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catch any exotic
bugs lately?
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Physical Habitat Evaluation of Small Stream Fishes: Point vs. Transect, Observation vs. Capture Methodologies

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ABSTRACT

Physical habitat data (velocity and depth of water, and percentage substrate composition) for several southwestern fishes collected by point and transect methodologies were similar. Velocity estimates showed less agreement and greatest variation. Choice of direct observation or capture by electrofishing as methods to locate fishes for habitat evaluation is problematic. Fish location techniques may induce more error in measurement of habitat than do different habitat evaluation techniques.

INTRODUCTION

Methods of habitat evaluation for fishes are many and varied, and are usually developed on a local or regional scale (Armantrout 1981). Philosophy and economics combined with specific agency needs and objectives are the driving forces in selecting respective methodologies; but, any method of habitat evaluation must be cost-effective, efficient, and reliable. Often, reliability suffers because of the overriding influence of the first two factors. Ideally, any approach to habitat evaluation must not only be reliable but should be locally, regionally, and, ultimately, nationally coordinated to preclude duplication of effort and to prevent conflicting results that present the land manager with a dilemma in implementating plans. If different results are produced, the nagging question arises, "Are the differences due only to technique?" On the other hand, similar results arrived at by different

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approaches to habitat evaluation will serve to strengthen and validate habitat information for use in both management and planning.

This paper describes a transect method of evaluating microhabitat of small stream fishes. It further seeks to answer two questions: "How similar are physical habitat estimations and measurements obtained by a point method compared to those obtained by a meter transect method? And, does the method used to locate the fish--direct observation or capture by electrofishing--affect the results obtained?" Data are from Aravaipa Creek, Arizona, an upper Sonoran Desert stream (elevation 300 m, modal flow 0.60 m^3/sec) in the southwestern United States.

APPROACH AND RATIONALE

A microhabitat may be interpreted as the point where a fish is observed or captured. Because many of the fishes inhabiting southwestern streams are diminutive "minnows" (Minckley 1973), it is perhaps even more important to quantify and describe microhabitats for these species. When defining habitat requirements of fishes, terminology such as "nose or snout velocity" have been used to describe the precise point or area occupied by an individual fish (Shirvell and Dungey 1983). Replicate measurements through time and space of habitat use at single points, most commonly designated either by observation or capture, are used to define physical habitat preference of species. Because fishes are mobile, location techniques, whether direct observation or capture, conceivably may result in erroneous definition of habitat use.

Three common methods of evaluating fish habitats are the reach, point, and transect approaches. The reach approach delineates the habitat in a short (10-50 m) reach of stream. This approach provides a general definition of habitat requirements of respective species within an arbitrarily designated area, but may not always be precise enough to be usable for management purposes. The point approach is described in the preceeding paragraph. Intermediate to a point or stream reach approach to habitat evaluation is the transect approach--examination of a small microhabitat area (1-2 m^2) of stream from which fish are captured. Definition of habitat within this area is based on data collected at multiple points along a meter transect. This approach, used in preliminary work on habitat evaluation of southwestern native fishes, is described below.

METHODS

Site Selection and Fish Location

Two methods of fish location for habitat evaluation also are compared here: (1) electrofishing and capture of fishes in a small area of stream, and (2) direct underwater observation of fishes. In the first, a microhabitat area (Fig. 1) was generally selected by initial capture of a target species, and at least two additional microhabitat areas 5 m distant were designated. Thus, each study section had a

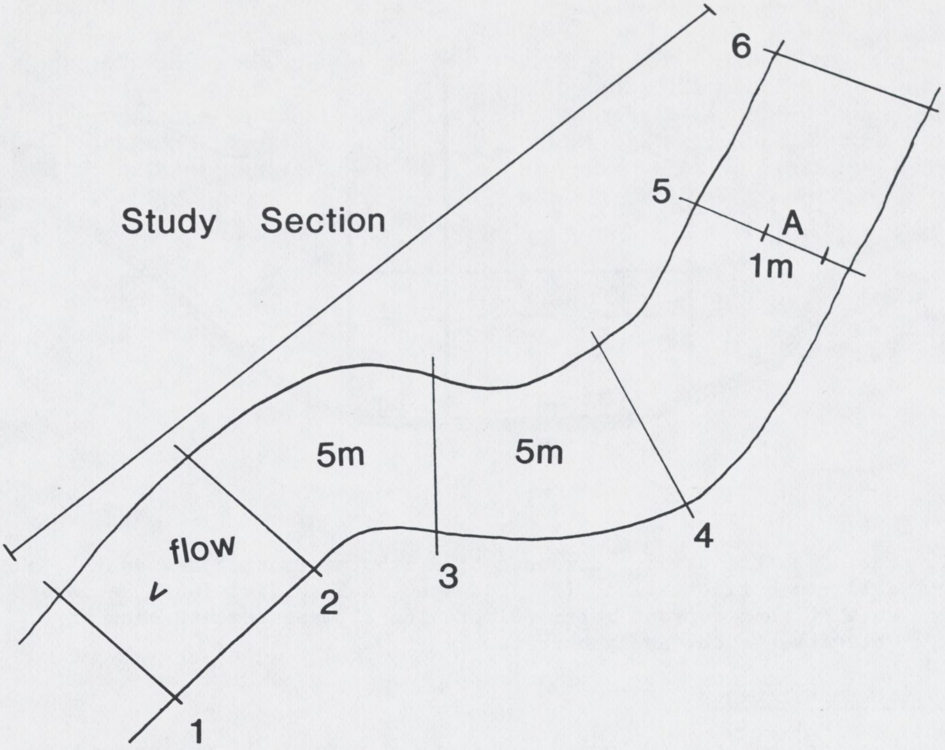

Figure 1. Stream sketch depicting location of 6 transects, 5 m apart, that constitute a study section. Position of habitat sampler (A; see Fig. 2) at transect 5 is indicated.

minimum of three transects (Fig. 1). Such a random uniform approach provides comparison of habitat where fish were present as well as absent. Care was taken to minimize disturbance near and within the stream prior to sampling. Fishes were captured by a backpack DC shocker and a block seine, encompassing approximately 1 m of stream width. Personnel operating the block seine and shocker entered the stream, the former slightly in advance of the latter. Immobilized fishes within a meter or two upstream from the block seine were washed into the net, retained in holding containers, and after processing, returned alive to the stream. In the second approach, underwater observations were conducted in an upstream direction with the aid of a snorkel and mask. Fish positions in a given area of stream were flagged for later habitat measurement.

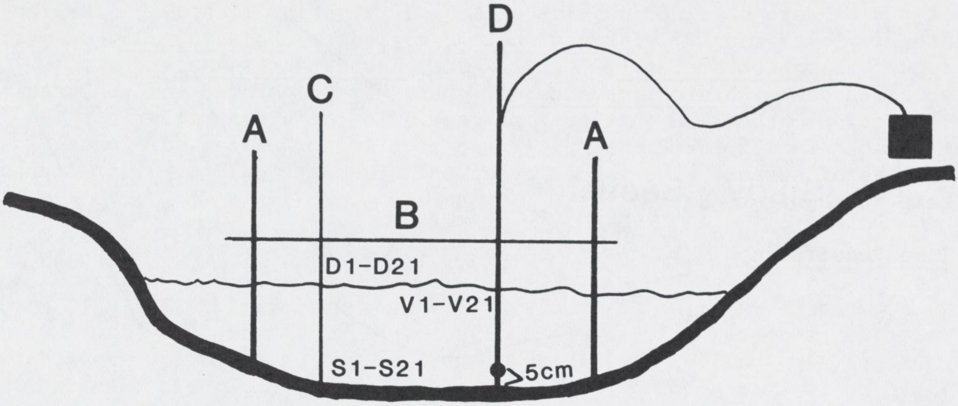

Figure 2. Habitat sampler composed of 2 laboratory ring stands (A), and a 132-cm horizontal rod (B) graduated in 5-cm divisions. A meter rule (C) and current meter (D) provide 21 measurements each of velocity, depth, and substrate.

Habitat Measurement

Physical habitat (velocity and depth of water, and substrate composition) was measured once fish from all sample areas had been processed. In the transect method, a habitat sampler (Fig. 2) was used to collect data. The apparatus consists of two laboratory ring stands, and a 132-cm-long, 1.27-cm-diameter aluminum rod graduated into 5-cm divisions (Medina 1984). The sampler was positioned within the area of fish capture, approximately perpendicular to streamflow.

Depth of water was measured and substrate class visually estimated simultaneously with a 1-m rule. The substrate classes were: (1) sand, <2 mm; (2) gravel, 3-16 mm; (3) pebble, 17-64 mm; (4) cobble, 65-256 mm; and (5) boulder, 256+ mm. Percentage of substrate in each size class and a substrate index (mean of class values) were calculated from measurements at 5 cm intervals along the transect. Velocity of water (cm/sec) at 5-cm intervals, approximately 5 cm above bottom, was measured with a direct-reading current meter. This approach provided three sets (velocity, depth, substrate) of 21 data points each for each microhabitat area.

For the observational or point method, single velocity and depth measurements were taken with a graduated wading rod and direct-reading current meter. Substrate was characterized at the point of fish capture and at two points 5 cm to the right and left of this point at right angles to flow. This method provided an estimate of a primary-secondary rank of size class composition.

RESULTS

Fishes

Data were obtained on five of the seven native fishes in Aravaipa Creek: loach minnow, *Tiaroga cobitis*; spikedace, *Meda fulgida*; desert sucker, *Catostomus clarki*; longfin dace, *Agosia chrysogaster*; and speckled dace, *Rhinichthys osculus*. Data were separated for analyses by collection method and whether fish were allo- or sympatric. In this study the former term means data were from two separated, disjunct reaches of stream. The latter group included data collected within the same reach of stream.

Time Requirements

The time required to complete a meter transect (i.e., 21 each velocity, substrate, and depth data points) varied with complexity of habitat. In shallow, slow water, less time was required to obtain data. Based on 27 transects, the mean time required to complete a transect was 3.8 minutes (range 2.4-5.2 min); however, most (50-75%) of this time is consumed by velocity measurement. By comparison, the combined time required to get single point measurements of the three physical habitat factors averaged less than 60 seconds. The transect approach required more time but gave up to 20 times the data points.

Intrasample Variation

The degree of variation in the three physical parameters within a microhabitat was determined using seven independent sets of data (not those shown in Tables 1 and 2), consisting of three parallel transects each positioned within the 1-m^2 area (the microhabitat) of stream; the seven sets were compared by analysis of variance (depth and velocity) and chi-square analysis (substrate). Of the seven sets, three each were in higher velocity waters (mean, 58-84 cm/sec) and one set was in a lower velocity reach (mean, 33-38 cm/sec). In only one set of comparisons of the seven (a higher velocity area) were variations in depth and variations in velocity significantly different ($F = 4.14$ and 5.74, respectively; $DF = 60$) among the three transects. Chi-square analysis of 35 data sets of substrate types (7 sets x 5 substrate classes) indicated that in only five data sets (14%) did substrates vary significantly between transects. All these occurred in the swifter water sample areas; three were in cobble substrate and one each in pebble and gravel types.

Sample Size Requirements

Sample size (n) needed to achieve a precision level of ±10% of the mean was calculated as:

$$n = \frac{4\,s^2}{(0.1\bar{x})^2}$$

TABLE 1. Comparison of habitat (as measured by transect method) occupied by five species of fish in Aravaipa Creek, September 1983, based on (1) electrofishing and (2) observations. Data under A are allopatric; under B sympatric. Underline denotes significant difference at the 0.05 confidence level (unpaired t-test) between (1) and (2).

Species	Substrate (size class) index		Depth (cm)		Velocity (cm/sec)	
	A	B	A	B	A	B
Tiaroga cobitis						
1	$\underline{2.06}$	2.38	$\underline{11.3}$	$\underline{12.0}$	$\underline{46.7}$	$\underline{43.0}$
2	$\underline{2.59}$	2.59	$\underline{9.5}$	$\underline{9.5}$	$\underline{31.0}$	$\underline{31.0}$
Meda fulgida						
1	$\underline{2.02}$	2.44	$\underline{11.8}$	$\underline{11.6}$	$\underline{49.5}$	$\underline{42.2}$
2	$\underline{2.47}$	2.47	$\underline{9.8}$	$\underline{9.8}$	$\underline{31.0}$	$\underline{31.0}$
Pantosteus clarki						
1	$\underline{2.06}$	2.43	11.4	12.0	$\underline{47.2}$	$\underline{43.0}$
2	$\underline{2.56}$	2.56	11.2	11.2	$\underline{33.0}$	$\underline{33.0}$
Agosia chrysogaster						
1	$\underline{2.02}$	2.54	$\underline{11.2}$	12.9	$\underline{46.8}$	$\underline{46.2}$
2	$\underline{2.54}$	2.54	$\underline{12.0}$	12.0	$\underline{33.7}$	$\underline{33.7}$
Rhinichthys osculus						
1	$\underline{2.03}$	2.5	$\underline{12.4}$	$\underline{13.1}$	$\underline{50.3}$	$\underline{45.5}$
2	$\underline{2.60}$	2.60	$\underline{9.6}$	$\underline{9.6}$	$\underline{35.0}$	$\underline{35.0}$

For 24 samples collected from Aravaipa Creek in April 1984, the sample sizes necessary to estimate depths ±10% ranged from 2 to 49 (mean = 13.77). Estimates of velocity sample sizes from the same data ranged from 3 to 70 (mean = 26.6). Ten (42%) of the 24 sample size estimates for velocity were greater than 21. By comparison, only 4 (15%) of the 24 depth transects displayed inadequate sample sizes.

Point Versus Transect Data

Velocity, depth, and substrate data estimated by transect and point methodologies were compared in August 1983. Transect data included the

TABLE 2. Comparison of habitat (as measured by transect method) occupied by three species of fish in a single reach in Aravaipa Creek, April 1984, based on location by electrofishing (1) and observations (2). Underline denotes significant difference at 0.05 level (unpaired t-test).

Species	Substrate	Habitat depth (cm)	Velocity (cm/sec)
Tiaroga cobitis			
1	2.62	17.5	33.3
2	2.73	17.0	27.6
Pantosteus clarki			
1	2.88	21.1	31.7
2	2.74	23.1	32.0
Agosia chrysogaster			
1	2.30	17.8	32.0
2	2.50	16.5	28.1

average for 21 data points along the meter distance described by the habitat sampler (Fig. 2). Point data were taken at that point along the transect where a fish was captured.

Of 53 paired substrate measurements, 29 sets (55%) of the primary (most abundant) substrate types (i.e., sand, gravel, etc.) recorded by the two methods were in agreement. An additional 20 (38%) of the paired substrates were inverse in agreement (i.e., estimated as primary by the point method and secondary by the transect method or vice versa) in substrate material or were different in the secondary type. The remaining 4 (8%) of paired measurements of substrate were in total disagreement.

Comparisons of depth and velocity values at the point along the meter transect where fish were located with calculated mean depth and velocity for the transect were not significantly different (T = 1.05, DF = 52) for either parameter. Mean point velocities were only 3.3 cm/sec greater (46.1 vs 42.8 cm/sec) than the transect average. Point depth estimates were 2.2 mm more (171.9 vs 169.7 mm) than mean depth for the meter transect.

TABLE 3. Comparison of physical habitat (as measured by transect method) occupied by five species of fish in a single reach of Aravaipa Creek, September 1984 based on electrofishing (1) and underwater observation (2). Underline denotes significance at 0.05 level (unpaired t-test).

Species	Substrate	Habitat depth (cm)	Velocity (cm/sec)
Tiaroga cobitis			
1	1.97	30.43	32.09
2	2.47	19.66	36.14
Meda fulgida			
1	2.32	23.92	40.61
2	1.93	25.79	18.03
Pantosteus clarki			
1	2.04	23.15	28.93
2	2.31	25.09	37.04
Agosia chrysogaster			
1	2.23	25.74	38.08
2	2.20	23.40	31.34
Rhinichthys osculus			
1	2.18	24.85	34.38
2	2.48	21.20	34.33

Observation Versus Electrofishing

Velocity, depth, and substrate data estimated at observed positions of fish differed from data generated by location with electrofishing gear (Tables 1-3). Initial comparisons of habitat (Table 1, data set A) were between 10 transects in a riffle disjunct (ca. 100 m upstream) from 16 transects where fishes were observed and their individual positions marked. Only depth estimates for the desert sucker, *Pantosteus clarki*, were not significantly different between the two methods. In all other cases, estimated velocities and depths based on electrofishing were greater; substrate indexes were smaller. By comparison, estimated habitat of the five transects that were electrofished within the upstream observational reach (Table 1, data set B) were more in agreement with habitat estimated by observation. Nevertheless, values were significantly different in half of the comparisons of the three habitat factors. All estimated velocities and three of five depth estimates, were significantly different; however, substrate indexes were not statistically different. Similar analyses of data collected in spring and summer 1984 in two larger, more uniform riffles in Aravaipa Creek again indicated generally significant differences in habitat factors as defined by the two locational methods (Tables 2, 3).

DISCUSSION

Fishes are variously mobile, and it is unrealistic to assume that the point location where a fish is electronarcotized or observed is always its ultimate or preferred habitat in terms of velocity, depth, and substrate. Granted, through replication of point data for a species, a preferred or typical habitat, theoretically, can be delineated. The meter transect approach utilized in this study attempted to sample and characterize a small (1-2 m^2) area of stream wherein an individual captured fish presumably lived and moved. Comparison of multiple transects within a 1-m^2 sample area suggested that a single transect is accurately describing the habitat within that area.

Sample size (21) produced by the transect method appears to be adequate for defining variation in depth data. Greater variation in velocity readings suggested an average of 27 velocity data points in the 1-m^2 area were necessary to attain a ± 10% confidence level. The direct-reading current meter employed in this work was very sensitive and therefore fluctuated widely in response to non-laminar flow. Often, velocity values recorded in highly turbulent water were an estimated midpoint of fluctuations of the current meter indicator dial. Variation in the 21 velocity estimates along a meter transect rendered differences between the transect mean and a single velocity measurement statistically insignificant. Most likely, a single measurement of velocity is much less reliable than 21, but both may possibly be inadequate estimates of velocity occupied by a small fish (<100 mm) because of both the dynamic, turbulent flow that often occurs in streams and the response of a fish to these changes.

The better method of determining fish location--electrofishing or observation--was not unequivocably established. Initial observational data (Table 1, 2A) suggested stream margin areas with lower velocity and less depth, were more commonly occupied by fishes in Aravaipa Creek. Electrofishing immobilized fish in the narrow, 2 m wide riffle that was deeper and swifter in the center. If specimens had not been previously observed in the margins of the stream, they would have been assumed to be occupying the deeper, swifter area in which they were captured in the block net and where habitat was subsequently measured. Although substrate was not significantly different between marginal and midstream transect measurements, mean depth and velocity were consistently (and frequently significantly) greater in midstream. Similar comparisons of observation versus electrofishing in spring and summer 1984 made in broader (4-5 m), relatively uniform riffles were again significantly different in 7 of 9 cases (Tables 2, 3). These data suggest method of location may be influencing the description of physical habitat of these fishes. The mechanism for this is not offered at this time.

Based on comparisons of depth estimates produced by the two methods of physical habitat evaluation, and agreement of a single point depth versus the transect mean depth, a single depth measurement at first would appear to be adequate to define a fish's preference for depth. However, sample size needed (14 data points) in the transect method to achieve a precision of ±10% of the mean suggested that a single measurement is unlikely to give a reliable estimate of depth. Mean transect velocity was not significantly different from point velocity because of the great variation in this statistic. Based on underwater observations of fish behavior, a single measurement is unlikely to give a reliable estimate of a fish's preferred or optimum velocity. For statistical comparison, multiple estimates of depth and velocity in a given area of fish capture or encompassing a point marked by observation provide a larger sample size and presumably greater reliability. Personal preference, manpower and funding will dictate whether the point or transect method or electrofishing versus underwater observation will be utilized.

The data do not unequivocably suggest one method to be superior to the other; however, for reasons discussed below, I suggest that capture by electrofishing and habitat description by the transect approach are more reliable, both biologically and statistically. Estimates of substrate composition by the point and transect methods were in harmony only half the time. Of those cases (37%) wherein the secondary type of method was the primary of the other, the two were frequently reversed apparently because of too few (3 versus 21) data points and the qualitative, subjective nature of the point approach. Further, the transect method removes subjectivity of classification by producing data on percentages of substrate types and an index (mean of substrate types) of the area.

Capture by electrofishing has advantages. Electrofishing a small (1-m^2) area of stream has a greater potential to obtain data on more than one species of fish and, in addition, data on a number of individuals of each species than does underwater observation. Capture also gives opportunity to obtain size, sex, and perhaps species (in case of fry) data that, although possibly obtainable by observation, are certainly less reliable. Sampling a small area of stream is especially desirable if a schooling species is encountered. Further, if fish populations are high and one's objective is to get point locational data, selection of an individual point becomes arbitrary at best. Another advantage of electrofishing is the ability to obtain fish location data in turbid water--an impossible or certainly less reliable task using observation (Northcote and Wilke 1963). Also, capturing many individuals of a species in a small microhabitat gives more reliability to that area being defined as optimum habitat. In addition, the random uniform sampling approach provides presence-absence habitat data for comparison; the point method does not.

Further examination of the influence of electrofishing on fish location in different habitat types (pools and riffles) as opposed to location by observation is needed. Species specific behavior response to the two locational methods, and general habitat type (i.e., upper elevation, clear montane versus low elevation, turbid streams) have to be considered before selecting either method. Turner and Tafonelli (1983) suggested that the fishes in Aravaipa Creek may respond differently to electrofishing. Based on underwater and general observations in this stream, I agree with their conclusions as to the efficiency of collecting the respective species by electrofishing. Others (Goldstein 1978; Orth et al. 1981; Fred Everest, pers. comm.) have demonstrated that approach and gear can affect fish population and habitat estimates. Indeed, fish location techniques may induce as much or more error into estimates of habitat use than do the differences in habitat evaluation methodologies.

LITERATURE CITED

Armantrout, N. B. (ed.). 1981. Acquisition and utilization of aquatic habitat inventory information. Amer. Fish. Soc., Bethesda, MD. 376 pp.

Goldstein, R. M. 1978. Quantitative comparison of seining and underwater observation for stream fishery surveys. Prog. Fish Cult. 40(3):108-111.

Medina, A. L. 1984. A profile meter for obtaining surface relief and substrate measurements in streams. USDA For. Serv. Res. Note RM-437, 5 pp. Rocky Mtn. For. and Range Exp. Stn., Fort Collins, CO.

Minckley, W. L. 1973. Fishes of Arizona. Ariz. Game and Fish Dept., Phoenix, AZ.

Northcote, T. C. and D. W. Wilke. 1963. Underwater census of stream fish population. Trans. Amer. Fish. Soc. 92(2):146-151.

Orth, D. J. et al. 1981. Considerations in the development of curves for habitat suitability criteria. pp. 124-133. In N. B. Armantrout (ed.) Proceedings of Acquisition and Utilization of Aquatic Habitat Inventory Information.

Shirvell, C. S. and R. G. Dungey. 1983. Microhabitats chosen by brown trout for feeding and spawning in rivers. Trans. Amer. Fish. Soc. 112(3):355-367.

Turner, P. R. and R. J. Tafonelli. 1983. Evaluation of the instream flow requirements of the native fishes of Aravaipa Creek, Arizona, by incremental methodology. Report to U.S. Fish and Wildlife Service, Albuquerque, N. Mex. 118 pp.

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Most lack of relationship to SC can be found under "Limitations & Constraints" section.

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PART II: METHODOLOGY SUMMARY FORMS

The Methodology Summary Forms that follow represent an attempt to encapsulate many of the methods that are and could be used to establish appropriate instream flows. They are all limited to 1 page in length, and have the following headings:

Methodology: The name of the author, the species, the formal name of the method, and any other name by which it is known.

Type of Method: Either **empirical** or **conceptual**, depending on whether the model was derived by fitting a regression (or some other fitting technique) to data to determine the form of the model, or alternatively, forming the model conceptually; **biologically weighted** or not depending on whether the raw data were transformed to some measure of biological suitability prior to incorporation in the model; **basin variables** are those specific to the basin in which the stream lies, such as drainage area, rather than to the stream itself; **discharge variables** are various measures of the amount of flow; **hydraulic variables** are the variables normally present or derived in hydraulic simulation models and include such things as depth, velocity, and wetted perimeter; **structural variables** are those that are important biologically because of their size or placement, such as % undercut banks; **biological variables**, of which there are very few, are things such as number of fish species in the drainage; and **other physical/chemical variables** are factors like pH, temperature, and annual rainfall. A complete list is found in Chapter 2.

Equation: Most of the methods can be reduced to an equation and this is presented along with a list of the variables in the equation.

Correlation Coefficient: The empirical models invariably have a correlation coefficient associated with them as a byproduct of their construction. Many of the other methods have been tested, and if they predict a measurable variable, the correlation between the value of the measured variable and the predicted value is shown. If they predict an index, any correlation between the index and a measurable value, presumably related to the index is shown. In most cases, the coefficient of determination (the correlation coefficient squared) is shown, since it is numerically equivalent to the percent of the variability in the modelled quantity explained by the model. For one-variable models, r or r^2 is used. For multivariate models, R or R^2 is used.

Source Documentation: The most recent or complete document describing the model is cited.

Objective: The intent of the authors of the method (to the extent it is apparent) is summarized.

Level of Effort: The amount of effort that must be expended to use the method (low, moderate or high), with a brief description of why.

Model Development: A summary of the reasoning and strategy used by the authors to create the model.

Basic Assumptions: If there are some otherwise unobvious assumptions incorporated into the model, they are reported under this heading. In most cases, the assumptions are evident and are briefly restated.

Limitations and Constraints: Deficiencies are noted here.

Relationship to Other Methods: A few of the most closely related methods are cited under this heading.

Quality of the Documentation: This heading provided us the opportunity to comment (usually obliquely) on whether it was worth the trouble to look up the source document, and also generally to point out the kinds of things it would be useful to have in model documentation.

Experimental Tests of the Methods: If we found any papers that attempted to test or validate the method, they are cited here, sometimes along with the results of the test if it could be summarized.

Published Enhancements to the Method: When we began, we thought that many of the methods might have been improved by subsequent authors, and we would cite them here. Usually, such was not the case.

Critical Review of the Method: We usually only cited papers under this heading if they involved a specific and fairly intensive critical review, not simply mentioned the method in passing.

Published Comparisons With Other Methods: This heading is reserved for papers which applied the method along with others to the same stream, to find out how the results compared.

Critical Opinion: This is our opinion of the utility and general quality of the model.

The order of the Methodology Summary Forms that follow is by author's name to facilitate location. Most of the methods presented have variables that are directly or indirectly related to discharge, so that the model could be used as an instream flow model. A few, however, do not, and are incorporated because either they are part of a series, most of the others of which do have flow terms, or because they are predictive of standing crop, even though they contain no flow terms.

CHAPTER 8: CONCLUSIONS

The earliest and simplest instream flow methods are based on the premise that below identifiable flow thresholds, physical habitat becomes limiting to fish and other stream and riparian biota. These methods characteristically use physical features of the drainage basin or some measure of historical unregulated flow to establish the threshold, and usually carry the recommendation that flows be maintained above the threshold.

More recently, focus has shifted to the physical and hydraulic characteristics of the affected stream reach, and the idea of an instream flow threshold has been replaced with the idea of a continuous functional relationship between flow and habitat quality--with the implication that unless there is some other limiting factor such as food availability, fish and other biota rotenone ① ex. are continuously limited by physical habitat. In the most widely used of these methods, fish habitat has been characterized by a small subset of the habitat features known to influence fish ? population size. Other models exist which are intended to include all of the habitat features thought to influence the wellbeing of fish, but little effort has been made to establish functional relationships between the output of these models (which in some cases is standing crop) and flow.

It is obvious that physical habitat can be limiting to fish populations, and that most, if not all, of the commonly used variables can contribute to that limitation. As flows decrease, in the absence of pools the water will at some point become too shallow for fish; as flows increase, velocities in parts of the water column may become too high for fish. Availability of spawning gravel of the correct size can limit reproduction; cover in many forms certainly influences the way fish distribute themselves in streams; temperature is definitely limiting at upper and lower critical levels. These and other physical variables are influenced by flow, so that it is feasible to combine them in some way and display the result as a function of flow, as most of the newer instream flow methods do. Such a plot illustrates the incremental effects on habitat of altering instream flow, and carries with it the implication that as habitat quality increases, carrying capacity will also increase, and ideally, so will the biological populations occupying the habitat. The question of appropriate flows then becomes one of how much, if any, decrease in habitat from the maximum, or historical obtainable is acceptable.

Are the functional relationships between habitat quality and instream flow that are the output of current models accurate depictions of reality? Is it true that carrying capacity and populations will decrease if the habitat described by these models is reduced from maximum, or from the existing levels? The only published test of the effects of diminishing flow and habitat in experimental channels (Rimmer 1985) does not support that contention, and the little evidence that does comes mostly from descriptive correlations between habitat and standing crop in unregulated streams, rather than in regulated or diverted ones. For example, the adult Weighted Usable Area index calculated by the FWS PHABSIM model at yearly low natural stream flows has been shown to be significantly correlated with brown trout biomass in several studies, but no form of this index has produced convincing correlations for other salmonids, or any other fish species except adult rock bass, and the correlations are not always significant for brown trout. Nor has the index been tested for its predictiveness. There has been only one model that has been shown to predict standing crop of trout (Binns and Eiserman 1979). All of the many FWS fish habitat suitability index methods that have been tested have produced either very poor, or unconvincing, correlations with standing crop.

channels were poor analogs.

If the state of the art is to be advanced and the legitimacy of this type of modeling established, there is a major need for studies that specifically examine the effects of stream regulation and diversion, and for modeling efforts that go through the proper cycle of development, experimental testing, and revision until the resulting models are both descriptive and predictive.

To be predictive, the models must use measurable response variables. It would be very useful to future modeling efforts if enough were known about how physical factors influence fish populations to permit the construction of mechanistic models. The extremely poor predictiveness of the moderately mechanistic FWS HSI models, however, is not encouraging. It is more likely that successful models will be based on descriptive field observations, such as the behavioral ones used in the IFIM models, and on regression and other statistical techniques using field data.

CHAPTER 9: RECOMMENDATIONS FOR FUTURE RESEARCH

Future research into instream flow methods and into the question of appropriate instream flows, falls naturally into five areas:

1. Research intended to improve and refine existing methods
2. Research designed to test the validity of existing methods
3. Research intended to develop and test the validity of new methods
4. Research to evaluate the effects of flow alteration directly
5. Research into techniques for maintaining or improving biological productivity and integrity concomitant with flow diversion and regulation

The purpose of this chapter is to characterize each of these areas and to suggest lines of inquiry within each area that are needed and would be productive. All five areas are important and we feel that none should be neglected in future research activity.

RESEARCH INTENDED TO IMPROVE AND REFINE EXISTING METHODS

All of the existing instream flow and habitat quality methods presently in use have clear limitations and would benefit from refinement. Since these methods will continue to be the basis for instream flow requirements in hydroelectric project licenses until better methods are developed, it is important to identify and document the shortcomings and to develop refinements that decrease the chances of misapplication and increase confidence and usefulness. These refinements are not necessarily the best long-term solutions, but could be quite valuable in the short term.

a. **Development and Documentation of Techniques for Determining the Flows that Result in Maintenance of All or Some Percentage of Historic Habitat Rather Than the Maximization of Potential Habitat** Most current interpretation of PHABSIM output is based, unrealistically, on curves of habitat versus discharge, without consideration of the amount and timing of habitat availability in the unregulated stream. The availability of well documented techniques to put instream flow recommendations into historical perspective would encourage users to develop this perspective and increase the appropriateness of recommendations.

b. **Examination of the Amount and Causes of Site-Specific Variability in Suitability Index Curves** There is a large amount of data just becoming available that shows significant differences in the shape and position of SI curves for the same species. Preliminary evidence implicates body size differences and presence of other species most strongly. Other candidate variables include the possibility that velocity and depth preference change with discharge, and that velocity preference is related more to relative velocity than to absolute velocity. This project would collect curves from as many sources as possible to establish the range of existing SI curves. The sources should include the FWS Instream Flow Group, which is presently serving as a repository for SI curves, and other agencies and utilities that have developed their own curves. The product of this first phase would be a collection of species curves collected to date and providing an indication of within- and between-species variation. A second phase of the research should be the experimental determination of the sources of the variation in curve shape for a few selected species. This second phase would rule out experimental bias or differences in technical approach among sources of the SI curves as the cause of

no such thing

Really very few available.

differences in shape, and would provide a basis for curve selection in any given instance.

c. **Research and Development into the Need and Potential for Producing SI Curves that Reflect Preference from Data on Habitat Utilization** There is a current vogue for "correcting" utilization curves for preference, but the results of such corrections are frequently non-intuitive and in some cases quite unrealistic. It is not clear that such corrections are either desirable or feasible, and it would be valuable to explore the topic thoroughly. One approach might be to use available techniques to make the corrections and then experimentally alter the habitat to see if utilization follows predicted preference.

d. **Research into the Use of Bivariate and Multivariate Suitability Indices** Initial steps have been taken in the direction of developing bivariate suitability indices for the HABTAT model, but FWS has stopped supporting such studies. Since the biological responses to variables such as depth and velocity are not likely to be independent, there is reason to continue work to determine if bivariate and multivariate input variables would improve model performance.

e. **Examination of Site-Specific Variation in the Relationships Between Absolute Weighted Usable Area and Characteristic Standing Crop in Unregulated Streams** Instream flow decisions are often based on relative WUA, choosing the maximum WUA possible or some percentage of it. The possibility exists that maximum natural fish populations are characteristically obtained in unregulated streams with values of absolute WUA much less than the maximum possible. This situation would occur if, as WUA increased, habitat no longer was limiting and some other variable, such as food availability, became limiting. If this were the case, specific levels of absolute WUA could become instream flow criteria, and would result in lower recommended flows than those based on maximum relative WUA. This possibility could be

— also could result in rec. higher flows?

explored by compiling and analyzing data on absolute WUA and fish population size from existing instream flow studies.

f. **Development and Documentation of Techniques for Using the HABTAT Model in Situations Where the Hydraulic Simulation Models Do Not Work** There are many instances in current IFIM applications in which habitats which do not model well hydraulically are ignored. These habitats include cascades and rocky runs, and sometimes constitute much of the habitat in a stream. Furthermore, these habitat types may have very different relationships to flow from the more easily modeled habitats. There have been some direct applications of the HABTAT model to measured hydraulic data, but none that compare them with the results from the same stream using hydraulic simulation, or which evaluate the consequences to the overall recommendation of failing to include portions of a stream which do not model well.

g. **Characterization of Regional Differences in Discharge and Basin Characteristics** Tennant's suggestion (1975) that minimum flows equivalent to thirty percent of the average annual flow, and Larsen's policy (1980) of linking minimum flows to the drainage basin area are examples of instream flow policy based on regional stream flow characteristics. Application of these criteria outside of their location of origin are likely to be inappropriate, but there are no studies showing the ways in which criteria of this sort should change from region to region. This research would compile basin size, flow duration, and other information from streams throughout the United States and illustrate the regional variations that result from applying various types of minimum flow logic. The product would be a translation of a number of simple instream flow criteria from their regions of origin to the rest of the United States. It would serve as a benchmark to evaluate the reasonableness of local recommendations.

RESEARCH TO TEST THE VALIDITY OF EXISTING METHODS

Instream flow methods are intended either to be used directly to recommend flows that will protect the environment or to produce a functional relationship between some aspect of environmental quality and flow. In most cases, the methods have been developed conceptually and the accuracy of the methods in achieving their desired result has not been adequately tested. The research suggested here is intended to address some of the most important questions of model validity. These fall into two categories: internal validity of models--the correctness of underlying assumptions; and external validity--the accuracy with which model response variables correspond to or predict environmental responses.

a. **Research to Establish Criteria for Instream Flow Model Performance** One of the principal difficulties facing critics of existing models is the absence of accepted criteria for model performance. Instream flow and habitat quality models have proliferated and have been applied with little evidence of their accuracy or regional applicability. This project would develop a set of standards against which models should be tested before being applied in regulatory decision making. The purpose of the research would be to define criteria intended to induce model developers and users to go through the proper stages of testing and validation prior to implementation.

b. **Examination of the Assumption Underlying the PHABSIM Model that Large Amounts of Marginal Habitat are Biologically Equivalent to Small Amounts of Excellent Habitat When Depth, Velocity, and Substrate Type are the Variables** This study addresses the central dogma underlying the Weighted Usable Area concept. It could be approached either by identifying naturally occurring examples of both types of habitat and measuring standing crop, or by setting up experimental areas approaching the extremes of the two habitat types and measuring carrying capacity or production relative to surface area. If this concept is invalid, the HABTAT model is also inherently invalid, yet the concept has not been tested directly.

c **Research to Determine if Biological Responses to Flow Alteration Reflect Changes in Habitat Described by Instream Flow Models** Most studies testing the validity of instream flow methods have been done primarily on streams with natural unregulated flows. The important question, however, is whether the impacts of diversions and regulations associated with hydroelectric projects are adequately predicted using instream flow models. Such research requires direct measurement of the biological entity of interest (standing crop, riparian strip width, etc.) and the output of an instream flow model. There are three types of experimental protocol: studies of similar parallel streams, one of which is diverted or regulated; studies using a diverted stream as its own temporal control--measuring differences in biological response and model response before and after changes; and studies using a stream as its own spatial control, measuring biological and model responses above and below impoundments and diversions.

Nehring's
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D-J type?

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extensive →

d. **Research to Determine Which Correlations Are Appropriate Between Model Output and Biological Response in Regulated or Diverted Streams** This is an alternative approach to the previous protocol, and differs from it by not using controls. It is the general approach used in most published validation studies, and consists of collection of both standing crop information and habitat quality information at a series of locations. But rather than using instantaneous habitat values, other measures of habitat values would be explored. An example of this approach is the work of Loar et al. (1985), in which the minimum annual value of WUA was more strongly correlated with fish standing crop than the instantaneous WUA measured at the time fish were sampled. More exploratory work in this direction should include other habitat statistics (such as maximum annual WUA, mean annual WUA) as well as retrospective generation of habitat response variables into the past to look for some means of integrating the biological effects of temporal variation in model response variables. This sort of study is best done on data from a specific region, and could be carried out independently on existing data from several different areas of the United States.

RESEARCH TO DEVELOP NEW INSTREAM FLOW METHODOLOGIES

The goal of instream flow methods should be the ability to predict the effects of a particular stream flow regime on biological response. The existing methods are all deficient in this respect. The PHABSIM models include too few variables to be predictive (although changes in WUA may, in fact, result in changes in standing crop). The most predictive model (Binns and Eiserman 1979) is completely descriptive and empirically derived, but is non-mechanistic and therefore non-transferable geographically. The FWS HSI models are completely mechanistic, but their output is not correlated with standing crop. In none of these models has the development proceeded through the logical cycle of developing mechanistic hypotheses, constructing a mathematical model based on the hypotheses, testing the model with field data, then going back and refining the mechanistic hypotheses to begin another cycle. This section suggests several approaches to instream flow model construction, each of which is likely to improve model performance over existing levels.

mechanistic vs biological

a. **Research to Make Maximum Use of Modeling Techniques Used in Other Branches of Ecology** Most instream flow modeling is restricted to concepts that have evolved in fisheries biology, and there has been only the beginning of an effort to include modeling techniques such as discriminant, principal component, and cluster analysis. There has also been no incorporation of concepts such as habitat structural complexity, which has proved useful in avian ecological modeling, or of concepts such as species diversity and richness. This project would identify the entire range of techniques that have been successful or useful in other ecological arenas, and would develop suggestions for the application of the most promising ones.

b. **Development of New Regression Models Using a Combination of FWS, HSI< and Binns and Eiserman's Approach** This effort could be done independently in several different regional locations and would consist of attempting to duplicate the success of Binns and Eiserman's (1979) regression model, using site-specific suitability index transformations and other more sophisticated ? techniques. These might include the use of the response variables of established techniques such as WUA, Wesche WCR, and other habitat quality indices. When habitat quality indices such as these have failed to be descriptive of standing crop, the lack of strong correlation may be due, not to anything wrong with the index, but to the presence of other variables that also influence standing crop. The overall goal is to develop models that are predictive of standing crop and to put instream flow and physical habitat into the proper perspective along with temperature, water quality, trophic structure, and other biologically important variables.

c. **Determination of Limiting Factors for Use in Mechanistic Models** It is quite clear from the literature that many more environmental variables can be limiting to fish populations than are accounted for in most instream flow models, and that many of them are not strongly related to flow. If variables other than flow-related ones are limiting, alterations of flow will have no effect on standing crop. It is important to instream flow modeling, therefore, to determine under what conditions flow-related variables are limiting. Put another way, it is likely that over a wide range of depth and velocity, something else, such as food availability or cover, is limiting, and these may be essentially unrelated to flow. The purpose of this research is to determine at what flows flow-related variables become limiting. Various techniques are possible. If an experimental situation can be found where fish have the ability to emigrate if conditions become unacceptable, then behavioral responses may be effective indices of habitat quality. Another approach may be to examine population density in various equal-flow reaches of a structurally inhomogeneous stream.

DIRECT EVALUATION OF FLOW ALTERATION

The central question in instream flow studies is whether flow regulation or reduction have any effect on stream and riparian biota. This line of research is intended to document the effects of hydroelectric water use directly.

Documentation of the Effects of Existing Diversions The best way to document the effects of diversions, flow regulation, or pulsatile flows is to determine if adverse effects have occurred on existing projects. The most effective study would survey populations of interest in large numbers of affected stream reaches and compare them with suitable controls. Five classes of controls exist: above diversions on the same stream, prior to diversions on the same stream, prior to changes in the amount of diversion in the same reach; matched unregulated streams; and expectations based on regional surveys. The suitability of each type of control is probably site-specific. This research would be very valuable not only in answering the question of whether adverse effects occur, but in providing evidence of the magnitude of the effect.

Experimental Manipulation of Existing Diversions An alternative approach is a long-term study in which streams are held at various levels of diversion or exposed to various periods and types of flow fluctuation for several generations of the target organism. This approach allows each study reach to serve as its own control. While this seems to be the most straightforward approach, the potential for uncontrollable stream alterations resulting from year-to-year climatic variability are substantial.

RESEARCH TO IDENTIFY MITIGATIONS

Assuming that diversions, regulation, or pulsatile flows do cause adverse effects, is it possible that there are mitigations that can completely offset them? This line of research is intended to identify potential mitigations and test them.

