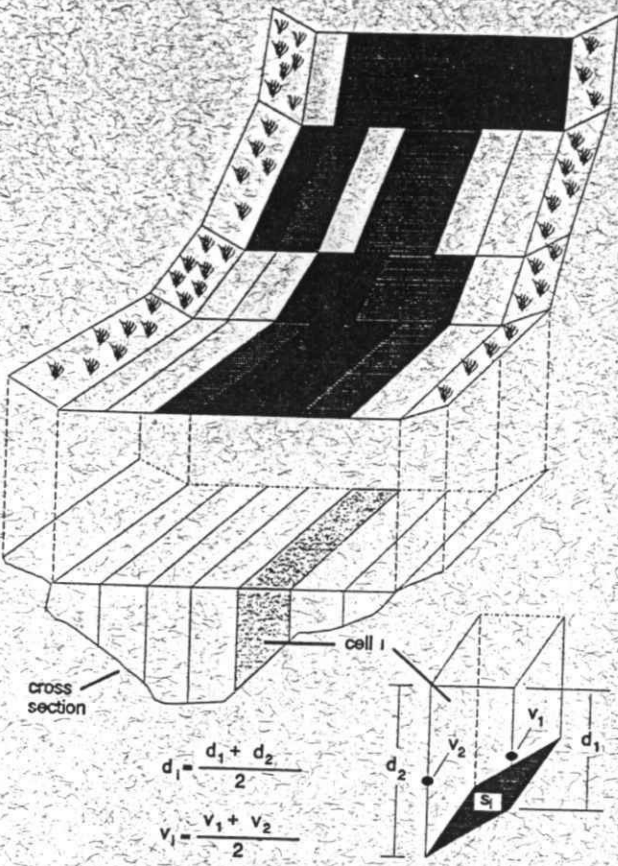
USING THE COMPUTER BASED PHYSICAL HABITAT SIMULATION SYSTEM (PHABSIM)



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CHAPTER 1: OVERVIEW OF PHYSICAL HABITAT SIMULATION SYSTEM

The four major components of a stream system that determine productivity for aquatic animals (Karr and Dudley 1978) are: (1) **flow regime**, (2) **physical habitat structure** (e.g. channel form and substrate distribution), (3) water quality (including temperature), and (4) energy inputs from the watershed (nutrients and organic matter). The complex interaction of these components determines primary production, secondary production, and ultimately the status of fish populations in the stream reach. PHABSIM is one component of a larger capability known as the Instream Flow Incremental Methodology. We will describe Version II of PHABSIM that has many major changes from Version I.

The Instream Flow Incremental Methodology assumes that flow-dependent physical habitat and water temperature may either increase or limit carrying capacity and therefore can be used to help manage the standing crop of fish in streams. In riverine systems, the amount and quality of suitable habitat can be highly variable within and among years. The observed population and biomass of fish and invertebrates may be depressed or stimulated by numerous preceding habitat events. Habitat-induced population limitations are related to the amount and quality of habitat available to fish and invertebrate populations at critical stages in their life history. Long term habitat reductions, such as reduced flows, may also be important in determining population and production levels. We limit PHABSIM use to river systems in which dissolved oxygen, suspended sediment, nutrient loading, other chemical aspects of water quality, and interspecific competition do not place the major limits on populations of interest. In regulated rivers below reservoirs, for example, reduced flows can negatively affect habitat availability and suitability in terms of reduced water depths, velocities, and cross sectional area while reservoir operations can decrease summer-fall temperatures and increase winter-spring temperatures.

The Instream Flow Incremental Methodology incorporates methods for estimating stream system changes in physical habitat as a function of flow through PHABSIM and water temperature as a function of flow through SNTEMP, but does not address other elements of water quality and energy inputs. Changes in physical components of the system are evaluated to derive an estimate of fisheries habitat quality and quantity. Incremental changes in flow are used to produce relationships between simulated depth and velocity and measured channel index (i.e., substrate and cover) with habitat potential for target species and life stages. The most common estimate of fisheries habitat potential is a combination of habitat quantity and quality referred to as Weighted Usable Area (WUA). Habitat potential frequently serves as input to some framework of project assessment and negotiating an instream flow. PHABSIM consists of several distinct steps as shown in Figure 1, which also identifies the main sources of measurement and modeling uncertainty that arise in application of PHABSIM. PHABSIM has been examined critically to determine its sensitivity to hydraulic simulation error, (Osborne et al. 1988), selection of options used to simulate microhabitat (Gan and McMahon 1990), and errors in habitat suitability curves (Shirvell 1989; Thomas and Bovee 1993; Waddle 1993). Recognition of these sources of uncertainty and their relative magnitudes is important in analysis and interpretation of PHABSIM results in the instream flow negotiation process.

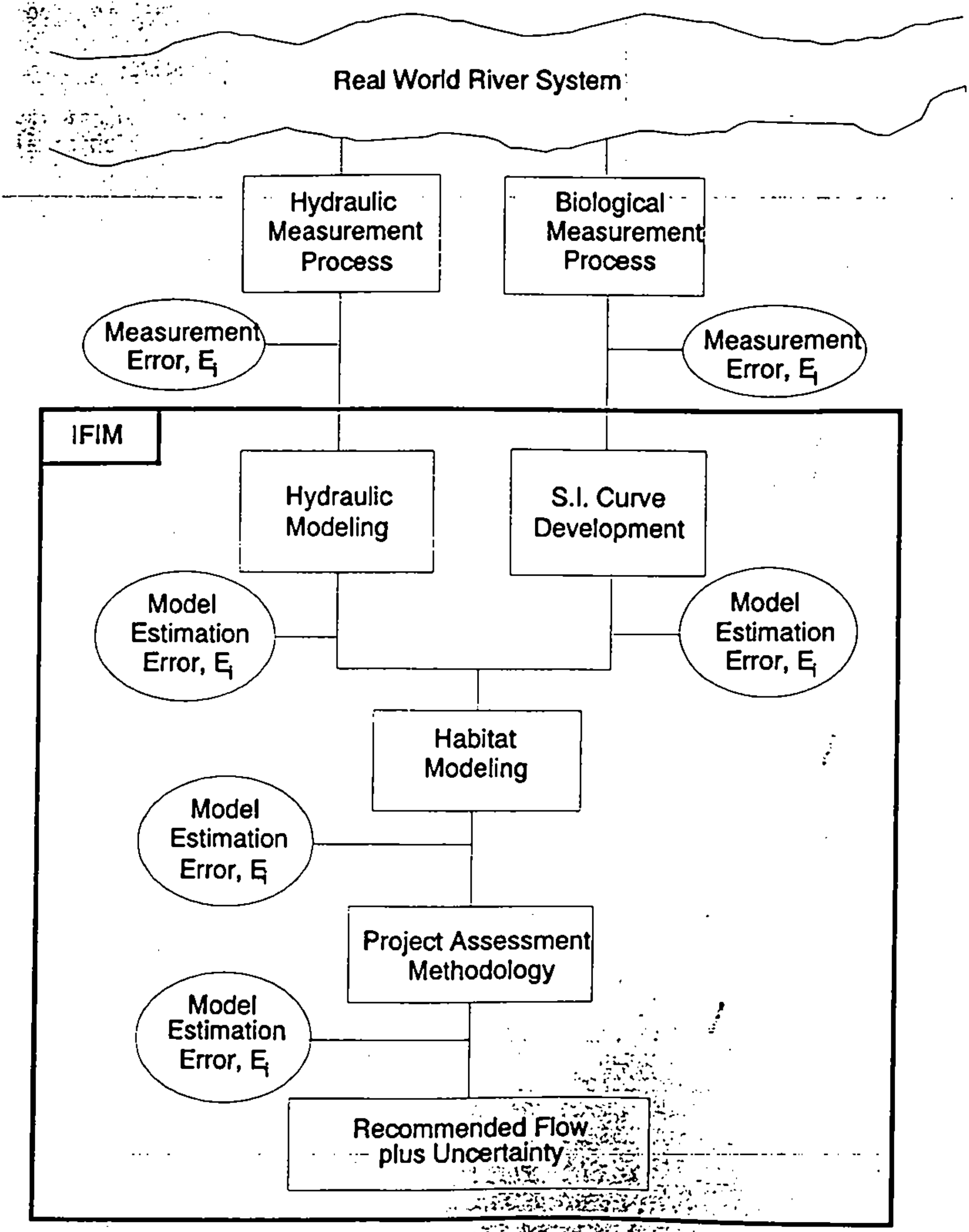


Figure 1. Component steps and sources of uncertainty in PHABSIM.

PURPOSE OF PHABSIM

The purpose of PHABSIM is to simulate a relationship between stream flow and physical habitat availability for various life stages of a species of fish or a recreational activity. The basic objective of physical habitat simulation is to obtain a representation of physical properties of a stream that can be linked through biological considerations, to a social, political and economic framework of evaluation. In order to provide a quantifiable measure of tradeoffs between instream and out-of-stream uses, PHABSIM analyzes the relationship between stream flow and physical habitat, or between stream flow and recreational river space. This relationship is a continuous function between physical habitat and stream flow. It can be used to examine tradeoffs between the value of water used instream with water used out-of-stream. Therefore, tradeoffs can be made between alternative uses and mutually acceptable management criteria developed. The decision as to best allocation of available water is a matter of negotiation among various interest groups.

PHABSIM was developed from concepts incorporated in the "Washington Method", but incorporates more variables including: depth, mean column velocity, substrate composition, nose velocity, adjacent velocity, cover, and distance from cover. The hydraulic simulation portion of PHABSIM can be used as a substitute for repeated empirical measurements at numerous flows. Data collection costs can be reduced approximately 75% compared to a totally empirical database. Flow events can be simulated that are too rare or too dangerous to measure or that do not currently exist. Habitat models can use any species that exhibit some form of microhabitat selection in stream environments at some time during their life history.

PHABSIM is intended for use in those situations where streamflow is the major determinant controlling fishery resource and field conditions are compatible with underlying theories and assumptions of current models, i.e., (1) steady state flow conditions exist within a rigid channel, and (2) individuals of a species respond directly to available hydraulic conditions. If these assumptions are reasonably met, the methodology has application to three basic types of analyses.

1. Quantification of Instream Flow Requirements
    a. Area Wide Planning
    b. Reservation or Licensing of Water Rights
2. Negotiation of Water Delivery Schedules
    a. Minimum Releases
    b. Yearly Flow Regimes (normal and dry year conditions)
3. Impact Analysis
    a. Streamflow Depletion
    b. Streamflow Augmentation
    c. Channel Alterations

STRUCTURE OF PHABSIM

PHABSIM can be broken down into four main components: 1) hydraulic data collection and entry, 2) hydraulic simulation, 3) habitat suitability curve development and validation, and 4) habitat modeling (Figure 2).

1) In field measurements, each transect is divided into cells (intervals) in which depth, velocity, cover value, and substratum type are measured.

2) In the software, cell-by-cell water depths, velocities, and roughness coefficients at different flows are simulated using standard hydraulic modeling techniques first developed by the Bureau of Reclamation and Corps of Engineers. Substrate and cover values from measurements, not simulations, are used.

3) PHABSIM contains a habitat suitability curve library and a module for use in developing functional relationships between depth, velocity, and channel index.

4) The habitat programs assume either that depth, velocity, and channel index (a user-defined combination of substratum and cover) condition within a cell establishes worth of habitat in the cell or that condition in the cell plus velocity in other cells or another location in the same cell nearby establishes worth of habitat in the cell.

HYDRAULIC SIMULATION MODELS IN PHABSIM

The techniques used to simulate hydraulic condition in a stream can have a significant impact on habitat versus streamflow relationship determined in the habitat modeling portion of PHABSIM. The correct choice of hydraulic models as well as proper calibration represents the most technically difficult step in the process of analyzing instream flows.

The hydraulic simulation programs in PHABSIM assume that the shape of channel does not change with streamflow over the range of flows being simulated. The results of hydraulic calculations are 1) water surface elevations and 2) velocities, in that order. Water depths are calculated in the habitat programs from water surface elevations simulated in the hydraulic programs. The water surface elevations are one-dimensional in that the same value for water surface elevation is used for any point on a cross section (hence the description that PHABSIM is a one-dimensional model). In contrast, velocity varies from cell to cell across any cross section. The hydraulic models assume water surface elevations are effectively independent of velocity distribution in the channel.

The approaches available for calculation of water surface elevations are (1) stage-discharge relationships, (2) use of Manning's equation, and (3) the step backwater method. The usual application of PHABSIM requires at least one set of water surface elevations to calibrate the model used. It is a rare application that does not have at least one set of water surface elevations available for calibration of the models. In many situations, a mixture of models is recommended and used to determine water surface elevations.

<u>WSP</u> Elevations - Water Surface Profile Program (WSP) uses the <u>step backwater method</u> to determine water surface elevations on a cross section by cross section basis. <u>Each cross section is related</u> to all others in the data set (a major advantage). The model should be calibrated to measured water surface elevations by adjusting Manning's roughness given in the data set. When more than two cross sections are involved the process should be repeated step-wise upstream; hence, the term "step backwater." The procedure calculates both a flow balance and an energy balance

between cross sections (a major advantage). WSP is good for backwater (pool) applications. Manning's n serves as a control of water surface elevation in WSP.

Velocities - Velocities are calculated that may be used in habitat modeling if and only if velocity measurements needed to calibrate IFG4 are not available. Velocities are simulated between verticals using cell roughness and conveyance factors. The output file produced by WSP is only for use in HABTAE/HABTAT, not HABTAM/HABTAV. The WSP program was originally developed by the Bureau of Reclamation.

MANSQ Elevations - MANSQ uses Manning's equation to calculate water surface elevations on a cross-section by cross-section basis. The model is calibrated using one set of water surface elevations. Just one mean channel velocity for an entire transect should be calculated, not a cell-by-cell set of velocities. Each cross section is independent of all other cross sections in the data set. MANSQ is good for riffles or shallow runs with no backwater effects.

Velocities - Velocities are calculated that may be used in habitat modeling if and only if velocity measurements needed to calibrate IFG4 are not available. Velocities are calculated at X-coordinate verticals. Velocities are averaged with the vertical to the right for the output file for HABTAE/HABTAT.

IFG4 IFG4 should be used primarily to calculate velocities after water surface elevations have been determined from WSP.

Elevations - IFG4 uses a stage-discharge relationship (rating curve) to calculate water surface elevations on a vertical by vertical basis unless they are supplied in the input data set. In the stage-discharge relationship and simulations, each cross section is independent of all others in the data set. IFG4 accepts water surface elevations from any of the other models when a rating curve produces erroneous results (rather common).

Velocities - Velocities are determined using techniques based on Manning's equation. The program is calibrated to a set of measured velocities. The recommended practice is to use one set of velocities although the program can be used when no or multiple velocity measurements are available. IFG4 should be used primarily to calculate mean velocities at each cell at unmeasured discharges. Velocity is measured and simulated at X-coordinate verticals. Velocities are averaged with the vertical to the right for the output file for HABTAE/HABTAT. Manning's n serves as a control of velocity (velocity distribution factor) in IFG4.

HEC2 Elevations - program is not part of PHABSIM, but can be used to determine water surface elevations. It uses the step backwater method like WSP to determine water surface elevations. HEC2 can do some things better than WSP such as predicting water surface elevations at a bridge or with a sheet ice cover. The HEC2 program is supported by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers.

Calculation of Water Surface Elevations

Techniques used to simulate water surface elevations are: a) an empirical stage-discharge equation based on measured data (IFG4): b) Manning's equation (MANSQ): and c) energy loss between cross sections is determined using Manning's equation and water surface elevations are calculated with the step backwater method of determining water surface profiles (WSP). Partly because all transects are tied together in the calculations, the latter method is theoretically most accurate under a wide range of flows and is recommended.

Use of Manning's equation assumes channel control, i.e., condition of channel controls the water surface elevation. In many rivers, water surface elevation will be section-controlled by rock ledges, riffles comprised of boulders and cobbles, gravel bars, and constrictions in width of channel. Many rivers have compound control, with section control during low flows and channel control for higher flows. With compound control, the expected stage-discharge relationship calculated in the IFG4 program is sometimes used for lower flows and water surface elevations determined using MANSQ for higher flows.

The step backwater calculations are used to determine water surface elevations at cross sections in which water surface elevation is controlled by hydrologic conditions at some downstream section. The calculations use Manning's equation to determine energy loss between sections. In some situations, variable backwater occurs and the WSP program is used to simulate water surface elevations. In relatively steep and rough streams, a mixture of stage-discharge, Manning's equation, and step backwater calculations should be used to determine water surface elevations.

Calculation of Velocities

The velocity distribution across a channel is calculated using empirical observations on which Manning's equation is based. The channel is divided into cells and the velocity calculated for each of these cells. The physical habitat is calculated on a cell-by-cell basis using these velocities.

HABITAT SUITABILITY CURVE DEVELOPMENT

A major component of PHABSIM involves development and selection of habitat suitability curves for use in habitat models. This course will not deal extensively with development of habitat suitability curves, but will provide the necessary background for their application.

HABITAT MODELS IN PHABSIM

There are two general types of habitat modeling in PHABSIM based on either average conditions in a entire stream channel or on distribution of velocity and depth among field measurement cells (and therefore computational cells) and the nature of the channel in a stream. The average parameter models, AVDEPTH and AVPERM, calculate wetted width and wetted surface for flows and water surface elevations supplied by the user. They determine width of a stream with water over some depth specified by the user. The average velocity is also calculated. The average condition models are not as widely used or useful as distributed parameter models.

Distributed Parameter Models

HABTAE- calculates areas or volumes or bed areas of microhabitat (using stepped or binary curves) or weighted usable area or volume, using cell mean column or nose velocities. Used primarily to describe fully mobile organisms under steady flow or gradually varying flow conditions. REPLACEMENT FOR HABTAT.

HABTAV- calculates areas (only) of microhabitat (using stepped or binary curves) or weighted usable area, using cell mean column or nose velocities and adjacent velocities in same or nearby cells and criteria describing necessary proximity to adjacent velocity. Used primarily to describe feeding stations for drift feeding fish under steady flow or gradually varying flow conditions.

HABTAM- calculates areas (only) of microhabitat or weighted usable area based on continuous suitable conditions within a specified distance from each cell. Used to describe composite microhabitat for organisms with limited mobility under unsteady flow or rapidly varying flow conditions. Developed for use in evaluating hydropeaking projects. Special assistance from a professional hydrologist is needed when applying PHABSIM to hydropeaking projects.

HABEF- calculates areas (only) of microhabitat or weighted usable area based on continuous suitable conditions in each cell at two different discharges or for two life stages or species. Used to calculate physical habitat at two stream flows (streamflow variation analysis and stranding analysis) or for two life stages (effective spawning analysis) or two species of fish (overlap analysis and competition analysis) using two separate runs created by HABTAE or HABTAV.

The programs using distributed parameters are HABTAE (meant to replace HABTAT that is no longer supported), HABTAV, and HABTAM programs. The HABTAE program assumes condition within a cell establishes worth of habitat in the cell. In contrast, the HABTAV program assumes condition in a cell plus velocity in other cells or another location in the same cell nearby establishes worth of habitat in the cell.

The HABTAE program is similar to the older HABTAT program with important additional capabilities in HABTAE. First, usable volume, bed area and surface area of habitat may be determined. Habitat conditions at each cross section can be determined. Third, discharge does not have to be constant through the stream study segment. All other habitat modeling programs require constant discharge from cross section to cross section in the stream study segment.

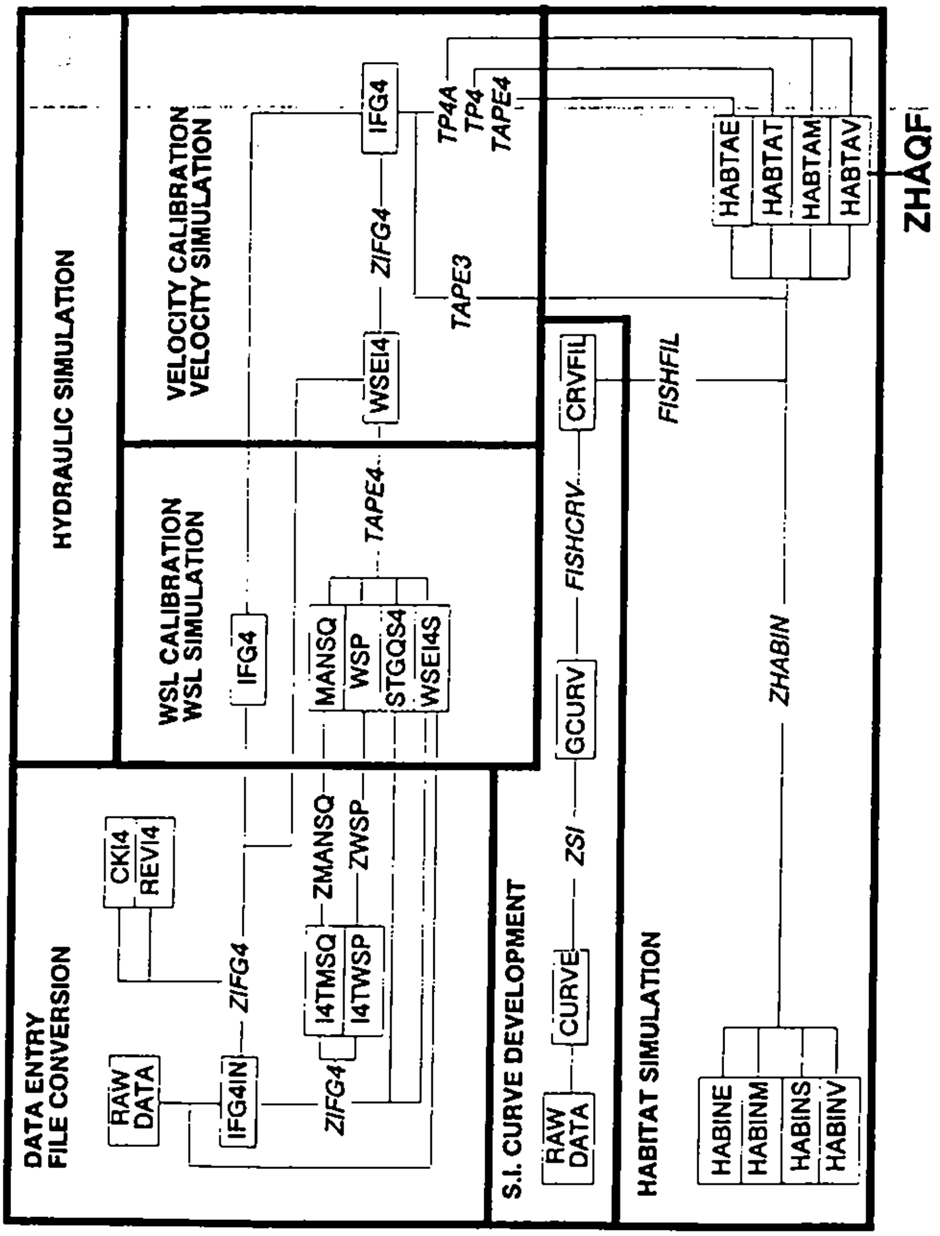


Figure 2. PHABSIM information flow. Programs are contained within boxes and default file names are italicized. INSERT ARROWS INDICATING DIRECTION OF DATA MOVEMENT.

CHAPTER 2. MODELING OPEN-CHANNEL FLOW

The most technically complicated element in application of PHABSIM involves calibration and simulation of hydraulic properties within the river channel. In most engineering curriculum. this subject is introduced at the undergraduate level during a course on hydraulics and again at the graduate level in an advanced course on open-channel flow. Given the time constraints of this course and varied background of participants. only a brief overview of basic concepts of open-channel flow can be provided. This overview is intended to provide an understanding of the vocabulary. definitions. and concepts necessary to proceed with application of PHABSIM hydraulic models for calibration of water surface elevations and velocity profiles within rivers.

TERMS AND DEFINITIONS FOR OPEN-CHANNEL FLOW

The following terms and their definitions are important since they constitute the vocabulary of hydraulic terminology within PHABSIM related to analysis of open-channel flow. The relationships between these terms and physical properties within river channel or cross-section(s) are illustrated in Figures 1 and 2.

Width (w): The distance across a channel or cell at the water surface measured normal (i.e.. perpendicular) to the flow (Figure 1).

Depth (d): The vertical distance from a point on the streambed to the water surface. The cross section area divided by surface width.

Thalweg Depth (y): Vertical distance of the lowest point of a channel section (the thalweg) to the water surface. Maximum depth of cross section.

Hydraulic Depth (d): Equivalent to mean depth: d = Area/Width.

Reach Length: The length of a section or piece (the reach) of a stream measured by following the thalweg. Reach length is the logical or actual distance from the current cross section to the downstream cross section. Reach length weight is a multiplier representing the percentage of the distance to the next upstream cross section that is represented by the current cross section. - practically [illegible]

Longitudinal Profile: A plot of water surface elevations. and best if it includes thalweg elevations. against reach length. Used in hydraulic simulation to verify that water is running downhill continuously.

Discharge (Q): The rate of flow. or volume of water flowing past a given place within a given period of time. traditionally expressed as cubic feet per second (cfs).

Water Surface Elevation (WSL): The streambed elevation plus water depth. Also called water surface level.

<u>Stage:</u> The elevation, or vertical distance of the water surface above some datum (i.e., a plane of known or arbitrary elevation).

<u>Stage of Zero Flow (SZF):</u> The water surface elevation when water, under hydraulic control, would stop flowing. The stage of zero flow when measured in the field is usually the lowest ground elevation of a hydraulic control. Because hydraulic controls "migrate" with variation in discharge, measurement of SZF is difficult and is best done when flow is extremely low and water is not turbid.

✱ (constant in (Q=0) [illegible] equation

<u>Cross Section:</u> Two-dimensional section across a stream channel perpendicular to direction of the flow. Also called a transect (Fig. 1).

<u>Cross-sectional Area (A):</u> The area of the cross section containing water, normal to the direction of flow. Also called conveyance area. A = Depth*Width.

<u>Wetted Perimeter (P):</u> The distance along the bottom and sides of a channel cross section in contact with water. Roughly equal to width + 2 times the mean depth (Figure 1).

<u>Hydraulic Radius (R):</u> The ratio of the cross sectional area to wetted perimeter, R = A/P. For wide shallow channels, R approximates hydraulic depth. Also called characteristic length (L).

<u>Mean Velocity (V):</u> The mean rate of water movement or travel past a given place, should not be confused with discharge. The discharge in a cross section or cell divided by area of a cross section or cell, traditionally expressed as feet per second (fps). Mean column velocity is usually measured at 60% of water depth (measured from the surface) if less than 2.5 ft or averaged at 20% and 80% of water depth.

<u>Cell, Field Measurement:</u> An increment of width of a stream channel. Both field measurement cells and computational cells are used in PHABSIM. Field measurement cells are bounded by vertical lines in the stream (where depth and velocity measurements were made) that define the left and right edge of a cell from a headpin on the bank looking upstream.

<u>Cell, Computational:</u> An increment of width of a stream channel. The center of a computational cell in HABTAE/HABTAT is a vertical in the cell midway between field measurement cell boundaries and the computational cell extends both ways to the field measurement cell boundaries. The center of a computational cell in HABTAM/HABTAV is at a field measurement cell boundary and extends both ways to the verticals midway between field measurement cell boundaries.

<u>X,Y-coordinate:</u> For a cell, the X-distance is measured from a head pin to describe the cross section for an IFG4 data set. The Y-distance is the elevation of the stream bed at the X-coordinate.

<u>Hydraulic Slope (S_h):</u> The change in elevation of water surface between two cross sections, divided by distance between cross sections (Figure 2).

Bottom Slope (S_o): The change in average elevations of the bed between two cross sections, divided by distance between them (Fig. 2).

Energy Slope (S_e): Change in total energy (potential and kinetic) available, divided by distance between cross sections (Fig. 2). Energy slope cannot be measured effectively, but can be approximated with bottom slope.

Thalweg Slope: Change in elevation of the bed, measured at point of maximum depth (=thalweg depth) (y), divided by distance between cross sections.

Roughness (n): Coefficient (used in Manning's equation for computing average velocity of flowing water) of resistance to flow (energy loss) caused by particle or vegetative friction, material size, and channel features.

Velocity Adjustment Factor (VAF): The ratio of discharge for which velocities are being simulated to the sum of simulated cell velocities times cell areas. VAF's are used to adjust simulated velocities and test the accuracy of the simulation.

Conveyance Factor (CFAC): The conveyance factor describes the ability of a cross section or cross section cell to transport (convey) water downstream. The standard conveyance factor formula is (1.49 times A times R^2) divided by n.

Continuity Equation: Flow equals velocity time cross-sectional area. $Q= V*A$. Also referred to as flow balance and mass balance.

Bernoulli's Equation: (In the case of uniform flow) Energy balance. Conservation of energy. First law of thermodynamics.

Figure 1.

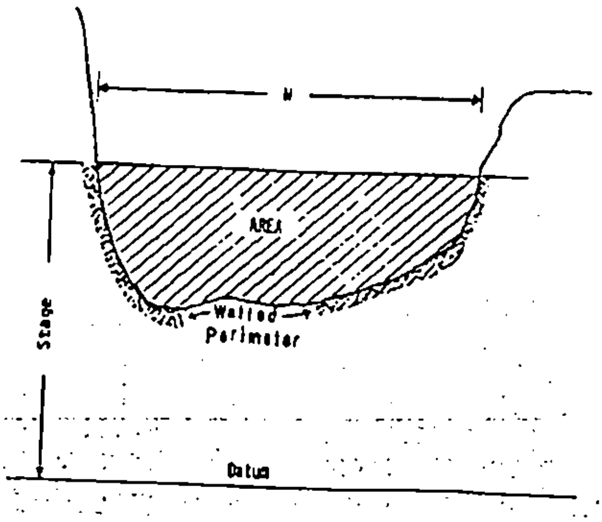
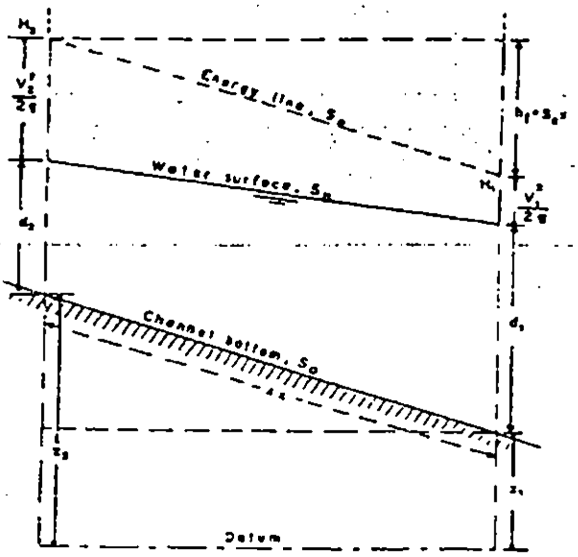


Figure 2.



CONCEPTS AND THEORY

Types of Flow: One set of classification for open-channel flow is derived from a consideration of spatial and time dependency.

A. Steady flow - Time Criteria
  1. Uniform flow
  2. Varied flow
    a. Gradually varied flow
    b. Rapidly varied flow

B. Unsteady flow - Spatial Criteria
  1. Unsteady uniform flow (rare)
  2. Unsteady flow (i.e., unsteady varied flow)
    a. Gradually varied unsteady flow
    b. Rapidly varied unsteady flow

Uniform Flow and Varied Flow: *Space as the Criterion.* Uniform flow by definition means that depth of flow is the same at every cross-section of the channel. Thus, hydraulic, energy, and bottom slopes are parallel. If flow is varied, depth of flow changes along the length of the channel. Varied flow may be either steady or unsteady. Since unsteady uniform flow is very rare, the term "unsteady flow" is used to designate unsteady varied flow exclusively. Varied flow is classified as either rapidly or gradually varied. The flow is rapidly varied flow if depth changes abruptly over a comparatively short distance: otherwise, it is gradually varied. Rapidly varied flow is manifest in an abrupt change in depth, such as observed in local phenomenon like hydraulic jumps and hydraulic drops. PHABSIM hydraulic models assume uniform gradually varied flow conditions predominate within the river.

Steady Flow and Unsteady Flow: *Time as the Criterion.* Uniform flow may be steady or unsteady, depending on whether or not depth changes with time. Flow in an open channel is said to be steady if depth of flow does not change or can be assumed constant during the time interval under consideration. The flow is unsteady if depth changes with time. Applications of PHABSIM in conditions other than steady flow should not be undertaken without involvement of a knowledgeable hydraulic engineer and an alternate method of hydraulic modeling should be considered.

Steady uniform flow is the fundamental type of flow treated in open-channel hydraulics. The depth of flow does not change during the time interval under consideration. This is one of the primary assumptions of hydraulic models used within PHABSIM and all reference to uniform flow in PHABSIM refers to this type of flow classification.

Unsteady uniform flow requires that water surface fluctuates from time to time while remaining parallel to the channel bottom. This condition is practically impossible to achieve even under laboratory conditions and will ot be considered further.

States of Flow: The state or behavior of open-channel flow is governed by effects of viscosity and gravity relative to inertial forces of flow. Depending on the effect of viscosity relative to inertia, flow may be laminar, turbulent, or transitional. The flow is laminar if viscous forces are so strong relative to inertial forces that viscosity plays an important part in determining flow behavior. In *laminar* flow, water appears to move in smooth inear paths. The flow is turbulent if viscous forces are weak relative to nertial forces. In *turbulent* flow, water moves in irregular paths. Between aminar and turbulent states there is a mixed, or transitional, state. The effect of viscosity relative to inertia can be represented by the Reynolds umber (Re).

The magnitude of *Re* is used to classify flow conditions as follows:

- *Re* is below approximately 500, flow is laminar;
- *Re* is between 500 and 2,000 flow is in transition; and
- *Re* is above 2,000 flow is turbulent.

e *Reynolds number (Re)* is defined as:

$$Re = \frac{VL}{vis} \tag{1}$$

ere:

V = mean velocity of flow
L = characteristic length (equal to hydraulic radius)
vis = kinematic viscosity of water

The effect of gravity upon the state of flow is represented by the ratio of inertial forces to gravity forces. The *Froude number (F)* is defined as:

$$F = \frac{V}{\sqrt{gD}} \qquad (2)$$

where:

V = mean velocity of flow
g = acceleration of gravity
D = hydraulic depth

When F is equal to unity, flow is defined as *critical*.

If F is greater than unity, inertia effects predominate, so flow has high velocity and is described as shooting, rapid, or torrential. This is referred to as *super-critical flow*. In super-critical flow conditions, hydraulic features upstream control water surface elevations.

If F is less than unity, gravity forces predominate, so flow has low velocity and is described as tranquil or streaming. This is referred to as *sub-critical flow*. In sub-critical flow, hydraulic features downstream control water surface elevation profile. Most instream flow studies are concerned primarily with sub-critical state of flow, although hydraulic simulations for recreational activities may deal with super-critical states of flow. In PHABSIM hydraulic simulations of water surface profiles within a river using step backwater modeling, sub-critical flow is assumed. WSP has the potential (although frequently not realized) to give the best water surface elevations under these conditions.

The combined effect of viscosity and gravity leads to definition of four types of flow in open channels if we ignore critical-transitional combinations, namely:

1) subcritical - laminar $F < 1.0$ and $Re < 500$
2) supercritical - laminar $F > 1.0$ and $Re < 500$
3) supercritical - turbulent $F > 1.0$ and $Re > 2000$
4) subcritical - turbulent $F < 1.0$ and $Re > 2000$

COMMONLY USED EQUATIONS FOR ANALYSIS OF OPEN-CHANNEL FLOWS

There are three major approaches to modeling open-channel flow in PHABSIM: 1) step backwater method (WSP program); 2) Manning's equation method (MANSQ program); and 3) empirical stage:discharge equation (IFG4 program).

CONTINUITY AND MASS BALANCE

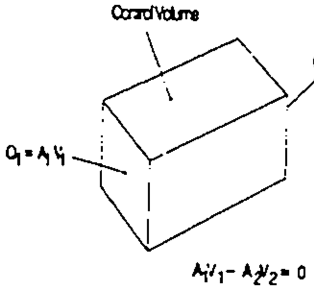
The water surface elevation in a stream defines cross-sectional area of flow. If velocity is also known, discharge can be calculated using the equation of continuity:

$$Q = AV \tag{3}$$

where:

Q = discharge
V = average velocity of flow through the cross section
A = area of cross section of flow

Under ideal conditions in which no gain or loss of flow occurs between two sections in a stream that defines a control volume, a Mass Balance is given by:



MANNING'S EQUATION

The Chezy equation was introduced in 1768 by a French engineer designing a canal for the Paris water supply. That equation is:

$$V = C\ (R\ S)^{1/2} \tag{4}$$

where:

C = square root of acceleration due to gravity divided by a constant
R = hydraulic radius
S = slope of energy grade line

In 1869, Ganguillet and Kutter published a rather complicated equation for C that received considerable popularity. Gauckler in 1868 and Hagen in 1881 arrived at the conclusion that the data used by Ganguillet and Kutter were fitted just as well by a simpler equation stating that C varies with the sixth root of R. According to Henderson (1966), in 1891 the Frenchman Flamant wrongly attributed this conclusion to the Irish engineer Robert Manning, and expressed it in the form:

$$V = \frac{R^{2/3}\, S_e^{1/2}}{n} \qquad (5)$$

Manning's equation in British units is expressed as:

$$V = \frac{1.486}{n}\, R^{2/3}\, S_e^{1/2} \qquad (6)$$

where:

V = mean velocity in channel, in feet per second
1.486 = English units correction (cube root of 3.28 feet per meter)
R = hydraulic radius, in feet.
S_e = slope of energy grade line.
n = coefficient of roughness, referred to as Manning's n.

By substituting into Q=VA, Manning's equation equivalent (English units) is expressed as:

$$Q = \frac{1.486}{n}\, R^{2/3}\, S_e^{1/2}\, A \qquad (7)$$

ENERGY BALANCE AND BERNOULLI'S EQUATION

In Manning's equation, the slope required as an input is the slope of the energy grade line. This slope is defined as the difference in total energy at two (or more) channel sections, divided by distance between them. The total energy at a channel section is found with the open-channel form of Bernoulli's equation:

$$H = z + d + \frac{V^2}{2g} \qquad (8)$$

where:

H = total energy head, in feet (meters).
z = elevation of the bed, in feet (meters).
d = average depth for section, in feet (meters).
V = average velocity in feet per second (meters per second).
g = acceleration of gravity, 32.2 ft/sec^2 (9.8 m/sec$_2$).

For practical purposes, it can be seen (Figure 2) that the terms z + d equal water surface elevation (WSL) for a given cross section. Referring to Figure 2, slope of the energy grade line is:

$$S_e = \frac{H_2 - H_1}{\Delta x} \qquad (9)$$

If the assumption is made that flow in the channel is uniform, then bed slope, hydraulic slope, and energy slope are considered equal. $S_o = S_h = S_e$. Therefore, this equation represents <u>Energy Balance</u> between two adjacent cross sections of the stream.

PREDICTING THE STAGE-DISCHARGE RELATIONSHIP

The determination of the relationship between stage at a cross section and discharge associated with that stage is <u>the first step in hydraulic calibration</u> and simulation phases of PHABSIM. The stage or water surface elevation is used for simulation in two ways: (1) depth distribution is found for each cross section by subtraction of bed elevations across the channel from the stage; and (2) stage identifies location of the free surface, and is used to establish boundaries for some of the equations that describe velocity distribution. If stage and bed elevation are known, depth may be determined at any location on the cross section.

Several approaches may be used in prediction of stage-discharge relationships. Approaches described in this section include: (1) use of Manning's equation when uniform flow is assumed (MANSQ); (2) calculation of water surface profiles under conditions of gradually varied flow (WSP); and (3) direct determination with varying numbers of measurements (IFG4 or STGQS4). These three approaches represent three main hydraulic modeling options within PHABSIM using the models MANSQ, WSP, and IFG4 or STGQS4. Detailed treatment on specific application of these models is presented later. The generalized concepts for each of these three approaches to determination of the stage-discharge relationships are considered next.

MANNING'S EQUATION ASSUMING UNIFORM FLOW CONDITIONS (MANSQ)

This approach can be used to determine the stage-discharge relationship for individual cross sections. The uniform flow assumption allows use of measured hydraulic slope instead of energy slope, since, by definition, they are equal. In addition, this approach assumes that flow variations caused by changes in channel configuration are negligible (i.e., no backwater effects). Generally, the more uniform the channel, the more reliable the results using this approach. As the channel becomes less uniform, reliability of the results deteriorates. The application of the MANSQ model in pools is generally problematic since pools are generally created by backwater effects of a downstream hydraulic control.

In this approach, Manning's equation is solved for n at one discharge, for which the following measurements must be made: (1) water surface elevation and discharge at the measured flow, (2) hydraulic slope; and (3) dimensions of the channel cross section. No velocities are required at cross-sections (except to obtain a discharge measurement).

The cross-sectional area and hydraulic radius are determined by cross-sectional measurements and stage. Manning's n may then be computed for the cross section by solving Manning's equation for n:

$$n = \frac{1.486}{Q} R^{2/3} S^{1/2} A \qquad (10)$$

Manning's n is then assumed constant in subsequent calculations where new stages are calculated for different discharges.

Typical values of Manning's roughness coefficient n in a natural river channel are given in Henderson (1966) as:

Clean and straight	0.025 to 0.030
Winding, with pools and shoals	0.033 to 0.040
Very weedy, winding and overgrown	0.075 to 0.150
Clean straight alluvial channels	$0.031\ d^{1/6}$

(d=D-75 {3rd quartile} size in ft)

The photographs given by Ven Te Chow in his books form a useful supplement to, or even substitute for, field experience.

WATER SURFACE PROFILES UNDER VARIED FLOW CONDITIONS (WSP)

In many cases, assumption of uniform flow cannot be made, either because of channel conditions or because of modeling requirements of the instream flow study. The computation of water surface profile is a means of more accurately determining the stage-discharge relationship where interactions between the water surface of adjacent transects are directly computed. While the computations required for calibration of this type of model are more tedious, several computer programs are available that are capable of rapid computation of the water surface profile.

The determination of water surface profile requires essentially the same kind of data as the previous approach. However, the computation procedure is much different. This approach determines energy losses between two cross sections under assumed conditions of depth and roughness. The following discussion of this method is very general. For specifics, see the references at the end of this chapter for introductory texts on open-channel flow. Given the discharge, elevation of the bed, distance between cross sections, and an assumed value for Manning's n, the computations follow this general sequence:

1. Starting at the downstream-most cross section, a water surface elevation is assumed or given. For the next section upstream, an elevation is assumed; this elevation will be verified or rejected on the basis of subsequent calculations.

2. The depth of flow is computed for corresponding water surface elevations.

3. The cross-sectional area is determined from channel dimensions and assumed water surface elevation.

4. The mean velocity is calculated using the continuity equation for the known discharge and cross-sectional area.

5. The velocity head ($V^2/2g$) is calculated. and total energy head determined by addition to the starting water surface elevation.

A separate set of calculations is then made using Manning's equation:

6. The hydraulic radius is determined for the cross section. using the above assumed water surface elevation.

7. The energy slope between adjacent cross sections is determined by:

$$S_e = \frac{n^2\ V^2}{2.22\ R^{4/3}} \tag{11}$$

where:

n = assumed value for Manning's n
V = mean velocity calculated in Step 4 above
R = hydraulic radius from Step 6 above

8. The friction loss between two adjacent cross sections is found by multiplying average energy slope by the distance between stations.

9. This friction loss is added to the computed total head at the first station. to give total energy head at the next upstream station. If the value obtained does not agree closely with that found in Step 5. a new water surface elevation is assumed and the process repeated until agreement is obtained.

10. Even though internal agreement may be obtained within computations. computed water surface elevations may not agree with those measured in the field. In this case. the value of Manning's n is changed. and the process repeated until energy-balance water surface elevations calibrate with observed water surface elevations.

11. Once calibration is achieved. Manning's n is assumed constant. and the flow profile computed for other discharges of interest. (If additional water surface and discharge measurements are available. Manning's n value can be varied as a function of discharge).

DIRECT DETERMINATION OF STAGE-DISCHARGE RELATIONSHIP (IFG4 or STGQS4)

One method of obtaining a relationship between stage and discharge is to measure the discharge at various stages from stage of zero flow to bank full and to develop an empirical regression equation relating discharge to stage. Water surface elevations (WSL's) from WSP are recommended for the calculations. In general. water surface elevations from WSP are recommended over those obtained from a stage-discharge relationship because of the variable location of hydraulic controls at different flows.

A stage-discharge relationship is influenced by a number of channel factors such as cross-sectional area, shape, slope, and roughness. The interaction of these factors control the stage-discharge relationship. If the stage-discharge relationship does not change with time, the control is stable and can be used without adjustment for changes over time.

The stage-discharge equation can be assumed to be of the form:

$$Q = a\ (WSL - SZF)^{b} \tag{12}$$

where:

Q = discharge
WSL = stage or water surface elevation
SZF = stage of zero flow
a = constant derived from measured values of discharge and stage.
b = constant derived from measured values of discharge and stage.

This equation can be transformed to a linear relationship between stage and discharge by taking the log of the equation. A simple linear regression is then *performed* to develop a predictive equation. To determine stage for any cross section at any interpolated or extrapolated discharge, stage is calculated directly from this empirical equation. An example of a measured stage-discharge relationship for Oak Creek near Corvallis, Oregon, is given in Figure 3.

VELOCITY-DISCHARGE RELATIONSHIPS

The second step in hydraulic modeling within PHABSIM involves <u>determination of velocity profiles</u> at each cross-section within the river. PHABSIM models velocities for single cross sections, and uses the results to represent stream segments. When taking mean column velocities, also take nose velocities and vice versa. This allows for a better job of simulating nose velocities or mean column velocities, respectively. If the velocity distribution is measured for each flow of interest, data can be used directly and no analytical procedure is needed to estimate the velocity distribution. This is being done more frequently with intensively studied and managed rivers. In most cases, only limited resources are available to do field work in any particular instream flow study; hence, estimates must be made of the velocity distribution at flows for which velocities were not measured.

Velocity predictions are made using techniques that are similar to those used to predict stage. However, for any discharge there is only one stage per cross section whereas velocity varies from place to place across each cross-section. Figure 4 illustrates two ways of expressing the velocity distribution in a channel. Figure 4a shows the distribution as a series of contour lines connecting points of equal velocity (real world). Figure 4b shows the velocity distribution as a series of mean velocities in a group of adjacent channel subdivisions or cells (PHABSIM world). The conceptualization of velocity distribution within the PHABSIM system is the type shown in Figure 4b. Essentially, each computational cell of a cross section is treated separately, with its own depth, substrate, and average velocity. Any number of subdivisions may be used to define the velocity distribution in this manner; the more computational cells per cross section, the more detailed the description of the velocity distribution.

In the following discussions, approaches to estimating the velocity distribution in a cross-section are described. The first section describes use of Manning's equation where no velocity measurements are made to calibrate the equation. The second section discusses calibration of Manning's n with a series of measured velocities at one flow. The third section describes a procedure using more than one set of measured velocities.

Figure 3

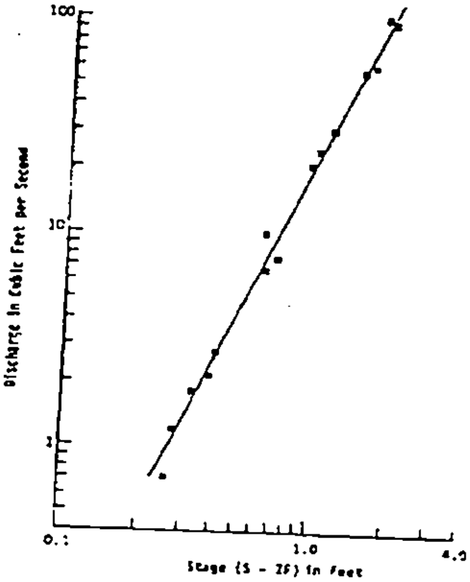
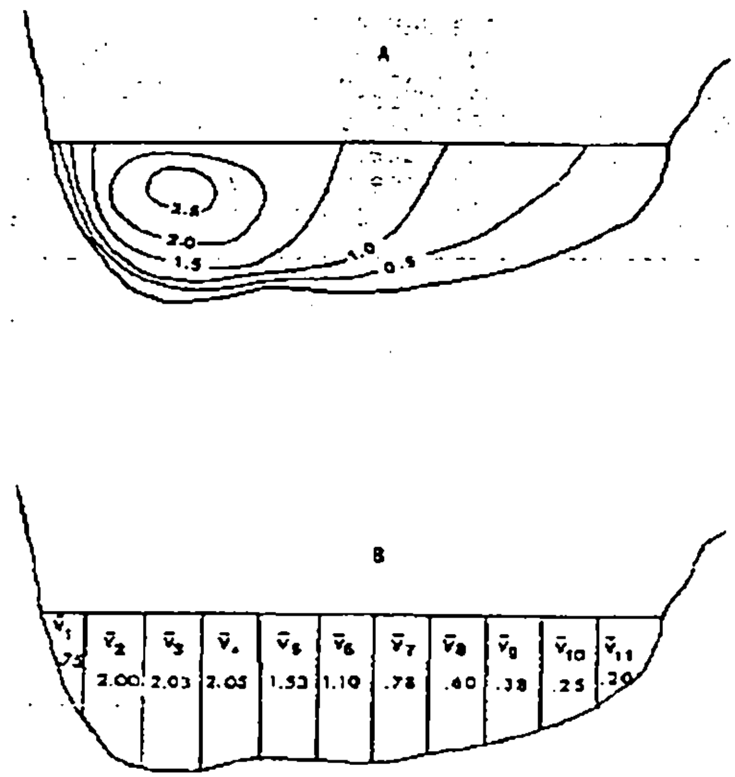


Figure 4



MANNING'S EQUATION WITH NO VELOCITY MEASUREMENTS

THIS METHOD IS NOT RECOMMENDED!

This approach requires the stage-discharge relationship to be known from some previous computation procedure. Other data requirements include dimensions of the cross section and slope (S_n if uniform flow assumption is made, S_e if gradually varied flow). A knowledge of roughness (Manning's n) for each cross section is also recommended. The Manning's n value is used as a velocity distribution factor for each cell of each cross section. This method is not recommended, but it may be used in cases where no cell velocities were measured. It is more accurate to measure a set of velocities for each cross section than to estimate n values.

The computation procedure is started by subdividing the cross-section into a series of computational cells, as shown in Figure 5. Each computational cell has geometric properties of cross-sectional area (a_i), hydraulic radius (r_i), and each has a roughness coefficient (n_i). The following assumptions are made to continue the computation procedure:

1. The slope is the same for all computational cells.

2. There is no slope of the water surface normal to direction of flow (i.e., no tilting across the channel). This is assumed by all of the hydraulic programs, except IFG4 option 18, which does not work with habitat modeling programs.

3. Each channel segment is trapezoidal (right angles at the water surface but not on stream bottom).

The mean velocity for each cell may be calculated from Manning's equation as follows:

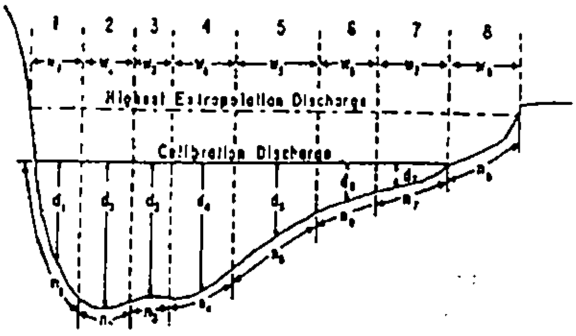
$$v_i = \frac{1.486}{n_i} r_i^{2/3} S^{1/2} \tag{13}$$

where:

v_i = mean velocity of cell segment.
r_i = hydraulic radius (a_i/w_i) for cell, based on stage as determined previously, and on dimensions of the cell.
S = slope, as previously described.
n_i = roughness coefficient for cell.

The calibration of this equation could be simplified considerably by assuming that the roughness coefficient is the same for every cell (i.e., $n_1 = n_2 \ldots = n_i = n_o$), where n_c is the roughness coefficient for the whole cross section as determined in computation of the stage-discharge relationship. The validity of this assumption depends on uniformity of the channel and channel materials, roughness of the banks, and so forth. In most situations, it will be apparent that assumption of constant roughness will not be true. In other cases, there will be cells that will be out of the water at the same time the calibration measurements were made (for example, segment 8 in Figure 5). Either situation may require an estimation of Manning's *n* for a particular channel segment.

