requirements.

Fish species for which biological criteria are being developed can be roughly divided into five classes:

1. Economic species   sport and commercial fishes which are considered important and desirable by the public, and are of importance to the objectives of the State and Federal management agencies.

2. Indicator species   those species with narrow habitat tolerances, inhabiting areas of streams which are particularly sensitive to changes in flow. It is assumed that if conditions remain suitable for the indicator species, all other resident species will continue to find suitable habitat there and species composition will remain constant.

3. Endangered or threatened species - these are species which may be locally abundant, but with a highly restricted distribution, or those which occupy much of their former range but in greatly reduced numbers.

4. Nongame species - species which may act in direct competitior with any of the other desirable species.

5. Forage species - this classification applies to those organisms occupying intermediate positions in the food chain, including both forage fish and aquatic invertebrates.

Most present-day methods of assessing flow address only one, or occasionally two, of the above species classes. Frequently, a particular life history stage, or a certain time period is singled out as being critical for the continued well-being of a fish population. A flow recommendation for a relatively long time period may be based on an *a priori* assumption about critical conditions for a small and rather definite time period. For example, spawning success is commonly considered a critical factor in the maintenance of a fish population, but habitat evaluations for fry and juvenile fish are almost universally neglected.

It must be recognized that regardless of the methods or the biological criteria employed, there are always assumptions of which the biologist must be aware. Some assumptions are expressed, while others are implied, and each exerts an influence on the conduct of the study and its eventual defense. Value judgements which should be made during any streamflow assessment involves these assumptions; i.e., whether or not the assumptions appear logical and are acceptable for the case at hand, and the ability of the field practitioner to logically defend the assumptions.

The types of criteria concerned herein are termed elective criteria. The expressed assumption is that the distribution and abundance of any species is not primarily influenced by any single parameter of streamflow, but related by varying degrees to all hydraulic parameters. It is further assumed that a species will elect to leave an area when streamflow conditions become unfavorable, and will generally not voluntarily remain in the area until conditions become lethal.

Probability curves are based on the assumption that individuals of a species will tend to select the most favorable conditions in a stream, but will also use less favorable conditions within a defined range, with the probability of use decreasing as conditions approach the end points of the total range (Figure 1). These curves are integral to the use of the IFG Incremental Instream Flow Method, which will be described under a separate title, available from the Cooperative Instream Flow Service Group. Instream Flow Information Paper 8 (in preparation).

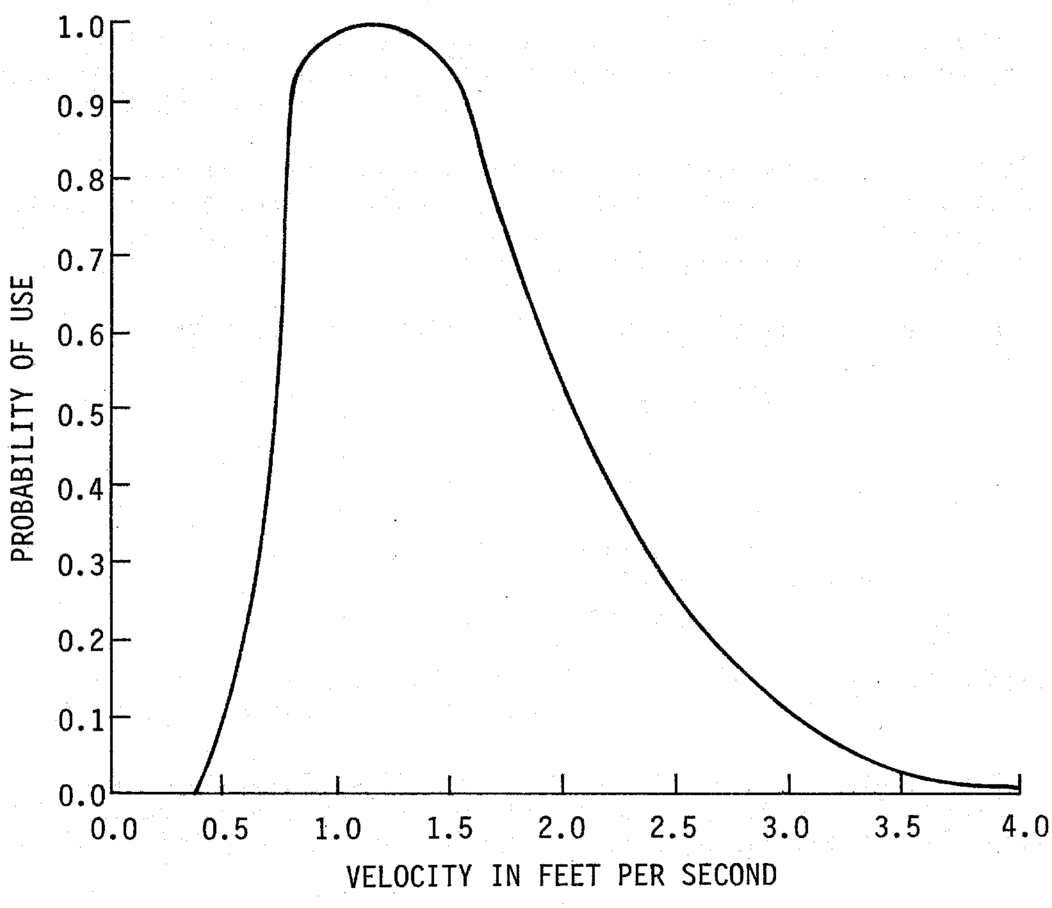

Figure 1: Example of probability criteria used in the IFG Incremental Method.

PROBABILITY-OF-USE CURVES

All of the curves constructed by IFG have been developed from information available in the literature and when available with, extensive utilization of unpublished data from agency files. Two basic types of information were used in the construction of these curves; that derived from field observations with directly measured hydraulic parameters, and that derived from descriptions of fish distribution with general descriptions of the habitat, and with hydraulic parameters calculated from the stream description. Methods of analysis of this information varied according to the format in which the information was presented.

CURVE UNITS

All curves are in English units, except the substrate curves. Depths are given in feet, velocities in feet per second, and temperatures in degrees Farenheit.

Substrates were categorized by a modified Wentworth particle size scale, when possible (Table 2). In most cases, the field data contained only a descriptor of the bottom type (i.e., gravel, rubble, etc.) rather than a size range. These substrate types were coded as shown in Table 1.

Table 1. Substrate Codes Used for Curve Construction.

1	Plant detritus
2	Mud
3	Silt
4	Sand
5	Gravel
6	Rubble
7	Boulder
8	Bedrock

Notice that a mixture of two different (but adjacent) substrate types may be described by this code.

For example, a numeric code value of 5.5 refers to a bottom which is composed of a 50:50 mixture of gravel and rubble. A value of 4.2 would refer to a substrate which is 80% sand and 20% gravel, whereas

Table 2. Modified Wentworth Particle Size Scale.

	RANGE mm	Approx. MEDIAN mm
Mamouth Boulder	4000	--
Very Large Boulder	3500 - 4000	3750
	3000 - 3500	3250
	2500 - 3000	2750
	2000 - 2500	2250
Large Boulder	1650 - 2000	1825
	1330 - 1650	1490
	1000 - 1330	1165
Medium Boulder	830 - 1000	915
	665 - 830	750
	500 - 665	580
Small Boulder	415 - 500	450
	335 - 415	375
	250 - 335	290
Large Cobble	190 - 250	220
	130 - 190	160
Small Cobble	100 - 130	115
	64 - 100	85
Very Course Gravel	50 - 64	57
	32 - 50	40
Coarse Gravel	16 - 32	24
Medium Gravel	8 - 16	12
Fine Gravel	4 - 8	6
Pea Gravel	2 - 4	3
Very Course Sand	1 - 2	1.5
Sand	.062 - 1	.5
Silt-Clay	.062	--

a 4.8 value would be 20% sand and 80% gravel. Intermediate code values refer to a percentage mixture, not a size gradation.

FREQUENCY ANALYSIS

Frequency analysis was preferred over all other curve construction techniques because the shape of the curves could be directly determined. Data for frequency analysis consisted of measurements of depth, velocity, and substrate at individual capture or observation locations for individual fish. Additional information included the species observed and its length for each set of hydraulic parameter data, as well as information such as water temperature, use of cover objects, etc.

Frequency analysis was occasionally possible using data obtained from laboratory experiments testing the preference or tolerance of a species, or life history phase of a species, to single or multiple hydraulic parameters. An example would be tests on the swimming ability of fry of a certain species at different temperatures. The applicability of such experimentally derived data to frequency analysis depended upon the number of replications obtained and the variety of conditions tested by the experiment. Table 3 shows the type of data most commonly used in frequency analysis.

A consistent procedure was followed in the definition of optimum conditions and probabilities of use for each species and life stage:

1. Each hydraulic parameter was assessed independently by listing a continuum of the parameter, starting at zero, and extending, in equal increments, to or beyond the total range of use.

2. The total number of individuals of a certain species and life stage was tallied and assigned to the appropriate increment of each parameter.

3. Total numbers (frequency of individuals) in each parameter increment were summed.

4. Adjacent increments were then clustered to reduce the variance typical of such a distribution. Clustering was limited to two adjacent increments, but each increment was clustered two ways to determine the pattern giving the least variance (Table 4).

Table 3. Data Sheet Typically Used in Frequency Analysis for the Construction of Electivity Curves

Stream Shoshone Creek Below Hot Creek Date 7/21/77

Location Idaho Observer Cochnauer & Nelson

Water Temp. 70^{o} Method Electro Shock

Species	Length (Ft)	Depth (Ft)	Velocity (Ft/sec)	Substrate	Comments
Rb	.7	1.5	.552	Gravel	Pool
Rb	.6	1.0	.771	Gravel	Middle of Stream
Brn	1.0	.9	.858	Gravel	Middle of Stream
Brn	1.1	1.2	.988	Gravel	Next to Bank
Rb	.6	1.2	.988	Gravel	
Rb	.3	.7	.661	Gravel	Next to Bank
Ct	.7	.8	.269	Gravel/Rubble 6" 10"	Middle of Stream
Brn	.7	.8	.269	Gravel/Rubble 6" 10"	
Rb	.9	.9	.269	Gravel/Rubble 6" 10"	
Rb	.8	1.7	.484	Gravel	Aquatic Vegetation Middle of Stream
Rb	.8	1.7	.484	Gravel	
Rb	.7	2.4	.527	Gravel	Middle of Stream
Ct	1.0	1.7	.539	Gravel/Rubble	Aquatic Vegetation Middle of Stream
Rb	.8	1.7	.484	Gravel	Aquatic Vegetation Middle of Stream

Table 4. Example of Frequency Analysis for Velocities Over Winter Steelhead Redds (Actual Data) Oregon Game Commission (1968), Hunter (1973).

