The Concept of Weighted Usable Area
as Relative Suitability Index

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Abstract:

A terminology revision is proposed for the concept of weighted usable area, the habitat index which varies by discharge in a PHABSIM analysis under the Instream Flow Incremental Methodology. Weighted usable area has been traditionally computed as the sum of stream surface area within a study site, weighted by multiplying area by habitat suitability variables (most often velocity, depth, and substrate or cover) which range from 0.0 to 1.0 each, and normalized to square units (either feet or meters) per 1000 linear units. The argument is made that multiplication of actual surface area by dimensionless suitability variables results in a dimensionless habitat index that can no longer be properly referred to as area. Relative Suitability Index is proposed as a replacement to more accurately describe the concept, since habitat suitability variables are computed from species observations as the likelihood of occurrence. Examples of significant ongoing governmental policy and interpretation misunderstandings deriving from using weighted usable area as equivalent to habitat are provided as reason for change.

Introduction

A key element of the Instream Flow Incremental Methodology is the functional relationship between a metric for physical microhabitat and streamflow (Bovee et al. 1998). This relationship allows integration of microhabitat with macrohabitat and the direct comparison of alternative flow regimes, and is the basis for incrementalism. Incrementalism distinguishes the IFIM from less flexible methods for evaluating the biological effects of streamflow, such as standard setting techniques like the Tennant Method (1976). The microhabitat metric most frequently associated with the IFIM is computed using the Physical Habitat Simulation (PHABSIM) system of the IFIM and is referred to as weighted usable area, or WUA.

The definition of weighted usable area was first presented in 1977 in Instream Flow Information Paper No. 3 (Bovee and Cochnauer 1977):

> “The weighted usable area is defined as the total surface area having a certain combination of hydraulic conditions, multiplied by the composite probability of use for that combination of conditions. This calculation is applied to each cell within the multidimensional matrix. This procedure roughly equates an area of marginal habitat to an equivalent area of optimal habitat.”

One year later, Bovee (1978) published the same definition and stated that WUA is also “roughly equivalent to the carrying capacity of a stream reach, based on physical conditions alone.” The IFIM Primer (Stalnaker et al. 1995) says WUA is “the wetted area of a stream weighted by its suitability for use by aquatic organisms or recreational activity,” and its units are in square feet or square meters, usually per specified length of stream. Finally, the manual of lecture notes for introductory IFIM training adds that PHABSIM produces

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"output expressed as usable or optimal microhabitat area, or an index of microhabitat area (weighted usable area)."

Illustrations of the WUA concept typically take the form of line-drawing mosaics of stream cells as either two or three-dimensional trapezoids, the areas of which are characterized by various combinations of weighted suitabilities for hydraulic or structural conditions (Figure 1). At each discharge over a range of hydraulic conditions and associated suitabilities, the sum of weighted equivalent area is plotted and expressed as a functional relationship between discharge and unit microhabitat area for any particular target species (Figure 2).

The validity of the WUA concept has been vigorously debated ever since. Many researchers have demonstrated correlations between WUA and fish populations or biomass, especially when the effects of flow or recruitment over time are considered (Nickelson et al. 1979; Stalnaker 1979; Wesche 1980; Gowan 1985; Loar 1985; Conder and Annear 1987; Bovee 1988; Jowett 1992; Nehring and Anderson 1993; Bovee et al. 1994; Gallagher and Gard 1999). Others have also presented failures to demonstrate such correlations or otherwise criticized the assumptions, models, variables, or interpretations (Mathur et al. 1985, 1986; Granholm et al. 1985; Shirvell 1986, 1987, 1989; Scott and Shirvell 1986; Morhardt 1986). In spite of these criticisms, the IFIM (along with WUA) has become one of the most widely used approaches in the world for evaluating instream flow needs (Bovee et al. 1998; Dunbar et al. 1998; Tharme 2002).

Problems with Weighted Usable Area as Area

The wide acceptance of the IFIM does not mean its implementation is without problems. While the IFIM was envisioned, designed, taught, and continuously described by its developers as a "decision-support system to help…determine the benefits or consequences of different water management alternatives", the IFIM is also widely "misconstrued, misinterpreted, and in some cases misused" (Bovee et al. 1998). Commonly, the elaborate IFIM process of legal/institutional analysis, problem diagnosis, study objective design, multi-parameter modeling, linkage with hydrology, alternatives analysis, and negotiation and resolution is reduced to equivalence with PHABSIM (Gore et al. 2002). Commonplace in the refereed and gray literature are examples where the terms IFIM and PHABSIM are used interchangeably (Wissmar et al. 1994; Scruton et al. 1996; MORE)

After working with the IFIM in commercial applications for over 23 years, I have come to believe that much of the abuse of the method is due to how the WUA discharge relationship is perceived by many IFIM participants, reviewers, and negotiators, not to mention judges, hearing officers, and the general public. Typically, WUA is seen as representing actual physical area within a stream and that this physical area is equivalent to broader ecological definitions of "habitat." This image inevitably triggers the attitudes and policies that all habitat must be protected and enhanced, and any flow besides the one showing the highest amount of "habitat" is unacceptable. At this point, further biological or hydrological interpretation such as time series analysis is discouraged because it often requires judgment that can conflict with the simple goal of maximum habitat protection.

