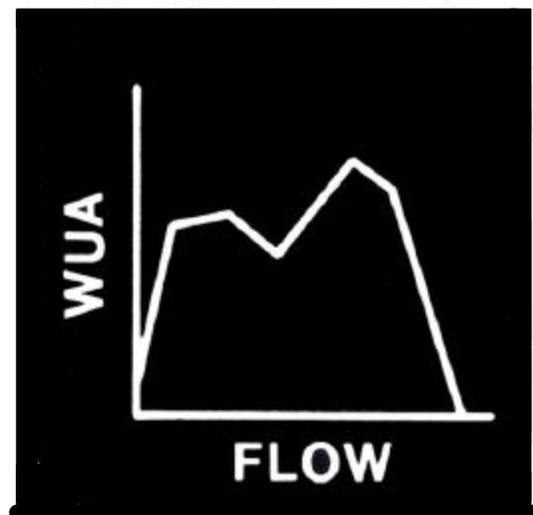


# PHABSIM for Windows

User's Manual and  
Exercises  
Midcontinent Ecological  
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## Preface

### *A Brief History of PHABSIM*

In the 1970's a major change in terminology regarding maintaining streamflow to protect aquatic organisms in streams was introduced. To some, the change was considered merely semantic. But to those whose pioneering work led to the change, it was both substantive and significant. The change was from common usage of the term "low flow" or "minimum flow" to the common usage of the term "instream flow." During the early 1970's, the *Water Resources Research Catalog* served as an index of most of the ongoing research related to water resources, with each project identified by several key words. As late as 1975, the *Catalog* contained no research projects under the key words "instream flow," while at the same time, there were many studies using the key words "low flow."

The typical description of the concept of "low flow" in those days was something like this:

"Water is taken out of the stream for a variety of uses, such as irrigated agriculture, municipal and industrial. Low flow means that amount of water that must be left in the stream for the fish. With anything less than the low flow, the fish will die."

In a thoughtful piece published in the April 1991 edition of *Rivers*, Harvey Doerksen recalled how Don Tennant, then an aquatic biologist for the State of Montana, described the shortcomings of the "low flow" concept in human terms:

After many years, I still have a vivid recollection of a photographic slide that [Don Tennant] showed as part of his presentation at a conference. It was a picture of a family of perhaps half a dozen people crowded into a small bathroom. ... The point that Don wished to make was simply this: in the short run, a population of fish in the stream can make out quite well with an extreme low flow event, just as a family can tolerate the closeness that comes with crowding into a small bathroom. Over extended periods, however, the low flow could not be tolerated any better by a population of fish than sustained proximity could be tolerated by a family in a crowded bathroom. And yet, that very concept of maintaining a sustained low residual flow was the prevailing approach to protecting fish habitat.

One of the serious problems with the "low flow" approach was that biologists distinguished only between two relative conditions with respect to fish habitats: the level below which disaster would occur, and everything else. However, other water users made incremental assessments of their need. An irrigation district, for example, could project water quantity needs for any increment of irrigated acreage, but the biologists at the time did not have the technology to do similar incremental assessments of the potential impacts of various irrigated acreage scenarios.

In the late 1970's the U.S. Fish and Wildlife Service (FWS), through what then was its Office of Biological Services, received funding from the Environmental Protection Agency (EPA) to establish the Cooperative Instream Flow Service Group, which incorporated the combined talents of people from several federal and state agencies. The Group's central charge was to develop methods for quantifying the biological effects of altered streamflows.

The result of a concerted effort on the part of the Instream Flow Group was the Instream Flow Incremental Methodology (IFIM) (Stalnaker et al., 1995; Bovee et al., 1998), of which the Physical Habitat Simulation System (PHABSIM) is a major component. This new technology was highly

significant for at least two reasons. First, it allowed fishery biologists to *negotiate* acceptable flow levels with other instream and out-of-stream water users *from among a variety of possible scenarios*, in the same way that the other users had been doing for years.

Second, the change in the prevailing terminology from “low flow” to “instream flow use” meant that biologists no longer were trying to find that magical flow level below which a stream should not be dewatered. Instead, they were in a position to assert instream flow *needs* for fish habitats and other environmental values. Furthermore, they could do so in terms of the seasonal life cycle needs of the fish (or other aquatic organisms) over the annual hydrograph. This change was thus an instrument through which fish and associated environmental values were viewed as legitimate water users among many, instead of merely a residual, after the water users had been served.

This change was not easy, nor did it occur overnight. In developing PHABSIM, the Instream Flow Group drew on several developments in instream habitat assessment that were available at the time. Two developments were of particular importance, the Washington Method (Collings et al., 1972) and the univariate curve concept. The Washington Method provided the concept of mapping depth and velocity conditions over gravel bars and applying binary suitability functions for salmon spawning in streams in the Pacific Northwest. The area of a gravel bar suitable for spawning was evaluated at several measured discharges by calculating the area having a suitability value of 1 for both depth and velocity. Approximate suitable spawning area for unmeasured intermediate flows was estimated by interpolation.

Binary suitability functions (the observed condition is assigned a value of 0 or 1, unsuitable or suitable) produced a value of 0 for some stream areas that, although not optimally suitable, were observed being used by salmon. The use of a univariate suitability function, which ranked various depths or rates of flow velocity on a 0 to 1 scale and allowed a smooth function covering the entire range of conditions, was proposed by Waters (1976).

The Washington Method, even when modified to include the univariate curve approach, requires numerous empirical measurements at different discharges. This limits the number of discharges for which habitat can be evaluated and the number of study areas that can feasibly be evaluated with time, manpower, and budget constraints.

The Instream Flow Group combined standard one-dimensional hydraulic simulation techniques with the Washington Method and the univariate curve concept to produce PHABSIM. PHABSIM uses the hydraulic simulation models to predict depth and velocity at unmeasured flows using basic physical and engineering principles that were standard practice in the 1970's. The resulting software suite multiplied surface area for a section of stream by the univariate suitability curve values for depth, velocity, and channel condition to arrive at a habitat index called Weighted Usable Area.

This software suite was first implemented on Control Data Corporation mainframe computers accessed by terminals connected over telephone lines. The software consisted of numerous small piecemeal programs that were cost-effective to develop and use in the mainframe environment. Numerous small files were required for data input and numerous output files were produced. This placed a major burden on users of the software to manage large numbers of files with often similar (but slightly different) contents. It also produced a legacy of program names such as IFG-4.

During 1984 and 1985 the PHABSIM program suite was moved to microcomputers. A basic menu-driven interface for the PHABSIM program was developed in 1989. The PHABSIM Version 2 (DOS) (Milhous et al., 1989) programs were distributed until September 2000 as the standard version of PHABSIM software.

With the advent of the Windows graphical user interface, it became evident that the PHABSIM program suite would serve a wider audience if input data and model results could be displayed graphically during an application of the software. Development of the Windows interface for PHABSIM fulfills commitments made to the U.S. Fish and Wildlife Service in the mid-1990's. Two principle goals were pursued while developing PHABSIM for Windows: (1) to keep the functionality of all core programs and retain backward compatibility to PHABSIM Version 2, and (2) to simplify the bookkeeping and calibration processes. We sought to both improve clarity of the various options for each program and graphically display the results of applying each program. The ability to view plots of model results during the calibration and option selection processes greatly speeds up calibration and increases understanding of the effects of selecting various habitat simulation options.

To ensure the quality of PHABSIM for Windows, extensive testing and comparison with the DOS-based PHABSIM Version 2 was performed. Several data sets were run through both versions and all options of all programs were run and compared. In addition, both English and metric units were tested to ensure that entire analyses could be reliably conducted in metric units. Our emphasis was on retaining the full set of PHABSIM analytical functions and extensively testing the programs rather than on adding program enhancements.

### *Use of This Document*

This document is a combined self-study textbook and reference manual. The material is presented in the general order of a PHABSIM study placed within the context of an IFIM application. The document may also be used as reading material for a lecture-based course. This manual provides documentation of the various PHABSIM programs so every option of each program is treated.

This text is not a guidebook for organization and implementation of a PHABSIM study. Use of PHABSIM should take place in the context of an IFIM application. See Bovee et al. (1998) for guidance in designing and performing a PHABSIM study as part of a larger IFIM application.

The document concludes with a set of 12 laboratory exercises. Users are strongly encouraged to work through the laboratory exercises prior to applying the software to a study. Working through the exercises will enhance familiarity with the programs and answer many questions that may arise during a PHABSIM analysis.

### *Changes Between PHABSIM Version 2 and PHABSIM for Windows*

The first obvious change between PHABSIM Version 2 (DOS) and PHABSIM for Windows is use of the Windows graphical user interface and development of the necessary interface programs. The graphical user interface program now includes considerably more code than the analytical core programs. Additional benefits of developing an extensive interface program include the following: file management is largely done by program; users no longer need to keep track of file names and the risk of removing a file needed at a later step has been essentially eliminated and each study site is kept in a separate, user-specified, project directory, reducing the risk of confusing project files.

In developing this version of PHABSIM, certain decisions were made regarding the structure of PHABSIM data and analyses. All cell definitions now match the data gathering approach taught in the IF305 field techniques course. The cell definition distinctions HABTAE and HABTAV have disappeared and all HABTAV options are now included in HABTAE. Thus, there is no HABTAV program. For consistency, HABTAM cell definitions also match those used in HABTAE. The 100 cell per cross section limit has been eliminated so an unlimited number of cells may be defined for each cross section.

Another difference is the consolidation of AVDEPTH and AVPERM into one program. In doing so, the options and outputs of both programs have been retained.

With these changes have come some differences in computed results. The core analytical programs were translated into C++ from Fortran. Different compilers have different methods of creating machine language so there can be small differences in results of numerical calculations. This is largely due to a combination of order of the calculation, round-off error, method of optimization used within the compiler, etc. While in most situations the differences between the DOS PHABSIM Version 2 and PHABSIM for Windows are very small, there are situations where these differences can accumulate.

The following is an example of possible calculation discrepancies that may occur between the DOS PHABSIM and Windows PHABSIM. Both the Windows and old DOS versions were run for the same study site. The results for a specific cell in the study site at the same discharge and one selected life stage are shown in Table 1.

For illustration, the Weighted Usable Area (WUA) calculation had equal velocity Suitability Index (SI) and channel index SI values (1.0 and 0.91 respectively.) For the species/life stage in question, the depth suitability curve had a steep slope at this point (depth of 0.8 = SI of 0.06 and depth of 0.85 = SI of 0.15). The steep slope of the suitability curve gave a large difference in suitability for a small difference in calculated depth. Thus, noticeable differences in the final computed WUA value between DOS PHABSIM Version 2 and PHABSIM for Windows are likely in situations where the SI criteria are very sensitive to changes in the parameter(s) (depth in this case) for that cell.

Thus, for a relatively small difference of 0.014 in WSL, we show a large difference in WUA for the cell. The WSL model is performing as expected and is within reasonable calibration error for the data set. The differences in water surface elevation have been determined to be due to compiler differences as all calibration parameters were set to the same values in both versions and the internal calculations were traced to ensure they were being accurately performed.

It should be noted that over an entire cross section or over a study site, few cells show these dramatic differences and the resulting calculated WUA differences are usually less than 1 to 2%. Although no study site WUA difference greater than 10% was found during testing, larger differences could occur if a study encounters a situation where numerous cells have differences similar to that illustrated above.

**Table 1.** Example of propagating differences between PHABSIM for Windows and DOS PHABSIM.

	Windows	DOS	Difference	% difference
Cell bed elevation	91.65	91.65	0	0.00
Water surface elevation	92.456	92.47	0.014	0.02
Depth	0.806	0.82	0.014	1.71
Depth Suitability Index	0.0708	0.096	0.025	26.25
Combined Suitability Index	0.0644	0.087	0.023	26.25
Weighted Usable Area	8.698	11.79	3.096	26.25

## Conventions Used in This Document

### *IOC References to Old PHABSIM*

PHABSIM Version 2 (DOS) (Milhous et al., 1989) used lines of numerical switches to control program options. These were referred to as IOC (originally input/output control) lines. Users became familiar with selecting program options by remembering items like “IOC 5 set to 2 and IOC 8 set to 1”. While these options are now described in the PHABSIM for Windows interface using text phrases, the old IOC numbers are also displayed with the text to aid experienced users in migrating to PHABSIM for Windows.

### *Menu Notation*

The PHABSIM for Windows software is menu driven through a graphical user interface and the familiar Windows point and click sequence to operate program menus and options. An abbreviated notation convention is used throughout this document to instruct readers in how to make option selections without filling a large amount of space on the page with screen images for each action to be performed.

The following example illustrates how to assign the calibration data sets to each of the desired simulation flows when using the STGQ model. The first item is part of the main menu list that is always displayed at the top of the main PHABSIM window. Subsequent items are submenu items or choices that users will see on the screen as they work across the line. The “/” character is a delimiter to separate higher-level menu items from lower level items. Menu navigation notation is always displayed in **bold** type.

Example notation for using PHABSIM for Windows menus:

“To assign calibration sets to specific simulation discharges, go to **/Models/WSL/STGQ Options/Assign Cal Sets** and click the check boxes for the appropriate discharge/cal set combinations in the table shown”.

To follow this example, the user would click on the main menu item **Models** followed by clicking in order the **WSL** item in a drop down menu, the **STGQ Options** tab, and the **Assign Cal Sets** button to arrive at the data entry table. This notation is further illustrated in Chapter 1.

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# **Chapter 1. Introduction to the Physical Habitat Simulation System (PHABSIM)**

## **Objectives**

This chapter provides a broad overview of the components of the Physical Habitat Simulation System (PHABSIM). The chapter begins with a summary of the Instream Flow Incremental Methodology (IFIM) to ensure readers are exposed to PHABSIM use in the broader context of IFIM. Readers already familiar with PHABSIM can move directly to Chapter 2.

## **Associated Laboratory Exercise**

Laboratory 1 introduces the structure and use of the PHABSIM for Windows software system and Laboratory 2 covers initial data entry steps required for a PHABSIM analysis.

## **An Overview of IFIM**

PHABSIM is part of a broad conceptual and analytical framework for addressing stream flow management issues called the Instream Flow Incremental Methodology (IFIM) (Stalnaker et al., 1995) (Figure 1-1). IFIM provides a problem-solving outline for water resource issues in streams and rivers. IFIM and PHABSIM were developed as aids to instream flow decision making. Thus, the structure addresses the decision making environment as well as the techniques for quantifying incremental differences in instream habitat that result from proposed alternative instream flow regimes. Figure 1-1 shows the major components and model linkages of IFIM and where elements of PHABSIM fit into this framework. Integration of PHABSIM with other modeling and analysis efforts is strongly encouraged under the IFIM framework.

“IFIM is based on the analysis of habitat for stream-dwelling organisms under alternative management treatments. One could logically question why habitat was chosen as the decision variable in IFIM when there are so many other factors (such as stream productivity or fishing mortality) that can potentially influence fish populations. The simplest reason for basing the analysis on habitat is that IFIM was designed to quantify environmental impacts, and impacts to habitat are the most direct and quantifiable.” (Stalnaker et al., 1995, p. 16).

The four major ecological components of a stream system that determine productivity for aquatic animals 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) (Karr and Dudley, 1981). The complex interaction of these components determines primary production, secondary production, and ultimately the status of fish populations in the stream. In riverine systems, the amount and quality of suitable habitat can be highly variable within and among years. Observed populations and biomass of fish and invertebrates can be expected to be a function of the four components operating on a variety of temporal and spatial scales. 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 be important in determining population and production levels.

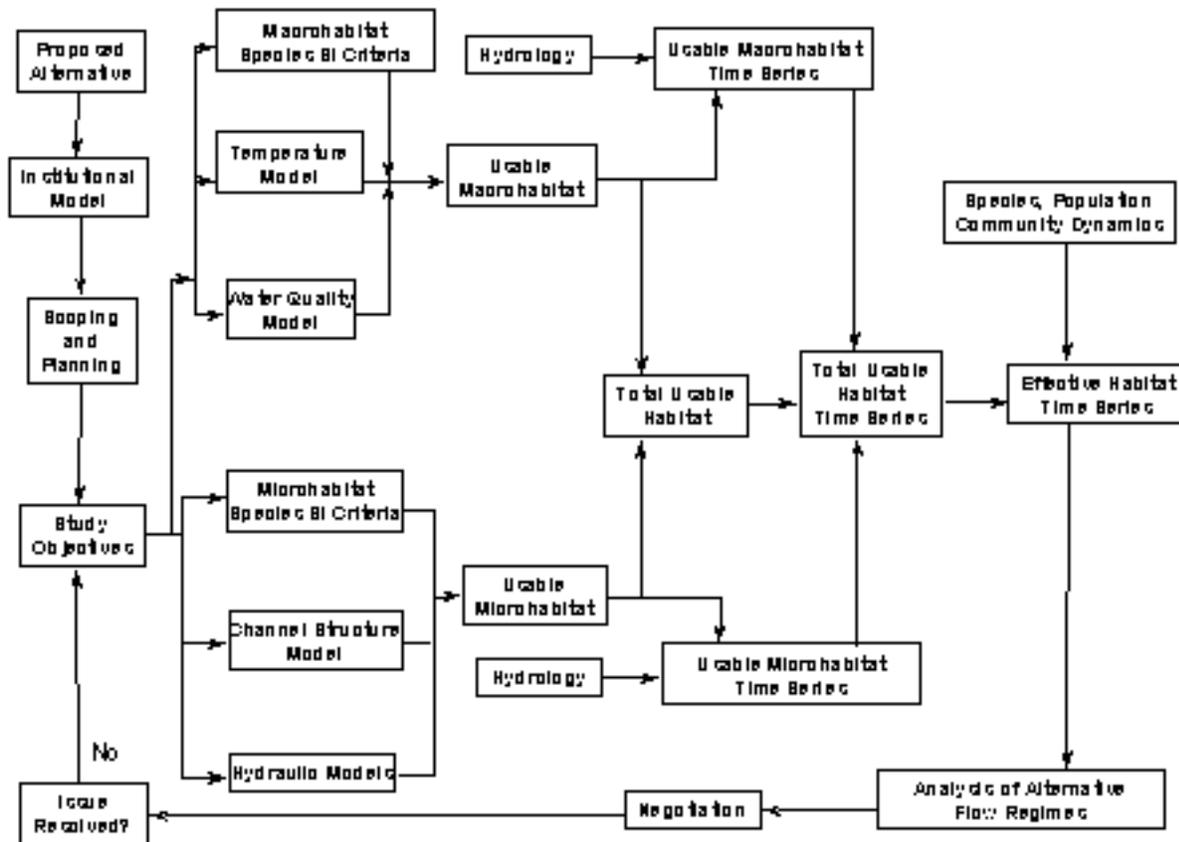


Figure 1-1. Major components of IFIM.

IFIM was designed to address these four ecological components in the context of management decisions concerning instream flow. As such, IFIM also includes mechanisms for analyzing the institutional aspects of water resource issues (i.e., the Institutional Model in Figure 1-1), study scoping and planning process, along with techniques for negotiation and resolution.

Two of the most important aspects of any PHABSIM study are that it is set in the IFIM framework and that it is adequately planned. When the problem scoping phase of an IFIM study indicates that the water management issue is an incremental rather than a standard setting issue, PHABSIM can provide the microhabitat component of the analysis (Stalnaker et al., 1995, Chapter 2). The IFIM study may also incorporate models and/or expert knowledge to assess water quality, water temperature, geomorphology, or other characteristic features of the stream and its current and proposed flow regimes that could influence habitat or populations of aquatic organisms within the stream corridor. In any IFIM application, care should be taken to ensure that the factors that control the instream habitat have been fully considered prior to the use of PHABSIM. For example, it would not make sense to only apply PHABSIM to a stream where the sole limit to habitat is water quality. An IFIM study in such a situation may be appropriately limited to only water quality induced limits to habitat quality and quantity. That is, **an IFIM study may be appropriately conducted without use of PHABSIM if physical habitat is determined not to be a major limiting variable.** A complete treatment of IFIM is beyond the scope of this document. Users of PHABSIM are strongly encouraged to read “*Stream Habitat Analysis Using the Instream Flow Incremental Methodology*” (Bovee et al. 1998) and “*A Primer for the IFIM*” (Stalnaker et al., 1995) and to conduct PHABSIM analyses within the framework of an IFIM application.

## *The Purpose of PHABSIM*

PHABSIM predicts physical microhabitat changes associated with flow alterations such as a reduction of stream flow from 125 cfs to 100 cfs in June. It provides a variety of simulation tools, which characterize the physical microhabitat structure of a stream and describe the flow-dependent characteristics of physical habitat in light of selected biological responses of target species and life stages. When interpreting PHABSIM results, an assumption is normally made that flow-dependent physical microhabitats are useful in determining carrying capacity and therefore are related to the instream flow needs or impacts of flow variations on fish or other aquatic organisms in streams.

The relationship of physical habitat to fish (or any other aquatic organism) production assumes the production of benefits for fish is limited by the availability of physical habitat. This assumption is not always true. Production may be limited by water quality (i.e., acid rain in the Canadian Shield region), by the activities of man (i.e., land use activities or over-harvesting of some species), or by events and conditions occurring at a temporal and spatial scale beyond the scope of the model application. In essentially all situations, physical habitat is a necessary, but not sufficient, condition for production and survival of aquatic organisms. Thus, PHABSIM results may best be viewed as an indicator of population *potential* in systems where the habitat conditions described in PHABSIM are major population constraints. The IFIM process (see Figure 1-1) contains a critical problem-scoping phase where the analyst(s) must evaluate the plausible limiting environmental variables before embarking on an instream flow needs study. The likely relationship of microhabitat to organism abundance needs to be determined on a case-by-case basis through localized studies or analyst consensus attained within the IFIM process.

To understand PHABSIM one must understand how the general term “habitat” is used. *Macrohabitat* refers to a longitudinal portion of stream within which physical and/or chemical conditions influence the suitability of an entire stream segment for an aquatic organism. *Mesohabitat* is a discrete area of stream defined by the channel geometry with similar physical characteristics, e.g., slope, width, depth, and substrate. Such channel geomorphic units (Hawkins, et. al. 1993) are commonly named pool, run, riffle, etc. *Microhabitat* refers to the small, localized areas within a larger scale mesohabitat unit used by an aquatic organism for specific behaviors (e.g., spawning). Microhabitat is typically described by a combination of hydraulic and/or physical variables such as, depth, velocity, substrate, and cover at a spatial scale of near zero to a few meters. Finally, *total habitat* is an aggregation of available wetted area conditioned by microhabitat and macrohabitat suitability. It is summed for all stream segments, i.e., total habitat is the area of a stream with suitable macro and microhabitat. The microhabitat measures in PHABSIM must be integrated to mesohabitat and total habitat spatial scales and evaluated over the appropriate spatial scale. The PHABSIM software does not directly provide this integration facility. Such integration is easily accomplished using spreadsheets and other commonly available commercial software.

PHABSIM estimates changes in physical microhabitat as a function of flow, but does not directly address other elements of stream systems such as water quality and energy inputs. However, as will be discussed in later sections of this manual, inclusion of other components of interest such as changes in channel configuration can often be accommodated. PHABSIM describes flow-dependent changes in physical components of the system and translates them into an estimate of the quality and quantity of microhabitat for aquatic organisms. Incremental changes in stream flow are used to produce relationships between simulated depth and velocity, measured channel index (e.g., substrate and cover), and microhabitat for target species and life stages. Similar relationships can be produced for broader mesohabitat conditions such as low or high gradient riffles, adequate density of woody debris, pools greater than a specified depth, etc. that can be related to communities as well as individual species of aquatic organisms.

The most commonly used output from PHABSIM is Weighted Usable Area (WUA). This habitat measure is a combination of physical microhabitat quantity and quality. WUA is expressed in units of microhabitat area per unitized distance along a stream (e.g., square feet per 1000 feet of stream or m<sup>2</sup> per 1,000 m). In IFIM,

microhabitat values derived from PHABSIM serve as input to an assessment of alternative stream flow management proposals leading to negotiation of flow regimes. These values may also be used in establishment of mitigation targets and for spatial niche analysis.

PHABSIM is intended for use in those situations where stream flow is one a limiting factor controlling aquatic resources and field conditions are compatible with the underlying theories and assumptions of the various habitat and hydraulic models. In practice, if the assumptions of the various hydraulic and habitat models are reasonably met, PHABSIM can be coupled with habitat time series analysis to incorporate the temporal component of habitat variability (see the IFIM general layout in Figure 1-1) to address a variety of applications which include but are not limited to:

- Quantification of instream flow requirements
  - ◊ Area wide planning
  - ◊ Reservation or licensing of water rights
  
- Negotiation of water delivery schedules
  - ◊ Minimum release schedules
  - ◊ Hourly, seasonal and yearly flow regimes (normal and dry year conditions)
  
- Impact analysis
  - ◊ Stream flow depletion
  - ◊ Stream flow augmentation
  - ◊ Channel alterations

Note that these outcomes follow from integrating PHABSIM analytical results with alternative discharge time series to arrive at habitat time series. PHABSIM alone does not address the issues of time varying habitat requirements to maintain species life cycles.