Velocity	Tally	Frequency: Left Cluster	Frequency	Frequency: Right Cluster		Probability
.9			0	0		0.0
1.0		1	0			
1.1	|		1	3		0.08
1.2	||	12	2			
1.3	𝍸 𝍸		10	19		
1.4	𝍸 ||||	17	9			0.54
1.5	𝍸 |||		8	20		
1.6	𝍸 𝍸 ||	28	12			
1.7	𝍸 𝍸 𝍸 |		16	31		0.86
1.8	𝍸 𝍸 𝍸	26	15			
1.9	𝍸 𝍸 |		11	35		
2.0	𝍸 𝍸 𝍸 𝍸 ||||	45	24		$\overline{36}$	1.0
2.1	𝍸 𝍸 𝍸 𝍸 |		21	37		
2.2	𝍸 𝍸 𝍸 |	26	16			
2.3	𝍸 𝍸		10	31		0.86
2.4	𝍸 𝍸 𝍸 𝍸 |	28	21			
2.5	𝍸 ||		7	23		
2.6	𝍸 𝍸 𝍸 |	29	16			0.67
2.7	𝍸 𝍸 |||		13	25		
2.8	𝍸 𝍸 ||	18	12			
2.9	𝍸 |		6	12		
3.0	𝍸 |	14	6			0.35
3.1	𝍸 |||		8	13		
3.2	𝍸	7	5			
3.3	||		2	4		
3.4	||	5	2			0.11
3.5	|||		3	4		
3.6	|	1	1			

5. The optimum for a given hydraulic parameter was defined by those incremental clusters which showed an obvious majority of observations, as well as being relatively uniform in frequency for each data cluster.

6. The optimum was then tested for variance with chi-square, using the null hypothesis that: within the area defined as the optimum for a given parameter, there is no significant difference in the frequency of observation within the optimum. If the null hypothesis could be rejected at any level of probability greater than 0.10, the optimum was redefined (re-clustered, or some clusters omitted) and retested by X^2. In some cases, the variance was such that the null hypothesis could be rejected at almost any level. Such cases were noted and treated in the evaluation of the curve. Curve evaluations will be explained in a later section.

7. Having defined the optimum, the mean or expected frequency within the optimum was calculated. The total frequency of each increment cluster was also found.

8. The probability of use for those increments falling within the optimum range was assigned a value of 1.0. Probabilities of use for each clustered increment outside the optimum were calculated simply by dividing the frequency for each cluster by the mean frequency for the optimum. For two adjacent clusters with approximately the same frequencies, the mean frequency for both was divided by the mean for the optimum.

This entire procedure for frequency analysis is illustrated in Table 4. The optimum was defined by the cluster groupings to the right of the frequency column, rather than those to the left less for two primary reasons: (1) clustering on the right resulted in less cluster-to-cluster variance, and (2) clustering on the left resulted in several secondary modes. Velocities of 1.7-1.8, and 2.3-2.4 feet per second, were not included in the optimum range. Inclusion of these frequencies introduced a statistically significant difference in the distribution. Therefore, the optimum range was reduced to between 1.9 and 2.2 feet per second.

Having defined the optimum range for a parameter, and having calculated the probability of use with respect to increments outside the optimum, the probabilities were plotted and a curve fitted to the distribution. Figure 2 shows such a plot for the data given in Table 4.

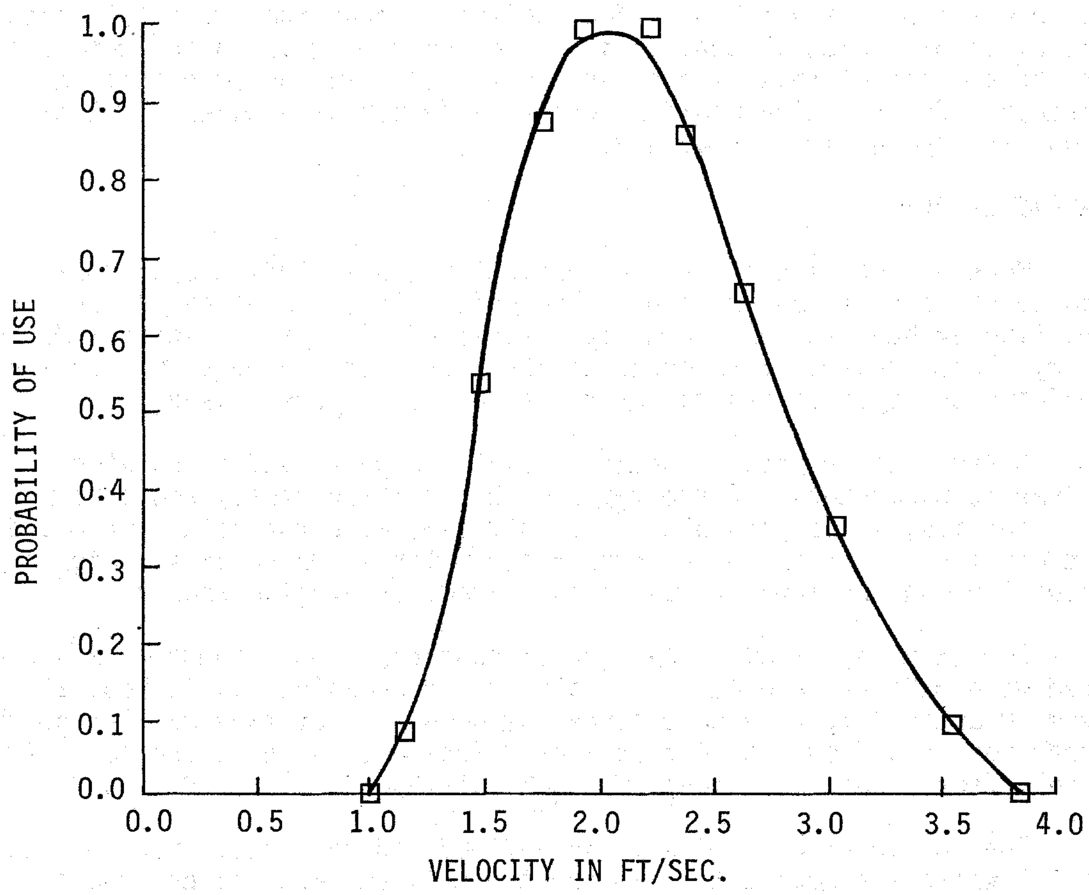

Figure 2: Example of probability curve constructed from the frequency distribution shown in Table 3.

RANGE AND OPTIMUM ANALYSIS

Where frequency of occurrence data was not available, the literature sometimes contained information on both the range and optimum conditions occupied by a species based on conditions measured in the field. In other cases, some of the parameters (particularly velocity) were calculated indirectly from measurements and descriptions of the stream reach.

Using this method, the portion of the total range of a given parameter representing optimum conditions was assigned a probabilty of 1.0, and the end points of the total range a probability of 0. A bell-shaped curve was then drawn to these four points. Occasionally, information was available which allowed modification of the curve to indicate skew. In the absence of this type of information, it was assumed that the frequency distribution would be essentially normal between the total range and the optimum (Figure 3).

PARAMETER OVERLAP

Much of the literature, in particular those studies dealing with ecological succession in streams, describes the fish fauna in terms of the type of habitat most commonly associated with each species. Moreover, these studies often describe the degree of use by a species and indicate the type of habitat which is seldom, if ever, used.

Given a description (including field-measured and calculated hydraulic parameters) of the types of habitat frequently and seldom used by a species, it is possible to roughly determine the total range and the optimum conditions of a certain parameter for a species. Figure 4 shows the concept involved under the parameter overlap approach.

For example, assume a particular species is most commonly associated with habitat type A, but is also found occasionally in habitat types B and C. It is almost never found in habitat type D. The depth range for A is from 3 to 6 feet, for B from 2 to 4 feet, and for C from 1 to 3 feet. The depth range for habitat type D is from 0.5 to 1.5 feet

The end point of the range is defined, in this case, as 1.5 feet in depth, while the smallest value for the optimum depth is defined as 3 feet. Thus, parameter overlap simply uses presence-absence information for habitat types as a tool to define total range and optimum conditions. Curve construction follows the same general procedure as the range-and-optimum technique.

Species X, Adults

Total Depth Range = 0.5 - 3.2 feet
Optimum Depth Range = 1.0 - 1.2 feet

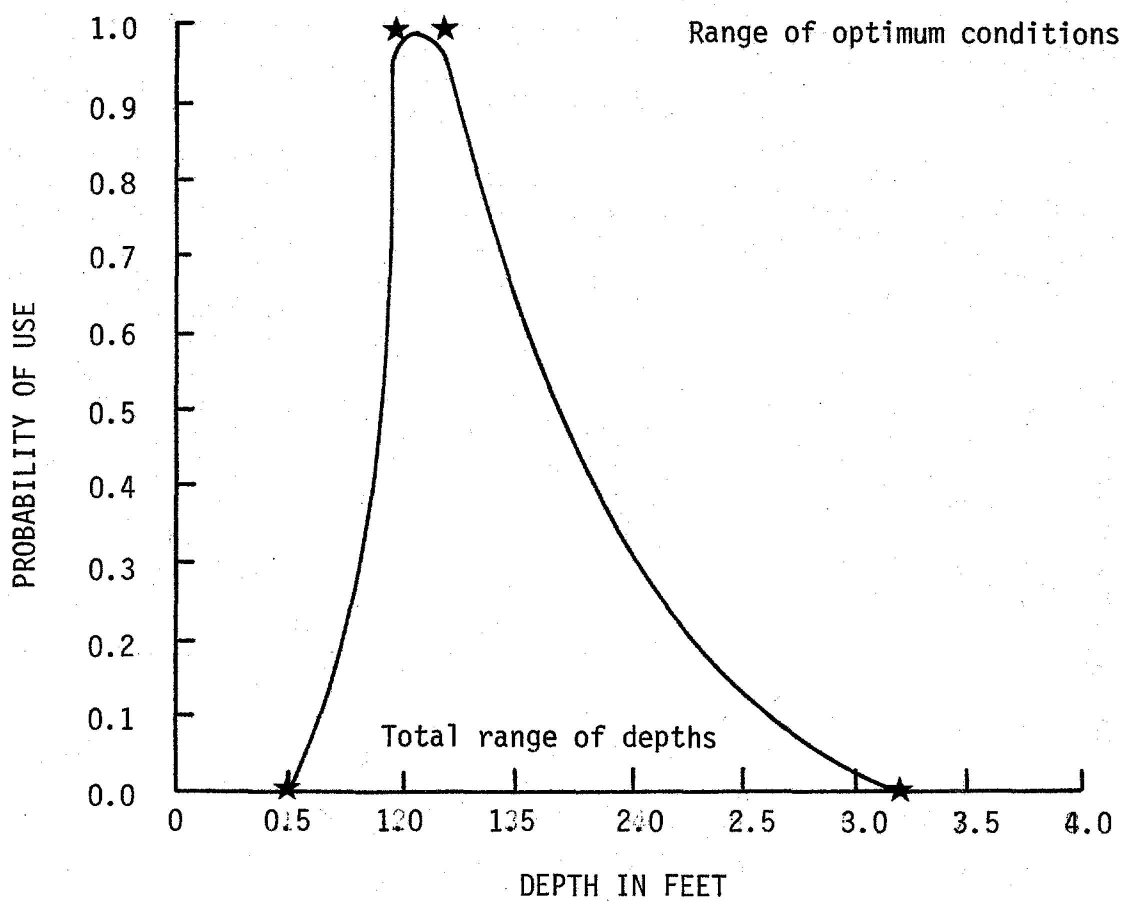

Figure 3. Example of a probability curve constructed using range and optimum analysis.