Figure 5



MANNING'S EQUATION WITH ONE SET OF VELOCITY MEASUREMENTS

THIS IS THE CURRENT RECOMMENDED METHOD!

Referring to the cross section shown in Figure 5, suppose that in addition to slope, width, depth, and discharge, a measurement of velocity was made at each vertical column separating each computational cell. Such velocity measurements would be repeated for each cross section. Each channel segment could then be assigned an average velocity, calculated from the measured velocities on either side of the segment. In this case, roughness for each cell may be calibrated using Manning's equation:

$$n_i = \frac{1.486}{V_i} D_i^{2/3} S^{1/2} \tag{14}$$

The roughness can then be used in simulation of velocities at other flows. This method provides a more accurate prediction of the velocity distribution at each cross section.

DIRECT DETERMINATION OF VELOCITY DISTRIBUTION

THIS METHOD IS NOT RECOMMENDED!

Figure 6 shows a cross section in which the velocity of each computational cell is determined at each of three different discharges. The average velocity for any computational cell where two or more such velocity measurements have been made, may be related to total discharge:

$$v_i = a_i\, Q_i^{b_i} \tag{15}$$

where v_i is mean velocity of the i-th channel segment when total discharge of the stream is Q. The constants a_i and b_i are obtained by fitting a least squares regression (after linearization of the equation by taking the log), to two or more velocity discharge data pairs. For discharges not measured, v_i is found by applying empirical constants a_i and b_i to discharge for which an estimate of v_i is desired.

The concept that average velocity in a cross section is related to the discharge by the equation $v = a\,Q^b$ appears to be well accepted in the literature (Park, 1977). The assumption is made that average velocity in a computational cell is also related to total stream discharge by an equation of the same form. This method provides a less accurate prediction of velocity distribution at each cross section.

VARIABLE ROUGHNESS AND SLOPE

An important consideration in application of these techniques to define or model the relationship between discharge and water surface or velocity is that these relationships can change as a function of discharge. Figure 7 shows the relationship between Manning's n as a function of discharge and Figure 8 shows the relationship between energy slope (S_e) and discharge at Oak Creek, near Corvallis, Oregon. It is apparent that the collection of a single data set at any given discharge may not provide an adequate representation of these relationships over a very wide range of target discharges. We will address these issues further during the presentation of specific hydraulic models.

The default slope value is 0.0025 and the default Manning's n value is 0.06.

Figure 6

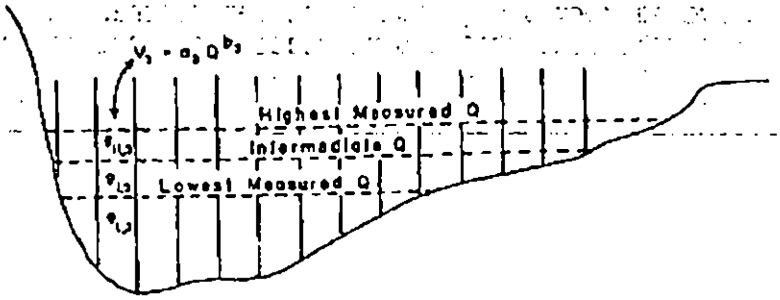


Figure 7

WSP CALIBRATION
Effect of Discharge on Roughness

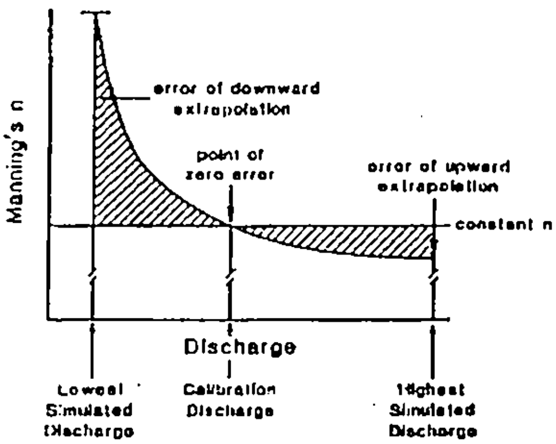
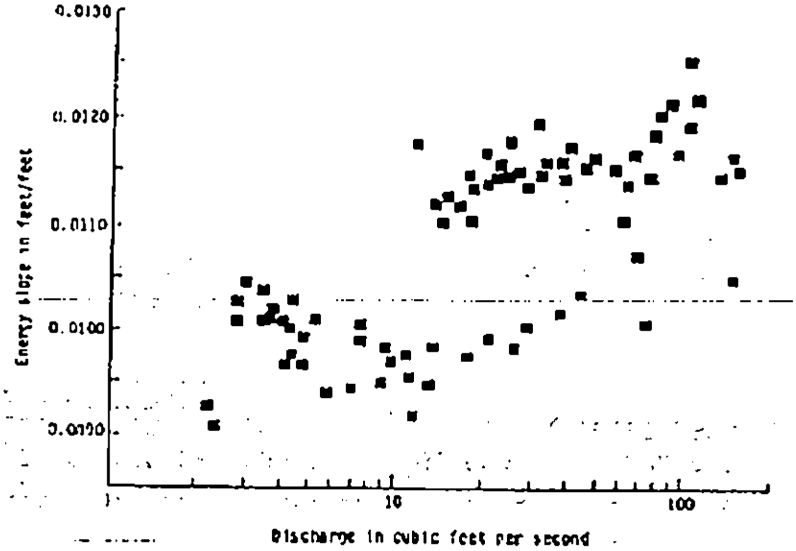


Figure 8



DETERMINATION OF STAGE OF ZERO FLOW

An important element in use of the PHABSIM hydraulic models concerns the proper designation of stage of zero flow (SZF). The SZF is important since it is used directly in computations of stage-discharge equations and can dramatically alter hydraulic simulation results. Unfortunately, most individuals initially have some trouble with proper selection of SZF. The easiest way to determine SZF is to plot thalweg elevations at each cross section, moving in an upstream direction as shown in the example in Figure 9.

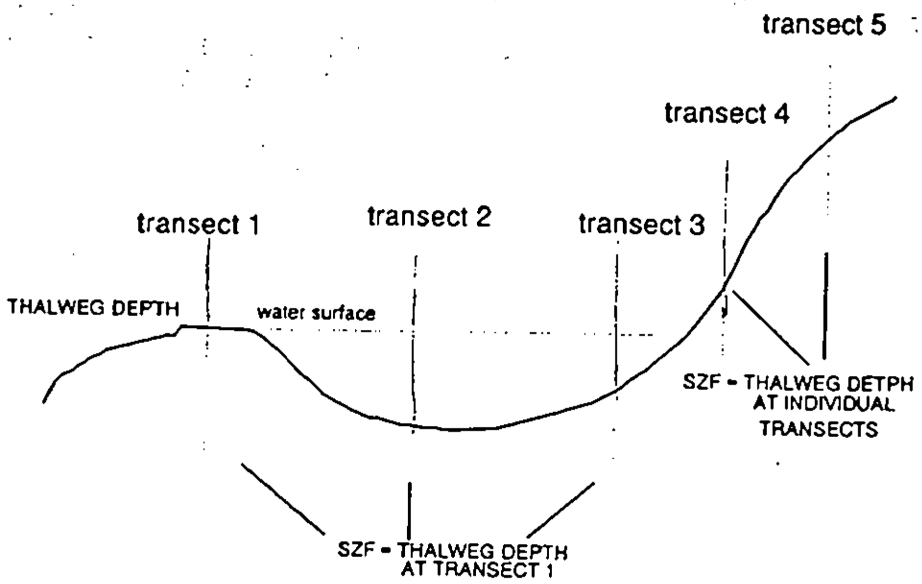


Figure 9. Example determination of Stage of Zero Flow among transects.

As can be seen SZF at transect 1 corresponds to thalweg depth at this section and will control the surface of the stream when the water level drops to this point. Flow will cease, hence the concept of the stage at which zero flow will occur. It should also be apparent that this same SZF should be used at transects 2 and 3. The individual thalweg depths should be used at the remaining transects as indicated.

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CHAPTER 3: SIMULATION OF WATER SURFACE ELEVATIONS

Introduction

Available techniques used to simulate water surface elevations include use of an empirical stage-discharge equation based on measured data, and empirical use of Manning's equation. In a third technique that is more theoretically based, energy loss between cross sections is determined using Manning's equation and water surface elevations calculated using the standard step backwater method of determining water surface profiles in rivers. Each of these approaches and associated programs in PHABSIM are briefly summarized below.

IFG4.	The IFG4 program uses a stage-discharge relationship to determine water surface elevations unless they are supplied in the input data set. When using the stage-discharge relationship, each cross section is treated independently of all others in the data set.
WSEI4.	Enters x,y coordinates, then STGQS4 takes IFG4 data set and uses a stage-discharge relationship to determine water surface elevations. STGQS4 uses a stage-discharge relationship to calculate water surface elevations based on calibration flows. The elevation data are usually added to an IFG4 data file.
MANSQ.	The MANSQ program uses Manning's equation to calculate water surface elevations. The model is calibrated using one set of water surface elevations. The calibration coefficient is Beta. Each cross section is simulated independently of all other cross sections in the data set.
WSP.	The Water Surface Profile Program (WSP) uses the standard step backwater method to determine water surface elevations. In the process, velocities are calculated that may be used in habitat modeling if velocity measurements needed to calibrate IFG4 are not available. The model is calibrated to measure water surface elevation by adjusting Manning's roughness given in the data set.

In the following section each of these programs are considered in some detail. Topics related to divided flow situations and using multiple hydraulic models will be covered in the next chapter.

Stage-discharge relationships - IFG4 and STGQS4

IFG4 is one of the easiest programs to use and is favored by consultants. The stage-discharge relationship requires at least three measured water surface elevations to be legitimate. Many things at any given cross section may invalidate a strict linear relationship including overbank conditions, major obstructions to higher flows, complex channel configurations, and backwater effects from a downstream hydraulic control.

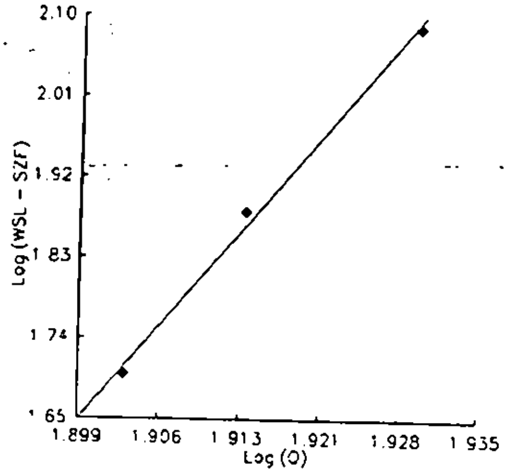


Figure 14. Example stage-discharge regression in IFG4. It is more desirable to calculate using logarithms, but label the axes with untransformed flow and stage values.

Both the IFG4 and STGQS4 programs can be used to derive the stage-discharge relationship at a cross section of the stream. The STGQS4 program uses the same computational procedures as the IFG4 program and transfers resulting predictions of the stage-discharge relationship to the WSL data lines in the corresponding IFG4 data set. The basic relationship is given by the following equation:

$$WSL - SZF = a\,Q^{b} \qquad (16)$$

where:

WSL = Stage or water surface elevation
SZF = Stage of zero flow
Q = Discharge
a,b = regression coefficients

Using a log transformation for this equation, results in a linear function of the form:

$$Log\,(\,WSL - SZF\,) = Log\,(a) + b * Log\,(Q) \qquad (17)$$

where water surface elevation has been adjusted by stage of zero flow (SZF). Given two or more measurements of the stage-discharge relationship at a cross section, the above equation is then solved for coefficients a and b that then serves as the basis upon which predicted stage is computed for any specified discharge. Figure 2 is an example of a regression fit for three stage-discharge pairs using the above equation.

Alternatively, the stage-discharge relationship shown in Figure 2 can be derived external to the IFG4 program using STGQS4, MANSQ, WSP, HEC2 or other appropriate programs. Assuming that an appropriate stage-discharge relationship has been developed, distribution of depths across the stream is obtained implicitly within the program by subtracting known ground/stream bed elevations at each vertical from predicted water surface elevation at the transect at the specified discharge.

MANSQ Program

MANSQ uses Manning's equation to calculate the water surface elevation at a cross-section. The program requires one set of water surface elevation-discharge pairs to calibrate the model for each cross-section. Each cross-section is assumed to be independent.

Manning's equation can be written in the form:

$$Q = \left[\frac{1.49}{n} * S^{1/2}\right] * A * R^{2/3} \tag{18}$$

In most applications of MANSQ there are two unknowns: the roughness n and the energy slope S. These two unknowns can be combined using a Water Transport Parameter (K) defined in the formula:

$$Q = K\ A\ R^{2/3} \tag{19}$$

and the value of K (a function of n and $S^{1/2}$) is determined from one set of discharge-water surface elevation pairs. The program also uses the equation:

$$K = K_o\left(\frac{Q}{Q_o}\right)\beta \tag{20}$$

$$K = k_o\left(\frac{R}{R_o}\right)\beta \tag{21}$$

where:

subscript o refers to calibration values and the β's are coefficients supplied by the user

The calibration of the MANSQ program involves a trial and error procedure to pick a β value that minimizes error between predicted and observed water surface elevations at each transect. The channel conveyance factor (CFAC) from REVI4 works out to be an excellent starting estimate of β (range is 0.0 to 0.6 with 0.15 not bad). If more than one set of discharge-water surface elevation pairs are available, the value of β can be determined as part of calibration of the model. The MANSQ program calculates average velocity in the channel and should not be used to simulate individual cell velocities. The IFG4 program should be used to simulate individual cell velocities.

WSP Program

The purpose of the WSP program is to simulate water surface elevations in the longitudinal direction along a stream. Velocities can also be simulated across the cross section. The calculation of water surface elevations start from a known water surface elevation at the most downstream cross section and uses the standard step backwater method to calculate water surface elevation at the next upstream cross section. The water surface elevation for the most downstream section must either be supplied by the user or the energy slope at the cross section must be given. If the slope is given, water surface elevation is calculated using Manning's equation. The Manning's roughness must be supplied for each cross section and may be varied either in the longitudinal or transverse directions as necessary and appropriate. The calibration data set is used to select roughness values that cause calculated water surface elevations to match as close as possible to the measured water surface elevation profile. If roughness is varied in the transverse direction (i.e. across the cross section) then the velocity distribution can all be matched to the observed velocity distributions. This method is not recommended.

In many cases only one set of velocities and water surface elevation measurements are available to calibrate the WSP model and most often the downstream transect is located at a hydraulic control. Water surface elevation is used in the calibration phase to obtain the energy slope at this transect. This slope is then used to determine initial water surface elevation for all discharge of interest. The WSP model is calibrated by adjusting roughness in Manning's equation. In the case of variable roughness across the cross section, Manning's equation is written as:

$$Q = \sum_{i=1}^{ncells} \frac{1.49}{n_i} * r_i^{2/3} * a_i * S^{1/2} \qquad (22)$$

where:

Q = total discharge at cross section
ncell = total number of cells across the cross section
n_i = roughness at cell i

r_i = hydraulic radius of cell i = depth of cell i
a_i = area of cell i
S = energy slope at the cross section

As was noted in the previous chapter, roughness varies as a function of the discharge. The WSP model will allow computation of the change in roughness as a function of discharge by using roughness multipliers. The roughness multipliers are used to adjust all the roughness in the cross section at the specified discharge using the following equation:

$$n_{iq} = n_{ic} * M_q \tag{23}$$

where:

n_{iq} = Roughness in cell i at a discharge of Q
n_{ic} = Roughness in cell i computed at the calibration discharge
M_q = Roughness multiplier at discharge Q; equals the Water Transport Parameter at the calibrated discharge divided by the Water Transport Parameter at any given discharge.

The value of the roughness multiplier M_q can be different for each discharge and will adjust the roughness for every cross section in the study reach at the specified discharge. Alternatively, we can rearrange Manning's equation to give hydraulic radius and area product terms as the independent variable:

$$A * (R)^{2/3} = \frac{(Q * n)}{(1.49 * S^{1/2})} \tag{24}$$

where:

A = Area of cross-section
R = Hydraulic radius
Q = Discharge
n = Manning's n
S = Slope

If we assume that roughness, n, and energy slope, S, are constant for all stream flows, then hydraulic radius (R) may be calculated using the results from calibration of the WSP program. Given the shape of the cross section, water surface elevation may be calculated because the term $AR^{2/3}$ is a unique function of the water surface elevation. Let K be defined as:

$$K = \frac{(1.49 * S^{1/2})}{n} = \frac{Q}{A * R^{2/3}} \tag{25}$$

Therefore, if the relationship between K and Q is known, then water surface elevation may be calculated. Also the value of M_q can be considered a way of adjusting slope as well as roughness. In many cases the USGS discharge measurement data can be used to derive an approximation of the function for K in the above equation by making the assumption of constant slope. An example of the determination of roughness multipliers is given in Appendix A of Information Paper 19.

Theory of WSP program

The WSP model is a water surface profile program that provides very detailed depth and transverse velocity information. The model can be used to predict the horizonal distribution of depth and mean column velocity over a range of stream flows with one set of field data. The objective of this type of hydraulic simulation is to be able to predict how depth, velocity, and widths vary for each cross section over a range of simulated discharges. Specific hydraulic relationships between physical channel and discharge must be met to evaluate these changes in reference to a stream study segment.

These relationships are defined using concepts of mass balance (continuity) and energy balance. The following example illustrates the step backwater computational process and introduces the relevant equations. In the example, a two cross section case will be described. When more than two cross sections are involved the process is repeated step-wise upstream; hence, the term step backwater. Note: For ease of presentation here, velocity, area, and flow variables are generally discussed for tranquil flow and for the entire cross section rather than for multiple cells in each cross section. For multi-cell cross section, certain computational details differ. The procedure calculates both a flow balance and an energy balance between the two cross sections.

The flow balance is calculated using the continuity equation:

$$Q_2 = Q_1 + \Delta Q \qquad (26)$$

where:

$Q_{1,2}$ = flow at each cross section as specified by the user
ΔQ = specified change in flow (usually zero) between sections

The velocity is calculated using the following equation:

$$V_i = \frac{Q_i}{A_i} \qquad (27)$$

where:

V_i = velocity at a cross section i
A_i = area of cross section i
Q_i = flow through cross section i

The energy balance is calculated using:

$$H_2 = H_1 + \Delta H \tag{28}$$

where:

$H_{1,2}$ = total energy at each cross section
ΔH = total energy losses as water moves downstream

The total energy value of the stream at a given cross-section is derived from the Bernoulli equation (Chow 1959).

$$H = z + d + \frac{v^2}{2g} \tag{29}$$

where:

z = elevation of channel bottom
d = depth of water
$v^2/2g$ = energy component due to flow velocity (called velocity head)
v = mean column velocity of water
g = gravitational constant

Between two points on the stream the Bernoulli equation can be written as

$$z_1 + d_1 + \frac{v_1^2}{2g} = z_2 + d_2 + \frac{v_2^2}{2g} - losses \tag{30}$$

This equation shows the net effects of energy. Effects due to change in bed elevations, depth and velocity are accounted for by losses accumulated between cross sections.

A third equation is used to relate energy and flow values so the procedure may cross check between flow and energy balances. Using user defined values of discharge (Q), roughness (n), calculated values for area (A) and hydraulic radius (R), Manning's equation is used to define the energy slope S_{ei}:

$$S_{ei} = \left[\frac{Q_i}{R_i^{2/3} * A_i} * \frac{n_i}{1.49}\right]^2 \tag{31}$$

where:

Q_i = discharge (cfs)
n_i = roughness coefficient

A_i = cross-section area (ft^2)
R_i = hydraulic radius (ft), e.g., area divided by wetted perimeter
S_{ei} = energy slope (subscripts refer to any cross section i)

Manning's equation is empirical. The roughness coefficient n is used to quantitatively express the degree of resistance to flow of the channel. The value of n is an indication of roughness of the sides, bottom, and other irregularities of the channel profile. The value is used to indicate the net effect of all factors of water downstream. The roughness coefficient is inversely proportional to velocity and strongly affects the velocity calculated by the WSP program.

Several basic assumptions are made in development of the water surface profile. These include assumptions that steady flow condition exist during the period field measurements were made and that boundary conditions remain rigid.

The basic step-backwater approach to compute water surface profile proceeds as follows:

1. Starting at the farthest downstream cross section, a water surface elevation ($WSEL_1$) is taken from user-supplied values or calculated from the user-supplied energy slope calculated from Manning's equation.

2. The energy slope for cross section 1 (S_{e1}) may be calculated from Manning's equation if water surface elevations are supplied or may be used directly if energy slopes are supplied. (Values of A, R, and V are determined from channel geometry, WSEL, and flow.)

3. The water surface elevation at the next cross section ($WSEL_2$) is estimated by projecting S_{e1} upstream the distance (L) between the two cross sections.

4. The energy slope at cross section 2 (S_{e2}) is calculated using Manning's equations and an average slope for the section is determined from

$$S_a = function(S_{e1}, S_{e2}) \tag{32}$$

5. Flow and energy balances at the two cross sections are performed using

$$Q_2 = Q_1 \tag{33}$$

and

$$H_2 = H_1 + S_{eL} + (other\ losses) \tag{34}$$

where:

$Q_1 = Q_2 =$ steady flow at both cross sections
$H_1, H_2 =$ total energy at both cross sections
$S_{eL} =$ energy losses over the distance L

Other losses such as expansion and eddy losses are calculated within the program.

6. The water surface elevation at the second cross section is calculated by removing the velocity head from the total energy head yielding:

$$WSEL_2 = H_2 - \frac{V_2^2}{2g} \tag{35}$$

7. The $WSEL_2$ values from steps 3 and 6 are compared and a numerical technique is used to adjust the estimated $WSEL_2$ values.

8. Steps 3 through 8 are repeated until there is close agreement between estimated and calculated water surface elevations.

9. The entire process is repeated for cross sections 2 and 3, 3 and 4, and so on until all cross section are processed.

A user should note that the computed water surface elevations may not agree with those measured in the field even though internal agreement may be obtained within the computations. In this situation, the value of Manning's n is changed by the user and the program rerun until the energy-balanced water surface elevation calibrate with observed water surface elevations. After calibration is achieved, Manning's n is assumed constant and the flow profile is computed for other discharges of interest.

The basic step-backwater procedure works well when discharges computed for the transects are in close agreement. The WSP program utilizes a method of discharge balancing to compute water surface elevations and velocities. When the user specifies a calibration discharge the program assumes that each cross section will convey that same flow. However, if computed discharge is different from specified discharge, the error may be transferred to adjacent cross section. If any errors are made in initial discharge measurements, the calibration of the model will be extremely difficult and may be in error.

The problem of being unable to calibrate is symptomatic of several potential sources of error:

1. Unsteady flow (flow was not the same at each cross section because it changed over the measurement period);

2. An error in stage measurement(s): and

3. Multiple errors in velocity measurement.

<u>Calibration of a WSP data set</u>

The objective in calibrating a water surface profile is to have calculated water surface elevations and mean column velocities for the input discharge match those actually measured in the stream. This process is achieved in two stages. The first step is to match predicted water surface elevation with the water surface elevation measured at each transect. The second step is to match predicted mean cell velocities with corresponding measured velocities across each transect. Unfortunately, calibration to velocities often has an influence on predicted stage; therefore, this calibration process must sometimes be iterated several times. Under current accepted practice, the IFG4 program is used in all velocity calibrations and simulations and use of WSP for this purpose is strongly discouraged. Note that the U.S. Geological Survey gauging station criteria accepts within plus or minus 5%.

Both calibration stages involve modification of roughness coefficients for each transect. Normally an increase in roughness coefficients increases predicted water surface elevation and reduces velocity. Decreasing Manning's n usually reduces predicted water surface elevation and increases velocity. However, from analysis of Manning's equation it can be seen that the potential exists for some unexpected results.

$$V = \frac{1.49}{n} R^{2/3} S_e^{1/2} \tag{36}$$

A progressive upstream increase in value of n sometimes has the effect of significantly increasing slope (S_e) and slightly reducing hydraulic radius. The effect is that the larger product of these two terms offsets the increased resistance to flow, which results in an increase in Velocity (V) rather than the expected decrease. This effect appears to happen more frequently for increasing n than the opposite effect when decreasing n. Although this phenomenon does occur occasionally, it is less likely that decreasing n will result in a decreased velocity.

The ability to calibrate a stream section to the precision required by the model will vary with hydraulic characteristics of the stream. Steep, rough streams will exhibit large fluctuations in water velocities and water surface elevations and will be difficult to calibrate. Conversely, slow moving streams will have few hydraulic fluctuations and may be easier to calibrate. Normal precision standards are to keep the predicted stage within ± 0.1 ft of measured stage <u>and</u> keep predicted velocities within ± 0.2 feet/sec of measured velocities ; we can generally do a lot better. **We can get to within 0.01 to 0.05 feet in the water surface elevation calibrations.** Investigator must be aware that specific situations may require establishment of more lenient or strict standards.

With these considerations in mind and the input file checked for data entry and measurement errors, the data set can be calibrated to water surface elevation at each cross section. This is accomplished by adjustment of the n values for all cells in each cross section until close agreement is achieved between calculated and observed water surface elevations. Adjustment of n values for a cross section can be approximated using:

$$= n * \frac{WSEL_o}{WSEL_c} \qquad (37)$$

where:

$\acute{n}$ = new Manning's n value
n = previous roughness value
$WSEL_c$ = observed water surface elevation
$WSEL_c$ = Calculated water surface elevation

This use of a uniform n value for each roughness cell in a cross section will usually not produce the same velocities as were measured in each cell. Since the IFG4 program should be used later for velocity calibrations, this is not of concern.

Hydraulic Controls

Transect selection for a stream study segment should definitely start and preferably end at hydraulic controls if at all practical. Calibration is considerably easier and better when starting and ending transects are located at hydraulic controls within the study segment. It is frequently possible to alter the water surface profile through an entire stream segment simply by modifying roughness of the downstream control. One overriding principle of the WSP model is that the most downstream transect must be on a control and all other controls in the stream segment must also be defined by a transect.

The first problem usually encountered is that the most downstream transect is not a control. The next problem occurs when a control in the middle of a stream segment has been missed in the field analysis. Another factor that occasionally causes calibration trouble is when the last cross section (most upstream one) is not on a control. This causes problems when the approach to an upstream control is steep and it becomes difficult to calibrate WSP when the last cross section is in a pool. It is very difficult to impose a sharp break in hydraulic slope when no upstream control is given as a reference point because the WSP program calculates slopes both downstream and upstream of a section and averages them for an estimate of slope at a section. Typically, predicted water surface elevations in upstream pool areas will be too high and the only way to bring them down is to use ridiculously small values of N. This problem is symptomatic of a rapidly varied flow situation where WSP should not be used.

One technique that can help solve the problem is to establish a bogus control section at the upper end of the study segment. Quite simply, this means that coordinates of the previous control are reproduced and given a bit more elevation than the previous control. This new section is then placed an appropriate distance upstream from the pool section. Sometimes the field crew will miss the downstream control and the control between a pool and some upstream feature. This is very similar to the previous problem and the solution is also similar. With this type of problem, elevation change between the pool and the control is large and the resulting predicted water surface elevation over the control is too low.

Usually the data analyst will be unaware of this problem in early stages of calibration. The symptom that one should look for is the need for very high n values at a control section to get predicted water surface elevation high enough. Usually a new transect positioned within the steep approach section will eliminate the problem. To determine coordinate elevations and stationing for this artificial transect, we normally average corresponding elevation from downstream and upstream transects and position the artificial transect halfway between.

The user may be alarmed at the idea of adding data to get a model to perform. These artificial transects are used to obtain agreement between predicted and measured values without resorting to equally artificial modifications of Manning's n. These artificial transects can be completely eliminated from the habitat programs by utilizing reach length weighting options in MODRLW that changes the TAPE3 file. This is accomplished by a change in upstream weighting of the new transect to 0.0. The net result is that the habitat programs will ignore the artificial transect in the analyses.

Divided Flow

Calibration of the WSP model can be difficult when flow splits into two or more channels. There are two generic types of problems presented by divided flow. The first, and most common, is equalization of water surface elevations on both sides of a flow division. The most common cause of this problem is crossing an island with one straight transect when a dogleg transect should have been used. By their very nature, islands rarely have the same bed and water surface elevation at equidistant points along the bank. Ideally, the transect should have crossed the island with a dogleg in order to obtain an equal water surface profile on both sides of the island. In braided channels, this will be the rule rather than the exception.

The two elevations may be averaged if the discrepancy between two water surface elevations is small compared to the difference in elevations between transects. However, if the discrepancy between water surface elevations is large, bed elevations of the smaller channel may be raised or lowered a distance equal to the difference in water surface elevations. If either of these options is not acceptable to the user, flow may be partitioned through each of the channels and each channel then calibrated as if it were a separate stream.

Flow partitioning is a necessity when the channel around one side of an island is much longer than around the other side. When the length of one channel exceeds the length of the other by a factor of 1.5 or more, flow partitioning should be considered. In essence, flow partitioning involves breaking up total discharge of the stream into component discharges for each channel. The program is calibrated for each channel at the component discharge as if it were a separate stream. At the calibration discharge this is a relatively easy procedure because field notes contain all the information needed to break out component discharges. The problem arises when alternative stream flows are modeled. At discharges other than the calibration discharge, proportion of the total flow carried by either channel changes as a function of total discharge. The process of flow partitioning is very difficult. It is advisable to consult an experienced hydraulic engineer before attempting analysis.

The problem is to determine component discharges at a range of unobserved flows so that a rating table can be built. This is done by first calibrating component channels as measured; then for some unobserved total discharge, component flows for each side channel are split out by estimation and run individually through the model. The energy loss between two channels must be the same for water surface elevations to equalize at the head of the island. The two component flows giving the same energy loss for both channels, which equals total flow in the channel, are the proper component flows. Such ratings can be built empirically.

Discharge Balancing

The above procedure works well when there is good agreement between computed discharges for all transects. However, errors in discharge measurements will result in calibration difficulty and error. This problem is due to a procedure used in both WSP and IFG4 called discharge balancing. Discharge balancing means that if 100 cfs is entered on the QARD card, it is assumed that each cross section is conveying 100 cfs. Suppose that one of the cross sections has a computed discharge of 150 cfs instead of 100 cfs. In this instance, it will be impossible to match all measured velocities without inducing an error in predicted stage. In fact, if velocities are matched to the detriment of the stage, it is likely that the error will carry over to adjacent transects. Therefore, an important first step in this instance is to isolate and correct the error.

This problem is symptomatic of several potential sources of error: (1) unsteady flow; (2) an error in stage measurement; (3) multiple errors in velocity measurements; (4) the basic difficulty in obtaining consistent discharge measurements in complex channel geometries with turbulent flow characteristic of most natural river systems. In the latter case, one is left with the obvious gap between reality of the natural world and the simplistic view taken by available modeling choices.

Unsteady flow can be determined by comparing discharges computed for all cross section.--If the discharges progressively increase or decrease, flow may be unsteady. If no pattern emerges, the investigator should check his equipment and transect location. Assuming that flow is steady, it is possible to isolate and correct the problem by checking stage and velocity data. Unsteady flow can also be determined from cross section staff gage readings. The best practice is to take staff gage readings at the start and end of each set of cross section velocity measurements to ensure ability to calibrate the model if unsteady flow occurs. If the gage reading is the same for all cross sections, flow is steady. It is imperative that gage readings be recorded in order to quantify unsteady flow condition.

It is relatively unusual for a surveying crew to obtain a bad reading on water surface elevation. However, it is not uncommon for the back sight reading to be incorrectly recorded or for a mistake in arithmetic to occur in computation of instrument height or water surface elevations. Gross errors should have been detected in water surface calibration. However, subtle but systematic errors may be found by comparing cross section survey notes with the stream gaging notes. You should come fairly close to obtaining the surveyed bed elevation by subtracting measured depth form given water surface elevation. There will be errors in the comparison, usually on the order of ± 0.1 to 0.2 ft. However, error should be random--some bed elevation too high, some too low, and some right on. If you find that bed elevations computed by subtracting depth from stage are consistently low, it is likely that water surface elevation is too low. The converse is also true. If you detect an error in measured stage, you should correct the error by raising or lowering the measured stage by the average bed elevation error as previously computed. Then, you should recalibrate the model to the new set of water surface elevations before proceeding on to velocity calibration.

The most common violation of the continuity equation is poor quantity stream gaging. The source of error ranges all the way from complexities of the channel to poor field work. In any event, by the time field notes are in hand, it is usually too late to remedy the problem by re-measurement. You should first check velocities in the field notes to make sure one or more mistakes have not been made in recording velocity. Be sure to take and record staff gage readings immediately before and after taking hydraulic measurements.

If all of the velocities are properly recorded, recheck the relationship between depth and bed elevation. If computed discharge is too high, it could be caused by an overestimation of cross-sectional area. Try re-computing the depths by subtracting bed elevations from stage. Then re-compute discharge using these computed depths. If re-computed discharge converges with calibration discharge, it may be assumed that the velocities are probably correct.

Usually, bad stream gaging is a result of poor estimation of mean column velocities. If not, errors may be detected in stage or bed elevations. If there are no random, gross errors in any single velocity measurement, it is probable that the error is a cumulative velocity measurement error.

Occasionally a run will be made where both water surface elevations and velocities will be higher than those measured. If this happens across all transects, too large a flow has been entered on the QARD card. Conversely, if all water surface elevations and velocities come out too low, the problem can be rectified by increasing discharge on the QARD card.

CALIBRATING WSL'S WITH MULTIPLE DATA SETS

Multiple Water Surface Elevations and Discharge Measurements

In those instances where multiple WSL and discharge measurements are available, one has several choices to accomplish calibration of WSL's.

IFG4 or STGQS4

The use of multiple stage-discharge data sets is required to calibrate IFG4 models. STGQS4 models have already been discussed. In practice, the STGQS4 model is used to develop stage-discharge relationship. Resulting water surface elevations for flows to be simulated are entered on WSL data lines of the IFG4 data file and velocity calibrations are accomplished.

WSP with multiple data sets

The WSP program can be used in those instances where multiple stage-discharge relationships are available. The general approach to calibrate the WSP model is given below.

1) Calibrate WSP for one set of stage-discharge data by adjusting n values until agreement between predicted and measured WSL profile is obtained. The set of stage-discharge data you use is somewhat subjective, but the highest flow is generally recommended as a starting point.

2) Once the data set has been calibrated to the high flow data set, add additional calibration flows to the data set with all roughness multipliers on the QARD lines set to 1.0.

3) Re-run the WSP data set and compare predicted WSL at the other calibration flows. Adjust both roughness multipliers on the QARD for the new calibration flows until agreement between predicted and observed water surface elevations are obtained.

4) Use the STGQS4 program or MANSQ program to develop stage-discharge relationship at the <u>downstream-most</u> transect.

5) Plot the roughness multiplier versus calibration discharge on log-log paper (see attached example) to develop a relationship between discharge and roughness multipliers.

6) Modify the WSP data set to add all flows of interest on the QARD lines. The flows on the QARD lines must also contain associated water surface elevations associated with the downstream-most transect. These WSL's are derived from the stage-discharge relationship found in step 4 above. Use measured WSL at the calibration flows and WSL from step 4 for other flows. Add roughness multipliers developed in step 5 for all flows of interest. One should recognize that the roughness multiplier is 1.0 for the flow used as the initial calibration of WSP.

7) Run the WSP program and transfer resulting stage-discharge data on the <u>TAPE3</u> output to the WSL data lines in the IFG4 data set and proceed with velocity calibrations.

MANSQ with multiple data sets

The MANSQ program can also be used with multiple stage-discharge data sets in a manner similar to the WSP program.

1) Review the REVI4 output using the IFG4 data set with all measured stage-discharge data sets for the regression equation between discharge and the CFAC term (i.e., the exponent) for all transects. Use this value as the starting β coefficient for each transect.

2) Construct a MANSQ data set using only calibration flows and enter β values at each transect selected in step 1.

3) Run the MANSQ program and compare predicted versus observed WSL at each transect for the calibration flows. Change the β coefficient at each transect and repeat this process until agreement is reached.

4) Add all flows of interest to be simulated on the QARD lines of the MANSQ data set and final values of β for each transect and make your production runs.

5) Transfer WSL information on the TAPE4 output to the IFG4 data file and continue.

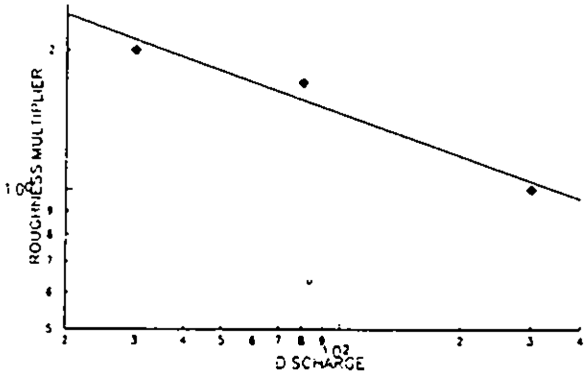


Figure 15. Determination of roughness multiplier versus discharge.

VELOCITY AND WATER SURFACE ELEVATION SIMULATION OPTIONS

WATER SURFACE ELEVATION SITUATION

WITH: SINGLE stage-discharge relationship
INDEPENDENT transects
1. MANSQ (adjust the betas)

WITH: SINGLE stage-discharge relationship
DEPENDENT transects
1. MANSQ (adjust the betas)
2. WSP (start with MANSQ)

WITH: MULTIPLE stage-discharge relationships
INDEPENDENT transects
1. IFG4
    a. best estimate for study segment {first calibrate velocities}
    or
    b. individual flow estimates for each cross section
2. MANSQ (adjust the betas)

WITH: MULTIPLE stage-discharge relationships
DEPENDENT transects
THIS IS THE CURRENT RECOMMENDED METHOD!
1. IFG4
    a. best estimate for study segment {first calibrate velocities}
    or
    b. individual flow estimates for each cross section
2. MANSQ (adjust the betas)
3. WSP (THE MOST ROBUST AND THE PREFERRED ALTERNATIVE)
    a. adjust Manning's n in all cells at calibration discharge
    b. adjust overbank roughness modifiers (both to same value)
    c. regress roughness modifiers versus flow
    d. generate starting WSL at first cross section
    e. run MANSQ and IFG4 and use individual flow estimates for each cross section

VELOCITY SITUATION
WITH: NO OR INCOMPLETE measured velocity sets.
1. Run IFG4
2. Plot velocity adjustment factor versus flow

WITH: ONE complete measured velocity set.
Take steps 1 and 2 above and
3. Examine velocities predicted versus velocities observed cell-by-cell for all transects

WITH: MULTIPLE complete measured velocity sets.
THIS IS THE CURRENT RECOMMENDED METHOD!
Take steps 1. 2. and 3 above and
4. Examine edge cells especially at flows greater than the measured (calibration) flow

CHAPTER 4: SIMULATING WATER VELOCITIES

Introduction

The IFG4 hydraulic model can use empirical measurements to predict cell velocities across the stream as a function of discharge. The velocities are determined using a special formulation of Manning's equation and calibrated to a set of measured velocities. The recommended and usual practice is to use one set of velocities. IFG4's major weakness is a difficulty in assigning roughnesses to edge cells at flows above the highest measured flow. One should carefully scrutinize the edge cells' velocities, especially at high flows.

Calibration and Prediction of Velocities

In the IFG4 program, there is a one-to-one correspondence between mean column velocities and the X coordinate of the vertical at which the velocity was observed. Velocities can only be provided at X coordinate values defined on the coordinate cards. The IFG4 program defines a cell as the region one-half way between two sets of adjacent verticals. This is best illustrated by reference to Figure 3. The cell defined by vertical *i* consists of the crosshatched region. A vertical is a measurement point specified by an X distance from the head stake (i.e., horizontal coordinate point). Note that the definition of a cross section cell in IFG4 is different than that used by the habitat modeling programs. However, the IFG4 program will automatically pass simulated water surface elevations and depth information to the habitat programs in the proper format.

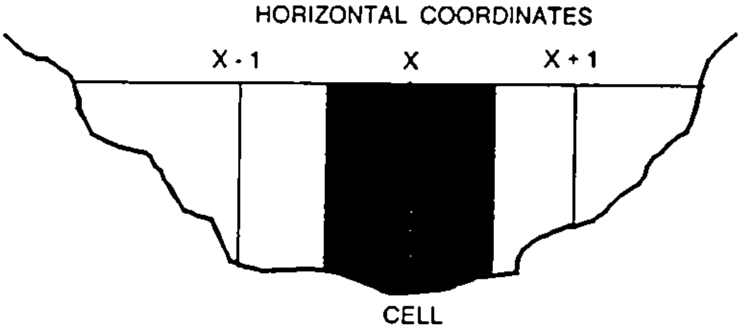


Figure 3. Example of a cell definition as used in the IFG4 program.

IFG4 WITH NO MEASURED VELOCITIES

THIS METHOD IS NOT RECOMMENDED!

The IFG4 program can be used to simulate velocities at a cross-section although no velocities were measured. If water surface elevation (stage), discharge, hydraulic slope, and dimensions of the channel cross-section are known, Manning's equation can be solved for n by substituting V = Q / A :

$$n = \frac{1.486}{V} R^{2/3} S^{1/2} \tag{38}$$

Manning's n is then assumed constant at 0.035 (or supplied in values on NS lines) Note: The default Manning's n value is 0.06 in subsequent calculations where new stages are calculated for different discharges, using:

$$V = \frac{1.486}{n} R^{2/3} S_e^{1/2} \tag{39}$$

S_e is assumed constant.

IFG4 WITH A SINGLE VELOCITY DATA SET

THIS IS THE CURRENT RECOMMENDED METHOD!

If one set of velocities is used to calibrate the IFG4 program, a different approach is taken based on solving Manning's equation for Manning's n at each vertical along a cross section. {Do not mistakenly take this as a recommendation that you only collect data at one flow}. Since slope, water surface, and observed velocity are given as part of the calibration data, this is accomplished by using Manning's equation written in terms of n_i at each vertical as the unknown:

$$n_i = [1.486 * S_e^{1/2} * d_i^{2/3}] / v_i \tag{40}$$

where:

n_i = Estimated Manning's n value at vertical i
S_e = Energy Slope for transect
d_i = Depth at vertical i
v_i = Velocity at vertical i

Note in the above equation that depth d_i at the vertical has been substituted for hydraulic radius and is computed from the difference between specified water surface elevation and bed elevation at each vertical. If a slope has not been provided (i.e., specified on XSEC input data line) a default slope of 0.0025 will be used. The specific slope used is not critical to calculation of velocities using this approach as will be shown below.

The measured velocity (v_i) at each vertical is obtained from the input data. Having obtained individual Manning's n values at each vertical, individual cell velocities can be computed at alternative discharges by:

$$V_i = [1.486/n_i] * d_i^{2/3} * S_e^{1/2} \quad (41)$$

IFG4 WITH MULTIPLE VELOCITY DATA SETS

THIS METHOD IS NOT RECOMMENDED!

If more than one set of velocity-discharge data sets are available for a cross section, the IFG4 program can use the following empirical equation to model the general relationship between discharge and velocity at each vertical:

$$V_i = c_i\ Q_i^{d_i} \quad (42)$$

that can be linearized through the log transformation to yield:

$$Log(V_i) = Log(c_i) + d_i * Log(Q_i) \quad (43)$$

The solution of this equation will yield an estimate of c_i and d_i and results in a similar relationship to the example provided in Figure 2, except that the Log of velocity replaces Log of (WSL - SZF).

Note that if IFG4 is supplied a Manning's n, the program will use that value.

Computational Procedures and Mass Balance

The area of the cell is computed by the following equation (Figure 3):

$$A_i = \frac{1}{2} * [(d_i + d_{(i-1)}) * (X_i - X_{(i-1)}) * 1/2] + \frac{1}{2} * [(d_{(i+1)} + d_i) * (X_{(i+1)} - X_i) *$$

(44)

where:

A_i = area of cell i
X_i = horizontal distance along the transect to point i
d_i = depth at vertical i

The apparent discharge computed for the transect is then determined by using the previous two equations to compute velocity and area at each cell and summing up individual discharges within each cell across the transect:

$$Q_{trial} = \sum_{i=1}^{ncell} A_i * V_i \quad (45)$$

This apparent or trial discharge is not necessarily the same as the discharge requested in the simulation. A mass balance is obtained by computation of a Velocity Adjustment Factor (VAF) such that calculated flow through the cross section is the same as simulated discharge. The VAF is computed by the following equation with fixed WSL in both Q's:

$$VAF = \frac{Q_{simulated\ at\ start}}{Q_{calculated\ at\ end}} \tag{46}$$

This ratio is then used to adjust individual cell velocities v_i to accomplish a mass balance for simulated discharges by the following equation:

$$V_i = v_i * VAF \tag{47}$$

This adjustment to velocities to achieve a mass balance on flows is also performed in the same manner within the WSP program. Note that slope does not appear in the four equations above and that the slope used in initial calculation of Manning's n will not influence final calculation of the velocity. The slope is important only in being able to compare n values from one cross section to another and from one stream to another. The addition of n values to the data set is easier if a reasonable estimate of slope is used to calculate roughness. The Manning's n value at this point within the IFG4 program really represents a velocity distribution factor.

The role of Manning's n in IFG4 is important since it functions as a velocity distribution factor and can have a significant impact on results of the habitat models. In general, a velocity must be supplied for each coordinate point and velocities not measured at previously dry verticals will be estimated. If the n value has been estimated for the cell, n value is utilized to calculate velocity at any simulated discharge. These areas are generally associated with fringe cells where only a fraction of total flow exists. However, these areas may be vary important to certain life stages of aquatic species and should be carefully considered. The value of n_i for dry cells can either be supplied by the user or if not known, the program will search adjacent cells for a given or calculated n_i or will assume a value of 0.06 if none are found. The user is referred to Information Paper 26 Table II.2 on page II.53 on discussions of IOC Options for computational control of velocity-Manning's n relationships in the IFG4 program.

Variable roughness in velocity simulations

Theory

The IFG4 hydraulic simulation model allows the user to adjust roughness in a cell as a function of depth in a cell. This option can help in reducing negative impacts resulting from a calculated roughness that is too high at the edges of the stream obtained when using the calibration data set. As was previously noted, roughness in a stream channel varies with discharges (see

Chapter 2) and can be modeled as a function of hydraulic radius and an index of bed material size by:

$$n = function\ (\frac{R}{D_i}) \tag{48}$$

where n is Manning's roughness, R is hydraulic radius, and D_i is an index to size of bed material. For many cases the function can be expressed as:

$$n = \alpha\ (\frac{R}{D_i})^{\omega} \tag{49}$$

where α and ω are empirically derived coefficients. If we then define n_o as roughness when hydraulic radius is 1.0 we can develop the following relationship:

$$n_o = \alpha\ (\frac{1}{D_i})^{\omega} \tag{50}$$

and new function for the relationship between Manning's n as a function of discharge can be given by:

$$n = n_o\ R^{\omega} \tag{51}$$

If the coefficient ω is known and one set of data available, the value of n_o can be determined using the equation:

$$n_o = \frac{n_c}{(R_c^{\omega})} \tag{52}$$

where the subscript c refers to Manning's n derived from the calibration data set. If enough data is available, the value of n_o and ω can be determined from regression analysis.

<u>Manning's n is effectively being used as a velocity distribution factor instead of a roughness coefficient.</u>

Another approach that is applicable to all rivers is based on stream morphology relationships given by:

$$n = r\ Q^{y} \tag{53}$$

where Q is stream flow, d is average depth, and r, y, c, and f are empirically derived coefficients. Combining equations in order to eliminate discharge Q.

$$d = c\,Q^{f} \tag{54}$$

yields:

$$n = r\left(\frac{d}{c}\right)^{\frac{y}{f}} \tag{55}$$

If we then define n_o' as roughness at a depth of 1.0; the value of n_o' can be expressed by the following relationship:

$$\acute{n}_o = r\left(\frac{1}{c}\right)^{\frac{y}{f}} \tag{56}$$

If we then define the exponent in the above equation as:

$$\beta = \frac{y}{f} \tag{57}$$

The following expression can also be developed to relate change in roughness as a function of discharge:

$$n = \acute{n}_o\,d^{\beta} \tag{58}$$

For most natural river channels hydraulic radius is approximately the same as average depth. consequently, it is safe to assume the following substitutions:

$$\omega = \beta \tag{59}$$

$$n_o = \acute{n}_o \tag{60}$$

Using the identities above as substitute for terms yields:

$$n = n_c\left(\frac{d}{d_c}\right)^{\beta} \tag{61}$$

where n is roughness at the flow of interest, n_c is calibration roughness; d is depth at the flow of interest, d_c is depth at the calibration flow and β is an empirical constant that needs to be determined.

Application of Theory

The IFG4 program should be used for determining distribution of cell velocities across a channel. The theory described in the previous section will change the velocity distribution by reducing velocities in shallow areas and increasing them in deeper areas. The program first calculates calibration roughness, n_c, using the equation:

$$n_c = \left(\frac{1.49}{v_c}\right) * d_c^{\frac{2}{3}} * S^{\frac{1}{2}} \tag{62}$$

where:

n_c = roughness at the calibration flow for a cell
v_c = velocity at the calibration flow for a cell
d_c = depth at the calibration flow for a cell
S = energy slope at the cross section

The calculation of n_c is made for each vertical (coordinate point) along an entire cross section. The program also calculates unit roughness, n_o, using the equation:

$$n_o = \frac{n_c}{(d_c)^{\beta}} \tag{63}$$

The user supplies the β coefficient and the same value for β is used for all verticals and for all cross sections.

For stream flows given on the QARD data lines in the IFG4 data file (i.e., flows of interest), the program uses either given water surface elevation or water surface elevations determined from a stage-discharge relationship to calculate depth at a vertical. The roughness (n) for the flow of interest is then calculated using the equation:

$$n = n_o \, (d)^{\beta} \tag{64}$$

By substitution, this equation is used for calculation of individual cell velocities. If a vertical has more than one calibration velocity, a log or semi-log function is used to calculate velocities and adjustments of n are not made for that particular vertical. The values of roughness written on output are the n_o for the calibration details table and n on the computational details table.

One additional point is that the mass balance option <u>must</u> be left on, otherwise irrational results may be obtained from simulation runs. To use the option, the user must set IOC (17) = 1 and the β coefficient must be specified on the NSLP data input line of the IFG4 data file (see IFG4 data file structure in Appendix A of Information Paper 26).

The value of the β coefficient can be determined from literature on hydraulic geometry of river channels (this is not β from MANSQ). The range of values for all but humid tropical channels is from 0.0 to -2.04 with a typical value being more in the range of -0.3 to -0.8. The value of the β coefficient is negative and has an unknown value. which requires judgment in its application.

The best approach available at this time is to assume a negative β term and run the IFG4 model to determine what happens to the roughness values. For higher flows. values of n_o should approach the handbook roughness for many of the verticals. The use of a lower limit for roughness is appropriate when using the variable roughness option (see IOC option 16).

Nose Velocities

Much attention has been given to the subject of mean column velocity versus nose velocity (also called focal point velocity) in PHABSIM applications for prediction of available habitat. The IFG4 hydraulic model offers the user several choices in computation of nose velocities either based on distribution of bed material particle sizes. regression equations based on mean and nose velocity measurements. or by empirical relationships based on the 1/7 power law and other methods. The application of these techniques however. is limited to those instances in which nose velocity habitat suitability curves are available from the study site and sufficient field data has been collected to support use of these hydraulic modeling options. A description of nose velocity calculations and options is included in the PHABSIM manual under IOC(14) for the four HABTA_ programs.

Assessment of Hydraulic Prediction Errors

The VAF serves as a general reference to quality of hydraulic simulations. In the event that a single velocity data set is used. VAF can be estimated by the following equation:

$$VAF=\frac{Q_{simulated}}{Q_{trial}} \tag{65}$$

As flows decrease from the calibration flow. VAF's should uniformly decrease from 1.0. Usually. if VAF's decrease up to the calibration flow you have a poor stage-discharge relationship for this transect. One solution is to take five flow measurements and break the stage-discharge relationship into a low flow and a high flow calibration. each with three flows. In general. the following rule of thumb should provide some indication of how one is doing by comparing computed VAF values with the indicated ranges and rating in Table 1.

Table 1. Range of VAF and rating of hydraulic simulations.