## **The Structure of PHABSIM**

The focus of this document is on the PHABSIM software, although some discussions on study scoping, study site selection, habitat mapping mesohabitat classification, cross section placement, and impact assessment are provided for completeness. Figure 1-2 provides a schematic “road map” to the basic modeling elements of PHABSIM. It also presents the flow of information between the various modeling components. The reader is strongly encouraged to refer to “*Stream Habitat Analysis Using the Instream Flow Incremental Methodology*” (Bovee, et al. 1998) for guidance in using PHABSIM as part of an IFIM study.

Figure 1-2 illustrates several key features representing both the conceptual and practical processes for modeling instream habitat in PHABSIM. First, a new project is defined and either an old (DOS) format data file is imported or raw field data is entered using the PHABSIM for Windows data entry interface. Once the data have been entered and checked, the analyst then proceeds with the calibration and simulation of water surface elevations using any (or a combination) of the three available hydraulic simulation models: STGQ, MANSQ, and/or WSP. Upon completion of the water surface elevation modeling, the analyst then proceeds to calibration and simulation of velocities within the VELSIM program. The selection or development and entry of appropriate target species and life stage habitat suitability criteria (HSC) curve data can be done in parallel as indicated in Figure 1-2. Finally, the user will select the appropriate habitat model(s) and set the required or desired modeling options and generate the habitat versus discharge results which are indicated by the box labeled habitat-flow relationship at the lower right of Figure 1-2. At this point, the microhabitat analyses are completed and these results can be integrated with macrohabitat results or utilized directly in the IFIM assessment framework as illustrated in Figure 1-1.

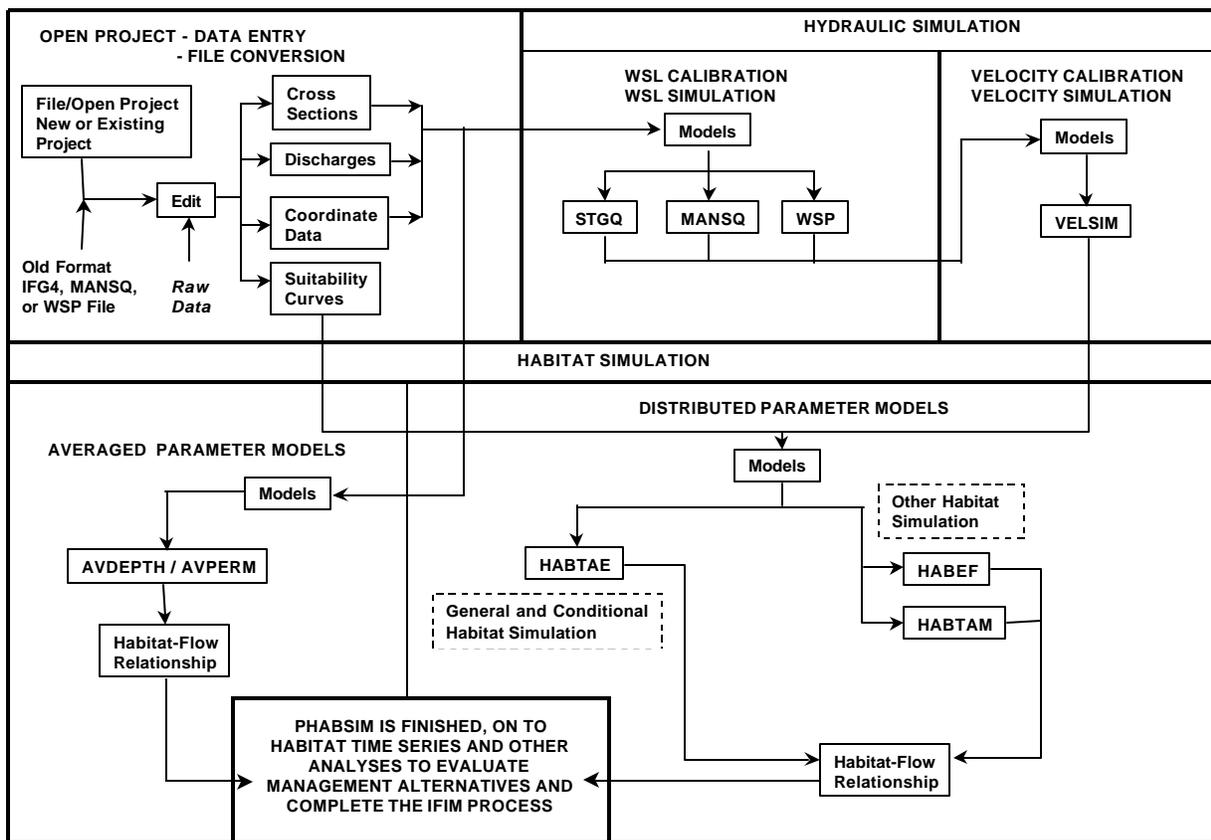


Figure 1-2. PHABSIM for Windows flowchart.

## Application of PHABSIM

Once PHABSIM has been determined to be an appropriate analysis tool in the scoping and tool selection stages of IFIM, the general approach to its application can be broken down into nine conceptual steps. These provide an initial outline for the application of the model and a guide to some of the issues involved. Individual studies may deviate from these steps and in all cases users should carefully consider, justify, and document decisions made to structure the analysis for a particular application.

The nine steps (see Bovee, et al., 1998, and Stalnaker et al., 1995) involved in application of PHABSIM within the IFIM context include:

1. Scoping: identification of habitat information needs and study objectives, selection of methods, IFIM Phase II (if PHABSIM is a selected method, proceed to steps 2 – 9 below)
2. Selection of target species or guild, selection or development appropriate micro and or macrohabitat suitability criteria, IFIM Phase II
3. Study area segmentation and study site selection, IFIM Phase III
4. Cross section placement and field data collection, IFIM Phase III
5. Hydraulic modeling, IFIM Phase III
6. Habitat modeling, IFIM Phase III
7. Derivation of total habitat time series, micro and macrohabitat, IFIM Phase III
8. Determination of habitat bottlenecks, IFIM Phase III
9. Evaluation of management alternatives and problem resolution, IFIM Phase IV

Although the remaining chapters of this manual will primarily focus on the technical aspects of the hydraulic and habitat modeling, and to a lesser degree on HSC and assessment frameworks, each of these conceptual steps is briefly described below. Reference materials on study scoping, field data collection techniques, and general approaches on impact assessment frameworks can be found in Bovee, et al. (1998) and *Data Collection Procedures for the Physical Habitat Simulation System* (Bovee, 2000).

### *Scoping*

This section gives a very brief outline of the project scoping process. The reader is encouraged to carefully read Bovee, et al. (1998) prior to engaging in an IFIM or PHABSIM study.

Project scoping should follow a pragmatic approach based on the importance of the issues to be addressed. Project records should include supporting evidence for each of the choices made. Project scoping should address the following questions:

1. **Why?** A statement of study objectives. The outputs, expectations, and requirements of the project should be stated in as much detail as practicable and, where possible, agreed before starting. The “why” is important for determining whether a PHABSIM study is appropriate to the problem.
2. **Where?** Identification of the impacted area or areas to be studied. A decision on the best approach to study site selection must be made, such as whether a critical or representative reach or stratified random sampling based on habitat mapping (mesohabitat classification) is more appropriate (or even a combination of the methods). How should the available mesohabitats be classified? How should mesohabitat study sites be selected? A further consideration is physical access and the location of gauging stations that can provide suitable hydrological data.
3. **Skills?** Identification of skills required and selection of personnel. PHABSIM applications generally require

input from a multidisciplinary team, including expertise in aquatic biology, hydrology, hydraulic and habitat modeling, interpretation of PHABSIM outputs, and possibly in negotiation.

4. **Limiting factors?** Use of PHABSIM for a study and interpretation of WUA results will be different if physical habitat is one of the factors limiting target species populations than if it is not limiting. Characterization of macrohabitat issues (e.g., water quality and temperature) and consideration of other factors such as exploitation and stocking, food availability and competition, channel dynamics and sediment transport may be necessary to link changes in habitat with production of target organisms. Such linkages may be best addressed with other models, or predictive techniques such as multivariate regression analysis or regression quantiles (Cook, et al., 2000). Habitat for food organisms may be modeled using habitat suitability criteria for selected invertebrate species.
5. **Which organisms?** Selection of target species and life stages. It is seldom possible to evaluate the effects of changes in physical habitat on all species or even life stages in a stream. During the scoping process, an indicator species or species which may be the most sensitive to habitat change, which characterizes changes in habitat for an assemblage of other species, or represents a major management interest of the participants in the instream flow assessment may be selected. The management issue driving the study, combined with advice from fisheries and conservation personnel, will determine if the study is to concentrate on a broad range of species, or a small number of specific species or life stages.

One method used to select species is to rank them, according to various criteria, including their importance, vulnerability, and extent of available information. Users should locate any existing sources of habitat suitability criteria information; assess their “transferability” (see below); and identify possible strategies for HSC curve development, if existing information is not available or is not sufficiently comprehensive. The importance of characterizing fish species by size/age class cannot be underestimated. Size will have a significant impact on what conditions constitute habitat. The characterization to be used must be compatible with available suitability data.

6. **When?** The temporal aspects of the study must be considered. This includes the timing of field data collection (e.g., when can high/low flows be considered? Is annually variable vegetation growth an issue?). Users are encouraged to construct species periodicity charts (which target species/life stages are important and when?) and determine the availability of suitable hydrological time series data (there is likely to be a requirement for flow data both with and without the artificial influence being investigated).
7. **Who?** The responsible parties must be identified and a clear commitment by those individuals and agencies to carry out the study stated in writing as part of the study plan.

### *Selection of Target Species and Suitability Curves*

Use of PHABSIM involves both the selection of target species as well as the development and/or selection of habitat suitability criteria curves for use in the habitat models. This document does not deal with development of HSC curves. A vital part of a PHABSIM study is defining what conditions provide favorable habitat for the target species being considered. Microhabitat in PHABSIM is defined by water depth, velocity, and channel index. Channel index represents substrate, cover, or other similar immobile variable(s) important in defining the physical habitat requirements of the target species. Habitat suitability criteria (HSC) have been referred to as suitability indices, suitability criteria, preference indices, preference curves, and suitability curves in previous IFIM-related publications and in the general literature. These terms are not

entirely synonymous, so the reader is cautioned to check the definitions used in each publication. An example of a set of HSC is provided in Figure 1-3.

It is important that consideration be given to the selection of habitat suitability criteria as early in the scoping process as possible for the following reasons:

1. The scoping process attaches an importance to HSC, which is otherwise easy to overlook. Their simple nature when presented graphically belies the effort behind their development, and interpretation. To simply adopt whatever curves are available after hydraulic modeling is complete may greatly hinder meaningful interpretation of habitat model outputs. Consensus about the HSC among project proponents, regulatory agencies, and other stakeholders early in the project planning process is often essential to successful completion of a PHABSIM study.
2. From the beginning of the analysis the scoping process determines the form and coding of the channel index data to be collected and indicates the areas in the stream that analysts should take care not to overlook.
3. If no acceptable habitat data exist, it may be necessary to initiate a data collection program which can require a long time period, even more so than the site data collection and hydraulic modeling phases of the analysis.
4. PHABSIM results are very sensitive to HSC.

A PHABSIM analysis report should either justify transferring habitat suitability criteria developed elsewhere to the study stream, refer to development of HSC curves specifically for the study in question, or document the agreements by which consensus on HSC curves for the study was attained.

#### Selection of Target Species

A fundamental step during the initiation of a PHABSIM study is the identification and selection of target species and life stages. Valuable data may be obtained from fisheries collection records, stocking records, and management agencies to determine the historical and existing structure of the fish community. In some stream systems, species and/or life stages (such as migrating salmonids) may only be present in the system for a short period. Historical records of fish numbers can be used in determining whether or not management decisions are to focus only on what is present now or on potential restoration and recovery efforts.

Once the initial list of candidate species and life stages has been assembled, data should be organized into a species and life stage periodicity chart which highlights the seasonal (e.g., at least as small as monthly divisions) use of the study area(s) by different life stages of the target organisms. Next, the availability of existing HSC should be determined and decisions made as to whether to proceed with collection of site specific habitat suitability data, collection of transferability testing data, and/or HSC reviews by species experts, from which a final set of curves can be determined. It may be possible to consider some species or life stages without developing locally derived HSC by using literature values. However, in applied PHABSIM studies, not all the target species or life stages have HSC available even from the broader literature sources. When development of site specific HSC is not an option, users may take a guiding approach to represent components of the fish community by mesohabitat use. Here again, literature values or expert consensus may be needed to define community-based HSC.

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#### Types of Suitability Curves

In general, suitability curves have been classified according to the following categories (Bovee et al., 1998, pp. 73–78):

- Category I** Expert opinion or literature curves. These are typically derived from a consensus of experts' accumulated knowledge of habitat use by a species' life stage(s) or by evaluating habitat use information found in the professional literature.
- Category II** Habitat Utilization Curves. These are derived directly from observations of habitat use of the target life stage and species.
- Category III** Habitat Preference Curves. These are derived from observation data on habitat use corrected for habitat availability.

#### Transferability of Suitability Curves

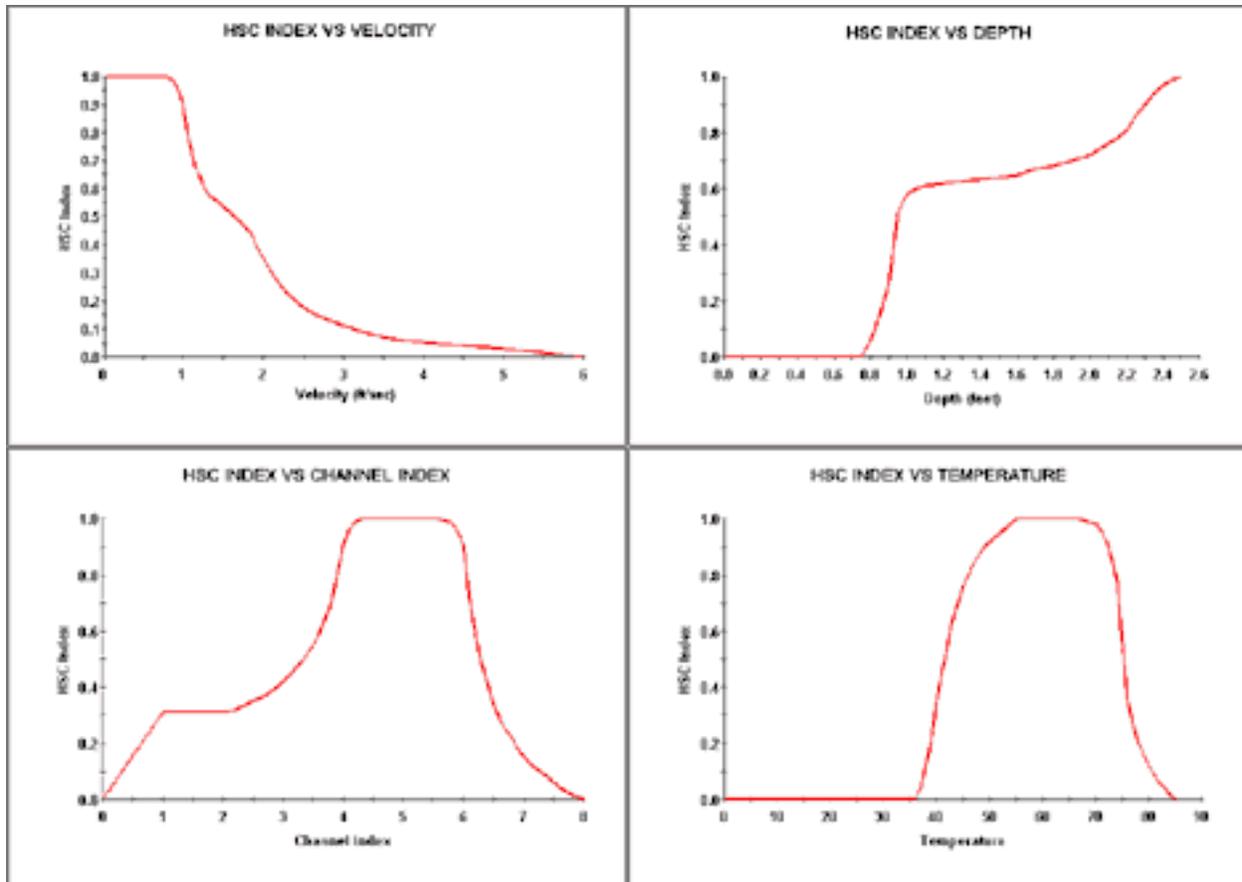
Regardless of how the data are collected, suitability curves will demonstrate some specificity to the stream(s) in which they were developed. With limited resource availability and the high cost associated with development of stream-specific suitability curves, use of HSC from other streams is common. Thus, checking for the appropriateness of the transfer is important. Avoiding development of study-specific HSC leads to considerable cost savings. The investigator must apply professional knowledge and judgment to evaluate if the source curves are meaningful for the current application and transferable. In the IFIM context, it is essential for all parties to agree on the HSC to be used for the study and to agree on their transferability. Thomas and Bovee (1993) and Groshen and Orth (1994) provide methods for quantitatively testing HSC transferability. Manly (1993) provides general guidance on modeling habitat selection by various animals.

For further discussion of habitat suitability criteria curves, see Bovee (1996), Bovee et al. (1998), and Chapter 3.

### *Segmenting the Study Area and Study Site Selection*

Three approaches are commonly used to sample microhabitat: a critical reach study site, a representative reach study site, or a collection of mesohabitat type study sites. (Bovee et al. 1998) All three require that the stream be segmented using a five-step process. These steps are as follows:

1. Identify the study area boundaries; that is, the reach of stream that is or will be impacted by an altered flow regime.



**Figure 1-3.** An example of Habitat Suitability Criteria for Adult Brown Trout (one life stage of one species).

2. Identify the study area boundaries; that is, the reach of stream that is or will be impacted by an altered flow regime.
3. Segment the study area into hydrologic segments that is reaches of stream that have a homogeneous hydrograph.
4. Segment the hydrologic segments into sub-segments based on geomorphologic factors that influence habitat suitability. For example, within a hydrologic segment there are two reaches that have distinctly different slopes but similar hydrographs. One reach has a mean slope of 1.5 feet per mile while the other is 2.8 feet per mile. Since this factor controls water velocity and sediment (substrate), variables used to describe microhabitat, the hydrologic segment should be further divided into two sub-segments.
5. Identify the type of study site(s) that will be sampled: critical reach study site, a representative reach study site, or mesohabitat type study sites. Once this decision is made then specific study sites are selected using a stratified random or stratified systematic sampling scheme. If the mesohabitat types approach is used then a mesohabitat type classification must be developed and proportions inventoried within each segment or sub-segment.

6. Place cross sections within each study site using a stratified random or stratified systematic sampling scheme plus place cross sections on all hydraulic controls within or on any hydraulic control having an influence on any portion of the study area.

The approach used depends on individual study objectives and may involve a combination of the above procedures. The procedure characterizes the study area microhabitat(s) important to the selected target species/life stages affected by the water resource issue in question. When initiating a study, the length of the study area, hydrologic segment(s), and sub-segment(s) over which the assessment is required should be quantified. The more homogeneous the stream segment or sub-segment is in terms of its hydrological and geomorphic characteristics, the more accurate the extrapolation from study site simulations to the entire study area will be.

#### Critical Reach

This approach uses a specific reach (or reaches) of the stream that is most sensitive to changes in flow, and/or is critical to the success of a particular species' life stage. If, for example, it is believed that the availability of spawning habitat is a limiting factor to recruitment of a particular fish species, then the selection of a study site(s) within the known spawning area may be an appropriate part of a study designed to specify a flow regime optimal for recruitment of the species.

A critical reach may be selected on the basis of basic criteria such as:

1. The reach may be highly affected by, or particularly sensitive to changes in stream flow. For example, the most sensitive reaches with respect to discharge may be elevated portions of the channel, such as riffles and gravel bars. Alternatively, the artificial influence being investigated may only have an impact over a confined area but that area may be highly important with respect to the target species/life stage being considered.
2. The critical reach may act as a biological control limiting a particular life stage of the target species. For example, if the availability of spawning habitat is known to be limiting trout populations, then the only known spawning area within an extensive section of river (e.g., a convex gravel bar) could be an appropriate choice for a critical reach. Or a low flow passage block that limits access to spawning areas could be the critical reach in an investigation.

The assumed role of a particular mesohabitat type as the limiting factor to success of the species/life stage should be verified by sampling whenever possible. For a single species, different mesohabitat types may be limiting to different life stages at different times of the year, and if the study addresses more than one target species, different mesohabitat types may be limiting to populations of the different species. In either case, it is important that the study site(s) represent(s) the full range of mesohabitat types present in the study area. This situation typically involves the use of a representative reach or mesohabitat classification. Some study designs may employ a stratified random sampling approach or a combination of all of the above, which usually involves using a "habitat mapping" strategy for weighting the data in PHABSIM.

#### Mesohabitat Study Site Selection

One general approach to selecting study sites using a mesohabitat classification is as follows:

1. Within the whole study area in question, hydrologic segments and, if appropriate, sub-segments are identified (e.g., defined by geomorphology or human influences such as channelization, dams, or diversions). This may include portions of a river where the stream hydrology is significantly different such as above or below a tributary inflow or below a water diversion.

2. A classification scheme is developed for delineation of specific mesohabitat types in the stream. These mesohabitat types correspond to channel geomorphic units such as deep glide, shallow glide, pool, riffle, and cascade. This may be accomplished using the skills of people familiar with the stream and the target species in question, as well as those trained in the use of PHABSIM. This may also be approached using any number of different habitat classification schemes published in the open literature or adopted by resource management agencies involved with the study. In addition to identifying different geomorphological features, (e.g., pools and riffles) the distribution of areas having cover (e.g., overhead cover, undercut banks, or floating aquatic plants) and areas thought to be of special ecological importance (e.g., backwater refuges) should be identified where appropriate. The flows under which the mesohabitat classification fieldwork should be carried out must also be considered.
3. The mesohabitat classification itself is then carried out. PHABSIM study sites are established at the selected locations and surveyed according to the techniques described in Bovee (2000). The data are entered into PHABSIM for Windows using a weighting scheme that causes the resulting habitat simulations to allocate the desired proportions of each habitat type in the final PHABSIM results. (See Chapter 4 for details on this “habitat mapping” procedure.)

Simply stated, the mesohabitat classification procedure involves a classification of mesohabitat types by inventorying (typing and measuring the length of) within each hydrologic segment and sub-segments in the stream. Then specific locations for PHABSIM study sites and cross sections are chosen to characterize these habitats. It may be possible to represent the entire study area with one representative reach. In most circumstances, such as in streams containing complex and variable habitat types, numerous study sites will be necessary. One common approach is to delineate the number and linear distribution of each mesohabitat type within each hydrologic segment and sub-segment using a predefined channel geomorphic unit classification scheme based on actual physical measurements. The investigator can then select cross sections within each of the mesohabitat types within a representative reach(s) within the study area, or a stratified random selection procedure or a combination of methods. The final weights given to each cross section during habitat modeling within PHABSIM are derived from the total mesohabitat classification results. In some studies, only mesohabitat types that are represented by some minimum amount (e.g., at least 5 to 10% of the total area) are included, unless a rarer habitat type is considered critical to the life history needs of the target species. The inclusion or exclusion of mesohabitat types based on the percentage composition or critical nature should be clearly identified during the study scoping process.

Another more detailed approach to mesohabitat classification involves the delineation of study sites of generally similar physical microhabitat identified through a survey which takes spot measurements of habitat variables such as stream width, maximum velocity, depth, substrate, and cover, along with a quantitative discrimination of these habitat variables. Analysis of the distribution of these habitat variables can enable a detailed discrimination of related habitat variables. For example, it may highlight distinctive areas within deep glides or shallow pools. Based on these analyses, specific locations for cross sections can then be accomplished as outlined above.

Still another variation on this basic theme for mesohabitat classification involves the random selection of a starting point within a specific hydrologic segment or sub-segment where mesohabitat classification is conducted over a longitudinal distance equivalent to approximately 20-30 channel widths. Based on the habitat types encountered, each type is assigned as a stratum and the specific habitat unit within a stratum is randomly selected. The location of cross sections in the selected habitat unit is then determined using a random selection process for the location within the specific habitat unit.