Several states have developed negotiating positions founded on the peak-of-the-curve approach. Washington State, for example, has said their instream flow recommendations are for "maximizing habitat" using "the peak of the habitat vs. discharge curve resulting from an *IFIM* study" [italics mine] (Beecher 1985; WDW 1990). Here is written policy equating WUA with habitat and also interchanging IFIM for PHABSIM. Negotiation and

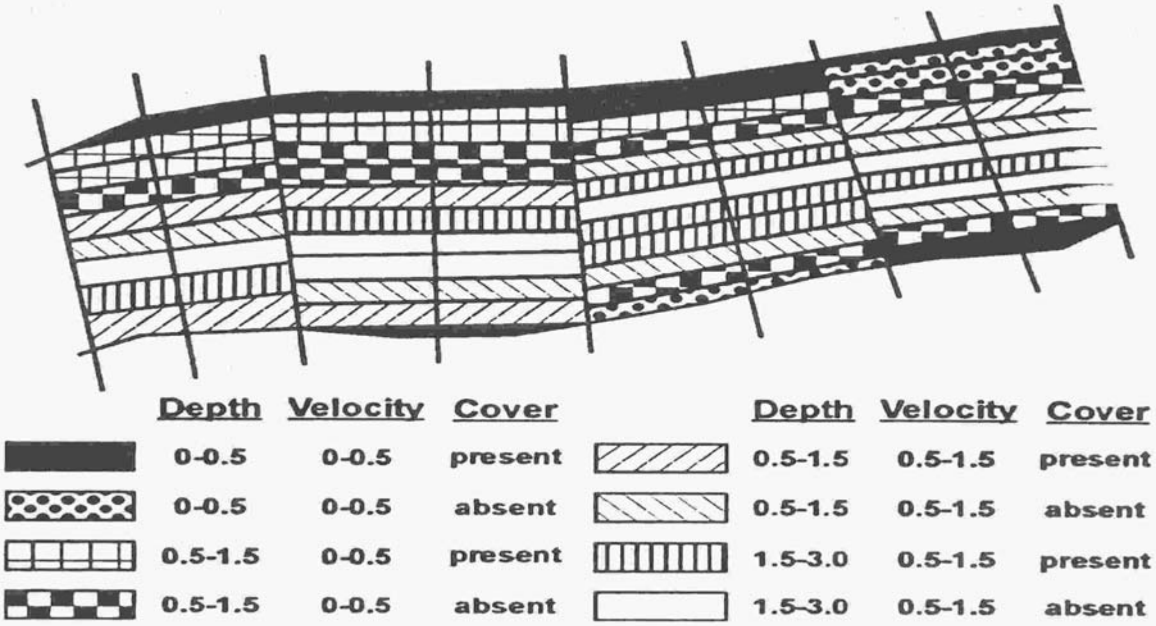

Fig. 4-14. Computer "map" of stream cells portraying the distributions of depth, velocity, and cover features from the hydraulic and channel structure models of PHABSIM.

Figure 1. Standard representation of a PHABSIM study reach with sampling "cells".