Research to Evaluate Effects of Habitat Manipulation on Instream Flow Model Output Improvement of physical and hydraulic microhabitat may be the least expensive and most effective way to offset habitat degradation from fluctuating and diverted flows, and it may allow much larger diversions and fluctuations than would otherwise to acceptable. Much work has been done in this field in the last five years, but there are no current synopses or critical reviews to guide users that may want to pursue stream habitat modification as an option. In evaluating the potential effects of stream improvements or possible instream flow requirements, it would be useful to have descriptions of the general effects on instream flow models that can be anticipated from various types of habitat improvements, and none presently exist. This research should begin with a review of the literature on the effects of natural structural microhabitat features and the associated hydraulic characteristics on stream fish and benthos populations, and include reviews both of observations in natural streams and of the theoretical basis for these effects based on the literature on experimental (laboratory-type) manipulation of habitat structure and hydraulics. The analysis should be accompanied by modeling of the effects on habitat (as measured by standard instream flow modifications).

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Now done!

Direct Manipulation of Habitat and Observation of Effects

Streams with populations evidently degraded by decreased flows should be subjected to experimental habitat manipulation to attempt to bring populations back up to target levels. A variety of techniques should be used to determine the best and most cost-effective methods. The techniques would include modifying pool/riffle ratios, increasing or decreasing cover, increasing structural complexity, and influencing autochthonous food production or allochthonous food input.

LIST OF REFERENCES USED IN EVALUATING INSTREAM FLOW METHODOLOGIES IN THE UNITED STATES

Aceituno, M.E., G.E. Smith, G. Ging, and D.M. Ward. 1985. Habitat Preference Criteria for Eastern Sierra Nevada Streams: Family Salmonidae. US Dep. Interior, Bureau of Land Management, Sacramento, CA.

Adams, J.N. and R.L. Beschta. 1980. Gravel bed composition in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 37:1514-1521.

> Measured temporal and spatial variability in gravel composition and examined factors affecting the amount and distribution of fine sediments; examined relationships to in-channel, watershed land-use, and watershed geomorphology variables.

Ahlgren, C.E., and H.L. Hansen. 1957. Some effects of temporary flooding on coniferous trees. Jour. For. 55:647-650.

Alexander, G.R. and E.A. Hansen. 1983. Sand sediment in a Michigan trout stream. Part II: effects of reducing sand bedload on a trout population. N. Am. J. Fish. Mgmt. 3:365-372.

> Reports population increases of brown and ainbow trout after reduction of sand bedload. Showed improved survival but not improved growth of young trout.

Allen, K.R. 1969. Limitations on production in salmonid populations in streams. IN Symp. on Salmon and Trout in Streams (T.G. Northcote, ed.) pp. 3-18. H. R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver.

> Reviews factors and mechanisms; found density and physical environmental conditions controlling.

Allen, J.D. 1981. Determinants of diet of brook trout (S. fontinalis) in a mountain stream. Can. J. Fish. Aq. Sci. 38:184-192.

> Studies feeding rates, time of day, and prey choice over summer; found abundance and size of prey primary determinants, modified by individual specialization.

Allendorf, F.W. and S.R. Phelps. 1980. Loss of genetic variation in a hatchery stock of cutthroat trout. Trans. Am. Fish. Soc. 109:537-543.

Alley, D. W., Jr. and H.W. Li. Unpublished. Microhabitat segregation and seasonal movements by fishes in a Sierra foothill stream. Unpublished ms. (1979). Univ. Calif., Davis. 41 pp.

> Examines physical and biological factors affecting spatial

distribution of seven native species in normal and drought years; describes diel and seasonal patterns of use; notes apparent lack of interspecies competition for space.

Andrews, W.H. and G.E. Madsen. 1976. Assessment of recreation and aesthetic instream flow methodologies. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. I, pp. 364-378. Am. Fish. Soc., Bethesda, MD.

Andrews, W.H., M.B. Masteller, D.E. Massey, R.J. Biurdge, and G.E. Madsen. 1976. Measuring the impact of changing streamflow on recreation activity. IN Methodol. for the Determ. of Stream Resource Flow Requirements: An Assessment (C.B. Stalnaker and J.L. Arnette, eds.), pp.148-166. Rep. FWS/OBS-76/03. Ogden, UT.

Annear, T.C. and A.C. Conder. 0. Relative bias of several fisheries instream flow methods. N. Am. J. Fish. Management (in press).

Applied Research and Analysis, Inc. (ARA). 1982. User's Guide for the Interactive USAE/LMVD Habitat Evaluation Computer Software System. Prepared for US Army Corps of Engineers, Lower Mississippi Valley Division, Vicksburg, MI.

Armantrout, N.B. (ed.). 1981. Proc. Symp. Acquisition and Utilization of Aquatic Habitat Inventory Information. American Fisheries Society, Bethesda, MD.

Armour, C.L., R.J. Fisher, and J.W. Terrell. 1984. Comparison of the Use of the Habitat Evaluation Procedures (HEP) and the Instream Flow Incremental Methodology (IFIM) in Aquatic Analyses. Rep.FWS/OBS-84/11. U.S. Fish Wildl. Serv. 30 pp.

Bachman, R.A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Trans. Am. Fish. Soc. 113:1-32.

Observed undisturbed wild fish for three years; described foraging, home ranges, social hierarchy, use of cover, growth patterns; compares energy efficiency of wild and introduced hatchery fish and postulates a mechanism for lower survival of hatchery fish.

Bain, M.B., J.T. Finn, L.J. Gerardi, Jr., M.R. Ross, and W.P. Saunders, Jr. 1982. An evaluation of methodologies for assessing the effects of flow fluctuations on stream fish. Final Tech. Report DOE/001-FWS-20733-1. U.S. Dep. Interior, Fish Wildl. Serv.

Bain, M.B. and J.T. Finn. Unpublished. Fish community structure in rivers with natural and modified daily flow regimes. Unpub. ms., Dep. Forestry Wildl. Mgmt., Univ. Mass., Amherst.

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

Location and orientation observed for varied water depth and velocity. Relates resting microhabitat preference to velocity, turbulence, light, depth, spatial limits, cover.

Baldridge, J.E. and D. Amos. 1981. A technique for determining fish habitat suitability criteria: a comparison between habitat utilization and availability. IN Proc. Symp. Acquisition and Utilization of Aquatic Habitat Inventory Information (N.B. Armantrout, ed.), pp. 251-258. American Fisheries Society, Bethesda, MD.

Bartschi, D.K. 1976. A habitat-discharge method of determining instream flows for aquatic habitat. In Proc. Symp. and Specialty Conf. on Instream Flow needs (J.F. Orsborn and C. H. Allman, eds.), Vol. II, sp. 285-294. Am. Fish. Soc., Bethesda, MD.

Bayha, K.D. 1976. Instream flows--the big picture. IN Proc. Symp and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. 1, pp. 95-131. Am. Fish. Soc., Bethesda, MD.

Bayha, K.D. 1978. Instream Flow Methodologies for Regional and National Assessments: A State-of-the-Art Review. Rep. FWS/OBS-78/61. U.S. Dep. Interior, Cooperative Instream Flow Service Group, Ft. Collins, CO.

Bayha, K.D. 1980. Instream Flow Studies and the Instream Flow Incremental Methodology in Water Resources Planning. Instream Flow Information Paper 13. USDI Fish. Wildl. Serv.,Instream Flow Group, Fort Collins, CO. 44 pp. + attachment.

Becker, C.D., D.A. Neitzel, and D.H. Fickeisen. 1982. Effects of dewatering on chinook salmon redds: tolerance of four developmental phases to daily dewaterings. Trans. Am. Fish. Soc. 111:624-637.

Examines survival and growth of four early stages with daily 1- to 22-hour dewaterings. Insolation and air temperature affected results in early fall.

Becker, C.D., D.A. Neitzel, and C.S. Abernethy. 1983. Effects of dewatering on chinook salmon redds: tolerance of four development phases to one-time dewatering. N. Am. J. Fish. Mgmt. 3:373-382.

Compares tolerances of four intergravel stages (cleavage egg to pre-emergent alevin) to one-time dewaterings of up to 12 days. Differences in hardihood are related to morphology.

Beland, K.F., R.M. Jordan, and A.L. Meister. 1982. Water depth and velocity preferences of spawning Atlantic salmon in Maine rivers. N. Am. J. Fish. Mgmt. 2:11-13.

Measured water depth and velocity (and temperature and day length) at active redds in four rivers; compares results with data from other studies.

Beschta, R.L., M.A. Shirazi, and W.K. Seim. 1982. Comment, reply on 'Stream system evaluation with emphasis on spawning habitat for sallmonids.' Water Resour. Res. 18(4):1292-1295.

Beyerle, G.B. and E.L. Cooper. 1960. Growth of brown trout in selected Pennsylvania streams. Trans. Am. Fish. Soc. 89:255-262

Bickerstaff, W.B., C.D. Ziebell, and W.J. Matter. 1984. Vulnerability of redbelly tilapian fry to bluegill predation with changes in cover availability. N. Am. J. Fish. Mgmt. 4:120-125.

Predation measured in pools at three levels of artificial plant cover and two predator densities. Describes predator-prey behavior patterns and evaluates effect of parental protection. Discusses implications for use of tilapia to control aquatic plants.

Bietz, B., J. Martin, K. Schiefer, and P. Campbell. 1985. Instream Flow Needs for Fish below Hydropower Facilities in Canada: A Management Guide to Assessment Methods. Prepared for Canadian Energy Assoc. by IEC Beak Consultants, Mississisauga, Ont.

Binns, N.A. 1979. A Habitat Quality Index for Wyoming Trout Streams. Monogr. Ser. 2. Wyoming Game Fish Dep., Cheyenne.

Binns, N.A. 1982. Habitat Quality Index Procedures Manual. Wyoming Game and Fish Department, Cheyenne.

Describes techniques of measuring, describing, and rating trout stream habitat, from planning through calculation. Instructions augmented with line drawings and photographs.

Binns, N.A. and F.M. Eiserman. 1979a. Evaluation of fluvial trout habitat in Rocky Mountain streams. IN Proc. Symp. on Mitigation, pp. 361-364. (Ft. Collins, CO, 16-20 July 1979).

Reviews models relating Habitat Quality Index attributes of streams with trout standing crop. Includes cases of prediction or documentation of impacts from water resource projects or management techniques.

Binns, N.A. and F.M. Eiserman. 1979b. Quantification of fluvial trout habitat in Wyoming. Trans. Am. Fish. Soc. 108:215-228.

Describes development and testing of Habitat Quality Index method of quantifying trout habitat. Physical, chemical, and biological habitat attributes were tested for their ability to predict standing crop.

Bisson, P.A. J.L. Nielsen, R.A. Palmason, and L.E. Grove. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low streamflow. IN Proc. Symp. Acquisition and Utilization of Aquatic Habitat Inventory Information (N.B. Armantrout, ed.), pp. 62-72. American Fisheries Society, Bethesda, MD.

Bjornn, T.C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, stream flow, cover, and population density. Trans. Am. Fish. Soc. 100:423-438.

Boreman, J. 1974. Effects of stream improvement on juvenile rainbow trout in Cayuga Inlet, New York. Trans. Am. Fish. Soc. 103:637-641.

Botsford, L.W., R. McKelvey, and D. Hankin. 1981. Comment, reply on 'Cycles in the northern California Dungeness crab population'. Can. J. Fish. Aquat. Sci. 38:1295-1297.

Boussu, M. F. 1954. Relationship between trout populations and cover on a small stream. J. Wildlife Mgt. 18:229-239.

Bovee, K.D. 1978. Probability-of-Use Criteria for the Family Salmonidae. Rep. FWS/OBS-78/07. U.S. Dep. Interior, Cooperative Instream Flow Service Group, Ft. Collins, CO. 88 pages.

Bovee, K.D. 1982. A Guide to Stream Habitat Analysis Using the Instream Flow Incremental Methodology. Instream Flow Information Paper 12. FWS/OBS-82/86. U.S. Dep. Interior, Cooperative Instream Flow Service Group, Ft. Collins, CO.

Bovee, K.D. and T. Cochnauer. 1977. Development and Evaluation of Weighted Criteria, Probability-of-use Curves for Instream Flow Assessments: Fisheries. Rep. FWS/OBS-77/63. U.S. Dep. Interior, Cooperative Instream Flow Service Group, Ft. Collins, CO. 49 pp.

Bovee, K.D., J. Gore, and A. Silverman. 1978. Field Testing and Adaptation of a Methodology to Measure "In-Stream" Values in the Tongue River, Northern Great Plains Region: Executive Summary. Prepared for U.S. Environmental Protection Agency, Rocky Mountain - Prairie Region.

Bovee, K.D. and R.T. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper 5. FWS/OBS-78/33. U.S. Dep. Interior, Cooperative Instream Flow Service Group, Ft. Collins, Co.

Brasch, J., J. McFadden, and S. Kmiotek. 1973. Brook Trout: Life History, Ecology, and Management. Publ. 226. Wisc. Dep. Nat. Resources, Madison.

Brink, V.C. 1954. Survival of plants under flood in the lower Fraser River Valley, B.C. Ecology 35:94-95.

Broadfoot, W.M. 1967. Shallow-water impoundment increases soil moisture and growth of hardwoods. Proc. Soil Sci. Soc. Am. 31:562-564.

Broadfoot, W.M. and H.L. Williston. 1973. Flooding effects on southern forests. J. For. 71:584-587.

Brocksen, R.W., G.E. Davis, and C.E. Warren. 1969. Analysis of Trophic Processes on the Basis of Density-Dependent Functions. Tech. Paper 2515. Pacific Coop. Water Pollution Lab., Oregon State Univ.

Bryant, M.D. 1983. The role and management of wood debris in West Coast salmonid nursery streams. N. Am. J. Fish. Mgmt. 3:322-330.

Bulkley, R.V. and R. Pimentel. 1983. Temperature preference and avoidance by adult razorback suckers. Trans. Am. Fish. Soc. 112:601-607.

Buma, P.G. and J.C. Day. 1975. Reservoir-induced plant community changes: a methodological explanation. J. Env. Mgt. 3:219-250.

Burns, J.W. 1972. Some effects of logging and associated road construction on northern California streams. Trans. Am. Fish. Soc. 101:1-17.

Burton, R.A. and T.A. Wesche. 1974. Relationship of Duration of Flows and Selected Watershed Parameters to the Standing Crop Estimates of Trout Populations. Water Resources Series 52. Water Resources Res. Inst., Univ. Wyoming, Laramie.

Butler, D. 1979. Stream Evaluation Project: Phase II--Texas. Publ. W/IFG- 79/W112. U.S. Dep. Interior, Coop. Instream Flow Serv. Group, Ft. Collins, CO.

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

Cairns, J., Jr., J.S. Crossman, K.L. Dickson, and E.E. Herricks. 1971. The recovery of damaged streams. Bull. Assoc. Southeastern Biologists 18:79-106.

Calhoun, S.W., E.G. Zimermann, and T.L. Beitinger. 1982. Stream regulation alters acute temperature of red shiner, N. lutrensis. Can. J. Fish. Aquat. Sci. 39:360-363.

California State Water Resources Control Board (SWRCB). 1984.

Decision approving Application 27352 (Diversion of Montgomery Creek, Calif.). SWRCB Decision 1599.

Cargill, A.S., II. 1980. Lack of rainbow trout movement in a small stream. Trans. Am. Fish. Soc. 109:484-490.

Carpenter, J.R. and C.A. Mitchell. 1977. Root respiration characteristics of flood tolerant red maple (Acer rubrum L.) and flood intolerant sugar maple (Acer saccharum Marsh.) trees. Hort. Sci. 12:54.

Chang, W.Y.B. and W.G. Sprules. 1981. Comment, reply on 'Advantages of eigenvectors over structure coefficients as indicators for selecting the response variables in principal components'. Can. J. Fish. Aquat. Sci. 38:1298-1300.

Chapman, D. W. 1966. Food and space as regulators of salmonid populations in streams. Amer. Natur. 100:345-357.

Chapman, D.W., and T.C. Bjornn. 1969. Distribution of salmonids in streams, with special reference to food and feeding. IN Symposium on Salmon and Trout in Streams (T.G. Northcote, ed.), pp. 153-176. H. R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver.

Chapman, D.W. and E. Knudsen. 1980. Channelization and livestock impacts on salmonid habitat and biomass in western Washington. Trans. Am. Fish. Soc. 109:357-363.

Chrostowski, H.P. 1976. Stream habitat and reduced flows. IN Proc. Symp. and Specialty Conference on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. I, pp. 534-543. Am. Fish. Soc., Bethesda, MD.

Clark, J. and B. McCarl. 1983. An investigation of the relationship between Oregon coho salmon (O. kisutch) hatchery releases and adult production using law of the minimum regression. Can. J. Fish. Aquat. Sci. 40:516-523.

Clark, R.D., G.R. Alexander, and H. Gowing. 1980. Mathematical description of trout-stream fisheries. Trans. Am. Fish. Soc. 109:587-602.

Cloern, J.E. 1976. The survival of coho salmon eggs in two Wisconsin tributaries of Lake Michigan. Am. Midland Natur. 96:451-461.

Coble, D.W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Trans. Am. Fish. Soc. 90:469-474.

Coble, D.W. 1982. Fish populations in relation to dissolved oxygen in the Wisconsin River. Trans. Am. Fish. Soc. 111:612-623.

Cochnauer, T. 1976. Instream flow techniques for large rivers. IN Proc. Symp. and Spec. Conf. on Instream Flow Needs (J. F. Orsborn and C. H. Allman, eds.), Vol. II, pp. 387-399. Am. Fish. Soc., Bethesda, MD.

Cochran, P.H. 1972. Tolerance of lodgepole and ponderosa pine seedlings to high water tables. N.W. Sci. 46:322-331.

Collings, M. 1972. A methodology for determining instream flow requirements for fish. In Proceedings of Instream Flow Methodology Workshop. Washington Dept. of Ecology. Olympia, Wash. pp. 72-86.

Collings, M. R. 1974. Generalization of spawning and rearing discharges for several Pacific salmon species in western Washington. USGS, Open File Report.

Collings, M.R. and G.W. Hill. 1973. The Hydrology of Ten Streams in Western Washington as Related to the Propagation of Several Pacific Salmon Species. Rep. USGS-WRD-73-023, NTIS PB 225 204. USGS, Water Resources Division, Tacoma, WA.

Comer, L.E., W.J. Grenney, and I. Dirmhirn. 1976. Stream temperature modeling. IN Proc. Symp. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 527-539. Am. Fish. Soc., Bethesda, MD.

Cooper, J.L. 1976. United States Forest Service stream survey procedure--Northern Region. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 300-313. Am. Fish. Soc.

Cooper, C.O. and T.A. Wesche. 1976. Stream Channel Modification to Enhance Trout Habitat Under Low Flow Conditions. Water Resources Ser. 58. Water Resources Res. Inst., Univ. Wyoming, Laramie. 170 pp.

Crouse, M.R., C.A. Callahan, K.A. Malueg, and S.E. Dominguez. 1981. Effects of fine sediments on growth of juvenile coho salmon in laboratory streams. Trans. Am. Fish. Soc. 110:281-286.

Crowder, L.B., J.J. Magnuson, and S.B. Brandt. 1981. Complementarity in the use of food and thermal habitat by Lake Michigan fishes. Can. J. Fish. Aquat. Sci. 38:662-668.

Culp, J.M., S.J. Walde, and R.W. Davies. 1983. Relative importance of substrate particle size and detritus to stream benthic macroinvertebrate microdistribution. Can. J. Fish. Aquat. Sci. 40:1568-1574.

Cummins, K.W., C.A. Tryon, Jr., and R.T. Hartman. 1964. Proc. Symp. Organism-Substrate Relationships in Streams. Spec. Publ. 4, Pymatuning Lab. Ecol., Univ. Pittsburgh, Linesville, PA.

Cuplin, P. and B. Van Haveren. 1979. Instream Flow Guidelines. US Dep. Interior, Bureau of Land Management, Washington.

Curran, J. and L. McLelland. 1980. Evaluation of Instream Flow Methods and Determination of Water Quantity Needs for Streams in the State of Nevada. Rep. W/IFG-80/W86. Nevada Dep. Wildl., Reno.

Devore, P.W. and R.J. White. 1978. Daytime responses of brown trout (Salmo trutta) to cover stimuli in stream channels. Trans. Am. Fish. Soc. 107:763-771.

Diana, J.S. and E.D. Lane. 1978. The movement and distribution of Paiute cutthroat trout, Salmo clarki seleniris in Cottonwood Creek, Calif. Trans. Am. Fish. Soc. 107:444-448.

Dickson, R.E., J.F. Hosner, and N.W. Hosley. 1965. The effects of four water regimes upon the growth of four bottomland tree species. Forest Sci. 11:299-305.

Dill, L.M. 1983. Adaptive flexibility in the foraging behavior of fishes. Can. J. Fish. Aquat. Sci. 40:398-408.

Dooley, J.M. 1976. Application of U.S. Bureau of Reclamation water surface profile program (WSP). IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 478-495. Am. Fish. Soc., Bethesda, MD.

Duff, D. 1981. General Aquatic Wildlife System (GAWS). USDA Forest Service, Intermountain Region, Ogden, UT.

Dunham, D.K. and A. Collotzi. 1975. The Transect Method of Stream Habitat Inventory--Guidelines and Applications. U.S. Dep. Agriculture, Forest Service, Ogden, UT. 98 pp.

Ecological Analysts, Inc. 1983. An evaluation of historical flow conditions in the Platte River as related to vegetation growth and habitat use by the endangered whooping crane and bald eagle and the threatened interior least tern. Prepared for Central Platte Natural Resources Institute. EA Engineering, Science, and Technology, Inc., Lincoln NB. 97pp.

Ecological Analysts, Inc. 1984. Literature Review Report on Channel Widening and Narrowing in 'Semiarid' Rivers. Proposal. EA Engineering, Science, and Technology, Inc., Lincoln, NB.

Edwards, R.J. 1978. The effect of hypolimnion reservoir releases on fish distribution and species diversity. Trans. Am. Fish. Soc. 107:71-77.

Edwards, E.A. 1983a. Habitat Suitability Index Models: Bigmouth Buffalo. U.S. Dep. Interior, Fish Wildl. Serv., Habitat

Eval. Proc. Grp. Rep. FWS/OBS-82/10.34.

Edwards, E.A. 1983b. Habitat Suitability Index Models: Longnose Sucker. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.35.

Edwards, E.A. and K. Twomey. 1982. Habitat Suitability Index Models: Common Carp. U.S. Dep. Interior, Fish Wildl. Ser., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.12.

Edwards, E.A., M. Bacteller, and O.E. Maughan. 1982. Habitat Suitability Index Models: Slough Darter. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.9.

Edwards, E.A., G. Gebhart, and O.E. Maughan. 1983a. Habitat Suitability Information: Smallmouth Bass. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.36.

Edwards, G.A., H. Li, and C.B. Schreck. 1983b. Habitat Suitability Index Models: Longnose Dace. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.33.

Edwards, C.J., B.L. Griswold, R.A. Tobb, E.C. Weber, and L.C. Woods. 1984. Mitigating effects of artificial riffles and pools on the fauna of a channelized warmwater stream. N. Am. J. Fish. Mgmt. 4:194-203.

Eifert, W.H. and T.A. Wesche. 1982. Evaluation of the Stream Reach Inventory and Channel Stability Index for Instream Habitat Analysis. Prepared for US Office of Water Resource Technology by Water Resources Res. Inst., Univ. Wyoming, Laramie.

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

Elser, A.A. 1976. Use and reliability of water surface profile program data on a Montana prairie stream. IN Proc. Symp and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 496-540. Am. Fish. Soc., Bethesda, MD.

Elwood, J.W. and T.F. Waters. 1969. Effects of floods on food consumption and production rates of a stream brook trout population.

Environmental Research and Technology, Inc. 1979. An Evaluation of Minimum Flow Requirement Methodologies for Fisheries in the Green River, Utah, Below the Confluence of the Yampa River. Publ. W/IFG-79/W113, Cooperative Instream Flow Service Group, US fish Wildl. Serv., Ft. Collins, CO.

Eriksen, C.H. 1966. Benthic invertebrates and some substrate-current-oxygen interrelationships. IN Organism-Substrate Relationships in Streams, pp. 98-115. Spec. Publ. 4, Pymatuning Lab. Ecology, Univ. Pittsburgh, Linesville, PA.

Erman, D.C. 1973. Upstream changes in fish populations following impoundment of Sagehen Creek, Calif. Trans. Am. Fish. Soc. 102:626-629.

Erman, D.C. and V.M. Hawthorne. 1976. The quantitative importance of an intermittent stream in the spawning of rainbow trout. Trans. Am. Fish. Soc. 105:675-681.

Erman, D.C. and G.R. Leidy. 1975. Downstream movement of rainbow trout fry in a tributary of Sagehen Creek, under permanent and intermittent flow. Trans. Am. Fish. Soc. 104:467-473.

Evans, M.S. 1981. Distribution of zooplankton populations within and adjacent to a thermal plume. Can. J. Fish. Aquat. Sci. 38:441-448.

Everest, F.H. and D.W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. J. Fish. Res. Bd. Canada, 29:91-100.

Farmer, A.H. Unpublished. Habitat model validation concepts. IN Proc. Workshop on Fish Habitat Suitability Index Models (J.W. Terrell, ed.). US Dep. Interior Fish and Wildlife Service, Western Energy and Land Use Team, Ft. Collins, CO.

Fausch, K.D. and M.G. Parsons. Unpublished. A Review of Models that Predict Standing Crop of Stream Fish from Habitat Variables. Draft (1984). Prepared for USDA Forest Service, Wildlife and Fisheries Ecology Unit, Ft. Collins, CO.

Fausch, K.D. and R.J. White. 1981. Competition between brook trout (S. fontinalis) and brown trout (S. trutta) for positions in a Michigan stream. Can. J. Fish. Aquat. Sci. 38:1220-1227.

Fausch, K.D., J.R. Karr, and P.R. Yant. 1984. Regional application of an index of biotic integrity based on stream fish communities. Trans. Am. Fish. Soc. 113:39-55.

Floyd, K.B., R.D. Hoyt, and S. Timbrook. 1984. Chronology of appearance and habitat partitioning by stream larval fishes. Trans. Am. Fish. Soc. 113:217-223.

Gamble, M.D. and E.D. Rhoades. 1964. Effect of shoreline fluctuations on grasses associated with upstream flood prevention and watershed protection. Agron. J. 56:21-23.

Gard, R. and D.W. Seegrist. 1972. Abundance and harvest of trout in Sagehen Creek, Calif. Trans. Am. Fish Soc. 101:463-467.

Garman, G.C. and T.F. Waters. 1983. Use of the size-frequency (Hynes) method to estimate annual production of a stream fish population. Can. J. Fish. Aquat. Sci. 40:2030-2034.

Geer, W.H. 1980. Evaluation of Five Instream Flow Needs Methodologies and Water Quantity Needs of Three Utah Trout Streams. Publ. W/IFG-80/W91, Cooperative Instream Flow Service Group, US Fish Wildl. Serv., Ft. Collins, CO.

Giattina, J.D. and R.R. Garton. 1982. Graphical model of thermoregulatory behavior by fishes with a new measure of eurythermality. Can. J. Fish. Aquat. Sci. 39:524-528.

Giger, R.D. 1973. Streamflow requirements of salmonids. Job Final Report, Project AFS 62-1. Oregon Wildl. Comm., Portland. 117 pp.

Gilbert, R.J. Unpublished. Assessments of selected habitat suitability index (HSI) models. IN Proc. Workshop on Fish Habitat Suitability Index Models (J.W. Terrell, ed.). US Dep. Interior Fish and Wildlife Service, Western Energy and Land Use Team, Ft. Collins, CO.

Gilbert, R.J., J.E. Hightower, and A. Rabern. 1983. Assessments of selected habitat suitability index (HSI) models. Am. Fish. Soc., 113th Annual Meeting, Milwaukee, WI.

Gill, C.J. 1970. The flooding tolerance of woody species--a review. For. Abstr. 31:671-688.

Gislason, J.C. 1985. Aquatic insect abundance in a regulated stream under fluctuating and stable diel flow patterns. N. Am. J. Fish. Mgmt. 5:39-46.

Glover, R.D. 1980. Evaluation of Instream Flow Methodologies and Determination of Water Quantity Needs for Nine Streams in the State of South Dakota. Rep. W/IFG-80/W92. Prepared for US Dep. Interior, Fish and Wildlife Servic Cooperative Instream Flow Service Group, Ft. Collins, CO.

Good, W.R. 1974. Some Effects of Spring Snowmelt Runoff on Aquatic Invertebrate Populations in a High Mountain Stream. Water Resources Series 50. Water Resources Res. Inst., Univ. Wyoming, Laramie. 103 pp.

Goodnight, W.H. and T.C. Bjornn. 1971. Fish production in two Idaho streams. Trans. Am. Fish. Soc. 100:769-780.

Goodyear, C.P. and S.W. Christensen. 1984. On the ability to detect the influence of spawning stock on recruitment. N. Am. J. Fish. Mgmt. 4:186-193.

Gore, J.A. 1978. A technique for predicting instream flow requirements of benthic macroinvertebrates. Freshwater Biol. 8:141-151.

Gore, J.A. and R.D. Judy, Jr. 1981. Predictive models of benthic macroinvertebrate density for use in instream flow studies and regulated flow management. Can. J. Fish. Aquat. Sci. 38:1363-1370.

Gorman, O.T. and J.R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59(3):507-515.

Gray, J.R.A. and J.M. Edington. 1969. Effect of woodland clearance on stream temperature. J. Fish. Res. Board Can. 26:399-403.

Gregory, K.J. and C.C. Park. 1974. Adjustment of river channel capacity downstream from a reservoir. Water Resources Res. 10:870-873.

Grenney, W.J. and A.K. Kraszewski. 1981. Description and Application of the Stream Simulation and Assessment Model: Version IV (SSAM IV). Instream Flow Inf. Paper 17. FWS/OBS-81/46. U.S. Dep. Interior, Fish Wildl. Serv., Washington, DC.

Grenney, W.J. and D.B. Porcella. 1976. Mathematical modeling of sediment transport as a methodology for determining instream flow requirements. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 515-526. Am. Fish. Soc., Bethesda, MD.

Griffith, J.S., Jr. 1972. Comparative behavior and habitat utilization of brook trout and cutthroat trout in small streams in northern Idaho. J. Fish. Res. Board Can. 29:265-273.

Grizzle, J.M. 1981. Effects of hypolimnetic discharge on fish health below a reservoir. Trans. Am. Fish. Soc. 110:29-43.

Gunning, G.E. and T.M. Berra. 1969. Fish repopulation of experimentally decimated segments in the headwaters of two streams. Trans. Am. Fish. Soc. 98:305-308.

Gurtz, M.E., J.R. Webster, and J.B. Wallace. 1980. Seston dynamics in southern Appalachian streams: effects of clear-cutting. Can. J. Fish. Aquat. Sci. 37:624-631.

Haefner, J.D. and J.B. Wallace. 1981. Shifts in aquatic insect populations in a first-order southern Appalachian stream following a decade of old field succession. Can. J. Fish. Aquat. Sci. 38:353-359.

Hansen, E.A. 1975. Some effects of groundwater on brown trout redds. Trans. Am. Fish. Soc. 104(1):100-110.

Hanson, D.L. and T.F. Waters. 1974. Recovery of standing crop and production rate of a brook trout population in a flood-damaged stream. Trans. Am. Fish. Soc. 103:431-439.

Harris, R.W., A.T. Leiser, and R.E. Fissell. 1975. Plant Tolerance to Flooding: Summary Report, 1971-1975. Dep. Environmental Horticulture, Univ. Calif., Davis. 30 pp.

Hartman, G.F. 1963. Observations on behavior of juvenile brown trout in a stream aquarium during winter and spring. J. Fish. Res. Board Can. 20:769-787.

Hartzler, J.R. 1983. The effect of half-log covers on angler harvest and standing crop of brown trout in McMichaels Cr., PA. N. Am. J. Fish. Mgmt. 3:228-238.

Haugen, G. and D. Duff (eds.). 1982. Best Management Practice for the Management and Protection of Western Riparian Stream Ecosystems. Prepared by the Riparian Habitat Committee, American Fisheries Society, Bethesda, MD.

Hausle, D.A. and D.W. Coble. 1976. Influence of sand in redds on survival and emergence of brook trout. Trans. Am. Fish. Soc. 105:57-63.

Havey, K.A. and R.M. Davis. 1970. Factors influencing standing crops and survival of juvenile salmon at Barrows Stream, Maine. Trans. Am. Fish. Soc. 99:297-311.

Hawkins, C.P., M.L. Murphy, and N.H. Anderson. 1982. Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon. Ecology 63:1840-1856.

Helle, J.H. 1982. Genetic considerations in management of wild and hatchery stocks of salmonids. IN The Role of Fisheries in the Management of Wild Salmonids, pp. 25-29. Northwest and Alaska Fisheries Center, Auke Bay.

Helm, W.T. 1984. Members call for Western Division action on standardization. Fisheries 9(2):10-13.

Herricks, E.E., and J.K. Furnish. Unpublished. Assessment of the availability and quality of information needed to calculate habitat suitability curves for selected benthic invertebrates. Eastern Energy and Land Use Team, U.S. Fish Wildl. Serv., Kearneysville, WV. Unpubl. ms. (1980). 28 pp.

Hesse, L.W. and B.A. Newcomb. 1982. Effects of flushing Spencer Hydro on water quality, fish, and insect fauna of the Nebraska River, NE. N. Am. J. Fish. Mgmt. 2:45-52.

Hickman, T. and R.F. Raleigh. 1982. Habitat Suitability Index Models: Cutthroat Trout. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.5.

Hilborn, R., C.J. Walters, R.M. Peterman, and M.J. Staley. 1984. Models and fisheries: a case study in implementation. N. Am. J. Fish. Mgmt. 4:9-14.

Hildebrand, S.G. (ed.). 1980. Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development, III: Water Level Fluctuation. Publ. 1591, Environmental Sci. Div., Oak Ridge National Lab., Oak Ridge, TN.

Hilgert, P. 1982. Evaluation of Instream Methodologies for Fisheries in Nebraska. Nebraska Tech. Ser. 10. Nebraska Game and Parks Commission, Lincoln.

Hook, D.D. and C.L. Brown. 1973. Root adaptations and relative flood tolerance of five hardwood species. Forestry Sci. 19:225-229.

Hooper, D.R. 1973. Evaluation of the effects of flows on trout stream ecology. Dep. Engineering Res., Pacific Gas and Electric Co., Emeryville, CA. 97 pp.

Hoppe, R.A. 1975. Minimum streamflows for fish. Paper distributed at Soils-Hydrology Workshop, US Forest Service, Montana State Univ., Bozeman, 26-30 January 1976.

Horner, R.R. and E.B. Welch. 1981. Stream periphyton development in relation to current velocity and nutrients. Can. J. Fish. Aquat. Sci. 38:449-457.

Horton, W.D. and T. Cochnauer. 1980. Instream Flow Methodology Evaluation, Biological Criteria Determination, and Water Quantity Needs for Selected Idaho Streams. Publ. W/IFG-80/W88, Cooperative Instream Flow Service Group, US Fish Wildl. Serv. Ft. Collins, CO.

Horwitz, R.J. 1978. Temporal variability patterns and the distributional patterns of stream fishes. Ecology 48:307-321.

Hunt, F.M. 1951. Effects of flooded soil on growth of pine seedlings. Plant Physiol. 26:363-368.

Hunt, R.L. 1969a. Effects of habitat alteration on production, standing crops ,and yield of brook trout in Lawrence Creek, Wisconsin. IN Symp. on Salmon and Trout in Streams (T.G. Northcote, ed.), pp.281-312. H.R. MacMillan Lectures in Fisheries. Univ. British Columbia, Vancouver.

Hunt, R.L. 1969b. Overwinter survival of wild fingerling brook trout in Lawrence Creek, Wisconsin. J. Fish. Res. Board Can. 26:1473-1483.

Hunt, R.L. 1974. Annual production by brook trout in Lawrence Creek during eleven successive years. Tech. Bull. 82. Wisconsin

Dep. Nat. Resources, Madison.

Hyra, R. 1978. Methods of Assessing Instream Flows for Recreation. Rep. FWS/OBS-78/34. U.S. Dep. Interior, Cooperative Instream Flow Service Group, Ft. Collins, CO. 129 pp.

Hyra, R. 1979. Methods of Assessing Instream Flows for Recreation (revised). Rep. FWS/OBS-79/38. U.S. Dep. Interior, Cooperative Instream Flow Service Group, Ft. Collins, CO.

Inskip, P.D. 1982. Habitat Suitability Index Models: Northern Pike. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.17

Irvine, J.R. and T.G. Northcote. 1983. Selection of young rainbow trout in simulated stream environments for live and dead prey of different sizes. Can. J. Fish. Aquat. Sci. 40:1745-1749.

Isaacson, J.A. 1976. Determining instream flows using the sag tape method and R2cross X computer program. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J. F. Orsborn and C. H. Allman, eds.), Vol. II, pp. 314-321. Am. Fish. Soc., Bethesda, MD.

Jacobs, K.E. and W.D. Swink. 1983. Fish abundance and population stability in a reservoir tailwater and an unregulated headwater stream. N. Am. J. Fish. Mgmt. 3:395-402.

Jenkins, T.J. 1969a. Night feeding of brown and rainbow trout in an experimental stream channel. J. Fish. Res. Board Can. 26:3275-3278.

Jenkins, T.M., Jr. 1969b. Social structure, position, choice and micro-distribution of two trout species (Salmo trutta and Salmo gairdneri) resident in mountain streams. Animal Behav. Mono. 2: 57-123.

Jensen, A.L. 1981. Optimum size limits for trout fisheries. Can. J. Fish. Aquat. Sci. 38:657-661.

Jester, D.B. and H.J. McKirdy. 1966. Evaluation of trout stream improvement in New Mexico. IN Proc. West. Assoc. State Game Fish Commiss., Butte, MT.

Johnsgard, P.A. 1956. Effects of water fluctuation and vegetation change on bird populations, particularly waterfowl. Ecology 37:689-701.

Jones, R.N. 1981. The community structure and interrelationships among darters (Percidae) in Glover Creek, OK. MS thesis, Oklahoma St. Univ., Stillwater.

Jones, J.R., B.H. Tracy, J.L. Sebaugh, D.H. Hazelwood, and M.M. Smart. 1981. Biotic index tested for ability to assess water quality of Missouri Ozark streams. Trans. Am. Fish. Soc. 110:627-637.

Kadlec, J.A. 1976. Methodologies for assessing instream flows for wildlife. IN Methodologies for the Determination of Stream Resource Flow Requirements: An Assessment (C.B. Stalnaker and J.L. Arnette, eds.), pp. 355-363. FWS/OBS-76/03.

Kauffman, K.G. 1976. Washington State's instream flow program action. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 84-95. Am. Fish. Soc., Bethesda, MD.

Keller, C.R. and K.P. Burnham. 1982. Riparian fencing, grazing, and trout habitat preference on Summit Creek, Idaho. N. Am. J. Fish. Mgmt. 2:53-59.

Kellogg, R.W. and J.J. Gift. 1983. Relationship between optimum temperatures for growth and preferred temperatures for the young of four fish species. Trans. Am. Fish. Soc. 112:424-430.

Kevern, N.R. and C. Gowan. 1984. Instream flow needs in critical areas of the Great Lakes region. Project 372404. Dep. Fish. Wildl., Michigan State Univ., East Lansing.

Kimble, L.A. and T.A. Wesche. 1975. Relationships between selected physical parameters and benthic community structure in a small mountain stream. Water Resources Ser. 55. Water Resources Res. Inst., Univ. Wyoming, Laramie. 65 pp.

Kimura, D.K. and N.A. Lemberg. 1981. Variability of line intercept density estimates (a simulation study of the variance of hydroacoustic biomass estimates). Can. J. Fish. Aquat. Sci. 38:1141-1152.

King, N.J. 1961. An example of channel aggradation induced by flood control. IN U.S. Geological Survey Professional Paper 424-B, pp. 29-32. USGS, Washington, DC.

Kirkpatrick, D.A. and T. Ameslav (eds.). 1983. Proc. Wild Salmon and Trout Conference. Washington Environmental Foundation, Seattle.

Knapp, W.E. 1980. Instream flow policy: a stimulus for attitudinal change. Presented at HCRS Conference: River Conservation and Revitalization: Agenda for the 1980s, Lake Mohonk, NY, 20 October.

Kwain, W-H. 1981. Population dynamics and exploitation of rainbow trout in Stokely Creek, eastern Lake Superior. Trans. Am. Fish. Soc. 110:210-215.

Kwain, W-H. and H.R. MacCrimmon. 1969. Age and vision as factors in bottom color selection by rainbow trout. J. Fish. Res. Board Can. 26:687-693.

Kwain, W-H. and H.R. MacCrimmon. 1969. Further observations on the response of rainbow trout to overhead light. J. Fish. Res. Board Can. 26:3233-3237.

Lamb, B.L (ed.). 1977. Protecting Instream Flows under Western Water Law: Selected Papers. Rep. FWS/OBS-77/47. Cooperative Instream Flow Service Group, Ft. Collins, CO.

Lamb, B.L. (ed.). 1979. Guidelines for Preparing Expert Testimony in Water Management Decisions Related to Instream Flow Issues (Revised). Rep. FWS/OBS-79/37. Cooperative Instream Flow Service Group. Ft. Collins, CO.

Lamberti, G.A. and V.H. Resh. 1983. Geothermal effects on stream benthos: separate influences of thermal and chemical components on periphyton and macroinvertebrates. Can. J. Fish. Aquat. Sci. 40:1995-2009.

Layher, W.G. and O.E. Maughan. Unpublished. Analysis and refinement of habitat suitability index models for eight warm water fish species. IN Proc. Workshop on Fish Habitat Suitability Index Models (J.W. Terrell, ed.). Draft ms (1984). US Dep. Interior, Fish and Wildlife Service, Western Energy and Land Use Team, Ft. Collins, CO.

Layher, W.G. and O.E. Maughan. 0. Relations between habitat variables and channel catfish populations in streams. Kansas Fish and Game Commission, Pratt.

Layher, W.G. 1983. Habitat Suitability for Selected Adult Fishes in Prairie Streams. Ph.D. diss. Oklahoma St. Univ., Stillwater.

Lee, R.M. and J.N. Rinne. 1980. Critical thermal maxima of five trout species in the southwestern United States. Trans. Am. Fish. Soc. 109:632-635.

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

Li, H.W. and R.W. Brocksen. 1977. Approaches to the analysis of energetic costs of intraspecific competition for space by rainbow trout. J. Fish. Biol. 11:329-341.

Li, H.W., C.B. Shreck, and K.J. Rodnick. Unpublished. Assessment of habitat quality models for cutthroat trout and coho salmon for Oregon's coastal waters. IN Proc. Workshop on Fish Habitat Suitability Index Models (J.W. Terrell, ed.). Draft ms (1984). US Dep. Interior, Fish and Wildlife Service, Western Energy and Land Use Team, Ft. Collins, CO.