VAF	Rating
0.90 to 1.10	good
0.85 to 0.90 or 1.10 to 1.15	fair
0.80 to 0.85 or 1.15 to 1.20	marginal
0.70 to 0.80 or 1.20 to 1.30	poor
less than 0.70 or greater than 1.30	way off

An additional check on quality of velocity simulations can be made in those instances when three of more sets of velocities are used and is the error in regression equation between velocities and discharge. These Velocity calibration errors (VCE's) are produced by the IFG4 program when IOC option 10 is set to 1. Table 2 provides the rule of thumb for ranges in VCE and corresponding ratings. Unfortunately, use of VCE'S can be confusing, and the output produced by I4VCE is not very helpful.

Table 2. Range of VCE and rating of hydraulic simulations.

VCE	Rating
90 % less than 0.10	good
90 % between 0.10 and 0.15	fair
90 % between 0.15 and 0.20	marginal
90 % between 0.20 and 0.25	poor
More than 10 % greater than 0.25	way off

QUALITY ASSURANCE IN HYDRAULIC MODELING

Experience has shown that a cookbook approach to PHABSIM is the exception rather than the rule, as each field crew, each river or stream, and each target species produces a unique jigsaw puzzle of data from which a holistic picture must be assembled. Nonetheless, experience has also provided a knowledge base forming a template against which future studies can be compared and evaluated. The careful reviewer should be able to judge overall quality of a PHABSIM study after scrutinizing appropriate elements with the outline of suggested tolerances or rules-of-thumb.

PAPERWORK NEEDED FOR EVALUATION

1. Copy of input data set and listing from CKI4 or IFG4IN.
2. Source of stage-discharge relationship (WSP, MANSQ, IFG4, other)
3. Copy of REVI4 or TREVI4 output that includes:
    a. Comparison of calculated with measured flows
    b. Beta Coefficients
    c. Mean error of stage-discharge regression
4. Copy of IFG4 output that includes velocity adjustment factors (ZVAFF)
5. Detailed review will also require:
    a. calibration details
    b. error and warning notes
    c. original field notes

GENERAL REVIEW OF INPUT DATA SET

1. The IFG4 input data set should be reviewed to see what simulations options are used and to look for obvious typographical errors. Either the CHKI4 or IFG4IN program should be used to print out the data set and scan for deviant maximum and minimum values.

2. Accurate discharge measurements mandate that no more than 5% of total discharge at a transect go through a single cell (vertical). This implies that at least 20 verticals be measured at a single transect. This requirement could be relaxed under very homogeneous flow conditions, or in very narrow streams. In practice, having no cell transmitting more than 10% of flow is minimally acceptable.

3. The stage of zero flow for each transect should be examined. A stage of zero flow higher than the lowest point in a cross section implies that the cross section is in a pool and will have standing water if stream flow were zero. A stage of zero flow lower than the lowest point implies that the cross section will be dry at zero flow. The stage of zero flow should make sense for each cross section and also between transects. This can usually be checked under the assumption that contiguous transects in a data set are entered in an upstream direction.

4. One needs to know whether a representative reach approach or a habitat mapping approach is being employed. Review reach lengths and weighting factors to see if they match your expectation. Field notes should to be examined here.

REVI4 OUTPUT

Much of the diagnostic data generated by REVI4 (or TREVI4) are presented as plots. REVI4 determines relationships between variables using log-log and semi-log relationships. Roughness is calculated and displayed. The stage-discharge relationship (and thus water surface elevations) are determined for the stream flows on the QARD lines, those that specify discharges to be simulated.

IFG4, if used in a stand-alone mode, will develop a linear log-log relationship between water surface elevations and discharge for each cross section. Many things at any given cross section may invalidate a strict linear relationship. Common problems include simulating over-bank conditions, major obstructions to higher flows such as fallen logs or heavy streamside vegetation, very complex channel configurations such as pocket water, and backwater effects from a downstream hydraulic control. Rating curves tend to follow a log-linear function as long as the channel cross-section being inundated is fairly homogeneous. A rectangular or parabolic channel will tend to have a log-linear rating curve until the banks are over-topped. Triangular channels, with shelves and banches, and braided channels all tend to have nonlinear rating curves. Out of channel flow is frequently nonlinear.

1. Compare flows calculated by IFG4 with given flows the user has entered for all cross sections and for each measurement set. This information is found with the Velocity Calibration Data for each cross section.

Rule of Thumb: The range of calculated discharges should be within plus or minus 25 percent of the mean of given discharges unless flows were expected to be different at each cross section, i.e., flows were measured on different days or were changing during measurement. (For low flows, around 10 cfs, this may not be true because small measurement errors may result in large percentage calculation errors.) If discharges are not within 25 percent of the mean discharge, then either:

a. the stage was changing;
b. inflow or outflow was occurring between cross sections; or
c. the quality of field data is suspect.

If you suspect there are problems with the field data, then there could be errors in:

a. bottom profile;
b. water surface elevations;
c. velocity measurements; or
d. calculation of the discharge.

2. Check Mean Error of the fit between predicted discharges and measured discharges (either the given flow [Q] or the calculated Q). This is the Mean Error value following the log-log function equation.

Rule of Thumb: The mean error should be 10 percent or less. If the mean error is greater than 10 percent, then one or more of the following could be in error and should be examined:

a. stage of zero flow;
b. measured stage;
c. initial discharge; or
d. the cross section is subject to variable backwater effects.

3. Check the beta coefficient of the stage-discharge relationship for each cross section. This value is the exponent in the log-log function equation. The beta coefficient follows the ** symbol.

Rule of Thumb: If the calculated slope of a rating curve is too steep, water surface elevations will be under-predicted at low flows and over-predicted at high flows, and vice versa. The beta coefficient should fall between approximately 2.0 and 4.5. If it is not within this range, then one or more of the following could be in error and should be examined:

a. stage of zero flow;
b. measured stage;
c. initial discharge; or
d. the cross section is subject to variable backwater effects.

4. Check Froude Numbers for the discharge at each cross section. The Froude Number should be less than one. It is not expected that a normal stream or river will be anything but sub-critical for typical range of flows. Consult a hydrologist if flow is critical or super-critical.

QUALITY CONTROL IN IFG4

IFG4 is one of the easiest programs to use and thus is favored by many consultants. IFG4's major weaknesses are in assumption of the linear log-log relationship, and a difficulty in assigning roughnesses to edge cells at flows above the highest measured flow. For these reasons, it is commonly felt that the quality of a stand-alone IFG4 simulation is best at unmeasured flows between the highest and lowest measured water surface elevations, next best in simulating unmeasured flows down to 0.4 of the lowest measured flow, and next best in simulating unmeasured flows up to 2.5 times the highest measured discharge. Externally supplying water surface elevations to IFG4 from either WSP or MANSQ may provide better predictions, provided that those alternative models are used properly. Even then, one must carefully scrutinize edge cells' velocities, especially at high flows.

1. IFG4 is subject to poor velocity prediction in edge cells above the highest measured flow. This is because roughness (Manning's n) of those cells is not known. Compare n values used at higher flows to see if they largely agree with n values for the rest of the channel. Significant deviations, unexplained by field notes of changes in substrate or vegetation, should be avoided.

2. As with any model, there are some estimates that have to be made when using IFG4. The roughness limitation or NMAX value is one such estimate. The roughness limit is not easily chosen and relies upon experience and some educated guesses. The roughness limitation is an attempt to limit the error inherent in estimating a real life situation.

The roughness of water at a point in a stream is a measure of energy loss, or friction, in a stream and changes according to depth. IFG4 allows only one roughness value for each point of a stream, regardless of changing flows. A limit on maximum roughness must be used to exclude some extreme conditions.

The most common example of this is at a point near the water's edge. At a low flow, the point may have a large roughness value, because the ratio of particle size to depth is close to one, and rocks and roots break up the water in the stream. At a high flow, however, the particles have little effect on the stream at that point, and roughness is relatively low.

To make a good judgment on maximum roughness in the stream you must consider:

a. The roughness at each point of the stream at different flows.

Take a look at the CALCULATED ROUGHNESS table in the REVI4 output file, and at the graph ROUGHNESS ACROSS CHANNEL FOR TRANSECT. Look for relatively high roughness values, and diversity of roughness for different flows at the same point. The ABC's on the graph correspond to different roughness values at each flow, or columns for roughness in the CALCULATED ROUGHNESS table. A relatively high roughness value for a point that has considerably lower roughness values for other flows must be controlled. Choose a roughness limit that excludes any such roughness value.

b. The roughness compared to depth.

Now look at the DEPTH VS. ROUGHNESS graph in the REVI4 output file. As depth decreases, you would expect roughness to increase. If any one point seems to break this pattern, consider setting the N maximum value lower than the roughness at that point.

c. The geometry of the stream at the points in question.

A rating curve works well in a U-shaped channel and not so well in a V-shaped channel nor in a braided channel. Look at the CROSS SECTION graph in the REVI4 output. Take a look at the points in the stream that have questionable roughnesses and draw a line to indicate the water surface at the flow in question (water surface, or stage, is given above the CALCULATED ROUGHNESS table). If there is a rise in stream bed where a high roughness value occurs, this is a good indication of a point where roughness needs to be controlled. The roughness limit applies to the entire stream being simulated, so compare results of the above considerations for all cross sections, and choose a roughness limit that will work for all cross sections.

QUALITY CONTROL IN MANSQ

Usually, the value from the regression equation in REVI4 output is a good starting point to begin calibrating the Beta coefficient. A median Beta coefficient for MANSQ is probably 0.22, with a range of 0.1 to 0.4. Beware using Beta coefficients larger than 0.4 as it is probably indicative of too narrow a range of measured discharges. In contrast, negative Beta coefficients usually indicates that the stream is very steep and the sides are covered with vegetation. It is rarely logical for a Beta Coefficient to be negative. A zero should be used instead.

In general, it is reasonable to expect that Beta coefficients will not vary much from transect to transect. Thus, the calibrated MANSQ model should have Beta coefficients within plus or minus 50% of each other. Finally, water surface elevations predicted by MANSQ should be within 0.1 foot of measured elevations.

REVIEW QUESTIONS

1. The basic process for hydraulic simulation is:

a. Collect data, run hydraulic simulation programs, run habitat modeling programs;

b. Simulate water surface elevations and velocities using IFG4 for best overall results;

c. Calibrate water surface at measured discharges, simulate water surfaces for all discharges, then distribute velocities;

d. Quality control of input data, calibrate water surfaces at measured discharges, simulate water surfaces for all discharges, quality control of WSL results, distribute velocities, then quality check all hydraulics simulations before habitat modeling.

1.d. Since hydraulic models are largely empirical models, they are entirely dependent on good field data for accurate results. An hour or two spent checking field data before leaving the river being studied can save days of frustration and guessing in transcribing data and calibrating hydraulic models. Once the data have been gathered the process is: calibrate water surfaces (using MANSQ, WSP or in some cases IFG4), distribute velocities using IFG4, and then proceed to habitat modeling. At each of these steps in hydraulic simulation, results must be checked for reasonableness.

Answer a is the general process in all of PHABSIM not just hydraulics.

Answer b was an early recommendation from the Fish and Wildlife Service. However, we have learned that use of IFG4 for simulating water surface elevations can produce larger errors than WSP or MANSQ so our recommendation is now "Use IFG4 for water surface elevations when your study site has the specific conditions for which it is best suited."

Answer c is also true, but if you omit quality control at each step you do not know how reliable or at which flows problems may exist in your final habitat-discharge relationship.

2. The slope(s) used in PHABSIM's hydraulic models is (are):
   a. bed slope;
   b. water surface slope;
   c. energy slope.

2.c. The models must consider total energy at the site. The slope used is the energy slope consisting of the sum of potential and kinetic energy due to elevation of the bed, depth and the velocity component ($v^2/2g$). Take care that you do not confuse slope of a regression line or other functional relationship with energy slope. If you had answered "all of the above" you would have been correct because the information needed to get bed slope and water surface slope must be available to the model to calculate the energy slope.

3. The minimum information needed to characterize the hydraulic properties of a stream site for use in PHABSIM is:
   a. Three sets of measurements at the site covering at least a one order of magnitude range of flows, all controls and bed movements;
   b. One set of measurements including discharge, velocity distribution and one or more slope measurements at other discharges;
   c. One set of measurements including discharge, velocity distribution and water surface slope at the site;
   d. A complete stage-discharge relationship for the site, including a hysteris loop for moving bed streams.

3.c. The minimum information needed to describe a mosaic of depth and velocity at a study site are contained in one set of measurements. It is far better if you have only one set of measurements that those measurements be taken at a high rather than a low flow. Extrapolation errors compress as you simulate lower than measured discharges, but expand as you simulate higher discharges.

Answer a would provide additional information that allows a more precise calibration of models to the site. The more discharges you have field measurements for, the better. Five measurements are better than three, especially if a wider range if discharges is captured.

Answer b contains additional information over answer c. It would allow more precise calibration of water surfaces over a wider range of flows. This approach may be necessary in rivers where it is life threatening to take velocity measurements at high discharges.

Answer d does not provide velocity distribution information; though it does give water surface information. Without the velocity distribution the velocity depth mosaic cannot be constructed.

PROGRAM LIMITATIONS AND USER ALTERNATIVES IN HYDRAULIC SIMULATION

MODEL LIMITATIONS	USER ALTERNATIVES
Rigid bed assumed e.g. does not describe bed changes with changing discharge.	Change bed profile and re-run model for each flow (bed obtained profile from either measurements or bedform model). Note: alternative channel designs can be simulated similarly, but requires detailed knowledge of open-channel hydraulics.
Constant roughness assumed.	The user can vary roughness by several methods. Select the method to suit the problem.
Unsteady flow not handled within model.	Combine separate model runs to simulate unsteady flow by step-wise steady flow runs. Unsteady flow conditions occurring at the time of data measurement require care in simulation, but can be handled.
Split channels are difficult.	Divide flow and run channels separately. Flow division requires extensive hydraulic knowledge.
Calibration problems for slope above 2 - 3%.	Use alternative models within PHABSIM for various stages of hydraulic simulation.
Unstable at high extrapolated discharges.	Extrapolation always merits scrutiny, the user can collect more data sets at high flow. The wider the range of flows collected for any data set, the better. The user should combine different hydraulic models to apply the most suited model to each local characteristic.
Three to five calibration sets desirable, one complete set required.	One set is sufficient; however, collect wider ranges of flow and more complete data sets for more precise hydraulic simulation.
All hydraulic controls must have transects.	True for WSP. The user can select other hydraulic models if a control was missed.

CHAPTER 5: CALIBRATION AND SIMULATION OPTIONS IN IFG4

Introduction

Two of the more difficult aspects in use of the IFG4 program involve: choice of model selection for various kinds of data sets; and understanding the various combinations of options related to stage-discharge relationships and velocities through control of the roughness factors. A general overview will first be provided for using IFG4 with different types of available data sets, followed by a presentation of the most pertinent IOC options affecting program computations.

IFG4 Modeling Choices Based on Velocity Sets

The IFG4 program should be used with one set of velocity data to calibrate the model. The single set of velocities are used to determine Manning's n value at each vertical that are used to distribute flow across the cross-section. These Manning's n values are effectively velocity distribution factors and not roughness factors in the usual energy loss sense. The water surface elevations that are required as part of velocity calibration and simulation process in IFG4 can either be determined within the IFG4 program if two or more stage-discharge sets are available or can be computed external to the program. Use of a single velocity calibration set has proven more reliable than use of three velocity calibration sets provided that water surface elevations are determined by using: 1) stage-discharge relationships based on three or more points; or 2) the WSP model calibrated to water surface elevations with a stage-discharge relationship for starting water surface profiles.

The specific approach to take should be determined by quantity and quality of the available data. The generalized procedures for use of various combinations of models to compute water surface elevations and then velocities is presented based on the number of velocity data sets as described below. These steps are intended to orient the user to the general process and are not always the best or only way to approach the problem. Experience over time will aid the user on what approaches to try.

USE OF SINGLE VELOCITY DATA SETS WITH IFG4

Using the WSP Model for Water Surface Elevations

When using this approach, the following steps should be followed:

1. Collect one set of velocity measurements and associated water surface elevations.
2. Prepare and check an IFG4 data file with the single velocity data set.
3. Place the single water surface elevation for the calibration velocity set on the WSL card for each cross section and the corresponding stream flow on a single QARD card and run the IFG4 program. Review the results and select options for the production runs.

4. Transform the IFG4 input file to WSP input file. Retain the IFG4 input file for the production runs.

5. Calibrate the WSP model to water surface elevations with constant roughness for all cells and transects.
6. Calibrate the WSP model to a constant roughness in each cross section but varying from cross section to cross section if there is a physical reason to do so. The roughness within a section can be varied also if there is a physical reason to do so.

7. Select the stream flows needed to develop the physical habitat versus stream flow relationship.
8. Select roughness multipliers, if appropriate.

9. Run the calibrated WSP model with the stream flows from step 7.
10. Use the WSEI4 program to read the TAPE4 from step 9 and place calculated water surface elevations on the WSL cards in the IFG4 data set. The stream flows from step 7 are also written as stream flows on the QARD cards in the IFG4 input file.

11. Make production runs with modified IFG4 input file.

Using the STGQS4 Model for Water Surface Elevations

When using this approach, the following steps should be followed:

1. Collect one set of velocity measurements.
2. Collect water surface elevations at each cross section for three or more stream flows.

3. Prepare and check an IFG4 data file with the single velocity data set.
4. Place the single water surface elevation for the calibration velocity set on the WSL card for each cross section and the corresponding stream flow on a single QARD card and run the IFG4 program. Review the results and select options for the production runs.

5. Select the stream flows needed to develop physical habitat versus stream flow relationship.
6. Use the stage-discharge data with the STGQS4 program to create the WSL cards in the original IFG4 data file for the production run.

7. Make the production run.

Using the MANSQ Model for Water Surface Elevations

When using this approach, the following steps should be followed:

1. Collect one set of velocity measurements and one set of water surface elevations for each cross section.
2. Prepare an IFG4 data file with the single velocity data set.

3. Place the single water surface elevation for the calibration velocity set on the WSL card for each cross section and the corresponding stream flow on a single QARD card and run the IFG4 program. Review the results and select options for the production runs.
4. Select stream flows needed to develop physical habitat versus stream flow relationship.
5. Use the single set of water surface elevation-discharge data with the MANSQ program to create a TAPE4 with water surface elevation and average channel velocities for the flows of interest.
6. Use the WSEI4 program to add the WSL cards (lines) to original IFG4 data set.
7. Make the production run.

USE OF MULTIPLE VELOCITY DATA SETS WITH IFG4

Use of two or more velocity calibration data sets with IFG4

The use of two or more velocity sets to calibrate the IFG4 model to velocities follows the same general steps as presented in the previous section. The difference is in determining the range of flows for which a particular data set will be used. One approach would be to calibrate the IFG4 model as follows: use the lowest measured discharge as a single velocity data set and use this model to simulate velocities at extrapolated flows below the lowest measured discharge; and use the highest measured discharge as a single velocity data set and use this model to simulate velocities at extrapolated flows above the highest measured discharge. For the range of flows between lowest and highest measured discharges two possible approaches are possible. One is to calibrate each velocity data set as a single velocity set and use the results over a specified range. The other approach is to use all data sets to calibrate the equation:

$$v_i = a_i Q^{b_i} \qquad (66)$$

The choice is a matter of judgment and should be dictated by a comparison of the results using several approaches.

Control of IFG4 Calibration and Simulation Options

Much of the capabilities of the IFG4 program lies in the ability of the user to provide specific control over all aspects of the computational procedures. The user should review available IOC options for the IFG4 program listed in Table II.2 starting on page II.53 of Information Paper 26. This review often results in confusion as to which combination(s) of options should be selected to achieve the desired results. This problem can be overcome by breaking up available options into several discrete conceptual parts that are provided below.

Adjusting WSL as a function of VAF's

IOC option 6: This option will allow a correction in WSL (i.e., stage) if the VAF is less than 0.90 or greater than 1.10. Errors in WSL simulation affect the VAF's as follows. If WSL is low, then the computed cross sectional area through which the specified discharge is computed is smaller and therefore the resulting simulated velocities are higher than would be obtained from a correct WSL value. Conversely, if WSL is high, the area is greater and the resulting simulated velocities are lower to achieve the specified discharge. This option is not generally utilized, since in practice, water surface elevations are determined external to the program and a better control is obtained through use of IOC options 5 and 8 as discussed below.

Mass Balance and VAF

IOC option 11: This option in essence will allow the user to ignore application of the VAF to achieve a mass balance within the IFG4 model. If IOC (11) is set, mass balance determined from application of the VAF will be ignored regardless of the combination of IOC options 5 and 8 selected.

Controlling the exponent in velocity-discharge regression $v = a Q^b$

IOC option 14: This option provides the user with the ability to control the way the IFG4 program handles regression of the velocity-discharge relationship. There are five (5) possible choices:

IOC (14) = 0 If IOC (14) is 0, then no control is imposed on the regression equation.

IOC (14) = 1 The regression equation is solved for all cells with at least three or more velocity discharge calibration data sets and the average of these B coefficients are applied to all cells in one or more calibration velocity sets has been collected. Cells that were dry at calibration flows will have velocity calculated from a) user input Manning's n if supplied, b) computed from Manning's n if an adjacent cell has one, or 3) the default value of 0.06 will be used if a and b are not available.

IOC (14) = 2 In this instance, the average B obtained from the regressions are applied only to those cells that have a single velocity calibration data set. All other cells are treated normally.

IOC (14) = 3 This allows the user to specify a maximum value of the B exponent by placing an upper limit on the BMAX line in the IFG4 data file (see page A.54 of Information Paper 26 for placement and format of the BMAX-line). If the program calculates a B term that is greater than the value specified on the BMAX data line, the B exponent is set to the maximum value for use in calculation of velocities for that cell.

IOC (14) = 4. This option will force the IFG4 program to use the average B from all regression for all cells in which one or two velocity calibration points have been collected. Cells with

	three or more velocity points will use their individual B exponents determined from the regression equation and dry cells are handled normally.
IOC (14) = 5	This option combines number 2 and 3 and will use the average B exponent for all cells with a single velocity calibration data set while imposing the limit as specified on the BMAX data line in the IFG4 data file.
IOC option 22:	This option provides the user with ability to terminate program execution if the B exponent exceeds 3.0. This is usually left on (i.e., default = 0) and would be indicative that regression of the velocity-discharge relationship may be abnormal within a given cell and should be evaluated.

Controlling roughness

Several options are available to the user to control the way in which the IFG4 program will use roughness.

IOC option 12:	This option allows the user to control the way in which the IFG4 program will calculate roughness or use the roughness if supplied.
IOC (12) = 0	This option will instruct the IFG4 program to use roughness for a cell if it is input on the NS lines of the IFG4 data file. If n is zero, the IFG4 program will compute the n value.
IOC (12) = 1	This option will result in IFG4 calculating the n value for cells that are wet, uses n if supplied for dry cells or will estimate n for dry cells if the n value in the cell is 0.
IOC option 15:	This option will allow the user to specify the maximum or minimum value of roughness computed with the Manning's equation during the simulation of velocities. The maximum and/or minimum value is specified on the NMAX data line of the IFG4 data file as indicated on page A.54 of Information Paper 26.
IOC (15) = 0	This will result in no limit on value of the estimated Manning's n value.
IOC (15) = 1	This will impose the limit for the maximum and/or minimum as specified on the NMAX data line. IF the estimated Manning's n value exceeds these limits, it will be set to the appropriate limit for use in all simulations of velocities in that cell.
IOC (15) = 2	This is essentially the same as number 1 except that the limits are imposed only in the case when the estimated n value > 0.0.
IOC option 16:	This option will allow the user to adjust the roughness in a cell as a function of depth in a cell. This is explored in more detail within the next section. This option can help reduce the negative impacts arising from too high a roughness at edges of the stream at lower discharges that

would be expected to become less rough as flow (i.e., depth) increases. NOTE: IOC (11) must be set to 0 or the results will be irrational when using IOC (16) = 1.

IOC (16) = 0 : This will ignore variable roughness.

IOC (16) = 1 This option will adjust roughness as a function of discharge and requires the user to specify a B exponent on the NSLP data input line within the IFG4 data file. The general equation for changing roughness as a function of depth is:

$$n = n_c * (d/d_c)^B \tag{67}$$

where:

n = Depth adjusted Manning's n value for the cell
d = Depth of the cell at the current discharge
d_c = Depth of cell at the calibration discharge
B = An empirical coefficient in the range from 0.0 to -2.04

This equation is discussed with the concepts of variable roughness as a function of discharge.

Controlling computation of stage and velocity-discharge relationships

The control of the velocity-discharge and stage-discharge relationship within IFG4 is accomplished through use of IOC options 5 and 8 in combination. These two options can cause some confusion at first until the user can get a firm understanding of their interactions. This is most easily accomplished by an examination of computational aspects or the IFG4 program. To facilitate the following discussions Table 1 has been provided that defines several terms necessary to understand the relationships between IOC options 5 and 8.

Table 1. Definition of terms related to the IFG4 computational procedures.

$Q_{calculated}$ = Discharge calculated from velocity data as input on VEL data lines, WSL as input on the CAL data line and X distance and bed elevations input on the cross section data lines of the IFG4 data file. The cross-section discharge specified (second discharge value) on the CAL data line of the IFG4 data file ("discharge for this cross section if IFG4 calculated the discharge").

$Q_{computed}$ = Discharge computed by interpolating from a known stage-discharge relationship in the simulation phase of the program.

$Q_{simulated}$ = The discharge to be simulated that is input on the QARD line of the IFG4 data file.

Q_{given} = The cross-section discharge specified (first discharge value) on the CAL data line of the IFG4 data file ("best estimate of discharge for this cross section").

IOC (5) = 0 and IOC (8) = 2 VELOCITY PRODUCTION

This combination of IOC options 5 and 8 represents the standard computational procedure in IFG4 and is summarized in Figure 1. Once the individual cell velocities have been determined, these velocities are adjusted with VAF as discussed previously.

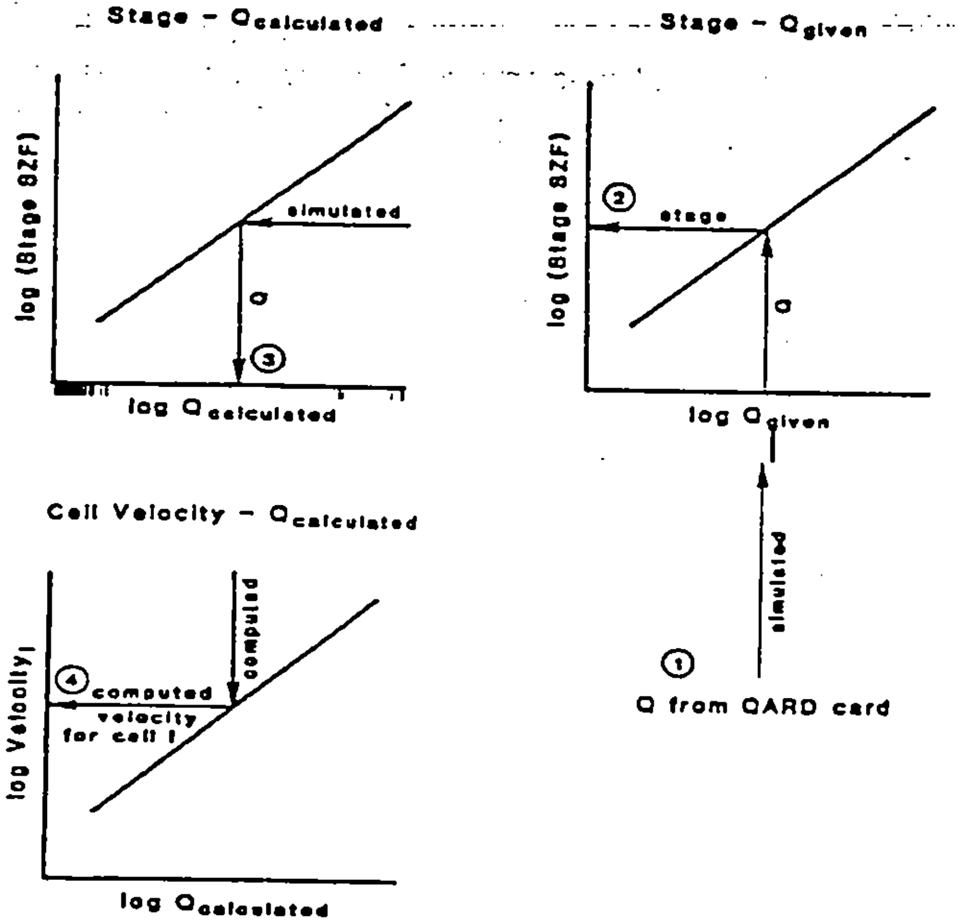


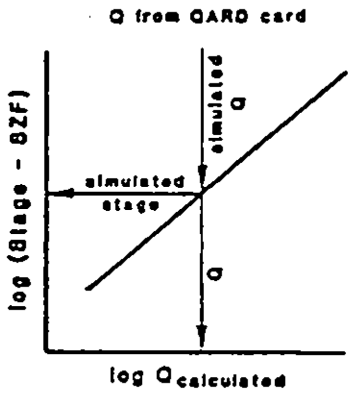
Figure 1. Computational procedures for IOC (5) = 0 and IOC (8) = 2.

IOC (5) = 0 and IOC (8) = 0 VELOCITY CALIBRATION

This combination calibrates stage-$Q_{calculated}$ and velocity-$Q_{calculated}$ relationships but bypasses the stage-Q_{given} step in calibration. In the simulation phase, flows to be simulated are entered directly to the stage-$Q_{calculated}$ relationship. The result is to cause $Q_{computed}$ to equal $Q_{simulated}$. The resulting individual cell velocities are then adjusted with VAF as in the standard procedure. The overall process is represented in Figure 2. This procedure tends to amplify the effect of individual errors in the velocity measurements that can be pronounced when simulating flows beyond the calibration data sets.

With IOC(5)=0 and IOC(8)=0, IFG4 uses internally calculated discharges for WSL calibration. Frequently, this will not be as reliable as setting IOC(5)=1, IOC(8)=0 and using measured discharges that are the same for all cross-sections.

Stage - $Q_{calculated}$



Cell Velocity - $Q_{calculated}$

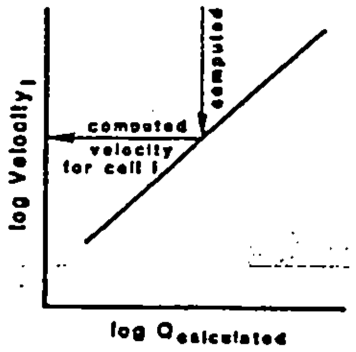


Figure 2. Computational procedures for IOC (5) = 0 and IOC (8) = 0.

IOC (5) = 1 and IOC (8) = 0 or 2 VELOCITY CALIBRATION

This combination does not calibrate a stage-$Q_{calculated}$ relationship. Instead, regressions are limited to development of stage-Q_{given} and cell velocity-Q_{given} relationships. In the simulation phase, flow to be simulated is used to determine stage from the stage-Q_{given} relationship and the unadjusted velocities are derived from the velocity-Q_{given} relationship. The velocity adjustment factor is then based on the ratio of $Q_{simulated}$ / $Q_{calculated}$. This procedure is illustrated in Figure 3. This option tends to ignore local errors in velocity measurements and force all simulations to fit the given best estimate of discharge supplied on the CAL data lines. This will tend to amplify effects of errors in estimating discharge and can produce large errors when extrapolating outside the calibration range for those transects that have a large discrepancy between Q_{given} and $Q_{calculated}$. This combination of IOC options can be used when one suspects a uniform error in velocity measurements that would cause $Q_{calculated}$ to be consistently above or below flow in the channel.

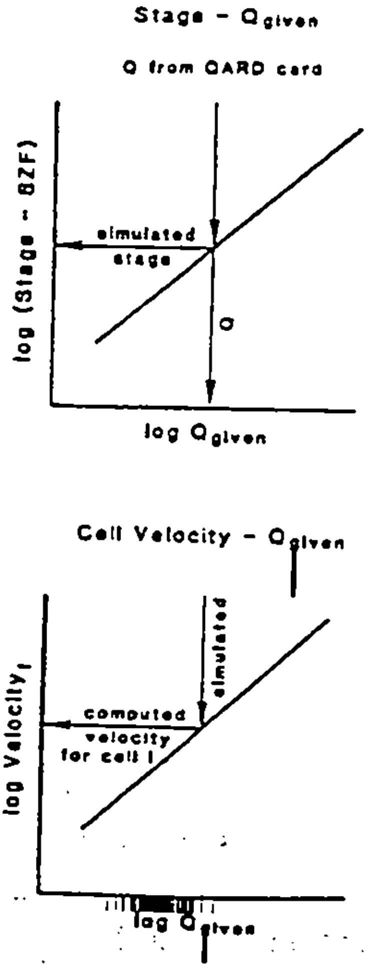


Figure 3. Computational procedures for IOC (5) = 1 and IOC (8) = 0.

IOC (5) = 0 and IOC (8) = 1 WSL CALIBRATION

The WSL's must be supplied to use this combination of IOC options and are supplied on WSL data lines in the IFG4 data file. There is no calibration of stage-discharge relationships. The cell velocity-$Q_{calculated}$ relationship is the only regression performed in the calibration phase. A WSL data line must be supplied for each flow to be simulated and have a one to one correspondence between order of the WSL values and order of the flows on the QARD data lines. In the simulation phase, the program uses the velocity-$Q_{calculated}$ relationship to derive unadjusted cell velocities as shown in Figure 4. The velocity adjustment factor is then computed as the ratio of $Q_{simulated}$ / $Q_{calculated}$ and applied as in the standard procedure. This option should be used when water surface elevations collected in the field are suspect or missing.

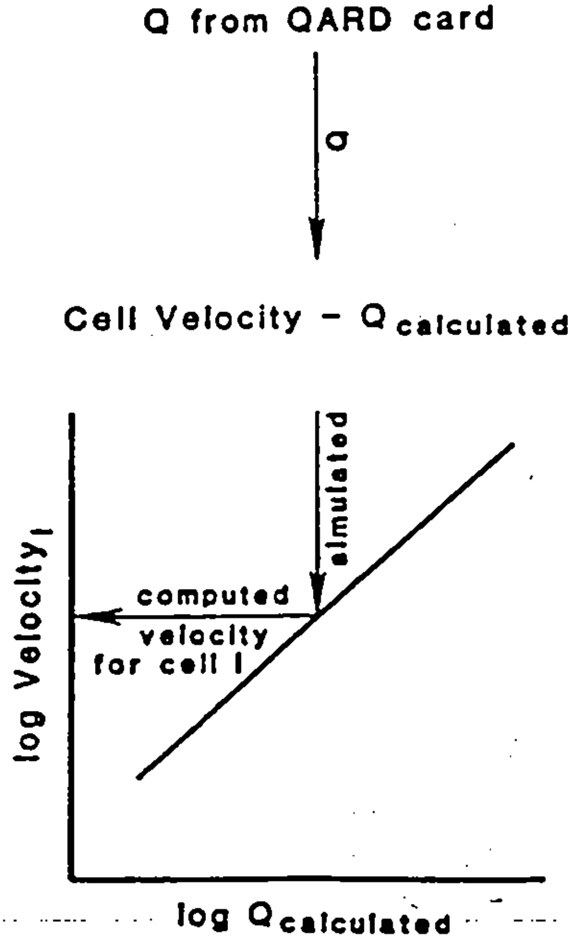


Figure 4. Computational procedures for IOC (5) = 0 and IOC (8) = 1.

IOC (5) = 1 and IOC (8) = 1 WSL PRODUCTION

As in the preceding case, water surface elevations must be supplied on the WSL data lines for each discharge to be simulated. Therefore, no stage-discharge regressions are required in the calibration phase. The calibration phase consists of fitting velocity-Q_{given} relationships. In the simulation phase, depths are determined from the WSL-given and velocities from the cell velocity-Q_{given} relationship as shown in Figure 5. The velocity adjustment factor is derived as indicated in the previous section and applied as in the normal procedure. This option combines substitution of input water surface elevations for the normal model regression step in the calibration phase and the compensation for uniform velocity measurement errors. This option should be used when uniform velocity measurement errors and error in the water surface elevation measurements are suspected.

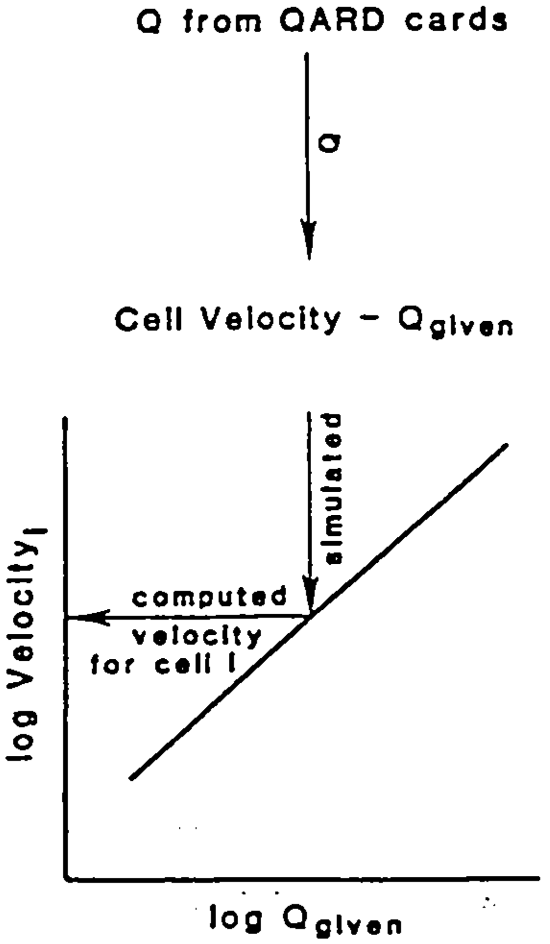


Figure 5. Computational procedures for IOC (5) = 1 and IOC (8) = 1.

CHAPTER 6: HABITAT MAPPING

The generally preferred habitat mapping option (replacing the once-favored representative reach approach) can be characterized as:

Stratified	not totally evenly distributed across the entire study area, but corrected back to measured habitat percentages in the final report
Random	not selective or systematic
Unequal-Effort	not allocated equally on the basis of habitat percentages but giving larger emphasis to infrequent habitat, unique habitat, and highly valuable habitat
Sampling	not a census but statistically based, thus providing reduced cost, greater speed, greater scope, and greater accuracy
of	
Mesohabitat Types	from habitat typing and mesohabtat mapping, not representative reaches
with	
Clustered	to allow hydraulically-linked analysis and decrease travel and setup cost for data collection
Transects	some used only for hydraulic modeling (hydraulic controls) and some only for habitat modeling (complex channels).

Here is an outstanding example from Homa, J., Jr., and L.J. Brandt. 1991. From Executive Summary. A 15.1 mile section of the Salmon River in Oswego County, New York, from 1.8 miles upstream of its mouth at Port Ontario to Lighthouse Hill Dam (river mile 16.9) was examined for aquatic habitat types. The segments were identified on topographic base maps. Initially, the riverbed was characterized using aerial photographs, followed by confirmation with field observations (ground truthing). The 15.1 miles were divided into 157 distinct habitat segments from 100 to 2,760 ft in length. Habitat segments were classified and grouped by depth (first order) (shallow, medium, deep), habitat (second order) (run, riffle, pool), river bottom (loose material, bedrock/loose material), and substrate (fourth order) (presence of one or more of large boulder, small boulder, cobble, gravel, sand, mud). Some habitat classes (chutes, step ledges, transition zone) were segregated and grouped separately. Preliminary examination of the predicted habitat from the habitat modeling phase of the research and subsequent studies have suggested that sorting for the Salmon River Unsteady Flow Model Research study did not need to go to the fourth order, but may be adequate if sorted only to general river bottom material.

Habitat typing was conducted in the field on foot mainly at low flow. Low-altitude aerial photos taken at low flows were more useful than high-altitude photos taken at high flow to delineate habitat suitability criteria. Aerial photo interpretation with ground truth was necessary to delineate habitat in detail. Topographic base mapping (scale, 1 inch = 200 ft) and half-scale reductions (1 inch = 400 ft) were useful for graphic purposes and for locating habitat segments in the field. However, the aerial photographs could have been used directly as base maps for habitat delineation. Some habitat suitability criteria (instream and overhead cover categories, such as pocket water, boulders, undercut-banks) were recorded but not used to classify and segregate habitat types; they may be useful in other habitat typing scenarios. Overall, habitat typing can be modified as needed on a site-specific basis. These data will be used for input into hydraulic and microhabitat models for use downstream of storage-and-release hydro projects.

From Introduction. The principal advantage of this method (habitat typing) is that a smaller number of transects may be used to estimate available habitat in the entire study segment in question than for other methods. Another advantage is that transects may be placed in specific locations for specialized purposes. Traditional techniques, such as representative reach, either require many more transects (at least one group per habitat segment) or only estimate habitat in areas of question, a critical reach such as a particular spawning riffle. The Salmon River downstream of the Lighthouse Hill Development was divided into 15 segments based on uniformity of habitat types. The traditional IFIM approach to choosing sampling sites would be to select one representative reach within each of the 15 segments. These representative sections would have all the habitat characteristics of the segment and would be sampled intensively with a group of transects, resulting in a large total number of transects.

In the habitat-typing method, the whole study site is mapped into smaller segments representing individual habitat types. The characteristics of each habitat are recorded and sorted, and similar segments are categorized together. A smaller number of transects representative of the habitat categories are then chosen, and results for the entire river reach are calculated, based on the proportions of the reach represented by each category.

From Methods and Materials. The mapping of the Salmon River for aquatic habitat consisted of seven steps, which are more fully described on the ensuing pages of this report:

1. Aerial photographs {black and white, late April timing} were interpreted stereoscopically for delineating channel and floodplain extent, tributaries, habitat type, shoreline, and bottom material.
2. In the field, the extent of each unique habitat was mapped, and information was recorded about its cover, substrate and shoreline material, and the quality and types of habitat.
3. The length of each habitat segment was measured and entered into a computerized matrix (spreadsheet) containing the stream habitat information collected in the field.
4. The depth of each habitat segment was determined by the Delphi technique.
5. A hierarchical classification was developed to collect segments with similar habitat characteristics so that segments would be assigned to the appropriate microhabitat transect or be identified as unassigned.

6. Habitat segments were then spot checked in the field by personnel familiar with the Salmon River for accuracy of classifications and similarity between habitat segments assigned to microhabitat transects.
7. All segments were checked in the office for the accuracy of their assignment to microhabitat transects by personnel familiar with the Salmon River.

The three major habitat types identified in the field were pool, riffle and run. A pool consists of relatively still water that is at least 2 ft deep. A riffle occurs when the water surface is broken (i.e., hydraulic jump) by rocks and other instream material. Extreme examples of a riffle are rapids or white water. A run contains moving water of various depths, but the surface is not broken. Since the minimum mapping unit was 100 ft, habitat was classified on the basis of abundant habitat present in each study segment. A minimal amount of habitat heterogeneity was therefore permitted. A segment boundary was identified when there was a distinct change in the water surface, gradient, channel type, size or abundance of bottom material, water depth, or cover from a previously defined habitat segment.

The two channel types were simple and complex (or multiple). A simple channel consists of only one well-defined channel (although it may contain more than one channel at higher flows), while a complex channel has two or more branches with islands between. Multiple channels are indicative of loose, readily sifted substrate material such as sand and gravel.

A chute is a section of river where velocities are high and the river bottom is smooth bedrock. It can extend the entire width of a section of river or only a portion of it. A ledge is the vertical break in bedrock that appears step-like. Exposed bedrock is necessary for either feature to exist. Chutes and ledges were considered to be important factors that influence fish migration in the Salmon River.

Several attempts, using different criteria in various order, were necessary to adequately sort and classify the segments. The early attempts involved segregating the segments first by pool, riffle, and run and second by substrate. This did not work well because segments that did not appear to have the same habitat (based on professional judgment) were sometimes grouped together. Additional efforts also involved trying to enhance differences by using river bottom material (i.e., loose or bedrock/loose). However, the classification was still inadequate. As a solution, it was decided in conference (by the Delphi technique, as mentioned above) to add depth to the list of qualities for each segment. Depth was an important factor that could distinguish one pool type from another, for example.

One problem still existed--how to account for chutes, ledges, and the transition zone. The transition zone was an atypical segment of the river. It is defined as that portion of the river that approaches the elevation of Lake Ontario. Hydraulically, the backwater of the lake affects the stage-discharge relationship at this location as the lake level changes independent of river stage. The possible influence of the Lake Ontario seiche {viz., sudden oscillation of the water of a lake or bay} is unknown, so this region was extracted and treated uniquely. It was decided to extract habitat segments that represented chutes, ledges, and the transition zone before segregating the remainder of the habitat segments. When these three unique habitat types were first extracted from the master list of segments before depths were separated, an accurate classification resulted.

From Results. There were 157 habitat segments totaling 79,880 ft (15.1 miles). The river consisted of the transition zone (1%), chutes and ledges (20%), shallow habitats (35%), medium-depth habitats (34%), and deep habitats (10%). The percentages were used to proportionately weight each transect in the habitat model. Water depth was used as a first sort, habitat was second, river-bottom material was third, and substrate was fourth.

From Discussion. The presentation of guidelines for the collection of data was also another important aspect of this research project. The following is a suggested list of guidelines for the collection of data for future habitat-typing studies.

1. Select professionals familiar with the study area.
2. Interpret low-altitude aerial photos obtained during periods of low flow when trees are leafless.
3. Field map habitat at discharge approximating flow of interest.
4. Compile/organize field notes and maps.
5. Develop classification hierarchy.
6. Field check data.
7. Assign segments and habitat transects to represent the distribution of habitat types on the river (weighting).
8. Produce final maps and tables.

The purpose of habitat typing was to allow weighting of microhabitat transect data collected at transects located at varying distances apart to be used in the instream flow model. In this way most of the habitat in a whole river study segment may be described by extrapolating from a few transects. It had been most common to design studies around representative reaches or reaches representing critical habitat. Morhardt et al. (1983) indicated that habitat mapping could be conducted before or after microhabitat transect data have been collected. Based on our experience on the Salmon River, we believe it would be more desirable to choose the location of microhabitat transects based on the results of microhabitat typing rather than place preselected microhabitat transect data in a typing scheme. The authors acknowledge that this is a very subjective statement and the influence on results are unknown. However, the statement is based on the knowledge that microhabitat transect placement would be somewhat affected by the method employed.

From Conclusion. Habitat typing using low-altitude aerial photographs together with ground truth was found to be a reliable method of classifying aquatic habitat types in the Salmon River study area. Input and critique by professionals familiar with the study area were not only desirable but were important aspects of this research. Quantification of habitat by depth (shallow, medium, deep); habitat type (run, riffle, pool, chute, ledge, transition zone); river bottom (loose material, loose material/bedrock); and substrate (later dropped) resulted in the classification of habitat segments into discrete habitat types. This scheme allowed a major portion of the study area to be represented by 24 microhabitat transects that were weighted proportionately to represent aquatic habitat. Habitat typing schemes have been successfully used on many studies and can be adapted to the specific characteristics of each study area.

EXAMPLE DESCRIPTION OF HABITAT TYPES
Habitat types used in the South Platte River of Colorado by Thomas and Bovee (1993) included:

LOW GRADIENT RIFFLE - No backwater effect. Water surface profile roughly parallel to thalweg profile and controlled by channel friction. Hydraulic gradient <0.003. Cross section uniform with depth <45 cm at low flow.

HIGH GRADIENT RIFFLE - No backwater effect. Water surface profile often appears 'stair-stepped'. Hydraulic gradient >0.003. Substrate consists mostly of boulders, with plunge pool formation among boulders below drops and small waterfalls. Transects highly varied with isolated deep areas.

POCKET WATER - No backwater effect for habitat type, but localized areas of backwater exist. Abundant random structural cover, usually scattered large boulders, creating many areas of low velocities (pockets) adjacent to high velocities. Depths and velocities change abruptly over short distances.

DEEP POOL - Strong backwater effect from downstream hydraulic control. Maximum depth >2 m at low flow. At least 25% of stream bed obscured by depth or structural cover.

MODERATE POOL - Strong backwater effect from downstream hydraulic control. Maximum depth 1-2 m at low flow. At least 25% of streambed obscured by depth or structural cover.

DEEP RUN/SHALLOW POOL WITH COVER - Moderate to weak backwater effects. Pool depth at thalweg 0.5-1 m at low flow. At least 25% of streambed contains structural cover.

DEEP RUN/SHALLOW POOL WITHOUT COVER - Moderate to weak backwater effects. Pool depth at thalweg 0.5-1 m at low flow. Little or no structural cover present.

CHUTE - Very deep, narrow channel incised in bedrock. Depths exceed 3 m at low flows, with moderate to high velocities at all but the lowest flows. Cover is sparse to non-existent.

Segmentation of the study area into reporting units is frequently done. Some further level of stratification of the study area (beyond study area segmentation) is recommended for consideration. One level of stratification, in combination with habitat types like those used above, has been useful in the Trinity River of northern California.

Strata M - heavily man-influenced by mining operations over the last 150 years
Strata R - heavily influenced by riparian woody vegetation encroachment since the closure of the dams in the 1960's
Strata B - heavily influenced by formation of a berm that limits flows to the main channel even at flows of 3000 cubic feet per second.
Strata N - more natural and less man-influenced by mining operations, riparian vegetation encroachment, and berm formation

Sampling schemes probably should be set up on the basis first of strata and then habitat types.

HABITAT MAPPING OPTIONS

Source: Williamson, S.C., et al. 1993.

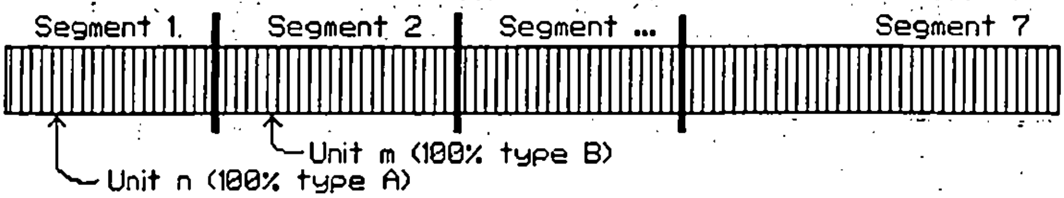
We considered four options for describing distribution of habitat availability in a study area (Figure 6). Option A is a representative reach mapping approach with equal length computational units and unequal length stream segments. For each stream segment, one flow:habitat function is calculated. This option assumes that habitat variability between stream segments is more important than habitat variability within segments. This type of mapping was once the recommended approach but has been replaced by the habitat mapping approach. For extremely large study areas, a combination of the habitat mapping approach within a stratified random sample of representative reaches is recommended.

Option B is a habitat mapping approach with unequal or equal length computational units. For each computational unit, one flow:habitat function is calculated and each unit may and frequently will have a unique function. Each identifiable habitat type is described by one or more PHABSIM transects (Morhardt et al., 1983). This option assumes that habitat variability between computational units is more important than habitat variability within computational units. This type of mapping is the one recommended for most applications.

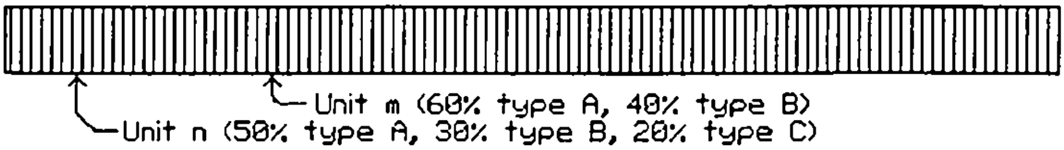
Option C is a mesohabitat mapping approach with objectively identifiable boundaries of unequal-length mesohabitats. For each mesohabitat type (not each computational unit), a unique flow:habitat function is calculated and each mesohabitat type may have a unique function. There is some homogeneity between computational units that are not immediately adjacent, so some level of stratification of computational units may be used. Option C assumes that variability between mesohabitat types is more important than habitat variability within mesohabitat types. This type of mapping is exemplified by the salmonid population and production model SALMOD of the Midcontinent Ecological Science Center.

Option D is a cell-by-cell mapping approach with unequal length computational units. For each PHABSIM cell (not each computational unit), a unique flow:habitat function is calculated within each mesohabitat type to account for the cross-sectional heterogeneity of the stream environment. Each cell by mesohabitat type may have a unique flow:habitat function. Computational units are delineated as in Option C. In this model, calculated movement between computational units would be replaced by calculated movement between usable habitat. Option D assumes that habitat variability between PHABSIM cells is more important than habitat variability within PHABSIM cells. This type of mapping is exemplified by the compensatory mechanisms models COMPMECH of the Electric Power Research Institute.