No single preferred method exists for selection of study sites or specific cross section locations. The specific approach taken should be determined during project scoping. It is strongly suggested that representatives of all parties in an instream flow issue participate in the cross section selection process.

## *Cross Section Selection and Field Data Collection*

The relationship between cross section placement, number of cross sections, and the subsequent field data collection of the hydraulic properties of the stream are critically important to the successful application and interpretation of PHABSIM.

### Cross Section Selection

The number and location of PHABSIM study cross sections is based on the habitat types identified by one of the above mapping strategies. If the distribution of habitats within the stream permits, a series of hydraulically linked cross sections should be chosen to facilitate the collection of field data and increase the flexibility in hydraulic and habitat modeling. The total number of cross sections will depend on habitat diversity, the extent or spatial domain of the study, and resources available. The number of cross sections within each study site will generally be small, but where resources permit, cross sections should be selected to provide replicate samples of habitat types to incorporate the inherent variability within a specific habitat type in a more robust manner.

In addition to the placement of cross sections in target mesohabitat types, it is frequently necessary to place an additional cross section at all hydraulic controls within or influencing each individual mesohabitat type. If a representative reach approach is being used, all hydraulic controls within a study site should be sampled, or if cross sections are clustered into groups, then the hydraulic control at the downstream end of each cluster should be included. Placing of cross sections at the hydraulic controls enables the user to consider the full range of hydraulic models in PHABSIM, including the step-backwater based WSP model. These additional cross sections can be ignored during habitat modeling and therefore will not necessarily contribute to the physical habitat calculations.

A variation on basic mesohabitat classification at a single flow involves mapping the changing proportions of the habitats (as mapped above) at different flows. This information can then be utilized to change the weighting of individual habitat type WUA versus discharge relationships as a function of flows to produce a composite WUA for the range of flows simulated in the study. For example, a stream may contain 30% riffle habitat at low flows, but only 10% at high flows. The particular utility of this type of approach has its own inherent bias. For example, a cross section located in a pool at one discharge may be subsequently classified as a run habitat at an alternative flow.

### Field Data Collection

PHABSIM data collection generally requires the following steps to be completed and reported.

1. Units of measurement must be chosen (metric or U.S. customary fps).
2. The selection of target discharges (usually three or more) where field data are required, as well as the selection of the best time to get high, medium, or low flow measurements. Data may be required from more than three flows in order to model the physical habitat correctly. For example, where the bed morphology is complex or where there is seasonal weed growth.
3. Survey headpins are driven into the bank at each cross section. These should be located to provide a stable horizontal and vertical datum and should be securely placed a reasonable distance away from the water to avoid disturbance during high flow events.
4. For each set of linked cross sections, a closed-loop survey through all headpins showing elevations and

distances is required.

5. A topographic survey of channel morphology (bed elevation) at each cross section (selected above), relative to the fixed cross section headpin. The investigator should ensure an adequate number of observations to describe the channel cross section and remember that each survey point will be used as a location for hydraulic measurement when covered by water.
6. A record of channel index parameters (substrate, and cover) at each of the points where bed elevation was taken. PHABSIM considers substrate and / or cover to be unchanging throughout the flow range, though the user may evaluate habitat for changing channel index conditions by creating more than one set of study project files.
7. Establish a temporary staff gage to check fluctuations in the water surface elevations during each discharge measurement.
8. Mean column velocities are measured at each survey point across each cross section. A full set of measurements should taken at several well spaced discharges. This is not essential but it is desirable since it allows the user maximum flexibility in velocity simulation and allows a more comprehensive assessment of simulation errors. Mean column velocity is measured at 0.6 of the depth up to depths of 2.5 ft. In depths greater than 2.0-2.5 feet, an average of readings at 0.2 and 0.8 of the depth is recommended if time and resources allow. See USGS stream gaging guidelines in Rantz and others (1982).
9. At each flow, wading rod depths should be noted at each wetted point where flow measurements are made.
10. At each flow, a survey of water surface levels at each cross section, relative to the cross section headpin. Repeated water surface elevation readings on the left, center and right of the channel provide best accuracy. This provides some data redundancy (wading rod depths are also taken) and provides an essential check on the survey techniques.
11. Any flow changes during fieldwork periods must be noted. A fixed staff gage located at a good cross section for measuring discharge should be read frequently to detect changes in discharge.
12. Field notes describing the stream and in particular every cross section. It is important always to collect as much information as possible.
13. Installation of a data logger for water surface level in lieu of a staff gage at a convenient point (the most downstream cross section or the best cross section for measuring discharge) can provide valuable additional information.

MESC recommends that at least three complete sets of water surface levels and at least a single velocity data set be collected to ensure maximum flexibility in the hydraulic model calibrations. However, in most channels, additional velocity sets at alternative flows are highly advisable, since a single velocity data set is unlikely to reflect the velocity distributions across all flow ranges. Additional water surface and velocity sets are particularly needed in complex channels where it may be necessary to measure several cross sections to capture multiple channels and other features. Available resources may limit time spent on data collection, so it is important to plan in advance on the number of data collection trips and the target discharge ranges necessary to meet data quality

objectives for the hydraulic and habitat modeling for a particular study. For example, in relatively uniform

channels, one or two velocity data sets may be adequate. In general, the more data (and more redundant data) one can collect, the greater the anticipated accuracy and reliability of the study. For a more complete description of field data collection considerations and techniques, see Bovee (2000).

### *Hydraulic Modeling*

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

The hydraulic simulation programs in PHABSIM assume that the shape of the channel does not substantially change with discharge over the range of flows being simulated. In practice, small changes in the bed topography will often occur between field data collection efforts at the high and low flows. If these differences are small, then they are ignored in the analyses. However, if significant changes in bed topography do occur between data collection field trips, these data should be treated as independent estimates of the hydraulic properties within the channel and used as independent data sets (evaluated as different project files) in the hydraulic model calibrations and subsequent habitat simulations.

The simulated hydraulic characteristics of the stream are the water surface elevations (i.e., depth) and 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 assumed to be the same across a single cross section (although depth varies since it is calculated by subtracting the bed elevation from the water surface level). In contrast, velocity varies from cell to cell across any cross section.

The approaches available for calculation of water surface elevations are: (1) stage-discharge relationships, (2) Manning's equation, and (3) the step backwater method. The absolute minimum data set used in the application of PHABSIM requires at least one set of water surface elevations. In standard practice, at least three sets of water surface elevations are targeted for collection along with at least one and preferably additional sets of velocity measurements.

#### Water Surface Elevation Modeling

The first step in hydraulic modeling within PHABSIM is the calibration and simulation of water surface elevations. Depending on the nature of the field data available, the following programs and approaches can be utilized:

**STGQ** The STGQ model uses a stage-discharge relationship (rating curve) to calculate water surface elevations at each cross section. In the stage-discharge relationship and its simulation, each cross section is independent of all others in the data set. The basic computational procedure is conducted by performing a log-log regression between observed stage and discharge pairs at each cross section. The resulting regression equation is then used to estimate water surface elevations at all flows of interest.

**MANSQ** The MANSQ program utilizes Manning's equation to calculate water surface elevations on a cross section by cross section basis and therefore treats each cross section as independent. Model calibration is accomplished by a trial and error procedure to select a  $\beta$  coefficient that minimizes the error between observed and simulated water surface elevations at all measured discharges.

**WSP** The Water Surface Profile (WSP) program uses a standard step-backwater method to determine water surface elevations on a cross section by cross section basis. The WSP program requires that

all cross sections being analyzed in a given model run be related to each other in terms of survey controls and sequence upstream. That is, each cross section's hydraulic characteristics in terms of bed geometry and water surface elevations are measured from a common datum. The model is initially calibrated to a measured longitudinal profile of water surface elevations by adjusting Manning's roughness, first for the entire study site and then at each cross section. Manning's roughness is then adjusted for subsequent measured longitudinal water surface profiles at other discharges by setting the roughness modifiers used within the model. This approach requires all hydraulic controls within the modeled study site are represented by cross sections.

In addition to these three water surface elevation models, PHABSIM can utilize water surface elevations derived at each cross section from external sources. This approach is discussed in the chapter on hydraulic modeling.

### Velocity Modeling

In PHABSIM for Windows, the **VELSIM** program is the principal tool used to simulate the velocity distributions within a cross section over the required range of discharges (i.e., the mean column velocity in each wetted cell in a study cross section at each simulation discharge). The technique relies on an empirical set of velocity observations (i.e., measured velocities) that act as a template to distribute velocities across a channel by solving for the 'n' in Manning's equation (in this context 'n' acts as a roughness distribution factor across the channel). The channel is divided into cells and the velocity calculated for each of these cells. The usual practice is to use one set of velocities as a template for simulating velocities for a particular range of discharges. When more than one set of empirical velocity measurements is available, a commensurate number of flow ranges can be simulated with different velocity templates. The program can be used when no velocity measurements are available. In this situation, velocity will be distributed across the cross section as a function of flow depth.

For further discussion of hydraulic modeling, see Chapter 2.

### *Habitat Modeling*

Habitat modeling transforms information on channel structure, modeled water surface levels and velocities into an index of the quantity and quality of available habitat using the HSC as the transfer function. This index of habitat is referred to as Weighted Usable Area (WUA) and is computed for each cell across each cross section at each modeled flow. The cell values are then summed to produce a composite or study site level WUA for a given discharge, for each separate species or life stage. This enables a relationship to be built up between a range of discharges and aggregate habitat availability for the whole study site. The options used in habitat modeling can affect the predicted habitat area relationship and magnitudes to some extent. Thus, the modeler should select the options in a reasoned manner, and should be consistent when modeling habitat at different sites if the results are to be comparable.

The two general types of habitat modeling options available in PHABSIM are based on either average conditions in an entire stream channel (i.e., the average parameter model) or on the explicit distribution of velocity, depth, and channel index across an entire cross section(s) (i.e., distributed parameter models). Each of these approaches is supported by a set of analysis tools that are described below in general terms and in more detail in Chapter 4. An additional group of effective habitat models deals with the value of distributed habitat under certain changes in flow.

#### The Average Parameter Model

The average parameter model, **AVDEPTH /AVPERM**, calculates a variety of hydraulic characteristics for each cross section in addition to a study site average view. These include wetted width, wetted perimeter, and wetted

surface area, cross sectional area, mean channel velocity, and average depths. They can also be utilized to determine the width of a stream with water that is over some arbitrary depth(s) specified by the user. These programs provide a wealth of information at a cross section or a study site level aggregate and should be examined in most applications.

### Distributed Parameter Models

This second habitat modeling category is based on the flow-dependent attributes of depth and velocity at each measured vertical, which are integrated with biological criteria in the form of HSC curves. The primary program using distribution parameters is the **HABTAE** model. In earlier versions of PHABSIM, there were two other habitat models, HABTAT and HABTAV. The functions of these two programs have been combined in the revised **HABTAE** program in PHABSIM for Windows. Options within **HABTAE** allow the user to select habitat calculation assuming the condition within a cell establishes the worth of the habitat in the cell or assuming the condition in a cell plus the velocity in adjacent cells or at another location nearby establishes the worth of the habitat in the cell. The **HABTAE** program also allows habitat to be determined in terms of volume (instead of the surface area), and provides a method for determining the habitat conditions at each cross section.

### Effective Habitat Analysis in PHABSIM

In addition to the two general categories noted above, a third class of habitat modeling involves the determination or evaluation of effective habitat. There are two programs available for effective habitat analysis in PHABSIM. The first is the **HABEF** program, which is used to determine availability of physical habitat considering two flows; in other words, the HABitat that remains EEffective when two flows are of importance. This situation often arises, for example, in the evaluation of reducing flows during the spawning period and subsequent incubation period or in hydro-peaking operations that have a daily minimum and maximum flow. In the case of spawning and incubation analyses, the spawning area at a cross section is not 'effective' unless the incubation period flow regime maintains the habitat in a suitable condition for the eggs to hatch.

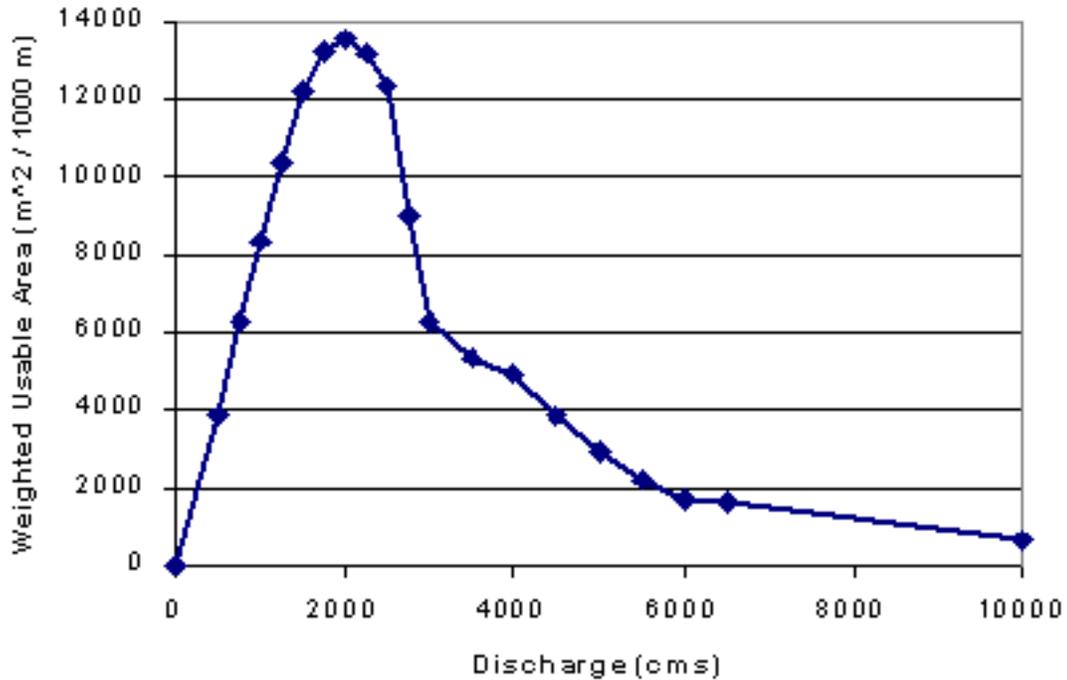
The second effective habitat model is the **HABTAM** program in which the species can move from cell to cell over a range of starting and ending discharges. In this model, effective habitat is defined as the habitat that remains usable when the species is forced to move due to flow fluctuations. The computational aspects of each of these habitat modeling options are discussed in detail in Chapter 4.

### *Interpreting PHABSIM and Completing the IFIM Process*

The end product of the habitat modeling in PHABSIM is the production of habitat versus discharge functions for each target species and life stage (Figure 1-4). These relationships represent the starting point for assessment of alternative flow regimes or impacts of a proposed project. In many instances additional analyses of such factors as channel and riparian maintenance flows, and/or water quality and temperature modeling will be needed to assess alternate flow regimes.

IFIM provides an assessment framework for use in the interpretation of PHABSIM results. In IFIM, stakeholders are encouraged to reach consensus on evaluation of these results in the context of the water resource decision at hand. Fortunately, there are a number of analytical approaches that can aid the investigator and water resource manager in this decision process. From a physical habitat modeling perspective, the most common (and recommended) approach is to conduct time series analysis based on the existing or anticipated flow regime(s) for the project. Habitat time series illustrate the dynamics of the temporal habitat change for a particular species and life stage during each season or critical time period under historical, existing, and proposed project flow scenarios. This aspect is one of the critical distinctions between an application of PHABSIM (which produces a habitat-flow relation) and a true IFIM study (which produces numerous alternative habitat time series). Some examples of

using PHABSIM within an IFIM study are treated in Chapter 5.



**Figure 1-4.** Example of a habitat-discharge relationship for a single life stage.

Habitat time series analysis quantifies project impacts or benefits in terms of habitat gains or losses when comparing flow scenarios to the selected project base line conditions. These analyses can also be used to generate habitat duration curves on a seasonal basis or compute habitat conditions that are continually below some prescribed threshold. It is a matter of professional judgement as to what adverse impact or benefit is represented by any quantitative change in habitat area or as a percentage change from baseline scenarios. Often the kind of water resource issue and the importance of the target species to the resource manager, dictate the level of impacts or benefits that are considered acceptable. In addition, establishing an instream flow regime will often require the integration of water quality or temperature during critical periods. It is also common to use alternative techniques such as channel maintenance flow computations during the peak runoff periods to select an appropriate flow regime rather than rely solely on the PHABSIM model outputs.

There are several approaches to habitat modeling available in PHABSIM. See Chapter 4 for treatment of each of the habitat models and their numerous options for generating and aggregating habitat values.

This concludes the overview of the background and general concepts in PHABSIM. This chapter concludes with an introduction to the PHABSIM for Windows software.

## Using the PHABSIM for Windows Menu System

The general steps for using the interface consist of clicking on the appropriate menu, tab, or button items to enter data, select options, run programs, or view output. In this manual each of those steps is presented in text in the following format:

**Main Menu/Next Menu/Next Menu or Tab:** Instructions for what you should do.

For example to run the STGQ model and generate simulated water surface elevations, click on **Models**, then **WSL**, followed by **Method** and the **STGQ** radio button. Then either click the cells in the data entry table where you wish to enter stage or click the **Set All** button to the right. That sequence of operations is noted in the documentation as:

**/Models/WSL/Method/STGQ:** Select **Set All** or click the cells for the cross section and discharge for which you wish to run the STGQ model.

The actions are:

Move mouse to **Models** item in the main menu, click.

Move mouse to **WSL** drop down menu item, click.

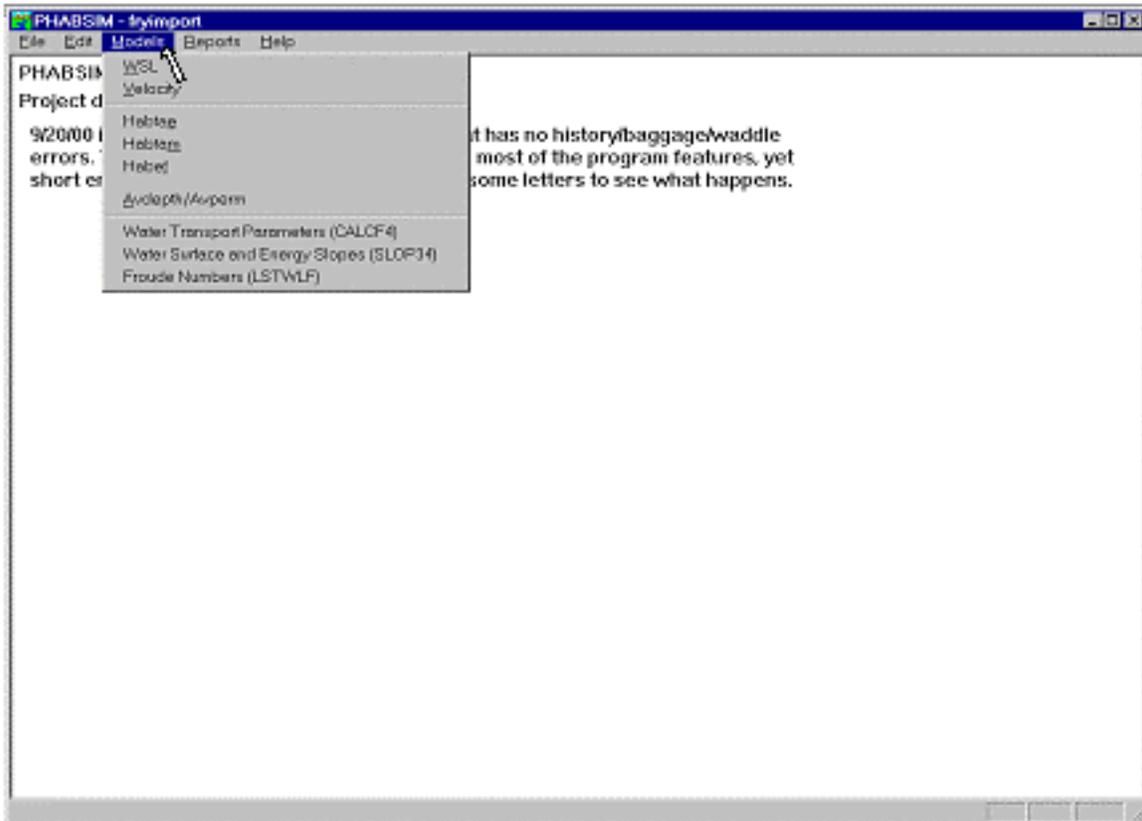
Move mouse to **Method** tab (if not already showing), click.

Move mouse to radio button (round button) for the model you wish to use (in this case **STGQ**), click. A black dot should appear in the middle of the round button.

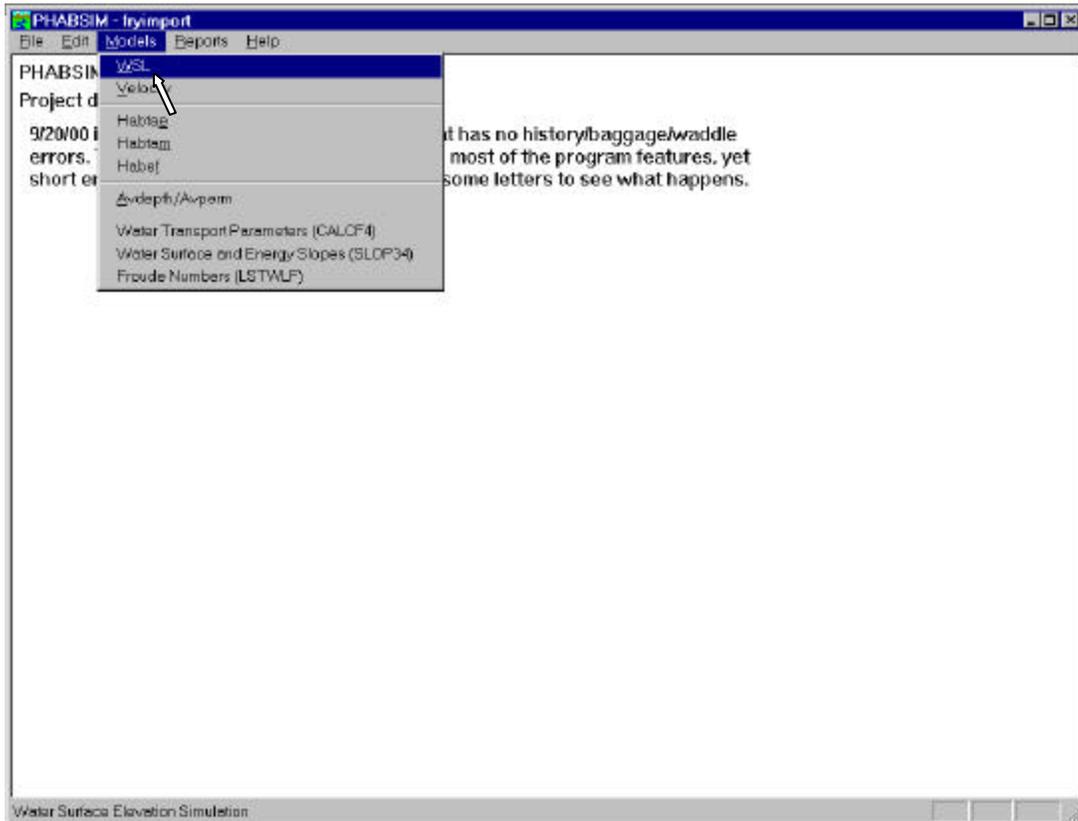
Move mouse to the individual cells for cross section and discharge where you wish to use STGQ and click each cell or click the **Set All** button.

The notation **../Method/WSP** is used in some places to abbreviate long entries such as **Models/WSL/ Method/STGQ** when moving within the same set of tabs.