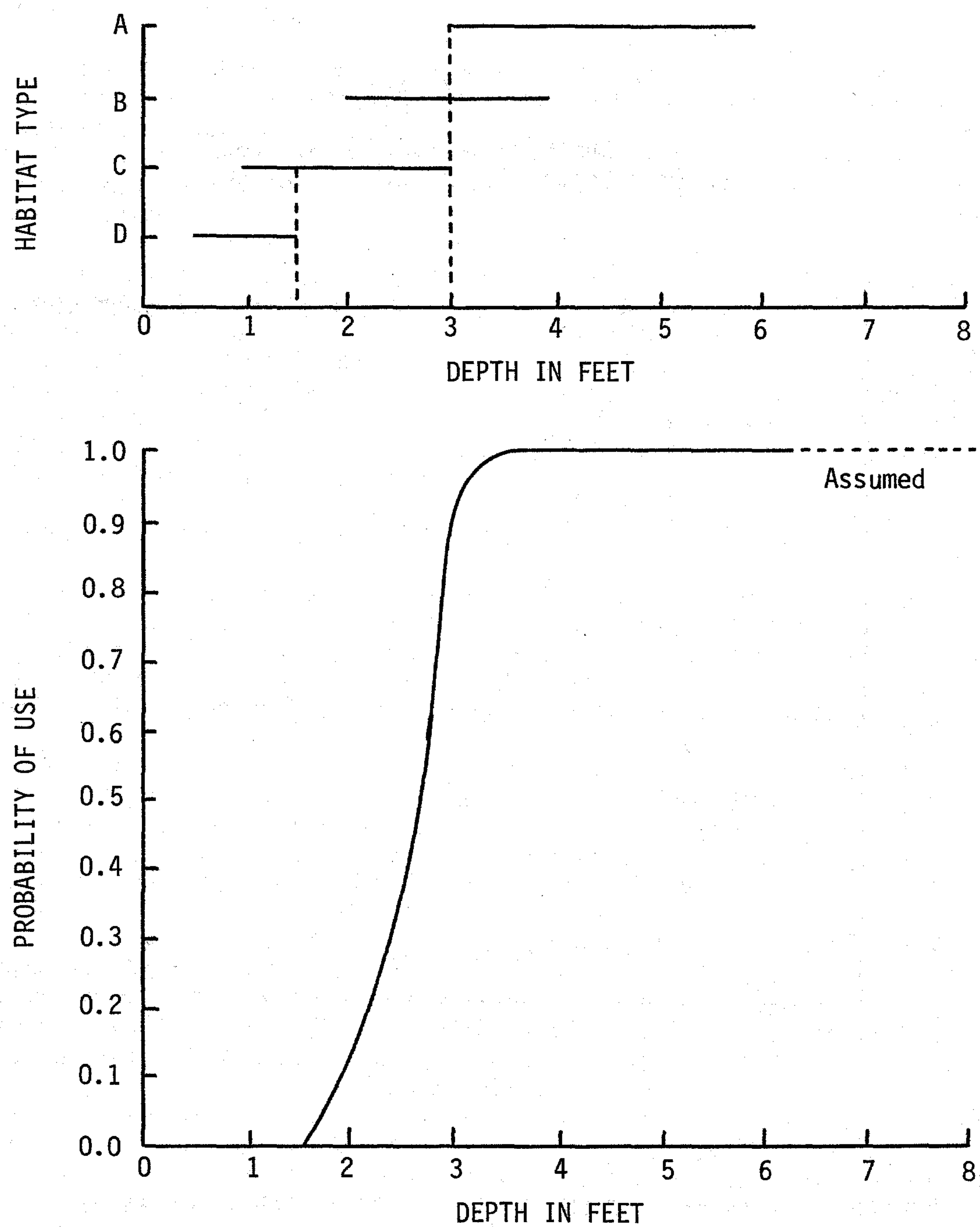

Figure 4. Example of a probability curve constructed using parameter overlap analysis. Type A optimum, B & C used, and D not used.

INDIRECT PARAMETER ANALYSIS

The determination of flow criteria for salmonid egg incubation is an example of indirect analysis, relating surface hydraulic conditions to subsurface hydraulics in the gravels. Essentially, a redd is located in an unconfined, submerged aquifer. Therefore, hydraulic conditions of the surface waters play an important role in determining hydraulic conditions through the gravels. Unfortunately, most studies examining the survival of eggs in redds were exclusively concerned with subsurface flow conditions, without discussion of surface flow factors.

Given an initial dissolved oxygen content high enough to provide good embryo survival, two hydraulic factors remain which determine the survival of eggs. The first is the velocity of water through the gravel, the <u>apparent velocity</u>, which is important in the delivery of oxygen to the embryos and in the removal of metabolic wastes. The second hydraulic factor is the tractive force, or shear stress, of the water. Certain shear stresses are desirable because they prevent the deposition of fines in the interstices of gravel. However, higher shear stresses can cause movement of gravel, resulting in redd destruction and egg mortality.

Therefore, the objective of the calculation of incubation criteria was to determine water column hydraulic conditions which would result in the desired apparent velocities, without scouring or filling the substratum.

The apparent velocity is a function of the hydraulic slope (water surface slope) and the permeability of the gravels. Terhune (1958) defines apparent velocity as:

$$Va = KS \qquad (1)$$

where,

Va = Apparent velocity in cm/hr
K = Permeability in cm/hr
S = Hydraulic gradient (dimensionless)

Apparent velocity may be related to surface hydraulics through the use of Manning's equation,

$$Vs = \frac{1.49}{n} R^{2/3} S^{1/2} \quad (2)$$

where,

Vs = mean velocity of surface water
n = roughness coefficient, assumed to equal 0.035 for all calculations
R = Hydraulic radius, equal to the conveyance area A (width X mean depth), divided by the wetted perimeter, (width + 2 X mean depth). For wide, shallow channels, the hydraulic radius approximates the mean depth.
S = Energy gradient; for uniform flow assumed parallel to hydraulic gradient.

From equations (1) and (2) it is seen that,

$$S = \frac{Va}{K} = \frac{V^2 n^2}{2.22 R^{4/3}} \quad (3)$$

and

$$Va = \frac{Vs^2 n^2 K}{2.22 R^{4/3}} \quad (4)$$

It may be shown that the limit of equation (4), as R approaches zero, is K. At small depths and velocities, fine sediment may deposit in the interstices of the gravel, lowering the value of K, the permeability.

Therefore, for a given slope and required apparent velocity, the critical factor at low flow is maintaining sufficient shear stress to prevent deposition of finer particles on the gravel. This critical shear stress is defined as:

$$\tau c = \omega RS \quad (5)$$

where,

ω = unit weight of water - 62.4 lb/ft^3
R = Hydraulic radius
S = Energy gradient, assumed parallel to hydraulic gradient

Survival rates of salmonid embryos, as a function of apparent velocity, were found in Wickett (1958), Coble (1961), and Cloern (1976). For a stipulated slope, K was calculated from equation (1) for each apparent velocity listed. Terhune (1958) listed particle size distributions for four different levels of permeability. Median particle size was plotted against permeability, and fitted by least squares to approximate particle sizes for intermediate permeabilities.

Having determined the particle size giving the desired permeability and apparent velocity, a tractive force was required which would prevent smaller particles from depositing.

It should be noted that the surface hydraulic conditions associated with embryo survival is not independent of slope nor of sediment concentration. For small slopes the tractive force for a given depth is small compared to those for large slopes. Water with a small suspended sediment concentration requires a lower tractive force to prevent deposition of fines, but also has an excess of energy with which to attack the streambed. Conversely, water carrying a load of suspended sediment requires a higher tractive force to prevent deposition on the gravel. Therefore, two different sources for tractive force were used. Incipient motion tractive forces were obtained from Leopold, et al. (1964). These values were used for clear water situations where the tractive force required is only great enough to prevent deposition of fines on the gravel. In those situations where the sediment concentration exceeds 200 mg/L or is composed largely of silt and fine sand, the tractive force must be higher. These higher values were obtained from Chow (1959) and reflect tractive forces which will maintain channel stability.

Having determined the appropriate tractive force for a given condition of slope and sediment concentration, equation (5) was then used to determine the critical depth (R) for that situation. This value of R was then substituted into equation (4) to determine the surface velocity associated with each value of R and Va. These values of R and Vs were then correlated to survival rates of eggs for small values of R and V.

For large values of R and V, movement of the gravel becomes limiting. It was found that for particle sizes larger than about 6 mm median diameter, the permeabilities became so high that the apparent velocity could be eliminated as a potential limiting factor.

Survival of eggs in large gravels was estimated as a function of the size of gravel capable of being moved by spawning fish. For brown trout (Salmo trutta), for example, a cumulative frequency distribution of redds located in various gravel sizes was constructed from data provided by Reiser and Wesche (1977)(Figure 5). All of the redds were located in gravels smaller than 80 mm median diameter, and 38% were located in gravels finer than 25 mm median diameter. Therefore, it was assumed that movement of the 25 mm gravels would result in the loss of