Option A. Homogeneous habitat assignment to fifty 1-km long computational units within seven stream segments for the Trinity River study area.



Option B. Percentage habitat assignment to fifty 1-km long computational units.



Option C. Homogeneous habitat assignment to 600 unequal length mapped computational units for the Trinity River study area.

Option D. Homogeneous habitat assignment to 600 unequal length mapped computational units to the cell-by-cell field measurement level.

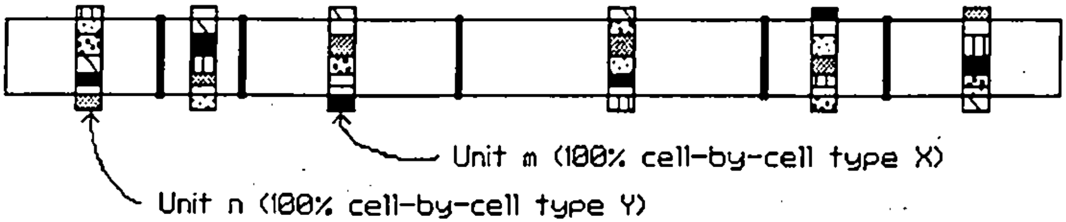


Figure 6. Four spatial modeling options considered for use. Options A and B represent the entire study area while C and D represent only a small portion of the study area.

CHAPTER 7: HABITAT MODELS

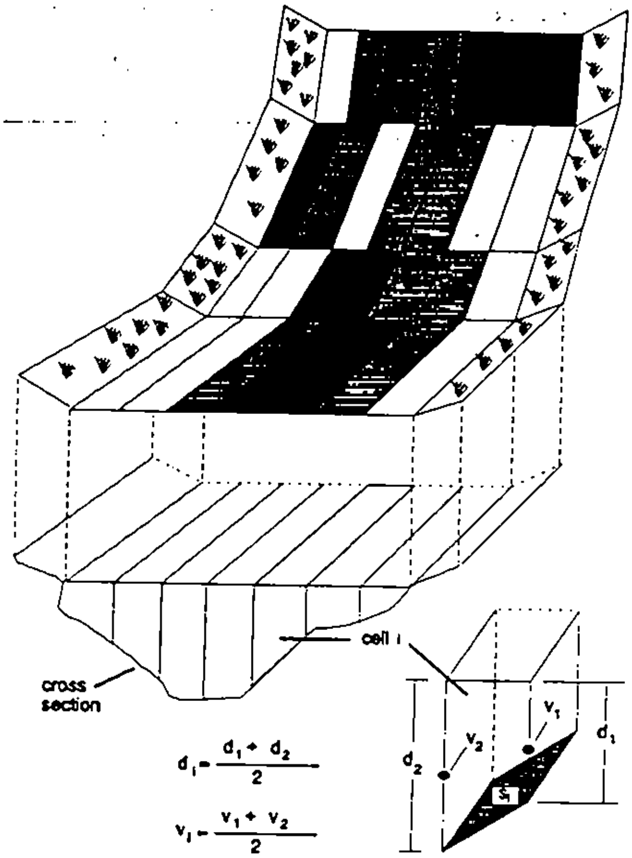


Figure 1. Relationship between component cell attributes that define a habitat cell for use in the habitat modeling process.

An appropriate hydraulic model has been applied to determine characteristics of the stream in terms of depth and velocity as a function of discharge. This information is now integrated with habitat suitability curves to produce a measure of the relationship between available habitat and discharge. The habitat modeling and habitat mapping steps are the most controversial and sensitive portions of the PHABSIM system. Figure 1 shows the basic representation of the channel cross section information for a series of transects that define a grid of habitat cells with their associated attributes of depth, velocity and channel index (i.e., substrate and cover).

The Instream Flow Incremental Methodology assumes that flow-dependent physical habitat and water temperature may either increase or limit carrying capacity and therefore can be used to help manage the standing crop of fish in streams. In riverine systems, the amount and quality of suitable habitat can be highly variable within and among years. The observed population and biomass of fish and invertebrates may be depressed or stimulated by numerous preceding habitat events. Habitat-induced population limitations are related to the amount and quality of habitat available to fish and invertebrate populations at critical stages in their life history. Long term habitat reductions, such as reduced flows, may also be important in determining population and production levels. We limit PHABSIM use to river systems in which dissolved oxygen, suspended sediment, nutrient loading, other chemical aspects of water quality, and interspecific competition do not place the major limits on populations of interest.

The most common estimate of fisheries habitat potential is a combination of habitat quantity (the usable area) and quality (the weighting) referred to as Weighted Usable Area (WUA). Habitat potential frequently serves as input to some framework of project assessment and negotiating an instream flow. PHABSIM has been examined to determine its sensitivity to hydraulic simulation error, (Osborne et al. 1988), selection of options used to simulate microhabitat (Gan and McMahon 1990), and errors in habitat suitability curves (Shirvell 1989; Thomas and Bovee 1993; Waddle 1993). Recognition of these sources of uncertainty and their relative magnitudes is important in analysis and interpretation of PHABSIM results in the instream flow negotiation process.

HABITAT SUITABILITY CURVES

The habitat model relies on curves relating hydraulic and channel characteristics to the habitat requirements of fish. These habitat suitability curves (also known as habitat suitability criteria, habitat suitability index or SI) describe the adequacy of various combinations of depth, velocity and channel conditions. The habitat model uses the habitat suitability curves, the simulated depths and velocities, and the recorded substrate and cover information to produce the habitat measure. This measure is known as weighted usable area (WUA) and has units of square feet per 1000 linear feet of stream length (regardless of stream width).

ASSUMPTIONS OF HABITAT MODELING

- Individuals select the most nearly optimum conditions within a (nearly steady-state) stream and will use less favorable areas with decreasing priority.

- Stream physical habitat parameters (depth, velocity, substrate, cover) can be depicted by a set of rectangular cells using conditions at the cell boundaries or centroids.

- Choice conditions for individual components of physical habitat can be represented (weighted) by a "suitability index" valued from 1.0 (optimum habitat) to 0.0 (unlivable habitat) that can be developed in an unbiased manner.

- Each cell can be evaluated independently by multiplying its area by its suitability index to form "weighted usable area".
- A meaningful "composite suitability index" can be mathematically calculated from a combination of several different suitability indexes.
- Individual cell values for weighted usable area can be summed to form "total weighted usable area" which is a meaningful comparative measure of overall stream habitat.

WUA is:

$$WUA = \sum_{i=1}^{n} \left(\prod_j S_{jk}\right)^x A_i / L \qquad (68)$$

where:

A_i is the surface area of cell i.
S_{jk} is the jth SI curve value for life stage k.
i is the cell index, which runs from 1 to n.
j is the index for SI characteristic, and
x is usually 1, but can be j.
L is the reach length in 1000's of feet.

STEPS

1. Define what constitutes microhabitat for the evaluation organism. Which variables are important? What ranges of conditions are suitable, unsuitable, optimal, and marginal? Develop habitat suitability curves on a scale from zero to one, one being optimum and zero unsuitable.

2. Describe the distribution of microhabitat variables. Use line-transect methods to quantify lateral and longitudinal distributions of physical attributes. Stream reaches are depicted as many small trapezoidal cells each with a discrete combination of physical attributes along with surface area and volume.

3. For each cell, the relative suitability for the appropriate combination of variables is calculated for each simulated flow. For example, use the juvenile rock bass habitat suitability curves. The cell has the following attributes: (a) Depth = 1.5 feet; (b) Mean column velocity = 0.4 fps; (c) Cover type = 3 (emergent vegetation/submerged branches); and (d) Surface area = 20 square feet. Read the SI value for each variable from the SI Curves: (a) SI (depth) = 0.75; (b) SI (velocity) = 0.67; and (c) SI (cover) = 0.75. Calculate Composite Suitability Index (CSI) for the combination of cell attributes: (a) Standard calculation is CSI = SI(depth) * SI(velocity) * SI(cover); and (b) CSI for this cell = 0.75 * 0.67 * 0.75 = 0.38. Calculate Weighted Usable Area for cell: WUA = Surface Area * Composite Suitability Index. WUA = 20 square feet*0.38 = 7.6 ft^2

4. Repeat step C for remaining cells: Determine cell attributes at other discharges. Repeat step C for all cells, with new cell attributes corresponding to discharges in Step E.

SUITABILITY INDEX AGGREGATION TECHNIQUES

Once the individual component suitabilities have been determined, the user has the option to select several different ways of aggregating these component suitabilities for a cell into a single cell's composite suitability index. A **multiplicative aggregation** can be employed (considered the default) and is given by:

$$C_i = V_i * D_i * S_i \tag{69}$$

where

C_i = Composite suitability index of cell i.
V_i = Suitability associated with velocity in cell i.
D_i = Suitability associated with depth in cell i.
S_i = Suitability associated with channel index in cell i. Frequently, channel index is not used or is used as a binary variate.

The component attributes of each cell are evaluated against the species and life stage habitat suitability curve coordinates for each attribute to derive the component suitabilities. This process is illustrated in Figure 2.

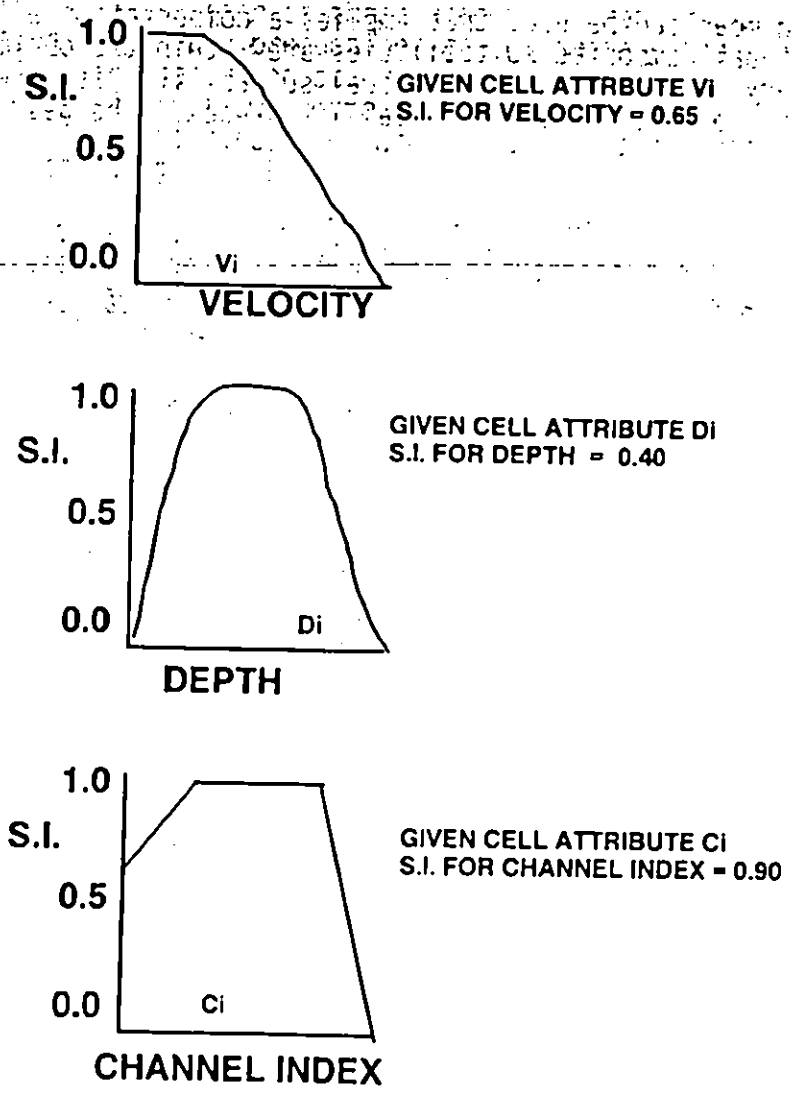


Figure 2. Determination of component suitabilities for individual cell attributes. Channel index is carried across from the data deck. not simulated.

The geometric mean can be used that implies a compensation effect. If two of three individual composite suitabilities are within the optimum range and the third is very low, the third individual suitability has a reduced effect on computation of the composite suitability index. The geometric mean is calculated as:

$$C_i = (V_i * D_i * S_i)^{1/3} \tag{70}$$

A most limiting factor (Liebig's Law of the Minimum) can be used to aggregate individual suitability factors by:

$$C_i = Min(V_i, D_i, S_i) \tag{71}$$

A conditional aggregation can be constructed by using one or more of the factors as a binary variate (0=unacceptable, 1=acceptable) and leaving just one factor as a continuous variate. This approach, like the most limiting factor, skirts the assumption that "A meaningful 'composite suitability index' can be mathematically calculated from a combination of several different suitability indexes." By their dimensionless and relative-value nature, indexes are not rigorously applicable on an absolute-value scale (viz., an index times a variable produces and index, not a variable). As more calculations are made with an index, the more nearly an absolute-value scale is implied and needed. With suitability indexes, the least number of continuous-value indexes in the calculations usually produces the most rigorous results.

Once the composite suitability index C_i has been determined the amount of Weighted Usable Area (WUA) is computed according to the following equation:

$$WUA = \sum_{i=1}^{n} A_i * C_i \tag{72}$$

where:

WUA = Total Weighted Usable Area in stream at specified discharge.
C_i = Composite suitability index for cell i.
A_i = Vertical view area of cell i.

ADDITIONAL ASSUMPTIONS IN PHYSICAL HABITAT MODELING

1) The four major components of a stream system that determine productivity for aquatic animals (Karr and Dudley 1978) are: (1) flow regime, (2) physical habitat structure (e.g. channel form and substrate distribution), (3) water quality (including temperature), and (4) energy inputs from the watershed (nutrients and organic matter).

2) The complex interaction of these components determines primary production, secondary production, and ultimately the status of fish populations in the stream study segment.
3) Physical habitat and flow regime (not water quality, temperature, nutrients, organic matter, or other factors) are limiting the population size and standing crop.

It should be emphasized that predictions of PHABSIM are made in terms of changes to physical properties of aquatic microhabitat (i.e., velocity, depth, and channel index) and do not predict changes in biomass of organisms (the next generation of the Instream Flow Incremental Methodology is in the model verification and validation stage). Much of the criticism in the literature stems from PHABSIM results being applied and interpreted without consideration for other population- and production-limiting factors such as water quality, temperature, food availability, and angling mortality.

Figure 3 shows the actual stream location for adult cutthroat trout in St. Charles Creek, Utah as a function of predicted cell suitabilities under conditions of abundant food resources. The small blocks in the grid are observed fish positions.

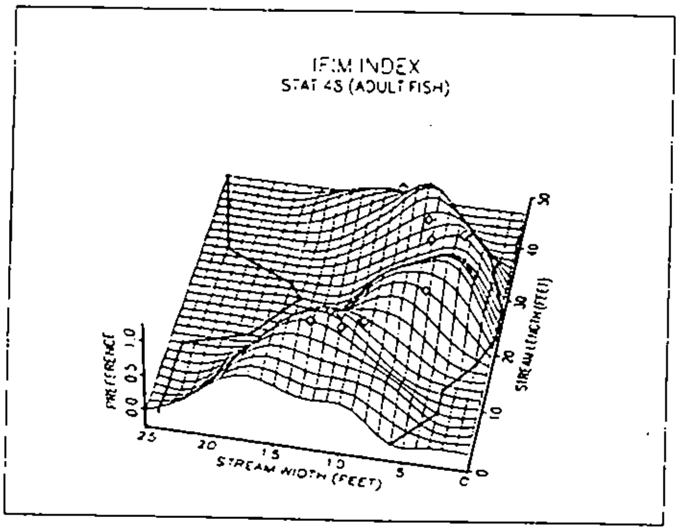


Figure 3. Predicted and observed stream location for cutthroat trout.

Figure 4 shows predicted and observed stream locations based on the net energy equivalence (gross energy input minus swimming and metabolic rate) for observed food densities. Figures 3 and 4 show essentially the same results. However, Figure 5 shows net energy equivalence for the same stream section in the absence of food and clearly shows that PHABSIM results in this instance would predict location of cutthroat trout in highly unfavorable energetic habitats.

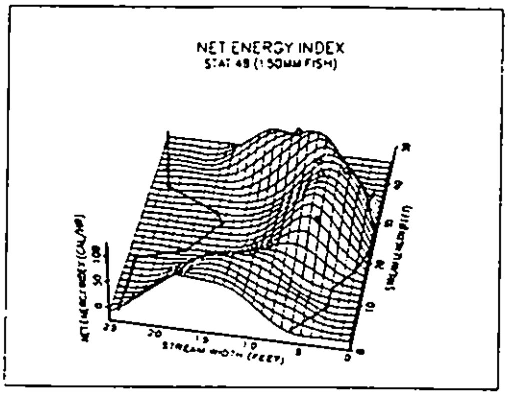


Figure 4. Predicted and observed fish locations using an energy balance model.

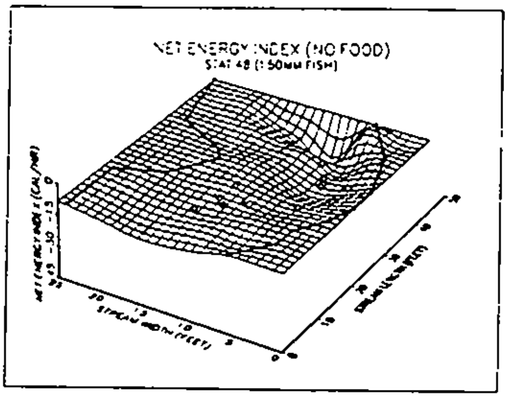


Figure 5. Comparison of PHABSIM predicted locations under no food conditions.

CHAPTER 8: HABITAT SUITABILITY CURVES

Introduction

Although hydraulic modeling merits close attention to quality assurance, it is well recognized that the most controversial aspect and largest source of error in PHABSIM lies in habitat modeling. In particular, great care needs to be employed in constructing and using habitat suitability curves with sufficient generality, reality, and precision to adequately reflect a fish species' selection of microhabitat in the study stream (Heggenes 1990).

Major questions include whether universal or river-specific suitability curves should be applied (Belaud et al. 1989; Orth 1987), whether microhabitat selection is a manifestation of habitat availability (Heggenes 1990; Shirvell 1989; Morhardt and Hanson 1988), and whether microhabitat selection by drift feeding salmonids is influenced by stream productivity (Smith and Li 1983; Bachman 1984; Fausch 1985). Nonparametric statistical methods have been developed for evaluating the transferability of a particular set of habitat suitability curves to a particular stream (Thomas and Bovee 1993).

Some background orientation into the development of habitat suitability curves is necessary to better understand their appropriate use in PHABSIM analyses. The reader is referred to Information Paper No. 21 "Development and Evaluation of Habitat Suitability Criteria for use in the Instream Flow Incremental Methodology" (Bovee 1986). This paper discusses data collection, gear limitation and sampling bias as well as data analysis techniques. The work also addresses issues related to validation and verification of habitat suitability data sets.

The Instream Flow Incremental Methodology (IFIM) is a habitat-based tool used to evaluate the environmental consequences of various water and land use practices. As such, knowledge about the conditions that provide favorable habitat for a species, and those that do not, is necessary for successful implementation of the methodology. In the context of the IFIM, this knowledge is defined as habitat suitability criteria: characteristic behavioral traits of a species that are established as standards for comparison in the decision making process. A prerequisite of any habitat-based methodology is knowledge about those conditions that constitute habitat and those that do not. The fact that different species of fish and macroinvertebrates occupy different habitat types in streams is intuitive to anyone who has spent any time observing the animals in the wild. There is a difference, however, between this intuitive knowledge and the ability to quantify the microhabitat characteristics selected by the organism. The quantification of these characteristics is what distinguishes microhabitat suitability curves from natural history descriptions.

Defining Who and When in Use of Habitat Suitability Curves

An initial step in any IFIM study is the designation of what species and life stages are to be considered in the analysis. This may not necessarily involve all species and life stages present in a river or may even involve the use of a species that presently is absent. Once the species and life stages have been identified, a species and life stage periodicity chart should be constructed in order to focus the investigator on key time periods during the year. An example of a typical species and life stage periodicity chart is provided in Figure 1. What should be evident is that the year can be broken down into discrete periods based on the presence and/or absence of specific species and life stages.

	Fall		Cold Season				Spring			Summer		Fall
Species - Life Stage	O	N	D	J	F	M	A	M	J	J	A	S
Western Silvery Minnow Adult	X	X					X	X	X	X	X	X
Plains Minnow Adult	X	X					X	X	X	X	X	X
Speckled Chub Adult	X	X					X	X	X	X	X	X
Flathead Chub Adult	X	X					X	X	X	X	X	X
Flathead Chub Ad/Juv			X	X	X	X						
River Shiner Juvenile										X	X	
River Shiner Adult	X	X					X	X	X	X	X	X
Red Shiner Juvenile	X	X								X	X	X
Red Shiner Adult	X	X					X	X	X	X	X	X
Sand Shiner Juvenile										X	X	
Sand Shiner Adult	X	X					X	X	X	X	X	X
Sand Shiner Ad/Juv			X	X	X	X						
River Carpsucker Juvenile	X	X								X	X	X
Channel Catfish Adult	X	X					X	X	X	X	X	X
Channel Catfish Juvenile	X	X					X	X	X	X	X	X
Channel Catfish Ad/Juv			X	X	X	X						
Flathead Catfish Juvenile	X	X						X	X	X	X	X

Figure 1. Example of a species and life stage periodicity chart.

TERMS AND DEFINITIONS FOR HABITAT MODELING

Instream physical habitat availability has been conceptualized and calculated with widely differing levels of complexity. The best-known are:

USABLE AREA {or volume} that may be divided into several categories such as optimal and marginal, is the area that falls within some set of values for one or more environmental variables. The data for constructing discontinuous-value bar graphs for suitability curves should be habitat utilization observations from the stream of interest, if possible. Suggested habitat categories have included: a) two categories - usable versus unusable; b) three categories - optimal, marginal; and unsuitable (including unusable); c) four categories - optimal, desirable, marginal, and unusable; and d) five categories - most desirable, desirable, least desirable, undesirable, and unused. Unfortunately, the terminology of the categories is ambiguous. The terms unused, unusable, undesirable, and unsuitable can refer to habitat in which fish were not found in the study stream (e.g., water too deep or shallow), habitat in which the fish could not hold for long (e.g., water velocity too high or low), and to habitat in which the fish could not survive for long (e.g., water temperature too high). In your study document, please specifically define the categories that you use.

WEIGHTED USABLE AREA {or volume} is usable area as defined above with each cell multiplied by a suitability index calculated for that cell. Summing is done across all cells in a cross-section or study segment. This converts total area, some of which is usually low value habitat, into units of prime (1.0-valued) habitat. Data for constructing continuous-value line graphs for suitability curves should be habitat use observations from the stream of interest. Mathematically, a unit-less index multiplied by an area produces an area (weighted usable area). Logically and statistically, however, multiplying a unit-less index times an area produces an usable area index (Gan and McMahon, 1990).

SUITABILITY INDEX is a 0.0 up to +1.0-valued (unit-less) scalar that imparts a relative value to habitat area compared with unacceptable (zero-value) and optimum (one-value).

To closer approximate ecological concepts, the following formulations are also used:

PREFERRED:AVOIDED AREA {or volume} is the usable area {or volume} as defined above with each cell multiplied by a -1.0 to 0.0 to +1.0-valued scalar {similar to correlation coefficients} that implies the relative value of that area compared to: unacceptable (-1.0; habitat not in the species' niche space or actively avoided habitat); neutral (0.0; available habitat used but not selected for by this species); and preferred (+1.0; available habitat selected for by this species if not already occupied).

HABITAT PREFERENCE INDEX is an alternative formulation to preferred:avoided area in which habitat use observations are divided by habitat availability for the stream of interest. Habitat preference indices have been widely used, but have some undesirable statistical and mathematical properties and generally are not transferable to other river basins. The only linear measure of preference is Strauss' linear electivity index (LE = r - p), where r = habitat use and p = habitat availability for the stream of interest.

MINIMUM VIABLE NICHE is the usable area (or volume) as defined above but taking into account that a number of different life-sustaining requirements (found in different cells) need to be in close proximity (i.e., using PHABSIM's adjacent velocity criteria) for those cells in the aggregate to adequately support n organisms of a particular life stage and size. Shear velocity zones, areas of rapid velocity change, have been shown to be an important hydraulic characteristic present in the microhabitat preferred by juvenile and adult salmonids. These shear zones provide escape cover and opportunistic feeding stations in slow velocity water while in close proximity to higher velocity water where drifting food is more accessible and abundant. Minimum viable niche can be more precise in estimates of carrying capacity, but are not transferable to other river basins with different habitat present.

OPTIMAL, SUITABLE, MARGINAL, UNSUITABLE, UNUSABLE HABITAT

A key element to the IFIM is the development of habitat suitability curves for the target species of concern. Categories of habitat suitability curves refer to how they were developed, the kind of data used to generate the curves, and how those data have been processed.

CATEGORY I HABITAT SUITABILITY CURVES are intended to be general (usable across the geographic range of a species) and are based on information other than field observations made specifically for the purpose of curve development in the target stream. These curves are termed "tolerance ranges and optimal conditions" and are derived from life history studies in scientific literature and from professional experience and judgment. Category I curves should be used in low-effort IFIM studies.

CATEGORY II HABITAT SUITABILITY CURVES are intended to be realistic (represent the specific stream and species) and are based on frequency analysis of field data on microhabitat conditions utilized by different life stages and species in the target stream. These curves are termed "utilization functions" should be developed across a broad range of flows and depict conditions that were being used when the observations were made. Utilization functions may not accurately describe a species' preferences because the preferred conditions may be in short supply. The Fish and Wildlife Service strongly recommends the development and use of Category II curves (in conjunction with tolerance ranges and optimal conditions from Category I curves) in high-effort IFIM studies.

CATEGORY III HABITAT SUITABILITY CURVES are intended to be more accurate (provide an unbiased estimator), but are highly stream specific. These curves are termed "preference functions" because they attempt to correct for availability bias by factoring out the influence of limited habitat choice. The purpose of this correction is to increase the transferability of the curves to streams that differ from those where the curves were originally developed, or in the same stream at different flows. There is strong evidence that correction for availability can produce even more biased curves and that Category III curves are usually not transferable to other streams. Extreme caution and a professional statistician should be used with development of Category III curves.

DEVELOPMENT OF HABITAT PREFERENCE CURVES FOR ANADROMOUS SALMONIDS

Direct observation techniques using a mask and snorkel were used to collect microhabitat suitability criteria describing depth, velocity, cover, and substrate used by anadromous salmonids of the Trinity River in Northern California (Source: Hampton 1988). Frequency distributions derived from continuous data seldom result in smooth curves (Figure 2). One method of alleviating inconsistencies is to increase the interval width (also called bin size). To what extent the intervals should be increased is often unclear. For construction of depth and velocity utilization curves the interval size used for each frequency distribution was calculated using Sturges Rule as cited by Cheslak and Garcia (1987). Sturges Rule provides an estimate of optimum interval size based on data provided as follows:

$$I = R \,/\, (1 + (3.322 * \mathrm{LOG}_{10}N))$$

where:
I = Optimum interval size
R = Range of observed values
N = Number of observations taken

A frequency bar histogram was constructed. The midpoints of each interval were then connected by a straight line. The resulting curve was then subjected to two series of three point running mean filters in order to reduce any noise in the form of large deviations between adjacent intervals if necessary. The interval containing the most observations was assigned a value of one and each of the remaining intervals were given a value proportional to its relative occurrence.

Preference curves describing mean column velocities preferred by chinook salmon and steelhead trout deviate significantly from the representative utilization curves (Figure 20). For all three species, high preference values correspond with low utilization values located in the upper limits of each utilization distribution where high water velocities are present. A closer examination of the spawning velocity use data revealed the source of these high preference values. When mean column water velocities begin to exceed about 3.0 feet per second, both the utilization and availability distributions begin to approach zero. This resulted in small probability ratios for both utilization and preference as can be expected, however, the ratio between use and availability ($P_i = U_i/A_i$) remained fairly large. Therefore, a large preference value resulted. It appears that the behavioral selection of one individual within the population yielded a misrepresentation of the actual preference for the majority of the population.

When both the use and availability distributions simultaneously enter the limits of their distributions there is a danger of misrepresenting actual preference simply because of small probability ratios involved. In these instances it is important that the investigator has a good understanding for the species under study so that any extraneous preference values can be recognized and corrected. To eliminate the influence of these outliers within the spawning velocity distributions for each species. I applied nonparametric tolerance limits which would include 90% of the use observations at a 90% confidence level. Tolerance limits were obtained from a table developed by Somerville as presented by Bovee (1986). Utilization and preference curves were then recalculated using those frequency values that fell within the 90% tolerance levels established.

It appears that juvenile chinook salmon and steelhead trout do not exhibit a strong preference for a particular depth range. Observations in the field have led me to believe that water velocity is the critical hydraulic parameter that determines final microhabitat selection for these two species and life stages during the spring, summer, and early fall months. A comparison of preference curves developed in this study with published use curves describing mean column velocities selected by spawning chinook salmon is present in Figure 24.

Shear velocity zones, areas of rapid velocity change, proved to be a critical hydraulic characteristic present in the microhabitats selected by juvenile chinook salmon and steelhead trout. These shear zones provided opportunistic feeding stations for juvenile salmon and trout where focal points could be established in slow velocity areas and yet still be in close proximity to higher velocity areas where food, available in the form of drift, is more easily accessible and more abundant. Net energy gain in these microhabitats is probably optimized because less energy is used to maintain focal points and distances traveled to capture prey items are reduced. Lisle (1981) describes the importance of large roughness elements (boulders and woody debris) as a key resource to fish habitat by providing a diversity of channel form and substrate conditions. These same roughness elements also provide important rearing habitat for anadromous salmonids by increasing velocity diversity through the formation of shear velocity zones. Habitat suitability curves based on focal point velocities, either taken as mean column water velocities or as fish nose velocities, fail to measure the presence of these shear velocity zones that are located adjacent to focal points and, therefore, may misrepresent actual fish habitat preferences for rearing salmonids. Preference curves that consider both focal point velocities and adjacent cell velocities would be a better measure of fish preference in these instances.

The concept that preference curves, by eliminating habitat bias, may be transferred to other streams or rivers is questionable. Development of preference curves depends on the available habitat within the area of study. It is important to validate that the available habitat in the system where the preference curves are being considered for use is similar to the available habitat present in the system where the preference curves were developed.

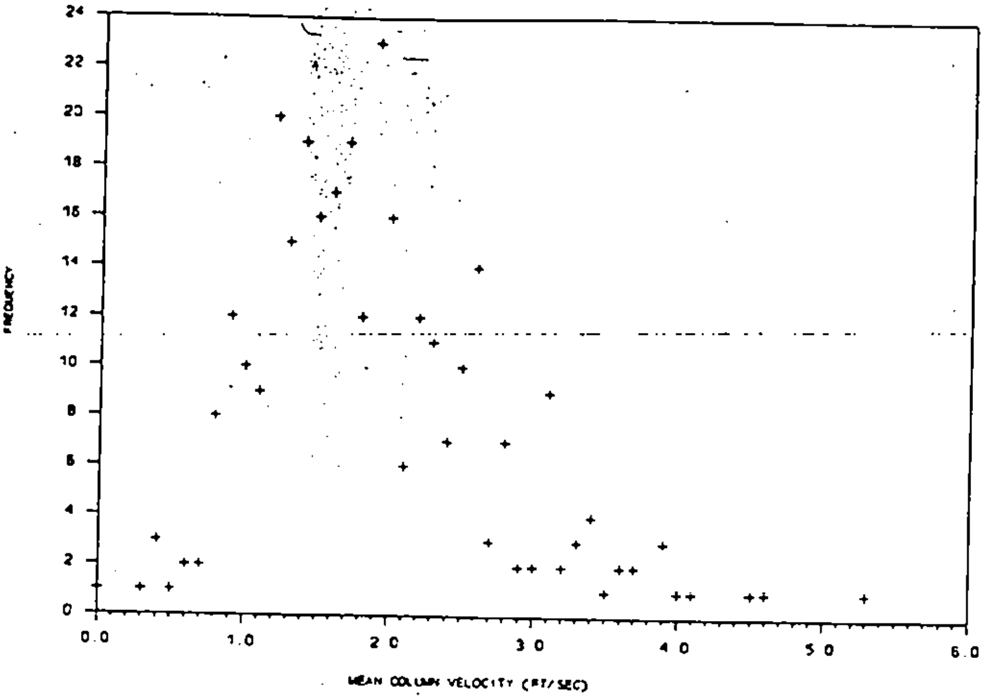


Figure 2. Observed frequency distribution of mean column velocities selected by spawning chinook salmon in the Trinity River, California, 1985-1987.

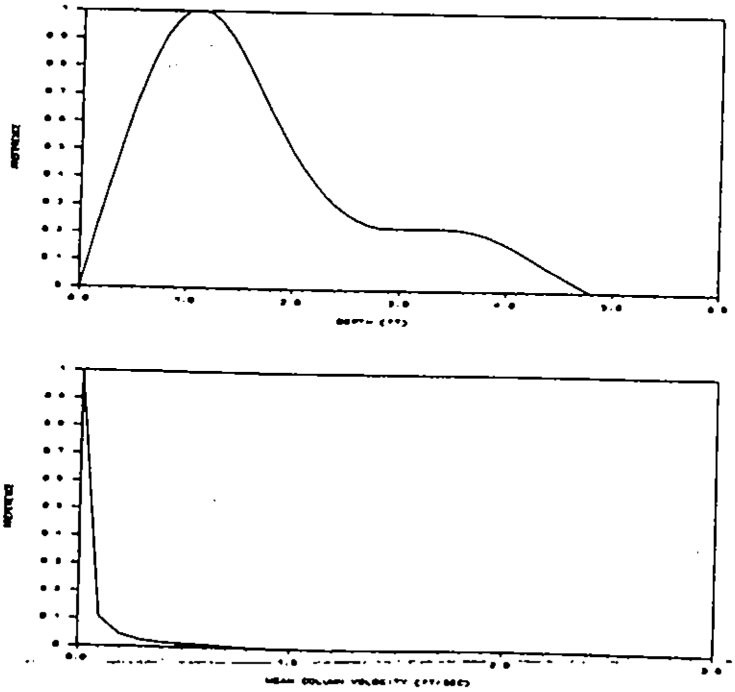


Figure 10. Habitat preference criteria for total depths and mean column velocities selected by coho salmon fry in the upper Trinity River, CA., 1985-1987.

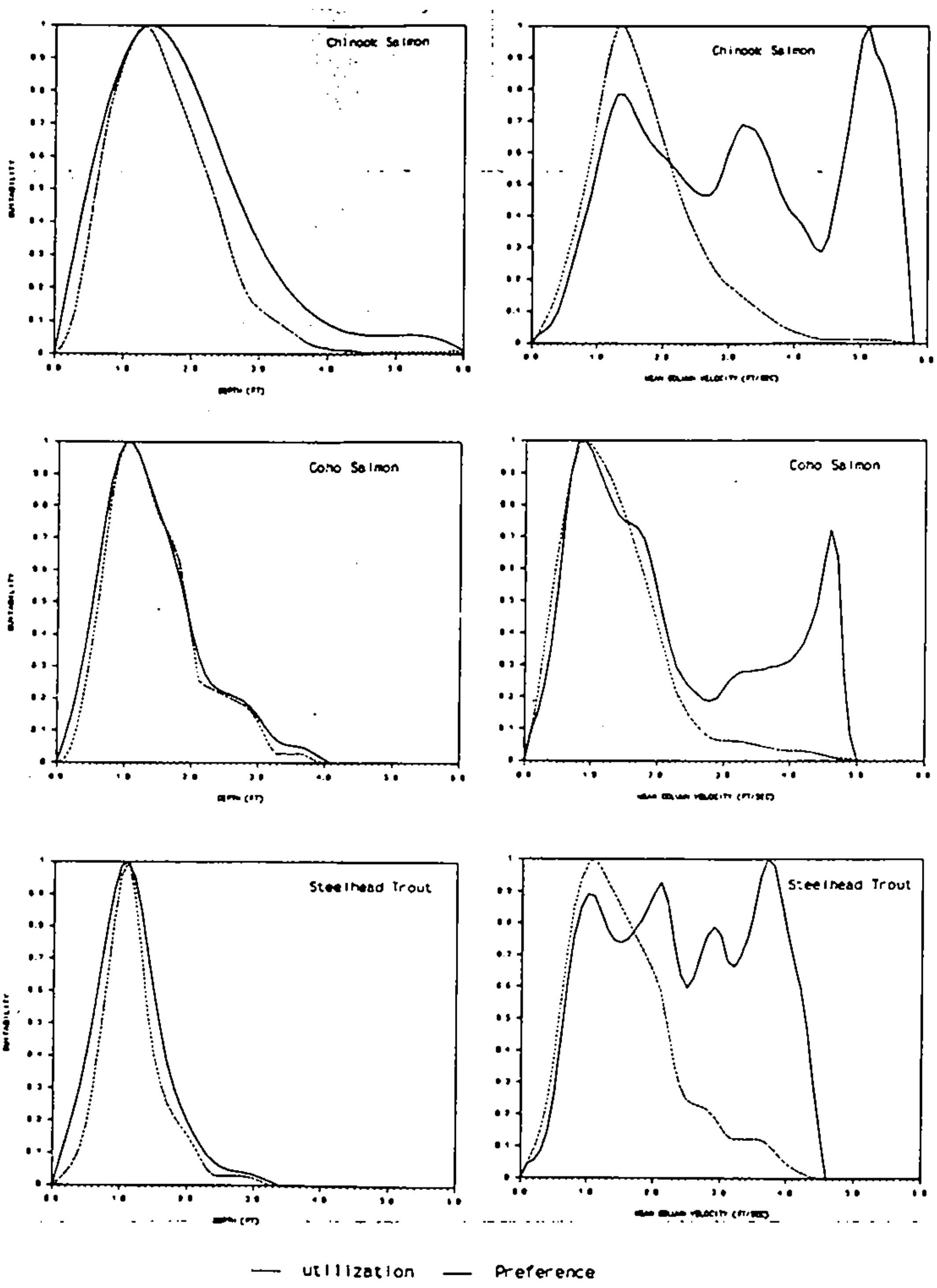


Figure 20. Habitat use and preference criteria for total depth and mean column velocity for spawning chinook and coho salmon and steelhead trout in the upper Trinity River, CA., 1985-1987.

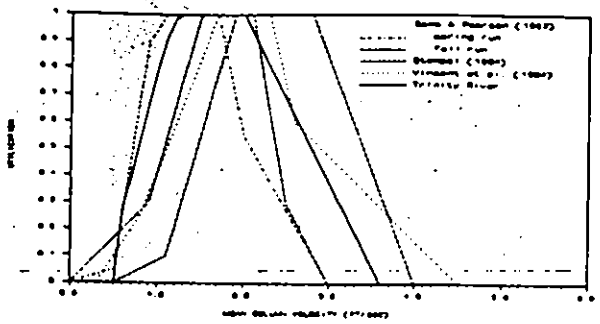


Figure 24. Comparison between preference criteria developed in the upper Trinity River with use criteria developed by other researchers for mean column velocities selected by spawning chinook salmon

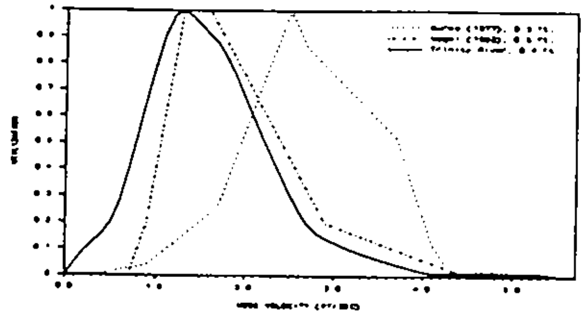


Figure 25. A comparison between use criteria of fish nose velocities selected by spawning chinook salmon in the upper Trinity River with spawning chinook salmon observed by other researchers in different systems

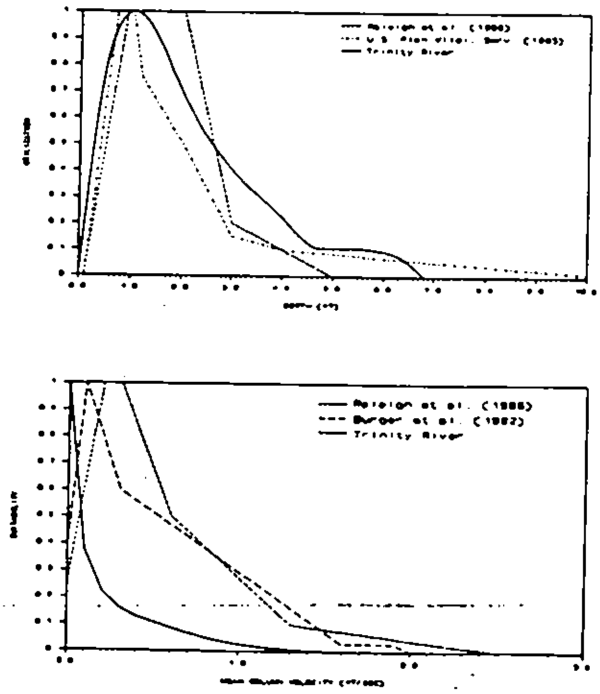


Figure 26. Comparison of preference criteria developed in the upper Trinity River with suitability criteria developed by other researchers for chinook salmon fry

THE MICROHABITAT COMPONENT

Habitat Suitability Curve Formats

There are several ways to express habitat suitability in graphical form. The easiest and least theoretical approach of distinguishing among the different types of microhabitat suitability curves is by the formats in which they are expressed. Three formats can be used with PHABSIM: binary criteria, univariate curves, or multivariate response surfaces. The differences between these formats are illustrated in Figure 2.

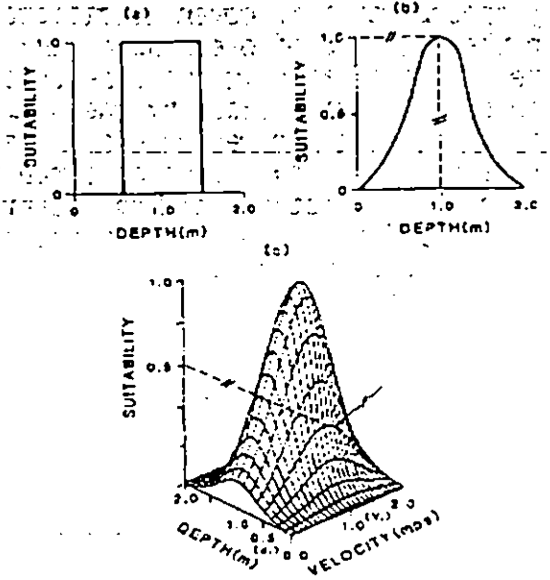
Binary Format

The binary (step function) format establishes a suitable range for each variable as it pertains to a life stage of interest, and is represented graphically as a step function (Figure 2a). The quality rating for a variable is 1.0 if it falls within the range established by the criteria. Any variable outside the criteria range is given a value of 0.0, which renders the cell unusable regardless of the quality assigned to the other variables. Therefore, a cell can be considered to be suitable habitat only if all the variables fall within their respective suitable ranges. The range considered to be usable is typically quite broad, often encompassing the conditions that 80 to 95% of the individuals are likely to inhabit.

Univariate Format

The univariate (continuous value) curve format establishes both the usable range and the optimum range for each variable, with conditions of intermediate usability expressed along the portion between the tails and the peak of the curve. Waters (1976) suggested the use of weighting factors between 0.0 and 1.0 to define habitat suitability for fish. He argued that, within the range of conditions considered suitable, there is a narrower range that fish select as preferred or optimal for that variable. This format expresses the behavioral characteristics of an animal as a series of univariate curves, rather than the block or step functions expressed by binary curves. The univariate curve format is shown in Figure 2b. The peak of the curve represents the most suitable, most used, or most preferred range for each variable. The tails of the curve represent the bounds of suitability for each variable. Conditions of intermediate suitability are expressed along the portion between the tails and peak of each curve. The preferred technique of determining values between 0.0 and 1.0 is to fit a curve to a frequency distribution of empirically derived data. Sometimes, only the optimal range and the locations of the tails are known, and intermediate values are estimated by either straight line or curvilinear connections between 0.0 and 1.0 on the curve.

Figure 2



Multivariate Format

Multivariate probability density functions can be used to compute suitability for several variables simultaneously. They are conveyed as three dimensional figures with suitability on the z-axis, and two independent variables on the x-y plane. An example of a three-dimensional orthogonal response surface is shown in Figure 2c. The axis of the response surface appears twisted as the interaction increases between two variables. This multivariate format has been demonstrated in Ken Voos' Ph.D. dissertation, but not used much in practice. Such interactions can also be approximated (with less concern about correlation between independent variables) by creating strata of one independent variable (frequently either suitable or unsuitable) and using another independent variable as a continuous value function.

Conditional Curves

An alternate way to describe behavior-induced interactions is to group intervals of a continuous variable and treat them as discrete variables. A continuous variable is one that can theoretically assume any value between two given values; a discrete variable is one in which intermediate values between two given values do not exist (or are assumed not to exist). As more, or finer, discrete intervals are defined for a variable, the series more closely approximates a continuous variable. Some variables, such as size, time of day, or season, are continuous but can be stratified into categories, whereas other variables, such as cover type, are truly discrete. The use of discrete variables is the basis for the development of conditional curves.

Conditional curves employ a separate set of criteria for each category of a discrete variable. A common example of conditional criteria is the development of separate curves for fry, juveniles, and adults because it is typical for each of these sizes of fish to use different types of habitat (e.g. slower, shallower water for earlier life stages). Conditional criteria are especially useful in describing behavioral interactions with respect to cover and substrate. Many species exhibit cover-conditional behavior, utilizing shallow water in the presence of overhead cover, fast water in the presence of large substrate, or deep water in the absence of overhead cover. Conditional criteria are in somewhat of a class by themselves. They may be expressed in any format: binary, curve, or response surface. The distinguishing format characteristic of this type of curve is the appearance in sets of two or more. An approach that is gaining acceptance is to employ a minimum or maximum usable depth criteria (in binary format) for a life stage as well as a univariate continuous curve for velocity.

Habitat Suitability Curve Development Study Goals and Objectives

One of the most important aspects of developing curves is the formulation of a study plan that addresses the goals of the study and the intended use of the results. The study plan should anticipate sampling strategies and methods, and potential sources of error or bias so that the results will meet the perceived needs of the study. Regardless of the goal, the study plan should include:

(1) a statement of purpose and objectives,
(2) a list of target species and their selection criteria,
(3) a description of data stratification procedures, and
(4) a list of variables to be measured or described and how they will be expressed.

The above items are required for all study plans. In addition, studies designed to develop empirical curves must also include:

(1) stream locations where the data will be collected,
(2) identification of sampling strategies and methods,
(3) an estimate of sample size requirements, and
(4) a list of necessary equipment and supplies.

The statement of purpose and objectives establishes the orientation of the study. Studies designed to produce curves for restricted use will have very different objectives from those intended for wide transferability.

Selection of Target Species

The selection of target species is often influenced by the intended audience for the curves. Some studies will concentrate on only one or two species of particular importance to a specific instream flow determination. Others may include many species, or guilds of species, to expand the biological data base as much as possible. The decision to study many species or only a few is important. It is generally more efficient to collect data on several species at the same time, but if some restrictions are not applied, the effort can be diluted among species of lesser interest. Investigators should consider the information content of each curve set when selecting target species. This is determined by the management importance of the species, its adaptations to riverine environments, and the amount of information already available for a particular area or stream type.

Data Stratification, Sampling Protocol, and Study Design

Data stratification refers to the subdivision of curves for a species to reflect spatial or temporal changes in microhabitat utilization patterns. Common divisions include size classes or age groups, diurnal or seasonal changes in habitat usage, different activity patterns, and variations in tolerable hydraulic conditions as a function of cover or substrate type. Understratification of data can be a serious problem, either resulting in overly broad curves or bimodal frequency distributions. The sampling protocol is a formalized description of the variables to be measured or described, and procedures for measuring, describing, and recording the data. The purposes for establishing a sampling protocol are to enhance consistency and reduce ambiguity. Many investigators use coding systems or abbreviations to record the species, size class, activity, substrate, and cover. An important aspect of the sampling protocol is to cross reference these codes to a written definition for each variable. The sampling protocol also defines how certain variables are to be measured, such as measuring the mean column velocity or the nose velocity at each location. Units of measurement should also be defined under this component of the study plan.

One of the most important elements for the design of category II and III curves is the selection of appropriate study areas. If transferable SI curves are the goal, habitat availability can be a major source of error in the development of these curves. The ideal study site would contain all conceivable combinations of microhabitat conditions in equal abundance. Fish observed in such a stream would reflect the true preference and avoidance behavior of the species, because the fish would have free and equal access to all microhabitat conditions. Although this ideal situation is virtually impossible to find in nature, the closer the study stream approximates this condition, the smaller the bias in the resulting curves. Other important considerations in the selection of the source stream are factors that may alter a species' selection of microhabitats, such as water quality, temperature, and the presence or absence of competitors or predators.

A coherent sampling strategy is necessary to avoid biases due to disproportionate sampling effort. Investigators who emphasize the quantity of observations rather than the quality, tend to sample more intensively where they expect to find fish (or macroinvertebrates). Consequently, the resulting curves become self fulfilling prophecies. This is an especially serious problem, because it is almost impossible to detect this type of bias. Selection of a particular sampling strategy is contingent on the intended sampling method, because certain strategies are compatible only with particular types of gear or data collection techniques.

Obtaining an adequate sample size is not only necessary to preserve accuracy in the curves, but also to facilitate fitting a function to the observed frequency distribution. Typically, 150 to 200 observations are necessary to construct a reasonably smooth histogram. An observation refers to a single location where microhabitat utilization is observed, regardless of the number of fish found at the location. The actual sample requirement may need to be adjusted up or down, depending on the variance of the samples. Sample size estimates of less than 150, however, may be symptomatic of restricted microhabitat availability in the source stream, suggesting that the study should be moved to another area.

Alternative Development Methods

Habitat suitability curves are not always developed from field studies. There are numerous situations that can dictate the formulation of category I curves, which are largely based on literature sources and professional judgment. Of the literature sources, reports of previously conducted curve development studies are much more useful than the more common life history or distribution and abundance studies. The habitat descriptions of the latter are usually not quantitative enough for the formulation of curves.

Development of category I curves by professional judgment is a common solution when data for higher categories are unavailable. Three techniques have evolved to this end: roundtable discussions, the Delphi technique, and habitat recognition. The roundtable is an informal, face-to-face discussion among group participants. The success or failure of such group interactions depends on the composition of the group and the leadership abilities of the moderator. The advantages of the roundtable approach are that all participants have equal access to information exchanged by the group, and feedback is instantaneous. The disadvantages of this approach include scheduling problems, repetitive meetings, a tendency to discount minority opinions, and potential domination of the group by strong personalities.

The Delphi technique was devised to overcome many of the disadvantages of face-to-face discussions. The most common Delphi exercise uses a questionnaire, developed by a small monitor team and sent to a larger respondent group. The use of the questionnaire surmounts two of the major problems of the roundtable approach. Respondents can participate at their convenience, so specific times do not need to be scheduled for meetings. The anonymous nature of the questionnaire also prevents the bandwagon effect of a group dominated by a strong personality. Whereas feedback is instantaneous in roundtable discussions, it is delayed in a Delphi exercise. This places a greater responsibility on the monitor team to be absolutely clear in the definitions of terms, and in communications in general. It may also be more difficult to prevent the introduction of tangential subjects, although this problem occurs with roundtable discussions as well.

Habitat recognition is founded on the premise that although the most qualified experts may not be able to quantify usable and unusable habitat, they can recognize it when they see it. This approach involves field data collection, but relies on the opinions of the experts rather than sampling of fish. Each participant is provided with a secret ballot and, at specific locations in the river, indicates whether or not the specified target organism would be likely to use that location. Microhabitat measurements are then made at the location. A frequency distribution of all the responses is then assembled. Each "yes" vote is assigned a frequency of one and each "no" vote is assigned a frequency of zero. Functional relationships are then fit to the frequency distributions using the same techniques that would be used for empirical data.

Many research biologists are critical of category I curves because of their lack of an empirical data base. When time or resources precludes the collection of empirical data. however. category I curves are much better than no curves at all. Verification studies comparing category I curves with subsequently developed category II curves have shown good agreement between the two. although category I curves are generally broader.