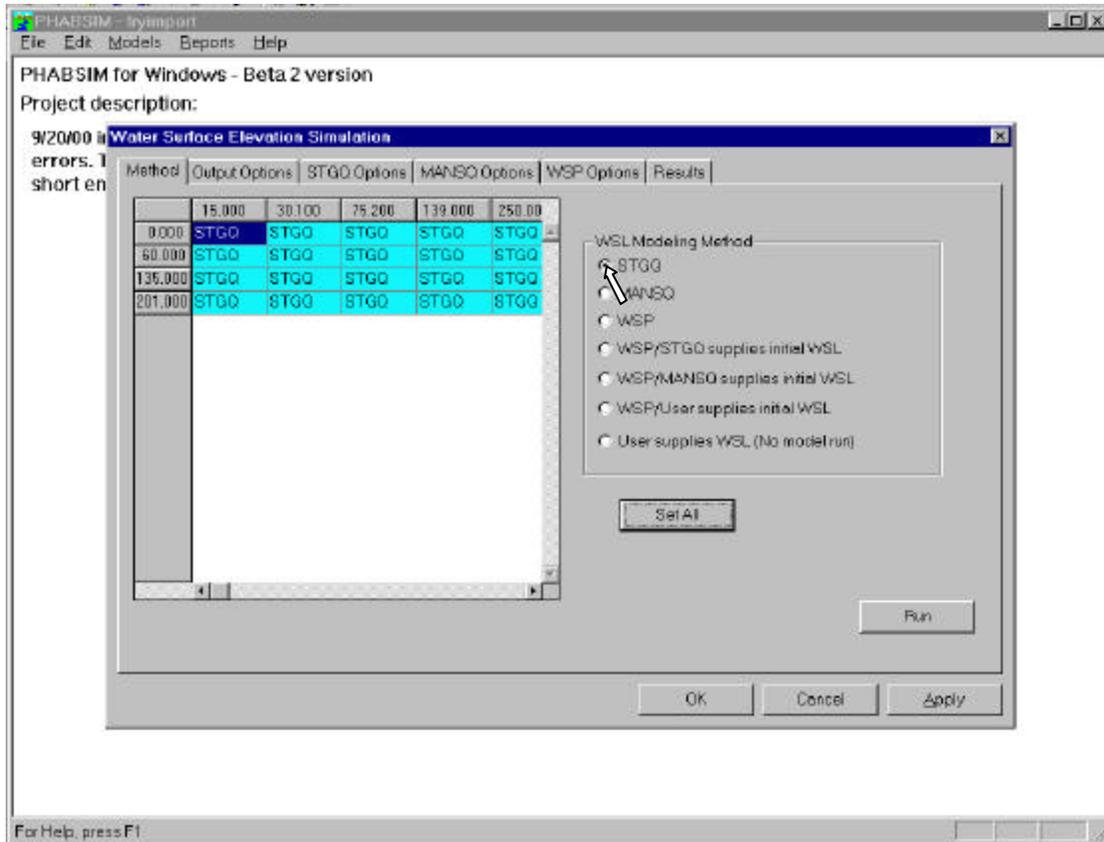
The following figures illustrate these operations.



**Figure 1-5.** Selecting the Models Menu Item. Move the cursor over the word Models and click. A drop down menu with the model categories will appear.



**Figure 1-6.** Selecting the WSL Menu Item. Move the cursor over the WSL item on the drop down menu and click.



**Figure 1-7.** Selecting the STGQ Radio Button followed by Set All, Result of the Set All Operation is shown.

This notation is used throughout this manual in lieu of repeating this sequence of figures for each operation to be performed. If the operations are not clear, click the first two or three items in the sequence and read the screen that appears. The next item in the command list will be shown on that screen.

## **PHABSIM for Windows File Structure**

PHABSIM for Windows uses a file structure designed to allow maximum flexibility in the analysis and reduce the amount of file management demanded of the user. To accomplish this, each study site is defined as a “project”. When creating a new project, the software will create a folder with the project name. Within the folder there will be several files with the project name and an extension. Most of the files are in a binary format and cannot be read without running PHABSIM for Windows. Table 1-1 contains a general description of the project files.

**Table 1-1.** Project files.

---

<project>.phb	- general project information	binary
<project>.pxs	- cross section data	binary
<project>.ppt	- point data	binary
<project>.pxp	- cross section point index	binary
<project>.pcl	- calibration set data	binary
<project>.pcv	- suitability curve data	binary
<project>.opt	- project options	binary
<project>.history	- project history file	text
<project>.hyd	- hydraulics output	binary
<project>.zout#	- accumulating ZOUT files	text
<project>.zvaff	- velocity adjustment factors	binary
<project>.zhaqf	- ZHAQF habitat-flow relation output	binary
<project>.11111e	- HABTAE output for curve 11111	binary
<project>.11111m	- HABTAM output for curve 11111	binary
<project>_options.txt	- dump of the options	text.
<filename>	- communication files have no extension	binary
<filename>.bin	- binary internal communication files	binary

---

**Notes:**

- The history file grows as analysis progresses. It is a text file that may be viewed with a text editor to see what steps have been taken in the analysis. This is especially useful when preparing testimony or when preparing reports where the analytical choices must be explained.
- A separate ZOUT file is created for each program run in the PHABSIM suite. ZOUT files contain analysis results and error messages. *The user is recommended to search the latest ZOUT file with a text editor after each model run for error messages.* The number of ZOUT files will grow as the analysis progresses. One may delete ZOUT files as results are stored in the project database. However, if files are deleted, the numbering sequence will start over with 1 or the next number above the lowest existing ZOUT. If you delete ZOUT10 through 17, ZOUT10 will be the next one created.
- A separate numbered result file is created for each species/life stage in a habitat simulation. The number is the habitat suitability criteria curve number for the particular species/life stage. These are binary files that contain the habitat-flow relation resulting from running HABTAE or HABTAM. The files are used at later stages of the analysis process and are the source of display of habitat results.
- The project\_options.txt file is created when the user instructs the interface to record options in **/Reports/Record Options**.
- The project.hyd file contains cell-by-cell depth and velocity information.
- The project.ZHAQF file may be produced by HABTAE or HABTAM.
- Cell-by-cell habitat results will be produced for each selected species/life stage. Those results will be contained in files named project.xxxxxxe, where the x's represent the HSC number. The extension will have an "e" or "m" matching the HABTAE or HABTAM program that produced the file.
- The internal communication files should be retained with the project as they can be useful when asking for assistance if the program fails.

## **Analysis Limits in PHABSIM for Windows**

PHABSIM for Windows contains few limits on the number of items that may be analyzed in one project. There is no limit on the number of cross sections that may be included in a project, although there is a practical limit of about 50 cross sections due to the difficulty of tracking all of the habitat issues that may be addressed. A second practical limit applies when using the step-backwater hydraulic model; numerous pool riffle sequences may prove difficult to calibrate unless cross section placement fully satisfies all of the assumptions of the model. Finally, smaller projects generally run faster and are easier to manage.

The number of cells on a cross section is not limited. This is in contrast to PHABSIM Version 2 for DOS, which had a 100 point limit per cross section. Also, the number of digits in x, y, and z position values is not limited by hollerith field lengths as in the previous version.

A limit of 30 discharges per habitat simulation has been retained in PHABSIM for Windows. Both programming costs and run time considerations contributed to this decision. In the event you need to simulate more than 30 discharges, we suggest you make a copy of the project and split the discharge range between two otherwise identical projects.

## **Summary of Chapter 1**

This chapter introduced PHABSIM as a component of the Instream Flow Incremental Methodology. A general outline of its use within the IFIM framework was given. Several activities such as study site selection, field data collection, and habitat suitability curve development were briefly described. Those activities are outside the scope of the PHABSIM software and are not further elaborated in this manual. The remaining chapters deal with the structure and use of the PHABSIM for Windows software. They are presented in the order of a typical PHABSIM analysis beginning with hydraulic analysis in Chapter 2.

## **Chapter 2. Hydraulic Modeling in PHABSIM**

### **Objectives**

This chapter introduces the basic concepts of hydraulic simulation in PHABSIM followed by a detailed explanation of the specific calibration and simulation options for each hydraulic model within PHABSIM. Calibration and simulation of water surface elevations are treated first followed by calibration and simulation of velocities. Specific steps in use of the software for each stage of hydraulic simulation are presented. The chapter concludes with a general discussion of how to evaluate hydraulic modeling results.

### **Laboratories**

The associated laboratories for this material are contained in Laboratory Exercises 3-7. They introduce the three principal water surface modeling options within PHABSIM, as well as the general approaches to velocity simulations. Laboratory 3 introduces the stage-discharge modeling of water surface elevations using STGQ, Laboratory 4 covers the use of the MANSQ model for this purpose, while Laboratory 5 introduces the use of the step-backwater model (WSP). Finally, Laboratory 6 covers the use of the VELSIM model for velocity simulations.

### **Introduction**

Flow in an open channel is a three-dimensional process. It includes response to change in the channel shape, secondary currents, and it varies continuously across and along the axis of the stream. Models of varying complexity capture the overall streamflow process to different degrees. In PHABSIM, the Water Surface Profile model (WSP) uses the step-backwater method to obtain a one-dimensional representation of flow. The STGQ and MANSQ models use empirical means to obtain similar transect-based representations of flow. The hydraulic models in PHABSIM operate with assumptions of a fixed bed profile and a sloped water surface that is level across each cross section. There are many empirical relations used to simplify flow representations so they can be represented on transects, rather than continuously. Thus, flow representations within PHABSIM are discretized as cells located across transects. The influence of the assumptions and one-dimensional form of PHABSIM models will become more apparent as the reader progresses through this chapter.

Hydraulic modeling within PHABSIM characterizes the physical attributes within the stream (i.e., depth, velocity, and channel index) over a desired range of discharges. This characterization could be accomplished by direct empirical measurements taken at small increments of discharge covering the range of discharges of interest for a habitat study. However, time, safety and funding constraints typically prevent this empirical approach. Fortunately, it is possible to sample the stream's hydraulic properties at a few target discharges and then rely on these data to calibrate one or more hydraulic model(s) and use the model(s) to predict the stream hydraulic attributes over the full range of discharges of interest in the study. The success or failure of this effort is dependent on the quantity and quality of the field data, the complexity of the physical nature of the stream, and ultimately the ability of the hydraulic models to reflect the physical processes in the stream.

The material in this chapter represents concepts and application strategies of elements contained in the hydraulic simulation portion of the information flow within the PHABSIM system as indicated by the area labeled hydraulic simulation in Figure 1-2. The chapter concludes with a section on evaluating hydraulic model results.

## *Terms and Definitions for Open-channel Flow*

Prior to presentation of these specific modeling approaches within PHABSIM, a brief introduction to the vocabulary and physical setting of open channel flows is necessary. A more technical and detailed treatment of the hydraulics of open channel flow can be found in any number of general texts on hydraulics such as Henderson (1966). Those readers who are interested in a more rigorous treatment of hydraulics should consult that or similar works.

The following terms and their definitions are important since they constitute the vocabulary of hydraulic analysis terminology within PHABSIM related to the analysis of open-channel flow and in particular to the use of hydraulic modeling options for the specific models within PHABSIM. The relationships between these terms and physical properties within a river channel or cross section(s) are illustrated in accompanying figures where possible. Figure 2-1 provides an idealized representation of a stream reach showing the location of several cross sections (transects), a hydraulic control, and a lateral view of a typical cross section profile.

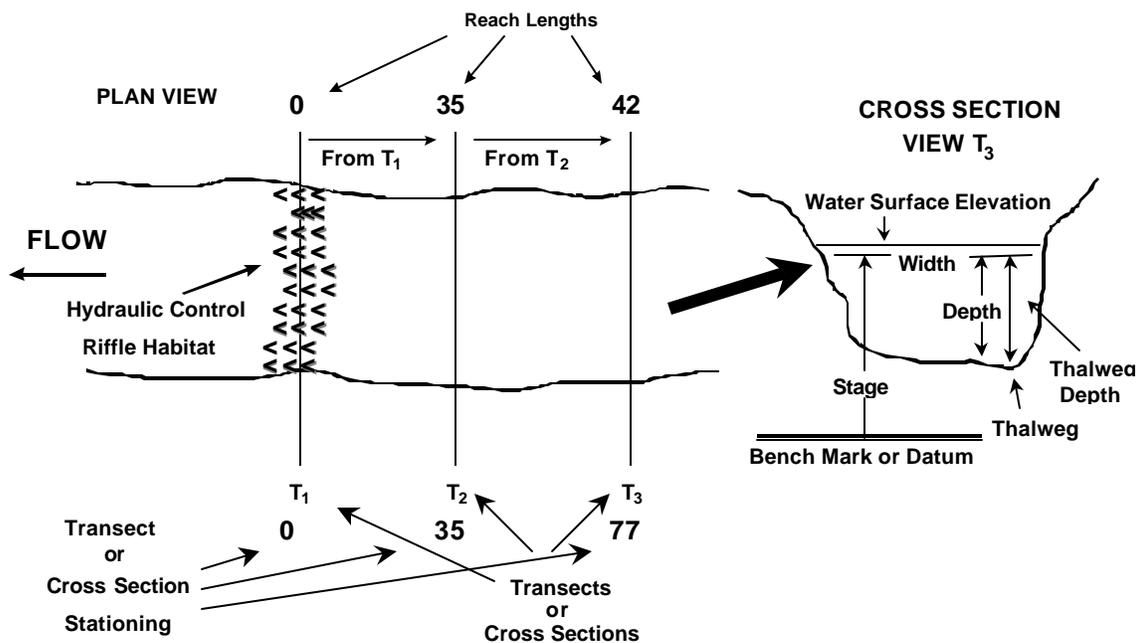
**Cross Section:** A two-dimensional (width and depth) section derived from measurement of lateral distance and stream bed elevation across a stream channel that is perpendicular to direction of the flow and is synonymous to a transect. These are indicated in plan view by  $T_1$ ,  $T_2$ , etc, in Figure 2-1 and in lateral view for  $T_3$ .

**Reach Length:** Reach length is the distance that the current cross section is located from the previous cross section and, therefore, by convention is measured in an upstream direction. The downstream-most cross section has a reach length of zero and as illustrated in Figure 2-1, the reach length for  $T_2$  is 35 feet, while the reach length for  $T_3$  is 42 feet. In practice, both the left bank and right bank distances between adjacent transect head pins are measured and typically the average distance is used as the reach length for hydraulic modeling. In hydraulic modeling within PHABSIM, the actual reach length is only important when using the WSP hydraulic model since WSP uses this distance to dissipate the energy between adjacent cross sections. Since the STGQ and MANSQ models analyze each cross section independently, reach lengths play no role in these hydraulic models. The use of reach lengths and reach length weighting factors (upstream weighting factors) is critical in habitat modeling since these factors are used to derive the longitudinal dimension of the habitat cells and thus contribute to determining habitat area. Reach lengths are discussed in more detail in the section on habitat modeling.

**Backwater:** An area of stream where the water surface elevation is controlled by a hydraulic control. An example of a typical backwater area is a pool upstream of a riffle. Backwaters also occur in secondary (or side) channels where water “backs up” from the main channel, though flow through the side channel is cut off at some point upstream.

**Hydraulic Control:** A section of the channel which “controls” the water surface elevation of the stream in an upstream direction under sub-critical flow conditions or in a downstream direction under super critical conditions. Hydraulic controls are most often associated with a shallow and raised section of stream or a steep section of the stream such as a riffle as illustrated in Figure 2-1. Hydraulic controls typically have a higher bed elevation than the backwater areas upstream. Hydraulic controls can also occur at major channel constrictions.

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**Figure 2-1.** Schematic of a PHABSIM representative reach and a typical transect.

**Hydraulic Control:** A section of the channel which “controls” the water surface elevation of the stream in an upstream direction under sub-critical flow conditions or in a downstream direction under super critical conditions. Hydraulic controls are most often associated with a shallow and raised section of stream or a steep section of the stream such as a riffle as illustrated in Figure 2-1. Hydraulic controls typically have a higher bed elevation than the backwater areas upstream. Hydraulic controls can also occur at major channel constrictions.

**Water Surface Elevation (WSL):** The height of the water surface at a cross section as measured (or predicted). The WSL can also be determined from the streambed elevation plus water depth. The WSL is also called the water surface level.

**Stage:** The elevation, or vertical distance of the water surface above some datum (i.e., height relative to the established bench mark used during surveying of the stream geometries or as predicted from the hydraulic models in PHABSIM. Stage is equivalent to WSL.

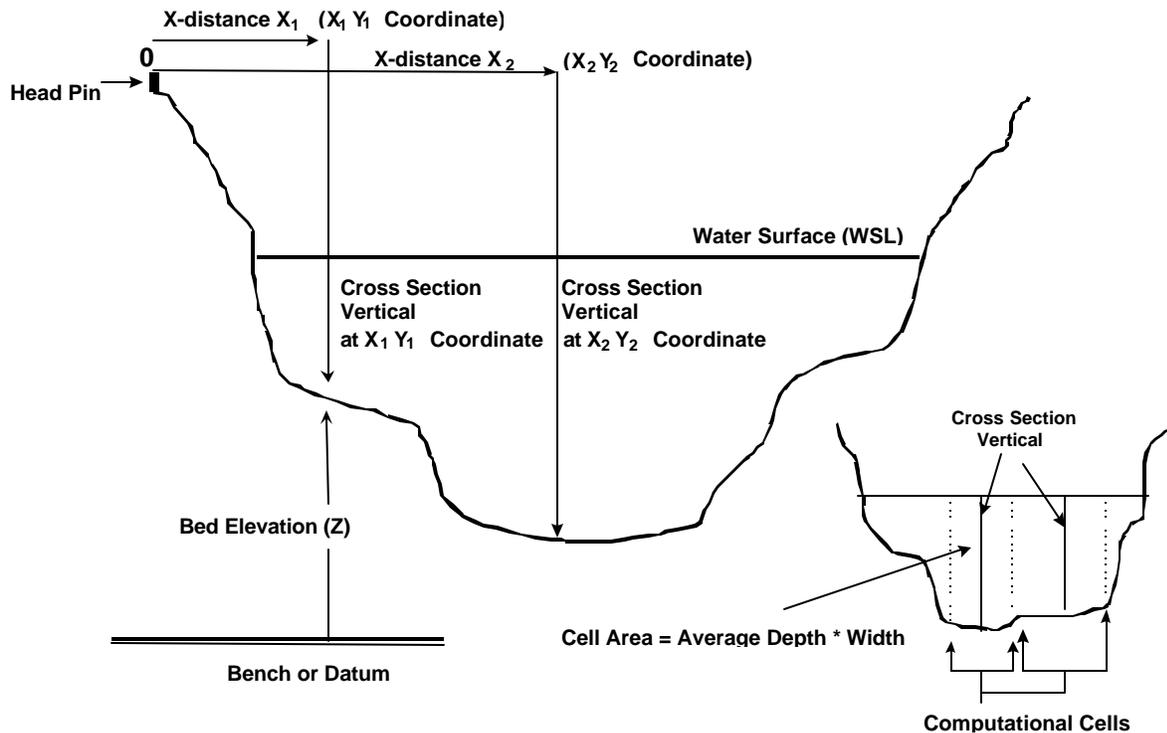
**Depth:** The vertical distance from a point on the streambed to the water surface. Depth is either measured or computed for each vertical.

**Hydraulic Depth:** Equivalent to the mean depth at a cross section; hydraulic depth is derived by dividing the cross sectional area of the flow by the width of the water surface.

**Thalweg Depth:** The vertical distance from the lowest point of a channel section (the thalweg) to the water surface. It is equivalent to the maximum depth of a cross section.

**Width:** The distance across a channel at the water surface, measured normal (i.e., perpendicular) to the flow.

Figure 2-2 provides a representation of a cross section view of a cross section (or transect) which relates the following hydraulic field data measurements to their equivalent terms as used by the various hydraulic (and habitat) models.



**Figure 2-2.** Schematic view of a Cross Section showing hydraulic measurement and modeling terms.

**X-distance (X):** Lateral distance measured from either the left or right bank head pin across the stream perpendicular to the axis of stream flow. X-distance must always increase when moving across the transect for use in the PHABSIM hydraulic models. The X-distance (X) in combination with the bed elevation (Y) represents the coordinate points or verticals that define the cross section geometry in PHABSIM.

**Bed Elevation (Z):** Height of the stream bed measured from some established bench mark or elevation reference point for the transect or cross section. Bed elevations are measured at each X-distance along the cross section. The bed elevation (Z), in combination with the X-distance (X) represents the coordinate points or verticals that define the cross section geometry in PHABSIM.

**X,Y,Z-coordinate:** The X-distance as measured from a head pin to a particular vertical along a cross section. The Y distance is the accumulated distance upstream from the first transect in a study site. Identifying transects by their Y distance is also called “stationing” (see Figure 2-1). The Z-distance is the elevation of the stream bed at the X,Y-coordinate above the datum.

**Cross Section Vertical:** An imaginary line perpendicular to the water surface at each X-distance where the bed elevation, depth, velocity, and channel index (see chapters 3, 4 and glossary) values are recorded and used to represent the hydraulic properties for the cross section.

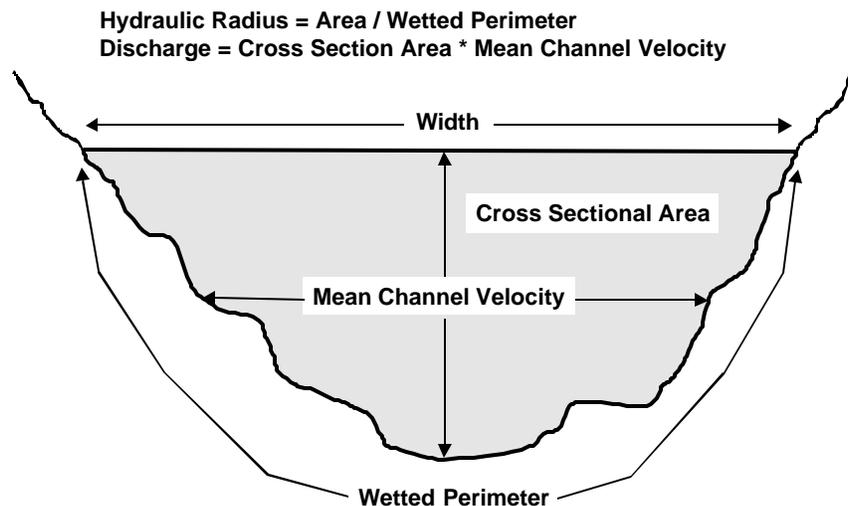
**Computational Cell (hydraulic programs):** The area of the cross section defined by one-half the distance to each adjacent cross section vertical such that the cross section vertical resides at the approximate center of the “cell”. Computational cells are used by the hydraulic simulation programs for computing the water’s edge based on the simulated water surface elevation, the predictions of velocities and individual cell discharges.

**Habitat Cell (habitat programs):** The area of the cross section lying between adjacent cross section verticals. Habitat cells have the average of the depth predicted at the bounding verticals and the average of the velocity at those verticals. The length of a habitat cell is determined from reach length and transect weighting factors.

**Cell Discharge (q):** Discharge computed within each computational cell based on the cell area and mean column velocity.

**Cell Area (a):** Computational cell area derived from the average difference between bed elevation and water surface elevations at the cell boundaries and the width of the computational cell.

Figure 2-3 shows an idealized representation of a cross section which defines the relationship between the following terms and definitions.



**Figure 2-3.** Cross section hydraulic terminology.

**Cross-sectional Area (A):** The area of the cross section containing water, normal to the direction of flow. It is also called the conveyance area. Cross sectional area is derived from the product of the average depth of flow times the width of flow.

**Wetted Perimeter (P):** The distance along the bottom and sides of a channel cross section in contact with water at a specific discharge and is roughly equal to the stream width plus 2 times the mean depth (hydraulic depth).

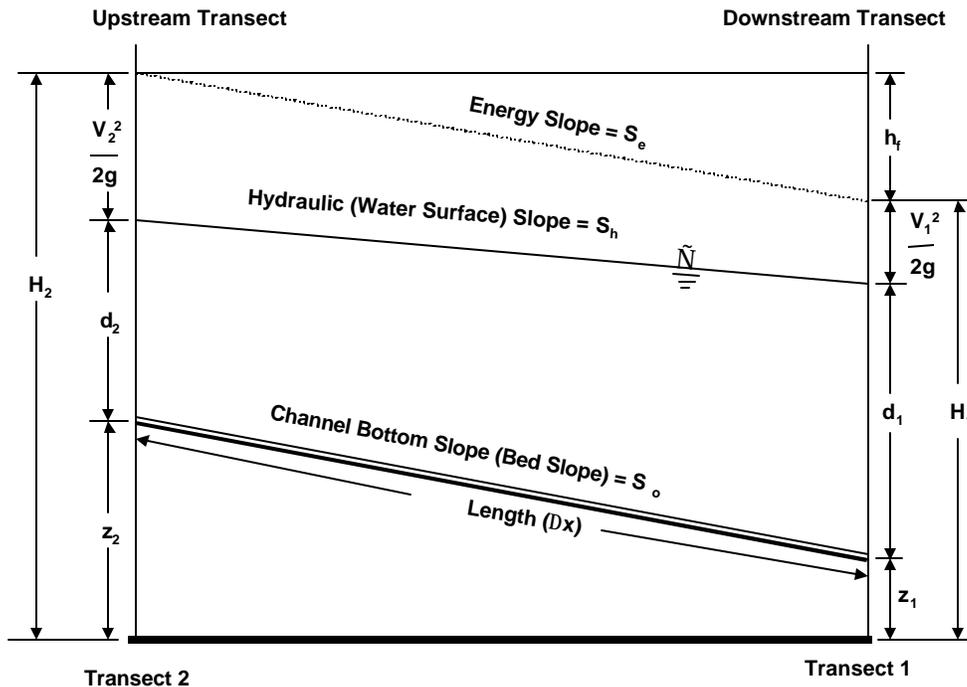
**Hydraulic Radius (R):** The ratio of the cross sectional area to wetted perimeter,  $R = A/P$ . For wide shallow channels, R approximates the hydraulic depth. Also called characteristic length (L).