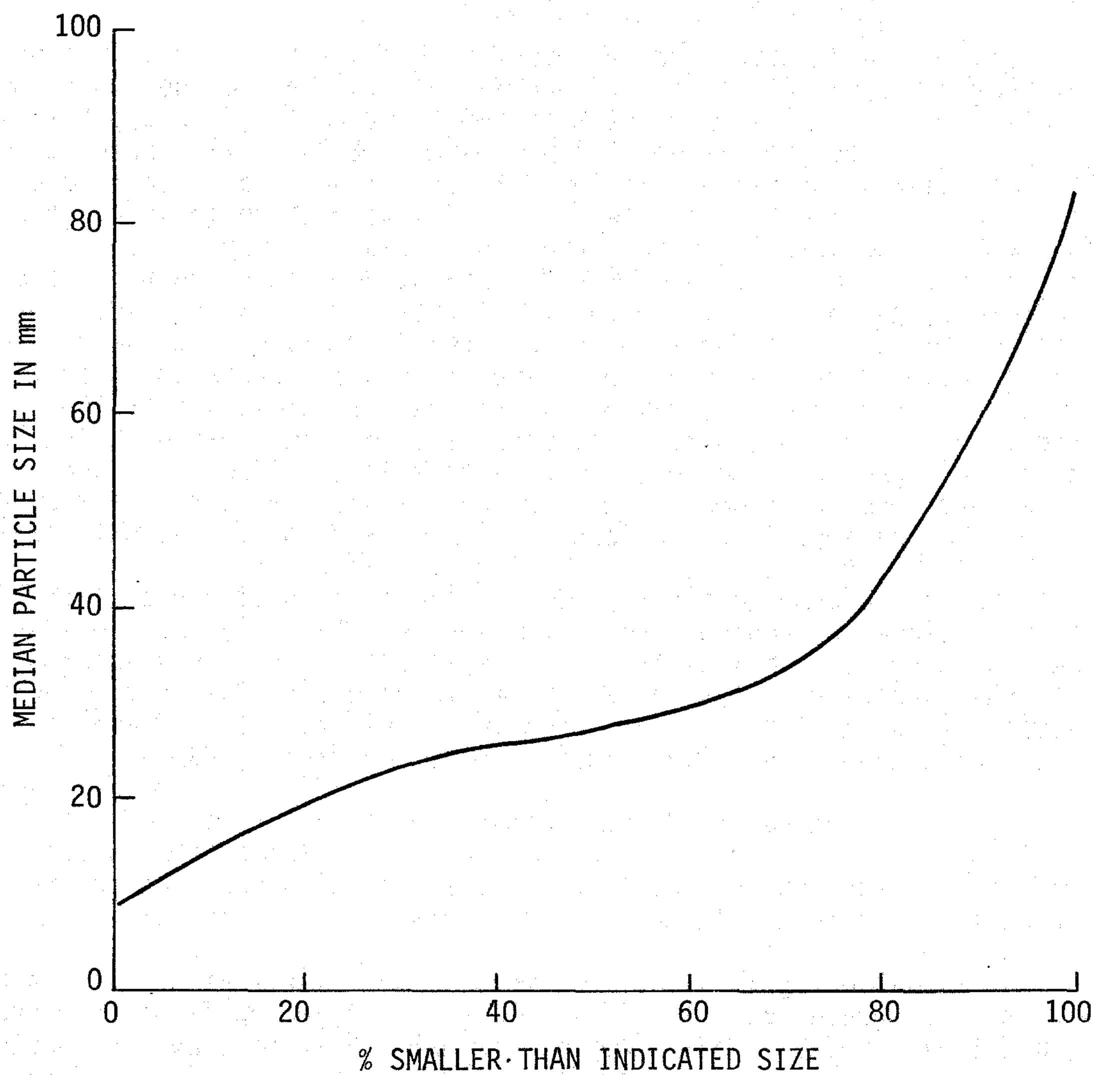

Figure 5: Cumulative percentage of median particle sizes in brown trout redds (Reiser and Wesche, 1977).

approximately 40% of the redds. Movement of the 40 mm gravels would result in destruction of 78% of the redds, etc. The same technique was used for other trout and salmon species.

Equation (5) was again utilized to determine the critical depth for a given slope. Again, critical tractive forces were obtained from Chow (1959) or Leopold et al. (1964).

EVALUATION CRITERIA

Because of the varying types of data used in the construction of the probability curves, some curves may be used with confidence for any level of instream flow assessment, while others should be used judiciously for only reconnaissnce level studies. Therefore, accompanying each set of probability curves is an outline matrix (see page) describing: (1) source material used in the construction of the curve, (2) analysis technique(s) used (frequency analysis, parameter overlap, etc.), (3) IFG evaluation rating, (4) Comments concerning specific curves, and (5) references cited.

The IFG evaluation for each curve was developed by strict adherence to the following criteria and guidelines:

I. Excellent

A. Frequency analysis utilizing at least 200 individual measurements, with samples collected over a wide range of hydraulic parameters and combinations of parameters.

B. Laboratory experiments with $\geq$200 replications, covering a wide range of hydraulic conditions.

C. X^2 test of optimum showing $p<0.10$ of significant difference of frequencies within optimum.

II. Good

A. Frequency analysis with suspected sampling bias; <200 measurements, or range of hydraulic conditions limited.

B. Frequency analysis using a mix of measured and calculated parameters; at least 100 measurements from a wide range of hydraulic conditions.

	Spawning				Adult				Juvenile				Fry				Egg Incubation			
SPECIES:	Velocity	Depth	Substrate	Temperature	Velocity	Depth	Substrate	Temperature	Velocity	Depth	Substrate	Temperature	Velocity	Depth	Substrate	Temperature	Velocity	Depth	Substrate	Temperature
IFG EVALUATION																				
REFERENCE																				
ANALYSIS																				
COMMENTS																				

Key to IFG Evaluation Matrix

IFG Evaluation:
- E - Excellent
- G - Good
- F - Fair
- R - Reconnaissance Grade

Analysis:
- FA - frequency analysis
- RO - range and optimum
- PO - Parameter overlap
- IN - indirect analysis

Reference: Refer to listed number in bibliography.

Comments: Refer to listed number on comment sheet (following IFG Evaluation Matrix).

C. Laboratory experiments with <200 replications, or limited range of hydraulic conditions.

D. X^2 test of optimum showing $0.10<P<0.25$ of significant difference of frequencies within optimum.

III. Fair

A. Frequency analysis with <50 measurements and limited range of hydraulic conditions.

B. Parameter overlap analysis using a mix of measured and calculated hydraulic conditions.

C. Laboratory experiments with three or fewer optional hydraulic conditions.

D. X^2 test shows significant variance within optimum, regardless of number of observations.

IV. Reconnaissance Grade

A. Parameter overlap analysis in which some or all hydraulic parameters were calculated from stream descriptions.

B. Parameter overlap analysis using measured, or mixed measured and calculated parameters, with a restricted range of hydraulic conditions.

These curves have been carefully constructed, using the best information available. However, the type of data available for each species and life history phase has dictated the analysis procedures. The principal difference between a rating of excellent, good, and fair is one of degree of reproducibility. Because field measured data was used in all three cases, there is relatively little subjectivity involved in obtaining the hydraulic parameters. However, reproducibility within the field measured parameters would be affected most by sample size, number of measurements, and the range of conditions tested.

For those curves rated as reconnaissance grade, there may be some question related to the accuracy of the physical parameters, since these were essentially best estimates of those parameters using various hydraulic equations and fairly subjective descriptions of the stream reach. These curves should not be used for site-specific instream flow assessments, because results obtained from these curves may be subject to challenge during adjudication or other defenses of the streamflow recommendation. However, the curves can provide useful information for reconnaissance level investigations and early planning studies.

All curves, regardless of their IFG rating, are subject to periodic review and revision as more data become available. The user would be well advised to update his own collection as new curves are produced. Field practitioners are encouraged to collect their own field data, and produce their own curves whenever feasible. IFG will attempt to keep abreast of new data produced and will continually upgrade the species curves.

DATA ACQUISITION TECHNIQUESFOR DEVELOPMENT OF PROBABILITY CRITERIA

For some species, existing data will be of poor quality, incomplete, or in the wrong format for frequency analysis. Sometimes it will be nonexistent. If for any of these reasons, biological criteria development requires the collection of field data, the several options listed below may be used.

OPTION 1 - INDIVIDUAL CAPTURE

This method is best applied to those species and life stages that tend to be solitary and sedentary. Electrofishing, spot concussion and (for some species) drifted gill nets, and SCUBA, snorkel, or surface observation are the most amenable field techniques for use with this method.

If electrofishing is used, care must be taken to spot-sample locations. Continuous application of the electric field may drive fish away from their original locations prior to capture, which will lead to false data. Stunned fish should be removed to a live car so that multiple sets of measurements are not made for the same fish (which under stress may select a different type of habitat).

At each location where the species of interest is observed or captured, a small maker buoy is dropped for later reference. These buoys may be inexpensively constructed (20¢) from concrete, nylon twine, and blocks of wood. They may be color-coded to represent different species, or different life stages. Plate I shows the construction of a marker buoy.

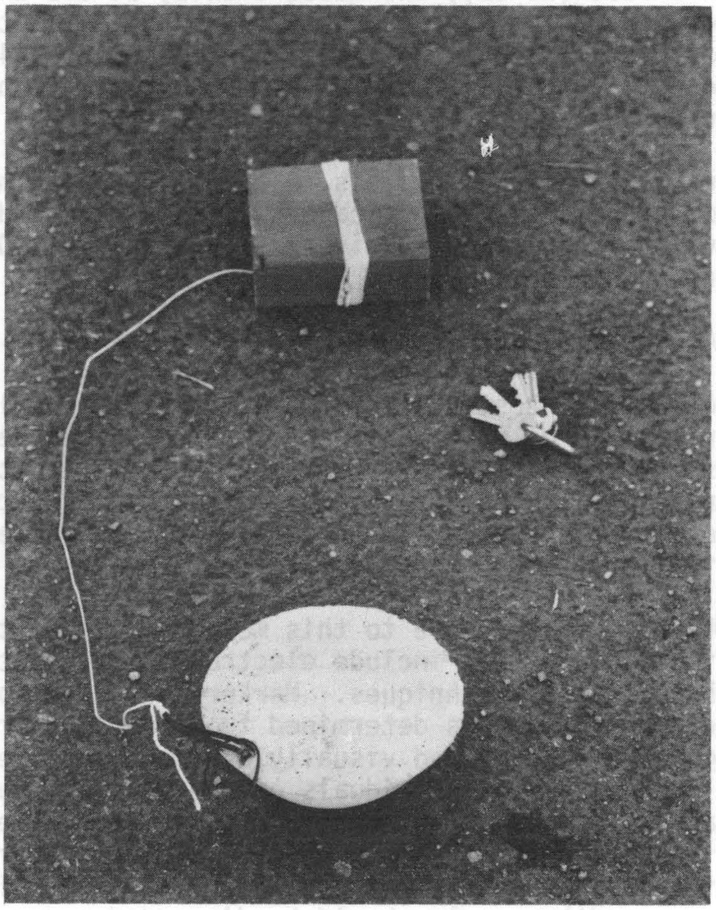

Plate I. Marker buoy used to mark fish locations for the collection of hydraulic data and subsequent development of probability criteria.

After completion of the sampling or observation run, the observer returns to each buoy, where measurements are made of the depth, velocity, substrate, and cover. The velocity sought is the mean velocity in the water column, therefore, velocities should be measured at 0.6 of the depth (from the surface) if the water is less than 3 feet (90 cm) deep. If greater than 3 feet (90 cm), two measurements, at 0.2 and 0.8 of the depth should be averaged. Substrate size should be estimated from the modified Wentworth scale (Table 2). In water deeper than 4 feet (120 cm), these measurements may be made from a boat using cable sounding gear and a current meter.

For univariate frequency analysis, a total of approximately 300 measurements for each life stage of each species are needed to ensure a representative analysis. For multivariate analysis, 1,000 to 2,000 measurements are required.

OPTION 2 - AREA GRID MEASUREMENTS

This method has its best application with species or life stages which school or form large congregations. Collection is nearly always required because the subjects are often small and difficult to identify by simple observation. Exceptions would include spawning congregations of adults where there is little doubt concerning the species, life stage, and activity.

Sampling techniques amenable to this method provided the subjects can be identified and counted, include electrofishing, spot concussion, seining, and observational techniques. Markers are used to outline areas of fish concentrations as determined from sampling or observation. A measurement grid is established visually over the outlined area (Figure 6) and the number of individuals of the species counted for each outlined area. Hydraulic parameters are measured at each grid intersection. Measurements of each parameter are then averaged, and the standard deviation calculated. If the standard deviation is greater than 25% of the mean, the sample should be discarded and option 1 used instead. Under option 2, the mean of several measurements (tested for variance) is used to represent a large number of individuals, rather than one at a time as in option 1.