Analytical Approaches to Habitat Suitability Curve Development

Once the data have been collected. they must be reduced to an easily interpretable graphical display. This involves fitting univariate or multivariate curves or functions to the data. Three basic approaches have evolved for the processing of habitat utilization and preference data: histogram analysis. nonparametric tolerance limits. and function fitting.

Histogram analysis is conceptually simple but. because of the discontinuous nature of utilization and availability histograms. may actually be more difficult to use than the other techniques. The basic approach is to fit a curve. by eye. to the frequency distribution. This is often fairly imprecise. because different investigators will draw different curves. One way to improve precision is by smoothing the histogram through the grouping of intervals. but this may result in a decrease in accuracy. Another technique is to use a statistical package to compute the residual sum of squares for each curve and use the curve that minimizes this statistic.

Nonparametric tolerance limits are used to determine a range of an independent variable within which a certain percentage of the population will be found. Suitability for a given interval is computed as:

$$SI = 2(1-P)$$

where P is the proportion of the population under the curve. Thus. the central 50% is assigned a suitability of 1.0. whereas the range including the central 90% has a suitability of 0.2. This approach has many desirable attributes. It is easy to use. it can be used with small sample sizes. it is insensitive to irregularities of the frequency distribution. and it does not require the presumption of any particular distribution or curve shape. Because the resultant suitability curve represents cumulative frequencies. however. the relative frequency distribution must be estimated in order to calculate the preference function.

Curvilinear regression techniques involve many of the same concepts as histogram analysis. except that a mathematical equation is used to draw the curve. Once an appropriate function has been chosen. a series of trials is made to determine the equation coefficients that will minimize the residual sum of squares. Many curvilinear regression programs contain solution algorithms that solve for the roots of an equation. Curvilinear regression techniques can be used to fit either univariate curves or multivariate probability density functions. Exponential polynomial equations are commonly used for multivariate analysis, and the logistic regression approach has been suggested as an alternative.

The primary advantage of using a multivariate function is that it can incorporate interactive terms between independent variables in the calculation of habitat suitability. The use of univariate curves assumes that the selection of certain environmental conditions is not significantly affected by variable interactions. The importance of this assumption has been a serious source of confusion and misunderstanding because some interactions have biological importance, and some do not. The error of attributing biological meaning to variable interactions when they are spurious is as serious as assuming independence when they are not. The most common types of biologically important interactions are related to hydraulics and cover types. Fish may use shallow water in the presence of overhead cover and deep water in its absence, but will not use shallow water without cover, for example. This type of interactive behavior is best described by developing conditional criteria. Interactions between depth and velocity have been assumed to be biologically important, but are usually artifacts of the sampling environment that are eliminated when the utilization function is corrected for availability. Curve developers should test their data for interactive terms and determine whether such interactions are biologically induced or merely artifacts of the environment. Univariate curves are much more flexible and are easier to use in PHABSIM than are multivariate functions. In many cases, they are more accurate than multivariate functions. If it is determined that the interaction terms have biological significance, however, the user may be required to use the multivariate format.

Habitat Suitability Curve Evaluation, Review, and Verification

The curves used in an IFIM application will often originate from streams other than those being evaluated with IFIM, because of the time and expense of developing an empirical data base. Furthermore, the stream under investigation may not meet the criteria of a good source stream for curve development. **Before off-site curves are used in an operational IFIM study, they must be evaluated to determine their adequacy for the needs of the study.** Evaluation consists of two parts: a review of comprehensiveness and a determination of accuracy. Curve testing rather than curve development is a much lower effort job and is applicable to many situations.

The review of comprehensiveness is concerned with the data stratification procedures and sampling protocol followed in the study. The purpose of this evaluation step is to determine whether the level of detail exhibited by the curves is compatible with the perceived needs of the IFIM study. This process will reveal information gaps, such as missing curves for a particular life stage, activity, or season. The review is also useful in determining the adequacy of the curves for certain variables with respect to the river in which they will be applied. In particular, it is important to determine whether nose velocities or mean column velocities were measured, and whether the velocity curves are appropriate to the study stream. The level of detail in substrate descriptions and the stratification of curves by cover type are also important determinants of the adequacy of the criteria. Often, it will be found that the existing curves are satisfactory, but that certain critical information is missing. Additional curves may need to be acquired, or existing information supplemented.

Evaluations of accuracy and precision can take two mutually exclusive pathways. The easiest, but least definitive, is a screening level review of the study plan and implementation. The other approach is to implement one of several field verification studies. These are more costly in terms of time and money, but the results can provide a solid basis for acceptance or rejection of the curves. Factors to be considered in a screening level evaluation include the diversity of the source stream, potential biases associated with the sampling design, and errors associated with data collection. A general rule is that curves may be transferred from highly diverse streams to those with lower diversity, but not the opposite. Parsons and Hubert (1988) described a method of determining the relative diversity of the source stream. Compare the utilization function with the preference function for the same data stratum. If the two are very similar, they were likely derived in a highly diverse environment. If they are radically different from one another, the preference curve should not be used. In this case, the curves probably originated from a very simple or restricted environment, and neither function is very accurate.

The investigator should also evaluate any potential biases inherent in the sampling design used in the curve study. Some sampling designs may be theoretically better than others, especially when data are pooled from several sources. In the context of a criteria review, however, the description of a sampling design at least indicates that the original researcher recognized its importance. Whether the best strategy was used is often less important than knowing that the field crew did not confine their sampling to places where they expected to find fish.

Types of error often associated with data collection are: precision, disturbance, and gear bias. Precision error refers to the ability to determine the focal point, or home range centroid. Precision errors are generally lowest for direct observation techniques, although pre-positioned electrodes and preset explosives also have lower precision errors. Area samplers, unless they are very small, generally exhibit the largest amount of precision error. Underwater video and radiotelemetry are intermediate, with the amount of error affected and controlled by the skill of the observer.

As a result of the review and evaluation phase, it may become apparent that some of the curves or functions should be modified before they are applied to the subject stream. The most common form of modification is extension beyond the limits of the existing curves. This is a matter of letting professional judgment take over where the data leave off. Actual modification involves changing the shape or the intercepts of the original functions.

Legitimate reasons for modifying curves include:

(1) addition of information not contained in the original data,
(2) resolution of differences between two or more models,

(3) incorporation of professional opinion in the final model, and
(4) formulation of a mixed model.

The purpose of these changes should be to improve the accuracy of microhabitat predictions in PHABSIM. It is not legitimate to change curves simply to alter the results of PHABSIM. This constitutes deliberate manipulation of the model to justify a preconceived outcome, a practice that can undermine the credibility of the user and the model.

The most definitive test of habitat suitability curves is mathematical convergence, where several investigators working in different areas derive the same functional relationships. This requires several replicate studies to be conducted on the same species, using the same data stratifications and sampling protocol in all the studies. Any deviations from one study to another invite divergence in the resulting curves. It is unreasonable to expect repeatability when the same procedures are not followed in any experiment. A goal of these studies should be to develop regional curves that are applicable for a species in a specified geographical area. The applicable regions should be determined on the basis of convergence, however, and not assigned by arbitrary boundaries. Until such curves are available, researchers must strive to develop comprehensive, accurate, and transferable curves, and users must continue to evaluate and test it.

Habitat Suitability Curves and Nomenclature

Habitat suitability curves have been referred to as:
1) Habitat Suitability Criteria (or Suitability Criteria)
2) Suitability Index (SI) Curves
3) Habitat Suitability Index (HSI) Curves
4) Proportion of Use (also improperly called Probability of Use)
5) Preference Curves (i.e., use corrected for availability) and
6) Selectivity Curves

A functional relationship between an independent variable (e.g., depth, velocity or channel index) is developed to represent the response of a species' and life stage's "use" over a scale of 0.0 (no use) to 1.0 (maximum use). How you get there depends on such factors as availability of data, data analysis technique, and professional judgment. The PHABSIM software system provides the user with a curve construction package that is described in detail in Appendix G of Information Paper 26.

CAUTION WITH THE SELECTION OF HABITAT SUITABILITY CURVES

Source: Waddle, T. 1992. Are High and Low Flow Habitat Values Really the Same?

Using depth and velocity suitability index criteria for adult brown trout from Raleigh, et al. (1986), the weighted usable area for adult trout at high discharges was less than at very low discharges (Figures 1 and 2).

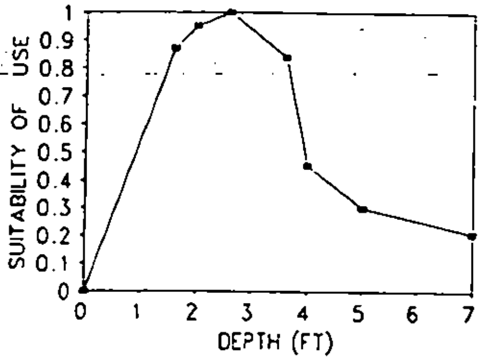


Figure 1. Brown Trout Adult Depth SI Curve

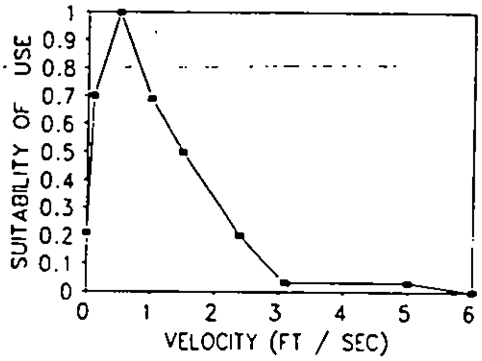


Figure 2. Brown Trout Adult Velocity SI Curve

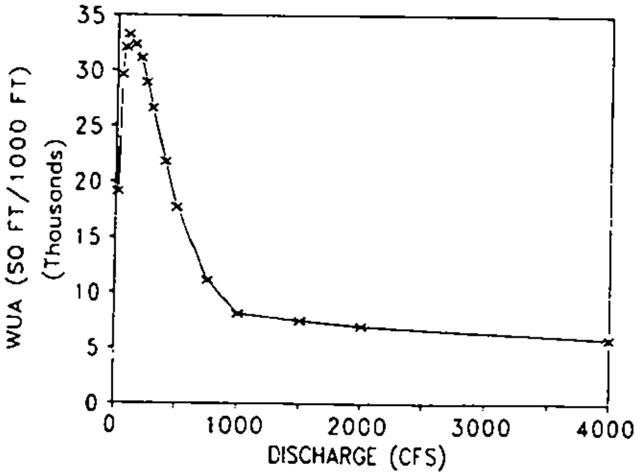


Figure 3. Initial Habitat - Discharge Relation Derived for Brown Trout Adults in the Dolores River

The habitat-discharge relation for brown trout adults in the Dolores River (from Raleigh et al. curves) implies habitat is more suitable for brown trout adults at discharges between 20 and 50 cfs than for discharges in excess of 500 cfs (Figure 3). If this were an accurate measure of survival potential, the population should have been limited by high flows from 1984 to 1989 and have thrived in 1990. However, the fish sampling evidence suggests the opposite.

Using four backwater simulations and two lateral velocity distribution techniques for each, I concluded that the habitat-discharge relation is relatively insensitive to errors in the hydraulic simulation and to small errors in field measurements. Figure 5 compares adult brown trout habitat-discharge relations using the Raleigh, et al. and Thomas and Bovee SI curves. From this graph, I concluded that the habitat description for the Dolores River is more sensitive to selection of SI curves than to hydraulics.

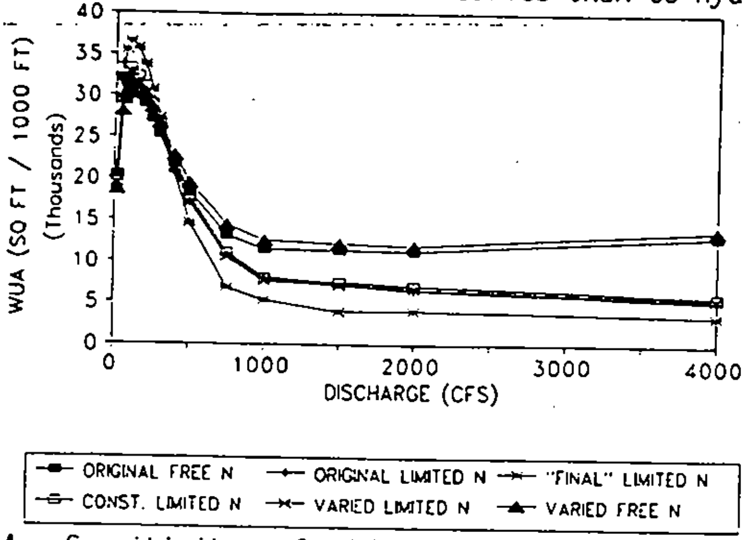


Figure 4. Sensitivity of Habitat - Discharge Relation to Alternate Hydraulic Simulations

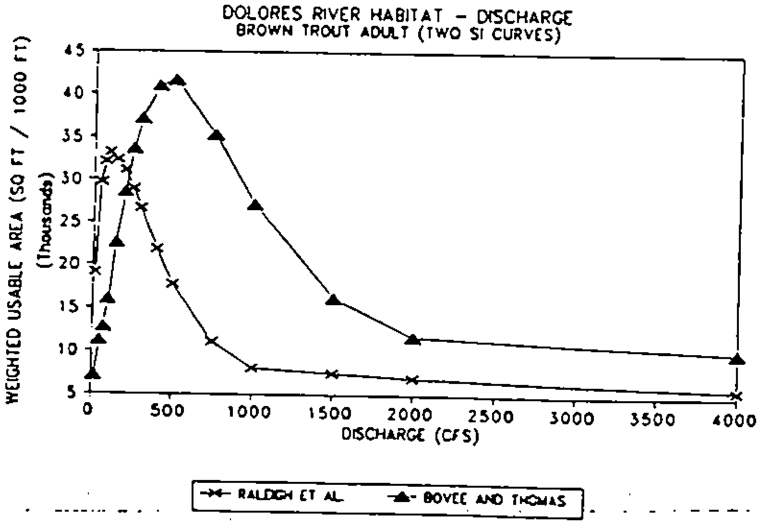


Figure 5. Dolores River Habitat - Discharge Relations for Adult Brown Trout Using Two SI Criteria

By comparing Figures 4 and 5 it is clear that errors in hydraulic measurements or hydraulic simulation alone cannot account for major differences in the habitat - discharge relation. The habitat - discharge relation calculated using the Thomas and Bovee SI curves has less habitat at low discharges than at high discharges. The habitat - discharge relation based on the Raleigh, et al. SI curves indicates that high flows produced the most limiting habitat. Thus, if we rely on the Raleigh, et al. curves, it appears there is little opportunity to avoid limiting events. In contrast, using the habitat - discharge relation derived from the Thomas and Bovee SI curves suggests low habitat events can be managed. The lowest habitat values from the Thomas and Bovee curves occur at the lowest discharges. It may be possible to use a portion of the project storage to augment low flows and relax the constraints of severely limiting habitat events.

Selection of SI curves can dramatically change the water management implications where instream flows are to be provided downstream of a reservoir. It is important that SI curves be chosen that best represent species behavior where instream flows are to be maintained. To this end, it is Fish and Wildlife Service policy that SI curves be evaluated for validity in each stream where PHABSIM is applied. Published curves such as the Raleigh, et al. curves are based on observations from one or more source streams. Procedures for testing the transferability of SI curves among different streams have been developed (Thomas and Bovee 1993). Extreme care must be exercised in selecting SI curves to assure the highest quality description of habitat needs.

PROBLEMS WITH PREFERENCE

Source: Slauson, W.L. 1992. Problems with Preference. Draft manuscript.

I began this paper by noticing two problems confronted by users of IFIM for predicting potential stream habitat: the requirement to use site specific habitat information and to account for different proportions of habitat available. Measures of habitat preference rather than habitat use were offered by users and developers of IFIM to overcome these problems. My study of a variety of preference measures (those proffered in IFIM plus others) applied to stream habitat data and my broader discussion of the properties of the preference measures leads to the conclusion that they do not solve the original problems.

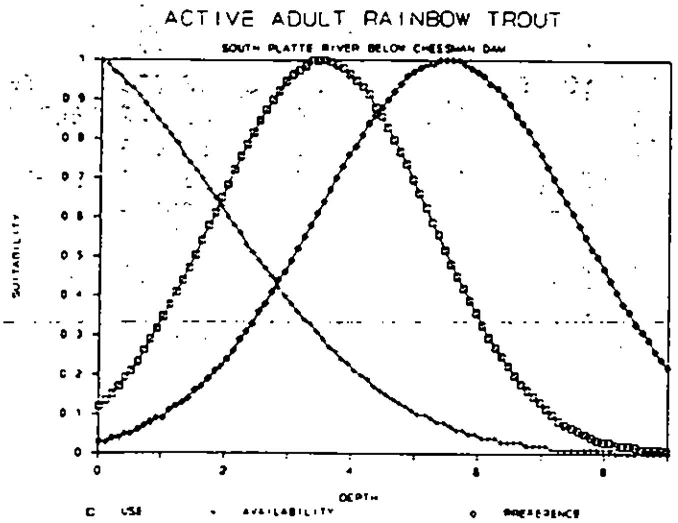
Abstract. Seven electivity {also called preference} functions were examined for depth and velocity preference of adult rainbow trout (*Oncorhynchus mykiss*) in the South Platte River, Colorado. A wider examination of the properties of the preference measures reveals severe problems including asymmetry, nonlinearity, and assumption violations. These problems make the usefulness of preference for modeling stream habitat suspect. In the following indices, r = proportion of resource used or consumed and p = proportion of resource available in environment. The seven electivity indices examined were: 1. Forage Ratio (FR=r/p: see Cock 1978); 2. Ivlev's (1961) Electivity (E=(r-p)/(r+p)); 3. Jacob's (1974) Electivity Index {(Q=r(1-p)/p(1-r)) or Logarithm(Q)}; 4. Jacob's (1974) Electivity Index (D= (r-p)/(r+p-2rp); 5. Strauss' (1979) linear electivity index (LE=r-p); 6. Manly et al.'s (1972) Index Alpha (Alpha=(r/p)/SUM(r/p)); and 7. Vanderploeg and Scavia's (1979a) Selectivity Coefficient (E asterisk=(Alpha-(1/n))/(Alpha+1/n)).

The properties {of the electivity measures} discussed by Lechowicz (1982) include symmetry, linearity, lack of sampling problems, and susceptibility to statistical tests. Linearity means that an incremental change in the proportion used will be reflected equally in the index regardless of use and availability. Only Strauss' linear electivity index LE is a linear measure of preference. All the preference measures, excepting LE under some circumstances, suffer sampling and statistical problems. Rare resource states will usually be poorly sampled yielding erroneous electivity estimates. The exception {to problems with statistical properties} is LE that will be normally distributed if use and availability are normally distributed (but this is not to be expected).

Source: Thomas and Bovee 1993

It has been postulated that habitat suitability curves should be transferable to streams having similar species composition, even though they might differ considerably in their physical characteristics. When habitat suitability curves are developed from data collected at locations utilized by fish in a stream, the curves only partly reflect actual microhabitat selection. The criteria will also reflect the conditions the fish had to choose from. This phenomenon is termed "environmental bias." It is widely recognized that microhabitat availability must be accounted for in order to reduce the influence of environmental bias. Until about 1988, the recommended approach was to factor out the bias mathematically. Although there were numerous indexes of electivity (also called preference) available, the most common approach was to use a "forage ratio." The relative frequencies of a variable at occupied fish locations were divided by the relative frequencies of the variable in the stream. Statisticians argued that this approach was not theoretically valid and should be discontinued.

We found that habitat suitability curves developed using the "preference function" approach were universally non-transferable to our destination streams. In this particular test, our source and destination streams were physically and biologically similar and the distributions of utilized microhabitats were virtually identical. Therefore, we concluded that both the physical availability and the behavior were the same in both streams, and that the non-transferability was due entirely to the method of constructing the curves.



Environmental bias can be eliminated if the habitat suitability curve data are collected from a stream having all combinations of microhabitat variables in equal proportions. Availability would then be a constant and no correction would be necessary. Such an ideal stream setting is nonexistent, but it is possible to construct a database that approximates the ideal. The first step is to select a source stream that is structurally and hydraulically complex. Microhabitat diversity is probably greatest at intermediate levels of streamflow, so sampling under extremely high or low flows should be avoided. The stream should also have a sufficiently high standing crop to force the target organisms into less-than-optimum areas. Otherwise, the habitat suitability curves are likely to be too narrowly defined.

TESTING TRANSFERABILITY OF HABITAT SUITABILITY CURVES

A transferability study is a statistical test with empirical data of the accuracy and repeatability of off-site curves. These studies require the collection of data in the subject stream. The confidence that can be placed in the results of a transferability study is directly related to the amount of effort invested in the study. This is a more rigorous exercise than evaluation of habitat suitability curves. The purpose is to determine whether curves adequately predict the behavior of the target species in the destination stream.

Procedure:

(a) Obtain complete sets of habitat suitability curves to be tested.
(b) Select and establish at least 3 study sites in destination stream. To extent possible, study sites should represent the same mesohabitat types present in source stream, although they may not be identical to mesohabitat types in source stream. Study sites in the destination stream should be as physically different from one another as possible. (e.g., shallow fast riffle, deep slow pool, and an area of intermediate but non-overlapping depths and velocities). Study sites should all be

approximately the same size-the area of the smallest mesohabitat type to be sampled becomes the sampling unit for all other study sites.

(c) Establish a grid of approximately equal-sized cells in each study site. Cells should also be the same size across study sites. Survey each site in such a way that a scale planimetric map of each site can be drawn.

(d) Directly measure or collect PHABSIM data to simulate microhabitat variables in each grid at an intermediate discharge (i.e. between 30% and 70% exceedance on the flow duration curve).

(e) Sample study site to determine locations of target organisms at the discharge measured at step 5. Diver observation using drop-line system preferred. Electrofishing by pre-positioned or mobile anode techniques acceptable provided that sampling in one cell does not affect sampling in nearby cells.

(f) Mark locations of observed fish with numbered tags and record species, size, and activity (at a minimum).

(g) Survey locations of tags using same position-referencing used for planimetric map.

(h) Using habitat suitability curves from source stream and direct measurements or PHABSIM simulations of destination stream, determine suitability category (unsuitable, marginal, optimal) of each cell in each study site.

(i) Using planimetric map and surveyed fish locations, determine which cells were occupied and unoccupied by target organism.

HYPOTHESIS

(a) Test unsuitable versus suitable curves.

(1) p_1 = the probability that a randomly selected cell is suitable and occupied and p_2 = the probability that a randomly selected cell is suitable and unoccupied.

(2) $H_0 : p_1 \leq p_2$

$H_1 : p_1 > p_2$

(3) The alternative hypothesis (H_1) states that proportionately more suitable cells are occupied than unsuitable cells.

(b) Test optimal versus marginal curves.

(1) q_1 = the probability that a randomly selected cell is optimal and occupied and q_2 that it is optimal and unoccupied.

(2) $H_0 : q_1 \leq q_2$

$H_1 : q_1 > q_2$

(3) The alternative hypothesis states that proportionately more optimal cells are occupied than marginal cells.

TESTS OF HYPOTHESES

(a) Data from all study sites combined to obtain counts of occupied and unoccupied cells and unsuitable, marginal, and optimal cells.

(b) Counts are cross-classified in a 2 X 2 contingency table (one for suitable/unsuitable test and one for optimal/marginal test).

(c) Test is a one-sided variant of a chi-square test for differences in probabilities (Conover 1971).

$$t = [N^{0.5}(ad - bc)]/[(a+b)\ (c+d)\ (a+c)\ (b+d)]^{0.5}$$

The test statistic t (which is the positive square root of the usual chi-square statistic) is compared to an entry in a table of the standard normal distribution. If the computed t statistic for any 2 X 2 contingency table is greater than 1.6449 then the null hypothesis can be rejected at the 0.05 level of significance.

Precautions with Habitat Modeling

1) Think about differences between mean column velocity and nose velocity in hydraulic simulations and habitat modeling. Beware of indiscriminant use of nose velocity. If you intend to simulate habitat with nose velocities, collect field data for <u>both</u> mean column and nose velocities. Do your hydraulic simulations from mean column velocities and then evaluate whether to use mean column or nose vlocities.
2) Know whether your source habitat suitability curves for velocity are based on mean column or nose velocity. Calculate the same velocity in your habitat models (IOC's 14, 16, and 17).
3) Be aware of differences in cell calculations between the habitat programs (IOC 8).
4) Understand the computational aspects of habitat programs before data collection. Record channel index values at each X-coordinate <u>and</u> halfway between each X-coordinate.
5) Check substrate and cover codes for usefulness. Make certain that you collected enough substrate data to use either of the families of habitat programs. This means recording twice as much substrate data but it is cheap to collect if you only have to go out and collect the data just once!!
6) Understand Weighted Usable Area. Calculate and present Usable Area (IOC(10)=1, IOC(19)=1, and CFMIN=0.15 and larger) as well as WUA.
7) Beware of preference curves. Don't use them if you aren't certain that they apply to your stream. Be particularly careful about the shift of the curve to the right and the right-hand tail of a preference curve.
8) Understand that some field data cross-sections are needed for hydraulic modeling (e.g., hydraulic control), but probably should not be used for habitat modeling. Also understand that some of the field data cross-sections are not needed (and will not calibrate very well) for hydraulic calibration. These cross-sections frequently have near zero or zero velocities and cannot be handled well with hydraulic simulation. All this means more data collection but better data analysis.
9) Don't overrate PHABSIM. It will come back and bite you if you don't understand what you are doing and why.

CURVLIB habitat suitability curves

The habitat suitability curve library (CURVLIB) of the Riverine and Wetlands Ecosystems Branch is designed to provide aquatic habitat requirement information and SI curve coordinate pairs to researchers using the Instream Flow Incremental Methodology physical habitat simulation system approaches and other instream flow assessment methods. At present (April 1992), CURVLIB contains 404 records with more than 1900 site specific SI curves developed for stream velocity, depth, substrate, cover, and temperature for approximately

124 species of fish, 20 species of macroinvertebrates, and five types of river recreation.

Each record summarizes a published report or other scientific literature containing SI curves for one or more species, or habitat information which may be used to generate curves. A description of the study site, conditions present, assumptions, constraints, and techniques used for data collection and analysis are included in the narrative for each record. The accompanying narrative enables researchers using curves from CURVLIB to evaluate the potential for curve transferability for use in their flow assessment project or study area.

For a complete listing of SI curves available, information for a particular species, or if you have any aquatic suitability data you would like added to CURVLIB, please contact Midcontinent Ecological Science Center, National Biological Survey, 4512 McMurry Avenue, Fort Collins, Colorado 80525-3400 (303)226-9391. (Extracted from article by Robert Hufziger in Habitat Evaluation Notes and Instream Flow Chronicle April 1992.)

Ask for the table "Availability of suitability index curves for IFIM analysis (December 1991)." The table cross references species with the five parameters above and the life stages of spawning, egg incubation, larva or fry, juvenile, adult, and all life stages. The table describes what kind of curves are available: "Category one SI curve available based on literature and/or expert opinion); Category two (utilization) SI curve available (based on field observations; for application in streams of similar size and complexity); and Category three (preference) SI curve available (based on field observations; environmental bias removed; more broadly transportable (now called transferable) to other streams)." Note that category three curves are no longer recommended as being more broadly transportable to other streams, partly because the environmental bias can easily be increased instead of removed by using preference calculations. The Fish and Wildlife Service recommends that you develop your own habitat suitability curves for the study stream, if at all possible, and compare your newly developed curve with category two curves from other similar streams (see Thomas and Bovee 1993).

Regardless of the source of a habitat suitability curve, one should always document why the relationships chosen are believed to have the most biologically meaningful interpretation. Failure to ask and answer this question on paper can and should lead to a great deal of skepticism on the part of reviewers. The Fish and Wildlife Service policy on this subject has changed from 1990 and before. Regardless of the type of the IFIM application, users should always conduct fish use field data collection along with the physical habitat field data collection to ensure that habitat suitability curves are applicable to the particular site. Accordingly, it is erroneous to obtain material from the curve library and use it in decision processes without performing a check. At the very least and in a study with minimal field data collection, this check may be as simple as securing buy-off from qualified experts on the species and river in question.

Habitat Suitability Curve Numbers and Habitat Output Control

In general, curve numbers are arbitrary and are composed of 5 or 6 digits as follows:

XXXYY OR XXYYZZ
NOTE OLD NEW

where:

XX = species number (formerly three positions in old XXXYY)
YY = life stage number
ZZ = activity number (an addition over former numbering convention)

The habitat programs will place output for up to 5 life stages for the same species side by side (i.e., same XXX curve numbers with different YY's). For example, the following output was produced by specifying curve numbers for Brown Trout as follows: Adult (10001). Juveniles (10002). Fry (10003). and Spawning (10004):

```
BROWN TROUT
      DISCHARGE      ADULT       JUVENILE      FRY        SPAWNING
* 1       13.00     3334.85      3831.74     3649.01      5756.08
* 2       23.90     4369.17      5174.69     3690.49      6230.57
* 3       34.90     5059.76      6091.32     4122.30      5698.28
* 4       45.80     5472.60      6668.37     4280.15      5249.49
* 5       56.70     5707.63      6989.66     4592.41      4829.91
* 6       67.70     5922.87      7105.22     4912.45      4407.91
* 7       78.60     6093.63      7135.64     5455.14      3972.62
```

FISHCRV File Format

Figure 3 provides an example of a typical FISHCRV file format. The first line of the file contains a title that identifies the material within the file. Each set of species and life stage information is contained within the block of information starting with "H" in column 1 and ending with the last line of data indicated by an "S" in column 1 (before the next occurrence of an "H" in column one. As many as 16 lines of velocity. depth and substrate may be present. The first x-coordinate for V and D must be 0.0 and the last x-coordinate must be 100.0 for each V. D. and S entry.

Figure 3. Example of a FISHCRV data file constructed with the RGCURV program. H means header: V means velocity: D means depth; S means channel index.

```
  HABITAT SUITABILITY CURVES FILE
H  21114  5   4   6   0 RAINBOW TROUT JUVENILE                      FEEDING
V  21114  0.00  1.00  0.50  1.00  1.60  0.00  2.60  0.00100.00  0.00
D  21114  0.00  0.00   .40  0.00   .70  1.00100.00  1.00
S  21114  1.00  1.00  2.00  1.00  6.00  1.00  7.00  1.00  8.00  1.00100.00
1.00
H  21215  4   4   6   0 RAINBOW TROUT ADULT                         FEEDING
V  21215  0.00  1.00  1.00  1.00  3.00  0.00100.00  0.00
D  21215  0.00  0.00  1.00   .20  1.60  1.00100.00  1.00
S  21215  1.00  1.00  2.00  1.00  6.00  1.00  7.00  1.00  8.00  1.00100.00
1.00
```

1) The same species and life stage curve I.D. number occurs on each line of data associated with the data. For example. rainbow trout juvenile-feeding (21114) occurs for all H. V. D. and S lines. The 211 is an arbitrary number

assigned to the species and 14 is an arbitrary number assigned to the life stage.

2) The header data line, designated with an "H" in column 1, followed by the curve I.D. number, and then 4 numbers: " 5 4 6 0". These represent the number of velocity, depth, channel index and temperature data pairs that will follow. The PHABSIM software allows a maximum of 99 data pairs for any variable. You are not allowed to enter a true vertical line, so make small changes in the x-coordinate for the next entry. These data are followed by the species name (40 characters of text) and then the life stage name (10 characters) on the header line.

3) Velocity data pairs are next as indicated by a "V" in column 1, followed by the curve number. Data pairs are values <u>for velocity and then S.I.</u>

4) Depth data pairs follow next and are indicated by a "D" in column 1.

5) Channel index data pairs follow next and are indicated by a "S" in column 1.

6) Temperature data pairs would follow next. PHABSIM Version 2 does not allow input and use of temperature data as a suitability curve so this should always be set to 0.

ROLES OF QUALITY ASSURANCE PARTICIPANT

ACTIVE PARTICIPANT is closely involved from study planning phase through problem resolution phase and has in-depth knowledge of all details of the study plan, reasons for deviations from study plan, and quality of data and products.

INTERMITTENT PARTICIPANT participates in development of the study plan and consults at critical junctures in data collection and analysis. Has good knowledge of study plan details, but not of deviations from study plan nor the quality of the field data and intermediate products.

POST-MORTEM PARTICIPANT reviews study plan after it has been developed. Then reviews report after the study has been completed and submits comments. May understand the study plan, but influence over contents is minimal. Able to discern deviations from study plan, but is too late to re-direct data collection or acquire missing data. Depending on training and experience, ability to judge quality of data and intermediate products can be good but will be unaware of most assumptions made during data collection and analysis.

QUALITY ASSURANCE IN HABITAT MODELING

Before beginning a major expenditure of effort in microhabitat modeling, the study participants should make an in-depth evaluation and be certain that they are satisfied with the following:

(a) Appropriate evaluation species.

(b) Reasonable response functions (discharge versus usable microhabitat for selected species and life stages). Evaluation of precise shape and magnitude of function requires in-depth review of inputs and models used to get there. General characteristics of usable microhabitat vs. discharge can be judged by consistency with characteristics of target organism.

(c) Appropriateness of variables used to describe microhabitat.

(d) Curve transferability evaluation and testing. It is Fish and Wildlife Service policy to verify curves and that, at the very least, they should be critically evaluated by species experts. Curve transferability testing is strongly recommended.

(e) Adequacy of habitat typing, stratification, and sampling. Missing critical habitat types may result in near-zero usable microhabitat for a life stage across all stream flows (Figure 9). Adequacy of the habitat stratifications should be consistent with the species and stream under study. Correct proportioning of habitat types within microhabitat model.

(f) Adequate level of detail in measurements.
    (1) Sufficient number of transects for the complexity of the habitat types sampled.
    (2) Extension of transects far enough onto the floodplain to allow simulation of flood flows. Avoid glass wall effect.

(g) Quality control in hydraulic simulations. Major problems are suggested by Type E and Type G microhabitat-discharge response functions found in Figures 10 (to a lesser extent), 11, and 12.

QUALITY ASSURANCE REQUIREMENTS CHECKLIST

1. Field notes
2. Photos
3. Data decks
4. Reach lengths, weighting factors
5. Habitat mapping, videos
6. Habitat suitability curves, substrate codes, cover codes
7. Velocity adjustment factors (tables and plots)
8. Weighted usable area versus flows
9. Smoothing algorithm
10. Post processing guilding (if any)

Figure 9. Microhabitat-discharge function characteristic of species having narrow habitat requirements in a stream lacking such habitat.

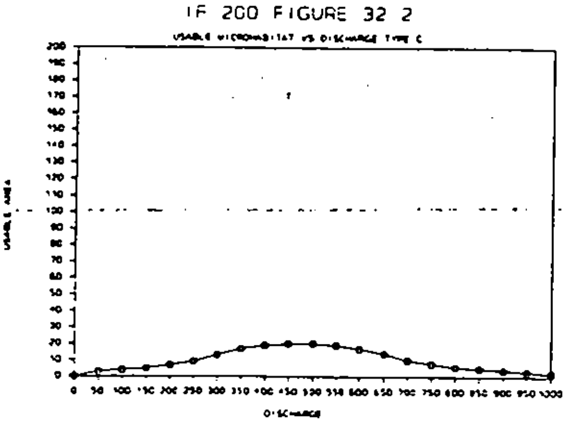


Figure 10. Microhabitat-discharge function characteristic of species that rely on cover or substrate types found only at stream margins. Also, some species for which one or more life stages is dependent on floodplain habitats available only during flood events.

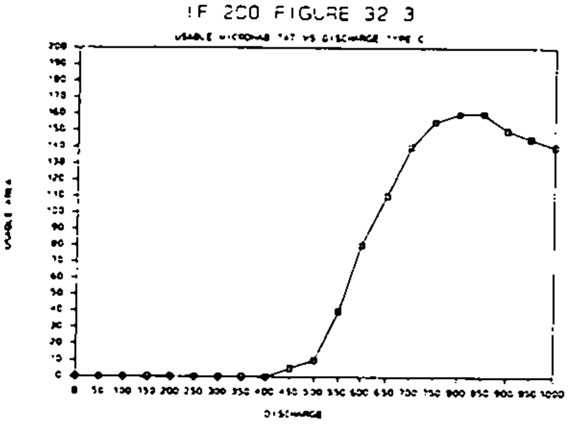
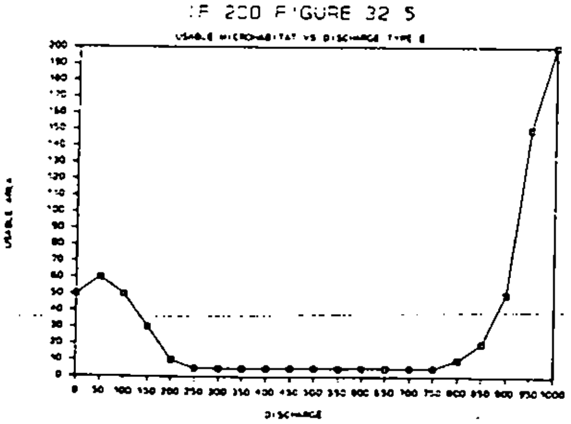


Figure 11. Microhabitat-discharge response characteristic of species having very low velocity tolerances, using main channel refugia at low flow and floodplain habitat at high flow. Also characteristic of severe problems in hydraulic simulation model.



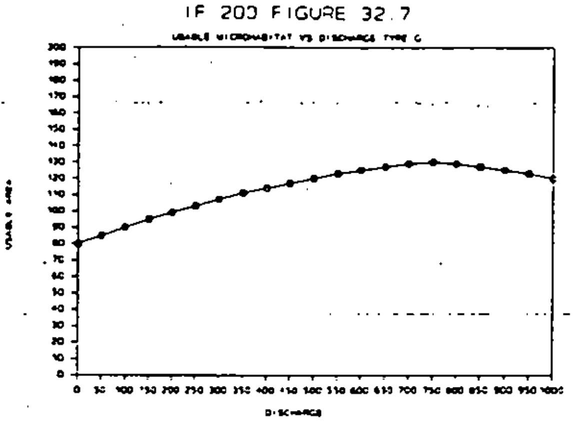


Figure 12. Microhabitat-discharge response may represent species with extremely generalized habitat tolerances, but most likely cause is overly broadened habitat suitability curve for target species. May also result from sampling streams or sites having little structural complexity.

A typical habitat-discharge relationship is provided in Figure 2. The output from the habitat modeling phase of PHABSIM provides the relationship between available habitat (WUA) and discharge for the target species and life stages of interest. The goal of habitat time series and project assessment methodologies is to allow the user to integrate this information with the available data on existing and/or proposed alterations of stream flows in order to assess potential impacts.

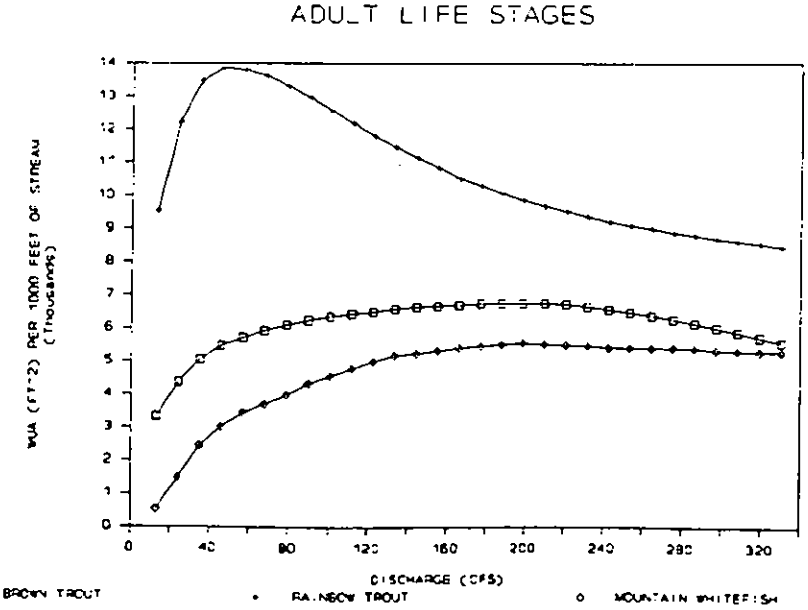


Figure 2. Example of habitat-discharge relationship.

Table 1. Availability of Suitability Index Curves for IFIM Analysis (December 1991)

Species	Spawning VDSCT	Egg Incubation VDSCT	Larva or Fry VDSCT	Juvenile VDSCT	Adult VDSCT	All VDSCT
Aquatic Invertebrates	00000	00000	33300	33300	00000	33300
Alewife	00101	00101	00000	00001	00000	00000
Bass, Largemouth	333X1	101X1	33311	33311	33311	00000
Bass, Rock	000X0	000X0	33330	33330	33330	00220
Bass, Smallmouth	33333	22201	33333	33333	33333	00220
Bass, Spotted	11101	11101	11111	11111	11111	00000
Bass, Striped	11XX1	111X1	11101	01001	01001	00000
Bass, White	222X1	011X1	22201	22001	22201	00000
Buffalo, Bigmouth	00100	00101	00010	00010	10011	00000
Buffalo, Smallmouth	001X0	101X1	10011	10011	10001	00000
Bullhead, Black	00111	00111	00011	10011	10011	00000
Carp, Common	33311	11011	33311	33311	33311	00000
Carpsucker, River	00000	00000	00000	33330	00000	00000
Catfish, Channel	33312	11011	33312	33332	33332	00000
Catfish, Flathead	00000	00000	00000	00000	33330	00000
Char, Arctic	00000	00000	00000	00000	00000	00000
Chub, Chiahuahua	00000	00000	00000	00000	22000	00000
Chub, Creek	101X0	101X1	10001	22211	22211	00000
Chub, Flathead	11100	11100	11000	11000	11000	33300
Chub, Hornyhead	00000	00000	00000	33300	00000	00000

KEY:

V - Velocity
D - Depth
S - Substrate
C - Cover
T - Temperature
0 - No SI Curve Available
X - No SI curve necessary (variable considered unimportant to species well-being)
1 - Category one SI curve available (based on literature and/or expert opinion)
2 - Category two (utilization) SI curve available (based on field observations; for application in streams of similar size and complexity)
3 - Category three (preference) SI curve available (based on field observations; local environmental bias reduced; less transportable to other streams)

Table 1. Availability of Suitability Index Curves for IFIM Analysis (December 1991)

Species	Spawning VDSCT	Egg Incubation VDSCT	Larva or Fry VDSCT	Juvenile VDSCT	Adult VDSCT	All VDSCT
Chub. Humpback	00000	22000	22200	22200	22200	00000
Chub. Lake	00000	00000	22200	22200	22200	00000
Chub. Roundtail	00000	00000	00000	33000	33000	00000
Chub. Speckled	00000	00000	00000	00000	11100	33300
Crappie. Black	33311	00011	33311	33311	33311	00000
Crappie. White	21211	00011	21211	12211	22111	00000
Cui-ui	33300	00000	00000	00000	00000	00000
Dace. Blacknose	111X1	111X1	10111	30311	33311	00000
Dace. Longnose	111X0	111X1	11101	11111	11111	00000
Dace. Speckled	00000	00000	00000	22200	22200	00000
Darter. Blackside	11101	00000	00000	00000	11100	00000
Darter. Channel	11101	00000	00000	00000	11100	00000
Darter. Fantail	33301	00000	33300	33300	33300	00000
Darter. Greenside	33301	00000	33301	33301	33301	00000
Darter. Johnny	00000	00000	00000	33300	33300	00000
Darter. Leopard	00000	00000	00000	22200	22200	00000
Darter. Orangebelly	12100	00000	00000	33300	33300	00000
Darter. Orangethroat	11100	00000	00000	22200	22201	00000
Darter. Rainbow	11100	00000	00000	22201	22200	00000
Darter. River	00000	00000	00000	00000	11100	00000
Darter. Slenderhead	00000	00000	00000	00000	22200	00000
Darter. Slough	00000	00000	10101	10101	10101	00000
Drum. Freshwater	121X1	000X0	00000	22201	22201	00000
Eel. American	00000	00000	00000	33300	00000	00000
Fallfish	01111	01111	00001	33301	00101	00000
Goldeye	222X0	000X0	00000	22200	22200	00000
Grayling. Arctic	111X1	111X1	11101	11X01	11X01	00000
Hardhead	00000	00000	00000	22200	22200	00000
Killifish. Plains	11100	11100	11000	11000	11000	00000
Killifish. Rio Grande	00000	00000	00000	00000	11100	00000
Logperch	11100	00000	00000	00000	11100	00000
Madtom. Freckled	00000	00000	00000	00000	33300	00000
Madtom. Slender	00000	00000	00000	22200	22200	00000
Minnow. Bluntnose	00000	00000	00000	33300	33300	00000
Minnow. Fathead	00000	00000	00000	00000	11100	00000

Table 1. Availability of Suitability Index Curves for IFIM Analysis (December 1991)

Species	Spawning VDSCT	Egg Incubation VDSCT	Larva or Fry VDSCT	Juvenile VDSCT	Adult VDSCT	All VDSCT
Minnow, Loach	33300	33300	33300	33300	33300	00000
Minnow, Plains	00000	00000	00000	22200	22200	33300
Minnow, Suckermouth	00000	00000	00000	22200	00000	00000
Minnow, Western Silvery	00000	00000	00000	00000	00000	33300
Mosquitofish	00000	00000	00000	00000	22200	00000
Muddler, Northern	00000	00000	00000	00000	00000	00000
Muskellunge	00000	00000	00000	00000	22200	00000
Paddlefish	111X1	111X0	00000	00000	11001	00000
Perch, Tule	00000	00000	00000	22200	22200	00000
Perch, Yellow	11101	11101	22201	22211	22211	00000
Pike, Northern	22200	00000	11101	22201	22201	00000
Pupfish, Red River	00000	00000	00000	00000	11100	00000
Redhorse, Black	00000	00000	00000	00000	00000	00000
Redhorse, Golden	00000	00000	00000	00000	00000	00000
Redhorse, Shorthead	00000	00000	00000	00000	00000	00000
Roach, California	00000	00000	00000	22200	22200	00000
Salmon, Atlantic	11101	22201	22201	11101	00000	00000
Salmon, Chinook	33331	111X0	33331	33332	00000	00000
Salmon, Chum	222X1	111X1	11101	XXXXX	XXXXX	00000
Salmon, Coho	33331	111X1	33331	33332	00102	00000
Salmon, Kokanee	222X1	000X0	000X0	00000	00000	00000
Salmon, Pink	333X1	222X1	11101	XXXXX	XXXXX	00000
Salmon, Sockeye	111X1	000X0	00000	00000	00000	00000
Sauger	111X1	111X1	12201	33331	33331	00000
Sculpin, Banded	00000	00000	00000	22200	22200	00000
Sculpin, Mottled	00000	00000	00000	00000	00000	00000
Sculpin, Riffle	00000	00000	00000	22200	22200	00000
Sculpin, Slimy	00000	00000	00000	22200	22200	00000
Shad, American	111X1	111X1	11101	22200	22200	00000
Shad, Gizzard	11101	11101	11001	11001	11111	00000
Shiner, Bigeye	00000	00000	00000	11001	11001	00000
Shiner, Bigmouth	00000	00000	00000	22200	22200	00000
Shiner, Blacktail	00000	00000	00000	00000	00000	00000
Shiner, Bluntface	00000	00000	00000	00000	22200	00000
Shiner, Common	101X1	101X1	10001	22200	00000	00000

Table 1. Availability of Suitability Index Curves for IFIM Analysis (December 1991)

Species	Spawning VDSCT	Egg Incubation VDSCT	Larva or Fry VDSCT	Juvenile VDSCT	Adult VDSCT	All VDSCT
Shiner, Emerald	00000	00000	00000	00000	22200	00000
Shiner, Red	00000	00000	00000	33300	33300	00000
Shiner, Redfin	000X0	000X0	00000	22200	00000	00000
Shiner, River	00000	00000	00000	33300	33300	00000
Shiner, Rosyface	00000	00000	00000	00000	22200	00000
Shiner, Sand	11100	11100	11000	33330	33330	00000
Shiner, Striped	00000	00000	00000	33300	33300	00000
ilversides, Brook	00000	00000	00000	00000	22200	00000
pikedace	33300	00000	33300	33300	33300	00000
Squawfish, Colorado	222X0	000X0	22201	22201	22201	00000
quawfish, Sacramento	00000	00000	00000	22200	22200	00000
Stonecat	21101	00000	21101	21101	22201	00000
Stoneroller	000X0	222X0	00000	22200	33300	00000
turgeon, Atlantic	11101	11101	11101	11101	11101	00000
Sturgeon, Gulf of Mexico	00000	00000	00000	00000	00000	00000
turgeon, Lake	00000	00000	00000	00000	22200	00000
Sturgeon, Shortnose	11101	11101	11101	11101	11101	00000
Sturgeon, Shovelnose	221X1	000X0	00000	00000	21101	00000
ucker, Blue	22201	00000	00000	00000	22201	00000
Sucker, Creek Chub	00000	00000	00000	00000	00000	00000
Sucker, Desert	00000	00000	33300	33300	33300	00000
Sucker, Longnose	111X1	111X1	22210	22200	00000	00000
Sucker, Northern Hog	00000	00000	22200	33300	33300	00000
Sucker, Razorback	00000	22000	11000	00000	22200	00000
Sucker, Sacramento	00000	00000	22200	22200	22200	00000
Sucker, Sonora	00000	00000	33300	33300	33300	00000
Sucker, White	222X1	111X1	22211	33311	22211	00000
Sunfish, Bluegill	333X1	101X1	33301	33311	33311	00000
Sunfish, Green	11101	10101	22201	22201	33311	00000
Sunfish, Longear	333X0	000X0	00220	33320	33320	00220
Sunfish, Orange-spotted	00000	00000	00000	22200	00000	00000
Sunfish, Redbreast	11111	11101	11111	11111	11001	00000
Sunfish, Redear	10011	10011	10011	10011	10011	00000
Trout, Brook	221X1	222X1	22211	22211	33311	00000

Table 1. Availability of Suitability Index Curves for IFIM Analysis (December 1991)

Species	Spawning VDSCT	Egg Incubation VDSCT	Larva or Fry VDSCT	Juvenile VDSCT	Adult VDSCT	All VDSCT
Trout. Brown	222X1	222x1	22211	33311	33311	00000
Trout. Bull	00000	00000	00000	22200	00000	00000
Trout. Cutthroat	332X1	222X1	33211	33221	33211	00000
Trout. Dolly Varden	33300	00000	33300	33300	00000	00000
Trout. Lake	00000	00000	00000	00000	00000	00000
Trout. Rainbow	222X1	222X1	22211	22211	33311	00000
Trout. Steelhead	33331	111X1	33331	33332	22202	00000
Walleye	33323	33323	33333	33333	33333	00000
Warmouth	10011	10011	10011	10011	10011	00000
Whitefish. Broad	00000	00000	00000	00000	00000	00000
Whitefish. Mountain	111X1	000X0	22201	22201	21201	00000
Boating. High Power						110XX
Boating. Sailing						110XX
Canoeing. River						110XX
Canoeing. Shoal						110XX
Water Contact. Skiing						110XX

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CHAPTER 9: MICROHABITAT COMPUTER MODELS

Introduction

The following programs are microhabitat models that estimate the usable physical habitat area for an aquatic species or the space available for specific types of recreational activities. The data used are the habitat suitability curves, stream channel geometry, water surface elevations, and cell velocities of the stream. The stream is broken down into a series of rectangular cells, the length and width of which are determined by the reach length stationing and the cross-sectional stationing, respectively, as entered in the hydraulic simulation. Each cell is then evaluated for its habitat suitability to various life stages and species, based on fixed characteristics of the cell (such as channel index) and variable characteristics of the cell (such as depth, velocity, and area).

The theory of the habitat modeling programs is based on the assumption that aquatic species will react to changes in the hydraulic environment. These changes are simulated for each cell in a defined stream segment. The stream segment simulation takes the form of a multi-dimensional matrix of the calculated surface areas of a stream having different combinations of hydraulic parameters (i.e., depth, velocity, and channel index). Depth and velocity vary with changes in discharge causing changes in the amount of available habitat. The end product of the habitat modeling is a description of habitat area as a function of discharge.

This habitat-discharge relationship is the basis of further analysis from which fishery and recreation management decisions are developed. By linking the habitat-discharge relationship with flow data, a habitat-flow relationship can be developed. This information can assist in identifying critical time periods for a given life stage, limiting habitat availability for each life stage (i.e., physical carrying capacity), and limiting habitat availability for different species. This method is particularly useful in evaluating potential changes in species composition because changes in hydraulic characteristics will initiate differential species reactions.