Loar, J.M. (ed.). 1985. Application of Habitat Evaluation Models in Southern Appalachian Trout Streams. Publ. 2383, Environmental Sci. Div., Oak Ridge National Lab. Oak Ridge, TN.

Loar, J.M. and M.J. Sale. 1981. Analysis of Environmental Issues Related to Small-Scale Hydroelectric Development, V: Instream Flow Needs for Fishery Resources. Publ. 1829, Environmental Sci. Div., Oak Ridge National Lab., Oak Ridge, TN.

Lotspeich, F.B. and W.S. Platts. 1982. An integrated land-aquatic classification system. N. Am. J. Fish. Mgmt 2:138-149.

Lowe, R.L. 1979. Phytobenthic ecology and regulated streams. IN The Ecology of Regulated Streams (J.V. Ward and J.A. Stanford, eds.), pp.25-34. Plenum, New York.

Luey, J.E. and I.R. Adelman. 1980. Downstream naural areas as refuges for fish in drainage-development watersheds. Trans. Am. Fish. Soc. 109:332-335.

MacCrimmon, H.R. and W-H. Kwain. 1966. Use of overhead cover by rainbow trout exposed to a series of light intensities. J. Fish. Res. Board Can. 23:983-990.

MacDonald, J.S. and R.H. Green. 1983. Redundancy of variables used to describe importance of prey species in fish diets. Can. J. Fish. Aquat. Sci. 40:635-637.

Malvestuto, S.P., W.D. Davies, and W.L. Shelton. 1979. Predicting the precision of creel survey estimates of fishing effort by use of climatic variables. Trans. Am. Fish. Soc. 108:43-45.

Marsh, P.C. and T.F. Waters. 1980. Effects of agricultural drainage development on benthic invertebrates in undisturbed downstream reaches. Trans. Am. Fish. Soc. 109:213-223.

Martinez, A.M. 1984. Identification of brook, brown, rainbow, and cutthroat trout larvae. Trans. Am. Fish. Soc. 113:252-259.

Mathur, D., R.M. Schutsky, E.J. Purdy, Jr., and C.A. Silver. 1981. Similarities in acute temperature preferences of freshwater fishes. Trans. Am. Fish. Soc. 110:1-13.

Mathur, D., R.M. Schutsky, E.J. Purdy, Jr., and C.A. Silver. 1983. Similarities in avoidance temperatures of freshwater fishes. Can. J. Fish. Aquat. Sci. 40:2144-2152.

McAllister, D.E. and R.J. Plank. 1981. Capturing fish measurements and counts with calipers and probe interfaced with a computer or pocket calculator. Can. J. Fish. Aquat. Sci. 38:466-470.

McFadden, J.T. and E.L. Cooper. 196_. Population dynamics of brown trout in different environments. ____:355-363.

McMahon, T.E. 1982. Habitat Suitability Index Models: Creek Chub. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.4.

McMahon, T.E. 1983. Habitat Suitability Index Models: Coho Salmon. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.49. 29 pp.

McNeil, W.J. 1964. Effects of the spawning bed environment on reproduction of pink and chum salmon. U.S. Fish and Wildlife Service, Fish. Bull. 65(2):495-523.

McNeil, W. J. and W.H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. Special Scientific Reprint (Fish.) 469. U.S. Fish Wildl. Serv.

Meador, M.R., A.G. Eversole, and J.S. Bulak. 1984. Utilization of portions of the Santee River system by spawning blueback herring. N. Am. J. Fish. Mgmt. 4:155-163.

Meehan, W.R. F.J.Swanson, and J.R. Sedell. 1977. Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply. IN Proc. Symp. Importance, Preservation, and Management of Riparian Habitat, Tucson, Ariz., 9 July 1977. USDA Forest Service.

Meinzer, O.E. 1927. Plants as indicators of ground water. Water Supply Paper 577. Dep. Interior, US Geological Survey, Washington.

Mense, J.B. 1975. Relation of density to brown trout movement in a Michigan stream. Trans. Am. Fish. Soc. 104:688-695.

Milhous, R.T. 1984. PHABSIM Technical Note No. 1: Selection of Number of Cells in a Cross Section.

Milhous, R.T., and K.D. Bovee. 1978. The stochastic variation of instream values in rivers. IN Verification of Math. and Phys. Models in Hydraulic Engineering, pp. 630-637. Proc. ASCE Hydraulic Div. Conf. Am. Soc. Civil Engineers.

Miller, J.M. 1974. The food of brook trout, Salvelinus fontinalis (Mitchill), fry from different subsections of Lawrence Creek, Wisconsin. Trans. Am. Fish. Soc. 103:130-134.

Miller, J.W. 1976. Relating fish production to stream flow levels using fish and water management models. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 545-561. Am. Fish. Soc., Bethesda, MD.

Mittelbach, G.G. 1981. Patterns of invertebrate size and abundance in aquatic habitats. Can. J. Fish. Aquat. Sci. 38:896-904.

Moore, S.E., B. Ridley, and G.L. Larson. 1983. Standing crops of brook trout concurrent with removal of rainbow trout from selected streams in Great Smoky Mountains National Park. N. Am. J. Fish. Mgmt. 3:72-80.

Morhardt, J.E. 1981. Water releases and trout habitat: the relationship in some Sierran streams. IN Waterpower '81. Proc. Internat. Conf. on Hydropower, pp. 443-452. U.S. Army Corps of Engineers.

Morhardt, J.E., D.F. Hanson, and P.C. Coulston. 1983. Instream flow analysis: increased accuracy using habitat mapping. IN Waterpower '83, Proc. Internat. Conf. on Hydroelectric Power. U. S. Army Corps of Engineers.

Morris, J.A. 1976. Instream flow evaluation for outdoor recreation. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 352-358. Am. Fish. Soc., Bethesda, MD.

Moyle, P.B., B.Vandracek, and G.D. Grossman. 1983. Responses of fish populations in the North Fork of the Feather River, CA, to treatments with fish toxicants. N. Am. J. Fish. Mgmt. 3:48-60.

Mueller, G. 1980. Effects of recreational river traffic on nest defense by longear sunfish. Trans. Am. Fish. Soc. 109:248-251

Mullan, J.W., V.J. Starostka, J.L. Stone, R.W. Wiley, and W.J. Wiltzius. 1976. Factors affecting upper Colorado River reservoir tailwater trout fisheries. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 405-428. Am. Fish. Soc., Bethesda, MD.

Mundie, J.H. and R.E. Traber. 1983. Carrying capacity of an enhanced side-channel for rearing salmonids. Can. J. Fish. Aquat. Sci. 40:1320-1322.

Mundie, J.H., S.M. McKinnell, and R.E. Traber. 1983. Responses of stream zoobenthos to enrichment of gravel substrates with cereal grain and soybean. Can. J. Fish. Aquat. Sci. 40:1702-1712.

Munson, B.H., J.H. McCormick, and H.L. Collins. 1980. Influence of thermal challenge on conditioned feeding forays of juvenile rainbow trout. Trans. Am. Fish. Soc. 109:116-121.

Murphy, M.L. and J.D. Hall. 1981. Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. Can. J. Fish. Aquat. Sci. 38:137-145.

Murphy, M.L., C.P. Hawkins, and N.H. Anderson. 1981. Effects of canopy modification and accumulated sediment on stream communities. Trans. Am. Fish. Soc. 110:469-478.

Naiman, R.J. and J.R. Sedell. 1980. Relationship between metabolic parameters and stream order in Oregon. Can. J. Fish. Aquat. Sci. 37:834-847.

Navarre, R.J. 1962. A new stream habitat improvement structure in New Mexico. Trans. Am. Fish. Soc. 91:228-229.

Nehring, R.B. 1979. Evaluation of Instream Flow Methods and Determination of Water Quantity Needs for Streams in the State of Colorado. Prepared by Colo. Div. Wildl. for US Dep. Interior, Fish and Wildlife Service, Cooperative Instream Flow Service Group, Ft. Collins, CO.

Nelson, F.A. 1980. Evaluation of Four Instream Flow Methods Applied to Four Trout Rivers in Southwest Montana (with Supplement). Publ. W/IFG-80/W90, Cooperative Instream Flow Service Group, US Fish Wildl. Serv., Ft. Collins, CO.

Nelson, D.A. and A.C. Miller. Unpublished. Application of habitat suitability index models for white crappie, bluegill, and largemouth bass. IN Proc. Workshop on Fish Habitat Suitability Index Models (J.W. Terrell, ed.). Draft ms (1984). US Dep. Interior, Fish and Wildlife Service, Western Energy and Land Use Team, Ft. Collins, CO.

Nelson, P.C., K.D. Bovee, and D.A. Mayhew. Component testing of the instream flow incremental methodology: a case study of experimental design in natural stream systems. Presented at the 35th Annual Meeting of AIBS. USDA Forest Service, Western Energy and Land Use Team, Ft. Collins, CO.

Neves, R.J. and G.B. Pardue. 1983. Abundance and production of fishes in a small Appalachian stream. Trans. Am. Fish. Soc. 112:21-26.

Newbold, J.D., D.C. Erman, and K.B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Can. J. Fish. Aquat. Sci. 37:1076-1085.

Newcombe, C. 1981. A procedure to estimate changes in fish populations caused by changes in stream discharge. Trans. Am. Fish. Soc. 110:382-390.

Newman, M.A. 1956. Social behavior and interspecific competition in two trout species. Physiol. Zool. 29:64-81.

Newman, R.M. and F.B. Martin. 1983. Estimation of fish production rates and associated variances. Can. J. Fish. Aquat. Sci. 40:1729-1736.

Nickelson, T. 1976. Development of methodologies for evaluating instream flow needs for salmonid rearing. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 581-599. Am. Fish. Soc., Bethesda, MD.

Nickelson, T.E., W.M. Beidler, and M.W. Willis. 1979. Streamflow Requirements of Salmonids. Oregon Dep. Fish Wildl., Portland.

Nickum, J.G. and J.W. Terrell. Unpublished. HSI model workshop synthesis and evaluations. IN Proc. Workshop on Fish Habitat Suitability Index Models (J.W. Terrell, ed.). Draft ms (1984). US Dep. Interior, Fish and Wildlife Service, Western Energy and Land Use Team, Ft. Collins, CO.

Niimi, A.J. 1983. Biological and toxicological effects of environmental contaminants on fish and their eggs. Can. J. Fish. Aquat. Sci. 40:306-312.

Noble, R.E. and P.K. Murphy. 1975. Short term effects of prolonged backwater flooding on understory vegetation. Crustaceana 40:22-238.

Northwest Energy Services Co. (NES). 1984. Verification of Habitat Utilization Criteria for Juvenile Fall Chinook Salmon in NF Lewis River, Wash. Prepared for Pacific Power and Light Co. by NES, Bellevue, WA.

Oliver, J.D., G.F. Holeton, and K.E. Chua. 1979. Overwinter mortality of fingerling smallmouth bass in relation to size, relative energy stores, and environmental temperature. Trans. Am. Fish. Soc. 108:130-136.

Orsborn, J.F. 1981. Estimating spawning habitat using watershed and channel characteristics. IN Acquisition and Utilization of Aquatic Habitat Inventory Information (N.B. Armantrout, ed.), pp. 154-161. American Fisheries Society, Bethesda, MD.

Orsborn, J.F. and F.D. Deane. 1976. Invstigation into Methods for Developing a Physical Analysis for Evaluating Instream Flow Needs. Dep. Civ., Environ. Eng., Washington St. Univ., Pullman.

Orth, D.J. and O.E. Maughan. 1982. Evaluation of the incremental methodology for recommending instream flows for fishes. Trans. Am. Fish. Soc. 111:413-445.

Orth, D.J., R.N. Jones, and O.E. Maughan. 1982. Considerations in the development of curves for habitat suitability criteria. IN Symp. on Acquisition and Utilization of Aquatic Habitat Inventory Information (N.B. Armantrout, ed.), pp. 124-133. American Fisheries Society, Bethesda, MD.

Oswood, M.E. and W.E. Barber. 1982. Assessment of fish habitat in streams: goals, constraints, and a new technique. Fisheries 7:8-11.

Ott, A.G. and K.E. Tarbox. 1977. Instream Flows--Applicability of Existing Methods to Alaskan Waters.

Ott, W.R. 1978a. Structure of environmental indices. IN Environmental Indices, Theory and Practice, Ch. 2. Ann Arbor Science, Ann Arbor, MI.

Ott, W.R. 1978b. Conceptual approaches. IN Environmental Indices, Theory and Practice, Ch. 5. Ann Arbor Science, Ann Arbor, MI.

Pajak, P. and R.J. Neves. 1983. The habitat evaluation procedure (HEP): a field evaluation for rock bass in two Virginia streams. Am. Fish. Soc. 113th Annual Meeting, Milwaukee.

Pardue, G.B. 1983. Habitat Suitability Index Models: Alewife and Blueback Herring. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.58.

Paulik, G.J. 1973. Studies of the possible form of the stock-recruitment curve. IN Fish Stocks and Recruitment (B.B. Parrish, ed.), pp. 302-315. Proc. Verb. Reun. Cons. Int. Explor. Mer 164.

Pennak, R.W. and E.D. Van Gerpen. 1947. Bottom fauna production and physical nature of the substrate in a northern Colorado trout stream. Ecology 28(1):42-48.

Pennington, C.H., J.A. Baker, and M.E. Potter. 1983. Fish populations along natural and revetted banks on the lower Mississippi River. N. Am. J. Fish. Mgmt. 3:204-211.

Persons, W.R. and R.V. Bulkeley. Unpublished. Evaluation of the riverine cutthroat trout habitat suitability index model. IN Proc. Workshop on Fish Habitat Suitability Index Models (J.W. Terrell, ed.). Draft ms (1984). US Dep. Interior, Fish and Wildlife Service, Western Energy and Land Use Team, Ft. Collins, CO.

Peterman, R.M. 1981. Form of random variation in salmon smolt-to-adult relations and its influence on production estimates. Can. J. Fish. Aquat. Sci. 38:1113-1119.

Phillips, C. 1976. Economic perspectives on instream flow requirements for recreation. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol I, pp. 229-247. Am. Fish. Soc., Bethesda, MD.

Phillips, R.W., R.L. Lantz, E.W. Claire, and J.R. Morning. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Trans. Am. Fish. Soc. 104:461-466.

Phinney, D.E. 1975. Repopulation of an eradicated stream section by brook trout. Trans. Am. Fish. Soc. 104:685-687.

Platts, W.S. 1976. Validity of methodologies to document stream environments for evaluating fishery conditions. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol II, pp.267-284. Am. Fish. Soc., Bethesda, MD.

Platts, W.S. and R.L. Nelson. 1983. The electronic capacitance meter: a tool for evaluating riparian-fishery habitat. N. Am. J. Fish. Mgmt. 3:219-227.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for Evaluating Stream, Riparian, and Biotic Conditions. General Tech. Rep. INT-138. U.S. Forest Service, Intermountain Forest and Range Exper. Station, Ogden, UT.

Platts, W.S., M.A. Shirazi, and D.H. Lewis. 1979. Sediment Particle Sizes Used by Salmon for Spawning with Methods for Evaluation. Rep. EPA-600/3-79-043. US EPA, Office of Resource Development, Corvallis Environmental Research Laboratory, Corvallis, OR.

Prewitt, C.G. and C.A. Carlson. 1977. Evaluation of Four Instream Flow Methodologies Used on the Yampa and White Rivers, Colorado. Report to USFWS, Contract YA-512--CT6-1BLM. Colorado State Univ., Ft. Collins.

Probst, W.E., C.F. Rabeni, W.G. Covington, and R.E. Marteney. 1984. Resource use by stream-dwelling rock bass and smallmouth bass. Trans. Am. Fish. Soc. 113:283-294.

Pruitt, T.A. and R.L. Nadeau. 1978. Recommended Stream Resources Maintenance Flows on Seven Idaho Streams. Rep FWS/OBS-78/68. U.S. Dep. Interior, Cooperative Instream Flow Service Group, Ft. Collins, CO.

Rabern, D.A. 1984. Development of habitat based models for predicting standing crops of nine species of riverine fishes in Georgia. MS thesis. Univ. Georgia, Athens.

Raleigh, R.F. 1982. Habitat Suitability Models: Brook Trout. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.24.

Reiser, D.W. and T.A. Wesche. 1977. Determination of physical and hydraulic preferences of brown and brook trout in the selection of spawning locations. Water Resources Res. Inst., Univ. Wyoming, Laramie. 112 pp.

Reiser, D.W. and R.G. White. 1983. Effects of complete redd dewatering on salmonid egg-hatching success and development of juveniles. Trans. Am. Fish. Soc. 112:532-540.

Rimmer, D.M., U. Paim, and R.L. Saunders. 1983. Autumnal habitat shift of juvenile Atlantic salmon in a small river. Can. J. Fish. Aquat. Sci. 40:671-680.

Rimmer, D.M., U. Paim, and R.L. Saunders. 1984. Changes in the selection of microhabitat by juvenile Atlantic salmon at the summer-autumn transition in a small river. Can. J. Fish. Aquat. Sci. 41:469-475.

Rinne, J.N. 1980. Spawning habitat and behavior of Gila trout, a rare salmonid of the southwestern United States. Trans. Am. Fish. Soc. 109:83-91.

Rinne, J.N. 1982. Movement, home range, and growth of a rare Southwestern trout in improved and unimproved habitats. N. Am. J. Fish. Mgmt. 2:150-157.

Risser, R.J., C.A. Fox, F.J. Lang, and T.C. Messick (eds.). 1984. Proc. Workshop Instream Flow Requirements for Riparian Vegetation in the Sierra Nevada, California. Prepared by Jones and Stokes Associates for Pacific Gas and Electric Company, Dep. Eng. Research, San Ramon, CA.

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

Rosgen, D. 1982. A procedure and rationale for securing favorable conditions of water flows on National Forest System Lands in Northern Wyoming. Draft ms. U.S. Forest Service. 86 pp.

Ruggles, C.P. 1966. Depth and velocity as a factor in stream rearing and production of juvenile coho salmon. Can. Fish Culturist 38:37-53.

Russell, R.L. and R.J. Mulvaney. 1973. Recommending streamflows to meet national forest needs. IN Proc. Seminar Hydrology and the Environment, pp.36-52. Water Resources Res. Inst., Univ. Wyoming, Laramie.

Sale, M.J., G.F. Cada, J.M. Loar, and P. Kanciruk. 1983. Application of habitat evaluation models in southern Appalachian trout streams. Presented at the 113th Annual Meeting of the American Fisheries Society, Milwaukee (abstract).

Sams, R.E. and L.S. Pearson. Unpublished. A study to develop methods for determining spawning flows for anadromous salmonids. (1963) Oregon Fish Commission, Portland. 56 pp.

Saunders, J.W. and M.W. Smith. 1962. Physical alteration of stream habitat to improve brook trout production. Trans. Am. Fish. Soc. 91:185-188.

Scarnecchia, D.L. 1981. Effects of streamflow and upwelling on yield of wild coho salmon in Oregon. Can. J. Fish. Aquat. Sci. 38:471-475.

Schindler, D.W., R.W. Newbery, K.G. Beaty, J. Prokopowich, T. Ruszczynski, and J.A. Dulton. 1980. Effects of a windstorm and forest fire on chemical losses from forested watersheds and on the quality of receiving streams. Can. J. Fish. Aquat. Sci. 37:328-334.

Schlesinger, D.A. and H.A. Regier. 1983. Relationship between environmental temperature and yields of subarctic and temperate zone fish species. Can. J. Fish. Aquat. Sci. 40:1829-1837.

Schlosser, I.J. 1982. Trophic structure, reproductive success, and growth rate of fishes in a natural and modified headwater stream. Can. J. Fish. Aquat. Sci. 39:968-978.

Seegrist, D.W. and R. Gard. 1972. Effects of floods on trout in Sagehen Creek, Calif. Trans. Am. Fish. Soc. 101:478-482.

Sheppard, J.D. and J.H. Johnson. 1981. Preference assessments of depth, velocity, and substrate types for juvenile salmonids and adult blacknose dace in Lake Ontario tributary streams. Presented at the 37th Northeast Fish and Wildlife Conerence, Virginia Beach, VA. New York State Dep. Environ. Conserv., Albany.

Shingleton, M.V., C.H. Hocutt, and J.R. Stauffer, Jr. 1981. Temperature preference of the New River shiner. Trans. Am. Fish. Soc. 110:660-661.

Shirazi, M.A. and W.K.Seim. 1981. Stream system evaluation with emphasis on spawning habitat for salmlonids. Water Resour. Res. 17:592-594.

Shirvell, C.S. and R.G. Dungey. 1983. Microhabitats chosen by brown trout for feeding and spawning in rivers. Trans. Am. Fish. Soc. 112:355-367.

Shortreed, K.S. and J.G. Stockner. 1983. Periphyton biomass and species composition in a coastal rainforest stream in British Columbia: effects of environmental changes caused by logging. Can. J. Fish. Aquat. Sci. 40:1880-1886.

Shumway, D.L., C.E. Warren, and P. Doudoroff. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Trans. Am. Fish. Soc. 93(4):342-356.

Shuter, B.J., J.A. MacLean, F.E.J. Fry, and H.A. Regier. 1980. Stochastic simulation of temperature effcts on first-year survival of smallmouth bass. Trans. Am. Fish. Soc. 109:1-34.

Sigler, J.W., T.C. Bjornn, and F.H. Everest. 1984. Effects of chronic turbidity on density and growth of steelhead and coho salmon. Trans. Am. Fish. Soc. 113:142-150.

Simons, D.B. 1976. Management of river systems. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. I, pp.255-289. Am. Fish. Soc., Bethesda, MD.

Skibitzke, H.E. and R.A. Bowen. 1983. A Basis for Mitigation Measures on the East Slope of the Sierra Nevada. Pepared for Groves Energy Company by H.E. Sibitzke and Associates, Tempe, AZ.

Smith, A.K. 1973. Development and application of spawning velocity and depth criteria for Oregon salmonids. Trans. Am. Fish. Soc. 102:312-316.

Southall, P.D. and W.A. Hubert. 1984. Habitat use by adult paddlefish in the upper Mississippi River. Trans. Am. Fish. Soc. 113:125-131.

Stalnaker, C.B. 1979. The use of habitat structure preferenda for establishing flow regimes necessary for maintenance of fish habitat. IN The Ecology of Regulated Streams (J.V. Ward and J.A. Stanford, eds.), pp. 321-337. Plenum, New York.

Stalnaker, C.B. and J.L. Arnette. 1976. Methodologies for determining instream flows for fish and other aquatic life. IN Methodologies for the Determination of Stream Resource Maintenance Flow Requirements: An Assessment. US Dep. Interior Fish and Wildlife Service, Washington.

Stalnaker, C.B. and R.T. Milhous. 1983. Responses to General Questions Compiled by Convenors of the Instream Flow Technology Section of the 1983 Hydropower Conference. US Dep. Interior Fish and Wildlife Service, Instream Flow and Aquatic Systems Group, Ft. Collins, CO.

Stefanich, F.A. 1951. The population and movement of fish in Prickley Pear Creek, Montana. Trans. Am. Fish. Soc. 81:260-274.

Stober, Q.J., R.E. Narita, and A.H. Hamalainen. 1978. Instream Flow and the Reproductive Efficiency of Sockeye Salmon. Completion Report for Project B-065-WASH, OWRT. 123 pp.

Stuber, R.J. 1982. Habitat Suitability Index Models: Black Bullhead. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.14.

Stuber, R.J., G. Gebhart, and O.E. Maughan. 1982a. Habitat Suitability Index Models: Bluegill. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.8.

Stuber, R.J., G. Gebhart, and O.E. Maughan. 1982b. Habitat Suitability Index Models: Green Sunfish. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.15.

Swank, G.W. and R.W. Phillips. 1976. Instream flow methodology for the Forest Service in the Pacific Northwest Region. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 334-343. Am. Fish. Soc., Bethesda, MD.

Sweetman, D.A. 1979. Protecting Flows in Montana: Yellowstone River Reservation Case Study. Rep. FWS/OBS-79/36. U.S. Dep. Interior, Cooperative Instream Flow Service Group, Ft. Collins, CO.

Swenson, W.A., G.D. Heberling, and J.W. Weinhold. 1982. Development and testing of a model for predicting year-class strength of smallmouth bass in the upper Mississipi River. IN Monticello Nuclear Generating Plant Environmental Monitoring Program 1980 Annual Report. Northern States Power Company, Minneapolis.

Swenson, W.A., T.D. Simonson, G.D. Heberling, and J.W. Weinhold. 1983. Influence of streamflow on nesting success and subsequent survival, feeding, growth production, and behavior of young smallmouth bass. IN Monticello Nuclear Generating Plant Environmental Monitoring Program 1982 Annual Report. Northern States Power Company, Minneapolis.

Swift, C.H. 1976. Estimates of stream discharges preferred by steelhead trout for spawning and rearing in western Washington. USGS Open File Report 75-155. U.S. Geological Survey.

Swift, C.H. 1979. Preferred Stream discharges for salmon spawning and rearing in Washington. USGS Open File Report 77-422. U.S. Geological Survey.

Swink, W.D. and K.E. Jacobs. 1983. Influence of a Kentucky flood-control reservoir on the tailwater and headwater fish populations. N. Am. J. Fish. Mgmt. 3:197-203.

Symons, P.E.K. 1968. Increase in aggression and in strength of the social hierarachy among juvenile salmon deprived of food. J. Fish. Res. Board. Can. 25:2387-2401.

Tappel, P.D. and T.C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. N. Am. J. Fish. Mgmt. 3:123-135.

Taylor, D.W. 1982. Riparian Vegetation of the Eastern Sierra: Ecological Effects of Stream Diversions. Contribution No. 6, Mono Basin Research Group. 56 pp.

Taylor, M.W. 1981. A generalized inland fishery simulator for management biologists. N. Am. J. Fish. Mgmt. 1:60-72.

Tennant, D.L. Unpublished. Instream flow regimens for fish, wildlife, recreation, and related environmental resources. Ms. circulated by U.S. Fish and Wildlife Service (1975). 30 pp.

Tennant, D.L. 1976. Instream flow requirements for fish, wildlife, recreation, and related environmental resources. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 359-373. Am. Fish. Soc., Bethesda, MD.

Terhune, L.D.B. 1958. The Mark VI groundwater standpipe for measuring seepage through salmon spawning gravel. J. Fish. Res. Board Can. 15:1027-1063.

Terrell, J.W. (ed.). Unpublished. Proc. Workshop on Fish Habitat Suitability Index Models. Draft ms (1984). US Dep. Interior, Fish and Wildlife Service, Western Energy and Land Use Team, Ft. Collins, CO.

Theurer, F.D. 1982. Instream water temperature model. Instream Flow Inform. Paper 16 (unpubl. ms.). U. S. Dep. Interior, Fish. Wildl. Serv., Fort Collins, CO. 131 pp.

Trial, J.G., C.S. Wade, J.G. Stanley, and P.C. Nelson. 1983. Habitat Suitability Information: Fallfish. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.48.

Trial, J.G., C.S. Wade, J.G. Stanley, and P.C. Nelson. 1983. Habitat Suitability Information: Common Shiner. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.40.

Trial, J.G., C.S. Wade, and J.G. Stanley. Unpublished. HSI models for Northeastern fishes. IN Proc. Workshop on Fish Habitat Suitability Index Models (J.W. Terrell, ed.). Draft ms (1984). US Dep. Interior, Fish and Wildlife Service, Western Energy and Land Use Team, Ft. Collins, CO.

Trial, J.G., J.G. Stanley, M. Batcheller, G. Gebhart, O.E. Maughan, and P.C. Nelson. 1983. Habitat Suitability Information: Blacknose Dace. U.S. Dep. Interior, Fish Wildl. Serv., Habitat Eval. Proc. Grp. Rep. FWS/OBS-82/10.41.

Trihey, E.W. 1979. The IFG incremental methodology. IN Proc. Workshop in Instream Flow Habitat Criteria and Modeling (G.L. Smith, ed.), pp. 24-62. Inform. Ser. No. 40. Colo. Resources Res. Inst., Colo. State Univ., Ft. Collins.

Trihey, E.W. and D.L. Wegner. 1981. Field data collection procedures for use with the physical habitat simulation system of the Instream Flow Group. U.S. Dep. Interior, Fish. Wildl. Serv,. Cooperative Instream Flow Service Group, Ft. Collins, CO. 151 pp.

Trotzky, H.M. and R.W. Gregory. 1974. The effects of water flow manipulation below a hydroelectric power dam on the bottom fauna of the upper Kennebec River, Maine. Trans. Am. Fish. Soc. 103:318-324.

Tschaplinski, P.J. and G.F. Hartman. 1983. Winter distribution of juvenile coho salmon before and after logging in Carnation Cr., B.C., and some implications for overwinter survival. Can. J. Fish. Aquat. Sci. 40:452-461.

Turner, P.R., J.W. Anderson, and M.A. Burrough. 1980. Instream Flow Studies of the Rio Chama, Rio Grande, and San Juan River of New Mexico: a Phase II evaluation of Instream Flow Methodologies. Prepared for US Dep. Interior Fish and Wildlife Service, Region 2 by Dep. Fish. Wildl. Sci., New Mexico St. Univ., Las Cruces.

Tyus, H.M., B.D. Burdick, and C.W. McAda. 1984. Use of radiotelemetry for obtaining habitat preference data on Colorado squawfish. N. Am. J. Fish. Mgmt. 4:177-180.

Uhler, R.S. 1979. Least squares regression estimates of the Schaefer production model: some Monte Carlo simulation results. Can. J. Fish. Aquat. Sci. 37:1284-1294.

Verstraete, G.A. 1976. Recreational IFN methodology: introduction. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 344-345. Am. Fish. Soc., Bethesda, MD.

Vigg, S.C. and D.L. Koch. 1980. Upper lethal temperature range of Lahontan cutthroat trout in waters of different ionic concentration. Trans. Am. Fish. Soc. 109:336-339.

Voos, K.A. 1981. Simulated use of the exponential polynomial/maximum likelihood technique in developing suitability of use functions for fish habitat. Ph.D. thesis. Utah State Univ., Logan. 85 pp.

Voos, K.A., W.J. Grenney, and K.P. Burnham. Unpublished. A model for fish habitat usability. Unpub. ms (1981). Cooperative Instream Flow Service Group, Ft. Collins, Colorado. 23 pp.

Ward, J.V. 1976. Effects of flow patterns below large dams on stream benthos: a review. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 235-253. Am. Fish. Soc., Bethesda, MD.

Waters, B. F. 1976. A methodology for evaluating the effects of different streamflows on salmonid habitat. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 254-266. Am. Fish. Soc., Bethesda, MD.

Waters, T.F. 1983. Replacement of brook trout by brown trout over 15 years in a Minnesota stream: production and abundance. Trans. Am. Fish. Soc. 112:137-146.

Weatherred, J.D., H.L. Silvey, and D.J. Pfankuch. 1981.Program Documentation for R2-CROSS-81. Rep. WSDG-AD-00004. USDA Forest Service, Watershed System Development Group, Ft. Collins, CO.

Webster, D.A. and G. Eiriksdotter. 1976. Upwelling water as a factor influencing choice of spawning sites by brook trout. Trans. Am. Fish. Soc. 105(3):416-421.

Wegner, D. Unpublished. Users guide to the physical habitat simulation model. (1980). U.S. Fish Wildl. Serv., Instream Flow and Aquatic Systems Group, Ft. Collins, CO. 164 pp.

Wesche, T.A. 1973. Parametric Determination of Minimum Stream Flow for Trout. Water Resources Ser. 37. Water Resources Res. Inst., Univ. Wyoming, Laramie. 102 pp.

Wesche, T.A. 1974. Relationship of Discharge Reductions to Available Trout Habitat for Recommending Suitable Stream Flows. Water Resources Ser. 53. Water Resources Res. Inst., Univ. Wyoming, Laramie.

Wesche, T.A. 1976. Development and application of a trout cover rating system for IFN determinations. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman,eds.), Vol. II, pp. 224-234. Am. Fish. Soc., Bethesda, MD.

Wesche, T.A. 1980. The WRRI Trout Cover Rating Method: Development and Application. Water Resources Ser. 78. Water Resources Res. Inst., Univ. Wyoming, Laramie.

Wesche, T.A. 1983. Overview of instream habitat evaluation methods currently applied in the Western Region. Presented at West. Div. Meeting of Am. Fish. Soc., Jackson, WY, 10-14 July 1983. Water Resour. Res. Inst., Univ. Wyoming, Laramie.

Wesche, T.A. and P.A. Rechard. 1980. A Summary of Instream Flow Methods for Fisheries and Related Research Needs. Bulletin 9, Eisenhower Consortium for Western Environ. Forestry Res. 122 pp.

Whisenant, K.A. 1970. Characteristics of smallmouth bass and Ozark bass populations in Buffalo National River, Arkansas. MS thesis. Oklahoma St. Univ., Stillwater.

White, R.G. 1976. A methodology for recommending stream resource maintenance flows for large rivers. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 376-399. Am. Fish. Soc., Bethesda, MD.

White, R.J., E.A. Hansen, and G.R. Alexander. 1976. Relationship of trout abundance to stream flow in Midwestern streams. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 597-615. Am. Fish. Soc., Bethesda, MD.

Whitlow, T.H. and R.W. Harris. 1979. Flood Tolerance in Plants: A State of the Art Review. Tech. Rep. E-79-2, U.S. Army Corps of Engineers, Washington.

Whitlow, T.H., R.W. Harris, and A.T. Leiser. 1979. Use of Vegetation to Reduce Levee Erosion in the Sacramento - San Joaquin Delta. Prepared for California Department of Water Resources by Department of Environmental Horticulture, Univ. Calif., Davis.

Whitlow, T.H., R.W. Harris, and A.T. Leiser. 1980. Use of Vegetation to Reduce Levee Erosion in the Sacramento - San Joaquin Delta. Prepared for California Department of Water Resources by Department of Environmental Horticulture, Univ. Calif., Davis.

Whitworth, W.E. and R.J. Strange. 1983. Growth and production of sympatric brook and rainbow trout in an Appalachian stream. Trans. Am. Fish. Soc. 112:469-475.

Wickett, W.P. 1958. Review of certain environmental factors affecting the production of pink and chum salmon. J. Fish. Res. Board Can. 15:1103-1126.

Wiley, R.W. and D.J. Dufek. 1980. Standing crop of trout in the Fontanelle tailwater of the Green River. Trans. Am. Fish. Soc. 109:168-175.

Witzel, L.D. and H.R. MacCrimmon. 1983. Redd-site selection by brook trout and brown trout in southwestern Ontario streams. Trans. Am. Fish. Soc. 112:760-771.

Workman, D.L. 1976. Use of the water surface profile program in determining instream flow needs in Sixteenmile Creek, Montana. IN Proc. Symp. and Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 505-513. Am. Fish. Soc., Bethesda, MD.

Wrenn, W.B. 1980. Effects of elevated temperature on growth and survival of smallmouth bass. Trans. Am. Fish. Soc. 109:617-625.

Wyoming Game and Fish Department. 1979. Evaluation of Methods Used in Recommending Instream Flows for Fisheries in Wyoming. Publ. W/IFG-9/W104. Cooperative Instream Flow Service Group, US Fish Wildl. Serv., Ft. Collins, CO.

X

Methodology: ANNEAR AND CONDER'S STATISTICAL WETTED PERIMETER METHOD

Type of Method: CONCEPTUAL USING DISCHARGE AND HYDRAULIC VARIABLES

Equation: MF = AF - LSD; MF = AF - 2LSD; MF = 2AF - LSD; MF = 2AF -2 LSD

MF = recommended maintenance flow
AF = mean annual flow
LSD = Fisher's Least Significant Difference statistic

Correlation Coefficient: None found.

Source Documentation: Annear, T.C. and A.L. Conder 1983. Evaluation of Instream Flow Needs for Use in Wyoming. Wyoming Game and Fish Department, Fish Division. Completion report for Contract No. YA-512-CT9-226. 247 pp.

Objective: To develop a reproducible method of identifying appropriate maintenance flows from plots of wetted perimeter versus discharge.

Level of Effort: Low, once a relationship between wetted perimeter and discharge has been determined either from field observation or using a hydraulic simulation model.

Model Development: The authors, frustrated by the lack of evident inflection points or other basis for selecting appropriate flows from plots of wetted perimeter versus discharge, decided to develop their own reproducible approach. They picked two reference flows: mean annual flow and twice mean annual flow, and then used Fisher's Least Significant Difference statistic on the combined data from all test riffles to determine (at the 90% confidence level) the deviation from that flow that resulted in a significant change in wetted perimeter. They then constructed the four families above as possible indicators of maintenance flow.

Basic Assumptions: This method has two fundamental assumptions. The first is that either mean annual flow or twice mean annual flow is an appropriate baseline from which to calculate acceptable reduction; the second is that the flow reduction which results in a statistically detectable change at the 90% probability level is reproducible and has some biological consequence. Since the size of the LSD is a function (at any given flow) of the homogeneity of the stream, A consequence of this assumption is that the less homogeneous the stream, the smaller the acceptable flow.

Limitations and Constraints: Lack of evidence that any of the values used have any biological significance.

Relationship to Other Methods: Uses the same wetted perimeter curve as Collings (1974), Nelson (1984), White (1976), and Weatherred et al. (1981).

Quality of the Documentation: No justification for the technique is provided.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: Source document.

Critical Opinion: This is an attempt to get around the fact that there is no inherent basis for selecting a point on a wetted perimeter versus discharge curve as an appropriate stream flow. The statistic chosen has no inherent biological meaning. The authors do not even commit to whether mean annual flow or twice mean annual flow is the appropriate starting point. The size of the LSD at any given flow is largely a product of the relative homogeneity of the transects chosen (or of the stream if the transects are representative), so that inhomogeneous streams will have lower acceptable flows. There is no basis presented for this result, although one might develop a line of reasoning to support it. Also, because of the characteristic shape of wetted perimeter versus discharge curves, the lower the base flow chosen, the larger will be the allowed reduction. We cannot see that this method offers much improvement over the arbitrary choice of a point on the curve.

✓

Methodology: BARBER ET AL.'S DIAGRAMMATIC MAPPING METHOD FOR COHO SALMON

Type of Method: EMPIRICAL USING DISCHARGES, HYDRAULIC AND STRUCTURAL VARIABLES

Equation: Age 0 coho: $\text{Log}_{10}\#/30\text{m} = 0.871 + 1.011\ \text{LogASA} * 0.01\text{RV} - 0.009\ \text{S}\ (R^2 = 0.76)$

Age 0 coho: $\text{Log}_{10}\#/30\text{m} = 2.305 + 1.236\ \text{Log}_{10}\text{PW} - 2.164\ \text{Log}_{10}\ \text{BT} + 0.031\ \text{CW}\ (R^2 = 0.59)$

Age 0 coho: $\text{Log}_{10}\#/\text{m}^2 = 0.473 + 0.421\ \text{ASA} - 0.004\ \text{S} - 0.013\text{G}\ (R^2 = 0.51)$

Age 1 coho: $\text{Log}_{10}\#/30\text{m} = 0.249 - 0.73\ \text{G} + 0.416\ \text{Log}_{10}\text{SS} + 0.006\text{RV} + 0.260\ \text{Log}_{10}\text{UB}\ (R^2 = 0.49)$

Age 1 coho: $\text{Log}_{10}\#/30\text{m} = 1.744 + 0.725\ \text{Log}_{10}\text{PW} - 2.219\ \text{Log}_{10}\text{PR}\ (R^2 = 0.36)$

Age 1 coho: $\text{Log}_{10}\#/\text{m}^2 = 0.049 + 0.102\text{RVP} - 0.004\text{G}\ (R^2 = 0.30)$

ASA = m^2 of substrate 8-256mm in diameter
RV = m^2 with overhanging vegetation
S = days elapsed from the first day of sampling in the field season
PW = pool width (m?)
BT = percent stream width over gravel and cobble
CW = channel width (m?)
G = gradient
SS = m^2 of water <50cm deep with a velocity <30cm * sec^{-1}
UB = m^2 of eroded overhanging stream banks
PR = pool rating: 1-5: 1 = wide, deep abundant shelter; 5 = narrow, shallow, with exposed shelter
RVP = m^2 with overhanging vegetation and velocity <30cm * sec^{-1}

Correlation Coefficient: Shown with equations.

Source Documentation: Barber, W.E., M.W. Oswood and S.J. Deschermeier. 1980. A fish stream habitat survey technique for predicting fish abundance. pp. 225-240 in (N.B. Armantrout, ed.) Proc. Symp. Aquisition and Utilization of Aquatic Habitat Inventory Information. Am. Fish. Soc., Bethesda, MD.

Objective: To document one method (the Diagrammatic Mapping Method) and test it and another (the USFS R-4 Transect Method) for their ability to predict standing crop of stream fishes.

Level of Effort: Moderate to high. All variables must be measured in the field.

Model Development: The Transect Method (fish/m^2 in the above equations) consists of measuring pool riffle and channel width, bank stability, and rating pool and substrate types along 5 transects. The Diagrammatic Mapping Method (DMM) consists of calculating the area of 14 types of habitat (including depths > and < 50cm, velocities > and < 30cm * sec^{-1}, substrate 8-256 mm in diameter, and a series of cover variables, with the thought that these areas may be correlated with fish standing crop. All of the transect variables and areas were individually regressed (expressed both as #/30m and #/m^2), in both untransformed and $\log_{10}$ transformed versions. The form of each variable having the strongest individual correlation coefficient was used (along with all the other variables) in a forward stepwise multiple regression model, with variables resulting in a <1% improvement in R^2 being excluded. The resulting equations are listed above. In the Transect Method, only those variables identified by Dunham and Collotzi (1975) were used. For the DMM, only the areas of habitat type were used.

Basic Assumptions: That the variables measured are the important ones. That the raw variables are appropriately used directly (or log transformed), rather than transformed using suitability curves. That the binary depth and velocity criteria are reasonable.

Limitations and Constraints: Even though depth and velocity were measured, they appear in only two of the equations, because they did not contribute to the strength of the regression in the others, possibly because the criteria are binary and the break point chosen may have little biological significance. The other variables are not necessarily strongly related to flow, so the utility of these models for instream flow determination is minimal. Also, there is little reason to think that either the model variables or parameters (coefficients) would be the same if linear regression were used on a new data set.

Relationship to Other Methods: The mapping of areas is not used in other techniques reviewed here, but the multiple linear regression is similar to Rabern (1984).

Quality of the Documentation: Brief, but the authors will send more on request.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: The binary criteria for depth and velocity probably makes the DMM method nonfunctional for instream flow analysis. Measuring the areas rather than sampling them using transects probably results in a more accurate stream characterization, however, and could readily be expanded to other methods.