Under the area grid approach a total of 100 to 200 outlined areas should be measured for each life stage and species.

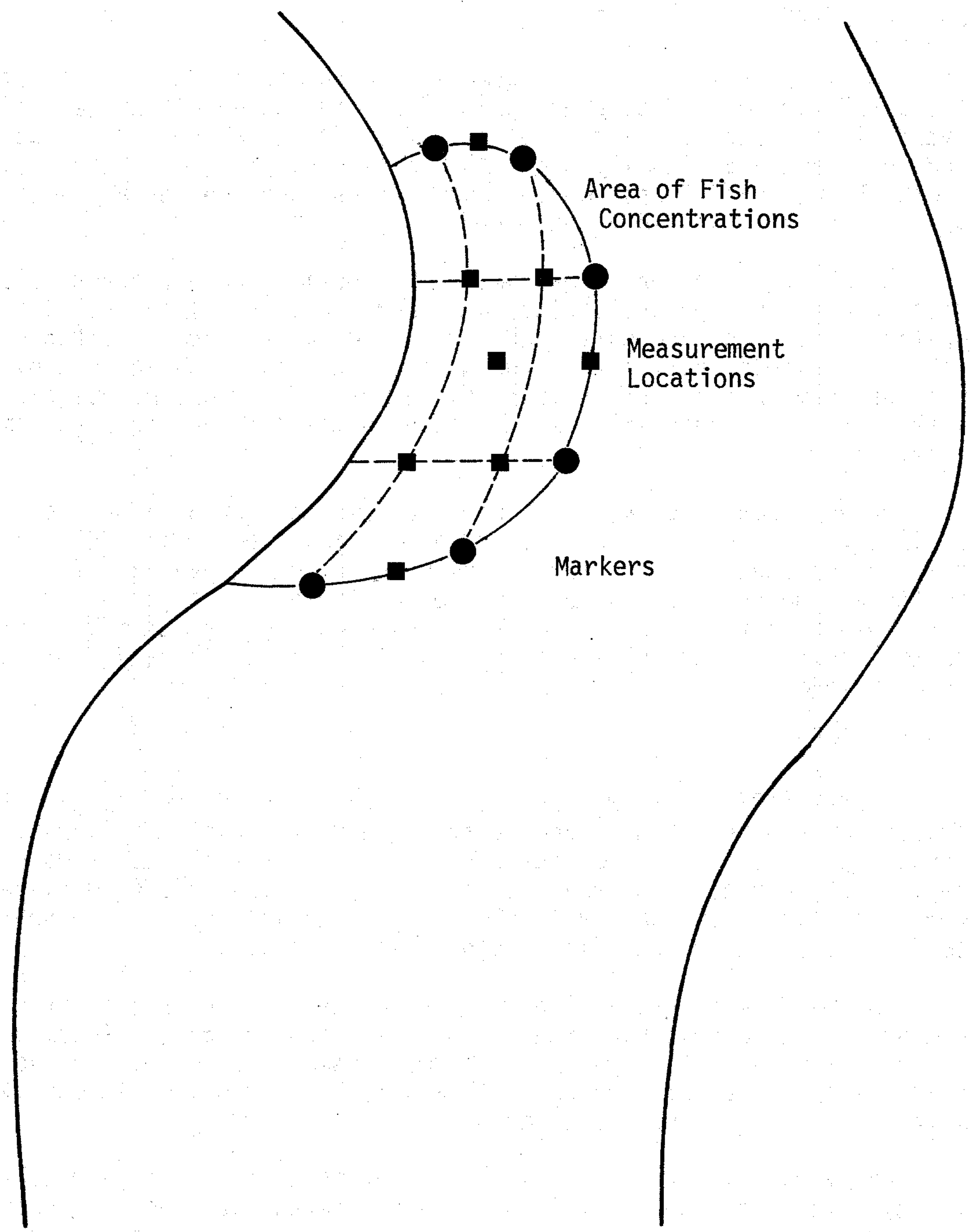

Figure 6. Outline grid method for determining flow criteria for species which occur in large groups.

OPTION 3 - PLANIMETRIC MAPPING

The mapping method may be used either for individuals or groups of fish, and can be used to study several species at once. Large scale hydraulic contour maps with isolines of equal depth, velocity, substrate, and cover are individually prepared for each sampling or observation reach (Figure 7). These contour maps are prepared for each discharge at which fish were sampled or observed.

Sampling techniques amenable to this option include electrofishing, spot concussion, spot poisoning, hook and line, trot line, seining, drifted gill nets, and batteries of strategically placed, baited hoop nets. Stationing gill nets or hoop nets with leads should be avoided because they sample fish in transit, not at rest. Problems associated with baited hoop nets will be discussed in the section entitled Sampling Bias.

During each sampling run, or for a sampling period, the locations of individuals or groups of fish at each discharge are marked on blank maps of the study reach drawn to the same scale (Figure 8). The distribution and numbers of fish observed or captured at each discharge are then entered onto the appropriate location on the contour maps. Hydraulic parameters for each fish location may then be read directly from the contour maps.

SAMPLING BIAS

Hunter (1973:p. 2) warns that "... measurements for ... game fish should be selected from an area that presents a variety of hydraulic conditions to the fish. Unless the fish is given a choice of water depths, velocities, and gravel size, the measurements taken will reflect the hydraulic conditions available in that specific stream and not the conditions ... which the fish would really prefer...".

In the determination of biological criteria, and particularly probability-type criteria, the minimization and avoidance of sampling bias is critical. The type of bias described by Hunter may be overcome quite simply by sampling areas with a wide variety of conditions available, by sampling several streams, or both.

However, sampling bias may also occur as a result of gear selectivity, sampling technique, or observation technique. Several examples are given below to warn of potential bias problems with different collection and observation techniques.

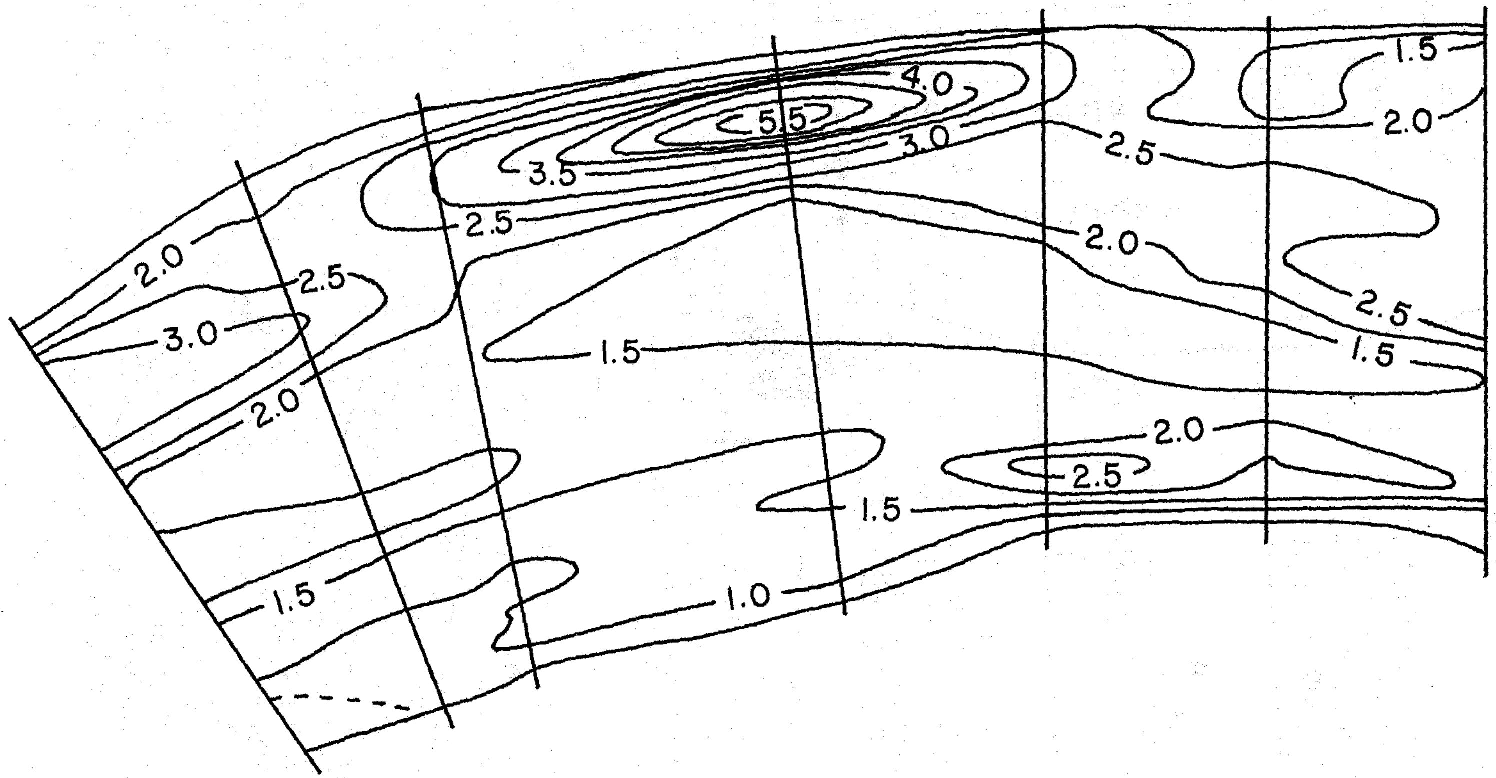

Figure 7. Example of a depth contour map used in the mapping method of criteria development, with depths in feet.