AVDEPTH and AVPERM Programs

The two general types of habitat modeling in PHABSIM are based on either average conditions in a entire stream channel (not cell by cell) or on distribution of velocity and depth among field measurement cells {and therefore computational cells} and the nature of the channel in a stream. The average parameter models, AVDEPTH and AVPERM, calculate wetted width, wetted surface and average velocity for flows and water surface elevations supplied by the user. They can determine width of a stream with water above some depth specified by the user. The average condition models are not widely used or as useful as the distributed parameter models.

The use of wetted perimeter, wetted width, and average velocity have long been used as indexes to the physical habitat in a stream. In using the wetted width or wetted perimeter, the assumption is made that all the area of the stream is of equal value to the instream flow activity of interest. The wetted perimeter and wetted width will always either stay the same or increase with depth. If these and the above assumptions can be made, then the use of the AVDEPTH and AVPERM programs is appropriate. Note that this approach is not recommended nor much used in practice.

The major difference between the AVDEPTH and the AVPERM programs is input to the programs. AVDEPTH uses a WSP type data set with at least two additional lines added to the top. The first line contains controls for the calculation and output for the AVDEPTH program; the other additional lines contain water surface elevations for the transects.

AVPERM uses a TAPE3 that contains unformatted cross section and segment data, and a TAPE4 that contains unformatted flow data. These two files are generated by the hydraulic simulation programs. In AVDEPTH, the weight on a cross section is always 0.5; in AVPERM, the weight is written to the TAPE3 resulting from the hydraulic simulation process. PHABSIM programs assume that the hydraulic variables measured at a cross section extend halfway to adjacent cross sections upstream and downstream. If this is not the case, upstream weighting factors should be applied.

The output resulting from AVDEPTH and AVPERM gives information for each cross section and a summary of the average parameters for a whole segment of stream including discharge, depth, cross-sectional data, and velocity. In addition, for each of the specified depths (maximum of five), AVDEPTH and AVPERM calculate the total width of the stream that is at least as deep as the specified depth (see Figure 3). The advantage of using the wetted width or wetted perimeter approach for developing indexes to physical habitat in a stream is that development requires much less field and office work than use of the weighted usable area approach used in the HABTA_ models. This savings in effort results from:

1. Species curve not having to be developed or obtained;
2. If using AVDEPTH, velocities need not be measured for the purpose of calibrating a hydraulic simulation model to velocities, although the discharge must be known; and
3. The interpretation of the results requires the use of only one factor (i.e., wetted perimeter or wetted width) in contrast to the many possible life stages (factors) that may need to be considered when using weighted usable areas.

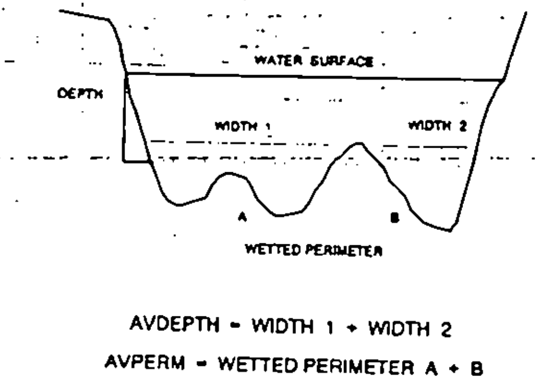


Figure 3. Example of AVDEPTH and AVPERM calculations.

The use of wetted width is a special case of weighted usable area in that the weights are 1.0 for all velocities, depths, and channel indexes. Because the wetted perimeter is nearly the same as the wetted width, the same can be said for the wetted perimeter as well.

HABVD PROGRAM

The HABVD program is a shortcut method of habitat modeling that uses data readily available from the U.S. Geological Survey and the logic and concepts of the HABTAE program. The resulting physical habitat versus streamflow relationship is not as valuable as the standard HABTAE output, but the results cost a lot less ($100 versus up to $5,000).

The logic of the program is basically the same as HABTAE except only one velocity and one depth is used to represent the habitat in the stream. Specifically, the weighted usable area (WUA) for a streamflow Q is:

$$WUA(Q) = A * f(V) * f(D) * f(CI) \tag{73}$$

where:
A = surface area per unit length (stream width) at streamflow Q
V = velocity at streamflow Q
D = depth at streamflow Q
CI = channel index

f ( ), g ( ), h ( ) are functions dependent on the species and life stage of interest (or recreational activity if recreation is of concern).

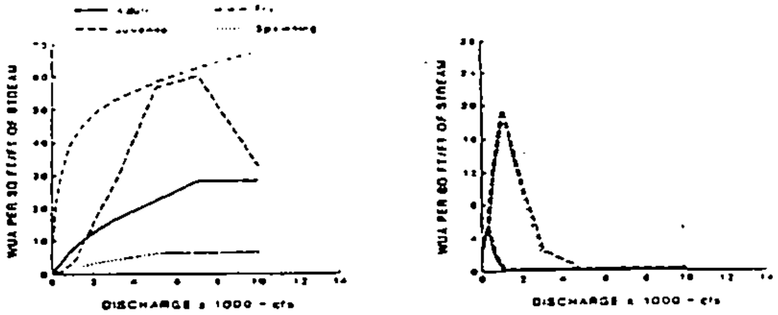
The summary of discharge measurements available for numerous gauging stations can be used to determine the velocity, average depth, and surface width. Not all USGS data are useful for this purpose because some of the data is collected at man-made controls such as weirs and bridges. Only data from reasonably natural measurement points should be used with the HABVD program.

When stream morphology relationships have been developed for a specific location, they can be used directly. One channel index value may be assigned for the whole section of the stream being analyzed. The stream morphology relationships are of the form:

$$v = k\,Q^{m}$$
$$d = c\,Q^{f}$$
$$w = a\,Q^{b}$$

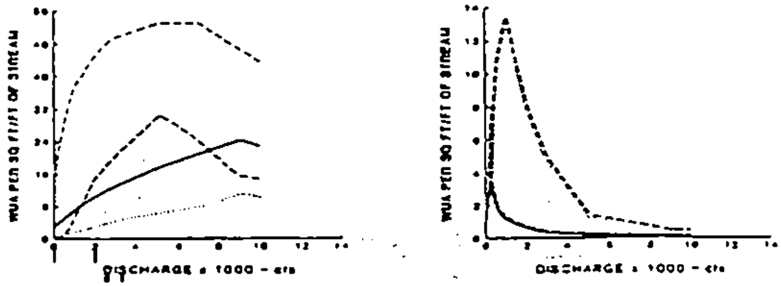
where: v = velocity at streamflow Q
d = depth at streamflow Q
w = stream width
k,m,c,f,a,b = coefficients (the sum of the coefficients m, f, and b must equal 1.)

If IOC(8)=0, the program calculates the coefficients from the data supplied. If IOC(8)=1, the program is supplied the coefficients in the format described in Appendix A "HABVD Streamflow or Stream Morphology Parameters File". The results from the HABVD program are different from the results from the HABTAE program. Different results from HABTAE and HABVD are shown below.



CHANNEL CATFISH - HABVD RESULTS

STONECAT - HABVD RESULTS



CHANNEL CATFISH - HABTAT RESULTS

STONECAT - HABTAT RESULTS

Figure 6. Comparison of predicted habitat for the HABTAE versus HABVD programs.

	WHEN TO USE	DISTINCTIVE OPTIONS	OTHER COMMENTS
HABTAE	1) Nose velocities using the 1/mth equation or Shear velocities are used. 2) Weighted Usable Volume, Weighted Usable Bed Area, or Weighted Usable Area are needed. 3) Usable habitat is desired. 4) Minimum contiguous width or suitability factors are used. 5) Different life stages depend on different types of velocities. 6) Metric data or output is needed.	1) Computes Weighted Usable Volume and Weighted Usable Bed Area. 2) Prints out distribution of composite suitability indices table. 3) Can calculate Usable Area instead of Weighted Usable Area. 4) Allows minimum contiguous width. 5) Can restrict velocity size. 6) Allows minimum composite suitability factor. 7) Uses Metric measurements. 8) Allows different velocity calculations for different life stages.	1) HABTAE has the most capabilities for velocity simulations (e.g., nose velocities). 2) HABTAE defines cells in the same way as HABTAT, even though it accepts TAPE4 files in either format.
HABTAT	Use HABTAE instead of HABTAT unless: 1) You want to enter stream geometry on input file instead of using TAPE3 file. 2) You need velocity-depth, velocity-channel index, or depth-channel index matrices.	1) Prints velocity-depth, velocity-channel index, or depth-channel index matrices. 2) Combines reach lengths before or after habitat calculations. 3) Defines how 0 cross section weights are used.	1) HABTAT has been replaced by HABTAE. 2) Cell boundaries are defined at measured verticals.
HABTAV	1) Fish prefer areas of differing velocities. 2) Eddies or backwaters provide fish habitat. 3) Situations where fish need a certain range of velocities within a certain distance.	1) Scans velocity in adjacent cells. 2) Scans for a minimum habitat velocity in adjacent cells. 3) Creates ZHCF file. (HABTAM does not produce ZHCF file.)	1) Cell boundaries are defined between measured verticals. 2) HABTAV is limited in velocity calculation methods.
HABTAM	1) Rapid fluctuations in the stream limit fish habitat. 2) Situations where fish migrate laterally in a cross section to take advantage of different velocities.	1) Computes and prints out migration details. 2) Prints out criteria coordinates. (HABTAV does not.)	1) Cell boundaries are defined between measured verticals. 2) HABTAM is limited in velocity calculation methods.

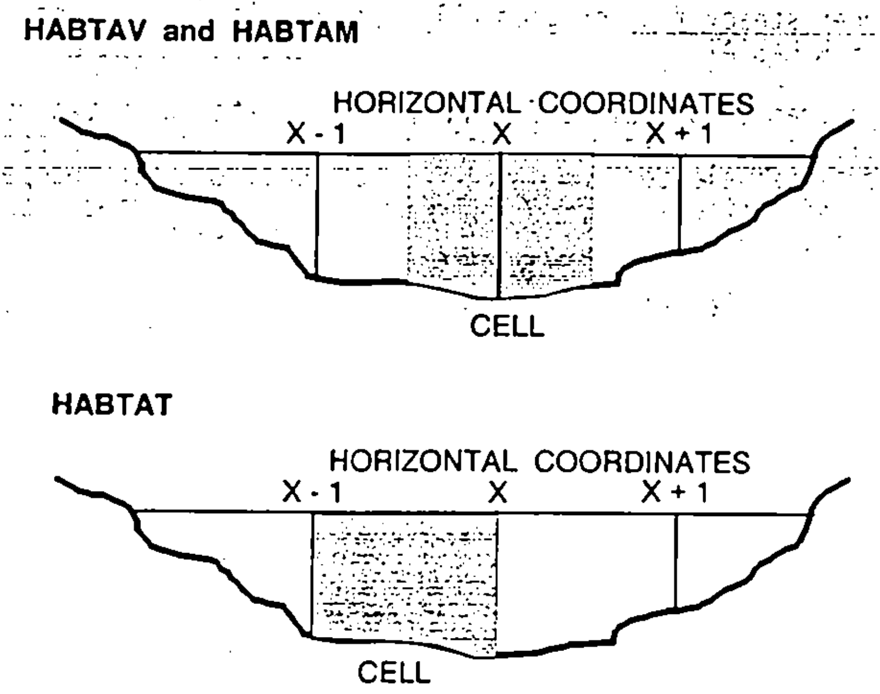


Figure 4. Computational cell boundaries for HABTAM/HABTAV and HABTAE/HABTAT. CHANGE HABTAT IN FIGURE TO HABTAE AND HABTAT

The most substantial difference between HABTAE/HABTAT and HABTAM/HABTAV is the definition of cells. The cell boundaries in HABTAE and HABTAT are at the measured verticals. HABTAM and HABTAV define cell boundaries halfway between the measurement verticals (refer to "PHABSIM Cell Calculations").

HABTAE cell centers are halfway between measurement cell boundaries and use the measured depth and velocity to the left and right. HABTAE also uses the channel index value taken from the X-coordinate vertical on the upstream-right (not left) side of the cell (be sure to correct for this when entering your data).

HABTAM and HABTAV cell centers are on a measurement cell boundary. They find mean depth for each cell centered on the X-coordinate vertical by calculating the cell area and dividing by the cell width. They use the velocity from IFG4 that is centered on the X-coordinate vertical. HABTAM and HABTAV use channel index values taken from the X-coordinate vertical in the middle of the cell (if you were careful enough to record it).

HABTAE PROGRAM

HABTAE- calculates areas or volumes or bed areas of microhabitat (using stepped or binary curves) or weighted usable area or volume, using cell mean column or nose velocities. Used primarily to describe fully mobile organisms under steady flow or gradually varying flow conditions. REPLACEMENT FOR HABTAT.

The HABTAE program (replacement for HABTAT) calculates weighted usable area (surface or bed) or weighted usable volume (WUV) for each cross section. Depending on the options selected to control the computations for independent versus dependent cross sections, output will contain: (1) weighted usable {water} surface area (WUA) (same as HABTAT, HABTAV, and HABTAM), (2) usable surface area (UA) (with specified minimum value for weight to describe what is usable), (3) weighted usable bed area (WUBA) that can be thought of as the weighted wetted perimeter times the segment length to derive an area estimate, and (4) weighted usable volume (WUV) that is the weighted usable area times the water depth

For surface area and dependent cross sections, the HABTAE program will give the same results as the HABTAT program provided that the same simulation options have been selected. Input to the HABTAE program are the options file created by the HABINE program, a FISHFIL file containing the habitat suitability curves of aquatic species and/or recreational activities, a TAPE3 file containing cross section data derived from either IFG4 or WSP, and a TAPE4 file containing the hydraulic data that is also derived from IFG4 or WSP.

Options in HABTAE not in HABTAT:

- Calculates and prints WUA, WUV, or WUBA for multiple or independent cross sections. IOC(1).
- Produces a distribution of composite suitability indices table. IOC(7).
- Allows use of minimum continuous width for composite suitability indices greater than 0. IOC(11).
- Can calculate velocities using the 1/mth power law equation. IOC(14)
- Allows specification of minimum composite suitability index. IOC(19).
- Can use metric units. IOC(20).
- Allows different calculations of velocities or velocity replacements for each individual life stage. IOC(21).

HABTAT options deleted from HABTAE:

All of the options in HABTAT are covered by the HABTAE program with the exception of IOC (1), (5), (7), (8), and (11). Of these options, IOC(1) and (5) may be useful; the others are rarely used.

- Print out any combination of these three matrices, IOC(1) and IOC(5):
  Velocity vs. Depth; Velocity vs. Channel Index;
  Depth vs. Channel Index
- Read hydraulic data from HABTAT input file, IOC(8).
- Write unformatted TAPE7 file, IOC(7) and IOC(11).

HABTAE INPUT/OUTPUT CONTROL (IOC) OPTIONS

Recommended starting values. See page V.36 of PHABSIM manual.
IOC's in bold lettering and shading are the most important for modification.

IOC	RECOMMENDED SETTING
1	0= Calculate WUA for a reach (units of $ft^2/1000$ ft)
2	1= Print cross section data
3	1= Print flow-related data for each cross section and flow
4	0= Do not print computational details: later, set to 1
5	1= Print WUA/WUVolume/WUBottomArea for each cross section
6	1= Print coordinates defining the habitat suitability curves
7	1= Print table of distributions of composite suitability indices
8	0= For cell mid-point velocities (HABTAE and HABTAT) See page V.2 1= For cell boundary velocities (HABTAV AND HABTAM)
9	0= Use combined suitability factor C.S.F. = [FUNCTION(VELOCITY)*FUNCTION(DEPTH)*FUNCTION(CHANNEL INDEX)]
10	0= Write WUA to ZHAQF file (If IOC(1)=0). We recommend that you also present results from IOC(10) = 1 = Write Usable Area to ZHAQF file.
11	0= Do not use minimum contiguous width test within a cross section
12	0= Use reach as rectangles (not trapezoids) in plane view
13	0= Do not write ZHCF file (for effective habitat analysis)
14	0= Calculate velocity for cell using mean column velocity
15	0= Abort run if velocity is less than 0.0 or greater than 15 fps
16	0= Use mean column velocities for habitat (If IOC(14)=0)
17	0= Use given simulated velocities [See constraints on IOC(14) and IOC(16)]
18	0= Do not use Channel Index values of 0.0 or blank to calculate WUA for cell
19	0= No minimum composite suitability index specified. We recommend that you also try IOC(19)=1 and CFMIN=0.15. This changes both WUA and UA sums.
20	0= Output in English units of measure
21	0= Use velocities selected by IOC(14), IOC(16), and IOC(17) [See constraints]
22	0= Do not use near shore (maximum distance for inclusion must be specified) habitat option.
23 and on	Additional options may be added.

HABTAV PROGRAM

HABTAV- calculates areas (only) of microhabitat (using stepped or binary curves) or weighted usable area; using cell mean column or nose velocities and adjacent velocities in same or nearby cells and criteria describing necessary proximity to adjacent velocity. Used primarily to describe feeding stations for drift feeding fish under steady flow or gradually varying flow conditions.

The HABTAV program simulates situations where fish habitat is determined by hydraulic parameters at the fish's location, as well as by velocities near the fish. In HABTAV, cells are defined by one measured vertical located at the center of the cell. See Figure 4 for a diagram of how the HABTAV and HABTAM programs view a cell location in contrast to how the HABTAE program views the cell location relative to verticals. The values of stream characteristics (depth, velocity, and channel index) for each cell are the values of the velocity, depth, and channel index at the measured vertical.

Option 1 in HABTAV scans the cross section a user-specified distance out from the cell for which the habitat is being simulated for a user-specified velocity in adjacent cells. If the velocity is found within the distance, the WUA calculated for the cell is multiplied by one. If the user-specified velocity is not found, HABTAV (with option 5 on) scans the cross section a second time for an initial velocity. This initial velocity is the first velocity where fish habitat is worth more than zero. HABTAV searches for a velocity between the initial velocity and the user-specified velocity closest to the user-specified velocity and then interpolates a worth for this velocity between zero and one. This worth is multiplied by WUA for a new value. If option 5 is off and the user-specified velocity is not found, WUA is multiplied by zero. The four conditions of habitat modeling controlled by a combination of options 1 and 5 is illustrated in Figure 5.

Input to the HABTAV program is the options file created by the HABINV program and these previously created files: (1) a FISHFIL containing habitat suitability curves of aquatic species and/or recreational activities created by the curve maintenance programs, (2) TAPE3 containing cross section data that is output from IFG4, and (3) TP4A containing hydraulic data that is output from IFG4. TP4A is a TP4 created with IOC(17)=1 in the IFG4 program and then renamed TP4A by the user. This version of TP4 is in HABTAM and HABTAV readable format rather than HABTAE readable format.

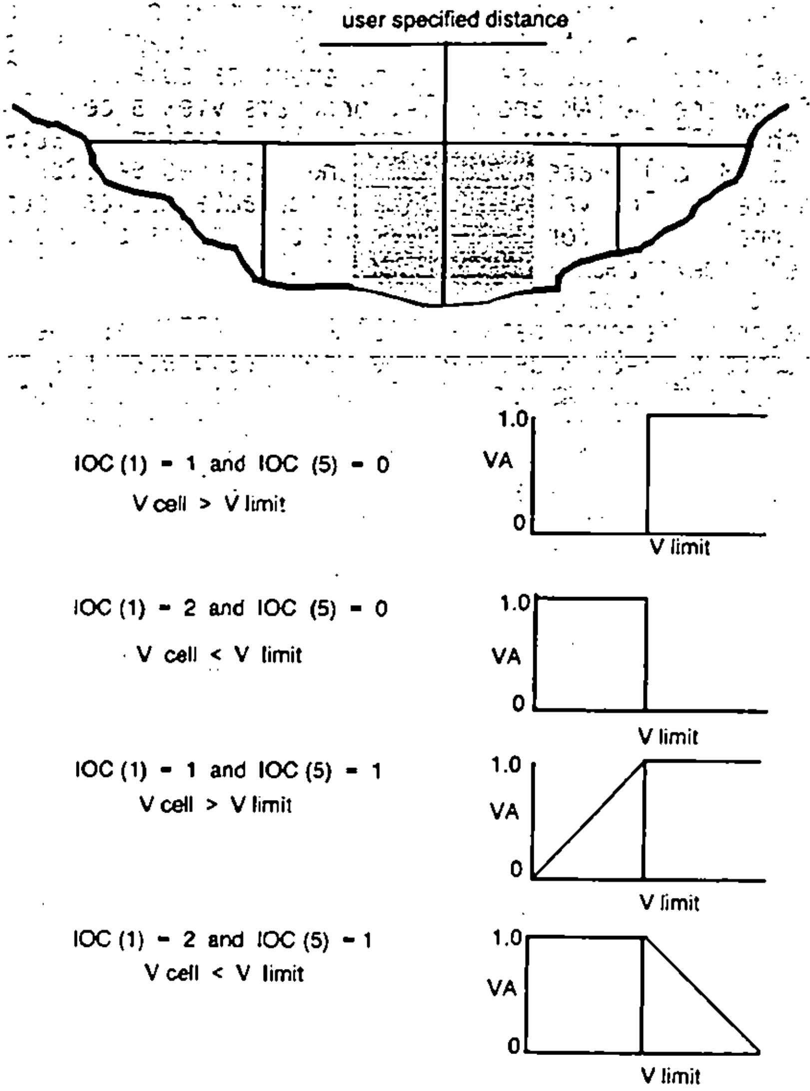


Figure 5. Examples for HABTAV for IOC options 1 and 5 combinations.

HABTAM PROGRAM

HABTAM- calculates areas (only) of microhabitat or weighted usable area based on continuous suitable conditions within a specified distance from each cell. Used to describe composite microhabitat for organisms with limited mobility under unsteady flow or rapidly varying flow conditions. Developed for use in evaluating hydropeaking projects. Special assistance from a professional hydrologist is needed when applying PHABSIM to hydropeaking projects.

The HABTAM program simulates situations in which fish or invertebrates can move laterally within a cross section in order to make use of the available weighted usable area (WUA) when there is a change in velocity. The logic of HABTAM is similar to that of HABTAE with three major exceptions: cell definition, channel index value used, and movement calculation. See Figure 4 for a diagram of how the HABTAM and HABTAV programs view a cell location in contrast to how the HABTAE program views the cell location relative to verticals. In HABTAM, cells are defined by one measured vertical located at the center of the cell. The values of stream characteristics (depth, velocity, and channel index) for each cell are the values of the velocity, depth, and channel index at the measured vertical.

The second major difference between HABTAE and HABTAM is the movement calculation performed by HABTAM between the user-designated starting flow and user designated ending flow. As in HABTAE, HABTAM calculates WUA at each designated flow using functions of velocity, depth, and channel index. HABTAM assumes that the available WUA at the user-designated starting flow is fully utilized. Considering the user-designated maximum allowable movement distance for each life stage of each species, the program calculates how much of the available WUA at the user-designated ending flow can be utilized. Fish are permitted to move only laterally from cell to cell within a cross section.

The user designates a starting flow, ending flow, and a maximum allowable movement distance for each life-stage of each species. The program looks only at the user-designated starting and ending flows for the movement calculations, and processes each cross section as a separate entity, that is, fish cannot move from one cross section to another. Assuming that the stream is saturated with fish at the starting flow (all WUA is occupied) and assuming that the flow is then changed to the ending flow, the program permits the fish to move in either direction within the cross section up to the maximum allowable movement distance for the particular life stage. The program then calculates how much (the maximum amount) of the WUA available at the ending flow can be utilized by the fish presently existing in the stream. The results will show that either all the available WUA at the ending flow can be utilized, or there is an excess of WUA available at the ending flow that cannot be used because there are no fish to use it.

The following assumptions are made in doing the movement calculations:

1. Fish movement is assumed to begin at the cell boundaries. Thus, when a fish is given a maximum allowable movement distance greater than zero, it is automatically permitted to move to adjacent cells. Any distance it might have to travel within its cell of origin is negated.

Input to the HABTAM program is the options file created by the HABINM program and the previously created files: (1) a FISHFIL containing habitat suitability curves of aquatic species and/or recreational activities created by the curve maintenance programs, (2) TAPE3 containing cross section data that is output from IFG4, and (3) TP4A containing hydraulic data that is output from IFG4. TP4A is a TP4 created with IOC(17)=1 in the IFG4 program and then renamed TP4A by the user. This version of TP4 is in HABTAM and HABTAV readable format rather than HABTAE readable format.

2. In situations where the maximum allowable movement distance places a fish on the border of two cells the fish is NOT permitted access to the further cell.

3. Since HABTAM calculates a cell width for each new flow it processes, the width calculated at the flow designated as the ending flow is used as the cell width for the movement calculation.

4. When a portion of a cell becomes dry at the user-designated ending flow, the fish are not permitted to move beyond that dry boundary point.

5. When a given life stage does not move at all, a value of 0.0 should be entered as the maximum allowable movement distance for that life stage. When this occurs, the program will select for the WUA with movement, the minimum of the WUA at the starting flow, and WUA at the ending flow.

HABEF Program

HABEF- calculates areas (only) of microhabitat or weighted usable area based on continuous suitable conditions in each cell at two different discharges or for two life stages or species. Used to calculate physical habitat at two stream flows (streamflow variation analysis and stranding analysis) or for two life stages (effective spawning analysis) or two species of fish (overlap analysis and competition analysis) using two separate runs created by HABTAE or HABTAV.

The HABEF program calculates the physical habitat considering the conditions at two stream flows and/or for two life stages or species of fish. The program uses two ZHCF files created by the HABTAE, HABTAV, or HABTAM programs, when IOC(13)=1, as input. In some cases, the second ZHCF file is a copy of the first. In other cases the files are for different life stages for the same species, or they may be for different species.

The information in each ZHCF file consists of information for each cell. The basic equation used in HABTAE, HABTAV, and HABTAM is that the usability of a cell, i, is given by the equation

$$WUA(i) = A(i) * CF(i)$$

where CF is some function of the velocity, depth, and the channel index for the cell. The information written to the ZHCF file consists of A(i) and CF(i) for each cell used in the physical habitat simulation.

The Weighted Usable Area (WUA) term as used in HABEF is defined by the equation:

$$WUA = \sum_{i=1}^{ncell} CF_i \, A_i$$

where CF is the suitability factor based on velocity, depth, and a channel index, and A is the area of a wet cell. The usable area (UA) is

$$UA = \sum_{i=1}^{ncell} \begin{cases} IF(CF \geq 0.001) & UA_i = A_i \\ IF(CF < 0.001) & UA_i = 0.0 \end{cases}$$

Options in the HABEF program are:

1. UNION OF LIFE STAGE 1 WITH LIFE STAGE 2
2. STREAMFLOW VARIATION ANALYSIS (MINIMUM WUA)
3. COMPETITION ANALYSIS
4. STREAMFLOW VARIATION ANALYSIS (MAXIMUM WUA)
5. MINIMUM OF LIFE STAGE 1 AND LIFE STAGE 2
6. MAXIMUM OF LIFE STAGE 2 AND LIFE STAGE 2
7. EFFECTIVE SPAWNING ANALYSIS
8. STRANDING INDEX ANALYSIS

Option	Analysis
1	Overlap analysis from calculating union of two life stages or species - useful when one is interested in the total habitat for a combination of species (i.e. brown and rainbow trout).
2	Streamflow variation analysis where the minimum weighted usable area for each cell is a comparison of the cell WUA's in each ZHCF file. Every ~~flow~~ cell in the first ZHCF file is matched with every ~~flow~~ cell in the second ZHCF file. Option 2 is useful when there are rapid changes in streamflow; i.e., hydropeaking. Option 5 is similar to Option 2 except for the matching of stream flows.
3	Competition analysis from calculating intersection of two species or life stages, e.g., would show where brown and rainbow trout compete for space.
4	Streamflow variation analysis where the maximum weighted usable area for each cell is a comparison of the cell WUA's in each ZHCF file. Every flow in the first ZHCF file is compared to every flow in the second ZHCF file. Option 4 is useful when there are slow changes in streamflow; i.e., normal changes due to dry vs. rainy season such as is typical for fall spawning in the northwest U.S.
5	Minimum WUA analysis that is similar to Option 2 except that the first flow in the first ZHCF file is compared only to the first flow in the second ZHCF file, the second to the second, and so forth through both files.
6	Maximum WUA analysis that is similar to Option 4 except that the first flow in the first ZHCF file is compared to the first flow in the second ZHCF file, the second to the second, and so forth through both files.
7	Effective spawning analysis is functionally similar to Option 2 except that if the cell WUA in the second file is greater then zero, then the WUA on the first is considered "effective"; but if the area in the second is zero, then the area on the first is considered "ineffective" and made equal to zero.
8	Stranding index analysis is functionally similar to Option 7 except the results on the second HCF file must indicate where stranding would not occur. In other words, the species curves used in HABTAE to generate the second HCF file should be for non-stranding. One possibility is that the suitability index for velocity and channel index would be 1.0 for all velocities and channel indexes. For depth, the index might be 0.0 for depths less than some minimum, and 1.0 for depths greater than the minimum. The user may have other approaches.

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APPENDICES TO ASSIST IN

USING THE COMPUTER BASED PHYSICAL HABITAT SIMULATION SYSTEM (PHABSIM)

APPENDIX A. PERSONAL COMPUTER STRUCTURE AND COMMANDS

DOS = DISK OPERATING SYSTEM (THE SET OF INSTRUCTIONS THAT RUNS THE COMPUTER

DIRECTORY = RELATED GROUP OF FILES LIKE A DRAWER IN A FILING CABINET

FILE = A SET OF INFORMATION STORED IN A PARTICULAR LOCATION (DIRECTORY) UNDER A PARTICULAR NAME (FILENAME)

COMMAND = STATEMENTS TYPED INTO THE KEYBOARD (FOLLOWED BY AN ENTER) THAT GIVE THE COMPUTER YOUR INSTRUCTIONS TO COMPLETE

AN INVERTED TREE DIAGRAM OF THE DIRECTORY STRUCTURE
  LEVEL 1: ROOT DIRECTORY, THE ONE FROM WHICH ALL OTHERS BRANCH AND THAT CONTAINS DOS
  LEVEL 2: FIRST LEVEL OF WORK DIRECTORIES. EXAMPLES INCLUDE WORDPERFECT AND PHABSIM
  LEVEL 3: FIRST LEVEL OF WORK FILES OR SECOND LEVEL OF WORK DIRECTORIES

COMMON SYSTEMS THAT YOU MAY COME ACROSS ON OTHER MACHINES:
  WORD PROCESSOR - WORDPERFECT, WORD
  SPREADSHEET - LOTUS 1-2-3, EXCEL
  DATABASE MANAGEMENT SYSTEM = dBASEIV, ORACLE
  STATISTICAL PACKAGE - SAS, SPSS-PC, BMDP-PC, SYSTAT

DIRECTORY MANAGEMENT COMMANDS

MAKE DIRECTORY	MD\name OF NEW DIRECTORY TO BE FORMED
CHANGE DIRECTORY	CD\name OF DIRECTORY TO MOVE TO
REMOVE DIRECTORY	ASK THE COMPUTER MANAGER FOR ASSISTANCE

FILE MANAGEMENT COMMANDS

DELETE filename	ERASING A FILE FROM WITHIN THE CURRENT DIRECTORY
RENAME oldname newname	RENAMING A FILE WITHIN THE CURRENT DIRECTORY
COPY filename A:	COPY A FILE FROM HARD DISK (THE CURRENT DIRECTORY) ONTO A FLOPPY DISK
COPY A:filename	COPY A FILE FROM A FLOPPY DISK INTO THE CURRENT DIRECTORY ON THE HARD DISK
DIR/P or SD	LIST FILES IN A DIRECTORY
FORMAT	FLOPPY DISKS MUST BE FORMATTED BEFORE THEIR FIRST USE OUT OF THE BOX
TYPE filename ¦MORE	TYPE A FILE OUT ONTO THE SCREEN FOR THE PURPOSE OF VIEWING IT (MAY ALSO USE "LIST")

COMPUTER TERMINOLOGY

ASCII ('ASK E') = AMERICAN STANDARD CODE FOR INFORMATION INTERCHANGE. A SYSTEM INDEPENDENT FILE FORMAT THAT CONTAINS NO SPECIAL CHARACTERS. IN THE TYPE COMMAND, EVERYTHING IS READABLE WITH NO UNUSUAL (UNREADABLE) CHARACTERS.

BOOT DISK = THE DISK (FLOPPY OR DISK) THAT CONTAINS THE DOS FILES NEEDED TO START THE COMPUTER.

BOOT UP OR REBOOT = START OR RESTART THE COMPUTER FROM THE POINT WHERE ELECTRICITY IS FIRST TURNED ON FOR THE MACHINE. THIS READS THE DOS INFORMATION FROM THE BOOT DISK.

WORK DISK = THE DISK ON WHICH DOS IS STORED AND ON WHICH MOST WORK IS DONE. IN A TWO FLOPPY DISK SYSTEM, THIS IS USUALLY DRIVE A: (THE TOP ONE). IN A ONE FLOPPY DISK AND ONE HARD DISK SYSTEM, THIS IS USUALLY DRIVE C: (THE HARD DISK).

RANDOM ACCESS = THIS MEMORY IS THE FASTEST AVAILABLE TO THE COMPUTER, BUT IS LOST WHEN THE COMPUTER IS REBOOTED OR TURNED OFF. YOUR MACHINES RAM MEMORY SIZE IS 640 KILOBYTES (640 TIMES 1024 BYTES).

HARD DISK = THIS MEMORY IS THE SECOND FASTEST AVAILABLE TO THE COMPUTER AND IS STORED SEMIPERMANENTLY ON THE COMPUTER EVEN WITH THE ELECTRICITY TURNED OFF. YOUR MACHINES HARD DISK MEMORY SIZE IS 20 MEGABYTES (20 TIMES 1024 TIMES 1024 BYTES).

FLOPPY DISK = THIS MEMORY IS THE SLOWEST AVAILABLE TO THE COMPUTER AND IS STORED PERMANENTLY ON THE REMOVABLE FLOPPY DISK. THIS IS THE BEST WAY TO STORE YOUR DATA FOR THE LONG TERM AND MOVE FILES FROM ONE MACHINE TO ANOTHER.

LOGGED INTO = THE CURRENT DIRECTORY

LOGGED OFF = TURNED THE COMPUTER OFF

ACTIVE DRIVE = THE DISK DRIVE THAT YOU ARE CURRENTLY IN (C: OR A: ON YOUR MACHINES)

PROMPT - ROOT DIRECTORY = C:\>

PROMPT - PHABSIM PROGRAMS DIRECTORY = C:\PHABSIM>

PROMPT - PHABSIM WORK DIRECTORY = D:\IF310

DOS COMMAND FORMAT SUMMARY TABLE

Name	Purpose	Format
AUTOEXEC.BAT	A file containing a series of commands for batch processing: ECHO. FOR. GOTO. IF. PAUSE. REM. SHIFT	see supplement
CHDIR (CD)	To change directories or display the current (working) directory	CD pathname
CLS	To clear the screen	CLS
CONFIG.SYS	A file containing commands to configure the DOS system (BREAK. BUFFERS. COUNTRY. DEVICE. FCBS. FILES. LASTDRIVE. SHELL commands)	see supplement
COPY	To copy specified file(s)	COPY [d1:][path1]file1 [d2:][path2]file2
DEL	To delete all specified files	DEL [d:][path]file
DIR	To list the filenames in a directory	DIR [path][file] [/P] [/W]
GRAPHICS	To load a graphics screen on a printer	GRAPHICS
MKDIR (MD)	To make a directory	MD path
PATH	To set a command search path	PATH [[d:path1] [:[d2:]path2][..]
PRINT	To print a text file on a printer (background print)	PRINT [d:]file1 [/T] [...]
REN (RENAME)	To rename a file	REN [d:][path] file1 file2
RMDIR (RD)	To remove a directory	RD [d:]path
SET	To set one string value equal to another	SET str1=str2

CONFIGURATION COMMANDS

Command	Purpose	Format
BUFFERS	To change number of disk data storage areas in memory	BUFFERS=nn
FILES	To set the number of files that can be open at one time	FILES=nn
SHELL	To cause alternate command processor to be loaded	SHELL=[path]file

BATCH COMMANDS

Command	Purpose	Format
ECHO	To turn on and off during batch file processing	ECHO [ON¦OFF] <message>
FOR..IN..DO..	To selectively process files by a DOS command	FOR %%<variable>IN (list)DO<command> %%<variable>
GOTO	To change sequence of execution of batch file statements	GOTO<label>
IF	To execute a DOS or batch command conditionally during batch processing	IF [NOT] <cond> <command>
PAUSE	To suspend execution of the batch file	PAUSE [message]
REM	To display a message during batch file processing	REM [message]
SHIFT	To allow access to more than 10 replaceable parameters	SHIFT

WHAT IS DOS?

--> Names: PC-DOS or MS-DOS

--> Meaning: Disk Operating System

--> Function: Controls all
- programs
- memory
- disk space
- printer

--> Prompt: drive:\directory\subdirectory>

examples - C:\> (root)
D:\IF310\LAB1>

--> Cursor: blinking mark, underline, or box

```
C:>_
```

DOS DISK DRIVE DESIGNATIONS

First Floppy Drive = A:
Second Floppy Drive = B: (optional)
First Hard Drive = C: (depends)
Second Hard Drive = D: (depends)

CHANGING DRIVES

```
C:\> d: <ENTER>

D:\>
```

DEFAULT DRIVE & DIRECTORY

Unless otherwise specified, DOS will act on the files located on the drive and path to which you are already "pointing".

KEYBOARD ENTRIES TO DOS

1) <-' = ENTER = RETURN
2) <- = Backspace = remove previous char
3) ESC = Escape = delete command
4) Special DOSEDIT functions:

a) Left and right arrows move within a command

b) Up and down arrows recall previous commands

c) INS = Insert = allows character insertion

d) DEL = Delete = deletes character under cursor

e) disables DOS function key editing

---

* = non-standard DOS command we supply

5) CTRL = Control

Press and hold Ctrl and press other key, such as CTRL-BREAK to exit most programs. Usually shown

<Ctrl-Break>

6) <Ctrl-Alt-Del> will "reboot" system

7) CLS = Clear the screen

8) PRINT = send file(s) to the printer

9) <Shift-PrtSc> = Print screen contents

WHAT ARE FILES?

--> A named collection of related information

--> Three general types:
- Program files
- Batch command files
- Data & Text files

--> All files have a beginning and an end (and a size)

--> Type DIR A: to find list of files on drive A:

--> All disks have a limited capacity for files

--> ADVICE: Use file names you can remember!

FILE NAMES

--> Two parts: file name and extension

--> Name: 1 to 8 characters,
letters and numbers

--> Extension: period followed by 0 to 3 characters or numerals
progress.001

--> Universal designator: * for a character group

--> Wildcard designator: ? for any single char.

--> Common extensions:

BAK	backup
BAT	batch
COM	program
DAT	data
DOC	documentation
EXE	program
SYS	system
TXT	text

--> Special files:

CON	keyboard/console
PRN	printer
NUL	null device

FILE OPERATIONS

--> COPY: COPY file1 file2

COPY myfile.bak myfile.dat
COPY a:myfile.* b:
COPY myfile.dat PRN

--> RENAME: REN file1 file2

REN myfile.dat other.dat

--> DELETE: DEL filename

--> LOCATING: WHEREIS filename *

--> VIEWING: LIST filename *

--> DIRECTORY: SD [file] *

* = non-standard DOS commands we supply

HIERARCHIAL DIRECTORY STRUCTURE

--> ORGANIZATION:

```
                    ROOT
   DOS    UTIL      WP       IF310   OTHER
          WORD      WED      LAB1    LAB2
```

```
-->     PATH NAMES:     [\][directory][[\directory...][\]

                        \IF310\LAB2\POUDRE.IN4

-->     EXPLORING:      type TREED                          *

-->     ADVICE:         move to working data directory
                        stay put
                        use defaults

* = non-standard DOS command
```

DIRECTORY COMMANDS

```
-->     CHANGE:         CD pathname

                        CD \IF310\LAB1

-->     MAKE:           MD dirname

                        MD DATA3

-->     REMOVING:       RD dirname

                        RD DATA3        (must be empty)
```

YOUR DOS ENVIRONMENT

```
-->     CONFIG.SYS:     SHELL=C:\COMMAND.COM /E:512 /P
                        FILES=20
                        BUFFERS=20

-->     AUTOEXEC.BAT:   PATH C:\IF310;...
                        SET\RMFORT.ERR=C:\IF310\RMFORT.ERR
                        PROMPT $p$g
                        GRAPHICS
                        DOSEDIT alias.lst

-->     REQUIREMENTS:   100% IBM-PC COMPATIBLE
                        DOS VERSION 3 OR LATER
                        512 K OR MORE
                        2 FLOPPY DISKS. HARD DISK DESIRABLE
                        132 COLUMN PRINTER CAPABILITY
                        IBM COMPATIBLE GRAPHICS PRINTER
                        25 LINE SCREEN
                        640 X 200 GRAPHICS CAPABILITY
                        MATH COPROCESSOR RECOMMENDED
                        ASCII FILE EDITOR
```

APPENDIX B. INTRODUCTION TO THE PROGRAM EDITOR

DESCRIPTION

ED is a program editor product of WORDPERFECT {ED was formerly called PE} that uses a similar template of commands. ED is a screen oriented editor that is easy to learn, fast, and well suited for editing large data files. This program is handy, but not necessarily a replacement for your own editor or word processor. A thorough review of the documentation is suggested to become familiar in ED.

STARTING ED

Simply type ED at the DOS prompt followed by the filename you wish to edit or if in the RPM interface, the ED will automatically be accessed when the editing function key is invoked. The following is an example for access to ED from the DOS command line.

```
C:\DATA>ED TAPE8.TPM
```

STATUS LINE

The bottom line of the screen contains a status line. It displays your filename, position in the file and other relevant information such as caps lock, numeric lock, insert mode, etc.

THE TEXT AREA

The rest of the screen is for your use for text editing.

EXITING ED

Pressing the F7 function key begins the exiting process. First ED asks if you wish to save the document, then if you wish to exit ED. Just respond with a Yes (Y) or No (N) to each of the prompts given. If you select to save a file that already exists, ED will ask if you wish to replace it. The F10 function key can also be used to save a file without exiting ED.

HELP FUNCTION

An on-line help function is available that can display help screens for each of the options. This is invoked by pressing the F3 function key. When this is pressed a help index is displayed that identifies which key or combination of Alt, Ctrl or Shift and Function Key will preform that task. Pressing the F3 key twice places a template of ED commands on the screen. Exit Help by hitting the spacebar.

CURSOR AND FUNCTION KEYS

FUNCTION KEYS

F1 - Cancel:	Cancels a feature or a function.
F2 - Search:	Lets you search in a forward direction.
Alt-F2 - Replace:	Lets you replace every occurrence of a string of text in a file.
F3 - Help:	Brings up the help template for ED.
F5 - List Files:	Lets you list and retrieve files.
Shift-F7 - Print:	Lets you access the print options.
F9 - Block:	Lets you define text to be moved. copied. cut. etc.
F10 - Save:	Saves a file or block of text
Shift-F10 - Retrieve:	Lets you retrieve a file.
Enter:	Press Enter to end a line of text. When you end a line of text in Program Editor. a <CR><LF> (Carriage Return. Line Feed) is inserted during normal editing. A <HRT> (Hard Return) is inserted when print format is on in Program Editor.
Hard Page (Ctrl-Enter):	In Program Editor. Hard Page inserts <PG#> which is replaced by the current page number)
Word Left or Word Right (Ctrl-← / Ctrl-→)	Moves the cursor to the beginning of the previous word. or the next word. A word is a group of characters separated from other characters by tabs. and/or spaces. or an end of line.
End:	Moves the cursor to the end of the current line.
Escape (Esc):	Moves the cursor a specific number of characters or lines. In Program Editor. you can also move a specific number of pages. Escape can also be used to repeat a feature a specific number of times.
Go To (Ctrl-Home):	Moves the cursor to a specific character or line. In Program Editor. you can also move to the top or bottom of the current page.
Page Up/Down:	Moves the cursor to the first line on the previous or next page.

Screen Up/Down (-/+ on numpad)	Moves the cursor to the beginning of the first or last line on the screen. and an additional screen each time it is pressed.
Home, Right Arrow:	Moves the cursor to the right edge of the screen.
Home, Left Arrow:	Moves the cursor to the left edge of the screen.
Home, Down Arrow:	Moves the cursor to the bottom of the screen. and an additional screen each time it is pressed.
Home, Up Arrow:	Moves the cursor to the top of the screen. and an additional screen each time it is pressed.
Hm, Hm, Right Arrow:	Moves the cursor to the end of a line.
Hm, Hm, Left Arrow:	Moves the cursor to the beginning of a line.
Hm, Hm, Down Arrow:	Moves the cursor to the end of all text.
Hm, Hm, Up Arrow:	Moves the cursor to the beginning of all text.

EDITING THE FILE

A. INSERTING TEXT
  1. Default is Insert
  2. Press the <INS> key to toggle between Insert and Typeover

B. ERASING TEXT (Deleting)
  1. Press the <Backspace> key to delete character to the left
  2. Press the <Del> key to delete character under cursor
  3. Press Ctrl-End to delete the rest of a line
  4. Other advanced commands

C. LOCATING and REPLACING TEXT
  1. Press F2 to locate a string down
  2. Press Alt-F2 to find and replace a string
  3. Press Shift-F2 to locate a string up

If you typed the wrong command. <ESC> will bring you back to editing mode.

PROGRAM EDITOR COMMAND SUMMARY

BASIC COMMANDS

COMMANDS		DESCRIPTION	KEY
CURSOR MOVEMENT			
	Char	Move right one character	Right Arrow
		Move left one character	Left Arrow
	Line	Move down line	Down Arrow
		Move up line	Up Arrow
		Move to beginning of line	Home. Home. Left Arrow
		Move to end of line	Home. Home. Right Arrow
	Page	Move down one page	PgDn
		Move up one page	PgUp
		Move down one screen	+ (numpad)
		Move up one screen	- (numpad)
	Word	Move right one word	Ctrl-Right Arrow
		Move left one word	Ctrl-Left Arrow
	Delete	Delete character under cursor	<Del>
		Delete left character	<Backspace>
		Delete to end of line	Ctrl-End
GOTO			
	Top	Move to the top of the file	Home. Home. Up Arrow
	Bottom	Move to the bottom of the file	Home. Home. Down Arrow
HELP		On-Line Help for commands	F3
INSERT		Insert a character	Any char while in Insert
LOCATE		Locate a word or phrase	F2
REPLACE		Replace a word or phase	Ctrl-F2
QUIT		Exiting the ED program	F7

APPENDIX C. UNDERSTANDING PHABSIM CELL CALCULATIONS

PHABSIM programs divide a stream into cross sections and cells to simulate stream geometry and habitat. There has been some confusion about the way the stream is actually modelled, and how calculations are done in the major simulation programs in PHABSIM. This report will describe the differences between IFG4, HABTAE, HABTAM and HABTAV.

This report will focus on the calculation of Depth, Velocity, and Channel Index. Throughout this report, a simplified data set is used to demonstrate the input and output to the various PHABSIM programs. The data set describes one cross section of a stream with only six points. Three stream discharges are used for testing: 50, 100, and 150 cfs. Figure 1 is a graph of the stream bed described by the data set. Each point on the stream bed is an observed X-Y coordinate point. Figure 2 shows a close-up of the measured values for the left cells in the cross section at 50 cfs. This shows where each value is measured for IFG4, with the exception of where channel index should be measured.

Three different methods are used by PHABSIM programs to describe the stream. IFG4 calculates the stream depths and velocities at each X-coordinate. HABTAV and HABTAM use each wet X-coordinate vertical as the center of a cell, and define the cell boundaries half way between the center of the cell and the adjacent X-coordinates. HABTAE use the X-coordinate verticals as cell boundaries. Figures 3 and 4 show how cells are defined by the major habitat simulation programs.

The most significant problem is that field data on channel index values need to be entered from different points for the two different approaches (See Figures 5 and 6). There are also some differences in the way cells are labeled, and which X-coordinate the cells correspond to. It is important that PHABSIM users know the difference in the way calculations are done, to record channel index data properly, analyze data correctly, and to correctly interpret results.