**Mean Channel Velocity (V):** The mean rate of water movement or travel past a given location. It should not be confused with discharge. Mean channel velocity at a cross section can be computed by dividing the discharge by the cross sectional area.

**Mean Column Velocity ( $v_i$ ):** At a vertical i, mean column velocity is usually measured at 60% of water depth (measured down from the water surface) if the depth is less than 2.5 feet. When depths exceed 2.5 feet, measurements are made at 20% and 80% of the water depth and the two values are averaged to obtain the mean column velocity.

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

Figure 2-4 illustrates the relationship between important hydraulic parameters and definitions applied between adjacent cross sections. These items define the principal factors and terms used by the WSP model to compute water surface elevations.



**Figure 2-4.** Energy relationships between transects.

**Hydraulic Slope ( $S_h$ ):** The change in elevation of water surface between two cross sections, divided by the distance (reach length) between cross sections.

**Bottom Slope ( $S_o$ ):** The change in average elevations of the bed between two cross sections, divided by the length.

**Energy Slope ( $S_e$ ):** Change in total energy (potential and kinetic) available, divided by the length.

**Velocity Head:** The square of the velocity divided by 2 times the acceleration due to gravity. Velocity head is computed at adjacent cross sections in order to estimate the energy slope between the adjacent cross sections. This is the kinetic energy term in the energy balance equation.

**Longitudinal Profile:** A plot of the water surface elevations at each cross section within a reach versus the cumulative reach length distances for the cross sections. It typically includes the thalweg elevations. Longitudinal profiles can be represented by either calibration data, simulated values, or both. These plots are used in hydraulic simulations to verify that water is running downhill over the range of discharges modeled. A typical example of a longitudinal water surface elevation plot is illustrated in Figure 2-5.

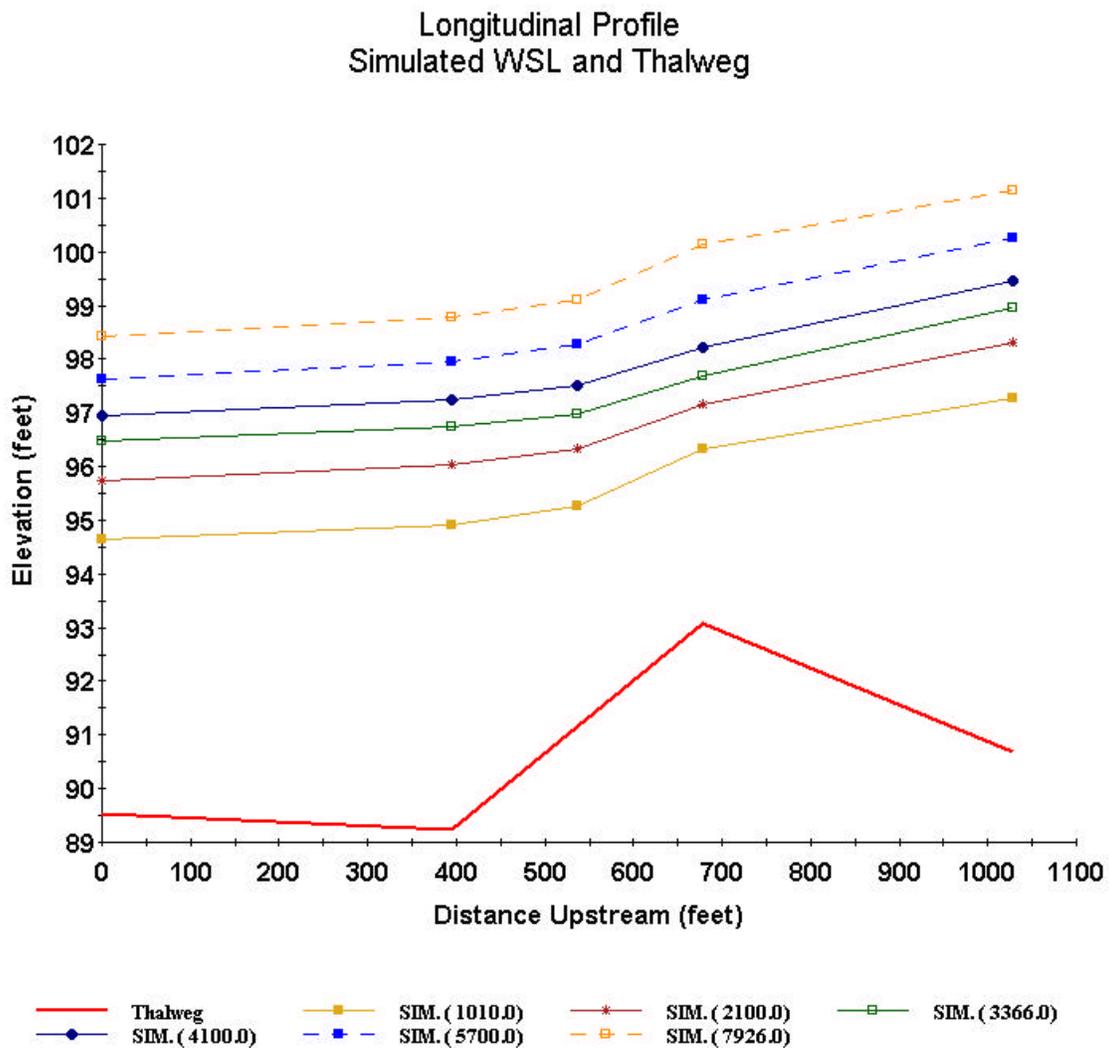


Figure 2-5. Simulated longitudinal water surface profiles.

The following terms are provided for completeness. They are treated in more detail in the specific sections on hydraulic models which follow. Additional terms and definitions related to hydraulic modeling can be found in Appendix 1.

**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 to maintain mass balance for the simulated discharge. Interpretation of the VAF-discharge relation is discussed below in the section dealing with calibration and simulation of velocities.

**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 for U.S. conventional units is:  $CFAC = (1.49 * Area * R^{2/3})/n$ , where R is the hydraulic radius and "n" is Manning's n value. For metric units the 1.49 becomes 1.00. Since the conveyance factor at a cross section generally follows a power law relationship to discharge  $CFAC = aQ^b$ , the exponent can be determined from multiple discharge measurements at a cross section and used as a good initial estimate for the calibration parameter  $\beta$  in the MANSQ model as discussed below. Also called Water Transport Parameter (WTP) in the CALCF4 program output file.

**Thalweg Slope:** The change in elevation of the bed, measured at the point of maximum depth (i.e. thalweg depth) divided by the distance between cross sections. In PHABSIM, the thalweg slope may also be referred to as bed slope as shown in Figure 2-4.

**Roughness (n):** A coefficient indicating the resistance to flow or energy loss caused by the combined effects of particle size, vegetative friction, and channel features. In PHABSIM, this is most often expressed with the use of "Manning's n" values.

**Stage of Zero Flow (SZF):** The water surface elevation when water would stop flowing by a particular cross section. The stage of zero flow when measured in the field is usually the lowest ground elevation at a cross section when the cross section is at a hydraulic control. However, for some river features such as pools, the SZF is the lowest point of the streambed at the downstream hydraulic control for the pool. Because hydraulic controls can "migrate" with variation in discharge, measurement of SZF is difficult and is best done when flow is extremely low and water is not turbid. The determination of the proper SZF is discussed in more detail in the section dealing with modeling of water surface elevations using the STGQ program.

## Equations Used For The Description and Analysis of Open-Channel Flow

Several fundamental equations and relationships are important to understand, since they constitute the computational basis for the various hydraulic models used within PHABSIM. A fundamental tenant of open channel flow is that continuity and mass balance of discharge must be maintained between adjacent cross sections for proper application of the hydraulic models. In addition, the overall energy balance due to friction losses between two adjacent cross sections must also be maintained. This is addressed in the hydraulic models within PHABSIM through the application of Manning's equation, which describes open channel flow in terms of measured cross section properties and relationships between the discharge, water surface elevation, velocity, and resistance to flow and the Bernoulli equation which evaluates longitudinal energy dissipation.

### *Continuity and Mass Balance*

The water surface elevation in a stream defines the cross-sectional area of flow if the bed geometry is known. If mean cross section (channel) velocity is also known, discharge can be calculated using the equation of continuity (see Figure 2-3):

$$Q = AV \tag{2-1}$$

where: Q = discharge (cubic feet per second, cubic meters per second)  
V = average velocity of flow through the cross section (feet/second, meters/second)  
A = cross section area of flow (square feet, square meters)

In practical applications, if no inflows or outflows occur within the study site and the water surface elevations do not change during the period of field data collection, the estimated or user-computed discharge for individual cross sections should yield estimates of the discharge that are alike for similar habitat types. Hydraulic data collection for a PHABSIM study is usually undertaken in habitat types important to fish and, therefore, some channel types that are not ideal for estimating discharge will be sampled. It is not uncommon that riffle habitats have discharges that are 10–20% higher than the discharge estimated in runs, which are more ideal in terms of estimating the “true” discharge. Conversely, discharge estimates in pools can typically be 10–20% lower than runs. When selecting the best estimate of discharge, users are encouraged to consider cross section conditions as a major determinant of the user-supplied “best estimate” discharge. For example, an average of the discharge measurements obtained from three run cross sections in a study site may be superior to an average of the flow measured at all cross sections.

### *Manning’s Equation*

One of the most widely applied equations used to describe flow in open channels is referred to as Manning’s equation (p. 96 in Henderson, 1966). The equation represents an alternative formulation of Equation 2-1 in which site specific channel characteristics are incorporated in order to describe the resistance of flow within the channel given the roughness of bed material, energy slope, and channel geometry. For U.S. conventional units Manning’s equation is:

$$V = \frac{1.486}{n} R^{2/3} S_e^{1/2} \quad (2-2)$$

where: V = mean channel velocity (feet/second, meters/second)  
1.486 = U.S. conventional unit correction (cube root of 3.28 feet/meter), or a value of 1.0 for metric units  
R = hydraulic radius, in feet (meters)  
S<sub>e</sub> = slope of the energy grade line  
N = coefficient of roughness, referred to as Manning’s n

This equation, in several different formulations, is used within PHABSIM in the MANSQ and WSP models for the simulation of water surface elevations and in the VELSIM program for the simulation of velocities.

### *Energy Balance and the Bernoulli Equation*

In Manning’s equation, the slope required as 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 the distance between them (refer to Figure 2-4). The total energy at a channel section is found with the open-channel form of the Bernoulli equation:

$$H = z + d + \frac{V^2}{2g} \quad (2-3)$$

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/second (meters/second)  
 G = acceleration of gravity, 32.2 ft/sec<sup>2</sup> (9.8 m/sec<sup>2</sup>)

For practical purposes, Figure 2-4 shows that the term z + d equals the water surface elevation (WSL) for a given cross section, therefore, the slope of the energy grade line can be determined by:

$$S_e = \frac{H_2 - H_1}{\Delta x} \quad (2-4)$$

If the assumption is made that flow in the channel is uniform, then bed slope, hydraulic slope, and energy slope are considered equal,  $S_b = S_h = S_e$ . Therefore, this equation represents the Energy Balance between two adjacent cross sections of the stream. The Bernoulli equation in conjunction with mass balance of the discharge and Manning's equation form the computational core to the WSP program as described later in this chapter.

## Applied Modeling of Water Surface Elevations in PHABSIM

Determining the relationship between the water surface (stage) and the discharge is the first step in the hydraulic calibration and simulation phases of PHABSIM (Figure 1-2). The stage is used to derive depth distributions for each cross section by subtraction of bed elevations across the channel from the stage. It is also used to identify the location of the free surface to establish boundaries (i.e., wetted cell locations) for some of the equations that describe velocity distributions. If stage and bed elevation are known, depth may be determined at any location on the cross section. Stage varies with discharge, so it is important to derive a reliable relationship between stage and discharge for the study site or hydraulic simulation results will be in error.

There are three approaches for predicting stage-discharge relationships in PHABSIM. The approaches described in this section include: (1) linear regression techniques based on multiple measurements from the field (the STGQ model); (2) use of Manning's equation (the MANSQ model); and (3) calculation of water surface profiles using standard step-backwater computations (the WSP model).

In the PHABSIM for Windows interface, all three models are accessed under the **/Models/WSL** menu. To provide maximum flexibility in modeling water surface elevations, the interface allows the user to select different models for different discharges at individual transects. Thus, it is possible to mix modeling approaches (including supplying water surface elevations from an outside source) for individual transects in a project and across the full range of discharges. The selected WSL calculation method is entered in the table displayed in the **/Models/WSL/Method** tab. Other tabs provide for selection of options within each model and are discussed below and in the laboratories.

**NOTE:** Graphs may be viewed on screen from several tabs within the WSL modeling section. In the options tabs, the graphics aid in checking the appropriateness of input to the particular WSL model to be run. The **Cross Section** and **Longitudinal** buttons in the **/Models/WSL/Results** tab allow the user to view the results of WSL modeling. These plots are useful in calibration and quality control of the WSL simulation process.

### *Modeling the Stage-Discharge Relationship by Regression*

One method of obtaining a relationship between stage and discharge is to measure the discharge at several stages and develop an empirical regression equation relating stage to discharge. In practice, typically three (MESC recommends three [3] or more) measurements of the stage and discharge are obtained at each cross section over as wide a flow range as practical or as necessary to meet the study objectives.

In a large number of channels, stage-discharge data of this nature has been found to be adequately approximated by the following equation:

$$(WSL - SZF) = a Q^b \quad (2-5)$$

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

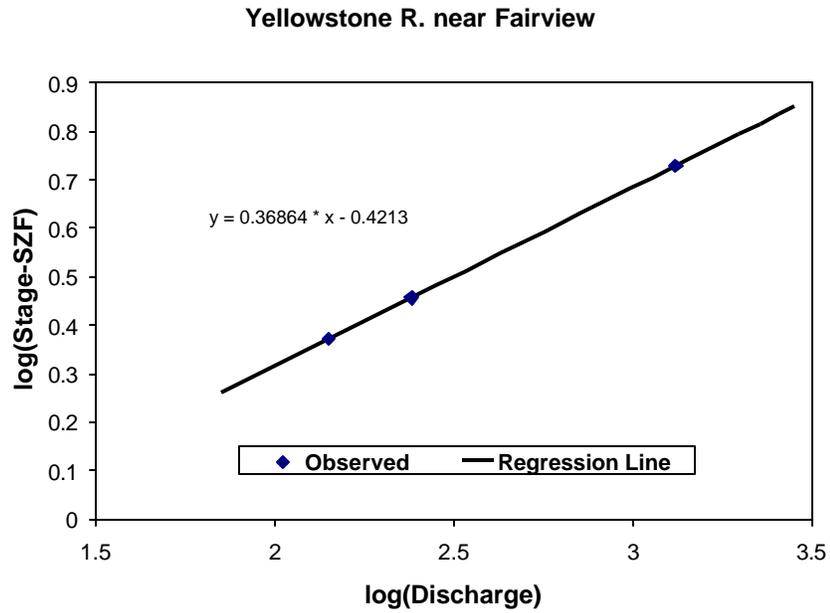
Note that we have included the SZF in Equation 2-5 since the stage-discharge relationship at a channel cross section is a function of the SZF at that specific location, as discussed below under the STGQ model. The SZF is used within the STGQ model and one option in MANSQ. It should be included whenever using alternative stage-discharge regressions. Equation 2-5 can be transformed to a linear relationship between stage and discharge by taking the log of the equation which yields:

$$\text{Log}(WSL - SZF) = \text{log}(a) + b * \text{log}(Q) \quad (2-6)$$

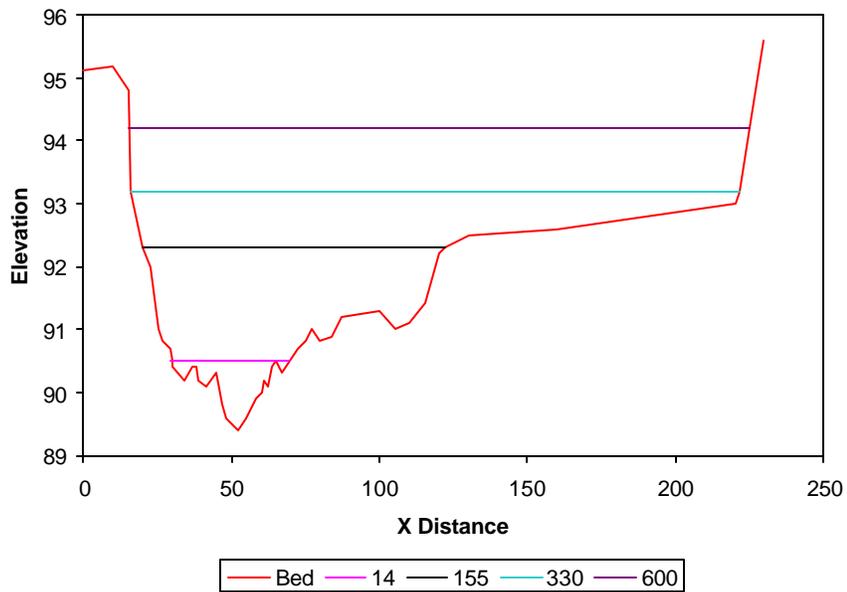
A simple linear regression can then be performed between the log of the discharge and the log of the water surface elevation (minus stage of zero flow) to determine the constants. The resulting regression equation is then used to predict stage over a desired range of discharges. An example of a measured stage-discharge relationship with the resulting regression equation derived from these data is given in Figure 2-6.

In some channels however, where complex geometry may result in a significant change in cross section area over a wide range in discharge as illustrated in Figure 2-7, or where a backwater effect from a downstream hydraulic control may occur, the stage-discharge relationship may not be log-linear as illustrated in Figure 2-8. In these instances, the user should take care to review the stage-discharge relation developed by the models in PHABSIM to ensure that the most accurate evaluation of the stage-discharge relationship is achieved. If the STGQ model is allowed to proceed normally, a single regression line will be derived from all of the data in the log-log domain as shown in Figure 2-9. In these instances, the analyst may choose to partition the data into multiple, piece-wise linear data sets and develop corresponding regression equations for specific ranges of discharges which are to be simulated as illustrated in Figure 2-10. In PHABSIM for Windows this can be accomplished by creating separate copies of the project for each regression range or by running STGQ for pairs of calibration flows and reentering the data in the methods table as fixed water surface elevations. Such two point lines have zero degrees of freedom and should be used for extrapolation with caution.

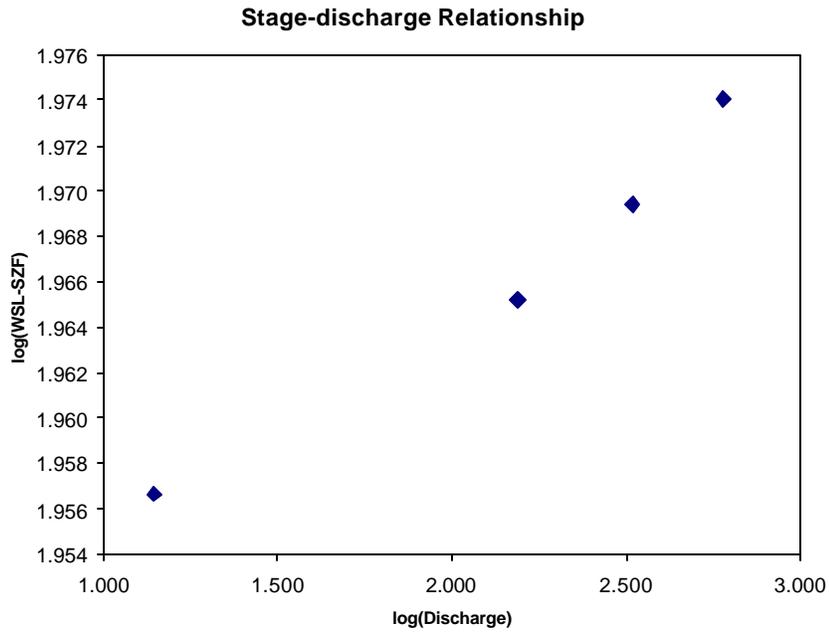
In addition, stage values may be generated entirely outside of PHABSIM and entered in the **/Models/WSL/Methods** table in lieu of running any of the PHABSIM models. Stage values entered in the **../Methods** table must be converted to normal domain; that is, one must exponentiate to remove the log conversion.



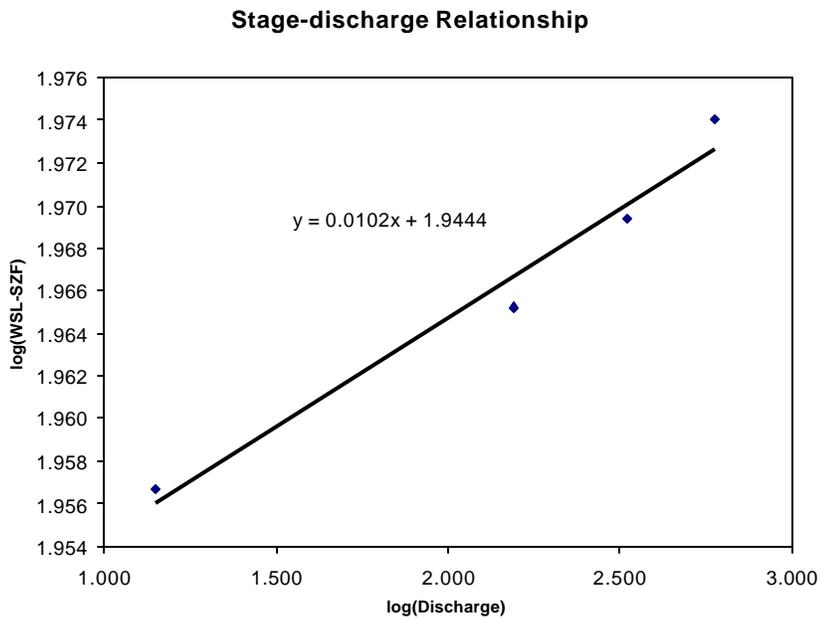
**Figure 2-6.** Example of a stage-discharge relationship based on three observed discharges.



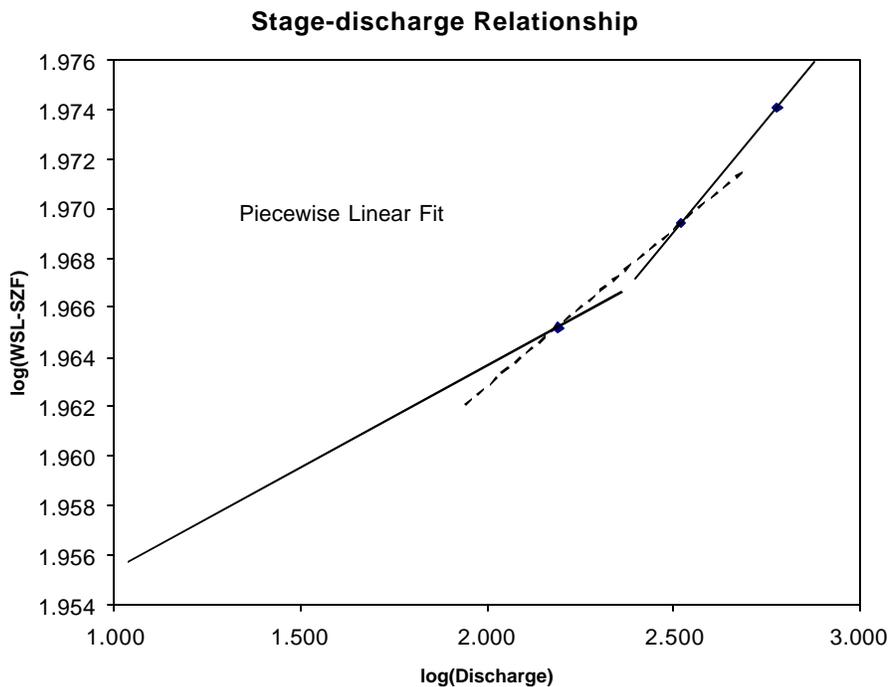
**Figure 2-7.** Asymmetrical cross section showing water surface elevations for four discharges.