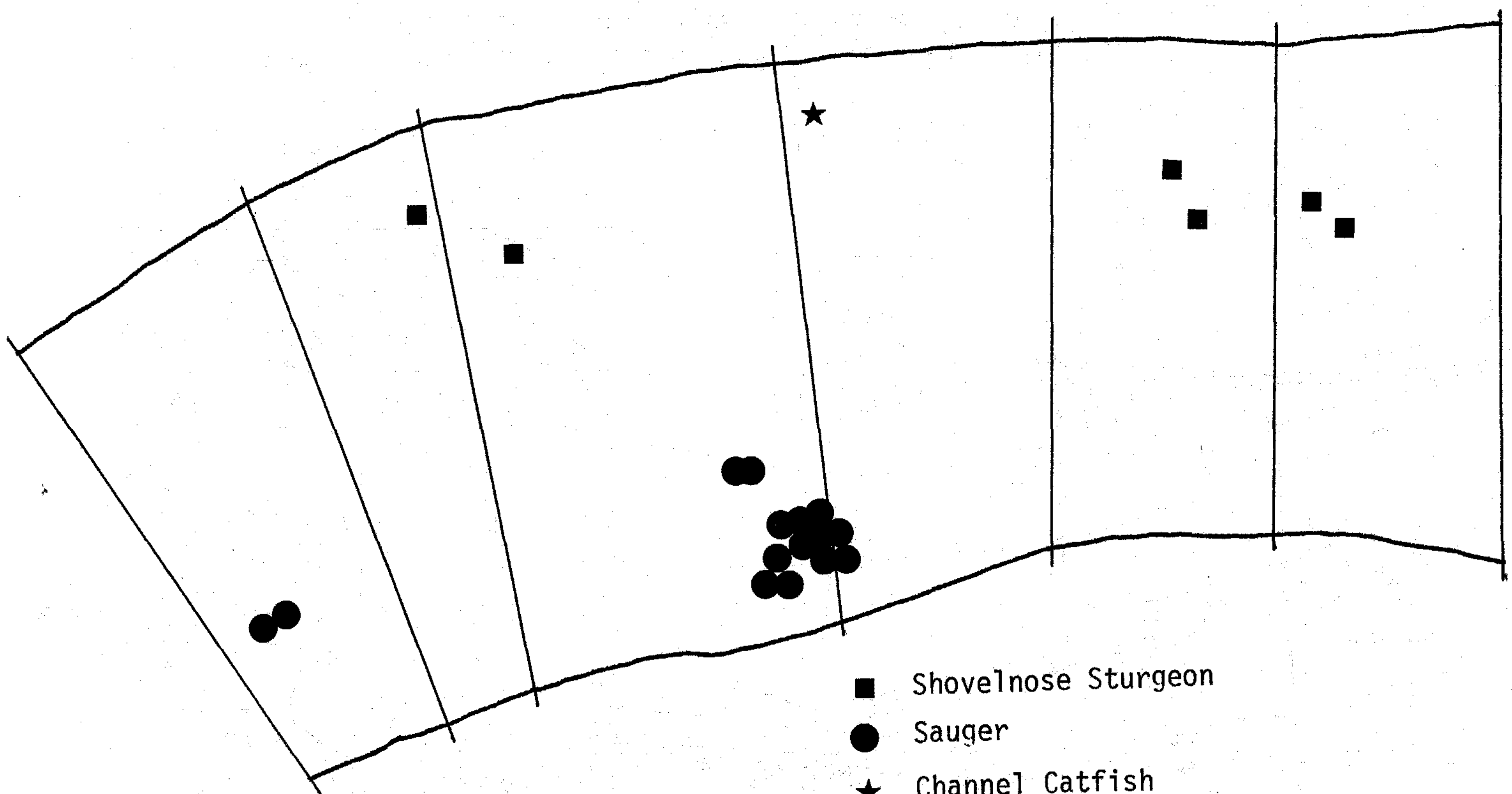

Figure 8. Species location and abundance map for area in Figure 7.

Surface Observation

Surface observation is difficult in swift, turbulent, or turbid water. Many potential subjects may be overlooked or mis-identified. Therefore, observation techniques are best applied in clear water where the Froude number ($f = V/\sqrt{gd}$, where V is the velocity, g is the acceleration due to gravity, and d is the depth) is <0.5.

Electrofishing

The limitations of this method were discussed earlier. They may be overcome by using a dead man switch to spot-sample discrete areas, rather than running the field continuously.

Drift Gill Nets

Drift gill nets can only be safely used where the channel is free from snags. Fish sampled by gill netting should give a distinct reaction (e.g. shovelnose sturgeon (*Scaphirhynchus platorynchus*) break to the surface) when first netted, so that their positions may be documented.

SCUBA or Snorkel Observation

Fish may be alarmed by the presence of a diver, depending on whether he approaches them from upstream or downstream. Fish reactions may vary, so it may be wise to experiment somewhat with approach patterns.

Baited Hoop Nets (and Trot Lines)

These are inherently biased since the fish are attracted to the sampling location from somewhere else in the stream. However, for some species, such as channel catfish (*Ictalurus punctatus*) they are the most efficient sampling devices. Sampling bias may be reduced somewhat by eliminating subjects drawn from outside the sample reach. This may be accomplished by setting a battery of "control" hoop nets at the most downstream limit of the sample reach, or by placing an "electric weir" across the lower end of the reach. These controls will intercept most of the in-migrants to the section. Hoop nets within the sample reach should be situated so that they are sampling a discrete habitat area.

Sampling bias may be reduced by a statistically random selection of sampling areas, and by using a combination of more than one sampling or observational technique. It is unlikely that bias can be eliminated completely, but it should be reduced wherever possible.

THE USE OF COMBINATION PROBABILITIES IN THE IFG INCREMENTAL METHODOLOGY

The IFG incremental methodology is rather unique among instream flow assessment procedures. At first glance, there appear to be few common features among various riverine habitat alterations: stream dewatering, flow augmentation, channelization, bank stabilization, habitat improvement, or sedimentation. Each appears to be a unique problem, requiring a unique solution. However, each of these problems involves some alteration of river hydraulics, and the responses of different species to those changes. Thus, it is possible to utilize a standard methodological approach in the solution of these problems.

The Incremental Method was developed by personnel of the Cooperative Instream Flow Service Group, U.S. Fish and Wildlife Service, Fort Collins, Colorado. The IFG incremental method allows quantification of the amount of potential habitat available for a species and life history phase, in a given reach of stream, at different streamflow regimes, with different channel configurations and slopes.

This method is composed of four components: (1) simulation of the stream; (2) determination of the distribution of combinations of depths, velocities, substrates, and cover objects, by area; (3) determination of a composite probability of use for each combination of depth, velocity, substrate, and cover (where applicable) found within the stream reach, for each species and life history phase under investigation; and (4) the calculation of a weighted usable area (roughly a habitat's carrying capacity based on physical conditions alone) for each discharge, species, and life history phase under investigation.

STREAM REACH SIMULATION

The purpose of a stream reach simulation is the determination of the distribution of depths, velocities, and bottom types within the channel at different levels of stream flow. Several hydraulic simulation techniques are available, ranging in difficulty from taking many current meter measurements at each discharge to be simulated, to simulating many discharges from one set of field measurements. A detailed description of the theoretical and field measurement considerations will be available under a separate title ("Theoretical Considerations, Data Collection, and Cross-section Analysis for Assessing Hydraulic Changes in Natural Stream Channels," IFIP 5, Cooperative Instream Flow Service Group, U.S.F.W.S., Ft. Collins, CO - in preparation).

The stream reach simulation utilized by IFG uses several cross-sectional transects, each of which is subdivided into 9 to 20 subsections. The computer program then treats each subsection as an essentially separate channel. The mean depth and velocity of each subsection may then be calculated for any stage (water surface elevation).

An area represented by these values of depth and velocity is calculated by multiplying the width of the subsection by half the distance to the next transect upstream and downstream (Figure 9).

The output of the stream-reach simulation is in the form of a multidimensional matrix showing the surface area of stream having different combinations of hydraulic parameters (i.e., depth, velocity, substrate, and cover when applicable). Table 5 illustrates a depth-velocity matrix, although the analysis is not limited to two dimensions. The outlined numeral in the upper left-hand corner of the first matrix refers to 195 square feet per 100 feet of stream having a combination of depths less than 1.0 feet <u>and</u> velocities less than 0.5 ft/sec. This is the total summation of areas within the stream reach with that combination of depths and velocities. These areas are not necessarily contiguous.

COMPOSITE PROBABILITY OF USE

The composite use probability of any combination of hydraulic conditions encountered in a study reach may be determined from the individual probability of use curves for each species and life stage.

Figure 10 illustrates probability of use curves for adult smallmouth bass for depths and velocities. For a given increment of each parameter the use probability is read directly from the curve. For example, the use probability for the depth increment of 3.5 feet is 0.37. The use probability for the velocity increment of 0.5 ft/sec is 0.81. The composite use probability for adult smallmouth bass for a depth of 3.5 feet <u>and</u> a velocity of 0.5 ft/sec is 0.30 (0.37 X 0.81). A composite <u>probability</u> is similarly calculated for each stream reach subsection.

Substrate or cover may also be incorporated into this determination of composite probability following the procedure detailed above. In the preceeding example, the composite probability for a stated combination of depth and velocity was found to be 0.30. If the substrate found with that combination of depth and velocity had a probability of use of 0.90, then the composite probability of use for that combination of depth, velocity, <u>and</u> substrate would be 0.27 (0.37 X 0.81 X 0.90).

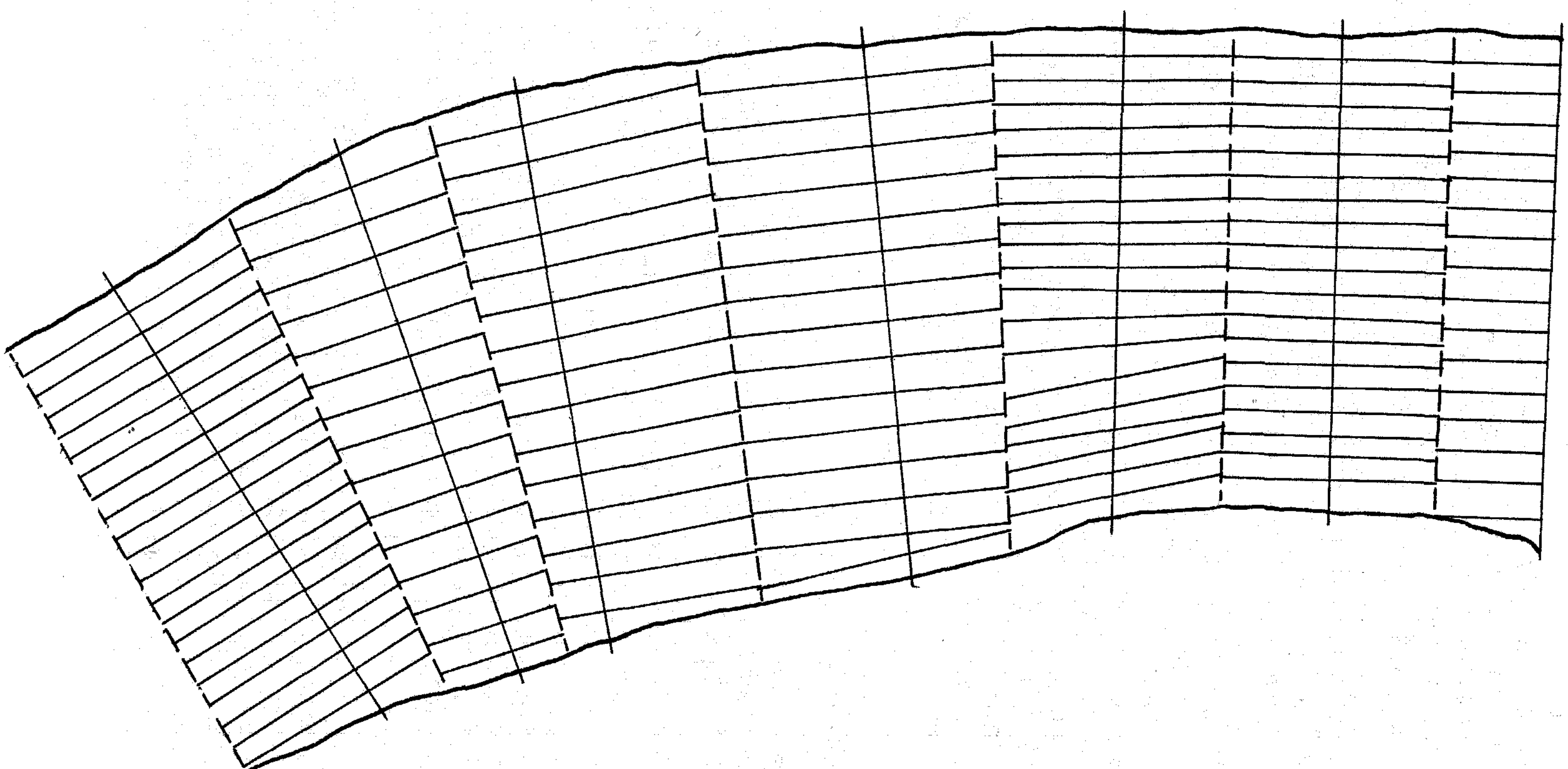

Figure 9. Computer conceptualization of simulated stream reach. Hydraulic parameters of depth, velocity, and substrate for each major transect subdivision assigned to area of subdivision block.