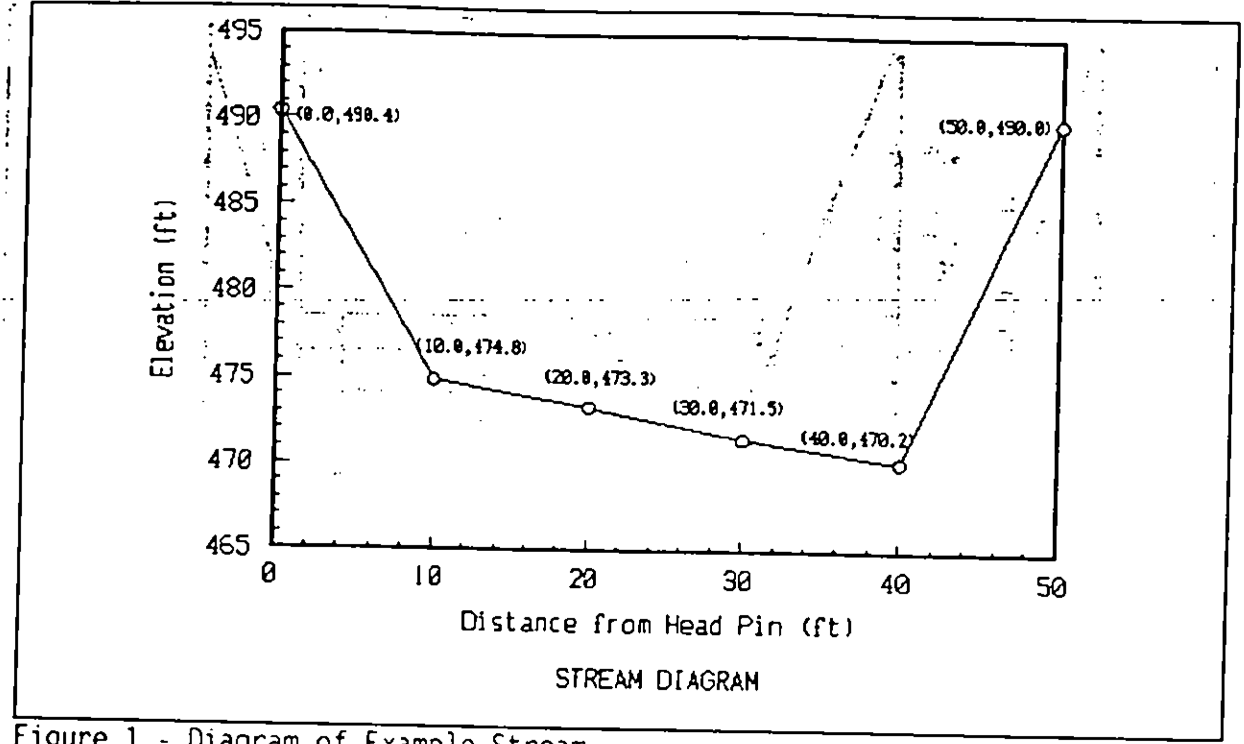

Figure 1 - Diagram of Example Stream

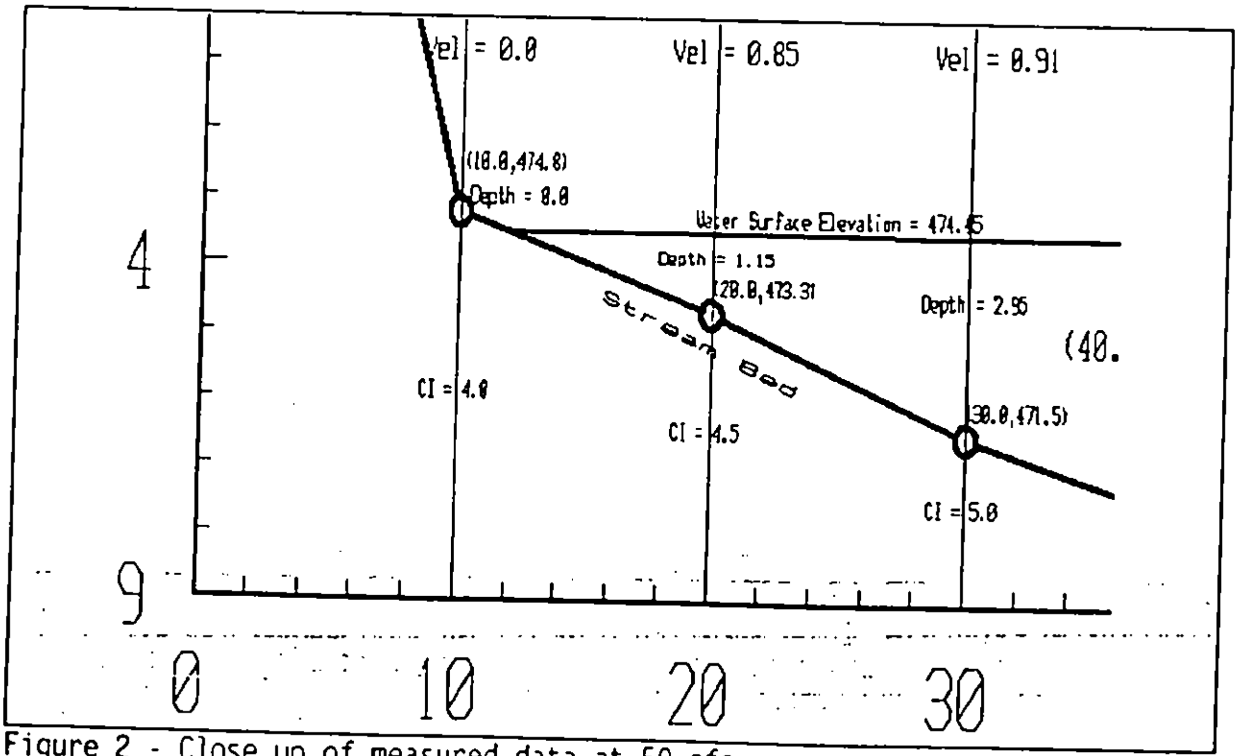

Figure 2 - Close up of measured data at 50 cfs

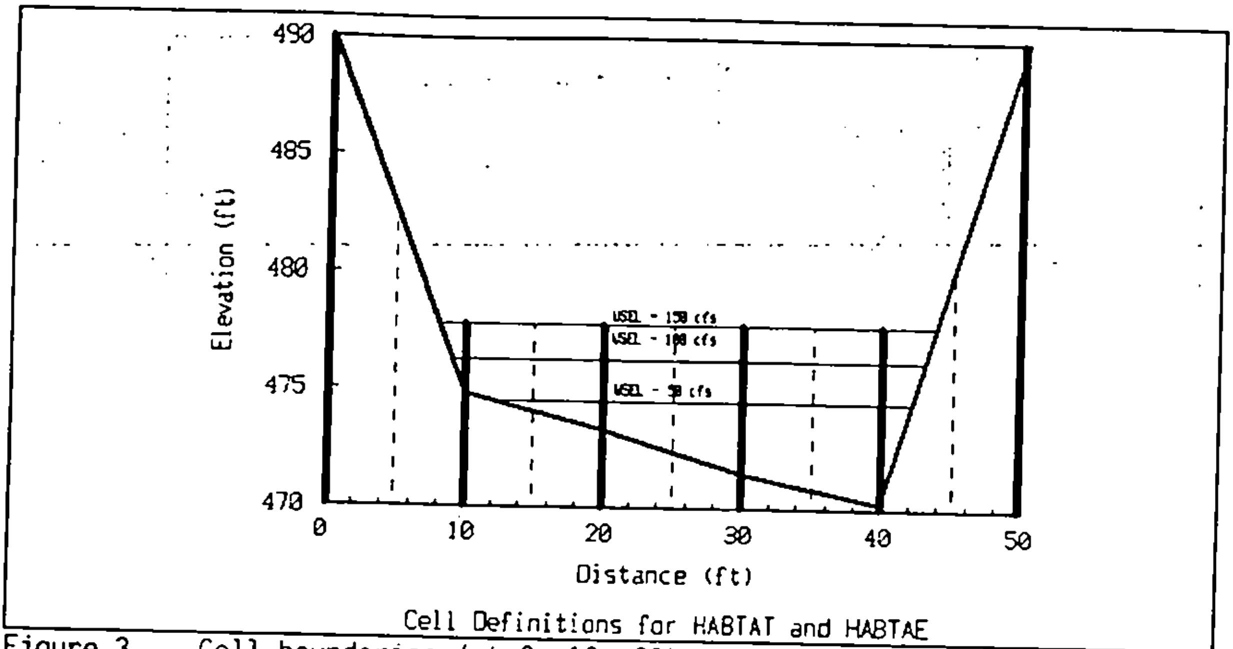

Figure 3 - Cell boundaries (at 0, 10, 20) are at field X-coordinates. Mean depth and velocity for cell center (at 5) is calculated from the two simulated values at that cell's boundaries (0,10).

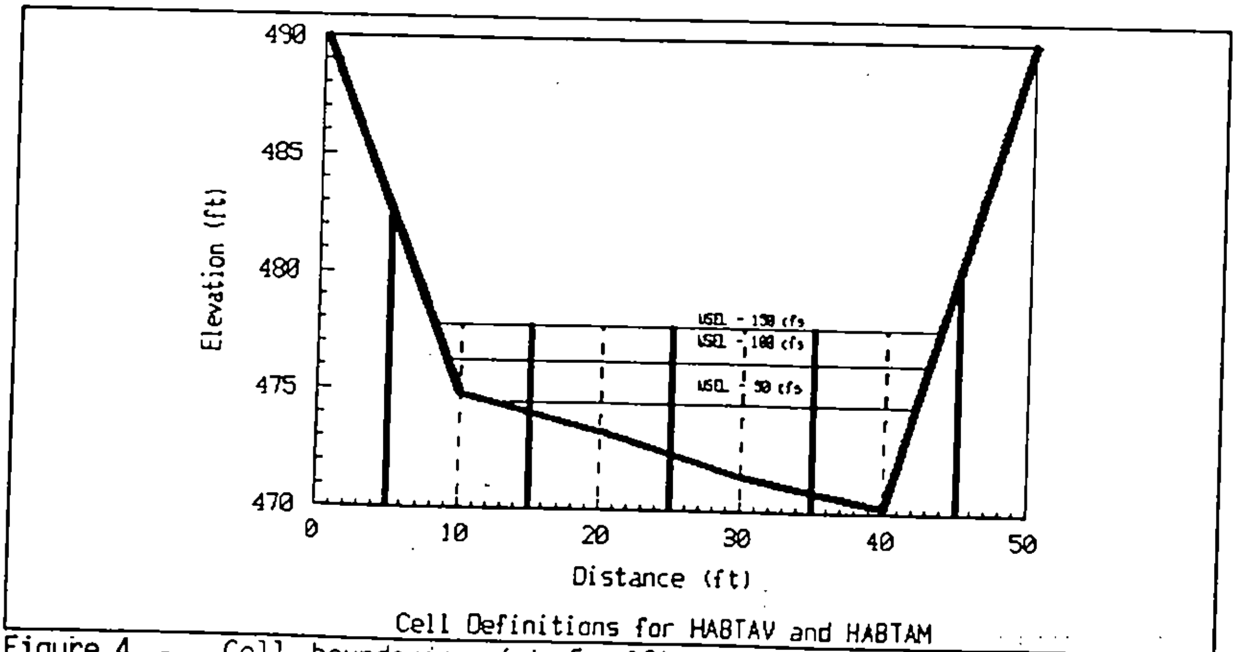

Figure 4 - Cell boundaries (at 5, 15) are midpoints between field X-coordinates (at 0, 10, 20). Simulated velocity for cell center (at 10) is used (not a mean value). Mean depth is calculated using a complicated equation.

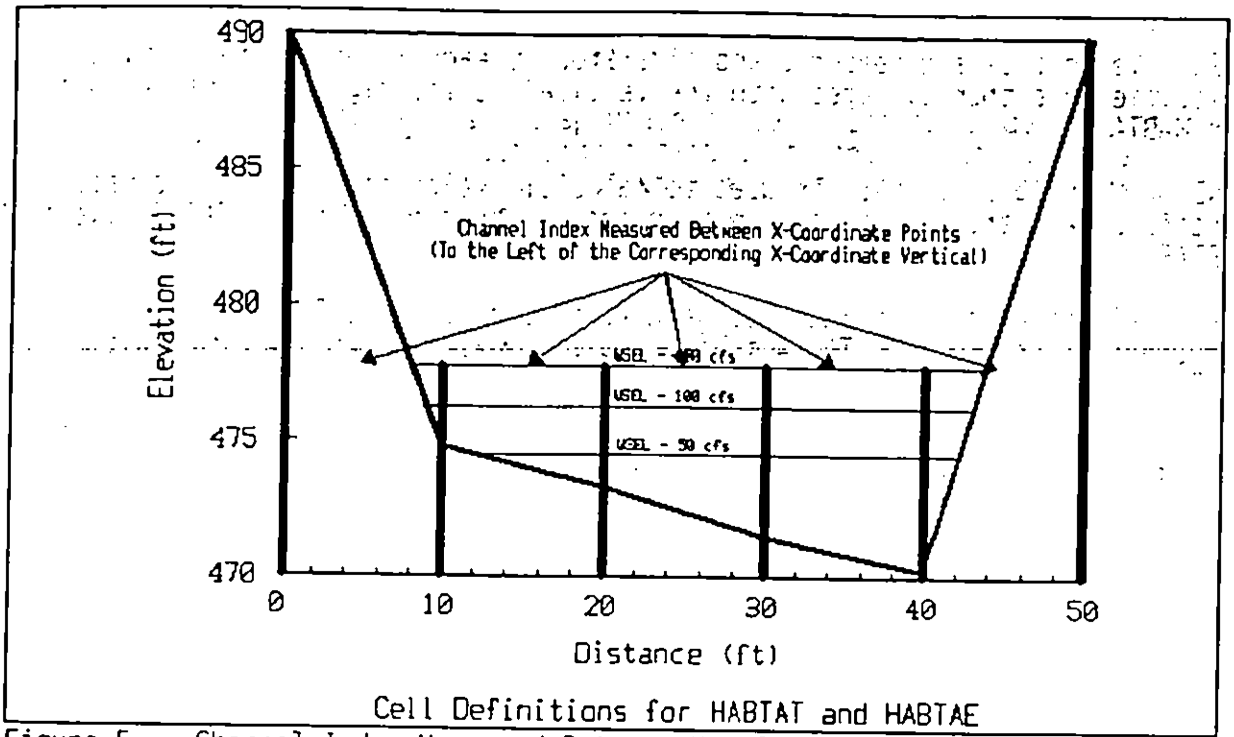

Figure 5 - Channel Index Measured Between X - Coordinate Verticals

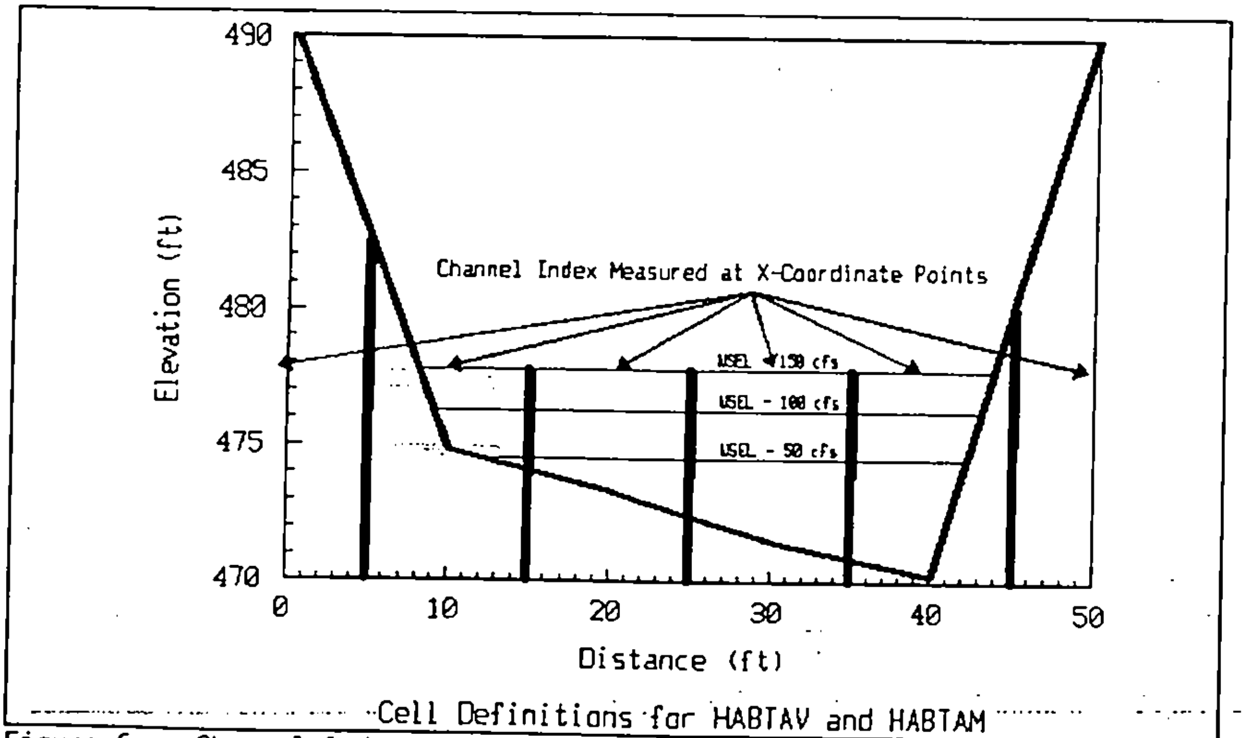

Figure 6 - Channel Index Measured at X - Coordinate Verticals

SUMMARY OF VELOCITY CALCULATIONS

IFG4 - Velocities are measured and simulated at each X-coordinate vertical. Velocities are then averaged with the vertical to the right for the TAPE4 file for HABTAE.

MANSQ - Manning's equation is used to calculate velocities at X-coordinate verticals, and the velocities are averaged to the right for the TAPE4 file for HABTAE.

WSP - Velocities are simulated between verticals using cell roughness and conveyance factors. The TAPE4 file produced by WSP can only be used with HABTAE.

HABTAE/T - Cells are bounded by X-coordinate verticals, so the average velocity between each pair of verticals is used. For HABTAT/HABTAE, the pair of velocities to be averaged are taken directly from the TAPE4 file.

HABTAV/HABTAM - The X-coordinate verticals are used as the simulation point in the middle of each cell. Velocities at each vertical from IFG4 are used. The velocity is from the vertical that is in the cell. The velocity is taken directly from the TAPE4 file.

SUMMARY OF DEPTH CALCULATIONS

IFG4 - Depths are used at each X-coordinate vertical for velocity simulation, but average depths between X-coordinates are written to the output file.

MANSQ - The mean depth for the entire cross section and the depths at X-coordinate verticals are used in Manning's equation.

WSP - Depth is calculated at each vertical by using the elevation of the previous cell and the slope and change in distance to the vertical.

HABTAE/T - Cells are bounded by X-coordinate verticals, so the average depth between each pair of verticals is used. For HABTAT/HABTAE, the pair of velocities to be averaged are taken directly from the TAPE4 file.

HABTAV/HABTAM - The mean depth for each cell is used. The mean depth is calculated using a complicated equation.

SUMMARY OF CHANNEL INDEX CALCULATIONS

IFG4, MANSQ, and WSP - do not use or calculate CI values; they just read them and pass them on to the HABITAT programs.

HABTAE/T - Channel index values are taken from the right vertical of each cell from the original data.

HABTAV/HABTAM - Channel index values for the X-coordinate vertical inside of each cell are used.

Differences

The obvious difference is the approach to cell-vertical modelling used by the habitat programs. The most significant difference is the way the channel index is used. Users need to understand that channel index should be entered differently for different PHABSIM approaches. The differences in the ZHCF files will be discussed later.

CELL-CALCULATION IN HYDRAULIC SIMULATION PROGRAMS

IFG4 and MANSQ simulate velocities and depths at each vertical. and then average depths for each cell in the output. The channel index values are simply passed to the Habitat simulation programs. WSP simulates velocities and depths between verticals.

The following is a simple IFG4 data set containing the six points describing the stream bed and three "calibration sets." or sets of measured velocities in each cell. for discharges at Q = 50. 100. and 150 cfs. The X and Y values. channel index. and measured calibration velocities for the vertical at X-coordinate 20.0 are highlighted.

```
SALMON RIVER. NEW YORK. UNSTEADY FLOW MODEL. SUMMER 1986 (CPINM)
PINEVILLE  S118M/SR-4/2-10-87 MEAN VELOCITY(SZF=471.5-GUESS)
IOC        1111000200100000000000000000000000000
QARD   50.0        (flows for simulation)
QARD  100.0
QARD  150.0
XSEC 118.0 100.0000 1.00   471.500  0.001000
     118.0  0.0490.4 10.0474.8 20.0473.3 30.0471.5 40.0470.2 50.0490.0 (XY Pairs)
NS   118.0       3.5       4.0       4.5       5.0       6.5       5.5 (CI)
CAL1 118.0   474.450     50.00     50.0   (WSEL and Q for calibration set 1)
VEL1 118.0            0.85 0.91 0.68      (measured velocities at 50 cfs)
CAL2 118.0   476.660    100.00    100.0   (WSEL and Q for calibration set 2)
VEL2 118.0       0.07 0.72 1.00 0.7       (measured velocities at 100 cfs)
CAL3 118.0   477.410    150.00    150.0   (WSEL and Q for calibration set 3)
VEL3 118.0       0.16 0.85 1.31 0.91      (measured velocities at 150 cfs)
ENDJ
```

This chart from the IFG4 output shows the depth at each X-coordinate for the calibration sets. For Vertical 3. X = 20.0 (from above chart) Y. or the elevation. is 473.3. Thus. the depth at that vertical is the water surface elevation (at 50.1 cfs - calculated discharge) minus the elevation of the stream bed.

Depth at X3 = WSEL - Y3 or 474.45 - 473.3 = 1.15

The depth at each vertical is:

	Q = 50.1 WSEL = 474.45	Q = 100.1 WSEL = 476.66	Q = 150.0 WSEL = 477.41
1	0	0	0

2	0	1.86	2.61
3	1.15	3.36	4.11
4	2.95	5.16	5.91
5	4.43	6.46	7.21
6	0	0	0

Because the calibration flows are similar to the discharges on the QARD lines. the simulated velocities are similar to the velocities for each measured at each vertical on the calibration sets. The simulated depth is again averaged between the depth at the corresponding vertical and the vertical to the right.

For example. for Q = 50 cfs. the simulated water surface elevation is 479.49. Since the water surface is below the elevation at X = 10.0. the actual depth at X = 10.0 is 0. The depth at X = 20.0 is the water surface elevation minus the bed elevation:

Actual depth at X3 = (WSEL - Y3). or 474.49 - 473.3 = 1.19

IFG4 uses the verticals as cell boundaries and uses the *average depth* between the depths at X = 10.0 and X = 20.0 which is:

(Depth at X2 + Depth at X3)/2 or (Dx2 + Dx3)/2 = (0.0 + 1.19) / 2.0 = 0.60

The area is depth times Width or: .60 x 7.9 = 4.7.

(7.9 is the distance from the water's edge to the vertical at X = 20.0)

The velocity at X = 10.0 is 0. because the vertical at X = 10.0 is dry.

The table is confusing because the n value and Velocity are simulated at the vertical X = 10.0. but the Depth and Area are simulated for the cell between X = 10.0 and X = 20.0.

Simulated Flows

SIMULATED Q= 50.0 CFS. WSEL= 474.49
WATERS EDGE AT LEFT 12.1. AT RIGHT 42.2

VERTICAL	X	n	DEPTH	AREA	VELOCITY
2	10.0		0.60	4.7	0.00
3	20.0	0.061	2.09	20.9	0.82
4	30.0	0.107	3.64	36.4	0.88
5	40.0	0.182	2.15	4.6	0.65
6	50.0		0.00	0.0	0.00

(These simulated velocities are very similar to the calibration velocities)

The channel index values from IFG4 are associated with each vertical. and are simply written to the TAPE3 file: along with the X and Y points for the cross section.

TAPE3 FILE

```
CROSS SECTION = 118.0 REACH LENGTH = 0.00  WEIGHT ON REACH = 1.00
   NUMBER OF CROSS SECTION POINTS = 6
```

```
   X        Y      CHANNEL INDEX / ROUGHNESS
   0.0    490.40       3.50000
  10.0    474.80       4.00000
  20.0    473.30       4.50000
  30.0    471.50       5.00000
  40.0    470.20       6.50000
  50.0    490.00       5.50000
```

TAPE4 FILES

TAPE4 files contain the discharge, number of simulated velocities (greater than 0), the water surface elevation at the discharge, and the simulated velocities. IFG4 and MANSQ create different files for the HABTAV/HABTAV and the HABTAE habitat simulation programs. The TAPE4 files for HABTAV/HABTAM contain velocities at each X-coordinate vertical. The TAPE4 files for HABTAE contain velocities averaged between X-coordinates. WSP, because it simulates velocities between verticals only, produces a TAPE4 for HABTAE only.

The following are TAPE4 files created by IFG4 for HABTAV/M and HABTAE.

```
TAPE4 FILE for HABTAV/HABTAM
Cross Section    118.000

  FLOW    # OF VELS   WSEL                    VELOCITIES

  50.000      3     474.494   0.81671   0.88080   0.65513
 100.000      4     476.280   0.07002   0.80227   1.09238   0.77433
 150.000      4     477.785   0.15996   0.79393   1.23898   0.85388
```

The velocities shown here are the simulated velocities directly from IFG4. The first velocity is for the vertical at X = 20.0.

```
TAPE4 FILE FOR HABTAE
Cross Section   118.000

  FLOW   # OF VELS  WSEL                      VELOCITIES

  50.000      4     474.494   0.40836   0.84875   0.76796   0.32756
 100.000      5     476.280   0.03501   0.43614   0.94732   0.93335   0.38717
 150.000      5     477.785   0.07998   0.47695   1.01646   1.04643   0.42694
```

The velocities shown here are averaged between verticals. The first velocity is averaged between X-coordinates 10.0 and 20.0.

HABTAV/HABTAM CALCULATIONS

The following is a summary of the cell calculations (IOC(4)=1) produced by HABTAV or HABTAM using the sample data set for the first discharge. The first wet cell defined by HABTAV and HABTAM has a center at X = 10.0 and boundaries between adjacent verticals at X = 5.0 and X = 15.0. The velocity is from the vertical that is in the cell. In the first cell, that velocity is zero, since the vertical is actually dry. For the second cell, the velocity is taken directly from the TAPE4 file. The mean depth is calculated by HABTAV and HABTAM using a complicated equation. The area shown in this chart is actually the surface area of the cell, not the cross sectional area.

```
WSEL = 474.49    CELL INFORMATION:
 WIDTH       V      DEPTH   CHAN. INDEX  AREA     CF
  2.96     0.00     0.22       4.00      2.96    0.02
 10.00     0.82     1.23       4.50     10.00    0.20
 10.00     0.88     2.93       5.00     10.00    0.32
  7.17     0.66     3.42       6.50      7.17    0.50
```

HABTAV and HABTAM will not work correctly with just one cross section. A duplicate cross section was added for these examples.

HABTAT Calculations

The following is a description of calculation details (IOC(4) = 1) from the HABTAT program using the sample data set for the first discharge.

Calculation Details

```
 WSEL     XL      XR      YL       YR       CI    WIDTH   VEL  DEPTH   AREA    CF
474.49  12.04   20.00   474.49   473.30   4.50    7.96   0.41  0.60    7.96   0.05
474.49  20.00   30.00   473.30   471.50   5.00   10.00   0.85  2.09   10.00   0.36
474.49  30.00   40.00   471.50   470.20   6.50   10.00   0.77  3.64   10.00   0.47
474.49  40.00   42.17   470.20   474.49   5.50    2.17   0.33  2.15    2.17   0.77
```

Each cell is shown with its left and right boundaries (XL and XR with stages YL and YR). The average velocities are taken directly from the TAPE4 file for HABTAT/HABTAE. The depths are averaged between verticals, and are the same as in IFG4. The areas listed are not the cross sectional areas of each cell as in IFG4, they are the surface areas for the cell. The area is the width of the cell times reach length, or the length to the next cross section.

The channel index values correspond to the right side of the cell from the original IFG4 data set, in the opposite direction of the IFG4 calculations. In other words, when the channel index is entered into the data set, the Index for the cell to the left of the corresponding vertical should be used. Note that in this example, the same IFG4 input file was used for both types of habitat simulation. This is incorrect, the channel index values should have been shifted to the right on the IFG4 input file so that the channel index values used and listed by the habitat simulation programs would be consistent.

Unlike the other calculations in HABTAE, channel index values are not averaged between cells. Users of HABTAE should enter the channel index to the left of the corresponding vertical. The channel index value for the first point on the IFG4 data set <u>is not used</u> by HABTAE.

HABTAE Calculations

The following is an example of output from the HABTAE program using data in the format for the HABTAT program. The same habitat options are used.

```
   CELL      CELL REACH   CELL     CELL       MEAN                  TOTAL
 LFT EDG      LENGTH      WIDTH    DEPTH    VELOCITY    CF          AREA
      DISCHARGE -          50.00
   10.0        1.00         8.0     0.6         0.41    0.05         8.0
   20.0        1.00        10.0     2.1         0.85    0.36        10.0
   30.0        1.00        10.0     3.6         0.77    0.47        10.0
   40.0        1.00         2.2     2.1         0.33    0.77         2.2
```

The HABTAE output is in a different format, but the results are the same as the HABTAT results, and the channel index is used in the same way.

If the TAPE4 file is in the format for HABTAV/M, then HABTAE simply averages the velocities and computes habitat in the same manner as HABTAT. There is no difference in the output. HABTAE is an improvement and replaces HABTAT.

ZHCF FILES

The following are summaries of ZHCF files for the first discharge produced by the sample data set in HABTAT, HABTAV, and HABTAE: (HABTAM does not produce a ZHCF file.)

HABTAT ZHCF FILE

```
SALMON RIVER, NEW YORK, UNSTEADY FLOW MODEL, SUMMER 1986 (CPINM)
PINEVILLE  S118M/SR-4/2-10-87 MEAN VELOCITY(SZF=471.5-GUESS)
         9WINTER TROUT                                  ADUL
  FLOW     CROSS SECTION   NUMBER OF CELLS  CELL AREA    SUITABILITY FACTOR
(CF)
 50.000        118.00              5           0.0000          0.0000
                                               7.9630          0.0480
                                              10.0000          0.3617
                                              10.0000          0.4749
                                               2.1690          0.7724
```

HABTAE ZHCF FILE

```
SALMON RIVER, NEW YORK, UNSTEADY FLOW MODEL, SUMMER 1986 (CPINM)
PINEVILLE  S118M/SR-4/2-10-87 MEAN VELOCITY(SZF=471.5-GUESS)
         9WINTER TROUT                                  ADUL
 50.000        118.00              5           0.0000          0.0000
```

```
                                                 7.9630          0.0480
                                                10.0000          0.3617
                                                10.0000          0.4749
                                                 2.1690          0.7724
------------------------------------HABTAV ZHCF FILE------------------------------------
SALMON RIVER, NEW YORK, UNSTEADY FLOW MODEL, SUMMER 1986 (CPINM)
PINEVILLE  S118M/SR-4/2-10-87 MEAN VELOCITY(SZF=471.5-GUESS)
           9WINTER TROUT                                    ADUL

 50.000         118.00              5
                                                 0.0000          0.0000
                                                 2.9630          0.0222
                                                10.0000          0.1959
                                                10.0000          0.3169
                                                 7.1690          0.5000
```

The ZHCF files begin with the first possible cell in the data set, which is the cell between 0.0 and 10.0 for HABTAT/HABTAE and between 0.0 and 5.0 for HABTAV/HABTAM. The composite suitability factor (CF) is a standard combined function of the suitability curves and the depth, velocity and channel index values for the cell. It is not meaningful to compare ZHCF files from HABTAV with those from HABTAT or HABTAE, because the cells are defined differently.

LSTCEL

LSTCEL is a program that lists the information on the ZHCF files according to cells. The following are summaries of the output created by LSTCEL using each of the ZHCF files described above:

LSTCEL OUTPUT FROM HABTAV

```
 1          0.0   490.40    3.50    0.00    0.00    0.00
 2         10.0   474.80    4.00    0.02    0.93    1.00
 3         20.0   473.30    4.50    0.20    0.43    0.44
 4         30.0   471.50    5.00    0.32    0.14    0.13
 5         40.0   470.20    6.50    0.50    0.47    0.35
 6         50.0   490.00    5.50
```

LSTCEL OUTPUT FROM HABTAT/HABTAE

```
--------------------------------------------------------------------------------
VERTICAL        X        Y       CI     Suitability Factors
                                         50.0    100.0   150.0

 1             0.0    490.40    3.50    0.00     0.10    0.74
 2            10.0    474.80    4.00    0.05     0.66    0.62
 3            20.0    473.30    4.50    0.36     0.22    0.15
 4            30.0    471.50    5.00    0.47     0.24    0.15
 5            40.0    470.20    6.50    0.77     0.71    0.67
 6            50.0    490.00    5.50
```

The channel index values listed for vertical 3 for HABTAT/HABTAE and HABTAV/HABTAM are the same. For HABTAT and HABTAE the channel index values listed are taken from the left vertical on the IFG4 data set. To be consistent, channel index values should be taken from the right vertical. The cells listed for HABTAV and HABTAM are correct, and both TAPE3 files used were correct. LSTCEL has no way of recognizing the difference between ZHCF and TAPE3 files from HABTAV or HABTAT For this reason, we have added a prompt in LSTCEL to determine which habitat simulation technique is being used.

APPENDIX D: USE OF ZERO AND NEGATIVE VELOCITIES IN PHABSIM

This report discusses the use of zero and negative velocities in IFG4, negative velocities in MANSQ and WSP, negative velocities in habitat simulation, and zero and very small simulation flows in PHABSIM.

I. ZERO VELOCITIES IN IFG4

IFG4 (like most open-channel flow models) has serious drawbacks with measured wet cells with a velocity of zero. It is important to understand what is actually going on in the stream at a wide range of flows. The simulation should be divided into flow ranges to exhibit the same kind of behavior for the cells in question. In other words, the flow range should be divided into flow ranges that cause the cell to have a zero or negative velocity, and flow ranges with positive velocities. In some cases, a very small value of 0.001 should be used, especially if n values are computed for cells with a zero velocity over a wide range of flows.

It is important to distinguish between wet cell velocities with substantial depth and a velocity of 0, and cells at the stream edges with velocities of zero due to roughness, side channels, or shallow depth. These two situations should be handled in different ways. Zero velocities at the edges of the stream can be handled by using variable roughness. Zero velocities are not transferred to the habitat programs; therefore, very small values need to be used if the areas of low velocities at the stream edges are valuable.

The program CHGVEL changes all zero velocities to .001. This is advantageous for wet cells with zero velocities and for cells at the edge of the stream. If the cells at the stream edges are dry, the cells should be left blank.

There is no right way to calibrate IFG4 cells with zero velocities, however, there are several options to evaluate and compare.

Internal Cells with Zero Velocity

The recommended method for simulating velocities in IFG4 is to use the velocities on one calibration set. IFG4 then calculates the Manning's roughness value (N) and uses Manning's equation to simulate the velocity for each cell. The n values for wet cells with a zero velocity should be very high (more than 5.0). These values are entered on the NS lines in the data set. If you choose to have IFG4 compute the n value, use a very small velocity instead of zero for the cell in question. If the calibration velocity at a cell is zero and IFG4 is not forced to use n values from the NS lines (IOC(12)=0), the n value is borrowed from the closest wet cell and is used to simulate the new velocity.

Example: Below is a simplified IFG4 data set. At the low flows (first two calibration sets) the velocities for the verticals at 45.0 and 50.0 are zero. This indicates that a pool or subtle back eddy exists at the low flows. At the higher flow the pool is washed out making the velocities for those verticals substantial. IFG4 is set to calculate n values for all verticals.

```
ADAPTED FROM SALMON RIVER. NEW YORK. UNSTEADY FLOW MODEL
EXAMPLE FOR ZERO VELOCITIES
IOC       110000020100100000000000000000000000
QARD  10.0
QARD  20.0
QARD  35.0
QARD  50.0
QARD  75.0
QARD 100.0
QARD 125.0
QARD 150.0
QARD 175.0
QARD 200.0
XSEC 118.00000.0000 1.00   471.500  0.001000
     118.0  0.0480.4 15.0479.2 17.5474.8 20.0474.3 22.5473.5 25.0473.2
     118.0 30.0472.7 35.0472.0 40.0471.8 45.0471.8 50.0471.7 55.0471.4
     118.0 60.0475.2 65.0475.4 70.0475.6 75.0475.9 80.0476.5 85.0478.0
     118.0 90.0480.0
NS   118.0       4.0       4.0       4.0       4.0       4.0       5.5
NS   118.0       6.0       6.0       6.0       7.5       7.5       6.0
NS   118.0       5.5       5.5       4.5       4.5       4.0       4.0
NS   118.0       4.0
CAL1 118.0   474.450     38.00      38.0
VEL1 118.0                0.15 0.24 0.25 0.27 0.44 0.37 0.00 0.00 0.43
VEL1 118.0
CAL2 118.0   475.860     85.00      85.0
VEL2 118.0           0.25 0.40 0.65 0.50 0.60 1.00 0.65 0.00 0.00 0.70
VEL2 118.0
CAL3 118.0   477.810    163.00     163.0
VEL3 118.0           0.45 0.72 0.68 0.75 0.96 0.71 0.71 0.78 0.82 0.96
VEL3 118.0 0.26 0.33 0.66 0.27
ENDJ
```

If IFG4 is run using the first or second calibration set. the Manning's n value for the verticals in question (45 and 50) will be borrowed from the closest vertical with a non-zero velocity. The velocities will be similar to the velocities in the neighboring cells for all flows -- this is clearly not acceptable. If the zero velocities are replaced with very small values of .001. the simulated velocities will be very low. This method will simulate very small velocities at higher flows where it is known that the pool no longer exists.

If IFG4 is run using the third calibration set. the Manning's n value for the verticals in question will be based on the velocity in the third set. thus producing velocities for the cells at the lower flows. This is not acceptable for the low flows. but is fine for higher flows. If it is known (or can be estimated) that the pool begins to be washed out at 100 cfs. the simulation can be divided into two flow ranges -- from 0 to 90 cfs. and from 100 to 200 cfs.

IFG4 can then be calibrated for the high flow range using the third calibration set. The data set for high flows becomes:

```
ADAPTED FROM SALMON RIVER; NEW YORK; UNSTEADY FLOW MODEL
EXAMPLE FOR ZERO VELOCITIES
IOC       11000002010010001000
QARD 100.0
QARD 125.0
QARD 150.0
QARD 175.0
QARD 200.0
XSEC 118.00000.0000 1.00   471.500  0.001000
     118.0  0.0480.4 15.0479.2 17.5474.8 20.0474.3 22.5473.5 25.0473.2
     118.0 30.0472.7 35.0472.0 40.0471.8 45.0471.8 50.0471.7 55.0471.4
     118.0 60.0475.2 65.0475.4 70.0475.6 75.0475.9 80.0476.5 85.0478.0
     118.0 90.0480.0
NS   118.0       4.0       4.0       4.0       4.0       4.0       5.5
NS   118.0       6.0       6.0       6.0       7.5       7.5       6.0
NS   118.0       5.5       5.5       4.5       4.5       4.0       4.0
NS   118.0       4.0
CAL1 118.0   474.450     38.00     38.0
VEL1 118.0
VEL1 118.0
CAL2 118.0   475.860     85.00     85.0
VEL2 118.0
VEL2 118.0
CAL3 118.0   477.810    163.00    163.0
VEL3 118.0            0.45 0.72 0.68 0.75 0.96 0.71 0.71 0.78 0.82 0.96
VEL3 118.0 0.26 0.33 0.66 0.27
ENDJ
```

To solve problems with very low or zero flow, use very small velocities (.001) instead of zero for the verticals in question and let IFG4 calculate the Manning's n values.

The data set for low flows (using the second calibration set) becomes:

```
ADAPTED FROM SALMON RIVER, NEW YORK, UNSTEADY FLOW MODEL
EXAMPLE FOR ZERO VELOCITIES
IOC       11000002010010001000
QARD  10.0
QARD  20.0
QARD  35.0
QARD  50.0
QARD  75.0
QARD  90.0
XSEC 118.00000.0000 1.00   471.500  0.001000
     118.0  0.0480.4 15.0479.2 17.5474.8 20.0474.3 22.5473.5 25.0473.2
     118.0 30.0472.7 35.0472.0 40.0471.8 45.0471.8 50.0471.7 55.0471.4
```

```
     118.0 60.0475.2 65.0475.4 70.0475.6 75.0475.9 80.0476.5 85.0478.0
     118.0 90.0480.0
NS   118.0       4.0       4.0       4.0       4.0       4.0       5.5
NS   118.0       6.0       6.0       6.0       7.5       7.5       6.0
NS   118.0       5.5       5.5       4.5       4.5       4.0       4.0
NS   118.0       4.0
CAL1 118.0   474.450     38.00      38.0
VEL1 118.0
VEL1 118.0
CAL2 118.0   475.860     85.00      85.0
VEL2 118.0          0.25 0.40 0.65 0.50 0.60 1.00 0.65 .001 .001 0.70
VEL2 118.0
CAL3 118.0   477.810    163.00     163.0
VEL3 118.0
VEL3 118.0
ENDJ
```

The lowest flow could also be used to simulate low velocities. The second and third calibration sets will be used in this example. The TAPE4 files generated by running IFG4 on these two data sets can be combined to provide a simulation for this case. Below is a summary of the velocities on the final TAPE4 file.

FLOW	VELOCITIES AT VERTICALS:									
	20	25	30	35	40	45	50	55	60	65
10.00			0.21	0.74	0.53	0.00	0.00	0.65		
20.00	0.11	0.22	0.40	0.86	0.59	0.00	0.00	0.68		
35.00	0.43	0.38	0.52	0.96	0.64	0.00	0.00	0.72		
50.00	0.57	0.46	0.59	1.04	0.68	0.00	0.00	0.75		
75.00	0.71	0.55	0.66	1.11	0.72	0.00	0.00	0.78	0.18	0.12
90.00	0.76	0.58	0.69	1.14	0.74	0.00	0.00	0.79	0.26	0.22
100.00	0.53	0.60	0.79	0.60	0.61	0.67	0.70	0.83	0.15	0.18
125.00	0.59	0.66	0.86	0.64	0.65	0.71	0.75	0.88	0.20	0.25
150.00	0.64	0.71	0.91	0.68	0.68	0.75	0.79	0.92	0.24	0.30
175.00	0.69	0.76	0.97	0.71	0.71	0.78	0.82	0.96	0.27	0.34
200.00	0.73	0.80	1.01	0.74	0.74	0.81	0.85	1.00	0.29	0.38

The simulated velocities for cells with zero velocities at flows less than or equal to 90 cfs are zero. However, the same verticals exhibit substantial velocities above 90 cfs. Some cell velocities decrease between 90 and 100 cfs. This is caused by the substantial leap between the zero velocities for the verticals at 45 and 50 for 90 cfs and the velocities at 100 cfs.

Zero Velocities at Stream Edges:

There are several things to consider when the stream edges with zero or small velocities provide important habitat.

If velocities near the stream edges are known to stay close to zero even at higher flows, the n value should be very high. This can be accomplished by using a very small value (but not zero) for the velocities at those cells and letting IFG4 compute the n values. A very high n value can also be entered for the cell.

If the velocities near the stream edges stay close to zero for a certain range of flows, the simulation could be divided into several flow ranges.

If the velocities near the stream edges rise with flow, a zero or blank velocity should be used for the calibration flow(s) where the velocities are actually zero. IFG4 will borrow the n value from the closest wet cell. If the n value should be different from that of neighboring cells, the n values can be controlled by using IOC(15) or entering n values on the NS lines.

To avoid simulated n values that are too high for shallow cells, the roughness of a cell can be adjusted according to the depth of the cell using IOC(16) in IFG4. If this option is used, it should understand why it is needed and what values for n are rational. IOC(16) invokes the equation:

$$Nq = Nc * (Dq/Dc)^B$$

Where: Nq is the n value for the cell in question at some flow (q)
Nc is the n value for the cell at the calibration flow (c)
Dq is the depth of the cell at some flow (q)
Dc is the depth of the cell at the calibration flow (c)
B is a user defined coefficient, usually between -0.3 and -0.8

The relationship for n and Depth can be established by using IFG4 to simulate n values for several calibration sets.

II. NEGATIVE VELOCITIES IN IFG4

IFG4 does not model backwaters and eddies, although these phenomena are common in most streams. There are two ways to simulate negative velocities in IFG4 -- negative velocities can be used in the calibration sets, or negative roughness values can be entered on the NS lines of the IFG4 data set. The flow range that produces negative velocities in a cross section should be simulated separately from the rest of the flow range.

IOC 9 in IFG4 should not be used. This option requires the use of more than one calibration set, and the results produced using a semi-log fit are almost always erroneous.

Any cross section with negative velocities should also be measured at a flow that does not produce negative velocities, if possible. The point of low velocity between positive and negative velocity cells should also be measured. The simulation should then be divided at the flow where negative velocities change to positive (where an eddy begins to occur, or where it is washed out).

The negative velocities will increase as flows increase in the same order of magnitude as the positive flows.

Watch out for illogical results (extremely high positive and negative velocities) caused by a mass balancing problem in IFG4 with negative velocities. If mass balancing is on (IOC(11) = 1) IFG4 may increase both the negative and positive velocities for low flows in an effort to balance the cross section. The results can be ridiculous. When this occurs, the Velocity Adjustment Factors become large positive or negative values. This can be avoided by using small positive velocities, turning off mass balancing, or changing the simulation flow range.

Example: Below is a simplified IFG4 data set with negative velocities at two calibration flows:

```
ADAPTED FROM SALMON RIVER, NEW YORK, UNSTEADY FLOW MODEL
EXAMPLE FOR NEGATIVE VELOCITIES
IOC       1100000200001000100000000000000000000000
QARD  10.0
QARD  20.0
QARD  30.0
QARD  40.0
QARD  50.0
QARD  60.0
QARD  70.0
QARD  80.0
QARD  90.0
QARD 100.0
QARD 125.0
QARD 150.0
QARD 175.0
QARD 200.0
XSEC 118.00000.0000 1.00   471.500  0.001000
     118.0  0.0480.4 15.0479.2 17.5474.8 20.0474.3 22.5473.5 25.0473.2
     118.0 30.0472.7 35.0472.0 40.0471.8 45.0471.8 50.0471.7 55.0471.4
     118.0 60.0475.2 65.0475.4 70.0475.6 75.0475.9 80.0476.5 85.0478.0
     118.0 90.0480.0
NS   118.0       4.0       4.0       4.0       4.0       4.0       5.5
NS   118.0       6.0       6.0       6.0       7.5       7.5       6.0
NS   118.0       5.5       5.5       4.5       4.5       4.0       4.0
NS   118.0       4.0
CAL1 118.0   474.790     21.00      21.0
VEL1 118.0                0.48 0.49 0.54 0.55 0.56 0.27 -.11 -.29 0.33
VEL1 118.0
CAL2 118.0   475.760     50.00      50.0
VEL2 118.0           0.37 0.64 0.65 0.67 0.69 0.87 0.48 -.19 -.3  0.50
VEL2 118.0 0.24 0.21
CAL3 118.0   477.710    167.00     167.0
VEL3 118.0           0.45 0.70 0.72 0.75 0.86 0.94 0.78 0.68 0.62 0.76
VEL3 118.0 0.26 0.22 0.11 0.07
ENDJ
```

The following table of simulated negative velocities uses the same method as for the zero velocities above:

	VELOCITIES											
FLOW	20.0	22.5	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0
10.00		0.28	0.35	0.39	0.43	0.21	-0.09	-0.23	0.26			
20.00	0.44	0.48	0.53	0.54	0.56	0.27	-0.11	-0.29	0.33			
30.00	0.41	0.49	0.52	0.55	0.71	0.40	-0.16	-0.25	0.42			
40.00	0.54	0.57	0.60	0.62	0.79	0.44	-0.17	-0.27	0.46	0.15	0.08	
50.00	0.64	0.65	0.67	0.69	0.86	0.48	-0.19	-0.30	0.50	0.24	0.22	0.13
60.00	0.72	0.71	0.72	0.74	0.92	0.51	-0.20	-0.32	0.53	0.31	0.31	0.24
70.00	0.80	0.76	0.77	0.78	0.97	0.53	-0.21	-0.33	0.55	0.37	0.38	0.32
80.00	0.86	0.81	0.82	0.82	1.01	0.56	-0.22	-0.35	0.57	0.43	0.45	0.39
90.00	0.44	0.48	0.50	0.59	0.66	0.55	0.48	0.44	0.54	0.14	0.12	0.05
100.00	0.48	0.51	0.54	0.63	0.70	0.58	0.51	0.46	0.57	0.16	0.13	0.06
125.00	0.56	0.59	0.62	0.72	0.80	0.66	0.58	0.53	0.65	0.20	0.17	0.08
150.00	0.65	0.67	0.70	0.81	0.88	0.73	0.64	0.58	0.72	0.24	0.20	0.10
175.00	0.72	0.74	0.77	0.89	0.97	0.80	0.70	0.64	0.78	0.27	0.23	0.11
200.00	0.80	0.81	0.84	0.96	1.05	0.87	0.76	0.69	0.84	0.30	0.26	0.13

The jumps in flow between 80 cfs and 90 cfs are caused by the washout of the eddy and IFG4's inability to handle negative velocities well.

III. NEGATIVE VELOCITIES IN MANSQ AND WSP

MANSQ and WSP do not use calibration velocities to simulate new velocities. MANSQ will accept negative n values to produce negative velocities. WSP uses negative roughness values to indicate the thalweg, and will incorrectly interpret negative roughness values.

IV. NEGATIVE VELOCITIES IN HABITAT SIMULATION

PHABSIM programs do not consider negative velocities for habitat suitability. The PHABAR2 program converts negative velocities to positive velocities on the TP4 file that is used by the habitat simulation programs. If cells with negative velocities provide more valuable habitat, the use of negative velocities in habitat calculations should be reviewed. To consider negative velocities in habitat criteria, suitability curves and curve programs need to be adapted to allow negative velocities. Also, the habitat programs would need to be reviewed for negative values in different computations.

V. ZERO AND VERY SMALL SIMULATION FLOWS IN PHABSIM

IFG4 allows very small simulation flows. Simulation flows of zero are converted to 1.0 and the change is indicated with a warning message. Small simulation flows in IFG4 and MANSQ produce results similar to what is expected for zero flows. IFG4 simulations at low simulation flows are usually very inaccurate. Review the velocity adjustment factors at the low flows to determine the accuracy of the velocity simulations. The simulations may be improved by measuring the stream at an extremely low flow, or by entering water surface elevations that are very close to the stage of zero flow for very small flows. These water surface elevations are entered on the WSL lines in the IFG4 data set. MANSQ and WSP fail with zero simulation flows. WSP considers values of less than 1 on the QARD lines to be slopes rather than simulation flows.

	Zero Velocities	Negative Velocities	Zero Discharges
IFG4	If a calibration cell velocity is zero, the n value is borrowed from the closest wet cell. If a cell has a zero velocity for a wide range of flows, the velocity should be changed to 0.001. Simulate flows with velocities less than zero separate from flows with velocities greater than zero for greater accuracy.	Negative velocities can be simulated in IFG4 by using negative calibration velocities, or negative n values on the NS lines. Simulate flows with velocities less than zero separate from flows with velocities greater than zero for greater accuracy. Due to mass balance error, large negative velocities may be simulated when using multiple calib. sets.	IFG4 converts zero simulation discharges to 1.0 and displays a warning message. Very small simulation discharges (.01) will produce results similar to what would be expected at a discharge of zero (zero velocities and water surface elevations equal to the stage of zero flow); but IFG4 is inaccurate at low discharge.
MANSQ	Since calibration velocities are not used in MANSQ, zero velocities cannot be simulated by MANSQ for cells with some depth. It is not recommended to use MANSQ to simulate velocities.	Negative velocities cannot be simulated in MANSQ. MANSQ does not use calibration velocities or n values from the NS lines. It is not recommended to use MANSQ to simulate velocities.	MANSQ bombs with a zero simulation discharge. Very small simulation discharges (.01) will produce results similar to what would be expected at a discharge of zero (zero velocities and water surface elevations equal to the stage of zero flow).
WSP	Since calibration velocities are not used in WSP, zero velocities can only be simulated by entering large roughness values on the roughness lines. It is not recommended to use WSP to simulate velocities.	WSP uses negative roughness values as an indication of the thalweg for the cross section. WSP does not recognize negative roughness values and cannot simulate negative velocities. It is not recommended to use WSP to simulate velocities.	WSP bombs with a zero simulation discharge. Any discharge of less than .1 is considered to be a slope by WSP. Small discharges between .1 and 1 can be used to approximate zero discharge in WSP.
HABITAT PROGRAMS	Zero velocities at the edges of the cells are not passed to the habitat simulation programs unless a very small value for zero velocities was used in IFG4, or large roughness values were used in WSP. Zero velocities are used in suitability factor calculations based on the velocity suitability curve.	Negative velocities on the TAPE4 files created by the hydraulic simulation programs are converted to positive values by PHABAR2. The habitat value of vortex phenomena is expressed by low and high velocities in adjacent cells. HABTAM or HABTAV can then be used to adjust suitability according to the velocities in neighboring cells.	Near zero discharges from IFG4, WSP, or MANSQ will produce velocities near zero and depths close to the stage of zero flow.

APPENDIX E. REACH LENGTHS, REACH WEIGHTS, AND HABITAT TYPING

DEFINITIONS

The Reach length for a cross section is the distance to the next downstream cross section.

Reach length weights (or reach weights) defines the length of the stream in the upstream direction that is represented by the cross section. The weight is used as a multiplier applied to the reach length of the upstream cell. Example: If the reach length between cross sections (or the reach length for the upstream cross section) is 100 ft, and the downstream cross section has a reach weight of .3, then the first cross section represents 30 ft of the stream in the upstream section. By default, the upstream cross section represents the remaining 70 ft in the downstream direction.

A stream cell is the portion of a stream represented by one cross section in a longitudinal direction. A stream cell is not to be confused with a cell in a cross section, which is measured between verticals perpendicular to the stream. Figure 1 is a diagram of a stream with three cross sections. Notice that there are only two segments between the cross sections, but three stream cells, one per cross section. (The first cross section is measured at X = 100 for purposes described later in this report.)

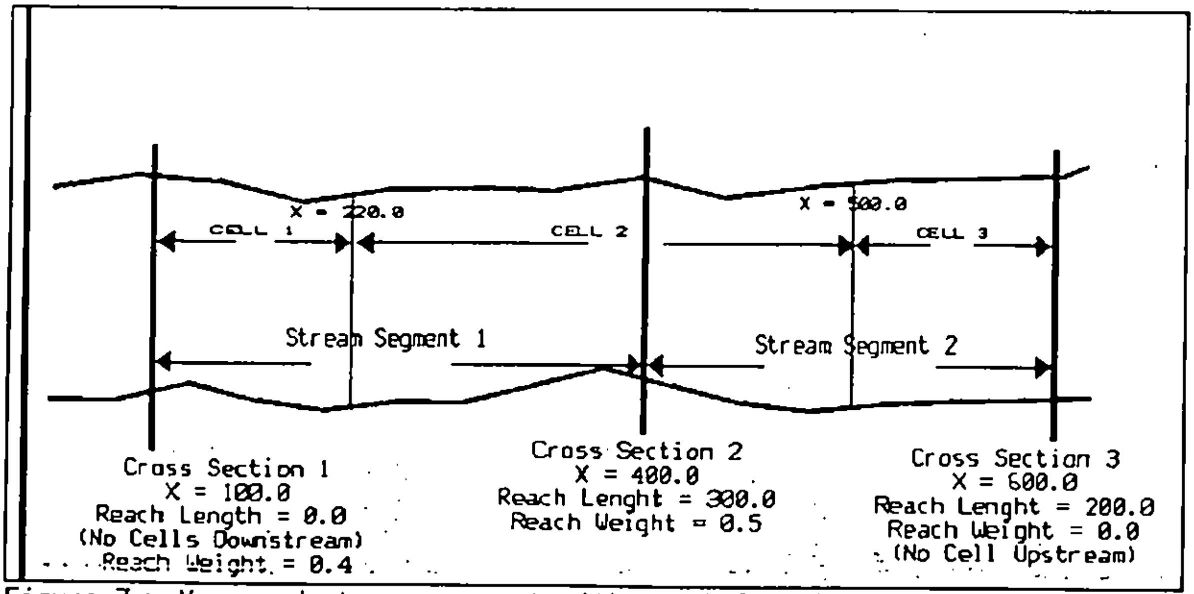

Figure 7 -- Measured stream segment with reach lengths and weights.