✓

Methodology: BINNS AND EISERMAN'S WYOMING HABITAT QUALITY INDEX PROCEDURE

Type of Method: EMPIRICAL USING BIOLOGICALLY WEIGHTED HYDRAULIC, STRUCTURAL, AND OTHER PHYSICAL/CHEMICAL VARIABLES

Equation:

$$HQI=([0.125*(x_1+1)^{0.807}*(x_2+1)^{0.877}*(x_3+1)^{1.233}*((x_3*x_4*x_9*x_{10})+1)^{0.631}*((x_7*x_8*x_{11})+1)^{0.182}]^{-1.12085})-1$$

HQI=Habitat Quality Index (1kg trout * ha^{-1})

[Note: All variables are scaled to dimensionless values from 0-4 prior to being used in the HQI regression equation]

x1 = late summer stream flow (% avg. daily flow)
x2 = annual stream flow variation (annual peak flow/ annual minimum flow)
x3 = maximum summer water temperature (C)
x4 = nitrate nitrogen ($mg*l^{-1}$)
x7 = % cover (% surface area)
x8 = % eroding stream banks (% total length)
x9 = relative amt. submerged vegetation
x10 = water velocity (rate of dye transport)
x11 = stream width (mean edge to edge at low flow)

Correlation Coefficient: $R^2 = 0.97$ between predicted and actual standing crop. (An extremely good correlation.)

Source Documentation: Binns, N.A. 1982. Habitat Quality Index Procedures Manual, Wyoming Game and Fish Department, Cheyenne. Binns, N.A. and F.M. Eiserman. 1979. Quantification of fluvial trout habitat in Wyoming. Trans. Am. Fish. Soc. 108:215-228.

Objective: To establish a mathematical relationship between an index of habitat quality (the HQI) and trout standing crop for use in habitat evaluations, assessment of habitat alterations, and instream flow modeling.

Level of Effort: Moderate. Each stream must be visited during the flows of interest and a series of observations made. Calculation of the Habitat Quality Index, however, can be done on a pocket calculator

Model Development: The model was developed by scaling the raw data from 22 potential input variables (all those listed above plus turbidity, depth, stream morphology [unexplained], bed material, silt deposition, nitrate nitrogen, total alkalinity, total phosphorus, total dissolved solids, hydrogen ion, stream bank vegetation, fish food abundance, fish food diversity, and fish food type) from 0 to 4 based on presumed habitat quality associated with different levels of each variable. Multiple linear regression was then employed between the response variable (Y or HQI, an estimator of standing crop) and the log-transformed scaled variables to determine which variables to retain to estimate the regression parameters. Those with partial correlation coefficients <0.28 were then rejected.

Basic Assumptions: That these are the important variables, and that their values during the low flow period during which they are measured determine the standing crop of trout as well.

Limitations and Constraints: The HQI index would not be expected to have the same parameters elsewhere.

Relationship to Other Methods: This method is somewhat similar to and precedes other linear regression fits of standing crop data to a collection of habitat variables (such as the work of Layher (1983) and Rabern (1984)). It differs from these, however, in that the raw variables are both arbitrarily scaled and log transformed prior to applying multiple linear regression, and the form of the final equation (exponential) is not used by other authors.

Quality of the Documentation: Completely documented.

Experimental Tests of the Method: Tested by the authors and by Annear & Conder 1983.

Published Enhancements to the Method: None found.

Critical Review of the Method: Annear & Conder 1983.

Published Comparisons With Other Methods: Annear & Conder 1983.

Critical Opinion: This model is an empirical fit to real data, and has been shown both by the authors and independently by Annear & Conder (1983) to be predictive of standing crop on other Wyoming streams. Because it is an empirical fit of data from a particular type of stream, it would not be expected to be universally predictive. Similar treatment of similar data from other types of streams in other regions might, however, result in equally predictive regional models.

X

Methodology: COLLINGS' PINK AND CHUM SALMON MODEL

Type of Method: EMPIRICAL USING BASIN, HYDRAULIC, AND STRUCTURAL VARIABLES

Equation: $PSD = 1.27\ V_1^{0.446} * V_4^{0.501} * V_5^{0.329} * V_8^{0.282}$

$$SSD = 0.425\ V_1^{0.411} * V_2^{-0.110} * V_4^{0.498} * V_5^{0.369} * V_8^{-0.236}$$

$$RD = 0.32\ V_1^{0.327} * V_2^{0.533} * V_4^{0.591}$$

PSD = Preferred Spawning Discharge ($ft^3 * sec^{-1}$), the discharge resulting in maximum spawnable area

SSD = Spawning Sustaining Discharge ($ft^3 * sec^{-1}$), the discharge at which the percentage reduction in spawnable area is "just less" than the percentage reduction in preferred discharge as discharge is decreased in increments of 5, 10, 15 and 25% of PSD

RD = Rearing Discharge; a discharge "selected somewhere near" the characteristic abrupt change in slope of the relationship between discharge and wetted perimeter (not species specific)

V_1 = drainage area (mi^2)
V_2 = mean basin altitude (ft)
V_4 = reach width (ft)
V_5 = % 1-3 inch gravel
V_8 = hydraulic radius (ft)

Correlation Coefficient: $R^2 = 0.90$ for PSD, $R^2 = 0.90$ for SSD, $R^2 = 0.85$ for rearing habitat

Source Documentation: Collings, M.R. 1974. Generalization of spawning and rearing discharges for several pacific salmon species in Western Washington. United States Geological Survey Open File Report, Tacoma, Washington. 39 pp.

Objective: To develop equations (using geomorphic input variables) useful for estimating the discharges that provide the maximum area for salmon spawning, the spawning-sustaining discharge (defined above - not less than 75% of the discharge producing the maximum spawning area) and the optimum rearing discharge.

Level of Effort: Low. All of the variables can be obtained from topographic maps.

Model Development At 50 different sites on 17 different streams, Collings measured the area having depths of 1.0-1.5 ft and velocities of 1.0-2.25 ft $* sec^{-1}$ at (usually) 10 different discharges, then plotted the area of preferred depth and velocity versus discharge and fitted a curve to it using the moving parabolic arc technique. The peak of the curve was considered to be the PSD, and the SSD was calculated from the shape of the ascending limb of the curve. The RD was calculated entirely differently, using only a plot of wetted perimeter versus discharge, and selecting a point on it "somewhere near the change in direction".

Basic Assumptions: That the most appropriate form of the linear regression model is a power function, and that the simple binary criteria for depth and velocity suitability are accurate and appropriate. For rearing discharges, the assumption is that the change of slope in the wetted perimeter versus discharge curve is a reasonable criterion.

Internal Error Checking: None.

Limitations and Constraints: The model does not address the question of whether either PSD or SSD are needed in any given situation, and does not justify the SSD or RD criteria. Also, it is unlikely that the model could be geographically transportable, though the same techniques could be used elsewhere.

Relationship to Other Methods: The power function multiple linear regression is the form used by Binns and Eiserman (1979). (The use of geomorphic input variables to predict appropriate discharges is reminiscent of Parsons et al. 1980.) The measurement of suitable area versus discharge is a precursor of the IFIM.

Quality of the Documentation: Complete

Experimental Tests of the Method: None found

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This method is quite interesting in that it provides a technique for using readily available map data to arrive at the same result that would be obtained using intensive transect measurements at many discharges. It is a sensible and successful attempt to find easily measured surrogate variables to predict optimum spawning discharges for anadromous species which may be limited by spawning site availability. The criteria for rearing discharges, however, is not so well justified.

X

Methodology: COLLINGS' SOCKEYE SALMON MODEL

Type of Method: EMPIRICAL USING BASIN AND HYDRAULIC VARIABLES

Equation: $PSD = 4.72 * V_1^{0.735} * V_3^{-0.267} * V_4^{0.571} * V_8^{-0.703}$

$SSD = 16.8 * V_1^{0.969} * V_3^{-0.272} * V_8^{-0.491}$

$RD = 0.32 * V_1^{0.327} * V_2^{0.533} * V_4^{0.591}$

PSD = Preferred Spawning Discharge ($ft^3 * sec^{-1}$), the discharge resulting in maximum spawnable area

SSD = Spawning Sustaining Discharge ($ft^3 * sec^{-1}$), the discharge at which the percentage reduction in spawnable area is "just less" than the percentage reduction in preferred discharge as discharge is decreased in increments of 5, 10, 15 and 25% of PSD.

RD = Rearing Discharge; a discharge "selected somewhere near" the characteristic abrupt change in slope of the relationship between discharge and wetted perimeter (not species specific)

V_1 = drainage area (mi^2)
V_2 = mean basin altitude (ft)
V_3 = reach altitude (ft)
V_4 = reach width (ft)
V_8 = hydraulic radius (ft)

Correlation Coefficient: $R^2 = 0.85$ for PSD, $R^2 = 0.85$ for SSD, $R^2 = 0.85$ for rearing habitat.

Source Documentation: Collings, M.R. 1974. Generalization of Spawning and Rearing Discharges for Several Pacific Salmon Species in Western Washington. United States Geological Survey Open File Report, Tacoma, Washington. 39 pp.

Objective: To develop equations (using geomorphic input variables) useful for estimating the discharges that provide the maximum area for salmon spawning, the spawning-sustaining discharge (defined above - not less than 75% of the discharge producing the maximum spawning area) and the optimum rearing discharge.

Level of Effort: Low. All of the variables except reach width can be obtained from topographic maps.

Model Development At 50 different sites on 17 different streams, Collings measured the area having depths of 1.0-1.5 ft and velocities of 1.0-2.25 ft $* sec^{-1}$ at (usually) 10 different discharges, then plotted the area of preferred depth and velocity versus discharge and fitted a curve to it using the moving parabolic arc technique. The peak of the curve was considered to be the PSD, and the SSD was calculated from the shape of the ascending limb of the curve. The RD was calculated entirely differently, using only a plot of wetted perimeter versus discharge, and selecting a point on it "somewhere near the change in direction".

Basic Assumptions: That the most appropriate form of the linear regression model is a power function, and that the simple binary criteria for depth and velocity suitability are accurate and appropriate. For rearing discharges, the assumption is that the change of slope in the wetted perimeter versus discharge curve is a reasonable criterion.

Internal Error Checking: None

Limitations and Constraints: The model does not address the question of whether either PSD or SSD are needed in any given situation, and does not justify the SSD or RD criteria. It is unlikely that the model could be geographically transportable, though the same techniques could be used elsewhere.

Relationship to Other Methods: The power function multiple linear regression is the form used by Binns and Eiserman (1979). (The use of geomorphic input variables to predict appropriate discharges is reminiscent of Parsons et al. 1981.) The measurement of suitable area versus discharge is a precursor of the IFIM.

Quality of the Documentation: Complete

Experimental Tests of the Method: None found

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This method is quite interesting in that it provides a technique for using readily available map data (except reach width) to arrive at the same result that would be obtained using intensive transect measurements at many discharges. It is a sensible and successful attempt to find easily measured surrogate variables to predict optimum spawning discharges for anadromous species which may be limited by spawning site availability. The criteria for rearing discharges, however, is not so well justified.

X

Methodology: COLLINGS' FALL CHINOOK SALMON MODEL

Type of Method: EMPIRICAL USING BASIN AND HYDRAULIC VARIABLES

Equation: $PSD = 209 \ V_1^{0.436} * V_3^{-0.112} * V_4^{0.544} * V_6^{0.187}$

$$SSD = 1.40 \ V_1^{0.449} * V_4^{0.503} * V_6^{0.116}$$

$$RD = 0.32 \ V_1^{0.327} * V_2^{0.533} * V_4^{0.591}$$

PSD = Preferred Spawning Discharge ($ft^3 * sec^{-1}$), the discharge resulting in maximum spawnable area

SSD = Spawning Sustaining Discharge ($ft^3 * sec^{-1}$), the discharge at which the percentage reduction in spawnable area is "just less" than the percentage reduction in preferred discharge as discharge is decreased in increments of 5, 10, 15 and 25% of PSD.

RD = Rearing Discharge; a discharge "selected somewhere near" the characteristic abrupt change in slope of the relationship between discharge and wetted perimeter (not species specific)

V_1 = drainage area (mi^2)
V_2 = mean basin altitude (ft)
V_3 = reach altitude (ft)
V_4 = reach width (ft)
V_6 = reach slope (ft/mi)

Correlation Coefficient: $R^2 = 0.81$ for PSD, $R^2 = 0.79$ for SSD, $R^2 = 0.85$ for rearing habitat.

Source Documentation: Collings, M.R. 1974. Generalization of Spawning and Rearing Discharges for Several Pacific Salmon Species in Western Washington. United States Geological Survey Open File Report, Tacoma, Washington. 39 pp.

Objective: To develop equations (using geomorphic input variables) useful for estimating the discharges that provide the maximum area for salmon spawning, the spawning-sustaining discharge (defined above - not less than 75% of the discharge producing the maximum spawning area) and the optimum rearing discharge.

Level of Effort: Low. All of the variables can be obtained from topographic maps.

Model Development At 50 different sites on 17 different streams, Collings measured the area having depths of 1.0-1.5 ft and velocities of 1.0-2.25 ft $* sec^{-1}$ at (usually) 10 different discharges, then plotted the area of preferred depth and velocity versus discharge and fitted a curve to it using the moving parabolic arc technique. The peak of the curve was considered to be the PSD, and the SSD was calculated from the shape of the ascending limb of the curve. The RD was calculated entirely differently, using only a plot of wetted perimeter versus discharge, and selecting a point on it "somewhere near the change in direction".

Basic Assumptions: That the most appropriate form of the linear regression model is a power function, and that the simple binary criteria for depth and velocity suitability are accurate and appropriate. For rearing discharges, the assumption is that the change of slope in the wetted perimeter versus discharge curve is a reasonable criterion.

Internal Error Checking: None.

Limitations and Constraints: The model does not address the question of whether either PSD or SSD are needed in any given situation, and does not justify the SSD or RD criteria. Also, it is unlikely that the model could be geographically transportable, though the same techniques could be used elsewhere.

Relationship to Other Methods: The power function multiple linear regression is the form used by Binns and Eiserman (1979). (The use of geomorphic input variables to predict appropriate discharges is reminiscent of Parsons et al. 1980.) The measurement of suitable area versus discharge is a precursor of the IFIM.

Quality of the Documentation: Complete.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This method is quite interesting in that it provides a technique for using readily available map data to arrive at the same result that would be obtained using intensive transect measurements at many discharges. It is a sensible and successful attempt to find easily measured surrogate variables to predict optimum spawning discharges for anadromous species which may be limited by spawning site availability. The criteria for rearing discharges, however, is not so well justified.

X

Methodology: COLLINGS' SPRING CHINOOK SALMON MODEL

Type of Method: EMPIRICAL USING BASIN, HYDRAULIC, AND STRUCTURAL VARIABLES

Equation: $PSD = 91.9 \quad V_1^{0.597} * V_2^{-0.243} * V_4^{0.340} * V_5^{-0.354} * V_7^{-0.482}$

$SSD = 45 \quad V_1^{0.587} * V_2^{-0.201} * V_4^{0.427} * V_5^{-0.393} * V_7^{-0.448}$

$RD = 0.32 \quad V_1^{0.327} * V_2^{0.533} * V_4^{0.591}$

PSD = Preferred Spawning Discharge ($ft^3 * sec^{-1}$), the discharge resulting in maximum spawnable area

SSD = Spawning Sustaining Discharge ($ft^3 * sec^{-1}$), the discharge at which the percentage reduction in spawnable area is "just less" than the percentage reduction in preferred discharge as discharge is decreased in increments of 5, 10, 15 and 25% of PSD.

RD = Rearing Discharge; a discharge "selected somewhere near" the characteristic abrupt change in slope of the relationship between discharge and wetted perimeter (not species specific).

V_1 = drainage area (mi^2)
V_2 = mean basin altitude (ft)
V_4 = reach width (ft)
V_5 = % of 1-3 inch gravel
V_7 = mean depth at 25% of stream width - mean depth at 75% of stream width [starting from the side which, when the division is completed, results in a dimensionless value >1.0]

Correlation Coefficient: $R^2 = 0.64$ for PSD, $R^2 = 0.64$ for SSD, $R^2 = 0.85$ for rearing habitat.

Source Documentation: Collings, M.R. 1974. Generalization of Spawning and Rearing Discharges for Several Pacific Salmon Species in Western Washington. United States Geological Survey Open File Report, Tacoma, Washington. 39 pp.

Objective: To develop equations (using geomorphic input variables) useful for estimating the discharges that provide the maximum area for salmon spawning, the spawning-sustaining discharge (defined above - not less than 75% of the discharge producing the maximum spawning area) and the optimum rearing discharge.

Level of Effort: Low. All of the variables can be obtained from topographic maps.

Model Development At 50 different sites on 17 different streams, Collings measured the area having depths of 1.0-1.5 ft and velocities of 1.0-2.25 $ft * sec^{-1}$ at (usually) 10 different discharges, then plotted the area of preferred depth and velocity versus discharge and fitted a curve to it using the moving parabolic arc technique. The peak of the curve was considered to be the PSD, and the SSD was calculated from the shape of the ascending limb of the curve. The RD was calculated entirely differently, using only a plot of wetted perimeter versus discharge, and selecting a point on it "somewhere near the change in direction".

Basic Assumptions: That the most appropriate form of the linear regression model is a power function, and that the simple binary criteria for depth and velocity suitability are accurate and appropriate. For rearing discharges, the assumption is that the change of slope in the wetted perimeter versus discharge curve is a reasonable criterion.

Limitations and Constraints: The model does not address the question of whether either PSD or SSD are needed in any given situation, and does not justify the SSD or RD criteria. Also, it is unlikely that the model could be geographically transportable, though the same techniques could be used elsewhere.

Relationship to Other Methods: The power function multiple linear regression is the form used by Binns and Eiserman (1979). (The use of geomorphic input variables to predict appropriate discharges is reminiscent of Parsons et al. 1980.) The measurement of suitable area versus discharge is a precursor of the IFIM.

Quality of the Documentation: Complete

Experimental Tests of the Method: None found

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This method is quite interesting in that it provides a technique for using readily available map data to arrive at the same result that would be obtained using intensive transect measurements at many discharges. It is a sensible and successful attempt to find easily measured surrogate variables to predict optimum spawning discharges for anadromous species which may be limited by spawning site availability. The criteria for rearing discharges, however, is not so well justified.

X

Methodology: COLLINGS' COHO SALMON MODEL

Type of Method: EMPIRICAL USING BASIN AND HYDRAULIC VARIABLES

Equation: $PSD = 1.75\ V_1^{0.528} * V_4^{0.390} * V_6^{0.132}$

$SSD = 1.09\ V_1^{0.564} * V_4^{0.402} * V_6^{0.165}$

$RD = 0.32\ V_1^{0.327} * V_2^{0.533} * V_4^{0.591}$

PSD = Preferred Spawning Discharge ($ft^3 * sec^{-1}$), the discharge resulting in maximum spawnable area

SSD = Spawning Sustaining Discharge ($ft^3 * sec^{-1}$), the discharge at which the percentage reduction in spawnable area is "just less" than the percentage reduction in preferred discharge as discharge is decreased in increments of 5, 10, 15 and 25% of PSD

RD = Rearing Discharge; a discharge "selected somewhere near" the characteristic abrupt change in slope of the relationship between discharge and wetted perimeter (not species specific)

V_1 = drainage area (mi^2)
V_2 = mean basin altitude (ft)
V_4 = reach width (ft)
V_6 = reach slope (ft/mi)

Correlation Coefficient: $R^2 = 0.81$ for PSD, $R^2 = 0.83$ for SSD, $R^2 = 0.85$ for rearing habitat.

Source Documentation: Collings, M.R. 1974. Generalization of Spawning and Rearing Discharges for Several Pacific Salmon Species in Western Washington. United States Geological Survey Open File Report, Tacoma, Washington. 39 pp.

Objective: To develop equations (using geomorphic input variables) useful for estimating the discharges that provide the maximum area for salmon spawning, the spawning-sustaining discharge (defined above - not less than 75% of the discharge producing the maximum spawning area) and the optimum rearing discharge.

Level of Effort: Low. All of the variables can be obtained from topographic maps.

Model Development At 50 different sites on 17 different streams, Collings measured the area having depths of 1.0-1.5 ft and velocities of 1.0-2.25 ft $* sec^{-1}$ at (usually) 10 different discharges, then plotted the area of preferred depth and velocity versus discharge and fitted a curve to it using the moving parabolic arc technique. The peak of the curve was considered to be the PSD, and the SSD was calculated from the shape of the ascending limb of the curve. The RD was calculated entirely differently, using only a plot of wetted perimeter versus discharge, and selecting a point on it "somewhere near the change in direction".

Basic Assumptions: That the most appropriate form of the linear regression model is a power function, and that the simple binary criteria for depth and velocity suitability are accurate and appropriate. For rearing discharges, the assumption is that the change of slope in the wetted perimeter versus discharge curve is a reasonable criterion.

Internal Error Checking: None.

Limitations and Constraints: The model does not address the question of whether either PSD or SSD are needed in any given situation, and does not justify the SSD or RD criteria. Also, it is unlikely that the model could be geographically transportable, though the same techniques could be used elsewhere.

Relationship to Other Methods: The power function multiple linear regression is the form used by Binns and Eiserman (1979). (The use of geomorphic input variables to predict appropriate discharges is reminiscent of Parsons et al. 1980.) The measurement of suitable area versus discharge is a precursor of the IFIM.

Quality of the Documentation: Complete.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This method is quite interesting in that it provides a technique for using readily available map data to arrive at the same result that would be obtained using intensive transect measurements at many discharges. It is a sensible and successful attempt to find easily measured surrogate variables to predict optimum spawning discharges for anadromous species which may be limited by spawning site availability.

Methodology: DUNHAM AND COLLOTZI'S U.S. FOREST SERVICE REGION 4 METHOD

Type of Method: CONCEPTUAL USING HYDRAULIC AND STRUCTURAL VARIABLES

Equation: % optimum habitat = [PMR + PSR + SBR + SER] * 4^{-1}

PMR = Pool Measure Rating = 100 -2 * ((W_p * W_s^{-1} * 100) -50); W_p = pool width, WS = stream width

PSR = Pool Structure Rating = % of total pool length rated 1, 2 or 3: (pools = or > average stream width with intermediate abundant shelter or depth >2 ft)

SBR = Stream Bottom Rating = % of total transect length over gravel and rubble

SER = Stream Environmental Rating = ((3 * B_b) + (4 * B_t)) * (4 * (B_b + B_t)$^{-1}$; B_b = bank locations with brush; B_t = bank locations with trees

Correlation Coefficient: None found.

Source Documentation: Dunham, D.F. and A. Collotzi. 1975. The Transect Method of Stream Habitat Inventory--Guidelines and Applications. USDA Forest Service, Ogden, UT 98 pp.

Objective: To determine appropriate instream flows in Utah.

Level of Effort: Moderate to high. The streams must be surveyed in the field.

Model Development: This method was originally intended to be used as a habitat rating method (Herrington and Dunham 1967), but since the habitat rating changes with flow, it is possible to plot the rating (percent optimum habitat) versus percent of existing discharge to form a curve. In all the examples shown, percent optimum habitat decreases as discharge decreases. No description is given of the rationale for selecting the particular set of input variables or for the technique of aggregating them.

Basic Assumptions: That the variables chosen, the way of expressing them and the method of aggregation are biologically appropriate.

Limitations and Constraints: The choice of variables and the means of scoring them appear rather arbitrary and are not well justified. The PMR would not change (except perhaps in the long term) with discharge, and there is no obvious reason why either the SBR or the PMR would change either. This leaves the only flow-dependent variable the PS, which includes consideration of size (relative width), depth (deeper is better), and cover (abundant is best). The output of the model is a plot of % optimum habitat versus some measure of discharge. It is left to the investigator to pick a point on the curve representing appropriate instream flow, and the guidelines for doing so are obscure.

Relationship to Other Methods: This is a conceptual combination of specific habitat variables in the spirit of the FWS HEP/HSI models, although with a much simpler aggregation technique.

Quality of the Documentation: Adequate.

Experimental Tests of the Method: Barber, Oswood and Deschermeier, 1980.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This method appears arbitrary in its selection of variables and means of aggregation. There is no reason to believe that it accurately reflects habitat quality for any particular species. When applied, it leaves the investigator with a plot of habitat versus flow, with no guidance on its interpretation.

X

Methodology: EDWARDS' FWS/HSI BIGMOUTH BUFFALO RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED HYDRAULIC, STRUCTURAL, AND OTHER PHYSICAL AND CHEMICAL VARIABLES

Equation: $HSI = [(V_1 * V_{13})^{0.5} * (V_2 * V_3 * V_4 2 * V_6 * V_8)^{1/6} * (V_5{}^2 * V_6 * V_9{}^2 * V_{11})1/3 * V_9]^{0.20}$

[Note: All values are transformed and scaled from 0-1 before being used in the model]

HSI = Habitat Suitability Index
V_1 = % pools during spring and summer
V_2 = mean maximum monthly turbidity (JTU) during summer
V_3 = pH
V_4 = maximum summer temperature (^oC)
V_5 = mean maximum temperature (^oC) in summer nursery habitat
V_6 = minimum dissolved oxygen ($mg * 1^{-1}$) during spring and summer
V_7 = mean velocity ($cm * sec^{-1}$)
V_8 = maximum salinity (ppt) during spring and summer
V_9 = dominate substrate type in spawning areas
V_{11} = water level fluctuation before and after spawning
V_{13} = % vegetation cover in pools

Correlation Coefficient: None found.

Source Documentation: Edwards, E.A. 1983. Habitat Suitability Index Models: Bigmouth Buffalo. US Fish and Wildlife Service. FWS/OBS-82/10.34. 23 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the aggregation used is appropriate. For any predictive use it must be assumed also that there is some relationship between HSI and fish production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose.

X

Methodology: EDWARDS ET AL.'S FWS/HSI LONGNOSE DACE RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED HYDRAULIC, STRUCTURAL, AND OTHER PHYSICAL AND CHEMICAL VARIABLES

Equation: HSI = lowest of V_1, V_2, V_4, V_5, V_6

[Note: All variables are transformed and scaled from 0-1 before being used in the model]

HSI = Habitat Suitability Index
V_1 = mean velocity ($m * sec^{-1}$)
V_2 = maximum riffle depth (m)
V_3 = % riffles
V_4 = % stream with substrate diameter of at least 5-20 cm
V_5 = mean maximum spring and summer temperature (°C) in riffle areas
V_6 = % cover

Correlation Coefficient: None found.

Source Documentation: Edwards, E.A., et al. 1983. Habitat Suitability Index Models: Longnose Dace. US Fish and Wildlife Service. FWS/OBS-82/10.33. 13 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but three of its input variables vary with discharge, and consequently it might be used to predict the effect of discharge on habitat suitability and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate. All of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the choice of the lowest value as a criterion is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, and that they all have equal weight. For any predictive use it must be assumed also that there is some relationship between HSI and fish production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity, or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models except that geometric mean aggregation is not used. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose.

Methodology: EDWARDS' FWS/HSI LONGNOSE SUCKER RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED HYDRAULIC, STRUCTURAL, AND OTHER PHYSICAL AND CHEMICAL VARIABLES

Equation: $HSI = [V_2 * V_3 * V_4^2 * V_5 * V_6]^{1/6}$

[Note: All values are transformed and scaled from 0-1 before being used in the model]

[This model uses only variables relating to embryo habitat suitability]

HSI = Habitat Suitability Index
V_2 = riffle depth (cm)
V_3 = velocity ($m*sec^{-1}$) in spawning area
V_4 = mean temperature (°C) during spawning and incubation
V_5 = % riffles in spawning area
V_6 = substrate type

Correlation Coefficient: None found.

Source Documentation: Edwards, E.A. 1983. Habitat Suitability Index Models: Longnose Sucker. U.S. Fish and Wildlife Service. FWS/OBS-82/10.35. 21 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but several of its input variables vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the aggregation used is appropriate. For any predictive use it must be assumed also that there is some relationship between HSI and fish production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity, or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose.

X

Methodology: EDWARDS ET AL.'S FWS/HSI SLOUGH DARTER RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED BASIN, HYDRAULIC, STRUCTURAL, AND OTHER PHYSICAL AND CHEMICAL VARIABLES

Equation: $HSI = [(2^{-1}) * (V_2 + V_6) * (V_1{}^2 * V_5{}^2 * V_6{}^2 * V_8)^{1/7} * (V_3 * V_4{}^2 * V_7{}^2)^{0.20}]^{0.25}$

[Note: All values are transformed and scaled from 0-1 before being used in the model]

HSI = Habitat Suitability Index
V_1 = minimum dissolved oxygen (mg * $^{1-1}$) during summer
V_2 = % pools during mean summer flow
V_3 = mean gradient (m * km^{-1}) in representative reach
V_4 = dominate substrate type
V_5 = mean temperature (^{o}C) spring to fall
V_6 = maximum monthly mean turbidity
V_7 = mean velocity (cm * sec^{-1}) at 0.6m during mean summer flow
V_8 = yearly pH levels

Correlation Coefficient: None found.

Source Documentation: Edwards, E.A. et al. 1982. Habitat Suitability Index Models: Slough Darter. US Fish and Wildlife Service. FWS/OBS-82/10.9. 13 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the aggregation used is appropriate. For any predictive use it must be assumed also that there is some relationship between HSI and fish production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity, or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose.

Methodology: EDWARDS AND TWOMEY'S FWS/HSI COMMON CARP RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED HYDRAULIC, STRUCTURAL, BIOLOGICAL, AND OTHER PHYSICAL AND CHEMICAL VARIABLES

Equation: $HSI = [(V_1 * V_3)^{0.5} * (V_1 * V_2 * V_3)^{1/3} * (7^{-1}) * (V_6 + 2 * [(V_7 \; V_9]^{0.5} + 2 * V_{12} + V_{14} + V_{11}) * V_1 * V_3 * V_8 * V_{10} * V_{13})^{0.20}]^{0.25}$

[Note that all values are transformed and scaled from 0-1 before being used in the model]

HSI = Habitat Suitability Index
V_1 = % vegetation in shallow cascading spring and summer
V_2 = % pool cover
V_3 = % pools during mean summer flow
V_6 = mean maximum monthly turbidity (JTU) during mean summer flow
V_7 = maximum midsummer temperature (°C)
V_8 = mean temperature (°C) during spawning
V_9 = maximum midsummer pool temperature (°C)
V_{10} = maximum depth (m) of pools during spawning
V_{11} = maximum salinity (pp+)
V_{12} = minimum dissolved oxygen ($mg*l^{-1}$) during midsummer
V_{13} = minimum dissolved oxygen ($mg*l^{-1}$) during spawning
V_{14} = pH level during the year

Correlation Coefficient: $r^2 = 0.02$ between HSI and standing crop (Gilbert 1984).

Source Documentation: Edwards, E.A. and K. Twomey. 1982. Habitat Suitability Index Models: Common Carp. U.S. Fish and Wildlife Service. FWS/OBS-82/10.12. 28 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability, and by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the aggregation used is appropriate. For any predictive use it must be assumed also that there is some relationship between HSI and fish production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitabiful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose.

Methodology: GEER'S UTAH WATER RECORDS METHODOLOGY

Type of Method: CONCEPTUAL USING DISCHARGE VARIABLES

Equation: WBF = Average of MMD for Sep., Nov., Dec., Jan., Feb., Mar.
SBF = Average of MMD for Apr., May, Jun., Jul, Aug., Sep.

WBF = Winter Base Flow = minimum allowable winter flow
SBF = Summer Base Flow = minimum allowable summer flow
MMD = Minimum Monthly Flow for period of record

Correlation Coefficient: None found.

Source Documentation: Geer, W.H. 1980. Evaluation of Five Instream Flow Needs Methodologies and Water Quantity Needs of Three Utah Trout Streams. Publication No. 80.20, Utah Division of Wildlife Resources. 194 pp.

Objective: To establish minimum winter and summer flows in Utah streams.

Level of Effort: Very low.

Model Development: Not described.

Basic Assumptions: That the mean minimum historic monthly flows are appropriate minimum flows.

Limitations and Constraints: Lack of any basis for the method.

Relationship to Other Methods: Similar to the New England Flow Recommendation Policy (Larsen 1980), in which the minimum flow is set at the 25-year median daily unregulated flow, and to the Montana Method (Tennant 1975), which sets the flow at 30% of the average annual flow.

Quality of the Documentation: The method is not justified in the documentation.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: Source document.

Critical Opinion: This method is essentially arbitrary. There is no evidence that the recommendations provided by its application are either necessary or sufficient to meet biological or other requirements.

X

Methodology: GILBERT'S FWS/HSI WARMOUTH RIVERINE MODEL

Type of Method: CONCEPTUAL USING DISCHARGE, BASIN, HYDRAULIC, PHYSICAL, AND CHEMICAL VARIABLES

Equation: $HSI = [(V_2 + V_5) * 2^{-1} * (V_2^2 * V_5^2 * V_{12})^{0.2} * [(V_1 + 2V_3 + V_6 + V_7 + 2V_8 + V_{10}) * 8^{-1}]^2 * (V_{12} * V_9^2 * V_2)^{0.25} * ((2V_{11} + V_4) * 3^{-1})]^{1/7}$

[Note that all values are transformed and scaled from 0-1 before being used in the equation]

HSI = Habitat Suitability Index
V_1 = growing season (days)
V_2 = average summer flow
V_3 = DO range during summer
V_4 = gradient
V_5 = % pools in summer
V_6 = pH range during year
V_7 = maximum summer flow
V_8 = mean water temperature June-September
V_9 = mean water temperature spawning
V_{10} = average summer flow
V_{11} = mean velocity during mean summer flow
V_{12} = water level stability during spawning

Correlation Coefficient: r^2 between standing crop and exponentially transformed HSI = 0.48; r^2 of HSI versus untransformed HSI = 0.13.

Source Documentation: Gilbert, R.J. 1984. Assessments of selected habitat suitability index (HSI) models, in (J. Terrell, edit.), Draft Proceedings of a Workshop on Fish Habitat Suitability Index Models. U.S. Fish and Wildlife Service. FWS/OBS-84.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the aggregation used is appropriate. For any predictive use it must be assumed also that there is some relationship between HSI and fish production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity, or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: Tested by the author.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose. The only empirical test of it shows extremely poor correlation between the HSI and standing crop.

Methodology: HICKMAN AND RALEIGH'S FWS/HSI CUTTHROAT TROUT RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED DISCHARGE, HYDRAULIC, STRUCTURAL, AND OTHER PHYSICAL AND CHEMICAL VARIABELES

Equation: $HSI = [([V_1 * V_3 * B_{12} * V_{13} * V_{14} * V_{17}]^{1/6} * (2^{-1}) * [[V_9 * V_{16}]^{0.5} + V_{11}])^{0.5} * [V_4 * V_6 * (V_{10} * V_{15})^{0.5}]^{1/3} * 3 * (V_6 + V_{10} + V_{15}) * [V_{10} * (V_8 * V_{16})^{0.5}]^{0.5} * Ce]^{0.2}$

Ce = lowest ? of V_2, V_3 or mean value of the site specific data: $(V_5 * V_7 * V_{16})^{1/}$ * (Area (m^2) of each site) * (total habitat area)$^{-1}$

[Note that all values are transformed and scaled from 0-1 before being used in the model]

HSI = Habitat Suitability Index
V_1 = mean maximum temperature (^oC) during summer
V_2 = mean maximum temperature (^oC) during embryo development
V_3 = mean minimum dissolved oxygen ($mg*l^{-1}$) during late growing season and embryo development
V_4 = mean thalweg depth (cm) during late growing season
V_5 = mean velocity ($cm*sec^{-1}$) over spawning areas during embryo development
V_6 = % cover during late growing season
V_7 = mean substrate size (cm) between 0.3-8 cm in spawning areas
V_8 = % substrate size class (10-40 cm) used for escape cover by fry and juveniles
V_9 = dominate (>50%) substrate type in riffle-run areas for food production
V_{10} = % pools during late growing season
V_{11} = mean % vegetation along stream bank during summer
V_{12} = mean % rooted vegetation an stable ground cover during summer
V_{13} = annual maximal or minimal pH
V_{14} = mean annual base flow regime as a percentage of the mean annual daily flow
V_{15} = pool class rating during the late growing season
V_{16} = % fines in riffle-run and spawning areas during mean summer flow
V_{17} = % of stream area shaded between 1000 and 1400 hours
Ce = embryo component of the HSI model

Correlation Coefficient: $r^2 = -0.03, -0.33, -0.28$ against measured standing crop for the interactive limiting factor, lowest suitability index, and average value methods respectively (Li and Schreck 1984).

Source Documentation: Hickman, T. and R.F. Raleigh 1982. Habitat Suitability Index Models, Cutthroat trout. U.S. Fish and Wildlife Service. FWS/OBS-82/10.5. 38 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the aggregation used is appropriate. For any predictive use it must be assumed also that there is some relationship between HSI and trout production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: Li and Schreck, 1984, showed very weak negative correlation between HSI and standing crop.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose. The only empirical test of it shows extremely poor correlation between the HSI and standing crop.

X

Methodology: HOPPE'S METHOD

Type of Method: CONCEPTUAL USING DISCHARGE VARIABLES

Equation: RF cover = daily flow exceeded 80% of the time
RF spawning = daily flow exceeded 40% of the time
RF flushing = daily flow exceeded 17% of the time

RF cover = recommended flow for minimum instream flow to support daily fish activities (cover, food production)

RF spawning = recommended flow for spawning periods

RF flushing = recommended flow for 48 hours during the year

Correlation Coefficient: None found.

Source Documentation: Hoppe, R.A. 1975. Minimum streamflows for fish. Paper distributed at Soils-Hydrology Workshop, USFS, Montana State Univ., Bozeman, Jan 26-30, 1976. 13 pp. (reviewed here from Wesche and Rechard 1980).

Objective: To recommend flows for spawning, flushing, and cover.

Level of Effort: Low.

Model Development: Not described in Wesche and Rechard (1980).

Basic Assumptions: That the criteria used are correct and appropriate.

Limitations and Constraints: No supporting justification.

Relationship to Other Methods: Similar to NGRP 1974, but with different criteria.

Quality of the Documentation: Not known.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: Stalnaker and Arnette 1976, Wesche and Rechard 1980.

Published Comparisons With Other Methods: None found.

Critical Opinion: The criteria used in this method appear to be arbitrary and unsupported. There is no way of assessing their appropriateness.

X

Methodology: INSKIP'S FWS/HSI NORTHERN PIKE RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED DISCHARGE, HYDRAULIC, STRUCTURAL, PHYSICAL, AND CHEMICAL VARIABLES

Equation: HSI = lowest value of V_1, V_2, V_3, V_4, V_5, V_6, V_7, V_8, V_9

[Note: All values are transformed and scaled from 0-1 before being used in the model]

HSI = Habitat Suitability Index
V_1 = ratio of spawning habitat to summer habitat divided by total midsummer area
V_2 = reduction in depth (m) during embryo and fry stages
V_3 = % of midsummer area with emergent or submerged vegetation
V_4 = logarithm (base 10) of total dissolved solids (ppm) during midsummer
V_5 = least suitable pH in spawning habitat during embryo and fry stages
V_6 = mean length of frost free season
V_7 = mean maximal weekly temperature (^{0}C) 1-2 m deep
V_8 = % of total surface area during summer that are pools or sluggish (<5 $cm*Sec^{-1}$) water
V_9 = stream gradient ($m*km^{-1}$)

Correlation Coefficient: None found.

Source Documentation: Inskip, P.D. 1982. Habitat Suitability Index Models: Northern Pike. U.S. Fish and Wildlife Service. FWS/OBS-82/10.17. 40 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the choice of the lowest value as a criterion is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, and that they all have equal weight. For any predictive use it must be assumed also that there is some relationship between HSI and fish production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity, or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models except that geometric mean aggregation is not used. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose.

Methodology: LARSEN'S USFWS NEW ENGLAND FLOW RECOMMENDATION POLICY

Type of Method: CONCEPTUAL USING DISCHARGE VARIABLES

Equation: ABF = 25 year median daily unregulated flow; or
ABF = 4 cfsm in spring, 0.5 cfsm in summer, and 1 cfsm in fall, and if storage is available, when the inflows are lower than these flows, inflow shall equal outflow but outflow shall not fall below 0.2 csfm unless reservoir capacity has been depleted.

ABF = Aquatic Base Flow - the minimum acceptable flow determined on a monthly basis
CSFM = cubic feet per second per square mile of drainage above the diversion

Correlation Coefficient: None found.

Source Documentation: Larsen, H.N. 1980. Policy Memorandum to Area Manager, New England Area Office from Regional Director, Region 5. U.S. Fish and Wildlife Service, 11 April 1980. 2 pp.

Objective: To encourage natural stream flows and perpetuate indigenous aquatic organisms.

Level of Effort: Low. If 25 years of daily flow records are available, the calculation is based on them. If not, the drainage area (square miles) must be calculated from maps.

Model Development: Not described.

Basic Assumptions: That median flows or the prescribed flows are sufficient for the indigenous fish fauna.

Limitations and Constraints: Lack of evidence that the prescribed flows are either necessary or sufficient to meet the objectives of the method.

Relationship to Other Methods: Similar to the Montana Method (Tennant 1975), in that the level of flow is set arbitrarily, but in this case as the median value rather than a percentage of the mean value. This is the only method we have found that bases flows on drainage area.

Quality of the Documentation: No justification for the method is provided.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: We have found no justification either for the use of median monthly flows as criteria, or for the 4 cfsm, 0.5 cfsm, and 1.0 cfsm criteria (although the latter approximate the average median monthly flows in 47 New England streams described in an attachment to the source document). Consequently, the method appears to be arbitrary.

Methodology: LAYHER AND MAUGHAN'S SPOTTED BASS HSI MODEL

Type of Method: CONCEPTUAL USING BASIN, STRUCTURAL, PHYSICAL, AND CHEMICAL VARIABLES

Equation: $HSI = (V_1 * V_2 * V_3)^{1/3}$

HSI = Habitat Suitability Index
V_1 = Suitability Index for stream gradient
V_2 = Suitability Index for substrate
V_3 = Suitability Index for water temperature

Correlation Coefficient: $Rr<0.10$, not significant

Source Documentation: Layher, W.G. and O.E. Maughan. In preparation. Analysis and refinement of habitat suitability index models for eight warmwater fish species. IN (J.W. Terrel, ed.) Proceedings Workshop on Fish Habitat Suitability Models. U.S. Fish and Wildlife Service, FWS/OBS-84. (IN preparation.)

Objective: To devise and test a habitat suitability model for spotted bass.