**Figure 2-8.** Log-log plot of stage-discharge for asymmetrical cross section above.



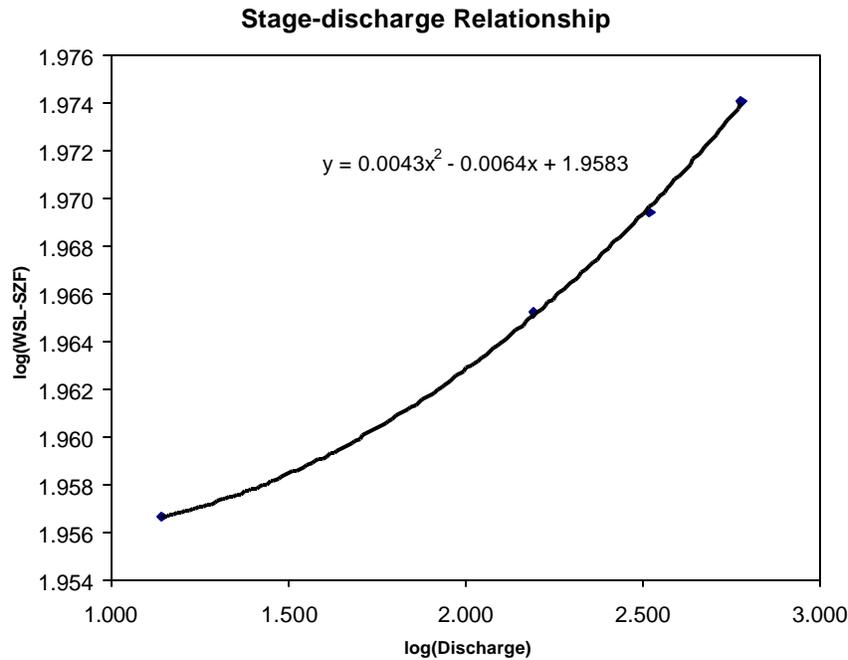
**Figure 2-9.** Default linear fit to non-linear stage-discharge data.



**Figure 2-10.** Multiple linear regression equations arranged to achieve a piecewise linear stage-discharge relation.

Alternatively, the user may also elect to fit a non-linear equation to the observed data for the purposes of modeling the relationship between stage and discharge as illustrated in Figure 2-11. It is advisable to use four or more points to allow for at least one degree of freedom in the regression. Non-linear fitting functions are available in various spreadsheet and statistical programs. The results may be inserted into PHABSIM as fixed WSL values in the methods table.

Regardless of whether the observed data is fit using a log-linear, piece-wise log-linear, or non-linear regression approach, the extrapolation of the regression equation to lower and higher discharge ranges than what was measured should be examined critically for reasonableness as discussed below. Upper and lower limits of extrapolated discharges are, to some degree, a matter of professional judgement and the specific analytical needs of a particular study. In general, the further away from the observed conditions, the greater the potential error between the actual stage and the stage predicted by extrapolation. The reasonable range of extrapolation varies among study sites so caution in extrapolation is advised.

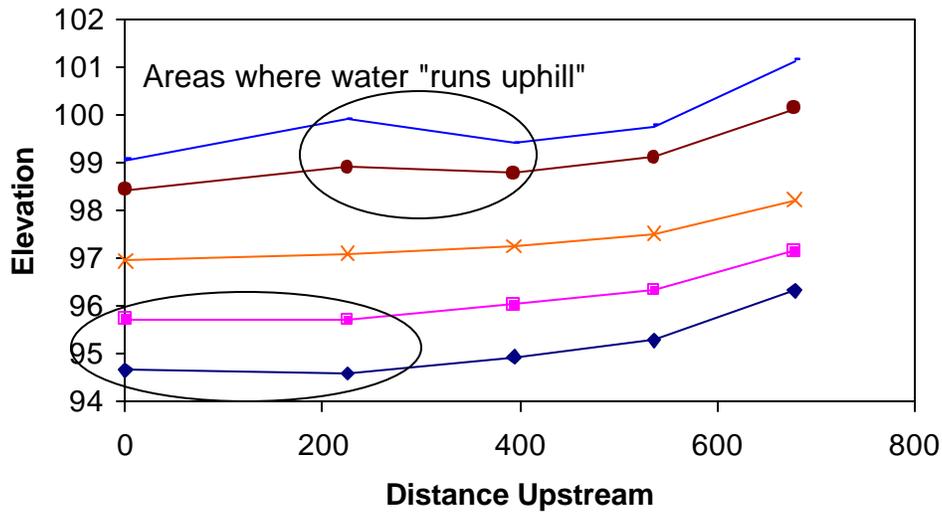


**Figure 2-11.** Non-linear function fit to stage-discharge data in logarithmic domain.

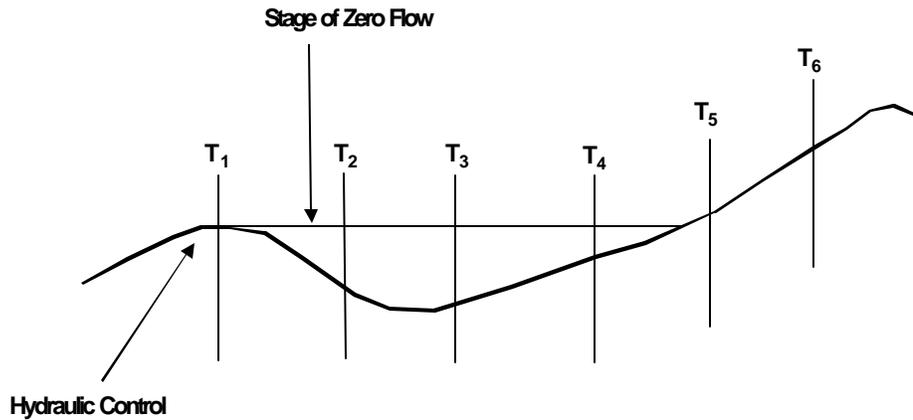
When using the regression approach, one should recognize that the regression equation developed for a specific cross section is independent of all other cross sections within a study site. Therefore, care should be exercised that internal consistency is maintained in the longitudinal profiles of the water surface elevations between adjacent cross sections within a specific study reach. For example, the results presented in Figure 2-12 show that the independent analysis of several cross sections using a log-linear regression approach (i.e., STGQ) results in the analysis predicting “water flowing uphill” for several discharges. Although the individual  $R^2$  values of each regression were high (e.g.,  $\geq 0.95$ ), longitudinal profile plots provide a simple diagnostic of model results that indicate an alternative modeling approach is required if the study requires simulating a range of discharges where water appears to flow uphill. Errors in water surface prediction will affect both the predicted depth and velocity values for this transect. Diagnostic evaluation of water surface modeling is discussed later in this chapter.

#### Determining the Stage of Zero Flow

Since the STGQ, and MANSQ models make use of the stage of zero flow (SZF) for computational purposes (see Equation 2-5 above and the MANSQ discussion below), it is important to understand how to obtain the proper SZF. The SZF is important since it is used directly in regression analysis of the stage-discharge equations in STGQ and in one simulation option within MANSQ. An error in estimating the SZF can alter hydraulic simulation results. The easiest way to determine the SZF is to plot the thalweg elevations at each cross section moving in an upstream direction as shown in the example provided in Figure 2-13.



**Figure 2-12.** Independent stage-discharge analysis can result in a simulated adverse water surface profile.



**Figure 2-13.** Longitudinal profile showing stage of zero flow.

As can be seen, the SZF at cross section  $T_1$  corresponds to the thalweg depth at this cross section and will control the surface of the stream when the water level drops to this point. At that level, 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 cross sections  $T_2$  through  $T_4$  since the elevation of the SZF at  $T_1$  will control the water surface at these next two upstream cross sections. The individual thalweg depths should be used as the SZF at transects  $T_5$  and  $T_6$ .

## *Stage-Discharge Analysis using Regression in PHABSIM – the STGQ Model*

The STGQ hydraulic simulation model predicts water surface elevation as a function of discharge. Given stage-discharge data, STGQ will automatically conduct the log-linear regression on the calibration data sets and determine the water surface elevations for all flows contained on the **/Edit/Discharges** table. When using the stage-discharge relationship, each cross section is treated independently of all others in the data set. This approach has the advantage that habitat areas from several locations in the stream (habitat mapping strategy) can be analyzed simultaneously. The principle disadvantage is that not all cross sections are well-suited for stage-discharge regression and the phenomenon of simulated adverse water surface gradients (see Figure 2-12) can occur. The STGQ program simulates water surface elevations using the stage-discharge relationship information supplied in the **/Edit/Cross Sections/Calibration Data** tab in PHABSIM for Windows.

### Running the STGQ Model

Once the STGQ model has been selected for a combination of cross sections and discharges in the **/Models/WSL/Method** table, the user selects options to be run for the study site in the **/Models/WSL/STGQ Options** tab. These selections are made by clicking on the model type, eg. **STGQ** and then clicking each of the transect/discharge boxes in the table to which that model is to be applied. The boxes will then contain the term “STGQ”.

Remember to review the output file **ZOUT** for error messages and inconsistencies in the data. (It will be the latest sequentially numbered ZOUT file in the directory where the project resides.) Error messages in the form of notes or other statements that do not appear on the screen or cause the program to abort may be written to the ZOUT file. Output from the STGQ model is variable depending on the selected simulation options. Examination of STGQ output is covered in the laboratory exercises.

### STGQ Options

The user has the ability to select a variety of simulation and reporting options during the execution of the STGQ model. The associated laboratory exercises will address the use of the most commonly used options and, therefore, a detailed discussion of each option will not be presented here. Table 2-1 lists each of the options within STGQ and provides a concise description of the function for each option.

### *A Practical Guide to Modeling Stage-Discharge Relationships Using the Regression Approach*

In most applications, the analyst will need to determine the “best estimate” of the discharge at a given calibration flow. Typically, the discharge calculated from observed velocity distributions may vary considerably between all measured cross sections. For example, it is not uncommon for the discharges computed within a single study reach in which the stage remains stable during field measurements to vary by as much as 25%. This is due to measurements being taken in pools, riffles, runs, etc. Generally, pools and riffles are poor areas for discharge estimation but are typically measured since they often represent critical habitat types necessary for evaluation as part of the instream flow investigations. Field crews should indicate during data collection which cross section(s) are best for estimation of the actual flow for a particular calibration set. The best discharge measuring sections are used to estimate the discharge for use in the regression analysis for all cross sections within the reach. The difference between the measured right and left bank water surface elevations can vary considerably with differences of 0.1 to 0.5 feet occurring in highly turbulent conditions. The analyst should select the average of the left and right bank, only the left or only the right, or other water surface elevation at each cross section in the regression equations based on the conditions reported in the field notes.

**Table 2-1.** Options in the STGQ program.

Option description	Action when set to indicated value
Write computational details (check box)	Prints the numerical details of the computed velocities and water surface elevations for each simulated discharge to ZOUT.
Assign Cal Set (Button)	Displays a table where the user assigns a CAL set to each discharge for each cross section.
Discharge (IOC 5) (click cell, click down arrow to change from Best Estimate of Q to Xsec (transect) Q)	Selects whether the best estimate of the discharge or the discharge measured at this transect is used in stage-discharge calculations. If no transect Q is supplied, defaults to best estimate.
WSL (Click cell, click down arrow to change to Left, Right, Average or User supplied WSL)	Selects which of the WSL values supplied in <b>/Edit/Cross Sections/Calibration Data</b> is used in WSL simulation.
SZF (check box for each transect)	Selects if the stage of zero flow is used in the WSL simulation. Default is yes (checked).
<b>Output Options (applies to all WSL Simulation Models)</b>	
Use (check boxes for each discharge)	Selects which discharges are simulated in the current run. Default is all (all boxes checked).

The analyst also has the option of using the actual calculated discharges at each cross section in the regression equations rather than the best estimate for the reach. The analyst may also elect to vary the water surface elevations at a cross section within the range of measured differences between the left and right bank in attempts to get a better log-linear regression fit to the data. Using discharges other than the best estimated discharge or water surface elevations different than the average should be carefully considered; but, this choice does not imply errors in modeling as long as a rational basis for the use of alternative data is clearly articulated and justified in the study report.

In some instances, the flow rate will change during the course of field data collection at a study reach either within the day or between successive days for a variety of reasons. This is most often noted by changes in the stage readings of the water surface elevation during field data collection or during data processing where calculated discharges show a consistent increase or decrease between successive measurements. A typical approach with data sets having these characteristics is to derive best estimates of the discharge for groups of cross sections, which represent consistent field measurements under similar flow conditions.

For example, the first three cross sections measured during the first field day may have a best estimate of discharge equal to 100 cfs at the low calibration set while cross sections 4 through 7, collected the next day, may have a best estimate of the discharge of 120 cfs. Because the STGQ program treats each cross section as an independent data set, it has the ability to accommodate different discharges between cross

sections for a given calibration set. In those instances in which the discharge changes during the collection of data at a single cross section, it is best to stop data collection until the flow stabilizes. However, if this is not an option, or this was determined in the office during review of data collection efforts, advanced modeling approaches beyond the scope of this chapter need to be undertaken. In those instances, the analyst should contact an experienced hydraulic engineer for technical assistance.

In summary, the following step-wise procedure can be followed for conducting stage-discharge modeling using the regression approach to estimate water surface elevations in PHABSIM.

1. Decide whether to use the best estimate of the discharge for each calibration set for all cross sections and whether to use the average of the right and left bank water surface elevations measured at each calibration flow. Be sure to check if the discharge remained constant during field collection efforts or whether different best estimates of the discharge need to be provided for different groups of cross sections. Finally, determine the appropriate stage of zero flow (SZF) for each of the cross sections.
2. Plot the log of the discharge versus the log of the WSL-SZF (**/Models/WSL/STGQ options/Stage Discharge Graph**) and examine the relationship for linearity or piece-wise linearity before proceeding. If the relationship at a cross section is not log-linear, consider an alternative modeling approach such as MANSQ or WSP or proceed with a non-linear analysis of the data (outside of PHABSIM for Windows) to predict the water surface elevations.
3. Ensure that all measured calibration data sets use the appropriate discharge and water surface elevations at each cross section and each calibration flow. Check that all such data are in the project file (See **/Edit/Cross Sections/Calibration Data**). When using a piece-wise linear approach, assign the Cal sets for a single “piece” and remove check marks from the rest to select the range of discharges you wish to simulate (**/Models/WSL/Output options** ).
4. Run the STGQ model (Click **Run** under the **../WSL/Method** tab) and examine the longitudinal profiles (**Longitudinal** profile plot in the **../Results** tab) of the water surface elevations for all spatially linked cross sections to determine the quality of the model results.
5. If the longitudinal profiles look reasonable for all simulated discharges, proceed to the velocity calibration and simulation step of PHABSIM. If not, examine alternative WSL modeling approaches using MANSQ and/or WSP.

Review the output file ZOUTnn for error messages and inconsistencies in your data. Error messages in the form of notes or other statements that do not appear on the screen or cause the program to abort may be written to the output file. Output from the STGQ model includes a listing of the calibration data used in the stage-discharge regression, and the regression equation with diagnostic statistics for each cross section.

### *Modeling the Stage-Discharge Relationship Using Manning’s Equation – The MANSQ Model*

The MANSQ model 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 if flow is uniform. In addition, this approach assumes that flow variations caused by changes in channel configuration are negligible (i.e., minimal backwater effects). Generally, the more uniform the channel, the more reliable the results using this approach, thus it is more reliable in run sections. The application of the MANSQ model in pools can sometimes be problematic since pools are generally created by backwater effects of a downstream hydraulic control. As was the case

in using the STGQ model, the MANSQ model also assumes that each cross section is independent of all other cross sections during calibration and simulations. Therefore, as indicated for the STGQ program, the longitudinal profile of the simulated water surface elevations should always be checked to ensure water is flowing down hill between spatially linked cross sections in a study reach.

The MANSQ model uses Manning's equation in the form:

$$Q = \left[ \frac{1.49}{n} * S^{1/2} \right] * A * R^{2/3} \quad (2-7)$$

and simplifies it to:

$$Q = KA_R^{2/3} \quad (2-8)$$

The value of K is determined from one set of measured discharge and water surface elevation pairs and measured channel geometry at a cross section. The program then uses additional calibration data sets (i.e., discharges and water surface elevations) to solve one of the following three equations selected by the user:

$$K = K_o \left( \frac{Q}{Q_o} \right)^\beta \quad (2-9)$$

$$K = K_o \left( \frac{R}{R_o} \right)^\beta \quad (2-10)$$

$$K = K_o \left( \frac{R_o}{R} \right)^{5/3} * \left( \log \left( 2.42 \left( \frac{R}{D50} \right) \right) / \log \left( 2.42 \left( \frac{R_o}{D50} \right) \right) \right) \quad (2-11)$$

where: subscript o refers to calibration values,  
 exponent  $\beta$  represents a coefficient supplied by the user for each transect, and  
 D50 is the median particle size on the stream bed.

Selection of the ratio of discharges, the ratio of the hydraulic radius, or the empirical relation between hydraulic radii and median particle size is a choice made by the investigator. There is no strong evidence to suggest the discharge ratio is generally superior to the hydraulic radius ratio. Functionally, given multiple sets of discharge-water surface elevation data at a cross section, the user employs a trial and error procedure for selecting a value of  $\beta$  that minimizes the error between observed and predicted water surface elevations at the calibration discharges, regardless of which equation formulation is used. Due to the ease of switching between the first two options, a trial-and-error approach may be used.

The third approach requires a sediment study to determine the median bed material size. This option cannot be used unless such a study has been conducted. When selecting the third option, the D50 value is entered in place of  $\beta$  (in the **/Models/WSL/MANSQ Options** tab). In all cases, the investigator should be able to justify the final calibrations by demonstrating minimum error between predicted and observed WSL at the calibration discharges.

The MANSQ  $\beta$  coefficients will typically be different for each cross section within a study reach. The range of the differences will depend on the variation in complexity of the channel at different cross sections. The range of  $\beta$  in typical applications is approximately 0.0 to 0.6;  $\beta$  cannot be less than 0. If calibrated  $\beta$  values fall outside this range, the results should be examined carefully, but such results do not necessarily imply that the data has errors or that hydraulic calibration is faulty. The investigator should examine the errors between predicted and observed water surface elevations in light of variations in cross section geometry and the observed ranges in discharge and water surface elevations. An average of several data sets evaluated at MESC yielded a  $\beta$  value of 0.22 for gravel bed channels. This may be a good starting estimate of  $\beta$  in the calibration process.

As previously noted, MANSQ treats each cross section independently. Therefore, once all cross sections have been suitably calibrated and the full range of desired discharges have been simulated, the longitudinal profiles of the water surface elevations should be checked for internal consistency (i.e., water flows downhill).

### Running the MANSQ Model

Once the MANSQ model has been selected for a combination of cross sections and discharges in the **/Models/WSL/Method** table, the user selects options to be run for the study site in the **/Models/WSL/MANSQ Options** tab. You may find that by selecting only the desired calibration flows in the table in the **/Models/WSL/Output Options** tab during the calibration phase, calibration of the model is somewhat easier due to reduced amounts of output to evaluate. However, the user should ensure that after successful calibration of the model all flows of interest have been selected in **../Output Options** prior to performing the final WSL production run.

Remember to review the output file (latest ZOUTnn file) for error messages and inconsistencies in the data. Error messages in the form of notes or other statements may be written to the output file that did not appear on the screen or cause the program to abort. Examination of MANSQ output is deferred to the Laboratory exercises.

### MANSQ Options

The user has the ability to select a variety of computational and reporting levels for the MANSQ program. The associated laboratory exercises will treat the use of the most commonly used options and therefore a detailed discussion of each option will not be presented here. Table 2-2 lists each of the options within MANSQ and provides a concise description of the function for each option.

**Table 2-2.** Options in the MANSQ program.

Option description	Action when set to indicated value
Write WSL calculations (check box)	Prints the water surface elevation calculations using Manning's equation to ZOUT.
Write initial Q/elevation table (check box)	Prints the initial discharge-elevation table to ZOUT.
Write critical WSL calculations (check box)	Prints critical water surface elevation (WSL at critical flow) calculations to ZOUT.
Modify hydraulic radius by hydraulic radius at SZF (check box)	Hydraulic radius is reduced by the hydraulic radius at the stage of zero flow.
Velocity equation (radio button for Manning's Chezy's equation)	Determines velocity equation used to compute mean channel velocity.
Hydraulic radius (radio button for normal or area-weighted)	Allows the hydraulic radius for a cell to be weighted by the area in a cell which results in an area-weighted hydraulic radius.
Conveyance adjustment (radio button for): Use $(Q/QC)^{**B}$ Use $(RH/RHC)^{**B}$ Use $((RHC/RH)^{**1.67}) * (\log(2.42(RA/D50)) / \log(2.42(RHC/D50)))$	Allows user to adjust conveyance in a river. If $\beta$ is not supplied, no adjustment in conveyance is made. Substitute D50 for the $\beta$ value (in the <b>Models/WSL/MANSQ Options</b> tab) when the third option is selected.
Selection of calibration set and $\beta$ value (table to the right)	Allows the user to select which calibration discharge set (1, 2, etc.) and best estimate versus local discharge are to be used as QC in MANSQ. Similarly, the $\beta$ values for each cross section are entered and changed in this table as part of the calibration process.
<b>Output Options (Applies to All WSL Simulation Models)</b>	
Use (check boxes for each discharge)	Selects which discharges are simulated in the current run. Default is all (all boxes checked).

### A Practical Guide to Calibrating MANSQ

The calibration of the MANSQ program involves a trial-and-error procedure to pick a  $\beta$  value that minimizes the error between predicted and observed water surface elevations at each transect. This can be summarized in the following steps:

1. Run **/Models/Water Transport Parameters (CALCF4)** by selecting that menu item. Use Notepad or Wordpad to view the **table.calcf4** file and search for the text string 'WTP' at each cross section. This is the conveyance factor. Locate the regression equation between discharge and the channel

conveyance factor or water transport parameter (WTP) term for each cross section. The exponent (B) in the WTP regression equation is an excellent initial estimate for the  $\beta$  coefficient for each transect in the MANSQ program. Alternatively, just make a guess (i.e., 0.22) and proceed.

2. Select MANSQ options in the **/Models/WSL/MANSQ Options** tab. Then take care to select which calibration flow you intend to use as the initial calibration flow since this will represent a “fixed” calibration set for the program. The calibration sets are numbered in order of ascending discharge magnitude. Then select only the CAL set flows shown in **./WSL/Output options**, that is remove the checks from all but the calibration flows. Enter your best estimate for  $\beta$  at each cross section either derived from the WTP regression exponent term or your initial guess. Click **Run**.
3. Go to the **./WSL/Method** tab and select MANSQ for all transects. ). Set the  $\beta$  coefficient at each transect (in the **./MANSQ Options** tab, change beta values in the table). Run the MANSQ program (**./Method** tab, click the run button). Compare the predicted versus observed WSL at each transect for all the calibration flows by moving to the **./Results** tab and noting WSL values in the table compared to observed values. The **Longitudinal** graph button in the **./Results** tab allows comparison of the observed and predicted WSL profile. Note that at the selected calibration flow the program will always return the given water surface elevation since this is an initial condition for determination of the K value at that discharge (see equations above). Change the  $\beta$  coefficient at each transect (**./MANSQ** tab, change beta values in the table) and repeat this process until the error between predicted and observed water surface elevations is minimized at all calibration flows. Remember each cross section is treated independently, so once one is calibrated, you can ignore it during the remaining calibrations of the other cross sections.
4. Once an adequate calibration is achieved, add all the flows of interest by checking the boxes in **./Output Options** and make the production run using MANSQ.
5. Check the predicted longitudinal profiles of the water surface elevations to ensure water flows downhill at all discharges.

As discussed in modeling water surface elevations with STGQ, the analyst can use the MANSQ program when discharges change between data collection efforts and/or cross sections. The calibration flows at each cross section or groups of cross sections are simply those used in the calibration process. Users may select different calibration flows for each cross section in the table in the **./MANSQ Options** tab. Similarly, the analyst can elect to use the computed discharge at each cross section rather than the best estimate of the discharge for the reach. Again, as long as a rational justification can be put forward and defended, these choices are a matter of professional judgement.

The reader is also encouraged to revisit the discussion in the section titled “A Practical Guide to Modeling Stage-Discharge Relationships Using Regression Approaches” provided above since many of the same situations will be encountered when applying the MANSQ model.