Table 5. Distribution of Different Combinations of Depth and Velocity, Expressed in Square Feet of Surface Area per 100 feet of Stream.

Velocity in feet per second

Depth (ft.)	.5	.5-.99	1.0-1.49	1.5-1.99	2.0-2.49	2.5-2.99	3.0-3.49	3.5	Row Total
1	195	26	-	-	-	-	-	-	221
1.0-1.5	90	47	-	41	17	6	6	93	300
1.5-2.0	29	38	32	44	108	79	38	172	540
2.0-2.5	6	29	23	9	111	131	143	175	627
2.5-3.0	6	15	55	79	41	64	41	105	406
3.0-3.5	9	17	15	12	32	3	149	-	237
3.5-4.0	9	20	-	17	47	17	82	-	192
4.0-4.5	-	20	-	11	50	35	17	-	133
4.5-5.0	-	11	-	5	115	20	-	-	151
5.0-5.5	-	-	-	7	23	15	-	-	45
5.5-6.0	-	10	-	-	31	20	-	-	61
Column Total:	344	233	125	225	575	390	476	545	2913

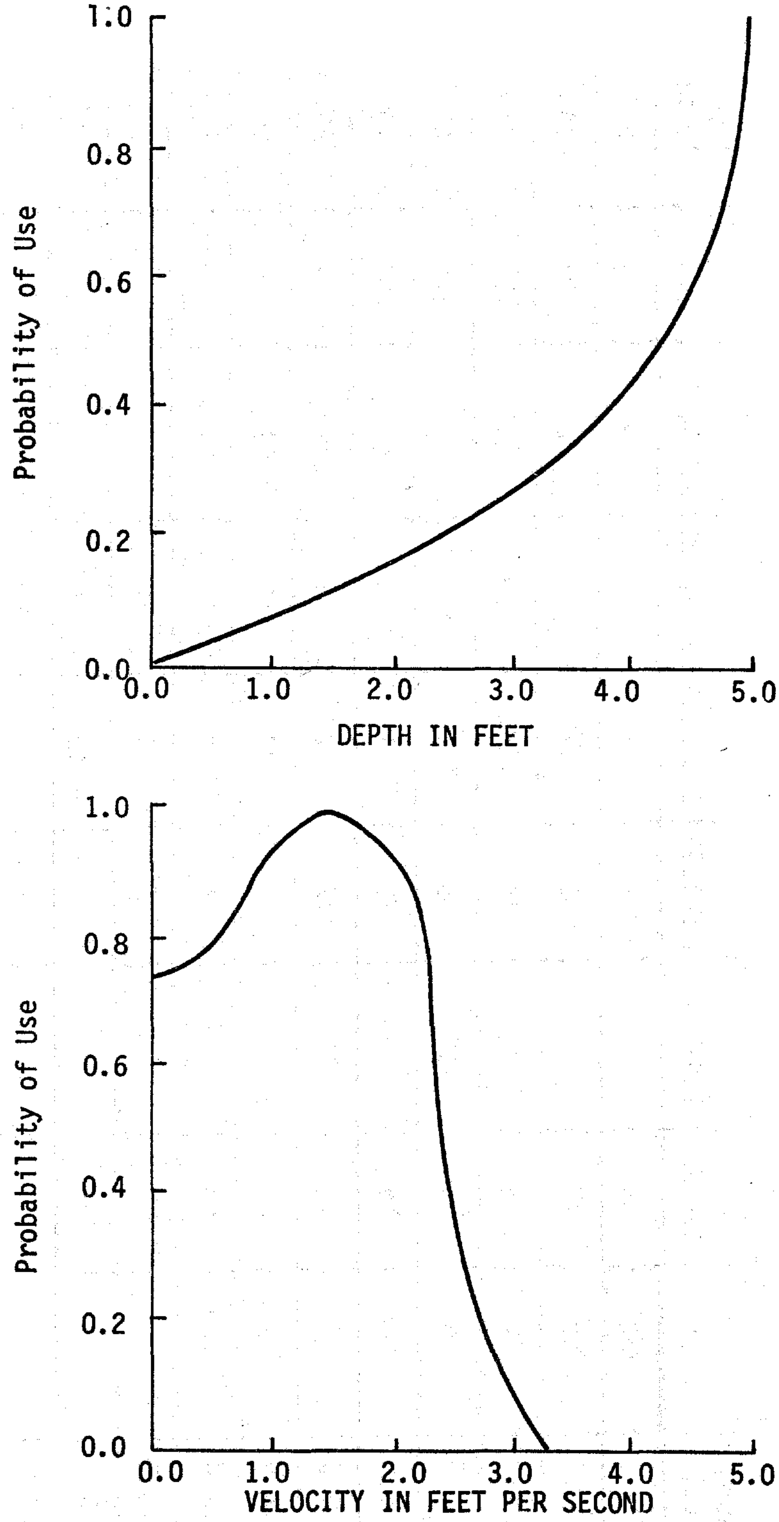

Figure 10. Probability of use curves for adult smallmouth bass.

WEIGHTED USABLE AREA

The weighted usable area is defined as the total surface area having a certain combination of hydraulic conditions, multiplied by the composite probability of use for that combination of conditions. This calculation is applied to each cell within the multidimensional matrix.

This procedure roughly equates an area of marginal habitat to an equivalent area of optimal habitat. For example, if 1,000 square feet of surface area had the aforementioned combination of depth, velocity, and substrate it would have the approximate habitat value of only 270 square feet of optimum habitat.

A worked example of an entire two-dimensional matrix (depth and velocity) is given in Table 6. In each cell of the matrix, the upper numeral refers to the surface area of stream having a certain depth-velocity combination. The numerals in parentheses refer to the weighted usable area. Due to the large number of calculations required for each reach matrix, a computer program has been developed by personnel of the Cooperative Instream Flow Service Group to make all calculations for as many species as desired from a single set of hydraulic input data (Main 977).

For each species and life stage, weighted usable area may be plotted against various monthly flow regimes, such as median monthly flows or 1-in-10 year monthly low flows (Figure 11) or against discharge (Figure 12). Such plots can show critical time periods for a given life stage, limiting habitat availability for each life stage (i.e., physical carrying capacity), and limiting habitat availability for different species. Since changes in hydraulic characteristics will initiate differential species reactions, the incremental method may be particularly useful in predicting changes in species composition. Because the output from the incremental method is directly tied to the physical carrying capacity of the stream, it is possible to determine the approxiate change in standing crop of a given species at different instream flow regimes. In the absence of better information, this relationship is assumed to be 1 to 1. Therefore, it is possible to calibrate the output with a standing crop estimate taken after the limiting month for a species. If the calibration standing crop is, for example, 10 Kg/ha at the calibration discharge (i.e., the discharge yielding the minimum weighted usable area), a flow regime which would cause a 50% decrease in weighted usable would yield only 5 Kg/ha for that species. This capability should be extremely useful when negotiating for flow reservations or reservoir releases from water management agencies.

Table 6: Calculation of weighted usable area for adult smallmouth bass, from **Table 4.**
Discharge = **800 cfs**

Velocity in feet per second

Depth (ft.)	<.5 (.75)	.5-.99 (.90)	1.0-1.49 (.98)	1.5-1.99 (.98)	2.0-2.49 (.73)	2.5-2.99 (.13)	3.0-3.49 (.03)	>3.5 (0)	Row Total
<1 (.05)	195 (7.3)	26 (1.2)	-	-	-	-	-	-	221 (8.5)
1.0-1.5 (.12)	90 (8.1)	47 (5.1)	-	41 (4.8)	17 (1.5)	6 (0.1)	6 (0.0)	93 (0)	300 (19.6)
1.5-2.0 (.16)	29 (3.5)	38 (5.5)	32 (5.0)	44 (6.9)	108 (12.6)	79 (1.6)	38 (0.2)	172 (0)	540 (35.3)
2.0-2.5 (.22)	6 (1.0)	29 (5.7)	23 (5.0)	9 (1.9)	111 (17.8)	131 (3.7)	143 (0.9)	175 (0)	627 (36.0)
2.5-3.0 (.27)	6 (1.2)	15 (3.6)	55 (14.5)	79 (20.9)	41 (8.1)	64 (2.2)	41 (0.3)	105 (0)	406 (50.8)
3.0-3.5 (.33)	9 (2.2)	17 (5.0)	15 (4.9)	12 (3.9)	32 (7.7)	3 (0.1)	149 (.15)	-	237 (25.3)
3.5-4.0 (.42)	9 (1.6)	20 (7.6)	-	17 (7.0)	47 (14.4)	17 (0.9)	82 (1.0)	-	192 (32.5)
4.0-4.5 (.53)	-	20 (9.5)	-	11 (5.7)	50 (19.3)	35 (2.4)	17 (0.3)	-	133 (37.2)
4.5-5.0 (.75)	-	11 (7.4)	-	5 (3.7)	115 (63.0)	20 (2.0)	-	-	151 (76.1)
5.0-5.5 (1.0)	-	-	-	7 (6.9)	23 (16.8)	15 (2.0)	-	-	45 (25.7)
5.5-6.0 (1.0)	-	10 (9)	-	-	31 (22.6)	20 (2.6)	-	-	61 (34.3)
Column Total:	344 (24.9)	233 (59.6)	125 (29.4)	225 (61.7)	575 (183.8)	390 (17.6)	476 (4.2)	545 (0)	2913 (381)