Level of Effort: Low

Model Development: The choice of variables and shape of suitability curves is not explained. For some reason, the authors did not use the 8 SI curves previously developed by them (Layher 1983). The model itself is simply (and arbitrarily) the geometric mean of the SI values for the three input variables.

Basic Assumptions: No formal selection procedure was used for variables, so it must be assumed they are the correct choice. Neither is there any explanation of the shape of the SI curves. The method of aggregation is completely arbitrary, and assumes equal weighting of the variables as well as appropriate scaling.

Limitations and Constraints: No evidence of validity.

Relationship to Other Methods: Similar to the FWS HEP/HSI models.

Quality of the Documentation: Minimal. The bulk of the paper is devoted to Layher's thesis (Layher, 1983), and no scatter diagram of the result is available.

Experimental Tests of the Method: This paper is a test of its own HSI method, although there is very little linear correlation between the HSI and standing crop.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: Although the authors report very low linear correlation between HSI and standing crop, they provide a figure which shows a clear non-linear relationship (but no indication of variance is shown). It can be assumed that the model as shown is not a good predictor of standing crop.

✓

Methodology: LAYHER'S WHITE CRAPPIE REGRESSION MODEL

Type of Method: EMPIRICAL USING PHYSICAL AND CHEMICAL VARIABLES

Equation: $SC = 250.91 + 15.34V_1 + 32.69V_2 - 265.02V_3 + 7.76V_4$

[Note: All variables are transformed into dimensionless suitability indices (0-1) prior to construction of the regression model]

SC = Standing Crop ($kg * ha^{-1}$) obtained by mark and recapture, with seining as the first collection method
V_1 = nitrate ($mg * l^{-1}$)
V_2 = phosphates ($mg * l^{-1}$)
V_3 = pH
V_4 = turbidity

Correlation Coefficient: $R^2 = 0.99$, N = 14

Source Documentation: Layher, W.G. 1983. Habitat suitability for selected adult fishes in prairie streams. Unpublished Doctoral Dissertation, Oklahoma State University. 333 pp.

Objective: To determine relationships between individual abiotic factors and biomass of fish populations.

Level of Effort: Moderate. Not many data are required.

Model Development: Layher used a data set collected at 420 sample sites in 16 Kansas river basins. Thirty physical variables were sampled. Standing crop was not strongly correlated with any of the variables, so the raw habitat data were transformed into suitability indices using a simple curve fitting technique: the range of each variable (e.g., water temperature ranged from 12-40°C) was subdivided into subranges (e.g., 12-16°C, 16-20°C, etc.), and the mean standing crop ($kg*ha^{-1}$) was calculated for each subrange. The mean values were then normalized to 1.0 (by dividing all means by the largest mean) and plotted as a vertical bar chart. A curve was then fit to the means by eye,and this became the suitability index (SI). The result of producing this type of SI was to smooth and or linearize the relationship between each variable and standing crop. Stepwise multiple regression was then done between subsets of standing crop (based on various techniques for estimating it used in collecting the original data set) and the SI. Each subset resulted in a different selection of variables and a different value for the parameter.

Basic Assumptions: That it is appropriate to develop SI curves using the entire data set and then apply them to subsets of the data.

Limitations and Constraints: The equation shown cannot be used other than in Kansas streams, and its validity has not been tested there. A similarly derived site-specific equation may be useful, however.

Relationship to Other Methods: This is an extension of the FWS HEP/HQI methodology. The SI curves are empirically derived from standing crop data rather than from presumed habitat suitability, as in the HEP models, or from frequency of occurrence (as in the IFIM/HABTAT model). The use of multiple linear regression with these SI values versus standing crop is similar to Binns and Eiserman (1979).

Quality of the Documentation: Lacking specifics on techniques for selecting variables and the rationale for specific SI curve building technique. Descriptive statistics on the original data set were also omitted.

Experimental Tests of the Method: Layher tested it himself as part of the study, trying it out on Oklahoma streams. The Oklahoma equations did not produce significant correlations, but when Kansas SI's were applied to Oklahoma data and multiple linear regressions were run, an insignificant R^2 usually resulted.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This model is useful principally in identifying the variables correlated with standing crop. Flow-related variables (including depth and velocity) were included in the model building trials, but did not increase the strength of the regression. Transformation of the independent variables to linearized SI curves appears to be a powerful technique for conditioning otherwise nonlinear data prior to fitting regression equation.

✓

Methodology: LAYHER'S CHANNEL CATFISH REGRESSION MODEL

Type of Method: EMPIRICAL USING BASIN, STRUCTURAL, OTHER PHYSICAL, AND CHEMICAL VARIABLES

Equation: $SC = 47.46 - 2.06V_1 - 7.65V_2 - 42.07V_3$

[Note: All variables are transformed into dimensionless suitability indices (0-1) prior to construction of the regression model]

SC = Standing Crop ($kg * ha^{-1}$) obtained by seining and shocking
V_1 = pH
V_2 = % pools
V_3 = gradient ($m * km^{-1}$)

Correlation Coefficient: $R^2 = 0.99$

Source Documentation: Layher, W.G. 1983. Habitat Suitability for Selected Adult Fishes in Prairie Streams. Unpublished doctoral dissertation, Oklahoma State University. 333 pp.

Objective: To determine relationships between individual abiotic factors and biomass of fish populations.

Level of Effort: Moderate. Not many data are required.

Model Development: Layher used a data set collected at 420 sample sites in 16 Kansas river basins. Thirty physical variables were sampled. Standing crop was not strongly correlated with any of the variables, so the raw habitat data were transformed into suitability indices using a simple curve fitting technique: The range of each variable (e.g., water temperature ranged from 12-40°C) was subdivided into subranges (e.g., 12-16°C, 16-20°C, etc.), and the mean standing crop ($kg*ha^{-1}$) was calculated for each subrange. The mean values were then normalized to 1.0 (by dividing all means by the largest mean) and plotted as a vertical bar chart. A curve was then fit to the means by eye,and this became the suitability index (SI). The result of producing this type of SI was to smooth and linearize the relationship between each variable and standing crop. Stepwise multiple regression was then done between subsets of standing crop (based on various techniques for estimating it used in collecting the original data set) and the SI. Each subset resulted in a different selection of variables and different values for the parameters.

Basic Assumptions: That it is appropriate to develop SI curves using the entire data set and then apply them to subsets of the data.

Limitations and Constraints: The equation shown cannot be used other than in Kansas streams, and its validity has not been tested there. A similarly derived site-specific equation may be useful, however.

Relationship to Other Methods: This is an extension of the FWS HEP/HQI methodology. The SI curves are empirically derived from standing crop data rather than from presumed habitat suitability as in the HEP models or frequency of occurrence (as in the IFIM/HABTAT model). The use of multiple linear regression with these SI values versus standing crop is similar to Binns and Eiserman (1979).

Quality of the Documentation: Lacking specifics on the techniques used for selecting variables and the rationale for specific SI curve building technique. Descriptive statistics on the original data set were also omitted.

Experimental Tests of the Method: Layher tested it himself as part of the study, trying it out on Oklahoma streams. The Oklahoma equations did not produce significant correlations, and when Kansas SI's were applied to Oklahoma data and multiple linear regressions were run, an insignificant R^2 usually resulted.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This model is useful principally in identifying the variables correlated with standing crop. Flow-related variables (including depth and velocity) were included in the model building trials, but did not increase the strength of the regression. Transformation of the independent variables to linearized SI curves appears to be a powerful technique for conditioning otherwise nonlinear data prior to fitting regression equation.

✓

Methodology: LAYHER'S LARGEMOUTH BASS REGRESSION MODEL

Type of Method: EMPIRICAL USING PHYSICAL AND CHEMICAL VARIABLES

Equation: $SC_1 = 11.62 + 36.31V_1$

$SC_2 = 27.29 + 164.44V_2 + 25.83V_3 - 148.05V_4$

[Note: All variables are transformed into dimensionless suitability indices (0-1) prior to construction of the regression model]

SC_1 = standing crop ($kg*ha^{-1}$) obtained by seining and shocking technique
SC_2 = standing crop ($kg*ha^{-1}$) obtained by seining only
V_1 = pH
V_2 = conductivity ($micromho * cm^{-1}$)
V_3 = phosphates ($mg * l^{-1}$)
V_4 = turbidity (JTU)

Correlation Coefficient: SC_1: $R^2 = 0.90$, N = 14
SC_2: $R^2 = 0.90$, N = 13

Source Documentation: Layher, W.G. 1983. Habitat Suitability for Selected Adult Fishes in Prairie Streams. Unpublished doctoral dissertation, Oklahoma State University. 333 pp.

Objective: To determine relationships between individual abiotic factors and biomass of fish populations.

Level of Effort: Moderate. Few data required.

Model Development: Layher used a data set collected at 420 sample sites in 16 Kansas river basins. Thirty physical variables were sampled. Standing crop was not strongly correlated with any of the variables, so the raw habitat data were transformed into suitability indices using a simple curve fitting technique: the range of each variable (e.g., water temperature ranged from 12-40°C) was subdivided into subranges (e.g., 12-16°C, 16-20°C, etc.), and the mean standing crop ($kg*ha^{-1}$) was calculated for each subrange. The mean values were then normalized to 1.0 (by dividing all means by the largest mean) and plotted as a vertical bar chart. A curve was then fitted to the means by eye, and this became the suitability index (SI). The result of producing this type of SI was to smooth and linearize the relationship between each variable and standing crop. Stepwise multiple regression was then done between subsets of standing crop (based on various techniques for estimating it used in collecting the original data set) and the SI. Each subset resulted in a different selection of variables and a different value for the parameter.

Basic Assumptions: That it is appropriate to develop SI curves using the entire data set and then apply them to subsets of the data.

Limitations and Constraints: The equation shown cannot be used other than in Kansas streams, and its validity has not been tested there. A similarly derived site-specific equation may be useful, however.

Relationship to Other Methods: This is an extension of the FWS HEP/HQI methodology. The SI curves are empirically derived from standing crop data rather than from presumed habitat suitability as in the HEP models or frequency of occurrence (as in the IFIM/HABTAT model). The use of multiple linear regression with these SI values versus standing crop is similar to Binns and Eiserman (1979).

Quality of the Documentation: Lacking specifics on techniques for selecting variables, and rationale for specific SI curve building technique. Descriptive statistics on the original data set were also omitted.

Experimental Tests of the Method: Layher tested it himself as part of the study, trying it out on Oklahoma streams. The Oklahoma equations did not produce significant correlations, and when Kansas SI's were applied to Oklahoma data and multiple linear regressions were run, an insignificant R^2 usually resulted.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This model is useful principally in identifying the variables correlated with standing crop. Flow-related variables (including depth and velocity) were included in the model building trials, but did not increase the strength of the regression. Transformation of the independent variables to linearized SI curves appears to be a powerful technique for conditioning otherwise nonlinear data prior to fitting regression equation.

✓

Methodology: LAYHER'S SLENDERHEAD DARTER REGRESSION MODEL

Type of Method: EMPIRICAL USING BASIN, STRUCTURAL, PHYSICAL, AND CHEMICAL VARIABLES

Equation: $SC = -1.44 + 6.88V_1 + 0.83V_2 + 1.34V_3$

[Note: All variables are transformed into dimensionless suitability indices (0-1) prior to construction of the regression model]

SC = standing crop ($kg*ha^{-1}$) obtained by mark and recapture using kill technique
V_1 = calcium hardness ($mg*l^{-1}$)
V_2 = maximum width (m)
V_3 = % riffle

Correlation Coefficient: $R^2 = 0.943$

Source Documentation: Layher, W.G. 1983. Habitat Suitability for Selected Adult Fishes in Prairie streams. Unpublished doctoral dissertation, Oklahoma State University. 333 pp.

Objective: To determine relationships between individual abiotic factors and biomass of fish populations.

Level of Effort: Moderate. Not many data are required.

Model Development: Layher used a data set collected at 420 sample sites in 16 Kansas river basins. Thirty physical variables were sampled. Standing crop was not strongly correlated with any of the variables, so the raw habitat data were transformed into suitability indices using a simple curve fitting technique: the range of each variable (e.g., water temperature ranged from 12-40°C) was subdivided into subranges (e.g., 12-16°C, 16-20°C, etc.), and the mean standing crop ($kg*ha^{-1}$) was calculated for each subrange. The mean values were then normalized to 1.0 (by dividing all means by the largest mean) and plotted as a vertical bar chart. A curve was then fitted to the means by eye, and this became the suitability index (SI). The result of producing this type of SI was to smooth and linearize the relationship between each variable and standing crop. Stepwise multiple regression was then done between subsets of standing crop (based on various techniques for estimating it used in collecting the original data set) and the SI. Each subset resulted in a different selection of variables and different values for the parameters.

Basic Assumptions: That it is appropriate to develop SI curves using the entire data set and then apply them to subsets of the data.

Limitations and Constraints: The equation shown cannot be used other than in Kansas streams, and its validity has not been tested there. A similarly derived site-specific equation may be useful, however.

Relationship to Other Methods: This is an extension of the FWS HEP/HQI methodology. The SI curves are empirically derived from standing crop data rather than from presumed habitat suitability as in the HEP models or frequency of occurrence (as in the IFIM/HABTAT model). The use of multiple linear regression with these SI values versus standing crop is similar to Binns and Eiserman (1979).

Quality of the Documentation: Lacking specifics on techniques for selecting variables, and rationale for specific SI curve building technique. Descriptive statistics on the original data set were also omitted.

Experimental Tests of the Method: Layher tested it himself as part of the study, trying it out on Oklahoma streams. The Oklahoma equations did not produce significant correlations, and when Kansas SI's were applied to Oklahoma data and multiple linear regressions were run, an insignificant R^2 usually resulted.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This model is useful principally in identifying the variables correlated with standing crop. Flow-related variables (including depth and velocity) were included in the model building trials, but did not increase the strength of the regression. Transformation of the independent variables to linearized SI curves appears to be a powerful technique for conditioning otherwise nonlinear data prior to fitting regression equation.

✓

Methodology: LAYHER'S ORANGETHROAT DARTER REGRESSION MODEL

Type of Method: EMPIRICAL USING STRUCTURAL, PHYSICAL, AND CHEMICAL VARIABLES

Equation: $SC = -13.40 - 2.75V_1 - 7.04V_2 + 10.37V_3 - 4.47V_4 + 20.64V_5$

[Note: All variables are transformed into dimensionless suitability indices (0-1) prior to construction of the regression model]

SC = standing crop ($kg*ha^{-1}$) obtained by seining
V_1 = calcium hardness ($mg * l^{-1}$)
V_2 = % pools
V_3 = sulfates ($mg*l^{-1}$)
V_4 = total alkalinity ($mg*l^{-1}$)
V_5 = temperature (^oC)

Correlation Coefficient: $R^2 = 0.97$ between the variables used to formulate the model and the standing crop used to formulate it.

Source Documentation: Layher, W.G. 1983. Habitat Suitability for Selected Adult Fishes in Prairie Streams. Unpublished doctoral dissertation, Oklahoma State University. 333 pp.

Objective: To determine relationships between individual abiotic factors and biomass of fish populations.

Level of Effort: Moderate. Not many data are required.

Model Development: Layher used a data set collected at 420 sample sites in 16 Kansas river basins. Thirty physical variables were sampled. Standing crop was not strongly correlated with any of the variables, so the raw habitat data were transformed into suitability indices using a simple curve fitting technique: the range of each variable (e.g., water temperature ranged from 12-40^{o}C) was subdivided into subranges (e.g., 12-16^{o}C, 16-20^{o}C, etc.), and the mean standing crop ($kg*ha^{-1}$) was calculated for each subrange. The mean values were then normalized to 1.0 (by dividing all means by the largest mean) and plotted as a vertical bar chart. A curve was then fitted to the means by eye, and this became the suitability index (SI). The result of producing this type of SI was to smooth and linearize the relationship between each variable and standing crop. Stepwise multiple regression was then done between subsets of standing crop (based on various techniques for estimating it used in collecting the original data set) and the SI. Each subset resulted in a different selection of variables and different values for the parameters.

Basic Assumptions: That it is appropriate to develop SI curves using the entire data set and then apply them to subsets of the data.

Limitations and Constraints: The equation shown cannot be used other than in Kansas streams, and its validity has not been tested there. A similarly derived site-specific equation may be useful, however.

Relationship to Other Methods: This is an extension of the FWS HEP/HQI methodology. The SI curves are empirically derived from standing crop data rather than from presumed habitat suitability as in the HEP models or frequency of occurrence (as in the IFIM/HABTAT model). The use of multiple linear regression with these SI values versus standing crop is similar to Binns and Eiserman (1979).

Quality of the Documentation: Lacking specifics on techniques for selecting variables, and rationale for specific SI curve building technique. Descriptive statistics on the original data set were also omitted.

Experimental Tests of the Method: Layher tested it himself as part of the study, trying it out on Oklahoma streams. The Oklahoma equations did not produce significant correlations, and when Kansas SI's were applied to Oklahoma data and multiple linear regressions were run, an insignificant R^2 usually resulted.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This model is useful principally in identifying the variables correlated with standing crop. Flow-related variables (including depth and velocity) were included in the model building trials, but did not increase the strength of the regression. Transformation of the independent variables to linearized SI curves appears to be a powerful technique for conditioning otherwise nonlinear data prior to fitting regression equations.

Methodology: LAYHER'S CENTRAL STONEROLLER REGRESSION MODEL

Type of Method: EMPIRICAL USING HYDRAULIC, STRUCTURAL, AND OTHER PHYSICAL AND CHEMICAL VARIABLES

Equation: $SC = 73.91 + 158.27V_1 + 72.01V_2 + 7.44V_3 + 18.59V_4$

[Note: All variables are transformed into dimensionless suitability indices (0-1) prior to construction of the regression model]

SC = Standing Crop ($kg * ha^{-1}$) obtained by marking using seining and recapture using shocking
V_1 = mean width (m)
V_2 = magnesium hardness ($mg * l^{-1}$)
V_3 = pH
V_4 = % run
V_5 = sulfates ($mg * l^{-1}$)

Correlation Coefficient: $R^2 = 0.90$ between the variables used to formulate the model and the standing crop used to formulate it.

Source Documentation: Layher, W.G. 1983. Habitat Suitability for Selected Adult Fishes in Prairie Streams. Unpublished doctoral dissertation, Oklahoma State University. 333 pp.

Objective: To determine relationships between individual abiotic factors and biomass of fish populations.

Level of Effort: Moderate. Not many data are required.

Model Development: Layher used a data set collected at 420 sample sites in 16 Kansas river basins. Thirty physical variables were sampled. Standing crop was not strongly correlated with any of the variables, so the raw habitat data were transformed into suitability indices using a simple curve fitting technique: the range of each variable (e.g., water temperature ranged from 12-40°C) was subdivided into subranges (e.g., 12-16°C, 16-20°C, etc.), and the mean standing crop ($kg*ha^{-1}$) was calculated for each subrange. The mean values were then normalized to 1.0 (by dividing all means by the largest mean) and plotted as a vertical bar chart. A curve was then fited to the means by eye, and this became the suitability index (SI). The result of producing this type of SI was to smooth and linearize the relationship between each variable and standing crop. Stepwise multiple regression was then done between subsets of standing crop (based on various techniques for estimating it used in collecting the original data set) and the SI. Each subset resulted in a different selection of variables and different values for the parameters.

Basic Assumptions: That it is appropriate to develop SI curves using the entire data set and then apply them to subsets of the data.

Limitations and Constraints: The equation shown cannot be used other than in Kansas streams, and its validity has not been tested there. A similarly derived site-specific equation may be useful, however.

Relationship to Other Methods: This is an extension of the FWS HEP/HQI methodology. The SI curves are empirically derived from standing crop data rather than from presumed habitat suitability as in the HEP models or frequency of occurrence (as in the IFIM/HABTAT model). The use of multiple linear regression with these SI values versus standing crop is similar to Binns and Eiserman (1979).

Quality of the Documentation: Lacking specifics on techniques for selecting variables, and rationale for specific SI curve building technique. Descriptive statistics on the original data set were also omitted.

Experimental Tests of the Method: Layher tested it himself as part of the study, trying it out on Oklahoma streams. The Oklahoma equations did not produce significant correlations, and when Kansas SI's were applied to Oklahoma data and multiple linear regressions were run, an insignificant R^2 usually resulted.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This model is useful principally in identifying the variables correlated with standing crop. Flow-related variables (including depth and velocity) were included in the model building trials, but did not increase the strength of the regression. Transformation of the independent variables to linearized SI curves appears to be a powerful technique for conditioning otherwise nonlinear data prior to fitting regression equations.

Methodology: LI, SCHRECK AND RODNICK'S CUTTHROAT TROUT DISCRIMINANT HABITAT ANALYSIS

Type of Method: EMPIRICAL HYDRAULIC, PHYSICAL, AND CHEMICAL VARIABLES

Equation: $C = C_0 + C_1V_1 + C_2V_2 + C_3V_3 + C_4V_4 + C_5V_5 + C_6V_6 + C_7V_7 + C_8V_8$

C = the classification score
C_1 to C_8 = the classification function coefficients for the Variables V_1-V_8
V_1 = % sand
V_2 = % boulders (30-91 cm)
V_3 = % pools
V_4 = % cobble (15-30 cm)
V_5 = coho density (#/m^2) → interspecific comp.
V_6 = pool area (m^2)
V_7 = gradient (%)
V_8 = velocity (cm/s)

Group	1 No Trout Present	2 <0.5 maximum Standing Crop	3 >0.5 maximum Standing Crop
C_0 =	0.535	0.593	1.089
C_1 =	0.343	0.375	0.810
C_2 =	-.068	-0.05	-0.19
C_3 =	0.183	0.225	0.279
C_4 =	119.8	131.1	224.1
C_5 =	-0.06	-0.07	-0.14
C_6 =	4.166	4.315	6.904
C_7 =	0.050	0.538	-0.03
C_8 =	-16.9	-20.7	-43.9

[For a given site, C is calculated using each of the 3 groups of classification function coefficients and the site is assigned to the group for which the value of C is highest]

Correlation Coefficient: This method resulted in 79% of the locations correctly classified (roughly comparable to an R^2 of 0.79).

Source Documentation: Li, H., C.B. Schreck, and K. Rodnick. 1984. Assessment of habitat quality models for cutthroat trout and coho salmon for Oregon's coastal streams. (In J. Terrell, ed.) Proceedings: Workshop on Fish Habitat Suitability Index Models. U.S. Fish and Wildlife Service FWS/OBS-84/xx. (Draft.)

Objective: To be able to classify habitats as to their potential for cutthroat trout production based on physical and biological characteristics.

Level of Effort: Moderate to high. The values of the variables must be measured in the field, and a response variable (such as standing crop) must also be measured to develop the coefficients.

Model Development: Standing crops were scaled from 0-1 by dividing by the maximum population size in the stream. Each of the 46 sites was then classified as Group 1, having no cutthroat trout, Group 2, having some but fewer than half the maximum density, or Group 3, having half or more than the maximum density. A stepwise discriminant analysis was then used to select a subset of the variables available, and to calculate and rank the discriminant function coefficients.

Basic Assumptions: The distribution of the population is multivariate normal, the components have linear relationships, the samples are representative of the total population, and all expected variance-covariance matrices of the population sampled are equal.

Internal Error Checking: None

Limitations and Constraints: The discriminant function coefficients and choice of variables are apparently stream-specific, and so must be calculated for the stream in question. Also, the resulting classification is not very informative when only three groups are used (though this is not an inherent limitation of the technique).

Relationship to Other Methods: The principal component analysis approach used by Bain and Finn (unpublished).

Quality of the Documentation: All coefficients are listed, but the raw data for standing crop are not displayed, and only the ranges of the variables are presented. The paper assumes that a standard computer statistical package will be used and does not describe the discriminant analysis technique.

Experimental Tests of the Method: The source document only.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: The general approach used here (similar to cluster analysis, principal component analysis and pattern recognition) is likely to gain increasing importance in classifying habitats. It may eventually provide information on specific thresholds for instream flow releases and, being empirically derived, is much more likely to produce accurate predictions than purely conceptual models. Interestingly, this particular model shows that the only flow-related variable (velocity) is also the least important one.

X

Methodology: MC MAHON'S FWS/HSI COHO SALMON HABITAT SUITABILITY INDEX MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED STRUCTURAL, BIOLOGICAL, PHYSICAL, AND CHEMICAL VARIABLES

Equation: HSI = lowest value of V_1, V_2, V_3, V_4, V_5, V_6, V_7, V_8, V_9, V_{10}, V_{11}, V_{12}, V_{13}, V_{14}, V_{15}

[Note: All values are transformed and scaled from 0-1 before being used in the model]

HSI = Habitat Suitability Index
V_1 = maximum temperature (^oC) during upstream migration
V_2 = minimum dissolved oxygen ($mg*l^{-1}$) during upstream migration
V_3 = maximum temperature (^oC) from spawning to emergence of fry
V_4 = minimum dissolved oxygen ($mg*l^{-1}$) to emergence of fry
V_5 = substrate composition (%) in riffle/run areas
V_6 = maximum temperature (^oC) during rearing
V_7 = minimum dissolved oxygen ($mg*l^{-1}$) during rearing
V_8 = % vegetation canopy over rearing stream
V_9 = vegetation index of riparian zone during summer
V_{10} = % pools during summer low flow period
V_{11} = % pools during summer that are 10-80 m^3 or 50-250 m^2 and have sufficient canopy to provide shade
V_{12} = % instream and bank cover during summer
V_{13} = % of total area consisting of quiet backwater and $\geq$ 45 cm deep pools with dense cover or deeply undercut banks during winter
V_{14} = maximum temperature (^oC) during winter in rearing streams and spring-summer in streams where seaward migration of smolt occurs
V_{15} = minimum dissolved oxygen ($mg*l^{-1}$) during April-July in streams where seaward migration occurs

Correlation Coefficient: r = -0.19, -0.21, and -0.07 between HSI and standing crop for the interactive limiting factor approach, lowest suitability index approach, and average value methods respectively (Li and Schreck 1984).

Source Documentation: McMahon, T.E. 1983. Habitat Suitability Index Models: Coho Salmon. U.S. Fish and Wildlife Service. FWS/OBS-82/10.49. 29 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability, and by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the selection of the minimum value of all SI's used is appropriate. For any predictive use it must be assumed also that there is some relationship between HSI and fish production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: Li and Schreck (1984) showed very weak negative correlation between this HSI and standing crop.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables, and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose. The only empirical test of it shows extremely poor, negative correlation between the HSI and standing crop.

X

Methodology: MC MAHON'S FWS/HSI CREEK CHUB RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED HYDRAULIC, STRUCTURAL, AND OTHER PHYSICAL AND CHEMICAL VARIABLES

Equation: $$HSI = [(V_1 * V_2 * V_3 * V_4 * V_{13} * V_{18})^{1/6} * (V_5 + V_6 + V_{20})/3 * (V_7 * V_8 * V_{11} * V_{12} * V_{19})^{0.2} * (V_9 + V_{10})/2 * (V_{14} * V_{16} * V_{16} * V_{17}{}^2)^{0.2}]^{0.2}$$

[Note: All values are transformed and scaled from 0-1 before being used in the model]

HSI = Habitat Suitability Index
V_1 = % pools during mean summer flow
V_2 = dominant (>50%) pool class rating during mean summer flow
V_3 = % pool cover during summer
V_4 = winter instream cover $(V_1 * V_2 * V_3)^{1/3} \pm 0.2$ or 1.0, whichever is smaller
V_5 = stream gradient $(m * km^{-1})$
V_6 = mean stream width (m) during mean summer flow
V_7 = mean maximum monthly turbidity (JTU)
V_8 = yearly pH levels
V_9 = vegetation index (%)
V_{10} = food production potential of substrate type (%)
V_{11} = mean summer water temperature (^{o}C)
V_{12} = minimum dissolved oxygen level $(mg * l^{-1})$ during summer
V_{13} = mean velocity $(cm * sec^{-1})$ during summer
V_{14} = mean water temperature (^{o}C) during spring
V_{15} = minimum dissolved oxygen levels $(mg * l^{-1})$ during spring
V_{16} = mean velocity $(cm * sec^{-1})$ in riffles during April-June
V_{17} = substrate type (%) in riffles during spawning
V_{18} = velocity $(cm * sec^{-1})$ during mean summer flow
V_{19} = mean midsummer shading (%) between 1,000 and 1,500 hours
V_{20} = mean maximum depth (m) during mean summer flow

Correlation Coefficient: None found.

Source Documentation: McMahon, T.E. 1982. Habitat Suitability Index Models: Creek Chub. US Fish and Wildlife Service. FWS/OBS-82/10.4. 23 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability, and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the aggregation used is appropriate. For any predictive use it must be assumed also that there is some relationship between HSI and creek chub production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose.

X

Methodology: MILHOUSE ET AL.'S IFG4 MODEL

Type of Method: CONCEPTUAL USING HYDRAULIC VARIABLES

Equation: $S = aQ^b$; $v_i = cQ^d$; $Q_i = w_i * d_i * v_i$, $Q = \sum_{i=1}^{n} w_i * d_i * v_i$

S = stage of the cross section
Q = total discharge in a cross section
Q_i = discharge in the ith cell along a transect
w_i = width of the ith cell along a transect
d_i = depth of the ith cell along a transect
v_i = mean velocity of the ith cell along a transect
s_i = stage-stage of zero flow at the ith cell along a transect
a,b,c,d = linear regression coefficients

Correlation Coefficient: None found.

Source Documentation: Milhouse, R.T., D.L. Wegner, and T. Waddle. 1984. Users Guide to the Physical Habitat Simulation System (PHABSIM). Instream Flow Information Paper 11. FWS/OBS-81/43. Revised January 1984. U.S. Fish and Wildlife Service.

Objective: To predict depths and mean column velocities at fixed locations on a transect across a stream as functions of discharge, specifically for use in the HABTAT model.

Level of Effort: High. Depths and velocities must be measured at at least 20 points along each transect of interest at at least three discharges.

Model Development: Fixed measurement points are established along one or more transects placed across a stream. Mean column velocity and stream stage (from which depth is determined by subtracting measured bed elevations) are measured at each point for three or more flows. Total discharge, Q, through each transect is calculated from measured velocities and cell widths and computed cell depths. The three Q's regressed against the corresponding cross sectional stages, S, and cell velocities, v_i. As a check on the reasonableness of the calculated discharge, stage is also regressed on a "known" Q (obtained from a gauge, or determined empirically from data collected at an easily measured hydraulic control station). Then, for a given simulation Q, stage is determined from the stage versus "known" Q regression. This value of stage is then applied to the stage versus "calculated" Q regression to arrive at a corrected Q for the transect which is used in the velocity versus Q regression to calculate a velocity for each transect cell for that simulated flow. At this point a series of velocities and depths have been predicted for a given simulation Q. A check of the reasonableness of the simulated values, and a corresponding correction factor are then applied to the data. This is achieved by computing Q from the predicted velocity and depth values and comparing it to the corrected Q, not the simulation Q. If there is a difference between these two values of Q, the velocities for each cell are adjusted by a coefficient sufficient to make the values equal, the Velocity Adjustment Factor (VAF), which serves in this model as an error statistic. This is done for each Q of interest, so there are as many VAF's as there are simulated Q's. The further from unity the VAF, the less correspondence there is between the regression of stage on "known" and simulated Q's. At each simulation discharge, depths and velocities (D_i and W_i) are output, and these data are the principal output of the IFG4 model.

Basic Assumptions: That the power function relationship between stage and discharge and velocity and discharge are appropriate, and that the corrective technique of using Velocity Adjustment Factors is reasonable.

Limitations and Constraints: Like all hydraulic models, the more complex and steep the bed, turbulent the flow, and shallow the water, the less likely the model is to produce accurate simulations. This model is laudable in that it provides several internal checks to evaluate the quality of the simulation.

Relationship to Other Methods: None found.

Quality of the Documentation: No justification for the goodness-of-fit statistics (VAF's and VPE's) or for their use as correction factors or criteria for acceptability of extrapolation.

Experimental Tests of the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: Hilgert (1981) and especially Butler (1979) ran identical data through the IFG4 and WSP models and got quite different results, but did not attempt to determine which was correct.

Critical Opinion: This is a novel approach to hydraulic modeling in that it is largely empirical (at least in the determination of parameter values, if not in selection of the form of the regression equation), whereas most hydraulic models are based on the Bernoulli and Manning's equations. It is surprising to us that no tests of the validity of this model have shown up in the literature.

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Methodology: MILHOUSE ET AL.'S FWS HABTAT MODEL (PART OF THE FWS IFIM PHABSIM MODEL)

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED HYDRAULIC AND STRUCTURAL VARIABLES

Equation: $$\mathrm{WUA} = \mathop{}\limits_{i=1}^{n} f_v\,(v_i) * f_d\,(d_i) * f_s\,(s_i) * A_i$$

WUA = Weighted Usable Area (ft^2)
v_i = the velocity in cell i
d_i = the depth in cell i
s_i = a coded value for substrate or cover
f_v = a transformation function transforming v_i to a value of 0-1
f_d = a transformation function transforming d_i to a value of 0-1
f_s = a transformation function transforming s_i to a value of 0-1
A_i = the surface area represented in the stream by the ith cell

Correlation Coefficient: Variable. See Chapter 6.

Source Documentation: Milhous, R.J., D.C. Wegner and T. Waddle. 1984. Users Guide to the Physical Habitat Simulation System (PHABSIM). Instream Flow Information Paper 11. FWS/OBS-81/43. Revised. January 1984. U.S. Fish and Wildlife Service.

Objective: To produce a functional relationship between a habitat index (WUA) and discharge for use in determining appropriate instream flows.

Level of Effort: Low, once the functional relationship between flow and depth and mean velocity at cells along cross-stream transects is obtained, either from direct observation or from the WSP or IFG4 hydraulic simulation models.

Model Development: The transformation curves (suitability indexes) for depth, velocity, and substrate are obtained by observing the depths, velocities, and substrate types utilized by fish in the field and establishing frequency histograms (usually with a curve fit to them, though there is no standard technique) with the dependent variable (suitability) scaled from 0-1.

Basic Assumptions: This model is based on the premises that changes in velocity, depth, and substrate (or cover) are adequate to describe the effects of flow on fish habitat, that the value of fish habitat can be determined by observing the frequency with which various velocities, depths, and substrates are used (or as a refinement, are preferred), and that the appropriate way of aggregating the transformed input variables is the one shown. A more subtle assumption is that large amounts of suboptimal habitat are as good as small amounts of good habitat.

Limitations and Constraints: The model simply produces plots of WUA versus discharge, but does not inherently indicate what might be the appropriate flows. Studies are beginning to appear which show that some forms of the WUA Index (for example, for incubation occurring under minimum annual flow conditions) are more strongly correlated with standing crop than others, but there are as yet very few data.

Relationship to Other Methods: This model appears to be a direct descendent of the Waters (1976) Method, with the principle improvements being that the transformation functions are determined (ideally) from field observation of habitat utilization rather than from a review of the literature, and the output is usually expressed as a function of discharge by using hydraulic data from a range of discharges. The transformation curves are similar to those used in the FWS HSI models and, as in the HSI models, the aggregation technique for the transformed variables is arbitrary.

Quality of the Documentation: Documented in several FWS Instream Flow Information papers.

Experimental Tests of the Method: Loar et al. 1985, Cada et al. 1983, Kevern and Gowan 1983, Wesche 1980, Orth and Maughan 1979, Nelson et al. 1985, Nehring 1979.

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Published Enhancements to the Method: Bovee 1982, Gore and Judy 1981, Morhardt et al. 1983.

Critical Review of the Method: Wesche and Rechard 1980, Loar and Sale, 1981.

Published Comparisons With Other Methods: 14 evaluation studies funded by the FWS (see text).

Critical Opinion: The HABTAT model has not generally been shown to be any more predictive of standing crop than many other less complex methods, but the approach of subsetting a stream into a large number of microhabitats, each changing independently with flow, should eventually prove to be more predictive than models which use fewer points. What is lacking in this, and most other models, is a documented understanding of what factors limit fish populations.

X

Methodology: MILHOUSE, ET AL.'S WATER SURFACE PROFILE (WSP) HYDRAULIC SIMULATION MODEL

Type of Method: CONCEPTUAL USING HYDRAULIC VARIABLES

Equation: $Se = (Q * n * (1.49 * A * R^{2/3})^{-1})^{2}$; $H = z + d + v^{2} * 2G^{-1}$

Se = energy slope %
Q = discharge $ft^{3} * sec^{-1}$
n = Manning's n (roughness coefficient)
A = cross section of water area (ft^{2})
R = hydraulic radius (ft) = $A * P^{-1}$
P = wetted perimeter (ft)
H = total energy value at a cross section
z = elevation of channel bottom (ft above reference point)
d = water depth (ft)
v = mean water velocity ($ft * sec^{-1}$)
G = 32 $ft * sec^{-2}$

Correlation Coefficient: None found.

Source Documentation: Milhous, R.T., D.L. Wegner, and T. Waddle. 1984. User's Guide to the Physical Habitat Simulation System (PHABSIM): Instream Flow Information Paper 11. FWS/OBS-81/43. Revised January 1984.

Objective: To predict, based on data collected at one discharge, how depth, velocity and stream widths vary for each cross section of a stream modelled over a range of simulated discharges.

Level of Effort: Moderate to high. Precise hydraulic measurements must be made in the field at all transects of interest. The computer modelling can be time consuming, since the program encourages multiple iterations to increase the model accuracy.

Model Development: The model, a step-back water procedure, is based on standard hydraulic equations (Manning's equation and the Bernoulli equation, both shown above). The user supplies either energy slope or water surface elevation, and both depth and mean velocity measurements for multiple points (verticals) along two or more transects. Se is calculated (or measured) for the most downstream transect and is used, along with distance, to predict the water surface elevation (WSE) of the next transect upstream. Total energy (H) is then calculated at the first transect using the Bernoulli equation (above) and at the second transect by incrementing the absolute elevation by the measured value of Z above that at the first transect, again using the Bernoulli equation. WSEL is then calculated at the second transect by subtracting the velocity head ($v^{2} * 2g^{-1}$) of the second transect from its total energy (H). Thus WSEL for the second transect is calculated two separate ways, and if the two results are dissimilar, the Se for the first transect is changed, and the process repeated until WSEL calculated by both methods is similar. Then WSEL of the second transect is compared to that measured in the field. If it is different, new values of Manning's n are tried until the two WSEL's are the same. Once this "calibration" procedure is complete, Manning's n is assumed constant and the Manning equation is subsequently used for calculating all hydraulic values of interest (principally depth and velocity at each cell as functions of Q). The whole procedure is then repeated on the next transect upstream.

Basic Assumptions: That Manning's n and energy slope remain constant as discharge changes. This assumption is particularly likely to be untrue for Manning's n. This particular implementation also assumes that the constant by which the kinetic energy head ($v^{2} * 2g^{-1}$) should be properly multiplied is equal to 1.0, when it may range as high as 2.0 or more in complex streams.

Limitations and Constraints: The steeper the slope and more complex the streambed, the greater the difficulty in accurately predicting WSEL's. At slopes greater than about 5%, the model is usually not internally consistent, and therefore cannot be used.

Relationship to Other Methods: Similar to the Army Corps of Engineers HEC-2 and the BLM PSEUDO models.

Quality of the Documentation: Does not describe the inner workings of the program.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: Hilgert (1981), and particularly Butler (1979) got quite different results when comparing IFG4 and WSP simulations linked to HABTAT utilization data.

Critical Opinion: The WSP model is sophisticated, and has the advantages of internal checking and calibration. Its main drawback for instream flow work is characteristic of all hydraulic models: it works best in channels of moderate, uniform slope and uniform bed and cross-sectional characteristics, and is difficult or impossible to apply, particularly at low flows, in mountain streams.

X

Methodology: NELSON'S MONTANA WETTED PERIMETER METHOD

Type of Method: EMPIRICAL USING HYDRAULIC VARIABLES

Equation: $\text{Log } S = b \text{ Log } Q + a$; $\text{WETP} = f(S)$

S = stage (water level) - stage at zero flow
Q = discharge ($ft^3 * sec^{-1}$)
a,b = regression coefficients determined by fitting a least-squares linear regression to the log-transformed data

WETP = wetted perimeter (ft) the distance from one edge of the stream to the other, measured along the bottom

Correlation Coefficient: None found.

Source Documentation: Nelson, F.A. 1984. Guidelines for using the wetted perimeter (WETP) computer program of the Montana Department of Fish, Wildlife and Parks.

Objective: To devise a relatively simple method for deriving instream flow recommendations.

Level of Effort: Low to moderate. One to five channel cross sections must be measured in the field, and the stage (water surface level) must be measured at each cross section at at least 3 different discharges.

Model Development: The computer model fits a linear regression to the relationship between stage and discharge measured at 3 discharges. Then, equipped with a cross-sectional diagram of the stream bed, it calculates the distance, measured along the stream bed from the water line on one side to the water line on the other, for a series of discharges. The result is a plot of WETP versus discharge. These plots of WETP characteristically increase steeply, then level off as discharges increase, and the basis of this method is to pick a point near where they begin to level off as the recommended instream flow. Nelson refers to this point on the curve as the "inflection point", but does not define it. The mathematical definition of an inflection point is that the second derivative of the function changes sign, i.e., the curve changes from concave to convex or vice versa. Most of the points chosen by Nelson on a series of these curves (Nelson 1980) do not meet this or any other evident criteria.

Basic Assumptions: That the stage-discharge relationship is adequately modeled by a linear regression of logarithm-transformed stage versus log-transformed discharge. That there is some point on the resulting curve that can be identified reproducibly. That this point has some relationship to biological response variables.

Limitations and Constraints: Only when there is a sharp change in slope of the WETP versus Q curve is the recomended flow well defined. The physical mechanism of such a change would be the filling of a well defined channel, with higher flows spilling out into the flood plain. The method therefore simply identifies the flow which fills the permanent channel. Whether this is an appropriate criterion for instream flow has not been established.

Relationship to Other Methods: The criterion for appropriate flow is identical to that of White (1976) and described by Collings (1974) for rearing habitat.

Quality of the Documentation: The model is described completely.

Experimental Tests of the Method: Randolph and White (1984) tried an experimental test, but got ambiguous results.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: Nelson (1980), Randolph and White (1984).

Critical Opinion: On most plots produced by this method, the selection of recommended flow is highly subjective, and we have not found any evidence indicating the appropriateness of the criterion, even when clear. The method appears to be tantamount to equating bank-full discharge to minimum appropriate flow.

Methodology: NICKELSON'S SALMONID HABITAT QUALITY METHOD

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED HYDRAULIC AND STRUCTURAL VARIABLES

Equation: $$HQU = \sum_{i=1}^{6} n_i/N * (i-k)$$

HQU = Habitat Quality Units

n_i = the number of cells having a value of i

N = the total number of cells observed

i= = $(V_1 + V_2 + V_3)$

k = a constant with a value of 1 for coho salmon

V_1 = 2 if depth >30 cm and velocity <30 cm * sec^{-1}, otherwise 1

V_2 = 2 if there are undercut banks and submerged roots, 1 if there is overhanging cover and submerged logs and roots, otherwise 0

V_3 = 2 if the substrate is cobble, 1 if gravel, otherwise 0.