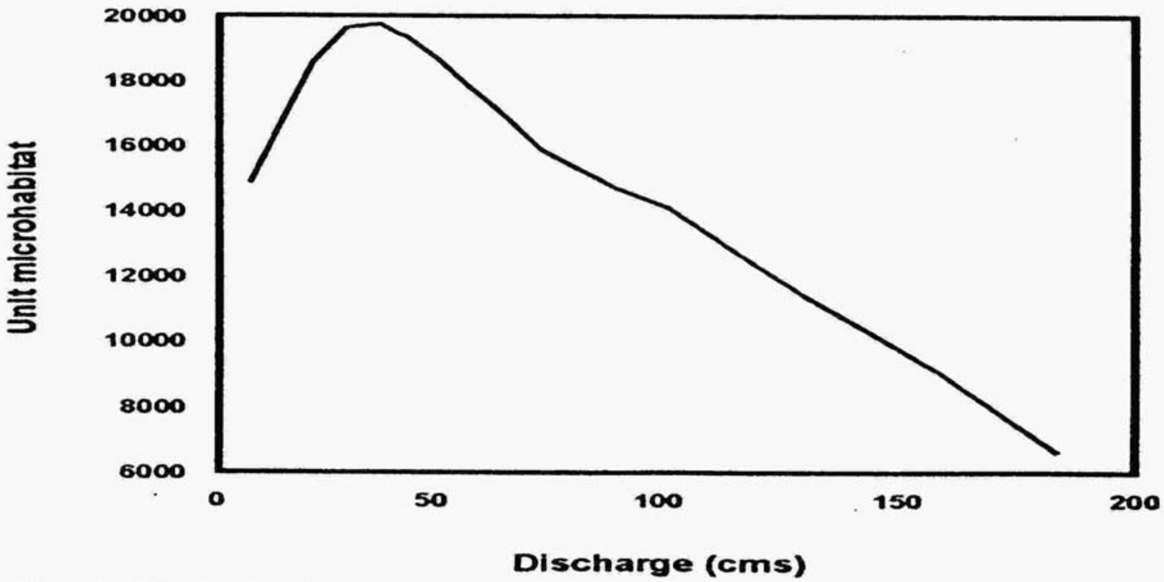

Fig. 4-16. Typical output from PHABSIM: a functional relationship between discharge and unit microhabitat area for a specific target organism. The units of microhabitat are expressed as area per unit length of stream.

Figure 2. Standard plot of the PHABSIM weighted usable area habitat index.

alternatives analysis are also discouraged because the Washington agencies "neither request nor endorse the use of time-series," which is a key element of a complete IFIM (Fig. 1-4 in Bovee et al. 1998). California has had an identical policy, expressed in numerous letters to the FERC and in positions before the Division of Water Rights of the State Water Resources Control Board. Wyoming has interpreted their PHABSIM studies almost entirely in the context of flows which deviate from the peak being the same as creating a loss of habitat. Many states, federal agencies, and other nations have promoted similar policies or taken similar approaches. Quite recently an important (unnamed) federal agency has even drafted a policy linking reductions from peak WUA with a determination of jeopardy under the Endangered Species Act.

Conceptualizing WUA as tangible physical area also promotes a tendency to try and put real fish into units of WUA. Instream Flow Information Paper No. 12 (Bovee 1982) devoted 36 pages to the idea of effective habitat time series and habitat ratios, which requires data on population density, or "the number or weight of fish per unit of weighted usable area." Williamson et al. (1993) expanded on the concept with a salmonid production model where density dependence capacities initiate fish movement. Even the newest instream flow models also depend on the need to place numbers of fish in units of WUA (Jager and Rose 2003). While such approaches may ultimately be made to work on the rivers under study, they are very unlikely to readily apply to other systems. The flaw, of course, is that units of WUA are not standard or transferable because they are derived from a range of habitat suitability criteria (HSC) and selectable combinations of variables (Mathur et al. 1985). Units of WUA from one study are certain to be different from units in another when HSC are different and when substrate and cover coding systems are customized at will. While WUA has been shown to correlate with biomass, it has not been shown that WUA units are transferable between studies. Where WUA-discharge functions will peak has also been shown to vary widely depending on the computational options used for the suitability variables, such as geometric mean or least limiting factor (Gan and McMahon 1990).

There are a few bright spots in this improper treatment of WUA. Some states have recently indicated a change in negotiating strategies away from peak-of-the-curve, another (unnamed) federal agency heavily involved with hydropower relicensing is promoting the use of habitat time series as part of flow alternative evaluation, and draft ESA policies concerning WUA have not been finalized. In addition, the recent book on instream flow methods by the Instream Flow Council states flatly that PHABSIM practitioners "should not prescribe a minimum instream flow standard by recommending the maximum habitat value from the WUA/discharge graph for a single life stage of a single species," because "doing so can result in unrealistically high recommendations that damage the credibility of the entire study and the study team." Time will tell if these changes translate into actual practice.

Weighted Usable Area is an Index

Scattered throughout the IFIM and PHABSIM literature are references to WUA as an ***index*** to various ecological parameters such as biomass, microhabitat area, or population size. Orth and Maughan (1986), in defending the method, voice their support for "the current practice of making the assumption that WUA is an index of potential fish biomass or numbers." IFIM training manuals state that PHABSIM produces "output expressed as…an index of microhabitat area" (IF200 Lecture Notes 1994). WUA can only be an index because perceived physical area is multiplied by unit-less habitat suitability attributes. These attributes were originally termed "elective criteria" (Bovee and Cochnauer 1977) under the assumption that species will elect to leave an area when conditions become unfavorable. Electivity is variously expressed as probability-of-use (or non-use), preference, suitability, or utilization over the possible range of conditions. Electivity indices range between 0 and 1, have no units, and are most commonly derived from frequency analysis of field observations.

Williamson et al. (1993) expressly discusses WUA as both an area and an index by stating "mathematically, multiplying a unit-less index times an area produces an area" but "logically and statistically…multiplying a unit-less index times an area produces an index." (He does not, however, elaborate on why these disciplines would reach a different conclusion.) It seems reasonable to conclude, if physical area and elective criteria are multiplied together, the result should be an area-weighted habitat suitability index with no units, rather than a suitability-weighted habitat area that retains units.