## **Modeling The Stage-Discharge Relationship Using A Step-backwater Approach – WSP**

### *General Theory of the WSP Model*

The WSP model is a water surface profile program that is used to predict how the longitudinal profile of the water surface elevation changes over a range of simulated discharges. Specific hydraulic relationships between the physical channel and discharge must be met to evaluate these changes in reference to a

particular stream reach being modeled. These relationships are defined using concepts of mass balance (continuity) and energy balance. Several basic assumptions apply. These include assuming steady flow conditions existing during the period of field measurements and assuming boundary conditions remain basically rigid (i.e. the channel geometry does not change substantially over the range of measured data sets).

The following example illustrates the step-backwater computational process and introduces the relevant equations. In the example, two cross sections will be described which were illustrated in Figure 2-13. When more than two cross sections are involved, the process is repeated step-wise upstream; hence, the term step-backwater. The flow balance is calculated using the continuity equation:

$$Q_2 = Q_1 + \Delta Q \quad (2-12)$$

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

The velocity is then calculated using the following equation:

$$V_i = \frac{Q_i}{A_i} \quad (2-13)$$

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 then calculated using:

$$H_2 = H_1 + \Delta H \quad (2-14)$$

where:  $H_{1,2}$  = total energy at each cross section  
 $\Delta H$  = total energy losses as water moves downstream

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

$$H = z + d + \frac{v^2}{2g} \quad (2-15)$$

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

The Bernoulli equation written in terms of two adjacent cross sections in the stream is therefore (see Figure 2-4):

$$z_1 + d_1 + \frac{v_1^2}{2g} = z_2 + d_2 + \frac{v_2^2}{2g} - \text{losses} \quad (2-16)$$

This equation accounts for the net effects of energy loss between two adjacent locations within the stream reach. Effects due to changes in bed elevation changes, depth, and velocity are accounted for by losses accumulated between cross sections and are accounted for within the WSP program.

An additional equation is used to relate energy and flow values so that the computational procedure can cross check between the flow and energy balances. Using the user-supplied data for discharge (Q) and roughness (Manning's n), and the calculated values for area (A) and hydraulic radius (R) from the measured data at each cross section, Manning's equation is used to define the energy slope  $S_{ei}$  at each location by:

$$S_{ei} = \left[ \frac{Q_i}{R_i^{2/3} * A_i} * \frac{n_i}{1.49} \right]^2 \quad (2-17)$$

where:  $Q_i$  = discharge (cfs, cms)  
 $n_i$  = roughness coefficient  
 $A_i$  = cross-section area (ft<sup>2</sup>, m<sup>2</sup>)  
 $R_i$  = hydraulic radius (ft,m), e.g., area divided by wetted perimeter  
 $S_{ei}$  = energy slope (subscripts refer to any cross section i)

Manning's equation is empirical, and the roughness coefficient "n" is used to quantitatively express the degree of resistance to flow in the channel. The value of Manning's "n" is an indication of the roughness of the sides, bottom, and other irregularities of the channel profile. The value is used to indicate the net effect of all factors which resist the movement of water moving downstream through the channel. Typical values of Manning's roughness coefficient n in a natural river channel are given in Table 2-3 (derived from Henderson [1966]).

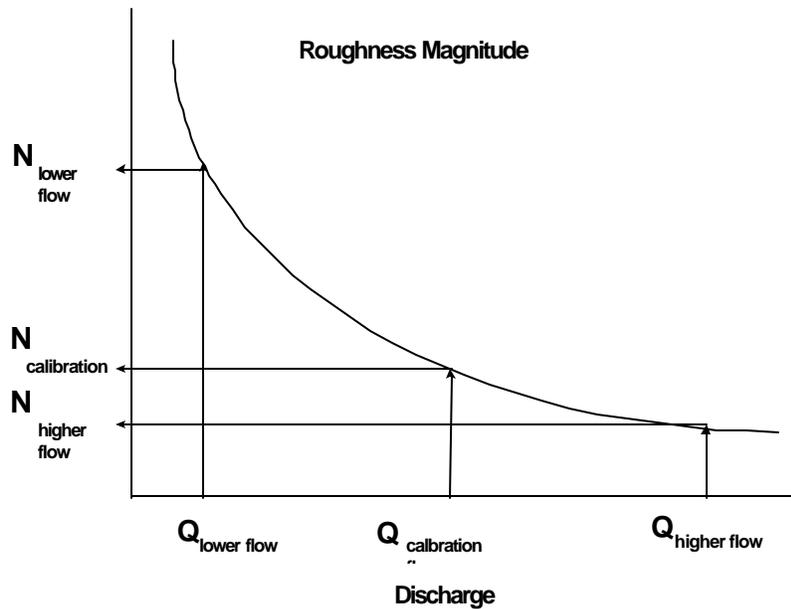
**Table 2-3.** Typical Manning's n values associated with channel types or conditions.

Channel type	Ranges of Manning's n
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 <sup>1/6</sup> (d = D-75 {3rd quartile} size in ft)

In the most general sense, the roughness or resistance to flow within a channel decreases with increasing discharge as illustrated in Figure 2-14. As can be seen the magnitude of Manning's n estimated for use in the model will be a function of the calibration discharge and will typically vary with simulated discharges according the general relationship shown in Figure 2-14.

This discharge-dependent change in roughness is accounted for in the WSP model by allowing the user to empirically determine this functional relationship and thus vary the Manning's n with discharge within the model as described below. Under practical working conditions, Manning's n values may fall outside

reported handbook ranges. This parameter in the model is attempting to integrate all kinds of resistance to flow that include “errors” in approximations such as fixed expansion and contraction coefficients, etc. Also, many of the cited handbook values are more indicative of high flow conditions. In addition, the presence of aquatic vegetation, for example, will result in much higher Manning’s values than would be obtained at the same cross section in the absence of vegetation. The overriding principal in the application of the WSP model and, in particular, deriving Manning’s n values is whether or not the model adequately predicts the observed water surface elevations.



**Figure 2-14.** Change in roughness magnitude with discharge.

#### Computational Process of the Step-Backwater Approach to Water Surface Modeling

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

1. Starting at the farthest downstream cross section, a water surface elevation ( $WSL_1$ ) is taken from user-supplied values or calculated from the user-supplied energy slope using 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, WSL, and flow.)
3. The water surface elevation at the next cross section ( $WSL_2$ ) is estimated by projecting  $S_{e1}$  upstream over 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:

$$S_e = \text{function}(S_{e1}, S_{e2}) \quad (2-18)$$

$$Q_2 = Q_1 \quad (2-19)$$

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

$$H_2 = H_1 + S_{eL} + (\text{other losses}) \quad (2-20)$$

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 associated with effects 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:

$$WSL_2 = H_2 - \frac{V_2^2}{2g} \quad (2-21)$$

7. The  $WSL_2$  values from steps 3 and 6 are compared and a numerical technique is used to adjust the estimated  $WSL_2$  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.

Users 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 WSP model. In this situation, the value of Manning's n is changed by the user and the program is rerun until the energy-balanced water surface elevations calibrate with observed water surface elevations at the single calibration flow. After this initial calibration is achieved, the additional calibration data sets are used to empirically derive the relationship between roughness and discharge illustrated in Figure 2-15 for use in the model as described in the following sections.

### WSP Options

The user has the ability to select a variety of computational and reporting levels during the execution of the WSP program. The associated laboratory exercises will treat the use of the most commonly used options in WSP and therefore, a detailed discussion of each option will not be presented here. Table 2-4 lists the options within WSP and provides a concise description of the function for each option. Although various hydraulic options were provided in the original WSP program, most of them have a limited applicability to PHABSIM studies. Thus, the options available in PHABSIM for Windows are limited to those relevant to habitat studies. For a detailed explanation of these options, the reader should consult a "Guide to the Application of the Water Surface Profile Computer Program" (U.S. Bureau of Reclamation, 1968).

**Table 2-4.** Options in the WSP program.

Option description	Action when set to indicated value
Use Critical Discharge Constraint (check box)	Forces water surface elevation to be at critical flow elevation if supercritical flow is detected. (Strongly recommend checking this box for most applications.)
Override Error Processing (check box)	Overrides certain error processing by overriding the limit on the allowable change in energy loss between two sections. WSP will not calculate the upstream water surface elevation if the change in elevation is too large and will not proceed further. Sometimes it is useful to review the results with a large change in water surface elevation between two cross sections to find the cross section(s) where the problem occurs. Suggest production runs should be made with this option off as the underlying problem should be dealt with first.
Write cell details (check box)	Writes cell calculation details to ZOUT.
Set “n” values (table)	N values are entered for each cross section and the entries revised to achieve calibration.
Set n modifiers “RMOD” (table)	Transect roughness modifiers are supplied to adjust n as a function of discharge.

**Output Options (this Applies to all WSL Simulation Models)**

Use (check boxes for each discharge)	Selects which discharges are simulated in the current run. Default is all (all boxes checked).
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*A Conceptual Overview of WSP Calibration*

Calibrating the Longitudinal Water Surface Profile

We begin by recalling that WSP assumes the cross sections are connected and contiguous within a study site. Then, from an applied perspective, the first calibration step in WSP involves the estimation of an appropriate Manning’s n value for the entire study site (that is, the same n is supplied for each cross section) which minimizes the error between observed and predicted water surface elevations at the selected discharge. In other words, the user selects a Manning’s n value for all cross sections which allows the WSP model to approximate the observed longitudinal profile of the water surface elevation at all cross sections at this initial (or base) calibration discharge. Normally an increase in the roughness coefficients increases the predicted water surface elevation and a decrease in Manning’s n usually reduces the predicted water surface elevation. The first phase of calibration consists of setting n for all cross sections, running WSP, evaluating the results, and adjusting n until suitable agreement between observed and simulated water surface elevation is achieved.

Note that the water surface elevation (or slope) at the downstream-most cross section is a given input to the model and as such, is not part of the actual calibration of WSP for the first cross section. If the user

has not measured the starting water surface elevations for all flows of interest and for which the WSP program will be used, then either the STGQ or MANSQ model (or other suitable approach) must be used to generate the starting water surface elevations at the down stream cross section.

One can provide an initial estimate of the Manning’s n value using handbook values based on the observed channel configuration and substrate characteristics (e.g., see Table 23, or [Chow, 1959]), however, the following technique provides a means of adjusting Manning’s n that empirically reflects the dynamics of the resistance to flow based on field measurements.

Begin by using the observed WSL and an initial estimate (obtained from handbooks or by professional judgement) for the Manning’s n value for the study site (a global value for all cross sections) and run the WSP model. Examine the output and record the average value of the computed slope obtained over the entire study site (see Equations 2-16 and 2-17, above).

Treating the initial estimate of Manning’s n and computed slope from WSP as “trial” values, along with the actual average measured slope for the study obtained from field measurements, the following equation will yield an adjusted estimate of Manning’s n for the study site.

$$n_{\text{needed}} = \frac{S_{\text{computed}}^{1/2}}{n_{\text{trial}}} * S_{\text{measured}}^{1/2} \quad (2-22)$$

This value can be substituted for the initial trial Manning’s n value for all cross sections. The WSP model can then be re-run to evaluate the overall fit of the simulated water surface profile. The user should not expect that the n selected will result in a “perfect” match of all observed WSL’s at all cross sections. When an apparent best fit has been obtained, proceed to “Calibration of WSP to Additional Longitudinal Profiles”, below.

#### Calibration of WSP to Additional Longitudinal Profiles using Roughness Modifiers (RMODs)

In this calibration step, the relationship between discharge and roughness observed in open channels illustrated in Figure 215 is derived empirically. Since the roughness varies as a function of discharge, some means must be used to take into account the changes in roughness with discharge. Therefore, the Manning’s n values obtained in the first step of the calibration must be modified appropriately in order to reproduce the observed longitudinal water surface profile at other calibration discharges. The objective is to select roughness modifiers so the new roughness (i.e., computed Manning’s n values used during program execution) minimizes the error between observed and predicted longitudinal profiles of the water surface elevations at the remaining calibration flows.

To accomplish this step of the calibration, the remaining calibration discharges and starting water surface elevations (or slopes) at the downstream-most cross section are provided to WSP using the table in the **/Models/WSL/Method** tab. The user then uses a trial and error procedure to select appropriate roughness modifiers for each new calibration flow which minimize the error between predicted and observed water surface elevations for all cross sections at each of the new calibration flows. Note that the RMOD value for the initial (or base) calibration discharge used during the first step for calibration of Manning’s n is 1.0 and should remain so for all simulations. The “base” condition represents our starting point for adjusting n as a function of discharge so it should be multiplied by 1.0 to preserve the starting point. Once the appropriate roughness modifiers associated with the other calibration discharges have been obtained, experience has shown that the roughness modifiers vary approximately with discharge as shown in Figure 2-15, which can be represented by a power law equation:

$$\text{RMOD} = a Q^b \quad (2-23)$$

The coefficient and exponent can be empirically determined from a linear regression between the logarithm of the RMODs and the logarithms of their associated calibration discharges. This regression equation is then used to derive the appropriate RMODs at all flows of interest to be simulated with the WSP model and entered along with the starting water surface elevations (or slopes) at the downstream cross section. A linear regression for RMOD values can easily be performed in a spreadsheet and is not included in PHABSIM for Windows.

The user should not expect that the RMODs will result in a “perfect” match of all observed WSLs at all cross sections for the remaining calibration discharges. The final selection of a particular RMOD value for a given calibration flow will be based on an attempt to minimize the error between predicted and observed WSLs between all cross sections at a particular calibration flow. Often, for example, one will accept a larger error at some cross sections to preserve a better fit over the entire study site and range of observed discharges. This will require the analyst to exercise some degree of judgement which must have a rational basis in light of the conditions at the study site and the needs of the particular study.

PHABSIM for Windows provides effective graphical tools for n calibration. Viewing longitudinal profile graphs in the **/Models/WSL/Results** tab can give a quick visual comparison of calculated and observed water surface values at each transect. Adjustments to n and RMOD values can be made and the WSP model re-run rather quickly, so a trial-and-error procedure for n and RMOD calibration is both feasible and timely.

#### Adjusting n Values for Individual Transects

It is tempting to adjust n values to obtain an exact match between measured and simulated water surface elevations at your selected “base” calibration discharge. While visually appealing, such a practice can: (a) maximize the impact of any measurement errors, and (b) result in a poor fit to measured water surface profiles at other measured discharges. If there is a poor fit at the other measured discharges, the analyst cannot be confident about the quality of the simulated water surface profiles obtained using widely varying Manning’s n values. In short, if n must vary over a wide range to obtain an exact match to the measured water surface profile at the calibration discharge, something is very wrong. *Such a practice is strongly discouraged.*

Instead, using different n values among cross sections at a study site should be based on some assessment of changes in the physical conditions among the cross sections. Such changes typically include variation in the bed material (where n represents bed particle roughness, e.g., friction) or in the channel configuration or bed form (where n also incorporates form roughness).

Because Manning’s equation does not differentiate between the types of roughness described by n, the user must supply (and defend) the rationale for varying n among cross sections. The initial “global” n approach captures the overall resistance to flow of the channel within the study site. Then, local variations in n may be considered where there is some physical justification. For example, if there is an area with large numbers of colluvial boulders in the stream, the boulder field would be expected to have a higher-than-site-average flow resistance. Other areas would be likely to have resistance below the average. Similarly, changing from a rectangular cross section in a riffle to a parabolic cross section in a pool may justify small local adjustments to n by trial and error. In general, adjustment of n values for individual cross sections more than approximately  $\pm 10\%$  ~15% of the global value for the study site needs to be justified by specific evidence about large changes in bed material or channel configuration. Whenever making local n adjustments keep two criteria in mind: (1) there must be some physical basis and (2) the

adjustment is intended to obtain a better match between predicted and observed water surface profiles. If an adjustment made to obtain a better water surface elevation match is contrary to the apparent physical processes in the channel, it cannot be defended.

Note that the Manning's n value at a downstream cross section can have an "impact" on the magnitudes of the Manning's n values at the remaining cross sections. During the calibration procedure, care must be taken to avoid a see-saw effect in selected n values.

### Determining Initial Water Surface Elevations for Calibrated WSP Models

The final required step for using the calibrated WSP model for WSL simulation is to define the starting water surface elevations at the downstream cross section for all unmeasured flows. The most common approaches are to use either a stage-discharge regression (STGQ model) or Manning's equation (MANSQ model). In both of these instances, the user can instruct the PHABSIM interface to extract the water surface elevations for a single cross section from the existing STGQ or MANSQ results by selecting the **WSP/STGQ** or **WSP/MANSQ** methods for the downstream-most cross section in the **Models/WSL/Method** tab. It is highly recommended that practitioners place the downstream-most cross section on a hydraulic control. This enables use of the STGQ or MANSQ model to establish starting WSL's for unmeasured discharges at the control cross section. Use of either STGQ, MANSQ, or another source of the initial conditions for backwater modeling, is the analyst's responsibility. The predictions of the water surface elevations produced by STGQ or MANSQ are transferred to the WSP model by the PHABSIM interface when the WSP/STGQ or WSP/MANSQ options are selected. If the water surface elevations for unmeasured discharges are obtained from an outside source, the user may enter those values using the **WSP/User supplies initial WSL** option in the **Models/WSL/Method** tab.

Regardless of the method used to supply initial WSP water surface elevations, the user must set appropriate RMOD values for all discharges prior to use of WSP for production runs. As stressed previously, the user should then check the overall quality of the hydraulic simulations by checking the longitudinal water surface profiles over the full range of simulated flows.

### A Step-by-Step WSP Calibration Strategy

The WSP program is used most often in those instances where multiple stage-discharge measurements are available. The following approach is provided as a guideline to calibrate the WSP model.

1. Select WSP as the water surface profile simulation method in **Models/WSL/Method**. Note the downstream cross section must have an entry of **WSP/STGQ**, **WSP/MANSQ**, or **WSP/User supplies initial WSL** and that the MANSQ or STGQ models must have been calibrated for the downstream cross section where WSP will be used. Supply an RMOD value for each discharge in the **../WSP Options** tab. Initial RMOD values can all be 1.0.
2. Run the WSP program and examine the results and ZOUT files to find the computed slope for the downstream-most cross section and use Equation 2-22 or trial-and-error to estimate a revised Manning's n value for the study site. Edit the cross section data so the all cross sections have this Manning's n value. Note: an error message: "WSP Terminated with an Unknown Error" usually indicates you did not supply an RMOD value for each discharge.
3. Re-run the WSP model and note the agreement of predicted WSL with observed values at the base discharge. Based on the difference between predicted and observed WSL, adjust the global Manning's n value for all cross sections and re-run the WSP model. Continue to change the

Manning's n value until the predicted and observed water surface elevations are as close as can be obtained with the global n applied to all cross sections. Some variation between the observed and predicted WSL values is likely to occur at some transects. But the overall error should have been minimized.

4. Adjust local (cross section by cross section) n values (within  $\pm 10\%$  ~15%) to reduce the remaining error between the observed and predicted water surface profile. Make those adjustments with the physical processes in mind and avoid adjustments that cannot be physically justified, i.e., do not "curve fit". Evaluate if the agreement error is within the tolerance limits that meet your study objectives. Remember, the WSP model works in an upstream manner and therefore the predicted WSL at the second cross section will be the starting WSL for making the predictions of the WSL at the third cross section, and so on proceeding upstream. For example, a low predicted WSL at the second cross section will "start" the model lower than wanted while attempting to reach the WSL at the next cross section. This can result in supplying unusual Manning's n values at the next upstream cross section in order to get agreement at that cross section. The user should also note that in many instances, exact agreement is not always possible and WSLs at some cross sections may be high while at others they will be low. Again, some level of professional judgement, based on experience, will be necessary in order to determine how close predicted versus observed water surface elevations must be to be acceptable for individual cross sections or for all cross sections. Once suitable agreement between predicted and observed water surface profiles has been obtained for the base discharge, proceed to step 5.
5. Once the initial longitudinal water surface profile has been calibrated by selecting the appropriate Manning's n values at each cross section, broaden the evaluation to include the remaining calibration discharges and starting water surface elevations at the down stream cross section. Select the other calibration discharges in **/Models/WSL/Output Options**. Initially the roughness multipliers (RMODs) for these new calibration flows can be set to 1.0. Or, based on whether the other calibration flows are higher or lower than your initial calibration flow, you can set the RMODs to be greater or less than 1.0 based on the relationship shown in Figure 2-15. New calibration flows greater than your initial calibration flow will require a Manning's n lower than 1.0, while new calibration flows lower than the initial calibration flow will require a Manning's n greater than 1.0. The relative magnitudes of the RMOD estimates will be a function of how different the magnitude of the discharges are relative to your initial calibration flow.
6. Re-run the WSP model with the new roughness modifiers and compare the predicted and observed WSL at all cross sections at these new calibration flows. Adjust the RMODs at the new calibration flows until suitable agreement between predicted and observed water surface elevations are obtained. Each discharge is computed independently within WSP so once an RMOD is found which works for a specific calibration flow, that RMOD can be left unchanged while continuing your work at the remaining calibration flows. RMODs should be adjusted to obtain an overall minimum error between predicted and observed WSL for all calibration discharges.
7. Perform a linear regression between the logs of the RMODs and the logs of the discharge and use this equation to estimate the RMODs for all flows of interest for the study that you plan to use the WSP model to predict the water surface elevations.
8. Use the STGQ program or MANSQ program to supply initial WSL's to WSP at the most downstream transect for all other discharges to be simulated. That is, use **WSP/STGQ** or **WSP/MANSQ** at the WSP starting transect in the **Models/WSL/Method** tab. Remember a starting water surface elevation must be specified for all flows of interest at the first or downstream-most cross section when using the

WSP model. If the STGQ or MANSQ models are used for WSP initial conditions, those models must be calibrated first before proceeding with WSP.

9. Add any additional desired discharges to the PHABSIM project using **Edit/Discharges**. RMODs determined from Step 7 must be associated with each of these flows (see the **WSP Options** tab) and the water surface elevation simulation must have those discharges specified in the **Models/ WSL/ Output Options** tab.
10. Check the quality of the hydraulic simulations by plotting the longitudinal profiles of the water surface elevations for all simulated discharges (use the **./Results/Longitudinal** graph button). Zoom in on the calibration discharges for one last comparison of the predicted and observed water surface profiles and make any final adjustments to n or RMOD as needed. If the very highest discharges produce unusual water surface profiles, check for predicted water surface elevations higher than the highest measured bed elevations. The model becomes invalid if WSL's significantly greater than the highest bed elevation are predicted. If such high discharges must be simulated, more field data is needed to define the channel at those heights.

### Some Practical Aspects of Calibrating and Use of the WSP Model

The quality of calibration that can be obtained for a stream section will vary with the hydraulic characteristics of the stream and the nuances of the field data. Steep, rough streams often exhibit large fluctuations in water velocities and water surface elevations and may be difficult to calibrate. Typically, achievable agreement between observed and simulated water surface elevations is  $\pm 0.01\sim 0.02$  feet ( $\pm 0.00305\sim 0.0061$ m) for the profiles at each calibration discharge. However, the investigator must be aware that specific situations may require establishment of more lenient or stricter standards. For example, an investigator may relax this standard somewhat at the highest calibration flow profile in order to achieve a closer agreement at the middle and lowest calibration flow profiles since this lower range of discharges is most important in view of the particular instream flow project under consideration.

Although text book values of Manning's n can serve as a reference point, it should be noted that many of these values are most appropriate for higher discharges at or near bank full conditions and as illustrated in Figure 2-15, may, in fact, be too low under lower flow conditions. In other words, do not be surprised if the calibration Manning's n values do not match the ranges reported in the hydraulic handbook values. This should not be a source of concern as long as a physically based meaning can be attached to the values. Perhaps the most critical factor should be how well the model is able to reproduce the observed data. This of course assumes that any obvious data collection and entry errors have adequately discounted or corrected.

The WSP model will produce unreliable results if water surface elevations significantly higher than the highest cross section elevations are necessary to simulate the desired discharges. Always review the longitudinal profile for realism of the simulation. When very high discharges must be simulated as part of a PHABSIM study, it is imperative that at least bed elevations high on the bank and water surface elevations for a discharge in the vicinity of the desired high discharge be collected to ensure the PHABSIM models can run within reasonable bounds.

### Hydraulic Controls

Transects should start and end at hydraulic controls if at all practical. Calibration problems are greatly exacerbated when starting and ending transects are not located at hydraulic controls. The effect of hydraulic controls in a WSP calibration are often profound. It is often possible to alter the water surface

profile through an entire reach simply by modifying the roughness at the downstream control. One overriding principle of the WSP model is that the downstream-most transect must be on a control and all other controls in the reach should be defined by a transect. This means the downstream control associated with specific habitat features, such as a pool, should be included even if they are of no interest for representing the habitat feature of interest.