REACH LENGTHS AND WEIGHTS

In PHABSIM hydraulic simulation, WSP is the only program that requires reach lengths. WSP uses the reach lengths for water surface elevation calculations using the backwater method. WSP also requires that the data set be in downstream to upstream order. IFG4 and MANSQ do not use reach lengths: they pass the reach lengths and reach length weights to the habitat programs via the TAPE3 file. Reach length weights are not used in hydraulic simulations.

For habitat calculations, the reach length and reach length weights are used to calculate the area of a stream cell. The reach length weights are used to define a stream cell boundary between cross sections.

The most obvious difficulty with this method is the way the first and last cross sections are handled (Figure 1). Notice that the first and third cells may be incomplete. The cross sections should represent a portion of the stream in both directions from the cross section. Stream Cell 1 should probably extend downstream from cross section 1, and Stream Cell 3 should probably extend upstream from cross section 3. In the field, the best cross section to describe a stream cell is usually at the center of the stream cell.

A distinction needs to be made between the real world stream and the modeled stream. Stream cells can be redefined or even re-dimensioned for purposes of the model. In effect, a model stream can be constructed that is simpler, but still effectively represents the original stream.

A number of methods can be used to redefine the cross sections in different cases to represent the stream cells.

In HABTAT or HABTAE, a reach length for the first cross section can be specified (Figure 2). In the example, this means that a distance can be specified downstream of the first cross section to extend the first cell. The last cell, however, still causes difficulty. There are two ways to extend the last cell.

1. "Move" the last cross section to the edge of the cell (Figure 3). The reach length for the last cell is changed to include the part of the stream upstream of the original cross section 3, and the weight of cross section 2 is adjusted to place the boundary at X = 500.

2. Add a "dummy" cross section to the end of the file (Figure 4) and specify a weight of 1 for the original last cross section. The dummy cross section is simply a copy of the last cross section. This cross section must be added to the IFG4 data set. Since the weight for this dummy cross section is zero and the weight for the previous cross section is 1, no area is attributed to this dummy cross section. <u>NOTE</u>: The use of a dummy cross section is not recommended. It can be very confusing to have an extra cross section during simulations. The dummy cross section method is described here because it has been used in the past, and it helps to explain the use of reach lengths and weights.

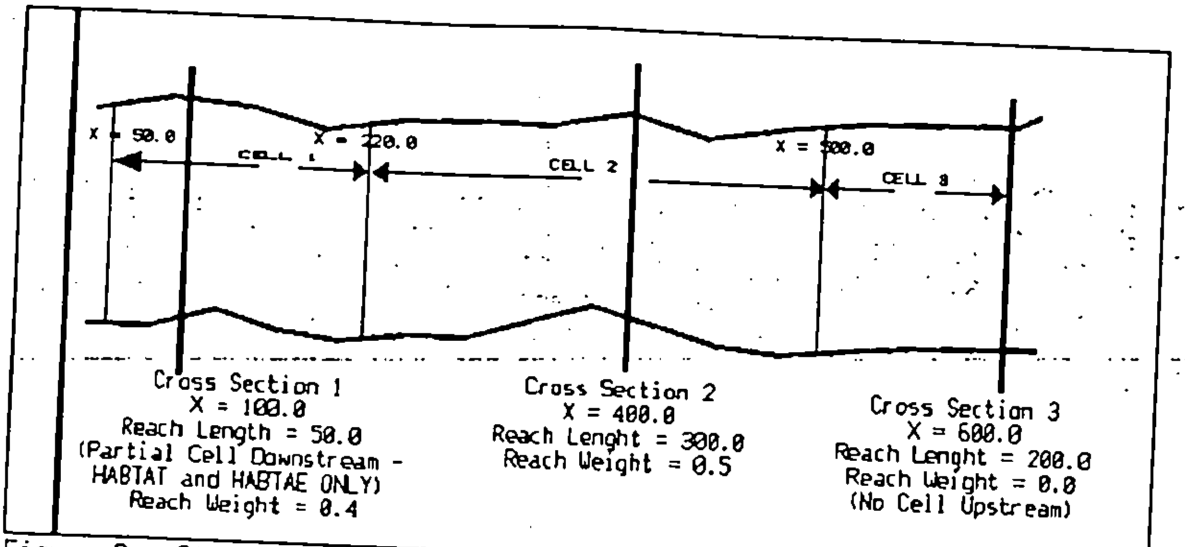

Figure 8 - Stream segment with extended downstream cell.

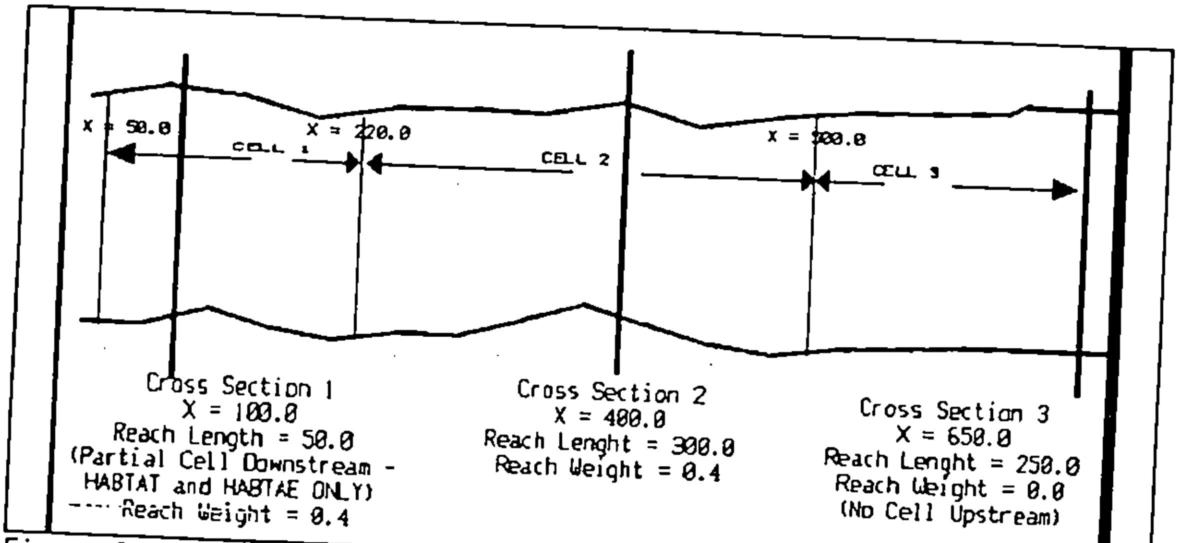

Figure 9 - Stream segment with extended upstream cell.

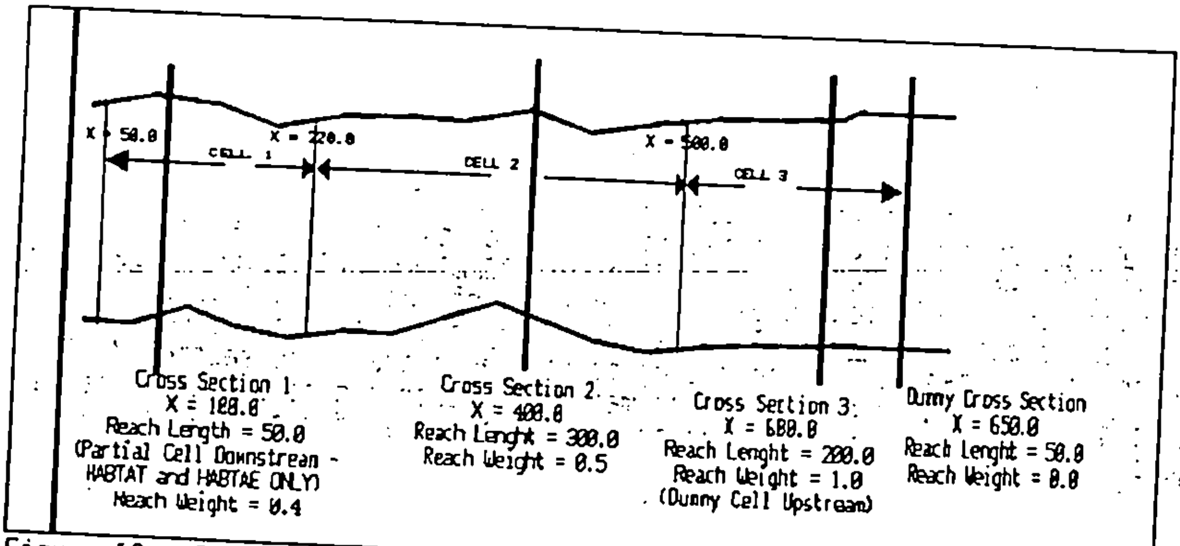

Figure 10 - Stream segment with extended upstream cell using dummy cross section.

Remember that the idealized stream must effectively model the real stream. The same amount of area must be represented by the same cross sections. First, we determine the lengths of all the stream cells. In our example, the length for the first cell is 170 ft., the second, 280 ft., and the third, 250 ft. A simplified stream can then be created by using weight factors of 1 (all area in between cross sections is represented by the downstream cross section). The reach lengths and weights become:

Cross Section	Reach Length	Reach Weight
1	0	1
2	170	1
3	280	1
DUMMY	150	0

if a dummy cross section is used, or

1	0	1
2	170	0.65
3	430	0

In the last example, the length of the two last stream cells are simply added together, and the weight for the second cross section adjusted so that the second cell has a length of 280 (430 * .65 = 280), and the third cell has a length of 150. See Figure 5.

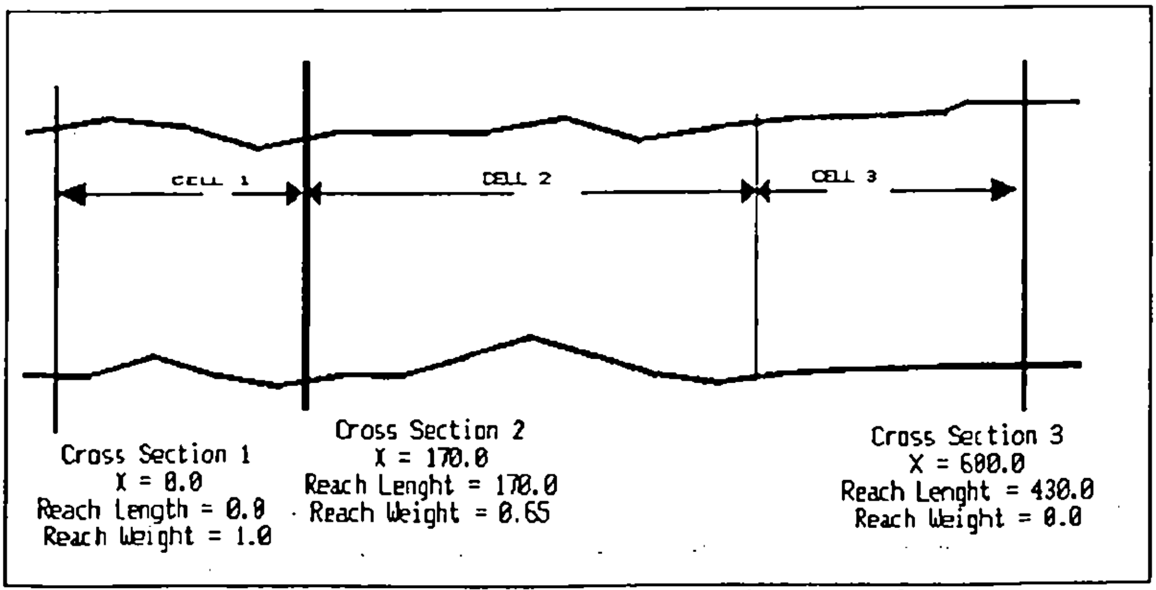

Figure 11 - Stream segment using cell lengths for reach lengths.

HABITAT TYPING

Habitat typing (as a part of habitat mapping) is a method used to create an "idealized" reach that more accurately describes the overall habitat for a long segment of a river. It is difficult to find a "representative reach" or short segment of a river that displays the same percentages of the various types of habitat found in the entire river study area. A more accurate approach is to map the habitat types present in a river and determine the percentages. Then a number of reaches of the stream can be studied that display the different habitat types. The result is a mix of detached stream segments, with a few cross sections for each segment. The segments can be combined in downstream to upstream order to run through WSP with some downstream control point as the first cross section. The reach lengths should be the actual distance between each cross section and the downstream control. The weight of the control section should usually then be set to zero before running IFG4. Each segment can also be run through the hydraulic simulation programs separately, and then combined in the TAPE3 and TAPE4 files.

The suggested method for combining these cross sections involves a somewhat complicated use of reach lengths and reach weights, based on the percentages of habitat each cross section represents.

For our simplified example, assume that only three habitat types were found, and three cross sections were found to model these types. Also assume that the three habitat types make up 20, 30, and 50 percent of the stream. We will construct an idealized reach that is 1000 ft long, representing 100 percent of the stream. Using simple math, the length of the cells represented by each cross section are 200, 300, and 500 ft, respectively. If the method from the previous example is used, the last two cells can be combined (Figure 6) or a dummy cross section can be added (Figure 7). The reach lengths and weights would be:

Cross Section	Reach Length	Reach Weight
1	0	1
2	200	.375
3	800	0
or,		
1	0	1
2	200	1
3	300	1
DUMMY	500	0

Perhaps the best advice in understanding reach lengths and weights is to remember that <u>reach lengths move downstream</u> and <u>reach weights move upstream</u>. It is also important to understand that the goal is to simulate stream cells of a given length using single cross sections within those stream cells. The stream cells can be defined in any way such that the area represented by each cross section of a stream is not lost.

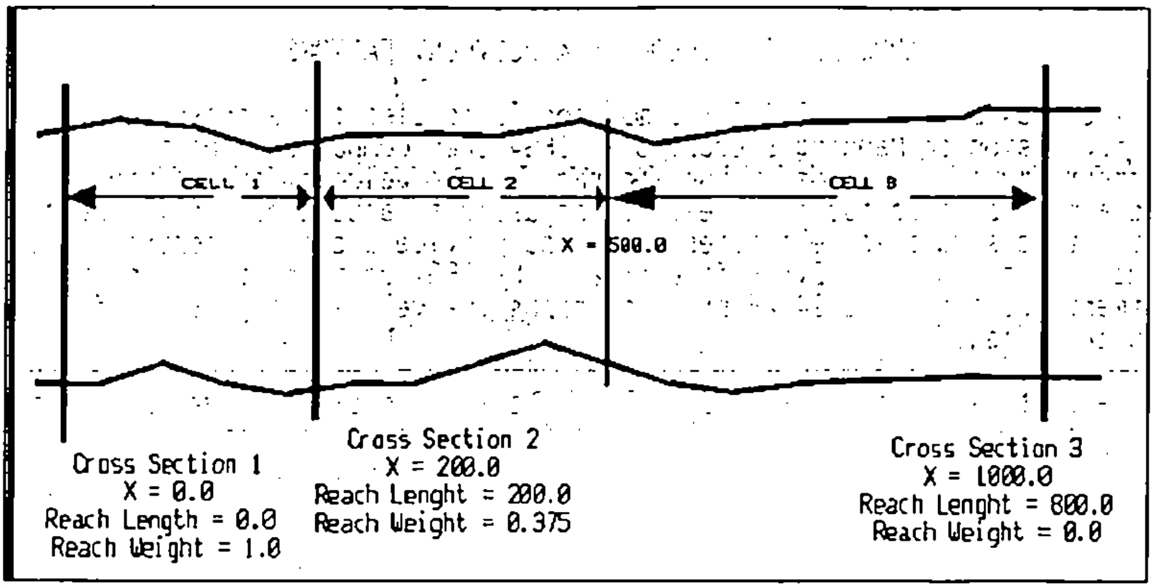

Figure 12 - Habitat typing stream segment with combined upstream cross sections.

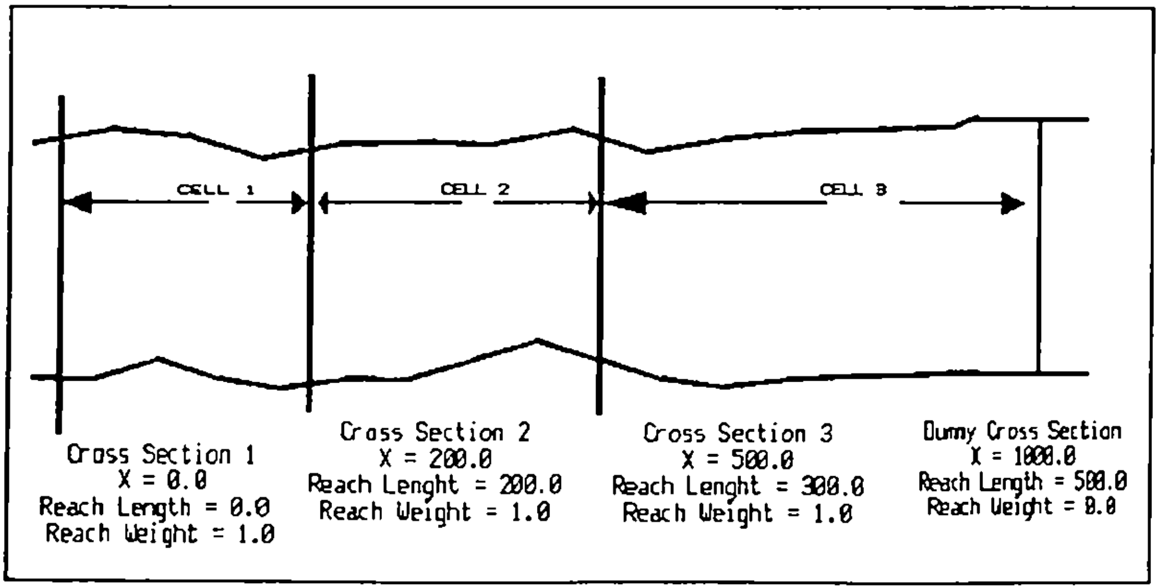

Figure 13 - Habitat typing stream segment using dummy cross section.

APPENDIX F. VELOCITY ADJUSTMENT FACTORS

The IFG4 program in PHABSIM simulates velocities for a cross section using regression or Manning's equation. IFG4 then computes velocity adjustment factors to increase the accuracy of the velocity computations, and to add a mass balance factor. Velocity adjustment factors not only provide an adjustment to simulated velocities, but also provide a quality control check for the simulation. The ZVAFF file created by IFG4 contains the velocity adjustment factors. The I4VAF program graphs the velocity adjustment factors for quick review.

Velocity Adjustment Factors (VAF's) are a ratio of the given simulation flow (from a QARD line) to the calculated flow based on velocities and water surface elevations simulated for that flow. VAF's are calibration factors based on given and calculated flows that are used to improve the simulated velocities. Some error will inevitably exist in the simulated velocities and depths and should be expected. The water surface elevations are assumed (on theoretical grounds) to be more accurate, while the velocities are adjusted to correct the error. The simulated flow for a cross section can be determined by multiplying the area of each cell by its velocity, and then summing the results for all cells across the cross section. In a simulation, this relationship can be described as:

$$Q_{sim} = \sum_{ncel}^{i=1} V_{cel(i)} * A_{cel(i)} = Q_{QARD}$$

where: V_{cel} - velocity for a cell,
A_{cel} - area for a cell,
$ncel$ - number of cells in cross section,
Q_{sim} - flow calculated using simulated velocities and areas, and
Q_{QARD} - input flow from which the velocities and areas are based from the QARD lines.

When the simulation is inexact, a constant can be added to this equation to adjust the relationship. The equation then becomes:

$$Q_{sim} * \text{Constant} = Q_{QARD}$$

or,

$$\text{Constant} * Q_{sim} = \text{Constant} * \sum_{ncel}^{i=1} V_{cel(i)} * A_{cel(i)} = Q_{QARD}$$

The constant is:

$$\text{Constant} = Q_{QARD}/Q_{sim} = \text{VAF}$$

This constant is called a velocity adjustment factor. The formula

$$\text{Constant (VAF)} * \sum^{i=1} V_{cel(i)} * A_{cel(1)} = Q_{QARD}$$

can also be expressed as:

$$\sum_{i=1}^{ncel} VAF*V_{cel(i)}*A_{cel(i)} = Q_{QARD}$$

Thus, this factor is applied to the velocities to equalize the simulated and given flows.

VAF CALCULATIONS

The actual calculations in IFG4 can include several different input and simulated data for Q_{sim}. Q_{QARD} is always the QARD flow being simulated. The velocity calculations use different methods defined by IOC 5 and 8 in IFG4.

USING VAF's FOR QUALITY CONTROL

VAF's equal to 1.00 indicate that the simulated velocities and depths exactly produce the given flow. The VAF's indicate the value of the simulation. The following limits have been suggested by Bob Milhous.

Velocity Adjustment Factor	Value of Simulation
0.90 - 1.10	Good
0.85 - 0.90, 1.10 - 1.15	Fair
0.80 - 0.85, 1.15 - 1.20	Marginal
0.70 - 0.80, 1.20 - 1.30	Poor
less than 0.70, greater than 1.30	Very poor

APPENDIX G. HABITAT PROGRAM DISTINCTIONS

The most substantial difference between HABTAE/HABTAT and HABTAM/HABTAV is the definition of cells. The cell boundaries in HABTAE and HABTAT are at the measured verticals. HABTAM and HABTAV define cell boundaries halfway between the measured verticals. The velocity calculations in HABTAE are more extensive than HABTAM/HABTAV velocity calculations (see IOC options 14, 16, 17, and 21). HABTAM and HABTAV also have some important options for considering habitat in neighboring cells and movement.

HABTAE and HABTAT

HABTAE is designed to take the place of HABTAT (support is being dropped for HABTAT--new options are not being added). The calculations in HABTAE are similar to those in HABTAT with a few exceptions. There are also several new options in HABTAE.

New options in HABTAE:

- Calculates and prints WUA, WUV, or WUBA for multiple or independent cross sections. IOC(1).
- Produces a distribution of composite suitability factors table. IOC(7).
- Allows use of minimum continuous width for composite suitability factors greater than 0. IOC(11).
- Can calculate velocities using the 1/mth power law equation. IOC(14)
- Allows specification of minimum composite suitability factor. IOC(19).
- Can use metric units. IOC(20).
- Allows different calculations of velocities or velocity replacements for each individual life stage. IOC(21).

The main disadvantage of HABTAE is that it has not been used as much as HABTAT. The error messages may not be as clear or extensive as those in HABTAT and the new options in HABTAE may be confusing to first time users.

HABTAT options deleted from HABTAE:

All of the options in HABTAT are covered by the HABTAE program with the exception of IOC (1), (5), (7), (8), and (11). Of these options, IOC(1) and (5) may be useful; the others are rarely used and can safely be removed from PHABSIM.

- Print out any combination of these three matrices, IOC(1) and IOC(5):
  Velocity vs. Depth
  Velocity vs. Channel Index
  Depth vs. Channel Index
- Read hydraulic data from HABTAT input file, IOC(8).
- Write unformatted TAPE7 file, IOC(7) and IOC(11).

IOC	HABTAE	HABTAT	HABTAM	HABTAV
1	Chooses between Weighted Usable Area, Volume, or Bed Area for habitat vs. flow calculations.	Prints out minimum and maximum matrix values for the matrices described in option 5.	Prints out movement calculation details.	Scans for velocity in adjacent scales.
2	Prints out cross section data. (TAPE3)	Prints out cross section data. (TAPE3)	Prints out cross section data. (TAPE3)	Prints out cross section data. (TAPE3)
3	Prints out flow related data. (TAPE4)	Prints out flow related data. (TP4)	Prints out flow related data. (TP4A)	Prints out flow related data. (TP4A)
4	Prints out WUA, WUV, or WUBA calculations.	Prints out WUA calculation details.	Prints out WUA calculation details.	Prints out WUA calculation details.
5	Prints out WUA, WUV, or WUBA for each cross section.	Prints any combination of 3 matrices: velocity-depth, velocity-channel index, or depth-channel index.	NOT USED	Controls how WUA is calculated when IOC(1)=1,2 and VLIM is not found in the current cell.
6	Prints criteria curve coordinates.	Prints criteria curve coordinates.	Chooses velocity type to scan adjacent cells.	Chooses velocity type to scan adjacent cells.
7	Prints out distribution of composite suitability factors table.	Writes habitat results to unformatted TAPE7 file.	Defines how channel index values of zero are used.	Defines how channel index values of zero are used.
8	Selects format of TAPE4 file. (HABTAT or HABTAM/HABTAV format)	Selects where hydraulic data is located. (TAPE3 or ZHABIN)	Prints out criteria curve coordinates.	NOT USED
9	Chooses habitat area calculation method.	Chooses habitat area calculation method.	Chooses habitat area calculation method.	Chooses habitat area calculation method.
10	Chooses between weighted habitat or usable habitat.	Prints out habitat area as a percent of total area.	Prints out habitat area as a percent of total area.	Prints out habitat area as a percent of total area.

IOC	HABTAE	HABTAT	HABTAM	HABTAV
11	Allows use of a minimum contiguous width of composite suitability factors greater than 0.	Selects the time base for output to TAPE7 file (IOC(7)=1)	NOT USED	NOT USED
12	Allows for variable reach lengths (bends).	Allows for variable reach lengths (bends).	Allows for variable reach lengths (bends).	Allows for variable reach lengths (bends).
13	Writes ZHCF file.	Writes ZHCF file.	NOT USED	Writes ZHCF file.
14	Chooses cell velocity calculation type.	Chooses cell velocity calculation type.	Chooses cell velocity calculation type.	Chooses cell velocity calculation type.
15	Chooses restriction of velocity size.	Combines reach lengths before or after calculations.	NOT USED	NOT USED
16	Selects given or nose velocities for habitat simulation.	Selects given or nose velocities for habitat simulation.	NOT USED	NOT USED
17	Chooses alternative velocity calculations.	Chooses alternative velocity calculations.	NOT USED	NOT USED.
18	Defines how zero channel index values are used.	Defines how zero channel index values are used.	NOT USED	NOT USED
19	Allows specification of minimum composite suitability factor.	Defines how zero cross section weights are used.	NOT USED	NOT USED
20	Selects English or Metric units.	NOT USED	NOT USED	NOT USED
21	Allows different velocities or velocity replacements for each life stage.	NOT USED	NOT USED	NOT USED
22	Allows distance from shore to limit habitat	NOT USED	NOT USED	NOT USED

HABTAM and HABTAV

HABTAM IOC option 1 allows a calculation for the movement of fish and invertebrates into neighboring cells in a cross section at different flows. This option allows the user to enter a starting and ending flow for habitat calculations for each life stage, as well as a movement distance for the fish. The program starts with the low flow and calculates the suitability of each cell. HABTAM then assumes that the usable area for the cross section is fully utilized. The suitability for the cross section at the ending flow is then calculated. If the same cells are usable at the ending flow, the cell is usable. If a usable cell at the starting flow is not suitable at the ending flow, the fish are allowed to "migrate" to adjacent cells at the ending flow. If there are no suitable cells close enough, then the original cell is considered unsuitable. If there are more cells that are suitable at higher flows, these cells are considered excess habitat; that is, they may be suitable, but there are no fish that can reach these cells in the cross section.

HABTAV does not use the same movement calculations as HABTAM. HABTAV adjusts the useability of one cell based on velocities in nearby cells at the same flow. This option is important in cases where the fish need to find a certain velocity in neighboring cells. This is also the best method to use where fish prefer a wide range of velocities within a short distance. IOC (1) and (5) allow the user to specify a scanning distance and velocity for neighboring velocities. The program then adjusts the suitability for a given cell by the availability of the velocities either greater than or less than the given velocity within the given distance. If IOC (5) is used, the user can specify an initial velocity at which the habitat worth of a cell becomes greater than zero. If the given velocity is not found in neighboring cells, HABTAV searches for a velocity between the initial and given velocity, and then interpolates the worth of that velocity.

OPTIONS IN THE HABITAT SIMULATION PROGRAMS

The following summary of the IOC options in the habitat simulation programs does not include all of the formulas. For more information, refer to the Physical Habitat Simulation System Reference Manual, Instream Flow Information Paper No. 26.

IOC 1

HABTAE

Determines if the weighted usable area (WUA), weighted usable volume (WUV), or weighted usable bed area (WUBA), is to be calculated, and if the WUA, WUV, or WUBA is to be calculated for an independent cross section or for a reach. If the option to calculate WUV for an independent cross section is selected, then the flows for that cross section do not have to be the same as for the other cross sections. If the WUA, WUV, or WUBA for a reach is being calculated, then the flows must be the same from section to section.

0 = Calculate WUA for a reach.
1 = Calculate WUA for independent cross sections.
2 = Calculate WUV for a reach.
3 = Calculate WUV for independent cross sections.
4 = Calculate WUBA for a reach.

5 = Calculate WUBA for independent cross sections.

HABTAT

Prints out the minimum and maximum matrix values for Option 5.
0 = Do not print minimum and maximum matrix values.
1 = Print minimum and maximum matrix values.

HABTAM

Prints out details of movement calculations. Recommend setting to zero.
0 = Do not print movement calculation details.
1 = Print movement calculation details.

HABTAV

Scans for velocity in adjacent cells.
0 = Do not scan adjacent cells for velocity.
1 = Scans adjacent cells within a user-defined distance (DIST) for velocity greater than or equal to a user-defined velocity (VLIM). If found, WUA for current cell = WUA * 1.
2 = Scans adjacent cells within a user-defined distance (DIST) for velocity less than or equal to a user-defined velocity (VLIM). If found, WUA for current cell = WUA * 1.

HABTAE/T/M/V

IOC 2

Prints out cross section data (from TAPE3). Recommend setting to one.
0 = Do not print cross section data.
1 = Print cross section data.

HABTAE/T/M/V

IOC 3

Prints out the flow related data (from TAPE4/TP4A/TP4) for each cross section evaluated at each discharge. Recommend setting to one (1).
0 = Do not print flow related data.
1 = Print flow related data.

HABTAE/T/M/V

IOC 4

Prints out all the computational details used in determining the Weighted Usable Area. (Weighted Usable Area, Bed Area, or Volume for HABTAE). Recommend setting to zero except when details are needed. Strongly recommend using only a few life stages and discharges when using this option. The size of the output file may be a constraint.
0 = Do not print computational details.
1 = Print computational details.

HABTAE

IOC 5

Prints WUA, WUBA, or WUV data for individual cross sections. Values are automatically printed if IOC(1)=1,3, or 5, but will not be printed if IOC(1)=0,2, or 4, unless IOC(5)=1.
0 = Do not print WUA/WUBA/WUV for each cross section.
1 = Print WUA/WUBA/WUV for each cross section.

HABTAT

Prints the matrices as described below. If chosen, this option prompts the user for minimum and maximum values for the matrices. These values are entered on the HEADER line of the habitat options file. Using this option will substantially increase the time of running the HABTAT program. Recommend setting to zero.

0 = Do not print matrices.
1 = Print velocity-depth matrix.
2 = Print velocity-channel index matrix.
3 = Print both velocity-depth and velocity-channel index matrices.
4 = Print depth-channel index matrix.
5 = Print both velocity-depth and depth-channel index matrices.
6 = Print both velocity-channel index and depth-channel index matrices.
7 = Print all three matrices.

HABTAM

Not used - set to "0".

HABTAV

When scanning has been turned on by setting IOC(1)= 1 or 2. this option controls how to calculate WUA in the current cell when VLIM is not found within the DIST.

0 = If VLIM is not found in adjacent cells. multiply WUA * 0.
1 = If VLIM is not found in adjacent cells. scans a second time for an initial velocity. VO. which is the first velocity where fish habitat is greater than 0. Then searches for a velocity between VO and VLIM that is closest to VLIM and interpolates a multiplier for the WUA for the current cell between 0 and 1 based on the found velocity.

NOTES: Explanation of the different combinations of IOC(1). IOC(5). and VO. If IOC(1)=1. IOC(5)=1. and VO > VLIM. it is meaningless to supply a VO. Likewise. if IOC(1)=2. IOC(5)=1. and VO < VLIM. it is meaningless to supply a VO. Reason: In the following cases. although a VO is supplied. it is not used.

- setting IOC(1)=1. IOC(5)=1. and VO > VLIM defaults to the same results as setting IOC(1)=1 and IOC(5)=0 (no VO); and
- setting IOC(1)=2. IOC(5)=1. and VO < VLIM defaults to the same results as setting IOC(1)=2 and IOC(5)=0 (no VO).

IOC 6

HABTAE/T

Prints out the coordinates defining the criteria curves. Recommend setting to one (1).

0 = Do not print criteria curve coordinates.
1 = Print criteria curve coordinates.

HABTAM/V

Scans adjacent cells for: (If neither IOC(6) nor IOC(14) equals 0. then they must be set to the same number.)

0 = Mean column velocity.
1 = Nose velocity - Use Empirical equation based on the 1/7th power law and user defined coefficients.
2 = Nose velocity - Use 1/7th power law equation.
3 = Nose velocity - use logarithmic velocity distribution equation.

IOC 7

HABTAE

Prints out a table of the distribution of composite suitability factors (CF). (If IOC(7)=1. then IOC(1) should not be set to 1.3. or 5. IOC(7) is automatically set to zero regardless of what is entered here if IOC(1)=1.3. or 5.): Recommend setting to 1.

0 = Do not print composite suitability factors table.
1 = Print composite suitability factors table.

HABTAT

Writes habitat results on TAPE7 (unformatted file). This option is seldom used. Recommend setting to zero.

0 = Do not write results on TAPE7.
1 = Write results on TAPE7.

HABTAM/V

Defines how channel index values of zero are used.

0 = Do not use a channel index value of zero in the calculation of WUA for that cell.
1 = Use a channel index value of zero in calculation of WUA for that cell.

IOC 8

HABTAE

Defines where velocities were calculated on the TAPE4.

0 = TAPE4 contains cell velocities (as per HABTAT).
1 = TAPE4 contains velocities at the coordinate points (as per HABTAV/M).

HABTAT

Instructs the HABTAT program where the hydraulic (cross section, reach, and flow) data is located. Usually set to one (1).

0 = Hydraulic data in HABTAT options file.
1 = Hydraulic data in TAPE3 and TP4 files resulting from an IFG4 or WSP run.

HABTAM

Prints out the coordinates defining the criteria curves. Recommend setting to one (1).

0 = Do not print criteria curve coordinates.
1 = Print criteria curve coordinates.

HABTAV

Not used - set to "0".

IOC 9

HABTAE/T/M/V

Controls how the calculation of habitat area will be made.

0 = Standard calculation -- Combined Suitability Factor (CF)=f(v)*g(d)*h(ci) where f(v)*g(d)*h(ci)) = variable preferences for velocity, depth and channel index. This is a simple multiplication of the velocity, depth, and channel index weights and implies synergistic action. Optimum habitat only exists if all variables are optimum.
1 = Geometric Mean -- CF=(f(v)*g(d)*h(ci))**0.333 This technique implies compensation effects; if two of the three variables are in the optimum range, the value of the third variable has less effect unless it is zero.
2 = Lowest Limiting Parameter -- CF=MIN(f(v)*g(d)*h(ci)) - This control determines the Composite Suitability Factor as the value of the most restrictive variable. This implies a limiting factor concept (i.e., the habitat is no better than its worst component), but is limited only by its worst element.

3 = User defined calculation using WFTEST subroutine. For assistance with coding this option, contact the National Ecology Research Center.

IOC 10

HABTAE

Determines selection of habitat area. The weighted usable area can be surface or bed. The usable area is all areas with a composite suitability factor greater than 0.001.

0 = Write weighted usable area or volume to ZHAQF file.
1 = Write usable (unweighted) area or volume to ZHAQF file.

HABTAT/M/V

Prints the habitat area as a percent of total area. Recommend setting to one (1).

0 = Do not print habitat area as a percent of total area.
1 = Print habitat area as a percent of total area.

IOC 11

HABTAE

Allows use of a minimum contiguous width of composite suitability factors greater than 0.

0 = Do not use a minimum contiguous width.
1 = Use a minimum contiguous width. WMIN lines are required with this option. The minimum width must be given for each curve set ID Number (life stage) - (can be zero).

HABTAT

Selects the time base of the WUA output. This option is used when IOC(7)=1. Recommend setting to zero.

0 = Flow data is not ordered chronologically.
1 = Flow data is ordered by months starting with October.
2 = Flow data is ordered by months starting with January.

HABTAM/V

Not used - set to "0".

IOC 12

HABTAE/T/M/V

Allows the reach length to vary from cell to cell (Variable Reach Length) across the stream (i.e., a bend).

0 = Use reach as rectangles in plane view.
1 = Use reach as trapezoids (describes bends - implies that ADDBEND was run on the TAPE3).

IOC 13

HABTAE

Writes a ZHCF file (unformatted file used for effective habitat analysis) with station ID, flow, cell area, cell WUA, and cell weighting factor. Recommend setting to zero unless there is a specific need for the ZHCF file.

0 = Do not write ZHCF file.
1 = Write ZHCF file.

HABTAT/V

Writes a ZHCF file (unformatted file used for effective habitat analysis) with station ID, flow, cell area, cell WUA, and cell weighting factor. Only one curve set at a time can be used with this option. Recommend setting to zero, unless there is a specific need for the ZHCF file.

0 = Do not write ZHCF file.
1 = Write ZHCF file.

HABTAM

Not used - set to "0".

IOC 14

HABTAE

Controls how the velocity for the cell is calculated. NOTE: IOC(14) in HABTAE is different than IOC(14) in HABTAT. If IOC(16) is not set to 0, then IOC(14) should not be set to 0.

0 = Mean column velocity.
1 = Nose velocity from empirical equation based on the 1/7 power law and user defined coefficients. User supplies the nose depth for which a velocity is to be calculated, and the calibration parameters A and B. These values are entered on the NOSE line.
2 = Nose velocity from 1/7th power law equation. User supplies nose depth on NOSE line.
3 = Nose velocity from logarithmic velocity distribution equation. The nose depth and the D65 of the bed material are supplied by the user on the NOSE line.
4 = Nose velocity from 1/mth power law equation.
5 = Nose velocity from 1/mth power law equation. Same as IOC(14)=4 except m is calculated using the equation $m = a*D^b$. Values for a and b are supplied on the NOSE line. Nose depth is also entered on the NOSE line.
6 = Nose velocity from 1/mth power law equation. Same as IOC(14)=4 except the nose depth (Dn) is measured from the surface. The values for nose depth and n are entered on the NOSE line.
7 = Nose velocity from shear velocity. To calculate the shear stress (τ), the Manning's roughness must be known. This value is entered on the NOSE line.

HABTAT

Controls how the velocity for the cell is calculated. If IOC(14)=4, 5, or 6, set IOC(16)=0.

0 = Mean column velocity.
1 = Nose velocity from empirical equation based on the 1/7 power law and user defined coefficients. User supplies the nose depth for which a velocity is to be calculated, and the calibration parameters A and B. These values are entered on the NOSE line.
2 = Nose velocity from 1/7th power law equation. User supplies nose depth on NOSE line.
3 = Nose velocity from logarithmic velocity distribution equation. The nose depth and the D65 of the bed material are supplied by the user on the NOSE line.
4 = Nose velocity from shear velocity. To calculate the shear stress (τ), the Manning's roughness must be known. This value is entered on the NOSE line.
5 = Nose velocity from Shield's parameter. When using this option, Manning's roughness, D65 of the bed material, and the specific gravity must be entered in the NOSE line. If specific gravity is not specified, 2.65 is used.

6 = Nose velocity from Froude number. Used in recreational analysis to give an index to turbulence.

HABTAM/V

Controls how the velocity for the cell is calculated. If neither IOC(6) nor IOC(14) equals 0, then they must be set to the same number.

0 = Mean column velocity.

1 = Nose velocity from empirical equation based on the 1/7 power law and user defined coefficients. User supplies the nose depth for which a velocity is to be calculated, and the calibration parameters A and B. These values are entered on the NOSE line.

2 = Nose velocity from 1/7th power law equation. User supplies nose depth on NOSE line.

3 = Nose velocity from logarithmic velocity distribution equation. The nose depth and the D65 of the bed material are supplied by the user on the NOSE line.

IOC 15

HABTAE

Limits the velocities allowed in the habitat simulation calculations. Strongly recommend setting to "0" or "1". If "2" is selected, there probably was an error in the hydraulic simulation process.

0 = Abort if velocities are less than 0 or greater than 15.

1 = Convert negative velocities to positive velocities; aborts if velocities are greater than 15.

2 = No restriction on velocities.

HABTAT

Increases the calculations by about 40% by not combining the total reach length assigned to a section early in the calculation. When IOC(12)=1, set IOC(15)=1.

0 = Combine reach lengths prior to calculations.

1 = Do not combine reach lengths prior to calculations.

IOC 16

HABTAE

Determines if given velocities (from TAPE4) or nose velocities are used in habitat simulation and determines how those nose velocities are calculated.

If IOC(16) is not set to 0, then IOC(14) should not be set to 0.

If IOC(16) is 1, 2, or 3, set IOC(17) to 0.

HABTAT

Determines if given velocities (from TP4 or direct entry) or nose velocities are used in habitat simulation and determines how those nose velocities are calculated. Set IOC(16)=0, if IOC(14)=4, 5, or 6.

IOC 17

HABTAE

Defines what to use as velocity as a replacement for velocity. These replacements should be treated as velocities and be entered on the "V" lines when entering the Curve Set Data.

If IOC(17) is not 0, then IOC(16) must be 0.

If IOC(17) is 1 or 2, then IOC(14) must be 0.

If IOC(17) is 3, then IOC(14) must be set to 7 and Manning's n, D65 of bed material, and the specific gravity must be entered on the NOSE line. If specific gravity is not specified, then 2.65 is used.

0 = Use given velocity.
1 = Use (velocity * depth) {a mv momentum approximation} as velocity.
2 = Use (velocity^2 * depth) {a mv^2 kinetic energy approximation} as velocity
3 = Use Shield's Parameter as velocity.

HABTAT

Defines what to use as velocity. IOC(17)=1 or 2 is for use with some recreation criteria such as wading.

0 = Use given velocity.
1 = Use velocity * depth as velocity.
2 = Use (velocity**2) * depth as velocity

IOC 18

HABTAE/T

Defines how channel index values of zero are used.

0 = Do not use channel index value of zero in calculating WUA for that cell.
1 = Use a channel index value of zero in calculation of WUA for that cell.

IOC 19

HABTAE

Allows the user to specify a minimum value for the composite suitability factor (CF). These minimum values are entered on the CFMIN line.

0 = No minimum composite suitability factor specified.
1 = Same minimum composite suitability factor specified for all life stages.
2 = A minimum composite suitability factor specified for each life stage.

HABTAT

Defines how cross section weights of zero are used.

0 = Change weights of zero to 0.5.
1 = Do not change zero weights.

IOC 20

HABTAE

Determines what units (traditional or metric) to write the output.

0 = Write output in traditional (English) units.
1 = Write output in metric units.

IOC 21

HABTAE

Allows different location of velocities or velocity replacements to be used for each life stage. This option is basically the same as allowing IOC(14), IOC(16), and IOC(17) to be selected for each life stage. NOTE: In this section IOC14, IOC16, and IOC17 (without parenthesis) refer to the values set on the INOSE and DNOSE lines, versus IOC(14), IOC(16), and IOC(17) which refers to the actual option number.

If IOC(21) is not equal to zero, then IOC(14), IOC(16) and IOC(17) should be set to zero. If they are not set to 0, the values entered on the INOSE and DNOSE lines will override the values set by IOC(14), (16), and (17) and on the NOSE and CELL lines.

0 = Use velocities that were selected by IOC(14). IOC(16). and IOC(17). Same velocity for all life stages.

1 = Allows using combinations of IOC16 and IOC17 for each life stage and specification as to whether mean or nose velocities (IOC14) are to be used. When using this option. IOC16 and IOC17 are mutually exclusive and are represented by the ICF parameter on the DNOSE line. The IOC14 value is set on the INOSE line.

ICF PARAMETER	IOC16 VALUE	IOC17 VALUE	Permissible IOC14 Values	Action
0 =	0	0	0.1.2.3.4.5.6.7	Use mean or nose velocity
1 =	1	0	1.2.3.4	Optimize velocity
2 =	2	0	1.2.3.4	Optimize velocity
3 =	3	0	0	Velocity = Mean velocity in top cell
4 =	0	1	0	Vel. Replacement = velocity * depth
5 =	0	2	0	Vel. Replacement = (velocity**2) * depth
6 =	0	3	7	Vel. Replacement = Shield's Parameter
7 =	0	4	0	Vel. Replacement = Froude Number

The DNOSE line contains the ICF parameter and the same information as on the NOSE and CELL lines. One INOSE line is required and a DNOSE line is required for each life stage where the IOC14 value on the INOSE line is not zero. See discussion of INOSE and DNOSE line in Appendix A - HABTAE format for more information.

2 = Allows selecting between a nose velocity and mean column velocity. One DNOSE line and one INOSE line are required.

APPENDIX H. ERRATA TO PHABSIM MANUAL

These are the contents of PHABSIM file ERRATA.PH2. They indicate changes to PHABSIM Version 2 since the manual was written.

ERRATA TO PHABSIM MANUAL
Last Updated 05-21-93

##########
05-13-93 ADDED INSTALL.BAT AND README.PH2 TO PHABSIM

INSTALL.BAT and README.PH2 are tools to help in the installation of the PHABSIM environment.

##########
05-13-93 ADDED README.RPM TO PHABSIM

README.RPM added to PHABSIM package. README.RPM lists errors associated with the RPM program.

##########
04-12-93 RVWTHWEG.BAT RENAMED RVWTHWE.BAT & FILE NAME CHANGES REQUIRED BY RPM

Although RVWTHWEG.BAT 2.4 works correctly, RPM can not handle a batch file name containing eight characters. Therefore, RPM will not run VWTHWEG. To solve this problem, the batch file RVWTHWEG.BAT has been renamed RVWTHWE.BAT (2.5). At the same time, the following files were updated to work correctly with the new name. The corrected versions of these 4 files are all 2.5.

PMBAT.DAT
PMHELP.HLP
PMLONG.FIL
PMSHORT.FIL

Also, there are actually two programs which are run from RVWTHWE.BAT. Character graphics are produced by VWTHWE.EXE; Screen graphics are produced by VWTHWEG.EXE. In the past, when referring to this program 'in general', the name used was VWTHWEG, this had to be changed to VWTHWE to get RPM to run properly. The two EXE files themselves have not changed; how the program name is referenced within RPM has been changed. That is, the menu itself, and the help screen now list VWTHWE, not VWTHWEG.

Make the following changes to the program directory to make VWTHWE run from RPM:

- replace RVWTHWEG.BAT with RVWTHWE.BAT
- replace the four files listed above
- if RPM is already installed,
    if using the short version of the menu

```
COPY PMSHORT.FIL PMCUR.FIL
if using the long version of the menu
COPY PMLONG.FIL PMCUR.FIL
```

##########
03-02-92 RUNNING THE CURVE PROGRAM

Unlike other PHABSIM programs, the CURVE program requires several files to be in the current working directory. They are:

CGA.BGI, LITT.CHR, UNHIS.EXE, UNXIN.EXE, UNXPOLY.EXE

The batch file RCURVE will give warning messages if these files are not in the current directory.

##########
02-28-92 NEAR SHORE HABITAT OPTION
(HABTAE IOC OPTION 22)

If IOC option 22 is 1 for HABTAE, only habitat within a user-defined distance from the banks of the stream is calculated. There must be a DSBANK line on the HABTAE input file directly above the HEADER line which contains the distance from any bank where habitat values are to be considered. The format for a DSBANK line is:

Cols.	Value
1 - 6	"DSBANK"
7 - 10	BLANK
11 - 20	Distance from water's edge for consideration

With option 22 on, HABTAE finds all of the banks in the stream, including banks for islands or sand bars. It then adjusts the suitability factor for each cell according to the amount of the cell that is within the given distance from any bank.

If the water surface elevation is higher than the elevation of the right and/or left most points of the stream, HABTAE uses the end points of the stream for cell calculations. If IOC 22 is 1, however, the banks used for near shore habitat are extrapolated outside the X range of the measured stream bed, but the cells are still defined by the extreme X coordinates. In other words, if the water surface elevation is above the left hand point of the stream (usually X = 0.0) HABTAE begins its calculations at the cell starting at X = 0.0. The bank computed for the near shore habitat option, however, is extrapolated outside of the measured stream coordinates, and will have a negative X value. In such a case, the habitat calculations for the stream may not be accurate.

The near shore option does not affect usable area, only the suitability factors (cf) and weighted usable areas (WUA) are changed.

##########
02-27-92 ASCII OUTPUT FILE OPTION

Several PHABSIM programs now include an option to produce ASCII output files for use with spreadsheet or graphics applications. The output files contain most of the information from the standard output file. with titles for each column in quotes. The ASCII files can be imported into LOTUS. using the IMPORT/NUMBERS option. as well as several other packages including GrafTool. Quattro Pro. Microsoft Excel. and Framework. Consult the documentation for the software package for directions for importing ASCII or ASCII delimited files.

The programs with the ASCII output file option are:

AVDEPTH. AVPERM. CALCF4. CKI4TXT. CMPVL4. CMPWSL. HABAE. HABEF.
HABOUTA. HABOUTS. HABTAE. HABTAM. HABTAV. I4VAF. IFG4. LPTHQF.
LSTCRV. LSTHCF. LSTP34. MANSQ. REVI4. SLOP34. WSP

Each of these programs will display the following prompt:

```
ENTER:  1  TO PRODUCE ASCII OUTPUT FILE FOR SPREADSHEET
           OR GRAPHICS APPLICATIONS
        0  FOR NO ASCII OUTPUT FILE
```

If the response is 1. the program will create the ASCII output file and print a message like:

```
ENTER <RETURN> TO CREATE ASCII FILE NAMED ZOUT.ASC
               OR ENTER A NEW FILENAME:
```

After the response is entered. the program will indicate the name chosen for the output file:

```
ASCII OUTPUT FILE IS ZOUT.ASC
```

##########
02-20-92 APPENDIX C CORRECTION

Page 2 of Appendix C "INFOWSP" should be "INFOQWP".

##########
MANSQ IOC OPTION 2 (Page II.75)
01-29-92

The formulas listed for adjusting conveyance in a river are not complete. The equations should be:

```
0 = Use N/Nc = (Q/Qc)**B
1 = Use N/Nc = (RH/RHc)**B
2 = Use N/Nc = (RHc/RH)**0.167)*(log(2.42(RH/D50))/log(2.42(RHc/D50))
```

##########

01-14-92 1/7 POWER LAW DEFAULT VALUES
HABTAE, HABTAM, HABTAT, HABTAV

When the 1/7 power law is used for nose velocity (HABTAE/HABTAM/HABTAT IOC(14)=2, HABTAV IOC(6)=2), the default value for A is 1.143, and the default value for B is .1429 in the equation:

$$Vn/V = A*(Dn/D)**B$$

##########

11-06-91 NUMBER OF POINTS IN A SUITABILITY CURVE

Up to 100 points are allowed on a suitability index curve in a FISHCRV or FISHFIL type file.

##########

10-21-91 HABTAE CELL DEFINITION OPTION

In the description of habitat simulation programs, Page V.1, end of paragraph 2, the PHABSIM REFERENCE MANUAL states: "The HABTAE program has the option of viewing cell boundaries either way," in reference to HABTAE option 17. This statement is incorrect. HABTAE does accept data from IFG4 in either HABTAV/HABTAM or HABTAT formats (ioc option 8), but the program logic for cells is always the same as that of the HABTAT program.

##########

10-03-91 OVERFLOWS, UNDERFLOWS, AND NON-NUMBERS IN PHABSIM OUTPUT FILES

If a value is produced by a PHABSIM program that is too large to be printed, or is not a number, the entire field will be replaced by characters. The characters mean the following:

\+ - positive infinity (overflow)
\- - negative infinity (underflow)
* - value too large to be printed
? - value is not a number

The most common problems are *'s in the output, produced by using numbers either too large or to small for the PHABSIM programs to handle; or ?'s in the output, usually caused by illogical or missing data. If you find ?'s in your output, but the data looks correct, there may be a problem with the program.