Unfortunately, most written discussions of WUA, including some by the Instream Flow Group, neglect to refer to WUA as an index and instead call it microhabitat area (e.g. Bovee 1994). This error comes from the idea of a stream being represented by trapezoidal cells, which while convenient for conceptualization, is not at all accurate. From a hydraulic perspective, point data on depth, velocity, and substrate or cover obtained at a vertical are very unlikely to remain uniform over any distance from the vertical (Kondolf et al. 2000), let alone for dozens of meters up and down stream. Velocity patterns can fluctuate turbulently over short time frames (Bhowmik and Xia 1993). Depth can vary quite rapidly, especially in streams with large bed elements where minor deviation from the vertical in any direction can cause a difference in depth of centimeters to meters (Figure 3). Velocity can also be highly variable any distance from the point measurement, in the vertical as well as the lateral direction, as can be illustrated with transect (Figure 4) data from an acoustic doppler current profiler (Figure 5). It would be more accurate to say that point data should be treated as proportional to the overall occurrence of the observed physical conditions within the stream, instead of visualized as physically extending out from the sample.

The biological perspective also argues against treating a point sample as a physical area. While we may be able to locate a fish in association with particular patterns of depth, velocity, substrate and cover, only the most naive would argue that those variables are the only reasons why a fish will locate at that spot. Often there are subtle cues of velocity gradients, feeding lanes, physical territory separators, proximity to hiding cover, learned behaviors, and any number of other influences, some of which we suspect, and many about which we are unaware or unable to measure or reasonably model. Much recent discussion about spatial scale (Railsback 1999; Guay et al. 2000, 2001; Williams 2001) in ecological modeling begs the question about whether such modeling to include these influences is even feasible. At best, fish are associated with depth, velocity, substrate, and cover by correlation with their abundance – saying they are choosing an area because of what is measured at a point is a considerable leap of faith.

Finally, a long-neglected topic in PHABSIM modeling is the choice of computational method in the linkage of hydraulic data with electivity indices. As pointed out in the computer manuals (Milhous et al. 1984, 1989, 2001) there are at least three ways to multiply the indices, along with either centroid or adjacent-averaged hydraulics, and the ability to test for specified velocities within a search distance prior to linkage. All of these produce different "quantities" of WUA (Gan and McMahon 1990), yet only one (simple multiplication) is in common practice, for no obvious reason besides tradition and simplicity. If there is no overriding reason to choose among the options, there is no reason to call the result area, as if all areas computed by the options are equal, even if they vary many-fold.

Figure 3. Fish occupying complex habitat with rapidly varying depth and velocity.

Figure 4. Riffle transect ready for depth and velocity data collection with an ADCP.