Correlation Coefficient: r^2 between coho biomass (g/m^2) and HQU = 0.72 in the example shown.

Source Documentation: Nickelson, T. 1976. Development of methodologies for evaluating instream flow needs for salmonid rearing, in Proc. Symp. Specialty Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 581-599. Am. Fish Soc., Bethesda, MD.

Objective: To develop a method that can be used in natural streams to estimate the influence of stream discharge on carrying capacity for salmonids.

Level of Effort: Moderate to high. Depths and velocities must be measured at a large [unspecified] number of locations in a stream. To use as an instream flow method, they must be measured at all discharges of interest.

Model Development: The assignment of values to V_1, V_2, and V_3 was based on personal experience of the authors or personal communications with other investigators, and is briefly documented in the text. The value of k is not explained. The aggregation technique simply reduces the value of each cell by k, normalizes the values so that HQU is independent of the number of cells sampled, and adds up the total points. The use of the k term removes from consideration cells below a threshold value.

Basic Assumptions: The model arbitrarily assumes that V_1, V_2, and V_3 are the appropriate variables for measuring habitat quality, assumes that depth and velocity combinations as specified are the appropriate criteria [most other methods treat the two variables separately...this one lumps them together] and assigns equal value to depth/velocity, cover, and substrate type. It also specifies that cells below a certain threshold value (determined by the size of k) do not contribute to habitat quality and that depth/velocity, cover, and substrate type contribute to the habitat independently of one another. [The V_1, V_2, and V_3 criteria shown are for coho salmon and would be different for other species; also k might have a different value for different species. The higher the value of k, the higher the value of i required to make a positive contribution to the HQU. In the author's example, values of (i-k) <0 were treated as 0].

Limitations and Constraints: Only a few of the potentially constraining habitat variables are used, and those may not accurately reflect habitat quality or fish production. Also, the aggregation of variables is entirely conceptual.

Relationship to Other Methods: The HQU is similar to Wesche's WRRI (1980) in that it is a simple aggregation of a few variables. The approach of sampling many different locations and adding up their values is similar to the summing techniques used in the IFIM.

Quality of the Documentation: Somewhat unclear. We rewrote the equation in a simplified form for this summary form.

Experimental Tests of the Method: Source document.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: The general idea of evaluating the habitat quality of a variety of places in a stream, then summing them up to get overall habitat quality is good. The i index applied to each cell in this model is simplistic and could probably be substantially refined.

Methodology: NICKELSON, BEIDLER AND WILLIS' OREGON STEELHEAD TROUT METHOD

Type of Method: EMPIRICAL USING HYDRAULIC, BIOLOGICALLY WEIGHTED HYDRAULIC, AND STRUCTURAL VARIABLES

Equation: $HQR_{st} = (EC + OH + T + VS) * A * [\ (DP * VP)] * n^{-1}$

HQR_{st} = Habitat Quality Rating for steelhead
EC = frequency of undercut banks, rootwoods, undercut boulders within 50 cm upstream with depths >5 cm
OH = frequency of overhanging cover at depths >5 cm
T = frequency of turbulence cover at depths >5 cm
VS = frequency of logs or boulders within 50 cm upstream
A = wetted area of study section (m^2?)
DP = relative value (0-1) of the depth at each location in the study area
VP = relative value (0-1) of the velocity at each location in the study area
n = number of locations examined in the study area

Correlation Coefficient: $r^2 = 0.79$ between standing crop and HQR_{st} for data collected in 1976 and 1977.

Source Documentation: Nickelson, T.E., W.M. Beidler and M.J. Willis. 1979. Streamflow Requirements of Salmonids. Final report, Oregon Department of Fish and Wildlife. Project No. AFS-62. 30 pp.

Objective: To develop a technique based on something more concrete than general observations and judgement for recommending minimum rearing flows in Oregon.

Level of Effort: Moderate to high. All variables must be measured in the field.

Model Development: This model is based on the premise that the depth and velocity transformation curves developed by Bovee (1978) are appropriate and that the resulting values (ranging from 0-1) should be multiplied together and then averaged over the entire study area. The result is then multiplied by an additive cover term (the sum of the fractions of various cover types throughout the study area), and the final result is multiplied by the absolute area.

Basic Assumptions: Like the FWS HABTAT model, this approach assumes that preferential utilization of particular depths and velocities by wild fish in the field is indicative of habitat quality and that the less preferred the combination of depth and velocity, the lower will be the productivity. This model also assumes that the relative fraction of various cover types is important and that these are to be added prior to multiplication. The inclusion of the area term affects only the absolute magnitude of the index and is thus unnecessary.

Limitations and Constraints: Based on the author's tests of the model, we calculated an r^2 of 0.128 between the HQR and standing crop for the test data set of 1978. Although 75% of the 1978 data points fell within the 95% confidence limits of the regression obtained from the 1976-1977 data set, these limits are very large. The 1978 data are so weakly correlated with standing crop that the model must be judged not at all predictive.

Relationship to Other Methods: This model is closely related to the conceptual model used by the FWS Instream Flow Service Group (Bovee 1982) but is implemented differently, taking the average of the multiplicand of depth and velocity probabilities-of-use and multiplying them by the area and a cover rather than a substrate term. The cover term is conceptual (like the terms in the FWS HSI models) and not based on empirical observations.

Quality of the Documentation: The criteria for variable selection are not described.

Experimental Tests of the Method: The source document tested it with a new (1978) data set and found very weak ($r^2 = 0.128$) correlation between HQR and standing crop.

Published Enhancements to the Method: None found.

Critical Review of the Method: Fausch and Parsons (unpublished).

Published Comparisons With Other Methods: None found.

Critical Opinion: The model explained only 13% of the variability in standing crop of steelhead in the test situation and clearly cannot be used for predicting standing crop. The addition of a cover term to the HABTAT-like model seems justified, but the cover term used appears arbitrary.

Methodology: NICKELSON, BEIDLER AND WILLIS' OREGON CUTTHROAT INSTREAM FLOW METHOD

Type of Method: CONCEPTUAL AND EMPIRICAL USING BIOLOGICALLY WEIGHTED HYDRAULIC AND STRUCTURAL VARIABLES

Equation:

$$\mathrm{HQR1} = A * P * (13.859\mathrm{D1} + 12.726\mathrm{D2} + 13.591\mathrm{EC} + 12.966\mathrm{OH} + 93.298\mathrm{T})$$

$$\mathrm{HQR2} = A * P * (\mathrm{D1} + \mathrm{D2} + \mathrm{EC} + \mathrm{OH} + \mathrm{T} + \mathrm{VS})$$

HQR1 = Habitat Quality Rating 1
HQR2 = Habitat Quality Rating 2
A = wetted area of the study section (m^2?)
P = velocity weighting factor (0.2 at velocities <0.05 and >0.25 m*sec^{-1}, increasing smoothly to a peak of 1.0 at 0.15 m*sec^{-1}.
D1 = frequency of depths 46-60 cm
D2 = frequency of depths >60 cm
EC = frequency of undercut banks, rootwads, undercut boulders within 50 cm upstream at depths >5 cm
OH = frequency of overhanging cover at depths >5 cm
T = frequency of turbulance cover at depths >5 cm
VS = frequency of logs and boulders within 50 cm upstream

Correlation Coefficient: $r^2 = 0.91$ for HQR1 versus standing crop (g) and $R^2 = 0.87$ for HQR2 versus standing crop (g).

Source Documentation: Nickelson, T.E., W.M. Beidler and M.J. Willis. 1979. Streamflow Requirements of Salmonids. Final report, Oregon Department of Fish and Wildlife. Project No. AFS-62. 30 pp.

Objective: To develop a technique based on something more concrete than general observations and judgement for recommending minimum rearing flows in Oregon.

Level of Effort: Moderate to high. All variables must be measured in the field.

Model Development: The velocity weighting factor is described as being determined from a plot of standing crop and mean velocity (not presented), which implies there is a relationship between the two that might itself be a predictive model. There is no description of how the coefficients in the equation of HQR1 were derived, but they appear to be the result of running a multiple linear regression model, perhaps between these variables and standing crop data collected in 1976 and 1977. The resulting model appears to be an additive linear regression model multiplied by two additional terms, one of which (p) is itself an index and the other of which is an absolute value. Therefore, it is an interesting combination of empirical and conceptual terms. The HQR2 model was developed, however, because "the coefficients [in the HQR1 model] have no biological meaning and are not necessarily a unique solution to the equation."

Basic Assumptions: The model assumes that the proper relationship between area, velocity, and cover terms is multiplicative; since area is treated as an absolute value, the outcome of the model is an index that should be equally good with or without this term. Velocity is treated as a fraction (of the ideal velocity), thus this term can degrade the effects of cover and area, but not enhance them. The cover term is (apparently) arrived at by estimating the relative weights (parameters) of a variety of fractional terms to characterize cover by multiple linear regression on standing crop. The authors drop the parameters in HQR2 and add an additional fractional term. Since the cover terms are internally additive and multiplied by numbers between 12 and 94 in HQR1 but not multiplied by anything in HQR2, the absolute magnitude of the resulting index is an order of magnitude smaller for HQR2. In HQR1, the frequency of turbulence is 7 times as important as the other terms, and the presence of logs or boulders upstream is not considered. In HQR2, all cover terms are of equal importance, including the presence of logs and boulders.

Limitations and Constraints: Based on the experimental tests, the model cannot be used for data from other years at the same site, and thus is not predictive.

Relationship to Other Methods: Slightly related to other models using preference/utilization functions.

Quality of the Documentation: The criteria for variable selection are not described.

Experimental Tests of the Method: The source document tested the indices with 1978 data and found them to be highly unpredictive.

Published Enhancements to the Method: Fausch and Parsons (unpublished).

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: There is no justification offered for this hybrid of a conceptual multiplicative aggregation coupled with a multiple linear regression of some of the terms, and it does not make intuitive sense to us. In any case, the authors have shown it to be unpredictive.

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Methodology: NICKELSON, BEIDLER AND WILLIS' OREGON COHO SALMON METHOD

Type of Method: EMPIRICAL USING HYDRAULIC VARIABLES

Equation: $SC = 6.05 (V_p) + 11.14$

SC = juvenile coho salmon standing crop (g)
V_p = pool volume (m^3)

Correlation Coefficient: $r^2 = 0.935$

Source Documentation: Nickelson, T.E., W.M. Beidler and M.J. Willis. 1979. Streamflow Requirements of Salmonids. Final report, Oregon Department of Fish and Wildlife. Project No. AFS-62. 30 pp.

Objective: To develop a technique based on something more concrete than general observations and judgement for recommending minimum rearing flows in Oregon.

Level of Effort: Low. Only pool volume must be estimated.

Model Development: Pool volume and standing crop were measured in 12 sections of four North Coast Oregon streams, and a least-squares regression performed.

Basic Assumptions: None

Limitations and Constraints: The model test suggested that the relationship would not be valid where pools exceed 100 m^3 in volume. A second model was developed, but the authors did not publish the parameters.

Relationship to Other Methods: These one-variable regressions are similar to Swift's 1979 work, but this is the only model we have found that uses just pool volume. Note that the FWS HSI coho salmon model uses 16 different variables, one of which is at its maximal level if approximately 50% of the stream consists of pools 10-80 m^3 in volume.

Quality of the Documentation: There is no indication how the authors arrived at this model.

Experimental Tests of the Method: The authors collected additional data in 1978 on more streams (source document) and found that the least-squares regression had different parameters (coefficients) and had an $r^2 = 0.72$.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: It is clear from this model that the larger the pool the more coho salmon it will contain. What is not clear is (1) whether a reduction in flow would decrease pool volume in these streams appreciably, and (2) whether such a decrease would also decrease the number of coho each pool could support. If both possibilities were true, then the method might be a useful instream flow technique.

X

Methodology: NORTHERN GREAT PLAINS RESOURCE PROGRAM (1974)

Type of Method: CONCEPTUAL USING DISCHARGE VARIABLES

Equation: RF_{month} = 10 percentile DF for months falling within the 15-85 percentile MMF

RF_{month} = recommended flow for each month

10 percentile DF = the flow exceeded on 90% of the days for the months in question for the period of record

15-85 percentile MMF = all months in the period of record except those with mean monthly flows in the highest and lowest 15%

Correlation Coefficient: None found.

Source Documentation: Northern Great Plains Resource Program, 1974. Instream needs sub-group report. Work Group C: Water. 35 pp. (as quoted in Wesche and Rechard 1980)

Objective: To establish minimum recommended instream flows.

Level of Effort: Low.

Model Development: The authors state that they decided to exclude the 15% of months with the highest MMF's and the 15% of months with the lowest MMF's "By adding and subtracting the variable $t_x(s)/ n$ (based on Student's t) to and from the monthly mean for the period of record [by which process] upper and lower limits are established between which is a given percentage of the observations." This seems to mean that they treated the mean monthly flows as estimates of some true mean monthly flow and used the t statistic at some [unstated] level of probability to exclude months with extreme MMF's from the subsequent daily flow analysis. They then chose the mean daily flow exceeded 90% of the time of record by month and recommended this flow as the appropriate minimum flow, with the provision that in unusually dry years the stream biota would have to share the lack of water with other users and endure lower flows.

Basic Assumptions: That the method for excluding months from the daily flow analysis is appropriate and that the 10th percentile cutoff for daily flows in the remaining months is the correct criterion.

Limitations and Constraints: Lack of data supporting any of the criteria chosen.

Relationship to Other Methods: Similar to the Montana Method (Tennant 1975), the New England Method (Larsen 1980) and the Utah Water Records Method (Geer 1980). The criteria for all of these are derived from the historical flow records by some arbitrary formulation.

Quality of the Documentation: Rambling.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: Alberta Environment 1983, in which preferred minimum flows (PMF's) were set at 60th percentile flows for the winter and 75th percentile flows for the summer. Flow criteria were then based on percentage of the time the PMF's would have to be exceeded.

Critical Review of the Method: Wesche and Rechard 1980.

Published Comparisons With Other Methods: None found.

Critical Opinion: The criteria used, both for the exclusion of outlying months (t statistic) and for flow criteria (10th percentile of daily flows), are completely arbitrary and differ from those used by other hydrological methods. The documentation offers no support for them, and there is little reason to believe they are appropriate.

X

Methodology: ORSBORN'S MAXIMUM STEELHEAD SPAWNING AREA METHOD

Type of Method: EMPIRICAL USING BIOLOGICALLY WEIGHTED, BASIN, AND DISCHARGE VARIABLES

Equation: $Q_{msa} = 40 * [A * H^{0.5} * SC^{-1} * Q_{aa}{}^{3} * Q_{f2p}{}^{-2}]^{0.33}$

Q_{msa} = Discharge resulting in maximum spawning area (cfs)
A = Drainage area (mi^2)
H = 2 * (mean basin elevation - station elevation); (ft)
SC = Slope of channel (ft * mi^{-1})
Q_{aa} = Average annual flow (cfs)
Q_{fp2} = Two year peak flood flow (cfs)

Correlation Coefficient: Not given.

Source Documentation: Orsborn, J.F. 1981. Estimating spawning habitat using watershed and channel characteristics (a physical systems approach), in Aquisition and Utilization of Aquatic Habitat Inventory Information (N.B. Armantrout, ed.), pp. 154-161. American Fisheries Society, Bethesda, MD. 376 pp.

Objective: To estimate the discharge at which maximum spawning habitat occurs for steelhead, using channel, hydrologic, and drainage basin characteristics.

Level of Effort: Low. Data are obtained from topographic maps and existing stream gauge records.

Model Development: This model is a reworking of the data presented in Swift (1976), supplemented with average annual flow and peak flood flow data. Swift used a multiple linear regression technique to relate his input variables to the response variable (discharge producing maximum spawning area). Orsborn has used four of the variables used by Swift (drainage area, mean basin elevation, station elevation, and slope of channel) and has added two hydrologic variables. He gives no explanation either for his choice of variables or for the seemingly arbitrary way in which they are combined.

Basic Assumptions: That the choice of variables and aggregation technique make biological sense.

Limitations and Constraints: The model does not adress the question of whether either Q_{msa} is needed in any given situation.

Relationship to Other Methods: This method uses some of the same input variables as Swift (1976), but the method of aggregation of the variables seems to be unique. The general approach is similar to that of Collings (1974) and Swift (1976) in calculating the discharge producing maximum spawning habitat from non-microhabitat variables.

Quality of the Documentation: Lacks any explanation of how the model was derived. The entire explanation consists of the statement that "the best combination of basin, channel and flow factors tested turned out to be as shown in [the model equation]."

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: Since Orsborn does not include any indication of goodness of fit of his regression, there is no way to tell if the addition of the flow terms result in a more predictive model than either Swift's (1976) toe-width or basin-parameter models or Swift's (1979) one-variable models (also without correlation coefficient). Orsborn's model is peculiar in that the parameters are neither combined in a way suggested by known causal relationships, nor in a completely mechanical way such as multiple linear regression.

Methodology: PARDUE AND CORDES' FWS/HSI ALEWIFE AND BLUEBACK HERRING HABITAT SUITABILITY MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED, STRUCTURAL, BIOLOGICAL, PHYSICAL, AND CHEMICAL VARIABLES

Equation: HSI = lowest value of V_1, V_2, V_3, V_4, V_5

[Note: All variables are transformed and scaled from 0-1 before being included in the model, and in some cases different transformations are used for alewife and blueback, as the model can only be applied to one species at a time]

HSI = Habitat Suitability Index
V_1 = dominant substrate type for spawning
V_2 = mean daily temperature during spawning season
V_3 = mean zooplankton density
V_4 = mean salinity during spring or summer
V_5 = mean surface temperature

Correlation Coefficient: None found.

Source Documentation: Pardue, G.B. and C.L. Cordes. 1983. Habitat Suitability Index Models: Alewife and Blueback Herring. U.S. Fish and Wildlife Service. FWS/OBS-82/10.58, 22 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but its input variables may vary with discharge, and consequently might be used to predict the effect of discharge on habitat suitability, and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the choice of the lowest value as a criterion is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, For any predictive use it must be assumed also that there is some relationship between HSI and fish production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models except that geometric mean aggregation is not used. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose.

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Methodology: PARSONS ET AL.'S NATURAL FISH HABITAT INDEX

Type of Method: EMPIRICAL USING BASIN VARIABLES

Equation: $FHI = 6.56 + 1.44BP + 0.00089BR - 2.02BA - 5.62CC$

FHI = Fish Habitat Index (dimensionless)
BP = Basin Perimeter (units not given)
BR = Basin Relief (units not given)
BA = Basin Area (units not given)
CC = Compactness coefficient (units not given)

Correlation Coefficient: 0.77 between FHI and HCS where HCS = fish habitat condition score

Source Documentation: Parsons, M.G., J.R. Maxwell, and D. Heller. 1981. A predictive fish habitat index model using geomorphic parameters, *in* Aquisition and Utilization of Aquatic Habitat Inventory Information (N.B. Armantrout, ed.), pp. 85-91. Am. Fish Soc.; Bethesda, MD. 316 pp.

Objective: To assess inherent fish habitat conditions without the influence of forest management. As a baseline to assess the effects of existing forest management.

Level of Effort: Minimal: Probably requiring no field work, depending on available data.

Data Requirements: The perimeter, relief, and area measurements appear to have been taken from a topographic map with minimal effort. The source of the compactness coefficient is not indicated, but was probably available information from soil surveys.

Model Development The dependent variable, fish Habitat Condition Score (HCS) for a stream, was based on an arbitrary rating from 0 to 10 of Flow, Pool:Riffle Ratio, Pool Quality, Effective Cover and Riffle Depth, Bottom Composition, and Sedimentation in a given reach, then multiplying each rating by an arbitrary weighting factor of 0 to 10 to achieve a score from 0 to 100. The total score for all variables was then divided by the total weight to achieve an unadjusted score from 0 to 10, which was then adjusted upward if salmonids were present, and was additionally weighted by the number of miles represented by each reach. Thirty-four geomorphic variables were then correlated with the HCS, and all but 10 were deleted owing to poor correlation. The remaining 10 were regressed on the HCS using backward stepwise regression, and four were retained in the resulting model equation shown above.

Basic Assumptions: That geomorphic conditions away from the watercourse are suitable indicators of natural fish habitat quality, and that the fish habitat condition variables used to determine the habitat condition score are the important ones. Also, that the fish habitat condition variables are rated (scaled) and weighted correctly, and that the adjustment based on numbers of salmonids present is appropriate. None of these assumptions was tested.

Limitations and Constraints: Probably only applicable in the basins in which it was developed. Explains only 60% of the variation in the fish habitat condition, and no correlation has been attempted between fish habitat condition and standing crop or production.

Relationship to Other Methods: Unusual in that although an empirical regression model is used, the dependent variable is derived arbitrarily. Other regression models usually have regressed fish habitat quality variables on fish population. This one regresses geomorphic land form features on fish habitat variables.

Quality of the Documentation: Descriptive, but not sufficient to allow independent testing. The scheme for rating and weighting HCS variables is not given, and the units of the geomorphic variables is not given.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This method is included only because it represents a novel approach to evaluating fish habitat that might profit from further development: the idea that for a given geographic area, undisturbed fisheries values are correlated with geomorphic variables that can be read mostly from maps. Application of the model elsewhere would probably be useless because the values of the parameters and choice of variables would probably differ. Derivation of a similar model might, however, be worthwhile, particularly if the fish habitat condition score were shown to be correlated with some objective measure of habitat quality such as standing crop.

Methodology: RABERN'S BOWFIN (AMIA CALVA) MODEL

Type of Method: EMPIRICAL USING DISCHARGE, HYDRAULIC, PHYSICAL, CHEMICAL, AND BIOLOGICAL VARIABLES

Equation: $SC = 133.847 + 0.783V_2 - 0.564V_3 + 8.813V_8 + 6.368V_{11} - 113.12V_{13} + 0.415V_{18} + 0.686V_{19}$

SC = bowfin standing crop ($kg*ha^{-1}$)
V_2 = mean stream depth (m)
V_3 = mean monthly flow (m^3*s^{-1})
V_8 = annual range of dissolved oxygen ($mg*l^{-1}$)
V_{11} = mean annual water temperature (^oC)
V_{13} = mean annual 5-day BOD ($mg\ O_2*l^{-1}$)
V_{18} = mean annual platinum color (platinum-cobalt units)
V_{19} = number of fish species in drainage

Correlation Coefficient: Overall $R^2 = 0.854$. Annual dissolved oxygen alone $r^2 = 0.476$. Platinum-cobalt color alone $r^2 = 0.258$.

Source Documentation: Rabern, D.A. 1984. Development of Habitat Based Models for Predicting Standing Crops of Nine Species of Riverine Fishes in Georgia. Unpublished M.S. thesis, Univ. GA.

Objective: To find correlations between readily available or easily predicted physical, chemical, and biological variables and fish standing crop.

Level of Effort: Low to high, depending on the availability of the data.

Model Development: Using a data set of 21 habitat variables plus bowfin standing crop from 67 rotenone surveys in Georgia, Rabern selected a subset of variables and estimated linear regression parameters. He used the method of minimum R^2 improvement to find the best 21-variable model, then eliminated the least significant variables using Mallows' Cp statistic. As alternative approaches, variables with $r<0.65$ with standing crop were eliminated prior to the stepwise multiple regression; variables with probability significance level >0.10 were discarded prior to regression; and the squares and cross products of the variables used in the first two alternatives were included as part of the regression. Variables were then eliminated from the four alternatives, again using Mallows' Cp statistic. Of the five multiple regression equations thus derived, the one with the largest R^2 (in this case, the original data set) was retained as the final model.

Basic Assumptions: The use of multiple linear regression implies a belief that the underlying relationships are linear (for which there is little, if any, evidence). There is also the implication that each variable in the original data set varied enough that its contribution to the regression (if any) would have been detected.

Limitations and Constraints: The choice of variables and magnitude of parameters would probably be different in a different geographical setting--there is no reason to believe that collecting the appropriate data for the variables and entering it into the equation would result in an accurate standing crop estimate in other types of streams and other localities, nor is there any evidence that altering any of the input variables would affect subsequent standing crops.

Relationship to Other Methods: This is a straightforward empirical regression model with no transformation or scaling of variables. Some other effective regression models such as Binns and Eiserman (1979) have been based on heavily transformed variables.

Quality of the Documentation: Very good. The only improvement would be inclusion of the raw data (a 21 * 67 matrix) to allow independent testing.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: Although empirical regression models such as this are probably limited in direct applicability to the streams from which they were derived (or to very similar ones), they may be very effective predictors of standing crop in these limited settings. Their predictiveness is dependent on whether or not the variables used to construct them are always correlated in the same way with standing crop. In this model, the most important variables are range of DO (meaning the bowfin can withstand low DO), high water temperature (which would restrict less tolerant species and decrease competition) and lack of color (indicating that bowfin prefer clear water). These appear to be the sorts of variables that would control population size. The next closest model had an R^2 of 0.747, but included only three variables (stream gradient, total carbon, and BOD), only one of which (BOD) was in the best model.

Methodology: RABERN'S CHAIN PICKEREL (ESOX NIGER) MODEL

Type of Method: EMPIRICAL USING HYDRAULIC, OTHER PHYSICAL/CHEMICAL, AND BIOLOGICAL VARIABLES

Equation: $SC = 3.295 + 0.02V_2 - 0.27V_6 + 0.158V_8 + 0.39V_{10} - 0.124V_{11} - 0.044V_{19}$

SC = chain pickerel standing crop ($kg*ha^{-1}$)
V_2 = mean stream depth (m)
V_6 = annual number of frost-free days
V_8 = annual range of dissolved oxygen ($mg*l^{-1}$)
V_{10} = mean annual air temperature (^{o}C)
V_{11} = mean annual water temperature (^{o}C)
V_{19} = number of fish species in drainage

Correlation Coefficient: $R^2 = 0.656$. For mean annual dissolved oxygen $r^2 = 0.210$. For mean annual air temperature $r^2 = 0.276$. For numbers of species $r^2 = 0.155$.

Source Documentation: Rabern, D.A. 1984. Development of Habitat Based Models for Predicting Standing Crops of Nine Species of Riverine Fishes in Georgia. Unpublished masters thesis, Univ. Ga.

Objective: To find correlations between readily available or easily predicted physical, chemical, and biological variables and fish standing crop.

Level of Effort: Low to high, depending on the availability of the data.

Model Development: Using a data set of 21 habitat variables plus chain pickerel standing crop from 21 rotenone surveys in Georgia, Rabern selected a subset of variables and estimated linear regression parameters. He used the method of minimum R^2 improvement to find the best 21-variable model, and then eliminated the least significant variables using Mallows' Cp statistic. As alternative approaches, variables with $r<0.65$ with standing crop were eliminated prior to the stepwise multiple regression; variables with probability significance level >0.05 were discarded prior to regression; and the squares and cross products of the variables used in the first two alternatives were included as part of the regression. Variables were then eliminated from the four alternatives, again using Mallow's Cp statistic. Of the five multiple regression equations thus derived, the one with the largest R^2 (in this case, the original data set) was retained as the final model.

Basic Assumptions: The use of multiple linear regression implies a belief that the underlying relationships are linear (for which there is little, if any, evidence). There is also the implication that each variable in the original data set varied enough that its contribution to the regression (if any) would have been detected.

Limitations and Constraints: The choice of variables and magnitude of parameters would probably be different in a different geographical setting--there is no reason to believe that collecting the appropriate data for the variables and entering it into the equation would result in an accurate standing crop estimate in other types of streams and other localities, nor is there any evidence that altering any of the input variables would affect standing crop.

Relationship to Other Methods: This is a straightforward empirical regression model with no transformation or scaling of variables. Some other effective regression models such as Binns and Eiserman (1979) have been based on heavily transformed variables.

Quality of the Documentation: Very good, The only improvement would be inclusion of the raw data (a 21 * 21 matrix) to allow independent testing.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: Although empirical regression models such as this are probably limited in direct applicability to the streams from which they were derived (or to very similar ones), they may be very effective predictors of standing crop in these limited settings. Their predictiveness is dependent on whether or not the variables used to construct them are always correlated in the same way with standing crop. In this model the most important variables are mean annual air temperature, mean annual dissolved oxygen, and number of other species. These do not appear to form a strong basis for prediction, and indeed, the correlations shown in this model are weak: Rabern's other models had $R^2 >0.50$.

Methodology: RABERN'S SPOTTED SUNFISH (LEPOMIS PUNCTATUS) MODEL

Type of Method: EMPIRICAL USING PHYSICAL, CHEMICAL, AND BIOLOGICAL VARIABLES

Equation: $SC = 4.717 - 0.335V_9 + 0.050V_8{}^2 + 0.005V_{19}{}^2 + 12.962V2_0{}^2 - 0.{}^{01}3V_8V_{19} - 0.551V_{19}V_{20}$

SC = spotted sunfish standing crop ($kg*ha^{-1}$)
V_8 = annual range of dissolved oxygen ($mg*l^{-1}$)
V_9 = annual minimum dissolved oxygen ($mg*l^{-1}$)
V_{19} = number of fish species in drainage
V_{20} = fractional distance of sample location from center to edge of species range

Correlation Coefficient: Overall $R^2 = 0.797$.

Source Documentation: Rabern, D.A. 1984. Development of Habitat Based Models for Predicting Standing Crops of Nine Species of Riverine Fishes in Georgia. Unpublished masters thesis, Univ. GA.

Objective: To find correlations between readily available or easily predicted physical, chemical, and biological variables and fish standing crop.

Level of Effort: Low to high, depending on the availability of the data.

Model Development: Using a data set of 21 habitat variables plus spotted sunfish standing crop from 67 rotenone surveys in Georgia, Rabern selected a subset of variables and estimated linear regression parameters. He used the method of minimum R^2 improvement to find the best 21-variable model, and then eliminated the least significant variables using Mallows' Cp statistic. As alternative approaches, variables with $R < 0.65$ with standing crop were eliminated prior to the stepwise multiple regression; variables with probability significance level >0.05 were discarded prior regression; and the squares and cross products of the variables used in the first two alternatives were included as part of the regression. Variables were then eliminated from the four alternatives, again using Mallows' Cp statistic. Of the five multiple regression equations thus derived, the one with the largest R^2 (in this case, the data set made up of variables having individual correlation coefficients of $R > 0.65$ and their cross products).

Basic Assumptions: The use of multiple linear regression implies a belief that the underlying relationships are linear (for which there is little, if any, evidence). There is also the implication that each variable in the original data set varied enough that its contribution to the regression (if any) would have been detected.

Limitations and Constraints: The choice of variables and the magnitudes of parameters would probably be different in a different geographical setting - there is no reason to believe that collecting the appropriate data for the variables and entering it into the equation would result in an accurate standing crop estimate in other types of streams and other localities, nor is there any evidence that altering any of the input variables would affect subsequent standing crop.

Relationship to Other Methods: This is a straightforward empirical regression model with no transformation or scaling of variables. Some other effective regression models such as Binns and Eiserman (1979) have been based on heavily transformed variables.

Quality of the Documentation: Very good. The only improvement would be inclusion of the raw data (a 21 * 67 matrix) to allow independent testing.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: Although empirical regression models such as this are probably limited in direct applicability to the streams from which they were derived (or to very similar ones), they may be very effective predictors of standing crop in these limited settings. Their predictiveness is dependent on whether or not the variables used to construct them are always correlated in the same way with standing crop. In this model, the important variables were the nearness to the center of the range, the general suitability for other fish species as well. It appears odd to us that SC is inversely correlated with minimum DO, but may only mean that the sunfish are tolerant of DO low enough to affect competitors adversely. The next closest model ($R^2 = 0.769$) was based on the original data set, did not include annual range of DO, and added specific conductivity, air temperature, turbidity, alkalinity, and color.

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Methodology: RABERN'S WARMOUTH (LEPOMIS GULOSUS) MODEL

Type of Method: EMPIRICAL USING PHYSICAL/CHEMICAL AND BIOLOGICAL VARIABLES

Equation:

$$SC = 86.133 - 0.469V_7 + 3.367V_{15} - 0.002{V_7}^2 + 0.019{V_{15}}^2 + 0.038{V_{19}}^2 + 0.018V_7V_{19} - 0.082V_{15}V_{19} - 3.856V_{19}$$

SC = warmouth standing crop ($kg*ha^{-1}$)
V_7 = specific conductivity ($micromho*cm^{-1}$)
V_{15} = mean annual methyl-orange alkalinity ($mg*l^{-1}$)
V_{19} = number of fish species in drainage

Correlation Coefficient: Overall $R^2 = 0.955$. For mean annual specific conductivity alone $r^2 = 0.306$. For number of other species alone $r^2 = 0.165$. For mean annual alkalinity alone $r^2 = 0.153$. Squared and cross multiplied variables accounted for 63.3% of the error.

Source Documentation: Rabern, D.A. 1984. Development of Habitat Based Models for Predicting Standing Crops of Nine Species of Riverine Fishes in Georgia. Unpublished masters thesis, Univ. GA.

Objective: To find correlations between readily available or easily predicted physical, chemical, and biological variables and fish standing crop.

Level of Effort: Low to high, depending on the availability of the data.

Model Development: Using a data set of 21 habitat variables plus warmouth standing crop from 25 rotenone surveys in Georgia, Rabern selected a subset of variables and estimated linear regression parameters. He used the method of minimum R^2 improvement to find the best 21-variable model, then eliminated the least significant variables using Mallows' Cp statistic. As alternative approaches, variables with $r<0.65$ with standing crop were eliminated prior to the stepwise multiple regression; variables with probability significance level >0.05 were discarded prior regression; and the squares and cross products of the variables used in the first two alternatives were included as part of the regression. Variables were then eliminated from the four alternatives, again using Mallows' Cp statistic. Of the five multiple regression equations thus derived, the one with the largest R^2 (in this case, the data set made up of variables having a significance level $P \leq = 0.05$ and their cross products)

Basic Assumptions: The use of multiple linear regression implies a belief that the underlying relationships are linear (for which there is little, if any, evidence). There is also the implication that each variable in the original data set varied enough that its contribution to the regression (if any) would have been detected.

Limitations and Constraints: The choice of variables and magnitude of parameters would probably be different in a different geographical setting--there is no reason to believe that collecting the appropriate data for the variables and entering it into the equation would result in an accurate standing crop estimate in other types of streams and other localities, nor is there any evidence that altering any of the input variables would affect subsequent standing crops.

Relationship to Other Methods: This is a straightforward empirical regression model with no transformation or scaling of variables. Other effective regression models such as Binns and Eiserman (1979) have been based on heavily transformed and scaled variables.

Quality of the Documentation: Very good. The only improvement would be inclusion of the raw data (a 21 * 3 matrix) to allow independent testing.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: Although empirical regression models such as this are probably limited in direct applicability to the streams from which they were derived (or to very similar ones), they may be very effective predictors of standing crop in these limited settings. Their predictiveness is dependent on whether or not the variables used to construct them are always correlated in the same way with standing crop. In this model, the data suggest a preference by warmouth for areas with increased levels of calcium carbonate and higher specific conductivity. The next best model ($R^2 = 0.893$) was based on the original data set and did not include V_7 and V_{15}. Instead, it included depth, flow, gradient, water temperature, turbidity, phosphorus, platinum color, # fish species in drainage, and fractional distance of sample locations from center to edge of species range.

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Methodology: RABERN'S LAKE CHUBSUCKER (ERIMYZON SUCETTA) MODEL

Type of Method: EMPIRICAL USING DISCHARGE, PHYSICAL, CHEMICAL, AND BIOLOGICAL VARIABLES

Equation:

$$SC = 5.286 + 0.016V_3 - 0.018V_6 + 0.035V_7 + 0.631V_8 + 0.509V_9 - 0.18V_{12} - 1.712V_{13} + 0.141V_{14} - 0.226V_{15} - 1.217V_{16} + 10.733V_{20}$$

SC = lake chubsucker standing crop (kg*ha^{-1})
V_3 = mean monthly flow (m^3*s^{-1})
V_6 = annual number of frost-free days
V_7 = specific conductivity (micromho*cm^{-1})
V_8 = annual range of dissolved oxygen (mg*l^{-1})
V_9 = annual minimum dissolved oxygen (mg*l^{-1})
V_{12} = mean annual turbidity (JTU)
V_{13} = mean annual 5-day BOD (mg O_2*l^{-1})
V_{14} = mean annual Ca and Mg hardness (as mg Ca*l^{-1})
V_{15} = mean annual methyl-orange alkalinity (mg*l^{-1})
V_{16} = mean annual total phosphorus (mg*l^{-1})
V_{20} = fractional distance of sample location from center to edge of species range

Correlation Coefficient: R^2 = 0.870. Turbidity had an r = -.334, and other single variables were even less well correlated.

Source Documentation: Rabern, D.A. 1984. Development of Habitat Based Models for Predicting Standing Crops of Nine Species of Riverine Fishes in Georgia. Unpublished masters thesis, Univ. GA.

Objective: To find correlations between readily available or easily predicted physical, chemical, and biological variables and fish standing crop.

Level of Effort: Low to high, depending on the availability of the data.

Model Development: Using a data set of 21 habitat variables plus lake chubsucker standing crop from 14 rotenone surveys in Georgia, Rabern selected a subset of variables and estimated linear regression parameters. He used the method of minimum R^2 improvement to find the best 21-variable model, then eliminated the least significant variables using Mallows' Cp statistic. As alternative approaches, variables with r<0.65 with standing crop were eliminated prior to the stepwise multiple regression; variables with probability significance level >0.10 were discarded prior regression; and the squares and cross products of the variables used in the first two alternatives were included as part of the regression. Variables were then eliminated from the four alternatives, again using Mallows' Cp statistic. Of the five multiple regression equations thus derived, the one with the largest R^2 (in this case, the original data set) was retained as the final model.

Basic Assumptions: The use of multiple linear regression implies a belief that the underlying relationships are linear (for which there is little, if any, evidence). There is also the implication that each variable in the original data set varied enough that its contribution to the regression (if any) would have been detected.

Limitations and Constraints: The choice of variables and magnitude of parameters would probably be different in a different geographical setting--there is no reason to believe that collecting the appropriate data for the variables and entering it into the equation would result in an accurate standing crop estimate in other types of streams and other localities, nor is there any evidence that altering any of the input variables would affect subsequent standing crop.

Relationship to Other Methods: This is a straightforward empirical regression model with no transformation or scaling of variables. Some other effective regression models such as Binns and Eiserman (1979) have been based on heavily transformed variables.

Quality of the Documentation: Very good. The only improvement would be inclusion of the raw data (a 21 * 14 matrix) to allow independent testing.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: Although empirical regression models such as this are probably limited in direct applicability to the streams from which they were derived (or to very similar ones), they may be very effective predictors of standing crop in these limited settings. Their predictiveness is dependent on whether or not the variables used to construct them are always correlated in the same way with standing crop. In this model, no individual variable was very important. The next best model (R^2 = 0.639) contained 4 variables: Turbidity, total carbon, frost-free days, and annual range of dissolved oxygen.

Methodology: RABERN'S SPOTTED SUCKER (MINYTREMA MELANOPS) MODEL

Type of Method: EMPIRICAL USING HYDRAULIC, OTHER PHYSICAL/CHEMICAL, AND BIOLOGICAL VARIABLES

Equation:

$$SC = - 147.385 + 1.420V_2 - 1.431V_3 + 0.300V_5 + 3.729V_{11} + 1.947V_{12} - 1.060V_{15} + 2.283V_{19} - 237.210V_{20}$$

SC = spotted sucker standing crop ($kg*ha^1$)
V_2 = mean stream depth (m)
V_3 = mean monthly flow (m^3*s^{-1})
V_5 = annual rainfall (cm)
V_{11} = mean annual water temperature (^oC)
V_{12} = mean annual turbidity (JTU)
V_{15} = mean annual methyl-orange alkalinity ($mg*l^{-1}$)
V_{19} = number of fish species in drainage
V_{20} = fractional distance of sample location from center to edge of species range

Correlation Coefficient: $R^2 = 0.775$. The geographic range variable (V_{20}) accounted for 29.3% of the residual error, and width, flow and rainfall explained 40.4%

Source Documentation: Rabern, D.A. 1984. Development of Habitat Based Models for Predicting Standing Crops of Nine Species of Riverine Fishes in Georgia. Unpublished masters thesis, Univ. GA.

Objective: To find correlations between readily available or easily predicted physical, chemical, and biological variables and fish standing crop.

Level of Effort: Low to high, depending on the availability of the data.

Model Development: Using a data set of 21 habitat variables plus spotted sucker standing crop from 65 rotenone surveys in Georgia, Rabern selected a subset of variables and estimated linear regression parameters. He used the method of minimum R^2 improvement to find the best 21 variable model, then eliminated the least significant variables using Mallows' Cp statistic. As alternative approaches, variables with $r<0.65$ with standing crop were eliminated prior to the stepwise multiple regression; variables with probability significance level >0.05 were discarded prior regression; and the squares and cross products of the variables used in the first two alternatives were included as part of the regression. Variables were then eliminated from the four alternatives, again using Mallows' Cp statistic. Of the five multiple regression equations thus derived, the one with the largest R^2 (in this case, the original data set) was retained as the final model.

Basic Assumptions: The use of multiple linear regression implies a belief that the underlying relationships are linear (for which there is little, if any, evidence). There is also the implication that each variable in the original data set varied enough that its contribution to the regression (if any) would have been detected.

Limitations and Constraints: The choice of variables and magnitude of parameters would probably be different in a different geographical setting--there is no reason to believe that collecting the appropriate data for the variables and entering it into the equation would result in an accurate standing crop estimate in other types of streams and other localities, nor is there any evidence that altering any of the input variables would affect subsequent standing crop.

Relationship to Other Methods: This is a straightforward empirical regression model with no transformation or scaling of variables. Some other effective regression models such as Binns and Eiserman (1979) have been based on heavily transformed variables.

Quality of the Documentation: Very good. The only improvement would be inclusion of the raw data (a 21 * 65 matrix) to allow independent testing.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: Although empirical regression models such as this are probably limited in direct applicability to the streams from which they were derived (or to very similar ones), they may be very effective predictors of standing crop in these limited settings. Their predictiveness is dependent on whether or not the variables used to construct them are always correlated in the same way with standing crop. In this model, it is not possible to tell the relative importance of the independent variables. The four alternative regression model configurations examined all had weak (R^2 <0.31) multiple correlation coefficients.