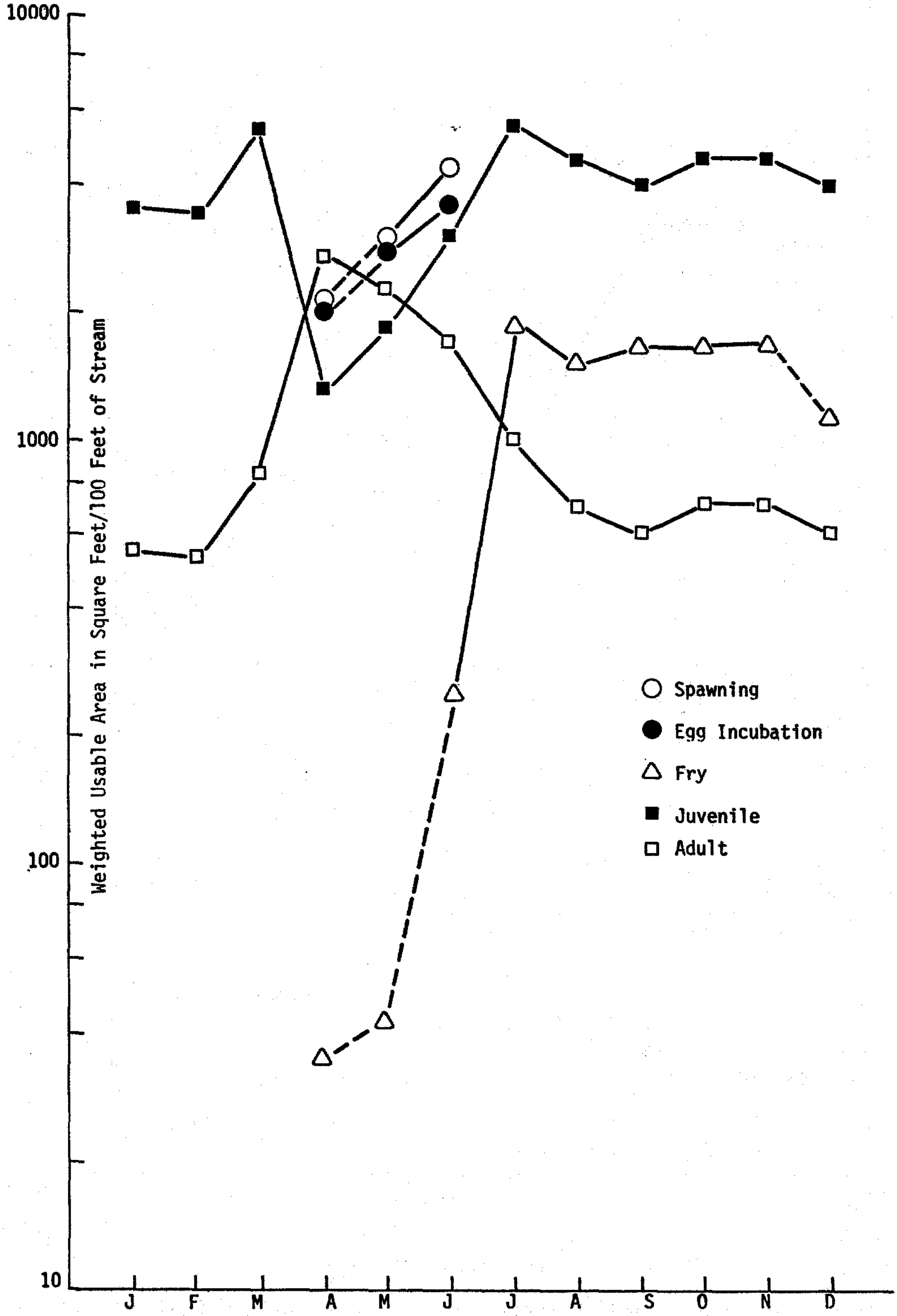

Figure 11. Weighted usable area vs. median (1 in 2 year frequency) monthly flows.

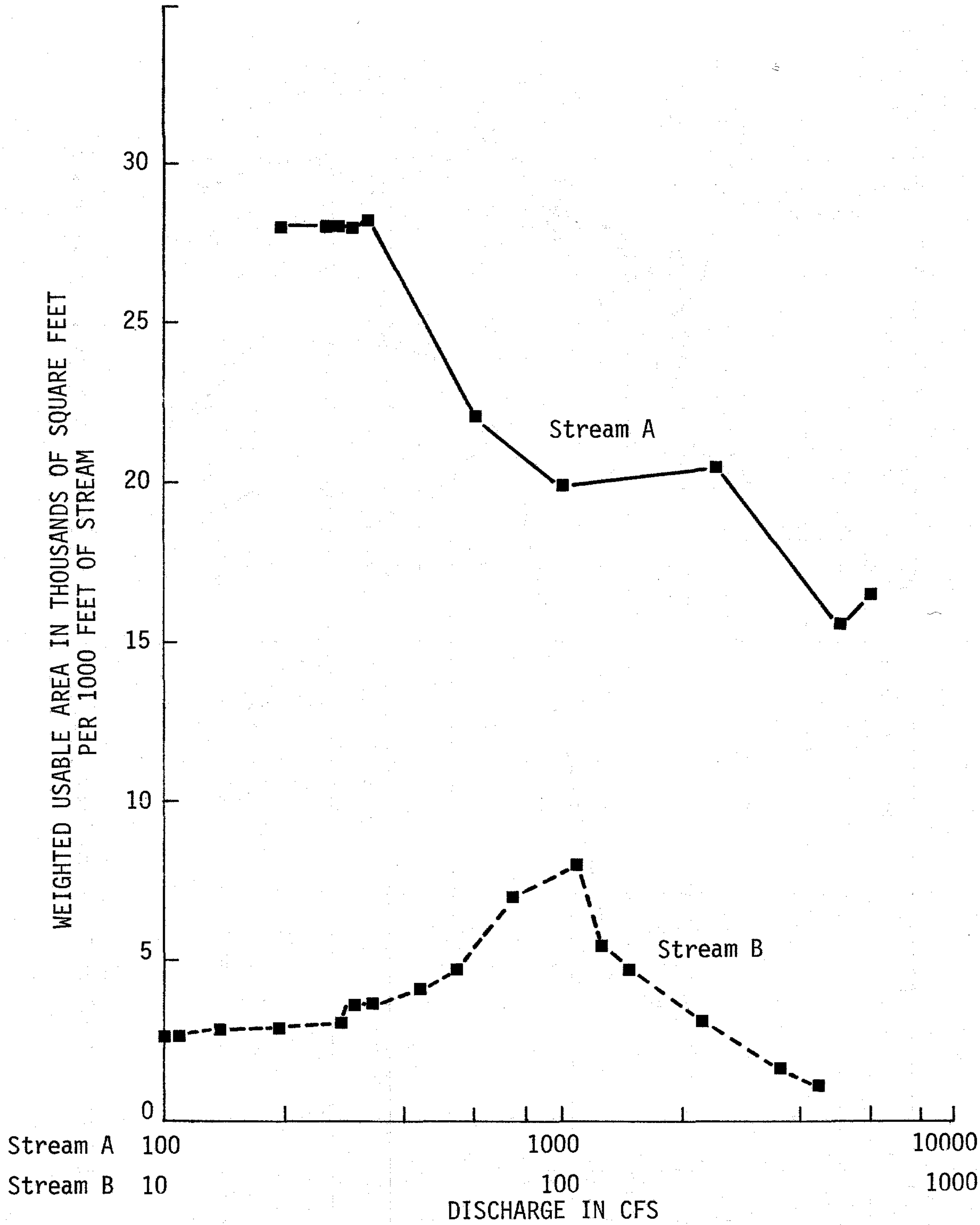

Figure 12: Discharge incremented approach to assessing habitat values of different stream flows in two streams, for juvenile smallmouth bass.

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1. Lamb, Berton Lee, Editor. Guidelines for Preparing Expert Testimony in Water Management Decisions Related to Instream Flow Issues. Fort Collins, Colorado, Cooperative Instream Flow Service Group, July 1977, 30 pages. (NTIS Accession Number: PB 268 597; Library of Congress Catalog Card No. 77-83281).

2. Lamb, Berton Lee, Editor. Protecting Instream Flows Under Western Water Law: Selected Papers. Fort Collins, Colorado, Cooperative Instream Flow Service Group, September 1977, 60 pages. (NTIS Accession Number: PB 272 993; Library of Congress Catalog Card No. 77-15286).

3. Bovee, Ken D., and Cochnauer, Tim, Editors. Development and Evaluation of Weighted Criteria, Probability of use Curves for Instream Flow Assessments; Fisheries. Fort Collins, Colorado, Cooperative Instream Flow Service Group, December 1977, 49 pages. (NTIS Accession Number: PB ; Library of Congress Catalog Card No. -).

BIBLIOGRAPHIC DATA SHEET	1. Report No. FWS/OBS-77/63	2.	3. Recipient's Accession No.
4. Title and Subtitle Development and Evaluation of Weighted-Criteria, Probability -of-Use Curve for Instream Flow Assessments: Fisheries.			5. Report Date December 1977
			6.
7. Author(s) Ken D. Bovee and Tim Cochnauer			8. Performing Organization Rept. No. IFIP-3
9. Performing Organization Name and Address			10. Project/Task/Work Unit No.
			11. Contract/Grant No.
12. Sponsoring Organization Name and Address Cooperative Insteam Flow Service Group; Western Energy and Land Use Team; Office of Biological Services; Rm. 206, Federal Bldg., 301 S. Howes St., Fort Collins, Colorado 80521			13. Type of Report & Period Covered
			14.

15. Supplementary Notes
Western Water Allocation/EPA Funds

16. Abstracts

This information paper documents the methods and procedures used in the construction of probability criteria curves. Weighted criteria are used to assess the impacts of altered streamflow regimes on a stream habitat. They are developed primarily for those habitat parameters most closely related to stream hydraulics: depth, velocity, substrate, and temperature. Guidelines for data collection, analysis and curve development are discussed.

17. Key Words and Document Analysis. 17a. Descriptors

probability curves
weighted criteria
data collection
stream hydraulics
altered streamflow
stream habitat

17b. Identifiers/Open-Ended Terms

Cooperative Instream Flow Service Group

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 53
Release unlimited	20. Security Class (This Page UNCLASSIFIED	22. Price

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues which have an impact fish and wildlife resources and their supporting ecosystems. The mission of the Program is as follows:

1. To strengthen the Fish and Wildlife Service in its role as a primary source of information on natural fish and wildlife resources, particularly with respect to environmental impact assessment.

2. To gather, analyze, and present information that will aid decisionmakers in the identification and resolution of problems associated with major land and water use changes.

3. To provide better ecological information and evaluation for Department of the Interior development programs, such as those relating to energy development.

Information developed by the Biological Services Program is intended for use in the planning and decisionmaking process, to prevent or minimize the impact of development on fish and wildlife. Biological Services research activities and technical assistance services are based on an analysis of the issues, the decisionmakers involved and their information needs, and an evaluation of the state-of-the-art to identify information gaps and determine priorities. This is a strategy to assure that the products produced and disseminated will be timely and useful.

Biological Services projects have been initiated in the following areas:

Coal extraction and conversion

Power plants

Geothermal, mineral, and oil shale development

Water resource analysis, including stream alterations and western water allocation

Coastal ecosystems and Outer Continental Shelf development.

Systems and inventory, including National Wetlands Inventory, habitat classification and analysis, and information transfer

The Program consists of the Office of Biological Services in Washington, D.C., which is responsible for overall planning and management; National Teams which provide the Program's central, scientific and technical expertise, and which arrange for contracting of Biological Services studies with States, universities, consulting firms, and others; Regional staff who provide a link to problems at the operating level; and staff at certain Fish and Wildlife Service research facilities who conduct inhouse research studies.

U. S. Department of the Interior

Fish and Wildlife Service

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.