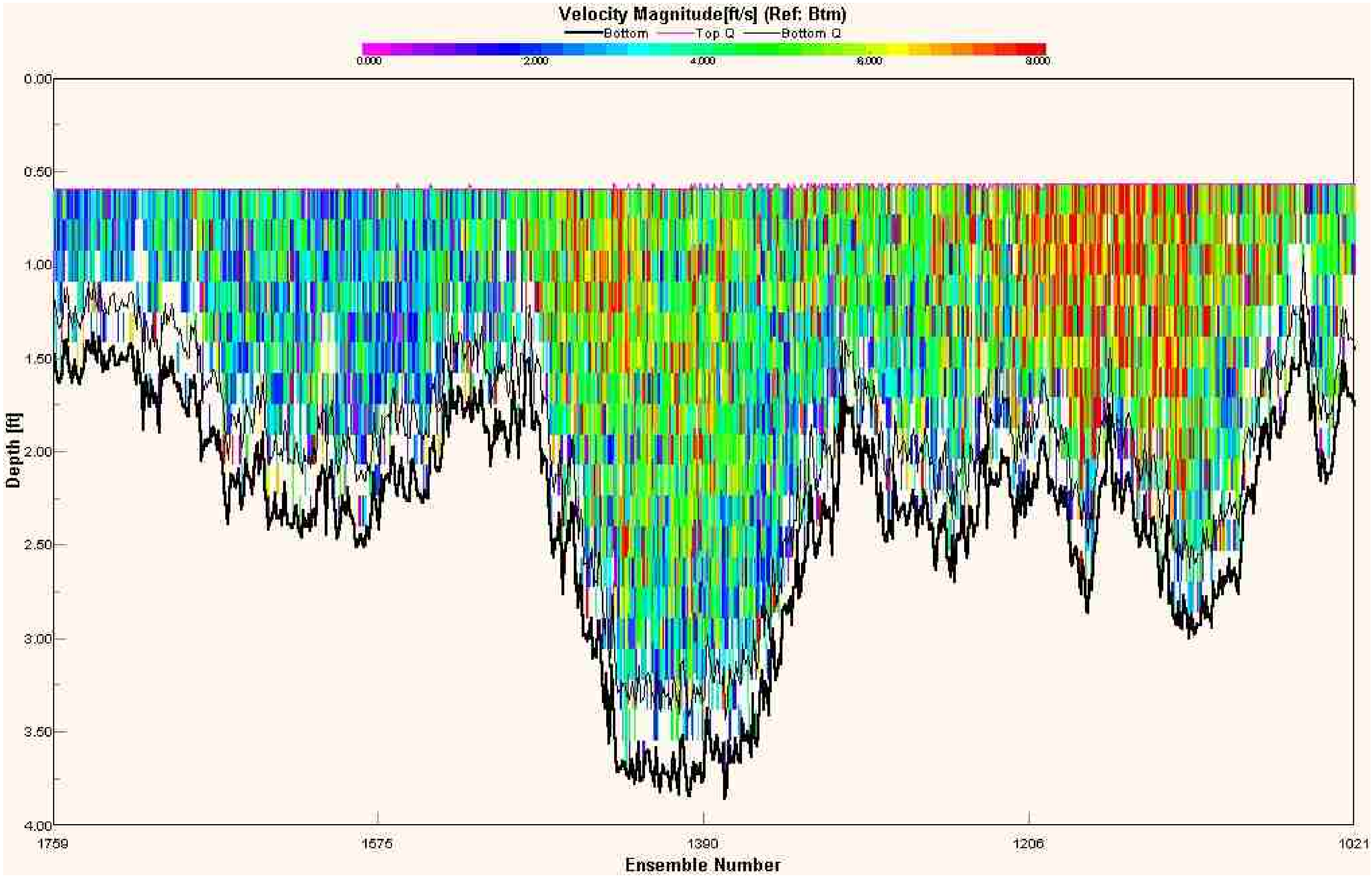

Figure 5. Standard ADCP depth and velocity plot of a riffle transect showing rapid variation in depth and velocity

Relative Suitability Index

In the interest of coining a name that is consistent with and true to the concept, I propose the term Relative Suitability Index. The RSI is composed of several individual parts, each of which is descriptive of separate aspects of habitat simulation and together give very clear meaning.

Relative – The function relating the PHABSIM habitat index to discharge should be described as "relative" as an indication that the index is not absolute and has no extrinsic value. Each PHABSIM study produces results that are only internally consistent with the choices made in that study and are not externally comparable to other studies where other choices were made. The magnitude and trend of any habitat index is strongly influenced by the habitat suitability criteria, the substrate/cover coding systems, the method of variable combination, and (to a lesser extent) the number, placement, data collection techniques, and calibration of the hydraulic models, plus the personnel involved. These differences effectively preclude comparing habitat index values across geographic, political, and technical boundaries, despite some attempts to do so (e.g. Hatfield and Bruce 2000).

Suitability – The RSI indicates the degree of correspondence between riverine hydraulics and the suitable range for specified habitat variable criteria. When PHABSIM extracts depth, velocity, and channel index data from a hydraulic file at any given flow, what is produced is essentially a frequency distribution of the sample values for each variable. The degree of overlap between the hydraulic frequency distributions and the habitat suitability criteria (which are also derived from frequency distributions) indicates how well the distributions match. In other words, the results indicate how compatible the hydraulic variables at any flow are with identified usage of the variables by aquatic species/life stages, so the results should be referred to as suitability, not area.

Index – The results of this linkage have been noted many times in the literature as being an index rather than a tangible area. Intuitively this is logical, since it is not possible to observe a river and identify any specific location as a unit of "weighted usable area." As noted by Williamson et al. (1993), the multiplication of a unit-less suitability index times an area produces an index, so retaining the name of the result as area and not index is inappropriate and even misleading.

Visualization of the Relative Suitability Index

If the results of a PHABSIM analysis are referred to as a Relative Suitability Index, a problem remains as to how the index should be visualized. One of the attractions of coining the term weighted usable area has been the ubiquitous images of trapezoidal cells in a river, each with its respective suitability summing to the whole. Even this picture is not entirely accurate because WUA for a reach is ultimately normalized to represent 1000 linear feet (or meters) of stream. The picture does not apply at all to transect data collected using habitat mapping (Morhardt et al. 1983), where transects are mostly non-contiguous. Instead of trapezoidal cells, each vertical sample point (Figure 6) can be seen as a small, dimensionless cylinder having a "unit" of one (Figure 7). The sample point is a cylinder because it has four "habitat" characteristics: a depth, a mean column velocity, a channel index for either substrate and/or cover, and some undetermined radius. The sample point cylinder unit of one is then multiplied by the respective suitabilities for the characteristics of the cylinder, giving it a suitability index value between zero and one (Figure 8).