Methodology: RABERN'S AMERICAN EEL (ANGUILLA ROSTRATA) MODEL

Type of Method: EMPIRICAL USING BASIN AND PHYSICAL/CHEMICAL VARIABLES

Equation:

$$SC = -2.517 - 0.581V_{15} - 6.25V_8 - 14.279V_4 + 0.056V_{21} + 0.012V_{15}^2 + 0.288V_{15}V_8 - 0.002V_{15}V_{21} + 1.108V_{16}V_{17} + 1.201V_4V_{17} + 0.317V_8V_{17} - 0.003V_{17}V_{21}$$

SC = American eel standing crop ($kg*ha^{-1}$)
V_4 = percent stream gradient (%)
V_8 = annual range of dissolved oxygen ($mg*l^{-1}$)
V_{15} = mean annual methyl-orange alkalinity ($mg*l^{-1}$)
V_{16} = mean annual total phosphorus ($mg*l^{-1}$)
V_{17} = mean annual total carbon ($mg*l^{-1}$)
V_{21} = distance from the Atlantic Ocean (km)

Correlation Coefficient: $R^2 = 0.975$; for alkalinity (V_{15}) alone, $r^2 = 0.213$, for dissolved oxygen range (V_8,) $r^2 = 0.158$. The interaction terms accounted for 31.3% of the error

Source Documentation: Rabern, D.A. 1984. Development of Habitat Based Models for Predicting Standing Crops of Nine Species of Riverine Fishes in Georgia. Unpublished masters thesis, Univ. GA.

Objective: To find correlations between readily available or easily predicted physical, chemical, and biological variables and fish standing crop.

Level of Effort: Low to high, depending on the availability of the data.

Model Development: Using a data set of 21 habitat variables plus American eel standing crop from 16 rotenone surveys in Georgia, Rabern selected a subset of variables and estimated linear regression parameters. He used the method of minimum R^2 improvement to find the best 21-variable model, then eliminated the least significant variables using Mallows' Cp statistic. As alternative approaches, variables with $r<0.65$ with standing crop were eliminated prior to the stepwise multiple regression; variables with probability significance level >0.05 were discarded prior regression; and the squares and cross products of the variables used in the first two alternatives were included as part of the regression. Variables were then eliminated from the four alternatives, again using Mallows' Cp statistic. Of the five multiple regression equations thus derived, the one with the largest R^2 (in this case, the data set made up of variables having individual correlation coefficients of $r>=0.65$ and their cross products) was retained as the final model.

Basic Assumptions: The use of multiple linear regression implies a belief that the underlying relationships are linear (for which there is little, if any, evidence). There is also the implication that each variable in the original data set varied enough that its contribution to the regression (if any) would have been detected.

Limitations and Constraints: The choice of variables and magnitude of parameters would probably be different in a different geographical setting--there is no reason to believe that collecting the appropriate data for the variables and entering it into the equation would result in an accurate standing crop estimate in other types of streams and other localities, nor is there any evidence that altering any of the input variables would affect subsequent standing crop.

Relationship to Other Methods: This is a straightforward empirical regression model with no transformation or scaling of variables. Some other effective regression models such as Binns and Eiserman (1979) have been based on heavily transformed variables.

Quality of the Documentation: Very good. The only improvement would be inclusion of the raw data (a 21 * 16 matrix) to allow independent testing.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: Although empirical regression models such as this are probably limited in direct applicability to the streams from which they were derived (or to very similar ones), they may be very effective predictors of standing crop in these limited settings. Their predictiveness is dependent on whether or not the variables used to construct them are always correlated in the same way with standing crop. In this model, mean annual alkalinity, range of annual variation in dissolved oxygen, and their interactions suggest distance to the Atlantic Acean was also important for this catadromous species, although it would make intuitive sense that SC would be negatively, not positively, correlated with it. But for this species, the regression equation using the original data set including stream width, annual rainfall, air temperature, water temperature, BOD, hardness, color, number of species, and DO in addition to the variables here, had a slightly better R^2 of 0.976, and a model containing only alkalinity and conductivity was only slightly less good ($R^2 = 0.88$)

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Methodology: RABERN'S GIZZARD SHAD (DOROSOMA CEPEDIANUM) MODEL

Type of Method: EMPIRICAL USING DISCHARGE, HYDRAULIC, PHYSICAL, CHEMICAL, AND BIOLOGICAL VARIABLES

Equation:

$$SC = 648.264 + 16.937V_1 + 0.384V_2 + 0.829V_3 - 0.773V_7 + 14.682V_8 + 26.277V_9 + 10.6V_{10} + 94.515V_{13} + 41.758V_{16} + 1.791V_{17} - 0.248V_{18} + 271.439V_{20}$$

SC = gizzard shad standing crop ($kg * ha^{-1}$)
V_1 = mean stream width (m)
V_2 = mean stream depth (m)
V_3 = mean monthly flow ($m^3 * s^{-1}$)
V_7 = specific conductivity ($micromho * cm^{-1}$)
V_8 = annual range of dissolved oxygen ($mg * l^{-1}$)
V_9 = annual minimum dissolved oxygen ($mg * l^{-1}$)
V_{10} = mean annual air temperature (°C)
V_{13} = mean annual 5-day BOD ($mg\ O_2 * l^{-1}$)
V_{16} = mean annual total phosphorus ($mg * l^{-1}$)
V_{17} = mean annual total carbon ($mg * l^{-1}$)
V_{18} = mean annual platinum color (platinum-cobalt units)
V_{20} = fractional distance of sample location from center to edge of species range

Correlation Coefficient: $R^2 = 0.962$; for mean flow, $r^2 = 0.518$; for average width, $r^2 = 0.387$; for average depth, $r^2 = 0.21$.

Source Documentation: Rabern, D.A. 1984. Development of Habitat Based Models for Predicting Standing Crops of Nine Species of Riverine Fishes in Georgia. Unpublished masters thesis, Univ. GA.

Objective: To find correlations between readily available or easily predicted physical, chemical, and biological variables and fish standing crop.

Level of Effort: Low to high, depending on the availability of the data.

Model Development: Using a data set of 21 habitat variables plus gizzard shad standing crop from 10 rotenone surveys in Georgia, Rabern selected a subset of variables and estimated linear regression parameters. He used the method of minimum R^2 improvement to find the best 21 variable model, then eliminated the least significant variables using Mallows' Cp statistic. As alternative approaches, variables with $r<0.65$ with standing crop were eliminated prior to the stepwise multiple regression; variables with probability significance level >0.05 were discarded prior regression; and the squares and cross products of the variables used in the first two alternatives were included as part of the regression. Variables were then eliminated from the four alternatives, again using Mallows' Cp statistic. Of the five multiple regression equations thus derived, the one with the largest R^2 (in this case, the original data set) was retained as the final model.

Basic Assumptions: The use of multiple linear regression implies a belief that the underlying relationships are linear (for which there is little, if any, evidence). There is also the implication that each variable in the original data set varied enough that its contribution to the regression (if any) would have been detected.

Limitations and Constraints: The choice of variables and magnitude of parameters would probably be different in a different geographical setting - there is no reason to believe that collecting the appropriate data for the variables and entering it into the equation would result in an accurate standing crop estimate in other types of streams and other localities, nor is there any evidence that altering any of the input variables would affect subsequent standing crop.

Relationship to Other Methods: This is a straightforward empirical regression model with no transformation or scaling of variables. Some other effective regression models such as Binns and Eiserman (1979) have been based on heavily transformed variables.

Quality of the Documentation: Very good. The only improvement would be inclusion of the raw data (a 21 * 10 matrix) to allow independent testing.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: Although empirical regression models such as this are probably limited in direct applicability to the streams from which they were derived (or to very similar ones), they may be very effective predictors of standing crop in these limited settings. Their predictiveness is dependent on whether or not the variables used to construct them are always correlated in the same way with standing crop. In this model, the most important variables are range of DO (mean monthly flow rate, average width and average depth). This suggests that the IFIM model might work well with gizzard shad. The next best model, with an R^2 of 0.664, did not use V, V_2, V_7, V_{10}, and V_{13}, but included gradient, rainfall, water temperature and number of fish species.

Methodology: RABERN'S BROWN BULLHEAD (ICTALURUS NEBULOSUS) MODEL

Type of Method: EMPIRICAL USING DISCHARGE, HYDRAULIC, PHYSICAL, CHEMICAL, AND BIOLOGICAL VARIABLES

Equation:

$$SC = 5379.605 - 160.855V_1 + 20.744V_2 - 16.209V_3 + 2.373V_6 - 2.201V_7 + 94.444V_8 + 177.971V_9 + 25.192V_{10} + 87.584V_{11} + 11.097V_{12} + 31.335V_{14} - 1708.715V_{16} - 78.309V_{17} + 15.099V_{18} - 9.707V_{19} + 1472.063V_{20}$$

SC = brown bullhead standing crop ($kg*ha^{-1}$)
V_1 = mean stream width (m)
V_2 = mean stream depth (m)
V_3 = mean monthly flow (m^3*s^{-1})
V_6 = annual number of frost-free days
V_7 = specific conductivity ($micromho*cm^{-1}$)
V_8 = annual range of dissolved oxygen ($mg*l^{-1}$)
V_9 = annual minimum dissolved oxygen ($mg*l^{-1}$)
V_{10} = mean annual air temperature (^oC)
V_{11} = mean annual water temperature (^oC)
V_{12} = mean annual turbidity (JTU)
V_{14} = mean annual Ca and Mg hardness (as mg $Ca*l^{-1}$)
V_{16} = mean annual total phosphorus ($mg*l^{-1}$)
V_{17} = mean annual total carbon ($mg*l^{-1}$)
V_{18} = mean annual platinum color (platinum-cobalt units)
V_{19} = number of fish species in drainage
V_{20} = fractional distance of sample location from center to edge of species range

Correlation Coefficient: Overall $R^2 = 0.848$.

Source Documentation: Rabern, D.A. 1984. Development of Habitat Based Models for Predicting Standing Crops of Nine Species of Riverine Fishes in Georgia. Unpublished masters thesis, Univ. GA.

Objective: To find correlations between readily available or easily predicted physical, chemical, and biological variables and fish standing crop.

Level of Effort: Low to high, depending on the availability of the data.

Model Development: Using a data set of 21 habitat variables plus brown bullhead standing crop from 16 rotenone surveys in Georgia, Rabern selected a subset of variables and estimated linear regression parameters. He used the method of minimum R^2 improvement to find the best 21-variable model, and then eliminated the least significant variables using Mallows' Cp statistic. As alternative approaches, variables with $r<0.65$ with standing crop were eliminated prior to the stepwise multiple regression; variables with probability significance level >0.05 were discarded prior regression; and the squares and cross products of the variables used in the first two alternatives were included as part of the regression. Variables were then eliminated from the four alternatives, again using Mallows' Cp statistic. Of the five multiple regression equations thus derived, the one with the largest R^2 (in this case, the original data set) was retained as the final model.

Basic Assumptions: The use of multiple linear regression implies a belief that the underlying relationships are linear (for which there is little, if any, evidence). There is also the implication that each variable in the original data set varied enough that its contribution to the regression (if any) would have been detected.

Limitations and Constraints: The choice of variables and magnitude of parameters would probably be different in a different geographical setting - there is no reason to believe that collecting the appropriate data for the variables and entering it into the equation would result in an accurate standing crop estimate in other types of streams and other localities.

Relationship to Other Methods: This is a straightforward empirical regression model with no transformation or scaling of variables. Some other effective regression models such as Binns and Eiserman (1979) have been based on heavily transformed variables.

Quality of the Documentation: Very good. The only improvement would be inclusion of the raw data (a 21 * 16 matrix) to allow independent testing.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: Although empirical regression models such as this are probably limited in direct applicability to the streams from which they were derived (or to very similar ones), they may be very effective predictors of standing crop in these limited settings. Their predictiveness is dependent on whether or not the variables used to construct them are always correlated in the same way with standing crop. In this model, none of the individual variables had large correlation coefficients.

X

Methodology: RALEIGH'S FWS/HEP BROOK TROUT RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED DISCHARGE, HYDRAULIC, STRUCTURAL, BIOLOGICAL, PHYSICAL, AND CHEMICAL VARIABLES

Equation:

$$HSI = [(V_4*V_6*(V_{10}*V_{15})^{0.5})^{0.33}*3^{-1}*(V_6+V_{10}+V_{15}) * (V_{10}*(V_8*V_{16})^{0.5})^{0.5}*((V_5*V_7*V_{16})^{0.33}) * ((V_9*V_{16})^{0.5}+V_{11})^{-0.5}]^{0.2}*(V_1*V_3*V_{13}*V_{14})^{0.25}$$

[where $V_6>(V_{10}*V_{15})^{1/2}$ and degraded water quality conditions cannot be compensated for by good physical habitat; plus several other assumptions detailed in Raleigh 1982. Note especially that all variables are scaled from 0-1, most non-linearly, before inclusion in the model]

HSI = Habitat Suitability Index (dimensionless)
V_1 = mean water temperature (^{o}C) at warmest time of year)
V_3 = mean DO ($mg*l^{-1}$) during low water period
V_4 = mean thalweg depth (cm) during low water period
V_5 = mean velocity ($cm*s^{-1}$) over spawning areas
V_6 = % instream cover during low water, depth $\geq$15 cm, velocity $\leq$15 $cm*s^{-1}$
V_7 = mean substrate diameter between 0.3-8 cm in spawning areas
V_8 = % substrate diameter between 10 and 40 cm in winter
V_9 = dominant substrate type (>50%) in riffle run areas (larger is better)
V_{10} = % pools during low water period
V_{11} = % vegetation along stream bank
V_{13} = mean annual maximal or minimal pH
V_{14} = mean annual minimum flow as % average daily flow
V_{15} = % area as large and deep pools
V_{16} = % fines in spawning areas

Correlation Coefficient: $r^2 = 0.06$ (calculated from the data of Trial et al. 1984) between HSI and trout per hectare.

Source Documentation: Raleigh, R.F. 1982. Habitat Suitability Index Models: Brook Trout. U.S. Fish and Wildlife Service FWS/OBS 82/10.24., 42 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability, and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the aggregation used is appropriate. For any predictive use it must be assumed also that there is some relationship between HSI and trout production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity, or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: Trial et al. (1984) showed very weak correlation between HSI and standing crop.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose. The only empirical test of it shows extremely poor correlation between the HSI and standing crop.

X

Methodology: SAMS AND PEARSONS'S ONE-FLOW METHOD

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED HYDRAULIC VARIABLES

Equation: $Q = WDV$

Q = optimum salmonid spawning discharge (ft^{3}*s^{-1})

W = the average width of the stream at 100-ft intervals over one representative mile of stream (ft)

D = average depth required over redds (ft)

V = average velocity required over redds (ft*s^{-1})

Correlation Coefficient: None found

Source Documentation: Sams, R.E. and L.S. Pearson. 1963. A study to develop methods for determining spawning flows for anadromous salmonids. Oregon Fish. Comm. Manuscript. 56 pp. (From Stalnaker and Arnette 1976).

Objective: To determine optimum spawning discharges from aerial photographs.

Level of Effort: Low.

Model Development: This method is based on the most basic of hydraulic equations, namely the equality that flow must be equal to cross sectional area times velocity.

Basic Assumptions: This approach assumes that for a given width and discharge, the depth and velocity terms will each be appropriate for spawning. In a general sense, this assumption is absurd because the equation can be satisfied with depths much too low for optimal spawning and velocities much too high, and vice versa, all depending on the energy slope and the bed roughness. From a practical standpoint however, the assumption may be reasonably accurate if the analysis is confined to known spawning areas.

Limitations and Constraints: Since the validity of the underlying assumptions is quite uncertain, this method is of value only for rough estimates of appropriate spawning flows.

Relationship to Other Methods: This is the simplest form of and general precursor to all of the physical microhabitat methods such as the USFS Region 6 method and the subsequent Waters method and USFWS HABTAT model. The basic premise, however, is identical: that the appropriate criteria for establishing instream flows are the velocities and depths preferred by the resident fish.

Quality of the Documentation: Not reviewed.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: Stalnaker and Arnette 1976, Wesche and Rechard 1980.

Published Comparisons With Other Methods: None found.

Critical Opinion: If the only data available are aerial photographs or measured widths of known spawning areas on a stream, this method will allow a rough first estimate of discharges needed to allow spawning. Much more sophisticated methods are now available, however.

X

Methodology: STUBER ET AL.'S FWS/HSI GREEN SUNFISH RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED, HYDRAULIC, STRUCTURAL, PHYSICAL, AND CHEMICAL VARIABLES

Equation: $HSI = [(V_1 * V_2)^{0.5} * (7^{-1}) * (2V_4 + V_5 + V_6 + V_7 + V_8 + V_{18}) * (V_9 * V_{10} * V_{12})^{1/3} * (2.5)^{-1} * (V_3 + 2^{-1} * [V_{11} + V_{13} + V_{14}])]^{0.25}$

[Note: All values are transformed and scaled from 0-1 before being used in the model]

HSI = Habitat Suitability Index
V_1 = % cover of pools during summer
V_2 = % pool area during mean summer flow
V_3 = gradient ($m*km^{-1}$) within representative reach
V_4 = minimum dissolved oxygen ($mg*l^{-1}$) during summer
V_5 = mean monthly pool turbidity (JTU) during summer
V_6 = pH during summer growing season
V_7 = maximum midsummer pool temperature (°C) (adults, juvenile)
V_8 = maximum midsummer pool temperature (°C) (fry)
V_9 = maximum pool temperature (°C) during spawning (embryo)
V_{10} = substrate composition within pools and spawning areas
V_{11} = mean pool velocity ($cm*sec^{-1}$) during mean summer flow (adults, juvenile)
V_{12} = mean pool velocity ($cm*sec^{-1}$) during spawning (embryo)
V_{13} = mean pool velocity ($cm*sec^{-1}$) during mean summer flow (fry)
V_{14} = mean representative reach stream width (m)
V_{18} = mean maximum monthly salinity (ppt) during growing season

Correlation Coefficient: None found, although Layher and Maughn (1984) tested a much simpler formulation, described on a separate Methodology Summary Form.

Source Documentation: Stuber, R.J. et al. 1982. Habitat Suitability Index Models: Green Sunfish. U.S. Fish and Wildlife Service. FWS/OBS-82/10.15. 28 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability, and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the aggregation used is appropriate. For any predictive use it must be assumed also that there is some relationship between HSI and fish production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: Li and Schreck, 1984, showed very weak negative correlation between HSI and standing crop.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose.

X

Methodology: STUBER'S FWS/HSI BLACK BULLHEAD RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED, HYDRAULIC, STRUCTURAL, PHYSICAL, AND CHEMICAL VARIABLES

Equation: $$\mathrm{HSI} = [(V_1 * V_2)^{1/2} * (V_1 * V_2 * V_3)^{1/3} * (2V_4 + 2V_5 + V_6 + [V_7 + V_8] * 2^{-1} + V_9)/7 * (V_1 * V_8 * V_{10} * V_{11} * V_{12})^{1/5}]^{1/4}$$

[Note: All values are transformed and scaled to dimensionless values from 0-1 prior to being used in the HSI equation]

HSI = Habitat Suitability Index
V_1 = % pools during summer
V_2 = % cover of pools during summer
V_3 = mean velocity ($m * s^{-1}$) during summer
V_4 = maximum midsummer pool temperature (°C)
V_5 = dissolved oxygen ($mg * 1^{-1}$) in pools during summer
V_6 = yearly pH range
V_7 = maximum salinity (ppt) during summer
V_8 = maximum salinity (ppt) May-July
V_9 = mean maximal monthly turbidity (ppm) during growing season
V_{10} = mean pool temperature (°C) during spawning
V_{11} = dominant substrate type in pools and spawning areas
V_{12} = % cover of pools during spawning

Correlation Coefficient: None found.

Source Documentation: Stuber, R.J. 1982. Habitat Suitability Index Models: Black Bullhead. US Fish and Wildlife Service. FWS/OBS-82/10.14. 26 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability, and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the aggregation used is appropriate. For any predictive use it must be assumed also that there is some relationship between HSI and fish production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose.

X

Methodology: SWANK AND PHILLIPS' U.S. FOREST SERVICE REGION 6 SINGLE TRANSECT WEIGHTED USABLE WIDTH METHOD

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED HYDRAULIC VARIABLES

Equation: Spawning Usable Width = length of transect >0.5 ft deep with velocities of 1.0-3.0 ft * sec^{-1}

Rearing Usable Width = length of transect between 0.5-3.0 ft deep with velocities of 0.2-1.6 ft * sec^{-1}

Food Production Usable Width = length of transect between 0.1-3.0 ft deep with velocities of 1.0-4.0 ft * sec^{-1}

Correlation Coefficient: None found

Source Documentation: Swank, G.W. and R.W. Phillips. 1976. Instream flow methodology for the Forest Service in the Pacific Northwest Region. *In* Proc. Symp. and Spec. Conf. on instream flow needs, J.F. Orsborn and O.H. Allman [eds.], Vol. II. pp. 334-343. Am. Fish Soc., Bethesda, MD.

Objective: To establish the flow with the greatest amount of usable habitat for spawning, rearing and food production for fish.

Level of Effort: Low to moderate. The authors suggest 3 transects per stream. Depths and velocities are to be measured at each of them at 3 flows.

Model Development: The model is essentially conceptual and arbitrary. Binary depth and velocity criteria (a given depth or velocity is considered either satisfactory or unsatisfactory...nothing in between) are presented with no supporting information or justification. Depths and velocities are measured at 3 flows (high, low, near average). Weighted usable width (the total distance across the transect meeting both depth and velocity criteria) is measured at each of the 3 flows, then a "bell shaped curve" is overlayed on the data. In the first example shown by the authors, the suitability of the "near average" flow is much higher than that of the high or low flows, but the flows are so far apart that there is no way to tell if the "near average" flow produced the maximum habitat. In the second example shown, measurements appear to have been made at 20 or more different flows and although the authors "fit" a curve to the data (apparently using a French curve or similar drafting appliance) the data appear to be completely uncorrelated and randomly distributed (and consequently no curve-fitting was justified).

Basic Assumptions: For proper application of this method, it must be assumed that the depth and velocity criteria are accurate, that using binary criteria is appropriate, and that the Weighted Usable Width changes in a way functionally related to flow so that a curve can be fitted.

Limitations and Constraints: The principal limitations are that 3 flows are probably insufficient to allow definition of the functional relationships sought, and that the criteria for habitat suitability are unsupported either in the choice of input variables or in their ranges of suitability.

Relationship to Other Methods: This method is one of the early attempts to relate measurements of depth and velocity at different discharges to habitat suitability. The basic technique is similar to that of Collings (1974), but the data analysis is much more primitive. This method is similar to the FWS IFIM, except that binary criteria are used, there is no numerical simulation between data points, and width is not extrapolated to area.

Quality of the Documentation: The method is described accurately, but is itself relatively undefined.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: Wesche and Rechard 1980.

Published Comparisons With Other Methods: Turner et al. (undated) applied the method, making measurements at 12 different discharges and fitting the curves by eye. This resulted in clear peaks of Weighted Usable Width.

Critical Opinion: If one accepts the habitat criteria offered, is willing to make measurements at many different discharges, and will settle for a single transect as representative of a stream, this method will establish the relationship between habitat and discharge as well as any other. The IFIM is essentially an expanded version of this idea.

X

Methodology: SWIFT'S WASHINGTON STATE CHINOOK, PINK AND CHUM SALMON METHODOLOGY

Type of Method: EMPIRICAL USING BASIN, DISCHARGE, AND HYDRAULIC VARIABLES

Equations:

$$Qcc = 4.22\,(Q_a)^{0.747}\ (SE = \pm\ 39\%);\quad Qr = 0.686\,(Q_a)^{0.824}\ (SE = \pm\ 53\%)$$

$$Qcc = 1.36\,(TW)^{1.24}\ (SE = \pm\ 40\%);\quad Qr = 0.139\,(TW)^{1.44}\ (SE = \pm\ 57\%)$$

$$Qcc = 32.5\,(7Q2)^{0.629}\ (SE = \pm\ 47\%);\quad Qr = 5.18\,(7Q2)^{0.750}\ (SE = \pm\ 61\%)$$

$$Qcc = 26.4\,(Qse)^{0.609}\ (SE = \pm\ 50\%);\quad Qr = 3.50\ Qse)^{0.766}\ (SE = \pm\ 54\%)$$

$$Qcc = 19.3\,(Qoc)^{0.577}\ (SE = \pm\ 54\%)$$

$$Qcc = 15.9\,(DA)^{0.698}\ (SE = \pm\ 55\%);\quad Qr = 2.62\,(DA)^{0.789}\ (SE = \pm\ 81\%)$$

Qcc = preferred spawning discharge (cfs)
Qr = preferred rearing discharge (cfs)
Qa = average annual flow (cfs)
TW = toe-of-bank width of channel (ft)
7Q2 = 7-day, 2-year low flow (cfs)
Qse = median September mean flow (cfs)
Qoc = median October mean flow (cfs)
DA = drainage area (square miles)

Correlation Coefficient: None given. We calculated it for $Qcc = 1.41\,(TW)^{1.23}$, $r^2 = 0.83$. This equation is slightly different from the author's. For drainage area, we got a better fit with a linear equation: for the power equation $Qcc = 16.1\,(DA)^{0.69}$, $R^2 = 0.68$, but for the linear equation $Qcc = -90.64 + 4.68\,(DA)$, $r^2 = 0.87$

Source Documentation: Swift, C.H. 1979. Preferred Stream Discharges for Salmon Spawning and Rearing in Washington. United States Geological Survey Open File Report 77-422. Tacoma, Washington. 51 pp.

Objective: To develop relationships for estimating the discharges preferred for spawning and rearing from several separate hydrological and geomorphological variables.

Level of Effort: Low.

Model Development Depth and velocity data were collected across transects on three reaches from each of 28 Washington state streams at (usually) 10 discharges. From these transect data, the amount of area meeting spawning velocity (0.75-3.25 $ft*sec^{-1}$) and depth (>0.5 ft) criteria was determined at each discharge. The preferred spawning discharge (Qcc) maximized the area meeting these criteria; the preferred rearing discharge (Qr) is "that which provides a wetted perimeter across the entire streambeds". Once Qcc and Qr were determined for each of the 84 reaches, one-variable linear regression equations were calculated for the relationships between them and each of the other variables.

Basic Assumptions: That the power function used is appropriate. We found that for drainage area a linear function resulted in a better fit. Also, that the binary velocity and depth criteria are correct.

Limitations and Constraints: These single-variable regression equations are only useful for predicting the flows that will result in maximal spawning habitat, or in maximum rearing habitat (which is much less well defined).

Relationship to Other Methods: Similar to and derived from Colling's 1974 and Swift's 1976 work, but restricted to one-variable regressions rather than the multiple regressions in the earlier studies.

Quality of the Documentation: The absence of correlation coefficients makes it difficult to evaluate the effectiveness of the models.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This method provides a very simple and apparently relatively accurate method for estimating the discharge which will result in maximum suitable spawning area. The definition of spawning area is simple, however, based on a binary depth and velocity criterion and not incorporating substrate composition. It is interesting that the flows maximizing spawning area are correlated with drainage area.

X

Methodology: SWIFT'S STEELHEAD SPAWNING DISCHARGE

Type of Method: EMPIRICAL USING BASIN VARIABLES

Equation: $Qdv = 4.64V_1^{0.448} * V_2^{0.533} * V_3^{-0.182} * V_4^{0.234}$; $Qs = 5.49\ V_1^{0.480} * V_2^{0.258} * V_4^{-0.179}$

$$Qr = 0.146\ V_1^{0.643} * V_2^{0.628} * V_3^{-0.173}$$

Qdv = Preferred spawning discharge ($ft^3 * sec^{-1}$), the discharge resulting in maximum spawnable area

Qs = Spawning sustaining discharge ($ft^3 * sec^{-1}$), the discharge at which the percentage rate of reduction in discharge equals the percentage rate of reduction in maximum spawnable area as discharge is decreased in increments of 5, 10, 15 and 25% of Qdv.

Qr = Rearing Discharge; a discharge "selected at the inflection of the curve [of wetted perimeter vs. discharge] where wetted perimeter begins to decrease rapidly as discharge decreases".

V_1 = drainage area (mi^2)
V_2 = mean basin altitude (ft)
V_3 = reach altitude (ft)
V_4 = reach slope (ft/mi)

Correlation Coefficient: $R^2 = 0.79$ for Qdv, $R^2 = 0.74$ for Qs, $R^2 = 0.85$ for rearing habitat.

Source Documentation: Swift, C.H. 1976. Estimation of Stream Discharges Preferred by Steelhead Trout for Spawning and Rearing in Western Washington. United States Geological Survey Open File Report 75-155. Tacoma, Washington. 50 pp.

Objective: To develop equations (using geomorphic input variables) useful for estimating the discharges that provide the maximum area for steelhead spawning, the spawning-sustaining discharge (defined above), but not less than 75% of the discharge producing the maximum spawning area, and the optimum rearing discharge. These equations, coupled with other requirements for steelhead propagation, are intended to be used for allocating stream flows on other streams.

Level of Effort: Low. All of the variables can be obtained from topographic maps.

Model Development At four cross sections at 54 different sites on 18 different streams, Swift measured the area having depths of 0.7-2.3 ft and velocities of 1.2-3.3 ft $* sec^{-1}$ at (usually) 10 different discharges, then plotted the area of preferred depth and velocity versus discharge and fitted a curve to it using the moving parabolic arc technique. The peak of the curve was considered to be the Qdv, and the Qs was calculated from the shape of the ascending limb of the curve. The Qr was calculated entirely differently, using only a plot of wetted perimeter versus discharge, and selecting a point on it "at the inflection of the curve".

Basic Assumptions: That the most appropriate form of the linear regression model is a power function, and that the simple binary criteria for depth and velocity suitability are accurate and appropriate. For rearing discharges, the assumption is that the "inflection point" in the wetted perimeter versus discharge curve is identifiable and is a reasonable criterion.

Limitations and Constraints: The model does not address the question of whether either Qdv or Qs are needed in any given situation, and does not justify the Qs or Qr criteria. Also, it is unlikely that the model could be geographically transportable, though the same techniques could be used elsewhere.

Relationship to Other Methods: Identical to Collings (1974).

Quality of the Documentation: Complete.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This method is quite interesting in that it provides a technique for using readily available map data to arrive at the same result that would be obtained using intensive transect measurements at many discharges. It is a sensible and successful attempt to find easily measured surrogate variables to predict optimum spawning discharges for anadromous species which may be limited by spawning site availability.

Methodology: SWIFT'S STEELHEAD TROUT TOE-WIDTH METHOD

Type of Method: EMPIRICAL USING HYDRAULIC VARIABLES

Equation: $Q_{dv} = 1.55\ (TW)^{1.16}$; $Q_s = 1.45\ (TW)^{1.05}$; $Q_{rz} = 0.164\ (TW)^{1.42}$

Q_{dv} = Preferred spawning discharge ($ft^3 * sec^{-1}$), the discharge resulting in maximum spawnable area

Q_s = Spawning sustaining discharge ($ft^3 * sec^{-1}$), the discharge at which the percentage rate of reduction in discharge equals the percentage rate of reduction in maximum spawnable area as discharge is decreased in increments of 5, 10, 15 and 25% of Q_{dv}

Q_r = Rearing Discharge; a discharge "selected at the inflection of the curve [of wetted perimeter vs · discharge] where wetted perimeter begins to decrease rapidly as discharge decreases"

TW = Width at toe of bank (defined as the horizontal distance "from the point where the streambed and one bank join, to the ground surface on the other bank" [we find this definition unclear]

Correlation Coefficient: $r^2 = 0.90$ for Q_{dv}, $r^2 = 0.87$ for Q_s, $r^2 = 0.81$ for rearing habitat

Source Documentation: Swift, C.H. 1976. Estimation of stream discharges preferred by steelhead trout for spawning and rearing in Western Washington. United States Geological Survey Open File Report 75-155. Tacoma, Washington. 50 pp.

Objective: To develop equations (using the toe-width input variable) useful for estimating the discharges that provide the maximum area for steelhead spawning, the spawning-sustaining discharge (defined above - not less than 75% of the discharge producing the maximum spawning area) and the optimum rearing discharge. These equations, coupled with other requirements for steelhead propagation, are intended to be used for allocating streamflows on other streams.

Level of Effort: Low. But toe-width must be measured in the field.

Model Development: At four cross sections at 54 different sites on 18 different streams, Swift measured the area having depths of 1.7-2.3 ft and velocities of 1.2-3.3 ft * sec^{-1} at (usually) 10 different discharges, then plotted the area of preferred depth and velocity versus discharge and fitted a curve to it using the moving parabolic arc technique. The peak of the curve was considered to be the Q_{dv}, and the Q_s was calculated from the shape of the ascending limb of the curve. The Q_r was calculated entirely differently, using only a plot of wetted perimeter versus discharge, and selecting a point on it "at the inflection of the curve".

Basic Assumptions: That the most appropriate form of the linear regression model is a power function, and that the simple binary criteria for depth and velocity suitability are accurate and appropriate. For rearing discharges, the assumption is that the "inflection point" in the wetted perimeter versus discharge curve is identifiable and is a reasonable criterion.

Limitations and Constraints: The model does not address the question of whether either Q_{dv} or Q_s are needed in any given situation, and does not justify the Q_s or Q_r criteria. Also, it is unlikely that the model could be geographically transportable, though the same techniques could be used elsewhere.

Relationship to Other Methods: A subset of the work of Collings (1974) and other studies in the source document.

Quality of the Documentation: Complete.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This Washington Toe-Width method is interesting because it produces strong correlations between a (presumably) easily measured stream variable (the toe-width) and the empirically determined discharge causing maximum spawning habitat, somewhat decreased spawning habitat, and rearing habitat. The definition of toe-width is unclear to us, however, and we would have trouble applying the method for that reason.

X

Methodology: TAYLOR'S RIPARIAN VEGETATION MODEL

Type of Method: EMPIRICAL USING DISCHARGE AND BASIN VARIABLES

Equation: $ERSW = 4.95Q - 0.034Q^2 - 0.057G + 0.62I - 0.02E$

ERSW = Expected Riparian Strip Width (m)
Q = mean annual discharge (m^3*s^{-1})
G = gradient ($m*km^{-1}$)
I = incision index (m)
E = elevation (m)

[The Incision index is calculated by making 10-20 measurements of the distance across a stream as determined by the 80-ft contour intervals on a 1:62,500 USGS topographic map, averaging the distance, then halving the mean value. Heavily confined streams have incision indices of 20-40 m. Meandering streams have indices of 100-200 m.]

Correlation Coefficient: None given, but Taylor states that the first two terms (Q and Q^2) alone account for 44% of the variance in ERSW (r = 0.66 [?]) and the model with all terms accounts for 67% of the variance (r = 0.82 [?]).

Source Documentation: Taylor, D.W. 1982. Riparian Vegetation of the Eastern Sierra: Ecological Effects of Stream Diversions. Contribution No. 6, Mono Basin Research Group.

Objective: To determine quantitatively the relationship between hydrologic and physiographic variables characteristic of eastern Sierra watercourses and the width of the riparian strip, for use in assessing the relative import of proposed hydroelectric development.

Level of Effort: Low. To apply the model predictively, the only data needed can be obtained in a few minutes from a standard USGS topographic map.

Data Requirements: Gradient, elevation, and incision index from a topographic map.

Model Development: The model was developed from data on undiverted streams at elevations between 1,500 and 3,000 m on the eastern slope of the Sierra Nevada in California. Riparian Strip Width, the response variable, was measured from 1:25,000 aerial photographs to the nearst 2.5 m at 5-10 points along homogeneous sections of stream and then averaged. The specific streams used are not identified. Average annual flows were taken from gauging stations operated by the City of Los Angeles, but not necessarily in close proximity to the study sites. The rationale for construction of the model is not explicitly stated, but it appears that at first a polynomial regression of riparian strip width on average annual flow was constructed, then additional terms were added using multiple regression. Other variables (including maximum and minimum mean monthly flows) were considered but were rejected because they were correlated with the mean annual flow term, which had been arbitrarily chosen as the most important flow variable.

Basic Assumptions: The principal assumption (if this model is to be used for predicting the effects of diversions) is that riparian strip width is responsive to changes in flow. An important part of this assumption is that there will be an incremental decrease in the width of the riparian strip with any reduction in average annual flow (as opposed, say, to a reduction in minimum summer flows).

Limitations and Constraints: Since the width of the riparian strip is highly dependent on soil and geomorphological conditions, the model would be expected to be highly local in applicability, possibly to only a short section of a given stream.

Relationship to Other Methods: This is a relatively standard empirical regression model, except for the initial selection and retention of a second-order term prior to multiple linear regression.

Quality of the Documentation: Very limited.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found, although Skibitzke and Bowen (1983) comment on the same topic.

Published Comparisons With Other Methods: None found.

Critical Opinion: Since Taylor was attempting to build a model that would predict the effect of diversions, it would have been much better to study streams that have been diverted (of which there are many in the area he studied). There is, so far, no evidence that decreases in mean annual flow have the effects on riparian strip width that application of this model would predict. Inspection of the second-order polynomial fit of averaged riparian strip width to mean discharge rate (Taylor's Figure 16) shows so much variance at flows greater than $0.2m^3*s^{-1}$ that there is essentially no correlation at all, even in undiverted streams.

X

Methodology: TENNANT'S MONTANA METHOD

Type of Method: CONCEPTUAL USING DISCHARGE VARIABLES

Equation: Q minimum = 0.1 AAF, Q good = 0.3 AAF, Q excellent = 0.6 AAF

Q minimum = minimum instantaneous flow recommended to sustain short term survival habitat for most aquatic life forms.

Q good = base flow recommended to sustain good survival habitat for most aquatic life forms.

Q excellent = base flow recommended to provide excellent to outstanding habitat for most aquatic life forms and for the majority of recreational uses.

AAF = Average Annual Flow (listed as Average Discharge by the USGS).

Correlation Coefficient: None found

Source Documentation: Tennant, D.L. 1975. Instream Flow Regimens for Fish, Wildlife, Recreation and Related Environmental Uses. Manuscript, U.S. Fish and Wildlife Service, Billings, Montana 30 pp. See also Tennant (1976).

Objective: A quick, easy method for determining flows to protect aquatic resources usable for establishing minimum flow standards and operational flow regimes.

Level of Effort: Very low to moderate. The basic method requires only that the average annual flow be known and that it be multiplied by a factor of between 0.10 and 0.60 to achieve the recommended flow. The technique for determining what multiplication factor to use is not spelled out, and is apparently intended to be derived by looking at the stream over this range of discharges, possibly measuring average velocities, depths, and width, and in some way relating them to habitat requirements of the target species.

Model Development: Sixteen hundred measurements of width, depth, and velocity showed that they all changed more rapidly from 0-10% ADF than at higher flows, and that at 10% AAF, 60% of the substrate was covered, depths averaged 1 ft, and velocities averaged 0.75 ft * sec^{-1}.

Basic Assumptions: That the 0.1, 0.3, and 0.6 AAF criteria are appropriate.

Limitations and Constraints: The recommendations resulting from application of the method are completely subjective and, as the author states, "The Montana Method can easily be modified to suit the convictions of any biologist...". The essence of the method is to take photographs of the stream at various flows, then taking into consideration the assumptions noted above, recommend the most appropriate and reasonable flow(s) that can be justified to provide protection and habitat for all aquatic resources. The U.S. Department of the Interior Bureau of Land Management (BLM) Instream Flow Guidelines on the use of this method (Cuplin and Van Haveren 1979.) point out that as the method "depends entirely on mean annual flow ... it would not take into account ... flow fluctuations or seasonal variability".

Relationship to Other Methods: None.

Quality of the Documentation: Tennant's publications are not very explicit about the steps to take in applying the method.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: Bayha 1973, Tessman 1980.

Critical Review of the Method: Wesche and Rechard 1980.

Published Comparisons With Other Methods: Hilgert 1982, Nehring 1979, Carron and McLelland 1980, Wyoming Game and Fish 1979, Annear and Condor 1983, Glover (undated), Horton and Cochnauer (undated), Orth and Maughan 1980, Turner et al. undated.

Critical Opinion: The main virtue of this method is that the only data it requires is the average annual flow. It allows the use of accessory habitat information, but provides little guidance on how to use it. Consequently, although it was intended by its authors as a technique for setting operational flows in a stream, it is too unsophisticated for that purpose by present standards.

X

Methodology: THOMPSON'S OREGON USABLE WIDTH METHOD

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED HYDRAULIC VARIABLES

Equation: $Q_{ms} = 0.8Q_{os}$; $Q_p = Q_{.25tw}$ and $Q_{.10cw}$

Q_{mi} = flows required to maintain 5.0 ppm intra-gravel O_2 in spawning Waters' beds

Q_{ms} = minimum acceptable spawning flow

Q_{os} = optimum spawning flow = the flow that covers the maximum amount of gravel with suitable depths and velocities

Q_p = flow requirements for passage

$Q_{.25tw}$ = flow resulting in 25% of the total width being at least 0.8 ft (chinook), 0.6 ft (coho, chum, steelhead and large trout), or 0.4 ft (trout) deep and velocities no greater than 8.0 ft $* s^{-1}$ (all but trout) or 4 ft $* s^{-1}$ (trout).

$Q_{.10cw}$ = flow that results in a single continuous cross-section of at least 10% of the total width meeting the $Q_{.25tw}$ criteria.

Q_{mi} = minimum flow for incubation

Correlation Coefficient: None found

Source Documentation: Thompson, K. 1974. Salmonids, in Anatomy of a River: An evaluation of water requirements for the Hell's Canyon reach of the Middle Snake River, pp. 85-103. Pacific Northwest River Basins Commissioner. Vancouver, WA. 203 pp.

Objective: To establish minimum spawning, incubation and passage flows.

Level of Effort: Moderate. Field data across transects must be collected at flows of interest, but there is no data processing to speak of.

Model Development: Not described.

Basic Assumptions: That the criteria chosen are appropriate.

Limitations and Constraints: The principal limitation is the arbitrariness of the flow criteria. There is no way of knowing if they are necessary or sufficient. The binary velocity and depth criteria are also arbitrary and can result in misleading conclusions.

Relationship to Other Methods: This microhabitat method is an outgrowth of work done by Sams and Pearson (1963) and is a forerunner of methods such as Waters' (1976) and Bovee's (1982), which use continuous (or multi-step discrete) functions rather than binary criteria for depth and velocity suitability. It presages them and is an advance over Sams and Pearson's one-step method, in that it measures depth and velocity at many points across transects rather than using averages across the entire stream.

Quality of the Documentation: The method used is adequately described, but the selection of criteria is not.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: Pruitt and Nadeau (1978) used the method with weighted rather than binary depth and velocity criteria.

Critical Review of the Method: Stalnaker and Arnette (1976), Wesche and Rechard (1980).

Published Comparisons With Other Methods: None found.