The remaining computation is area-weighting to adjust for the non-random nature of data acquisition. (Purely random sampling and hydraulic modeling are incompatible for

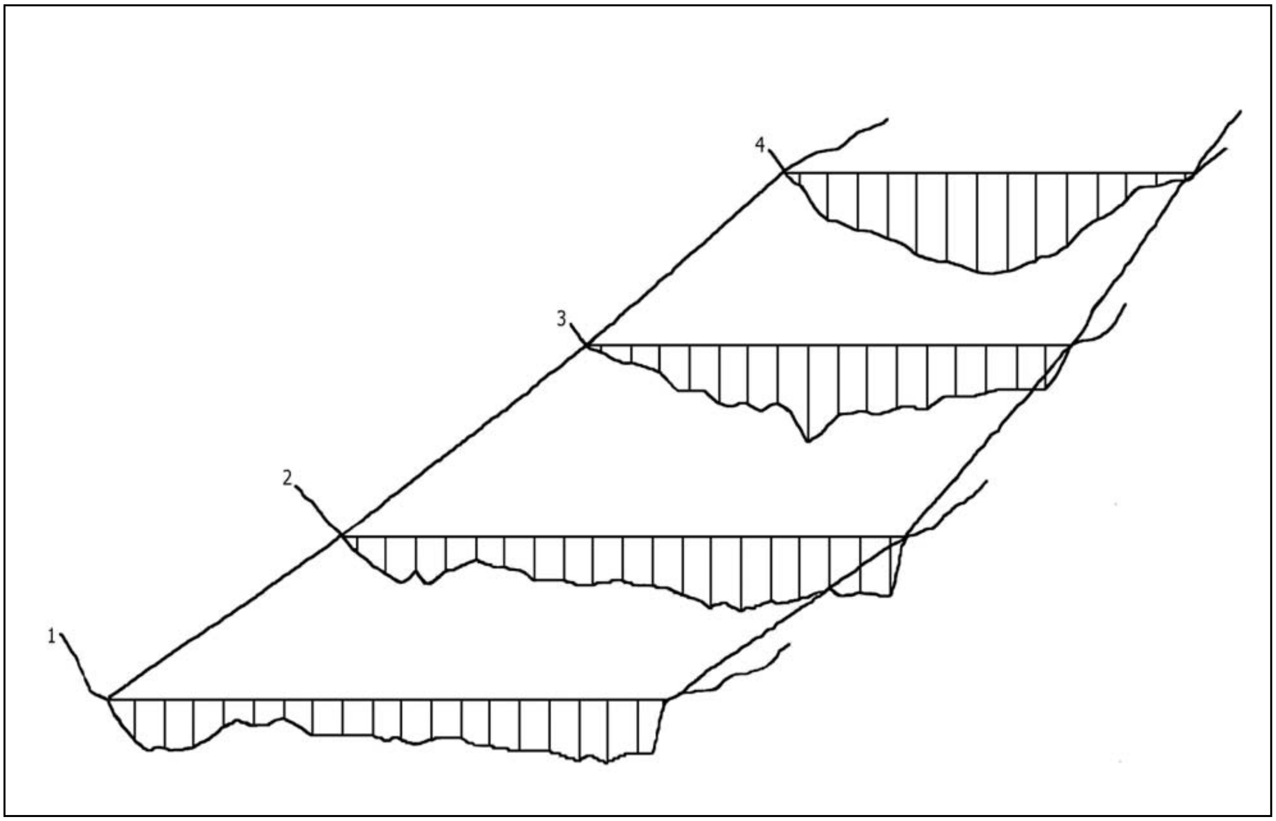

Figure 6. Typical transects showing sampling locations at verticals.

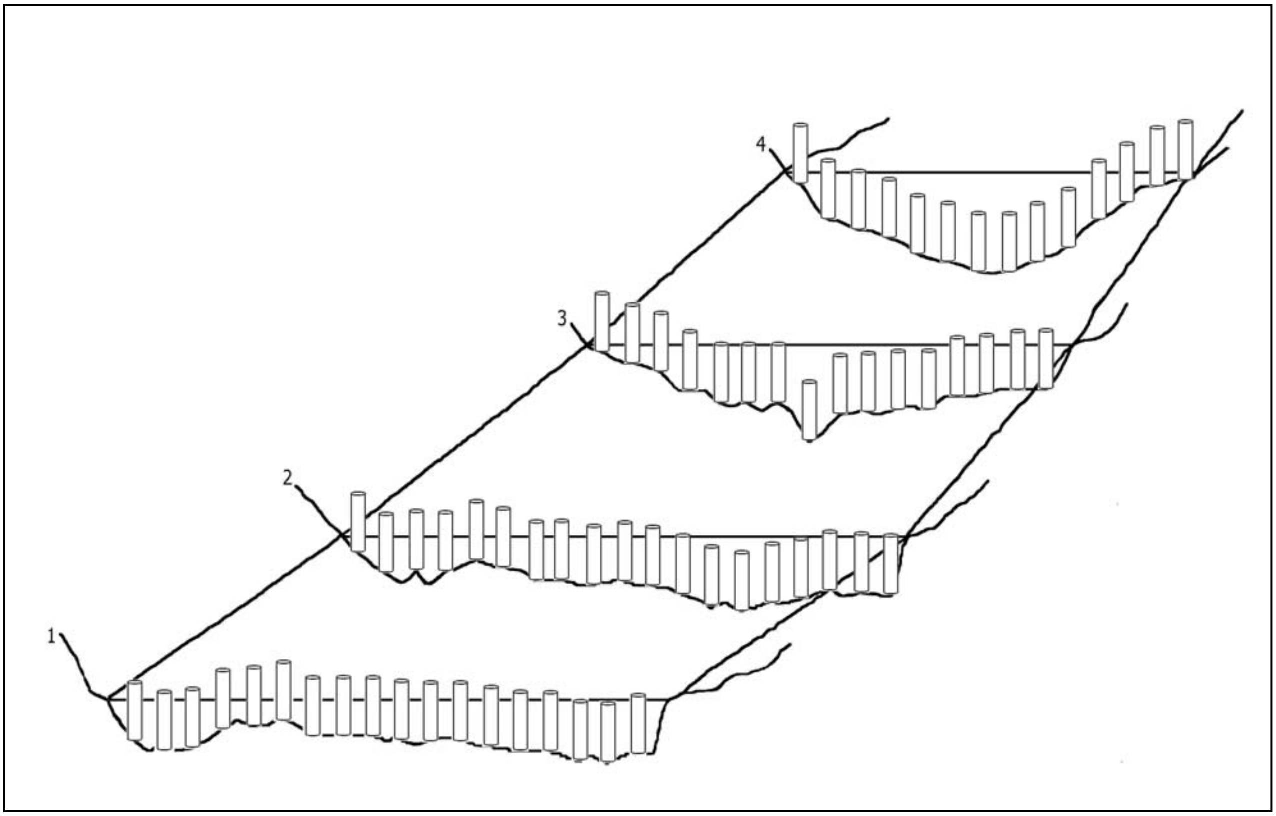

Figure 7. Transects showing sampling locations at verticals as single unit cylinders.

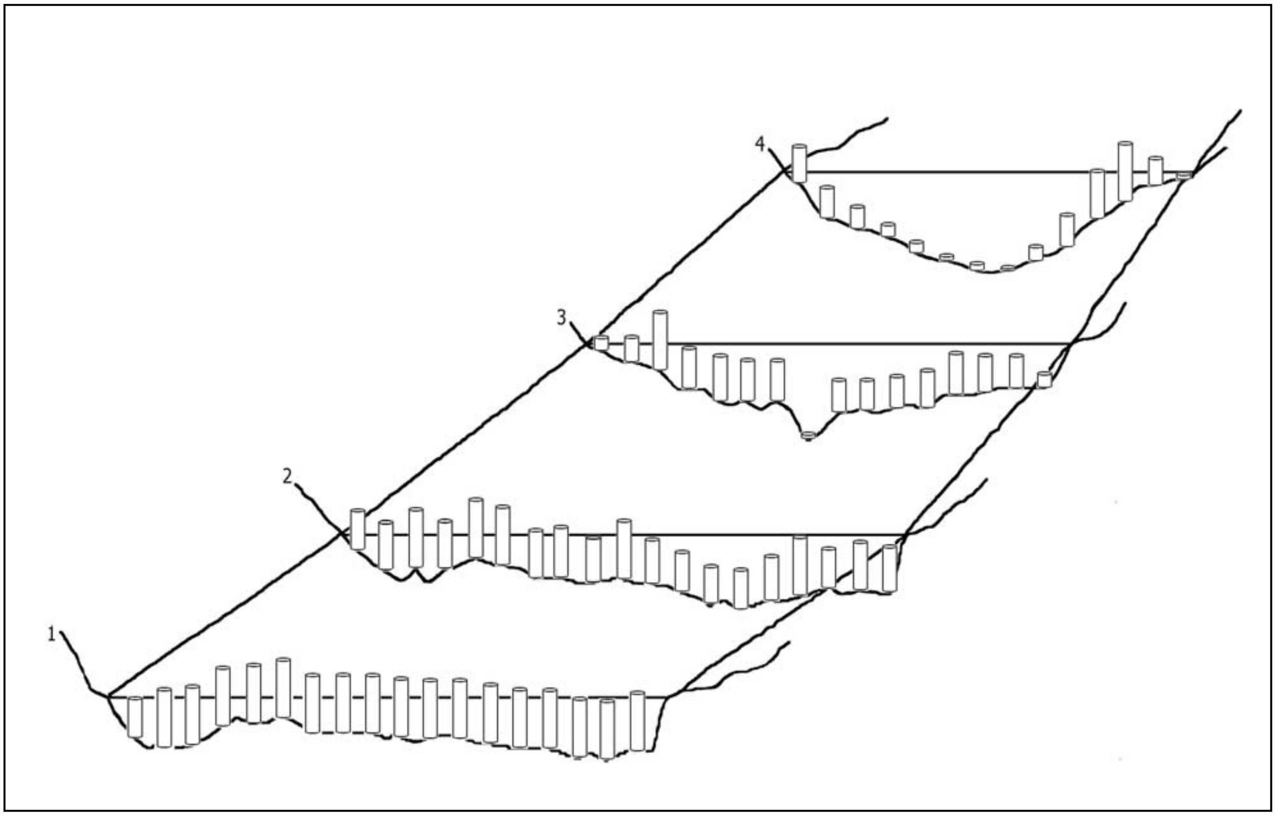

Figure 8. Transects showing sampling unit cylinders weighted by suitability.