Critical Opinion: This microhabitat instream flow method is a precursor to microhabitat methods that use weighted rather than binary criteria, and that incorporate hydraulic models. It is one of the earliest developments of the concept of depth, velocity, and especially substrate size and dissolved oxygen criteria, but has now been superseded.

Methodology: TRIAL ET AL.'S HEP/HSI ATLANTIC SALMON MODEL

Type of Method: CONCEPTUAL USING HYDRAULIC, STRUCTURAL, PHYSICAL, AND CHEMICAL VARIABLES

Equation: $HSI = [\text{lowest of } V_1, V_2, V_3, V_4, V_5]*[V_6*V_7*V_8]^{1/3}*[V_9*V_{10}*V_{11}]^{1/3}*[\text{lowest of } (V_{12}*V_{13}*V_{18})^{1/3}, V_{14}, V_{15}, V_{16}, V_{17}]$ or the lowest of the values in [] if any is <0.4.

[Note: All variables are transformed and scaled from 0-1 prior to use in the above equation; different variables based on the same parameter are scaled differently]

V_1 = maximum temperature
V_2 = average temperature
V_3 = average turbidity
V_4 = minimum oxygen
V_5 = minimum pH
V_6 = near-bottom velocity
V_7 = predominant substrate
V_8 = depth
V_9 = velocity
V_{10} = predominant substrate
V_{11} = depth
V_{12} = depth (reproduction)
V_{13} = velocity
V_{14} = spawning temperature
V_{15} = minimum pH in fall and winter
V_{16} = embryo incubation temperature
V_{17} = stream order
V_{18} = predominant substrate

Correlation Coefficient: $r^2 = 0.96$ for parr*ha^{-1} over an HSI range of 0.825-0.975 (3 data points) calculated from the data in the source document.

Source Documentation: Trial, J.G., C.S. Wade, and J.G. Stanley. HSI Models for Northeastern Fishes, in Proceedings Workshop on Fish Habitat Suitability Index Models (J.W. Terrell, ed.) Draft. FWS/OBS-84.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability, and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the aggregation used is appropriate. For any predictive use it must be assumed also that there is some relationship between HSI and fish production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity, or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: The source document includes a test.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose.

X

Methodology: TRIAL ET AL.'S FWS/HSI BLACKNOSE DACE RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICAL WEIGHTED, HYDRAULIC, STRUCTURAL, PHYSICAL, AND CHEMICAL VARIABLES

Equation: $HSI = [(4)^{-1} * (V_1 + V_2 + V_3 + V_4) * (V_5{}^2 * V_6)^{1/3} * (2)^{-1}([V_7 * V_8 * V_9{}^2]^{0.25} + V_{10})]^{1/3} *$
$[(V_{11} * V_{12})^{0.5} * (V_{13} * V_{14})^{0.5} * (V_{15} * V_{16})^{0.5}]^{1/3}$

[Note: All variables are transformed and scaled from 0-1 from nonlinear curves before inclusion in the model. A value of less than 0.4 in any of the components (adult, juvenile, fry, spawning, food-cover, water quality, shown above in parentheses is assumed to be limiting and overrides computed model values, so HSI = minimum component value]

V_1 = % stream area shaded
V_2 = % pools
V_3 = stream gradient (m/km)
V_4 = stream width
V_5 = most suitable maximum water temperature (°C) during summer
V_6 = mean turbidity (JTU) during growing season
V_7 = predominant substrate in riffle area
V_8 = stream depth (cm) in spawning riffles
V_9 = mean velocity (cm/sec) in riffle area
V_{10} = temperature range (°C) during spawning
V_{11} = predominant substrate in pools and slow channels
V_{12} = mean velocity (cm/sec) in pools and slow channels
V_{13} = predominant substrate in riffle area
V_{14} = mean velocity in riffle area
V_{15} = predominant substrate along stream margins
V_{16} = mean velocity along stream margins

Correlation Coefficient: $r^2 = 0.24$ (calculated from the data contained in Trial et al. 1984.

Source Documentation: Trial, J.G. et al. 1983. Habitat Suitability Index Models: Blacknose Dace. US Fish and Wildlife Service. FWS/OBS-82/10.41. 27 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability, and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the aggregation used is appropriate. For any predictive use, it must be assumed also that there is some relationship between HSI and blacknose dace production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity, or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: Trial et al. 1984 showed weak correlation between HSI and standing crop.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose. The empirical test of it shows poor correlation between the HSI and standing crop.

X

Methodology: TRIAL ET AL.'S FWS/HSI COMMON SHINER RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED, HYDRAULIC, STRUCTURAL, PHYSICAL, AND CHEMICAL VARIABLES

Equation: $HSI = [(V_1 * V_2 * V_3)^{1/3} * 4^{-1} * (V_4 + V_5 + V_6 + V_7) * (V_4 * V_8^2 * V_9)^{0.25}]$

[Note: All variables are transformed and scaled from 0-1 before being used in the model. A limiting-factor approach is used such that any component whose value is less than 0.4 is considered to be limiting.]

HSI = Habitat Suitability Index
V_1 = maximal summer temperature (°C) persisting for longer than 1 week
V_2 = minimal suitable pH during year
V_3 = mean turbidity (JTU)
V_4 = predominant substrate type
V_5 = % pools
V_6 = mean velocity ($cm * sec^{-1}$) at 60% of depth in pools
V_7 = predominant pool type
V_8 = mean water temperature (°C) during spawning
V_9 = mean velocity ($cm * sec^{-1}$) just above substrate in riffle area

Correlation Coefficient: None found.

Source Documentation: Trial, J.G. et al. 1983. Habitat Suitability Index Models: Common Shiner. US Fish and Wildlife Service. FWS/OBS-82/10.40. 22 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability, and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That these are the important variables and that the water quality and food-cover components represent the habitat requirements for all life stages except for the reproductive component, which is included as a separate such that any component whose value is less than The selection of 0.4 as a limiting level is arbitrary.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose.

X

Methodology: TRIAL ET AL.'S FWS/HSI FALLFISH RIVERINE MODEL

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED, HYDRAULIC, STRUCTURAL, AND OTHER PHYSICAL AND CHEMICAL VARIABLES

Equation: $HSI = 2^{-1} * [(V_1 * V_2)^{0.5} + (V_3 * V_4 * [V_5 * V_6])^{1/3}]$

[Note: All variables are transformed and scaled from 0-1 before inclusion in the model]

HSI = Habitat Suitability Index
V_1 = mean water temperature (°C) during warmest part of year for longer than 1 week
V_2 = mean turbidity (JTU)
V_3 = most common depth (m) at 1/4, 1/2, 3/4 distance across stream
V_4 = temperature from 12-20°C during spawning season
V_5 = predominant stream substrate type
V_6 = abundance of cover near spawning areas

Correlation Coefficient: None found.

Source Documentation: Trial, J.G. et al. 1983. Habitat Suitability Index Models: Fallfish. US Fish and Wildlife Service. FWS/OBS-82/10.48. 15 pp.

Objective: To convert habitat information into a numerical rating (Habitat Suitability Index) of the habitat quality. This HEP model was not intended to be used as an instream flow method, but it has many input variables which vary with discharge, and consequently can be used to predict the effect of discharge on habitat suitability, and, by extension, carrying capacity and standing crop.

Level of Effort: Moderate to high. Most of the variables have to be measured in the field. For use as an instream flow model they would have to be measured at several flows, including the ones of interest.

Model Development: The variables were selected because they were hypothesized to be important. They were then transformed and scaled from 0-1 based on information in the literature and personal observations. The basis for the complex aggregation of the final equation is not explained in the model documentation.

Basic Assumptions: That the appropriate variables were chosen, that they were transformed correctly, that they all have equal weight, and that the aggregation used is appropriate. For any predictive use it must be assumed also that there is some relationship between HSI and fish production.

Limitations and Constraints: Complete lack of evidence that the model output (HSI) is indicative of true habitat suitability, carrying capacity, or standing crop.

Relationship to Other Methods: Closely related to all other FWS/HEP models. The technique for scaling variables is similar to the one used by Binns and Eiserman (1979).

Quality of the Documentation: The basis for the aggregation technique is not explained.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This, like the other HEP/HSI models, is useful in the sense that it focuses attention on the process of choosing, transforming, scaling, and combining variables and suggests that many variables have an effect on habitat suitability. At present, however, there is little justification for using it for any other purpose.

X

Methodology: WATERS' CALIFORNIA METHOD

Type of Method: CONCEPTUAL USING BIOLOGICALLY HYDRAULIC AND STRUCTURAL VARIABLES

Equation:

$$RHU = \sum_{i=1}^{n} V_i * D_i * S_i * C_i$$

RHU = relative habitat units

V_i = velocity transformed and scaled at transect point i

D_i = depth transformed and scaled at transect point i

S_i = substrate categorized and scaled at transect point i

C_i = cover categorized and scaled at transect point i

[RHU values are calculated at several different discharges along several transects, and different transformation curves are used for resting microhabitat, spawning, and food production]

Correlation Coefficient: None found.

Source Documentation: Waters, B.F. 1976. A methodology for evaluating the effects of different stream flows on salmonid habitat, in Proc. Symp. and Specialty Conference on Instream Flow Needs (J.F. Orsborn and Allman, eds.), pp. 254-261. Am. Fish. Soc., Bethesda, MD.

Objective: To express quantitatively the relationships between stream flow and available food-producing, spawning, resting microhabitat, and cover areas for trout.

Level of Effort: High. Requires many hydraulic measurements at multiple flows.

Model Development: Velocity, depth, substrate type, and cover type were chosen as the conceptually important aspects of microhabitat for trout. Three different activities were selected for analysis: resting, spawning, food production. The transformation (weighting) curves were based on a literature review.

Basic Assumptions: That velocity, depth, substrate category, and cover type are the variables important to trout welfare; that the transformation curves used reflect value of the habitat to trout; that the multiplicative technique of variables scaled from 0-1 is the appropriate aggregation technique.

Limitations and Constraints: The plotted results of each of the three habitat categories versus discharge do not inherently provide any basis for determining appropriate instream flows. The curves only provide information on the rate of change of habitat with change of discharge. They provide no information on the absolute amount of habitat, or any way to determine what the appropriate amount is.

Relationship to Other Methods: This is the paper on which the USFWS IFIM is based, and is essentially identical to the HABTAT portion of it.

Quality of the Documentation: Complete.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: Bovee 1982, and most of the other publications of the USFWS Instream Flow Group.

Critical Review of the Method: Stalnaker and Arnette 1976, Wesche and Rechard 1980, Loar and Sala 1981.

Published Comparisons With Other Methods: None found.

Critical Opinion: This is the true precursor of the IFIM, which is an improvement over it only in the sense that it incorporates a hydraulic simulation model. A principal difficulty with both the Waters method and the IFIM is that neither provides any criteria for making a decision on the appropriate instream flow. Also, as in the IFIM, the arbitrary choice of input variables and method of aggregation, and the use of an unmeasurable output variable makes validation difficult.

X

Methodology: WEATHERRED ET AL.'S R2-CROSS-81 SAG TAPE METHOD

Type of Method: CONCEPTUAL USING HYDRAULIC VARIABLES

Equation: $n = (1.486A * R^{2/3} * S^{1/2}) * Q^{-1}$

n = Manning's n, a dimensionless coefficient of roughness
A = cross sectional area (ft^2)
R = hydraulic radius (ft) = A/P
P = wetted perimeter (ft)
S = slope of water surface (%)
Q = discharge ($ft^3 * sec^{-1}$)

Correlation Coefficient: None found.

Source Documentation: Weatherred, J.D., H.L. Silvey, and D.J. Pfankuch 1981. Program documentation for R2-CROSS-81. Watershed Systems Development Group, USDA Forest Service, Fort Collins, CO. 45 pp.

Objective: To estimate discharge, average velocity, wetted perimeter, cross-sectional area, maximum water depth, and hydraulic radius for unmeasured stages and discharges on the basis of measurements made at a single discharge.

Level of Effort: Low to moderate. Depths and water surface slope must be measured once in the field at transects of interest.

Model Development: The R2-CROSS-81 computer program utilizes field measurements of depth at a number of points along a transect at a single discharge to calculate cross sectional area and wetted perimeter at that discharge. It then uses these terms, water surface slope measured at that discharge, and Q, either obtained from a gauge or measured in the field, possibly at the same transect, to calculate Manning's n. Although the documentation is not explicit, it appears that the program subsequently treats S and n as constants, and based on the channel bottom configuration and using Manning's equation, recalculates Q, top width of water surface, average depth, average velocity, maximum depth, cross-sectional area, wetted perimeter, and hydraulic radius for user-selected stages (water surface elevations).

Basic Assumptions: This model calls for the use of water surface slope rather than energy slope in the Manning's equation. This assumption is violated unless a uniform flow condition exists at the measurement transect (i.e., water cross-sectional area and depth remain constant over a certain reach of channel and the velocity remains the same upstream and downstream of the measurement transect). (Uniform flow conditions do not usually exist in streams with complex beds and frequent changes of gradient.) This model also assumes that an average Manning's n across the entire stream is realistic (which is true only if the substrate size is uniform) and that Manning's n is constant with changes in flow, also unlikely to be true over a wide range of flows. It also assumes that S does not vary with flow, which is usually also untrue.

Limitations and Constraints: The assumptions listed above make extrapolation to flows other than the measured one more or less uncertain, depending on the complexity of the stream. The model also calculates only average depth and velocity for the entire channel, and in complex channels, these values may be very poorly indicative of the range and distribution of velocities and depths to which aquatic organisms respond. The R2-CROSS-81 model has no biological component, and thus must be used in conjunction with a habitat model to arrive at biological conclusions. Various authors have used its different outputs versus Q to estimate habitat.

Relationship to Other Methods: This model is a simple Manning's equation approach to characterizing stream hydraulics at flows other than the one measured. More complex models based on the same equation include the WSP (Bovee and Milhouse 1978), HEC-2 (U.S. Army Corps of Engineers), and PSEUDO (Bureau of Land Management).

Quality of the Documentation: The internal calculations of the model are not described.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: Nehring 1979, Curran and McLelland 1980.

Critical Opinion: If the only variables of interest are average depth and velocity as functions of flow, this model is probably adequate in streams of uniform slope and substrate type. Other models based on the same principle that treat the cross section cell by cell (e.g., the WSP model) give a much more fine-grained habitat characterization, however.

Methodology: WESCHE'S WRRI TROUT COVER RATING METHOD

Type of Method: CONCEPTUAL USING BIOLOGICALLY WEIGHTED HYDRAULIC AND STRUCTURAL VARIABLES

Equation: $WCR = PF_{obc}*(LF_{obc}*T^{-1}) + PF_{r-b}*(A_{r-b}*SA^{-1})$; $SC = \text{antilog}_{10}(0.0204 + 5.338WCR)$

WCR = WRRI [Water Resources Research Institute] Cover Rating (dimensionless)
SC = Standing Crop (lbs trout $*\text{acre}^{-1}$)
PF_{obc} = Preference factor of trout for overhead cover (dimensionsless)
LF_{obc} = ft of overhead bank cover $\underline{>}$=0.5 ft deep and $\underline{>}$=0.3 ft wide (ft)
T = length of thalweg in study section (ft)
PF_{r-b} = preference factor of trout for instream rubble-boulder aquatic vegetation areas (dimensionless)
A_{r-b} = surface area having depth>=0.5' and substrate >=3" (ft^2)

[Preference factor is defined as 0.75 for trout $\underline{>}$6" long (except in boulder and rubble areas where it is 0.25), and 0.50 for trout <6" long. A slightly different model was used for large streams]

Correlation Coefficient: r^2 between SC and WCR for smaller streams = 0.36 when all data were used and 0.59 when data within each reach were averaged before calculation of r^2.

Source Documentation: Wesche, T.A. 1980. The WRRI Trout Cover Rating Method: Development and Application. Water Resour. Ser. 78. Water Resources Research Institute, University of Wyoming, Laramie. 46 PP.

Objective: To establish a mathematical relationship between an index of cover and trout standing crop for use in instream flow modeling.

Level of Effort: Moderate. Much field work is required, but it is not particularly technical or demanding. There is very little data reduction needed.

Model Development: Not described.

Data Requirements: Requires field measurement of overhead bank cover, depth, and substrate size along transects at all flows of interest. Enough transects must be used to fully characterize the habitat, and there is no accompanying simulation method for predicting cover at different flows. Data analysis, however, is simple and can be done on a hand calculator. The output (either WCR or SC) could be plotted against discharge to form curves similar to IFIM curves of WUA vs. discharge.

Basic Assumptions: That the preference factors are accurate. No experimentation was done with the model to determine if other preference functions resulted in better fits.

Limitations and Constraints: The cover rating (WCR) is correlated to varying degrees with standing crop for brown trout, but for most subsets of the data tested by Wesche has a high coefficient of variation and is thus not very useful for predicting standing crop, and clearly is not predictive of standing crop for brook trout or cutthroat trout.

Relationship to Other Methods: The WRRI Trout Cover Habitat Rating Method produces an index of cover (WCR) which could be used by itself as a surrogate for habitat quality (comparable to the WUA of the IFIM PHABSIM method) and thus is comparable to the output of the FWS IFIM and HEP methods. Alternatively, it could be used as the basis for a habitat suitability index curve and would then be suitable for incorporation as one of the variables in a multivariate model like those of Binns and Eiserman and the FWS HEP group. Since, at least for brown trout, there is a correlation between WCR and SC, and Wesche has developed the equation (shown above) by developing a relationship between WCR and discharge in a particular stream, brown trout standing crop should be predictable on the basis of discharge.

Quality of the Documentation: Completely documented.

Experimental Tests of the Method: Wesche 1980.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: Although this method is intended to characterize trout habitat on the basis of cover, since it uses depth and substrate criteria for non-cover areas it is really a multivariate model. It is interesting that velocity, which is prominent in many similar models, is not included as one of the terms. The apparently strong correlations between standing crop and the cover variables suggest that cover should be incorporated in any predictive model. This study was done on undiverted streams, and therefore my not be applicable to predicting trout standing crops following diversion.

X

Methodology: WHITE'S IDAHO INSTREAM FLOW METHOD

Type of Method: CONCEPTUAL USING HYDRAULIC VARIABLES

Equation: None - the method uses the WSP computer program to generate a plot of wetted perimeter versus discharge.

Correlation Coefficient: None found.

Source Documentation: White, R.G. 1976. A methodology for recommending stream resource maintenance flows for large rivers. in Proc. Symp. and Speciality Conf. on Instream Flow Needs (J.F. Orsborn and C.H. Allman, eds.), Vol. II, pp. 376-399. Am. Fish Soc., Bethesda, MD.

Objective: To predict loss of habitat at reduced discharges, utilizing a computer hydraulic simulation model and relate this loss to physical and biological requirements. Also to recommend appropriate flows for passage, spawning, and rearing.

Level of Effort: Moderate. A thorough reconnaissance is followed by selection of transects representative of passage, spawning, and rearing habitat for key species.

Model Development: Passage selection criteria are arbitrarily defined as a minimum continuous depth of 5 ft over 25% of the potential block. Spawning criteria are defined as "some specified percent of the discharge resulting in maximum spawning area on 3 transects, [but is not specified]". Rearing criteria are defined as the "inflection point" on the wetted perimeter versus discharge curve, but is conditioned with the statement that "no studies have been reported which were specifically designed to determine the validity of this [criterion]". The instructions for determining recommended flows are: "After analysis of field data, recommended flows are assigned by month or 2-week period for each biological activity. The stream resource maintenance flow which is the highest for the critical biological activity of any given time period is the flow selected. Although the above approach does not take into consideration resident and/or anadromous salmonids, where these species are important their flow requirements should be evaluated as part of the overall recommendations."

Basic Assumptions: That the WSP model accurately reflects hydraulic changes with discharges, and that the criteria applied have biological validity.

Limitations and Constraints: The criteria for recommended flows are either arbitrary (for passage), undefined (for spawning), or unspecific (the point on the wetted perimeter curve identifying the appropriate rearing flow is not clearly identified).

Relationship to Other Methods: The wetted perimeter criterion is that of Collings (1974) and Nelson (1980).

Quality of the Documentation: Very little information provided.

Experimental Tests of the Method: Some data are available in Randolph and White (1984).

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: The method, as presented in the source document, is essentially unsupported and so non-specific that even if applied, it would be difficult to know what to do with the output.

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Methodology: WHITE ET AL.'S MIDWESTERN TROUT MODELS

Type of Method: EMPIRICAL DISCHARGE + BIOLOGICAL VARIABLES

Equations:

$SC_1 = 1598 + 75\ V_1 - 21\ V_2 + 63\ V_3$, $R^2 = 0.95$, (Brook + Brown Trout)
$SC_2 = 10.8 + 0.887\ V_3 - 0.246\ V_6$, $R^2 = 0.94$, (Brook + Brown Trout)
$SC_1 = 1105 + 105\ V_1 - 77\ V_3$, $R^2 = 0.83$, (Brown Trout)
$SC_1 = 1924 + 142\ V_1 - 3.4\ V_4$, $R^2 = 0.83$, (Brown Trout)
$SC_1 = 3977 - 0.897\ V_5$, $R^2 - 0.82$, (Brook Trout)
[only models with $R^2 > 0.80$ are included]

SC_1 = standing crop (# of age-0 trout)
SC_2 = standing crop (kg/km)
V_1 = mean flow, Jan-Feb (cfs)
V_2 = maximum flow, Mar 11 - May 31 (cfs)
V_3 = mean flow, Jun-Aug (cfs)
V_4 = peak momentum flow, Nov 1 - Mar 10 (cfs)
V_5 = maximum daily flow, Nov 1 - Mar 10 (cfs)
V_6 = standing crop in the previous spring (kg/km)

Correlation Coefficient: Shown along with equations.

Source Documentation: White, R.J., E.A. Hansen, and G.A. Alexander. 1976. Relationship of trout abundance to stream flow in Midwestern streams, in Proc. Symp. and Specialty Conf. on Instream Flow Needs (S.F. Orsborn and C.H. Allman, eds., Vol. II, pp. 597-615. Am. Fish. Soc., Bethesda, MD.

Objective: To determine, using multiple linear regression analysis, the most important flow variables affecting the numbers of age-0 brown and brook trout, and the biomass of brown and brook trout in Midwest streams.

Level of Effort: Low. Most equations require data available from gauge records.

Model Development: The above (and some additional) variables were used in multiple linear regression analyses, and the best models (those with $R^2 > 0.80$) are shown above. The purpose was to determine which, if any, flow variables were correlated with standing crop. Absolute values of mean winter flow were most strongly correlated, and absolute values of mean summer flow were next most strongly correlated.

Basic Assumptions: That the input variables are independent of one another (unlikely) and (for the interpretation) that there was a causal relationship between flow and standing crop rather than an incidental one related to unmeasured variables.

Limitations and Constraints: The purpose of the study was to find out which variables were important. The values of the parameters and the equations were developed for individual streams, and thus cannot be extrapolated to other streams.

Relationship to Other Methods: Many other multiple linear regression models similar to this are reviewed in this report.

Quality of the Documentation: Complete, other than original data.

Experimental Tests of the Method: None found.

Published Enhancements to the Method: None found.

Critical Review of the Method: None found.

Published Comparisons With Other Methods: None found.

Critical Opinion: This paper shows fairly strong relationships between absolute mean summer and winter flows and midwest trout populations. The equations cannot be used on other streams, and mean flows do not necessarily reflect minimum or sustained flow levels, but within the bounds of the study, the implication that standing crop is positively related to mean flow is clear.

A STREAM CLASSIFICATION SYSTEM [1]

DAVID L. ROSGEN [2]

Abstract.--A stream classification system is presented which categorizes various stream types by morphological characteristics. Delineation criteria are stream gradient, sinuosity, width/depth ratio, channel materials, entrenchment, confinement, and soil/landform features. Applications include riparian management guidelines, fisheries habitat interpretations, hydraulic geometry and sediment transport relationships.

INTRODUCTION

It has long been a goal for individuals working with rivers to define and understand the processes which influence the pattern and character of river systems. Their differences as well as their similarities under diverse settings pose a real challenge for study. One consistent axiom associated with rivers is that what initially appears complex is even more so under further investigation.

Obviously, over-simplification of such complex systems may appear presumptuous. However, the need to categorize river systems by channel morphology is apparent for the following reasons: 1) the need to predict a rivers behavior from its appearance; 2) the need to extrapolate specific data collected on a given river reach to another of similar character and; 3) the need to provide a consistent and reproducible frame of reference for those working with river systems.

Stream Classification

The effort to classify streams is not new. Davis (1899) first divided rivers into three stages; youthful, mature, and old age. Thornbury (1969) developed a system based on stream development in various valley types. Patterns were described as antecedent, superposed, consequent, and subsequent. The delineative criteria of these early classification systems required qualitative geomorphic interpretations creating delineative inconsistencies.

Straight, meandering, and braided patterns were described by Leopold and Wolman (1957). Lane (1957) developed quantitative slope-discharge relationships for braided, intermediate, and meandering streams. Khan (1971) similarly related sinuosity, slope, and channel pattern for sand bed channels.

One of the more popular classification schemes was developed by Schumn (1963). Delineation is based on channel stability (stable, eroding, or depositing) and mode of sediment transport (mixed load, suspended load, and bedload). Applications of this procedure have been used on Canadian Rivers by Mollard (1973). Other classification schemes have been developed by Melton (1935), Matthes (1956), Galay et al. (1973), and Kellerhals et al. (1972). A descriptive classification was also developed by Culbertson et al., (1967) which utilized depositional features, vegetation, braiding patterns, sinuosity, meander scrolls, bank heights, levee formations, and floodplain types.

With certain limitations most of these classification systems met the objectives of their design. However, the requirement for more detailed, reproducible, quantitative applications in wildland hydrology led to the development of the classification system presented here.

Stream Classification Criteria

The purpose of this classification scheme is to categorize natural stream channels on the basis of measurable morphological features. Thus, consistent and reproducible descriptions and interpretations can be readily obtained over a wide range of hydrophysiographic regimes.

There are many observable stream channel features governed by the laws of physics which operate to form the morphology of the present day channel. Stream morphology and related channel patterns are directly influenced by eight major variables including width, depth, velocity,

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discharge, slope, roughness of channel materials sediment load and sediment size (Leopold et al. 1964). A change in any one of these variables sets up a series of concurrent changes in the others, resulting in altered channel patterns. Since stream morphology is a result of an integrative process of mutually adjusting variables, those most directly measurable have been incorporated into the delineative criteria for stream types. Selection of the delineative criteria for stream classification was developed from detailed analysis of hundreds of streams over many hydrophysiographic regions and from portions of existing classification schemes.

The stream type classification is summarized in detail in Table 1 and includes the following criteria; channel gradient (measured as energy slope of the water surface); sinuosity (ratio of channel length to valley length); width/depth ratio (width at bankful stage divided by bankful depth); dominant particle size of bed and bank materials; entrenchment of channel and confinement of channel in valley; and landform features, soil erodibility, and stability.

Estuarine streams are also classified utilizing a system developed by Fisher et al. (1969). This classification scheme describes delta types on the basis of deltaic sequences. Four major types are identified; high-constructive lobate; high constructive elongate; high-destructive, tide dominated; and high-destructive, wave dominated deltas (Table 2).

Streams incised in a mixture of glacial ice and inorganic debris are also classified (Table 2).

Data from glacial and estuarine stream types are limited. Therefore, detailed channel morphology needs field verification for further description.

Table 2.--Estuarine and Glacial Stream Types.

Estuarine Streams (Deltas)

E1. High Constructive - Lobate shaped deltas with a wide, well defined delta plain and numerous distributary channels.
E2. High Constructive - Elongate deltas with a narrow delta plain with lateral distributary channels.
E3. High Destructive - Tide dominated deltas.
E4. High Destructive - Wave dominated deltas.

Glacial Streams

G1. Streams incised in glacial ice with mixture of tills involving coarse textured materials including small boulders, cobble, gravels, sands, and some silt.
G2. Streams incised in glacial ice with materials of silts, clays, and some sands. Typical of glacio-lacustrine deposits.

Table 1.-- Criteria for Stream Types.

STREAM TYPE	GRADIENT	SINUOSITY	W/D RATIO	DOMINANT PARTICLE SIZE OF CHANNEL MATERIALS	CHANNEL ENTRENCHMENT-VALLEY CONFINEMENT	LANDFORM FEATURE - SOILS/STABILITY
A1	4-10	1.0-1.1	10 or less	Bedrock.	Very deep/very well confined.	Deeply incised bedrock drainageway w/ steep side slopes and/or vertical rock walls.
A1-a	10 +	(Criteria	same as	A1)		
A2	4-10	1.1-1.2	10 or less	Large & small boulders w/mixed cobble.	Same	Steep side slopes w/predominantly stable materials.
A2-a	10 +	(Criteria	same as	A2)		
A3	4-10	1.1-1.3	10 or less	Small boulders, cobble, coarse gravel.	Same	Steep, depositional features w/predominantly coarse textured soils. Debris avalanche is the predominant erosional process. Stream adjacent slopes are rejuvenated with extensive exposed mineral soil.
A3-a	10 +	(Criteria	same as	A3)		
A4	4-10	1.2-1.4	10 or less	Predominantly gravel, sand, and some silts.	Same	Steep side slopes w/mixture of either depositional landforms with fine textured soils such as glaciofluvial or glaciolacustrine deposits or highly erodable residual soils such as grussic granite, etc. Slump-earthflow and debris avalanche are dominant erosional processes. Stream adjacent slopes are rejuvenated.
A4-a	10 +	(Criteria	same as	A4)		
A5	4-10	1.2-1.4	10 or less	Silt and/or clay bed and bank materials.	Same	Moderate to steep side slopes. Fine textured cohesive soils, slump-earthflow erosional processes dominate.
A5-a	10 +	(Criteria	same as	A5)		

STREAM TYPE	GRADIENT %	SINUOSITY	W/D RATIO	DOMINANT PARTICLE SIZE OF CHANNEL MATERIALS	CHANNEL ENTRENCHMENT-VALLEY CONFINEMENT	LANDFORM FEATURE - SOILS/STABILITY
B1-1	1.5-4.0	1.3-1.9	10 or greater ($\bar{X}$:15)	Bedrock bed, banks, cobble, gravel, some sand.	Shallow entrenchment. Moderate confinement.	Bedrock controlled channel with coarse textured depositional bank materials.
B1	2.5-4.0 ($\bar{X}$:3.5)	1.2-1.3	5-15 ($\bar{X}$:10)	Predominantly small boulders, very large cobble.	Moderately entrenched/ well confined.	Moderately stable, coarse textured resistant soil materials. Some coarse river terraces.
B2	1.5-2.5 ($\bar{X}$:2.0)	1.3-1.5	8-20 ($\bar{X}$:14)	Large cobble mixed w/ small boulders & coarse gravel.	Mod. entrenched/ Mod. confined.	Coarse textured, alluvial terraces with stable, moderately steep, side slopes.
B3	1.5-4.0 ($\bar{X}$:2.5)	1.3-1.7	8-20 ($\bar{X}$:12)	Cobble bed w/ mixture of gravel & sand - some small boulders.	Mod. entrenched/ well confined.	Glacial outwash terraces and/or rejuvenated slopes. Unstable, moderate to steep slopes. Unconsolidated, coarse textured unstable banks. Depositional landforms.
B4	1.5-4.0 ($\bar{X}$:2.0)	1.5-1.7	8-20 ($\bar{X}$:10)	Very coarse gravel w/ cobble mixed sand and finer material.	Deeply entrenched/ well confined.	Relatively fine river terraces. Unconsolidated coarse to fine depositional material. Steep side slopes. Highly unstable banks.
B5	1.5-4.0 ($\bar{X}$:2.5)	1.5-2.0	8-25 ($\bar{X}$:15)	Silt/clay.	Same	Cohesive fine textured soils. Slump-earthflow erosional processes.
C1-1	1.5 or less ($\bar{X}$:1.0)	1.5-2.5	10 or greater ($\bar{X}$:30)	Bedrock bed, gravel, sand, or finer banks.	Shallow entrenchment, poorly confined.	Bedrock controlled channel with depositional fine grained bank material.
C1	1.2-1.5 ($\bar{X}$:1.3)	1.5-2.0	10 or greater ($\bar{X}$:18)	Cobble bed with mixture of small boulders and coarse gravel.	Mod. entrenched/ Mod. confined.	Predominantly coarse textured, stable high alluvial terraces.
C2	0.3-1.0 ($\bar{X}$:0.6)	1.3-1.5	15-30 ($\bar{X}$:20)	Large cobble bed w/ mixture of small boulders & coarse gravel.	Mod. entrenched/ well confined.	Overfit channel, deeply incised in coarse alluvial terraces and/or depositional features.
C3	0.5-1.0 ($\bar{X}$:0.8)	1.8-2.4	10 or greater ($\bar{X}$:22)	Gravel bed w/mixture of small cobble & sand.	Mod. entrenched/ slight confined.	Predominantly moderate to fine textured multiple low river terraces. Unstable banks, unconsolidated, noncohesive soils.
C4	0.1-0.5 ($\bar{X}$:0.3)	2.5 +	5 or greater ($\bar{X}$:25)	Sand bed w/mixtures of gravel & silt (no bed armor).	Mod. entrenched/ slight confined.	Predominantly fine textured, alluvium with low flood terraces.
C5	0.1 or less ($\bar{X}$:.05)	2.5 +	5 or greater ($\bar{X}$:10)	Silt/clay w/mixtures of medium to fine sands (no bed armor).	Mod. entrenched/ slight confined.	Low, fine textured alluvial terraces. delta deposits, lacustrine, loess or other fine textured soils. Predominantly cohesive soils.
C6	0.1 or less ($\bar{X}$:.05)	2.5 +	3 or greater ($\bar{X}$:5)	Sand bed w/mixture of silt & some gravel.	Deep entrenched/ slight confined.	Same as C4 except has more resistant banks.
D1	1.5 or greater (X:2.5)	N/A Braided	N/A	Cobble Bed w/mixture of coarse gravel & sand & small boulders.	Slight entrenched/ no confinement.	Glacial outwash, coarse depositional material, highly erodable. Excess sediment supply of coarse size material.
D2	1.5 or less (X:1.0)	N/A Braided	N/A	Sand bed w/mixture of small to medium gravel & silts.	Slight entrenched/ no confinement.	Fine textured depositional soils, very erodable - excess of fine textured sediment.

Stream Sub-type Classification

Observations have indicated that over time major stream types can be altered in their pattern and associated response and feedback mechanisms by various influences. These influences can change specific factors of fisheries habitat, sediment supply, channel stability, etc. These influences have been grouped into a series of physical characteristics used to delineate stream sub-types (Table 3). The stream sub-type criteria are: 1) riparian vegetation; 2) Organic debris and/or channel blockages, 3) stream size (width), 4) flow regimen

Table 3.--Stream Sub-type Criteria

ORGANIC DEBRIS/Channel Blockages

(in Active Channel)

D-1	None
D-2	Infrequent debris, what's present consists of small, floatable organic debris.
D-3	Moderate frequency, mixture of small to medium size debris affects less than 10% of active channel area.
D-4	Numerous debris mixture of medium to large sizes - affecting up to 30% of the area of the active channel.
D-5	Debris dams of predominantly large material affecting over 30% to 50% the channel area and often occupying the total width of the active channel.
D-6	Extensive, large debris dams either continuous or influencing over 50% of channel area. Forces water onto flood plain even with moderate flows. Generally presents a fish migration blockage.
D-7	Beaver dams. Few and/or infrequent. Spacing allows for normal streamflow conditions between dams.
D-8	Beaver dams - Frequent. Back water occurs between dams - stream flow velocities reduced between dams.
D-9	Beaver dams - abandoned where numerous dams have filled in with sediment and are causing channel adjustments of lateral migration, evulsion, and degradation etc.
D-10	Man made structures - diversion dams, low dams, controlled by-pass channels, baffled bed configuration with gabions, etc.

RIPARIAN VEGETATION

Y1 - Rock

Y2 - Bare soil, little to no-vegetative cover

Y3 - Annuals, forbs

Y4 - Grass - perennial bunch grasses

Y5 - Grass - sod formers

Y6 - Low brush species

Y7 - High brush species

Y8 - Coniferous trees

Y9 - Deciduous trees

Y10 - Wetlands

  a. bog
  b. fen
  c. marsh

Note: Combinations of grass and brush understories with a coniferous overstory can be designated by combining sub type numbers, i.e., (Y4,7,8.)

Subscript letters may be used to identify specific vegetative associations, speciation, habitat types, or riparian types based on level of detail required by stream type user.

STREAM SIZE (S)

S-1	Bankfull width less than 1 foot.
S-2	Bankfull width 1-5.
S-3	Bankfull width 5-15.
S-4	Bankfull width 15-30.
S-5	Bankfull width 30-50.
S-6	Bankfull width 50-75.
S-7	Bankfull width 75-100.
S-8	Bankfull width 100-150.
S-9	Bankfull width 150-250.
S-10	Bankfull width 250-350.
S-11	Bankfull width 350-500.
S-12	Bankfull width 500-1000.
S-13	Bankfull width 1000+.

FLOW REGIMEN

General Category

E. - Ephemeral stream channels - flows only in response to precipitation.

S. - Subterranean stream channel - flows parallel to and near the surface for various seasons - a sub-surface flow which follows the stream channel bed.

I. - Intermittent stream channel - one which flows only seasonally, or sporadically. Surface sources involve springs, snow melt, artificial controls, etc.

P. - Perennial stream channels. Surface water persists year long.

Specific Category

1. Seasonal variation in streamflow dominated primarily by snowmelt runoff.
2. Seasonal variation in streamflow dominated primarily by stormflow runoff.
3. Uniform stage and associated streamflow due to spring fed condition, backwater etc.
4. Stream flow regulated by glacial melt.
5. Regulated stream flow due to diversions, dam release, dewatering, etc.

DEPOSITIONAL FEATURES (BARS)

B-1	Point Bars
B-2	Point Bars with Few Mid Channel Bars
B-3	Many Mid Channel Bars
B-4	Side Bars
B-5	Diagonal Bars
B-6	Main Branching with Many Mid Bars and Islands
B-7	Mixed Side Bar and Mid Channel Bars Exceeding 2-3X width
B-8	Delta Bars

MEANDER PATTERNS

M-1	Regular Meander
M-2	Tortuous Meander
M-3	Irregular Meander
M-4	Truncated Meanders
M-5	Unconfined Meander Scrolls
M-6	Confined Meander Scrolls
M-7	Distorted Meander Loops
M-8	Irregular with Oxbows, Oxbow Cutoffs

(perennial, ephemeral, subterranean, intermittent channels, streamflow variations and sources; stormflow, snowmelt, glacial fed, etc.), 5) depositional features, and 6) meander patterns.

As with the major stream types, these sub-types can be determined primarily from aerial photographs and topographic maps. The advantage of this more detailed sub-type delineation provides for higher resolution of interpretations while providing more flexibility for multiple applications.

Procedural Applications

The classification scheme is applicable only to certain river reaches as the river character can change in relatively short distances due to shifts in channel gradient, materials, entrenchment, etc. The stream typing is designed to be accomplished by use of aerial photographs and topographic maps. Field checking, however, is important as the actual gradients, dominant particle sizes and width/depth ratios can be validated for each major stream type.

There are various appropriate levels of applications. For some, only the major stream type delineation would be required. For others, however, stream sub-types may provide the needed resolution for consistent interpretations. This particular classification has been in use since 1978 for various applications including: 1) Development of minimum standards and guidelines for riparian areas; 2) establishment of sediment threshold limits for water yield models and soil loss-sediment supply evaluations; 3) development of hydraulic geometry y, relationships correlating discharge with width, depth, velocity slope, and cross-sectional area; 4) development of roughness coefficients for engineering calculations; and 5) relationships and coefficients for applications of tractive force equations; 6) establishing ratios of bedload to suspended load, nature, and size of sediment transport and sediment rating curves; 7) streampower/bedload transport rate relationships; 8) fisheries habitat interpretations; 9) fisheries habitat structural improvement guidelines; 10) channel stability relationships; 11) debris management guidelines; 12) stream restoration guidelines, and 13) direct linkage with land systems inventory and analysis.

SUMMARY

The development of a quantitative stream classification system utilizing channel morphological indices provides for some consistency in defining stream types for potential universal applications. The system has a multitude of applications for various purposes involving stream systems. This may be the first approximation of a system which will be refined over the years, as our knowledge and experience continues to fill in the narrowing gaps. It hopefully can be a vehicle to provide better communication between those studying riparian systems to promote a better understanding of river processes.

LITERATURE CITED

Culbertson, D. M., L. E. Young, and J. C. Brice. 1967. Scour and fill in Alluvial Channels, U.S. Geological Survey, Open File Report.

Davis, W. M. 1899. The Geographical Cycle, Geographical Journal, Vol. 14, pp. 481-504.

Fisher, W. L., L. F. Brown Jr., A. J. Scott, and J. H. McGowen. 1969. Delta Systems in the exploration for oil and gas, a research colloquium: Bur. Econ. Geol. Univ. of Texas at Austin.

Galay, V. J., R. Kellerhals, and D. I. Bray. 1973. Diversity of river types in Canada in Fluvial Process and Sedimentation: Proc. of Hydrology Symposium: National Research Council of Canada, p. 217-250.

Kellerhals, R., C. R. Neill, and D. I. Bray. 1972. Hydraulic and geomorphic characteristics of rivers in Alberta: Research Council of Alberta, River Engineering and Surface Hydrology Report 72-1, 52 p.

Khan, Hamidur, R. 1971. Laboratory Studies of Alluvial River Channel Patterns, Ph.D. Dissertation, Civil Engineering Department, Colorado State Univ., Fort Collins, Colo.

Land, E. W. 1957. A Study of the Shape of Channels Formed by Natural Streams Flowing in Erodible Material, Missouri River Division Sediment Series No. 9, U.S. Army Engineer Division, Missouri River, Corps of Engineers, Omaha, Nebraska.

Leopold, L. B., and M. G. Wolman. 1957. River channel patterns; braided, meandering, and straight: U.S. Geol. Surv. Prof. Paper 282-B.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial Processes in Geomorphology: Freeman, San Francisco, Calif. 522 pp.

Matthes, G. 1956. "River Engineering" Chap. 15. American Civil Engineering Practice., Abbott (editor), John Wiley and Sons.

Melton, F. A. 1935. An Emperical Classification of Floodplain Stream: Geographical Review. Volume 26.

Mollard, J. D. 1973. Air photo interpretation of fluvial features: in Fluvial processes and sedimentation: Research Council of Canada, p. 341-380.

Schumn, S. A. 1963. A Tentative Classification of Alluvial River Channels, U.S. Geological Survey Circular 477. Wash. D.C.

Thornbury, W. D. 1969. Principles of Geomorphology, 2nd Edition, John Wiley and Sons.