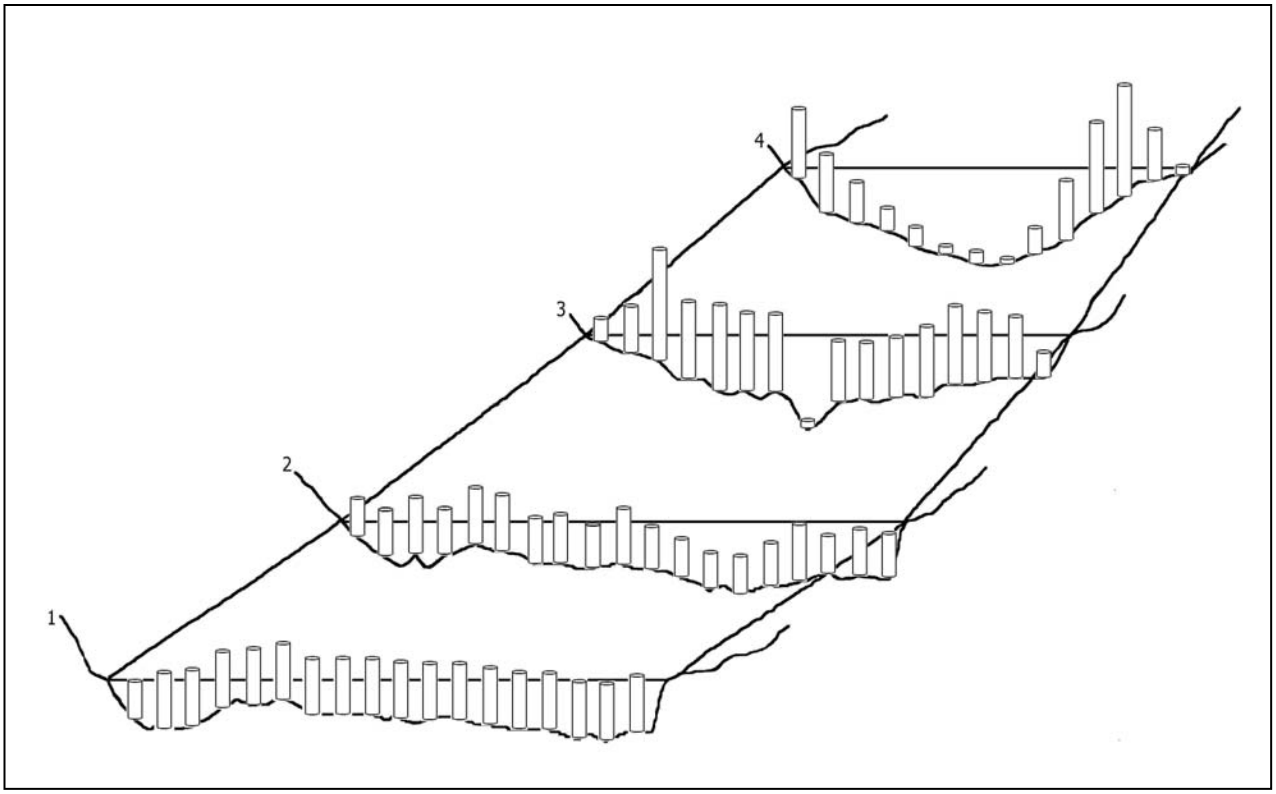

Figure 9. Transects showing sampling unit cylinders weighted by both suitability and habitat type percentages.

reasons of logistics and linkages between data points.) Each cylinder is multiplied by its separation distance from its neighbors, multiplied by the percentage length of stream represented by the sample, normalized to standard length (Figure 9), and the products all summed. The computational method and the results are identical to the traditional description, but the perspective is reversed from suitability-weighted samples of area (weighted usable area) to area-weighted samples of suitability (relative suitability index). The following benefits are expected to be derived from this change in perspective:

- The concept is intuitively, hydraulically, mathematically, and biologically more accurate.
- Misunderstandings regarding the nature of the concept are reduced.
- The potential for either accidental or intentional misuse is reduced.
- The change represents a return to the initial concepts of a habitat index.
- All studies correlating the index to biomass remain valid and unaffected.

Given the long use of the existing term weighted usable area, a change to the new term relative suitability index is likely to be quite difficult and prolonged. There will be resistance from traditionalists and from those who may disagree with the arguments presented here. Breaking old habits is not easy; however, the sooner the change is made, the sooner instream flow practitioners and researchers can return to more productive interpretation of PHABSIM results and develop improved methods for instream flow need recommendations.

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