### Divided Flow

Flow partitioning is a necessity when the channel around one side of an island is longer than the other side. When the length of one channel exceeds the length of the other by a factor of approximately 1.5 or more, or the channel configurations differ significantly, flow partitioning should be considered. In essence, flow partitioning involves breaking up the total discharge of the stream into component discharges for each channel. The WSP program is calibrated for each channel at the component discharge as if it were a separate stream (see below). At the calibration discharge(s), this is a relatively easy procedure because field notes should 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(s), the proportion of the total flow carried by either channel changes as a function of total discharge. The process of flow partitioning often is very difficult. It is advisable to consult an experienced hydraulic engineer before attempting this type of analysis. Basically, the problem is to determine the component discharges at a range of unobserved flows so that a rating table can be built. This is done by first calibrating the 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.

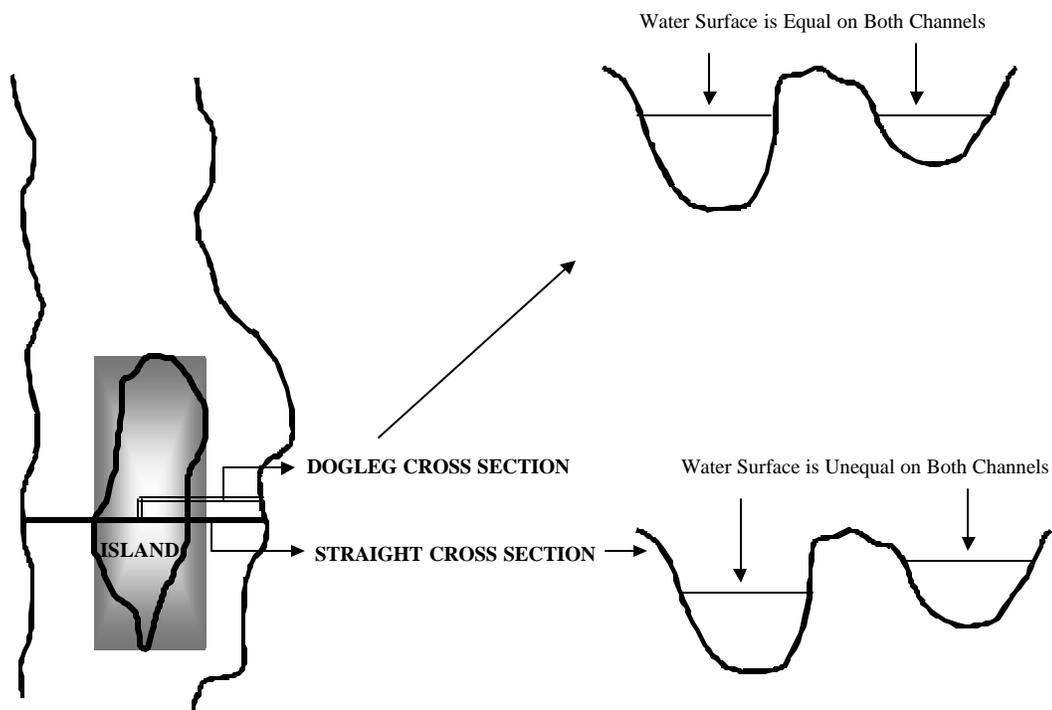
Calibration of the WSP model can be difficult when flow splits into two or more channels. In general, the water surface elevation models in PHABSIM are not designed to work in split channels. A few streams may have small enough differences between channels on either side of an island to follow one of the transect placement or data adjustment approaches described below. However, in most cases, those approaches will introduce considerable error. MESC recommends users partition the flow empirically through each of the channels and treat each channel as if it were a separate stream to be calibrated and simulated separately. This means that discharge measurements for the full channel and each side channel must be made for at least the calibration discharges. A regression of side channel discharge against full channel discharge (or other means to build a rating table) can then be used to determine the flow split for the unmeasured discharges to be simulated in the study.

When partitioning the flow, care must be taken to ensure that the water surface elevations simulated at the top of each separate channel are the same (or within an acceptable tolerance) for all discharges. This allows an island to be represented by four backwater models: main channel downstream of the island, left side channel, right side channel, and main channel upstream of the island. A backwater simulation can be run for the main channel downstream of the island to produce the starting water surface elevation for both side channels for all discharges of interest. Then the two side channels are simulated with Manning's  $n$  calibrated to produce the same water surface elevation at the top of the island. And finally, the main channel upstream of the island is simulated using the initial water surface elevations derived for all flows from the simulation of the two side channels. In PHABSIM for Windows, this will require four projects covering the four separate portions of the channel and ensuring that the transects at the partitions are duplicated in the appropriate data sets. Though tedious, this is the only way to assure that the flow conditions around the island are modeled accurately over a wide range of discharges.

When there are small differences between the two channels around an island and the study site is represented with a single backwater model, two generic types of problems are presented by divided flow. The first, and most common, is unequal 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 (see Figure 2-15). By their very nature, islands rarely have the same bed and water surface elevation at equidistant points along the bank. Ideally, the transect should cross the island with a dogleg in order to obtain an equal water surface profile on both sides of the island. In braided channels, this is 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 for all calibration flows. What constitutes small in this instance is a matter of judgement. 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. All of these manipulations of the data may introduce their own noise in the analysis. Again, splitting the study site into four backwater models is preferred.

The energy loss between the 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 should equal the total flow in the channel) are the proper component flows. If finding flow rates and energy losses that satisfy these conditions seems extremely tedious and difficult, it is! Alternatively, such ratings can be built empirically by collecting both water surface elevation and discharge data at several flows over the range of discharge of interest to the study. Hence, if you have split flow, plan on making many more water surface and discharge measurements in both the main channel and side channels.



**Figure 2-15.** Dealing with uneven water surface elevations across an island.

### Running the WSP Model

WSP must have starting conditions supplied at the downstream-most transect to which it will be applied. In the `/Models/WSP/Method` table select either **WSP/MANSQ**, **WSP/STGQ**, or **WSP/Supplied** for the

downstream starting condition at each starting transect for each discharge. Then fill with **WSP** upstream (fill down in the table) over the extent of the river to which WSP is to be applied. Make these selections by clicking on the model, e.g., **WSP/STGQ** and then clicking each of the transect/discharge boxes in the table to which that model is to be applied. An example of a completed WSL method table is shown in Figure 2-16.

Method	Output Options	STGQ Options	MANSQ Options	WSP	
	500.000	1010.000	1300.000	1816.000	2100.000
0.000	WSP-S	94.65000	WSP-S	WSP-S	WSP-S
394.000	WSP	WSP	WSP	WSP	WSP
536.500	WSP	WSP	WSP	WSP	WSP
679.000	WSP	WSP	WSP	WSP	WSP
828.000	WSP	WSP	WSP	WSP	WSP

**Figure 2-16.** Water surface elevation method table showing entries for WSP analysis.

Next, in the **../WSP Options** tab, enter a Manning’s n for each transect in the table on the left. Roughness modifiers, which are entered in the right hand table, will be discussed later. While in this tab, select the desired options using the check boxes and click **Apply**. Note, all combinations of WSL simulation models are run at once by clicking the **Run** tab in **../Method**. As with STGQ and MANSQ, after the models have run, compare simulated with observed water surface elevations using the tables and graphs in **../Results**. In general, for cross sections where WSP is applied, Manning’s n should be increased when the predicted WSL is low and decreased when predicted WSL is high. The WSL at the downstream transect is not changed by the WSP model. The laboratory exercises will provide you with experience with the WSP calibration process

Several key hydraulic parameters related to the computational procedure within WSP are output to ZOUTnn. Although not all of these variables are in the output for each cross section, they are usually located somewhere in the output from a WSP run. Their definitions are provided below and have been illustrated in Figure 2-4.

HF1 = Head loss computed at downstream section.  
HF2 = Head loss computed at upstream section.  
HSF = Slope ( $S_o$ ) of energy grade line at section.  
HV1 = Velocity head ( $v_1^2/2g$ ) computed for downstream section.  
HV2 = Velocity head ( $v_2^2/2g$ ) computed for the upstream section.  
Total Head = Total head loss ( $h_f$ ) between sections.

Remember to review the output file for error messages and inconsistencies in the data. Error messages in the form of notes or other statements may be written to the output file and not appear on the screen or cause the program to abort. Output from the WSP model is both extensive and variable depending on the particular run options that the user selects. Examination of WSP output is deferred to the laboratory exercises.

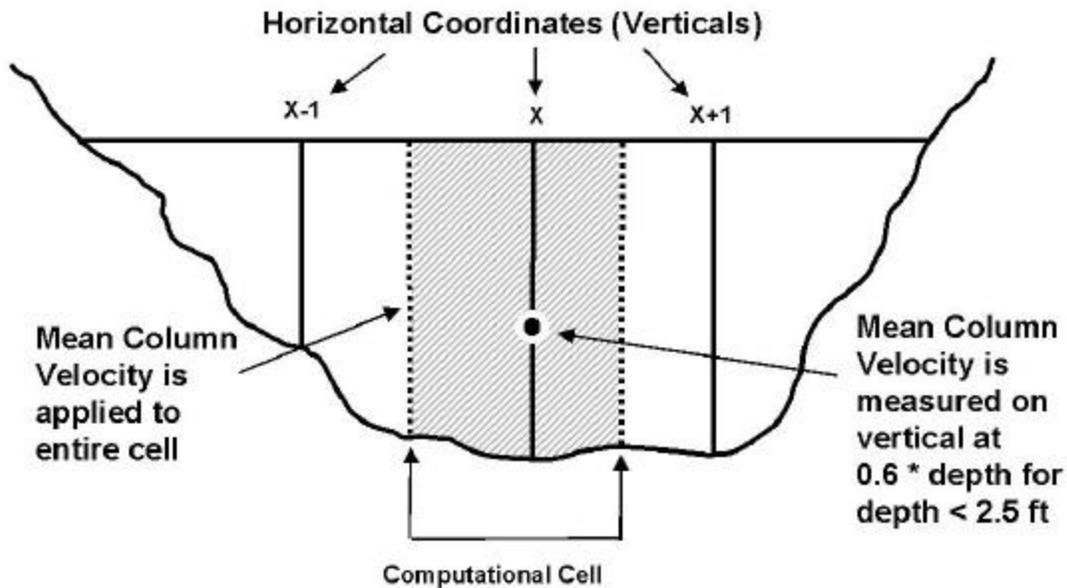
## Modeling Of Velocities In PHABSIM

The second major step of hydraulic modeling within PHABSIM involves simulating velocity profiles at each cross section within the river. Transect based open channel flow models face a serious limitation in simulating velocity distributions across the channel. Both step-backwater and stage-discharge type models were developed and have been verified only for whole channel calculations. Thus, lacking a theoretical method of distributing velocities, PHABSIM relies on empirical means to approach this problem.

PHABSIM models velocities for individual cross sections and as such treats the cross sections independently regardless of the model employed to generate the WSLs. In most cases, only limited resources are available to do field work in any particular instream flow study; hence, a limited number of velocity profile readings are used to estimate the velocity distribution at flows for which velocities were not measured. Within PHABSIM, the VELSIM model is used for all velocity predictions. Those velocity values are subsequently used in the habitat modeling portion of PHABSIM. Figure 2-17 illustrates the relationship between a measured velocity at a cross section vertical and a computational cell as viewed by the VELSIM model.

Note that both the STGQ and VELSIM programs define a computational cell as the region one-half way between two sets of adjacent verticals (see Figure 2-17). A vertical is a measurement point specified as the X (distance from the head stake) coordinate values (see Chapter 1). All references to the computational cell are then made to the vertical. Note that this definition of a cross-sectional cell is different from that used by the habitat models. These differences are discussed in more detail under the appropriate habitat models in Chapter 5.

In PHABSIM, each computational cell in a cross section is treated separately, with its own depth, substrate, and average velocity. In the VELSIM 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 or simulated. Velocities can only be provided at X coordinate values in **Edit/Cross Sections/Coordinate Data**. PHABSIM for Windows does not limit the number of subdivisions (or cells) used to define the velocity distribution across a cross section. Obviously, the more computational cells per cross section, the more detailed the description of the velocity distribution. The VELSIM program defines a cell as the region half way between two sets of adjacent verticals as illustrated in Figure 2-17.



**Figure 2-17.** Measured velocity and computational cell velocity.

### *Calibration and Simulation of Velocities*

In the following discussions, approaches to estimating the velocity distribution at 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 the use of Manning’s equation with measured velocities at one flow while the third section describes procedures using more than one set of measured velocities.

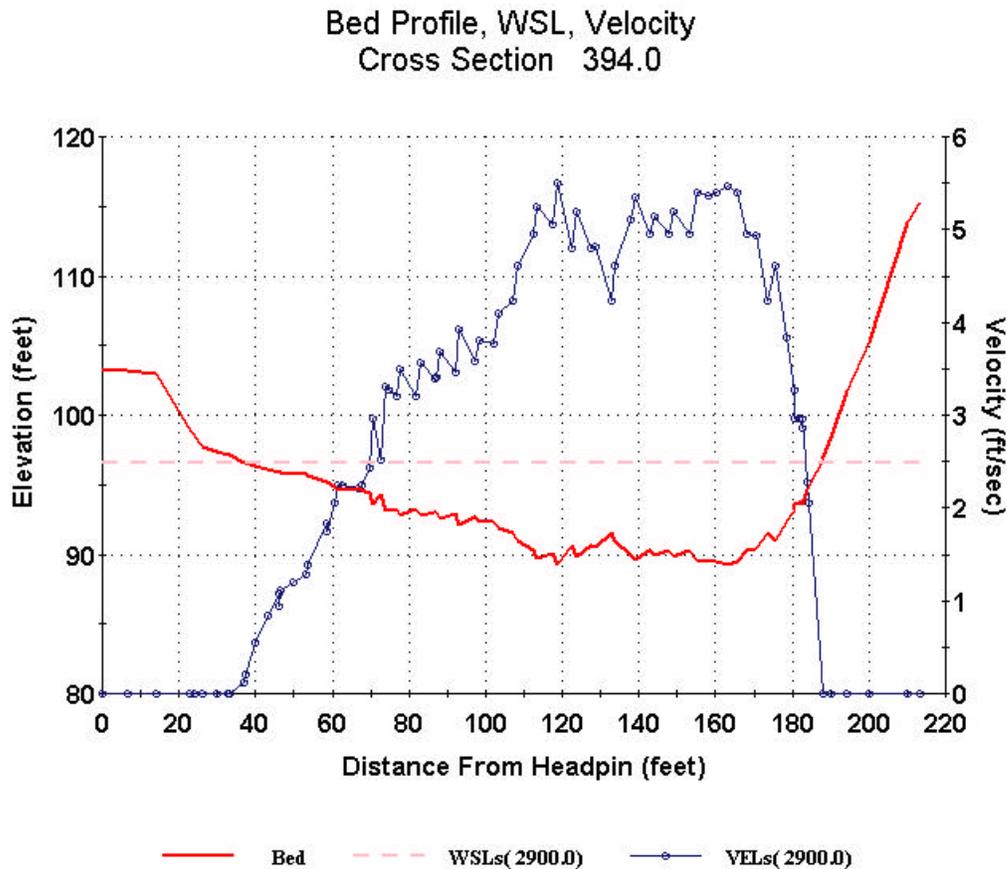
#### VELSIM with No Measured Velocities

The VELSIM program can be used to simulate velocities at a cross section although no velocities were measured. This is accomplished by rearranging Manning’s equation to solve for “n” in terms of the measured discharge and individual cell attributes and substituting the depth of flow for the hydraulic radius:

$$v_i = [1.49 * S_e^{1/2} * d_i^{2/3}] / q_i \quad (2-24)$$

The net effect of this approach is that the magnitude of the velocity predicted at any vertical across the cross section is directly related to the depth of flow, and, therefore, the relative magnitudes of the velocity distributions will mimic the channel geometry as illustrated in Figure 2-18. Note that in VELSIM, if a user specifies a Manning’s n value at a particular vertical, the VELSIM program will use that Manning’s n to compute velocities when employing Manning’s equation. The user should always check this type of simulation for realism. Experience has shown that under some circumstances, this approach yields satisfactory results, while in other circumstances it is not acceptable. Viewing plots, such as shown in

Figure 2-18 in **/Models/Velocity/Results**, allows visual detection of unusual velocity distribution patterns. Note that the velocity profile in Figure 2-18 is proportional to depth.



**Figure 2-18.** Simulated velocity distribution with no calibration data.

MESC suggests that this approach be limited to those cases where field conditions or equipment failures prevented collection of at least one velocity data set and limits of time (deadlines) or resources prevent collecting at least one velocity profile at a later time. The judgement is left up to the investigator and the particular objectives of the model application.

#### VELSIM with a Single Velocity Data Set

If one set of velocities is used to calibrate the VELSIM program, a different approach is taken based on an initial solution of Manning's equation to obtain an estimated Manning's  $n$  at each vertical along a cross section. This approach treats the observed velocity profile as a template for describing velocities for other discharges. Since slope, water surface, and observed velocity are given as part of the calibration data, Manning's equation can be solved for  $n_i$  at each vertical:

$$n_i = [1.486 * S_e^{1/2} * d_i^{2/3}] / V_i \quad (2-25)$$

where:  $n_i$  = estimated Manning's n value at vertical i  
 $S_e$  = energy slope for transect  
 $d_i$  = depth at vertical i  
 $v_i$  = measured velocity at vertical i

Note in this equation, that depth  $d$  at the vertical has been substituted for the hydraulic radius and is computed from the difference between specified water surface elevation and bed elevation at each vertical. The measured velocity ( $v_i$ ) at each vertical is obtained from the input data. If a slope has not been provided (i.e., specified in **Edit/Cross Section Data**) a default slope of 0.0025 will be used. The specific slope used is not critical to the calculation of velocities using this approach as illustrated below. Having obtained individual Manning's n values at each vertical, individual cell velocities can be computed at any alternative discharge by solving Manning's equation for velocity and using the initial Manning's n value derived from the calibration velocity set:

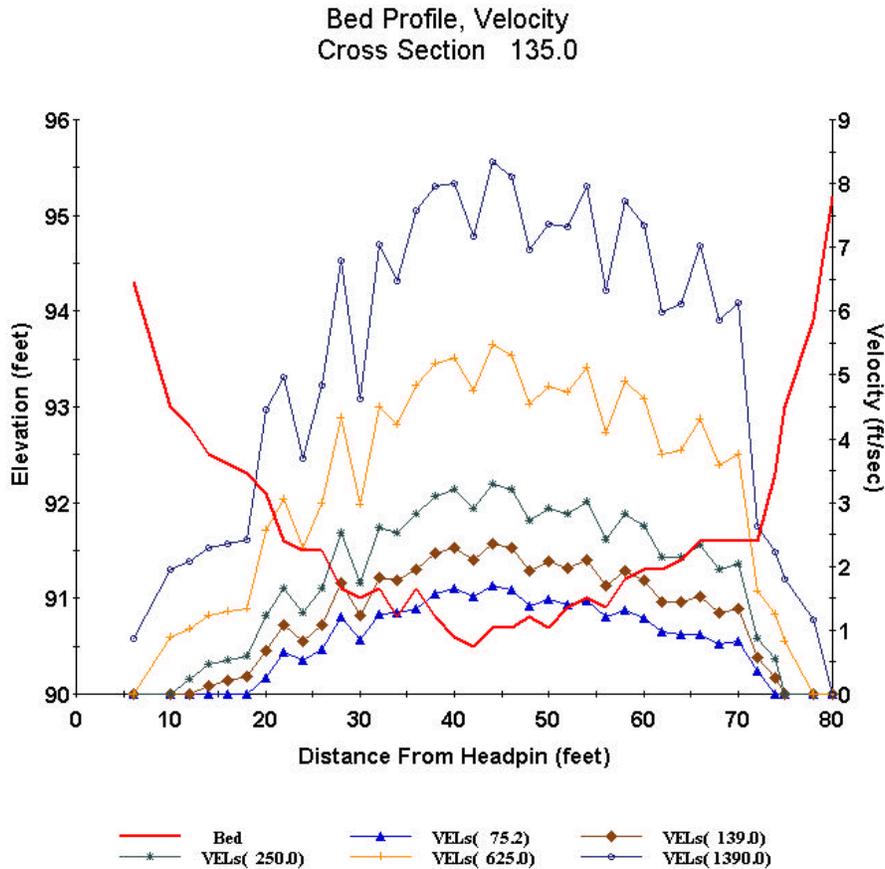
$$v_i = [1.486/n_i] * d_i^{2/3} * S_e^{1/2} \quad (2-26)$$

As noted above, if a user specifies a Manning's n value at a particular vertical, the VELSIM program will use that Manning's n in the computation of velocities when employing Manning's equation even though an initial calibration velocity had been provided. Figure 2-19 provides an example of a single observed velocity calibration set with the associated predicted velocities at the calibration flow. Since the best estimate of the discharge is typically used in the simulation of water surface elevations and the VELSIM maintains mass balance for the discharge, the simulated velocities at the calibration flow will not exactly "match" the observed velocities.

During simulation, if VELSIM simulates a water surface elevation at a cell for which no velocities were available for estimation of Manning's n or a Manning's n value was not supplied, the program will search for an adjacent cell to obtain an estimated or user-specified n value for use in the computation of velocities at that vertical. The user has several options for setting Manning's n in VELSIM either through a calibration velocity template or by estimation. These options are discussed in more detail at the end of this section.

#### VELSIM with Multiple Velocity Data

Although the investigator may have measured multiple velocity sets for use in the study, MESC recommends that the multiple velocity calibration data sets be treated as independent data sets for modeling purposes. The recommended strategy uses the highest observed velocity data set to simulate at all flows higher than the highest measured flow, the lowest observed velocity set to simulate flows lower than the lowest measured flow, and user judgement for which discharge ranges between observed velocity sets to assign each calibration velocity set. For example entirely different velocity distributions between a high flow velocity data set and a medium or low flow velocity calibration set may be found when channel geometry is very different at the associated stages. In this instance, the use of a single calibration data set over all ranges of discharges would not accurately reflect the observed velocity profiles at alternate discharges. One strategy would be to "switch" among different calibration data sets at the break in the channel geometry. The investigator would only need to determine the elevation at which this break in channel shape occurs and then determine the appropriate flow from the water surface modeling. It should also be apparent that this exercise is somewhat idealistic in that only a single cross section is shown. In practice, the user would need to consider all cross sections within the modeled reach and will therefore likely need to find a single "compromise discharge" where velocity calibration sets are changed in the model.



**Figure 2-19.** Velocity distribution for a single calibration discharge.

Following the strategy recommended above will result in dissimilar velocity profiles for discharges immediately above and below the break between assigned flow ranges. In some channels, this effect can be pronounced. Lacking additional velocity profile measurements, the exact transition between the calibration set velocity profiles is unknown.

An alternate scheme is provided in PHABSIM for Windows to handle this situation. That is to replace the velocity values in the ranges between observed calibration flows with a smooth transition based on the assumption that a log-log linear transition takes place. After VELSIM has been run with calibration sets assigned to each discharge of interest, the **Velocity Regression** tab is accessed. When clicked, the Run Velocity Regression button causes velocity values for each cell in the ranges between calibration discharges to be predicted using a two point regression. These values replace the values produced by running VELSIM. Note: this approach affects only the velocities in the discharge ranges between calibration discharges.

#### VELSIM Computational Procedures and Mass Balance

In order to more fully understand the remaining computational aspects of velocity simulation within the VELSIM program, the following section describes the governing equations and process by which the

VELSIM program maintains a mass balance between the requested simulation discharge and computed discharges, given its implicit computation of individual cell velocities.

The area of the cell is computed by the following equation:

$$A_i = \frac{1}{2} * [(d_i + d_{(i-1)}) * (X_i - X_{(i-1)}) * 1/2] + \frac{1}{2} * [(d_{(i+1)} + d_i) * (X_{(i+1)} - X_i) * 1/2] \quad (2-27)$$

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

The “trial” discharge computed for a requested simulated discharge at the transect is then determined by using the velocity predictions for each computational cell derived from the velocity simulation method selected. These values are used to calculate cell discharges which are summed for all cells across the transect:

$$Q_{\text{trial}} = \sum_{i=1}^{\text{ncell}} A_i * v_i \quad (2-28)$$

This apparent or trial discharge is not necessarily the same as the discharge requested in the simulation. Reference to Figure 2-15 shows the relationship between discharge and roughness and should indicate that a particular Manning’s n value derived from a velocity calibration set at a single discharge will not be the “correct” Manning’s n value at higher or lower discharges. This is the same basic concept that led to the use of RMODs in the calibration of the WSP program. An index of the difference between the requested simulation discharge and computed discharge derived from the velocity simulations is called the Velocity Adjustment Factor (VAF) and is computed by the following equation:

$$\text{VAF} = \frac{Q_{\text{requested for simulation}}}{Q_{\text{calculated from velocity simulations}}} \quad (2-29)$$

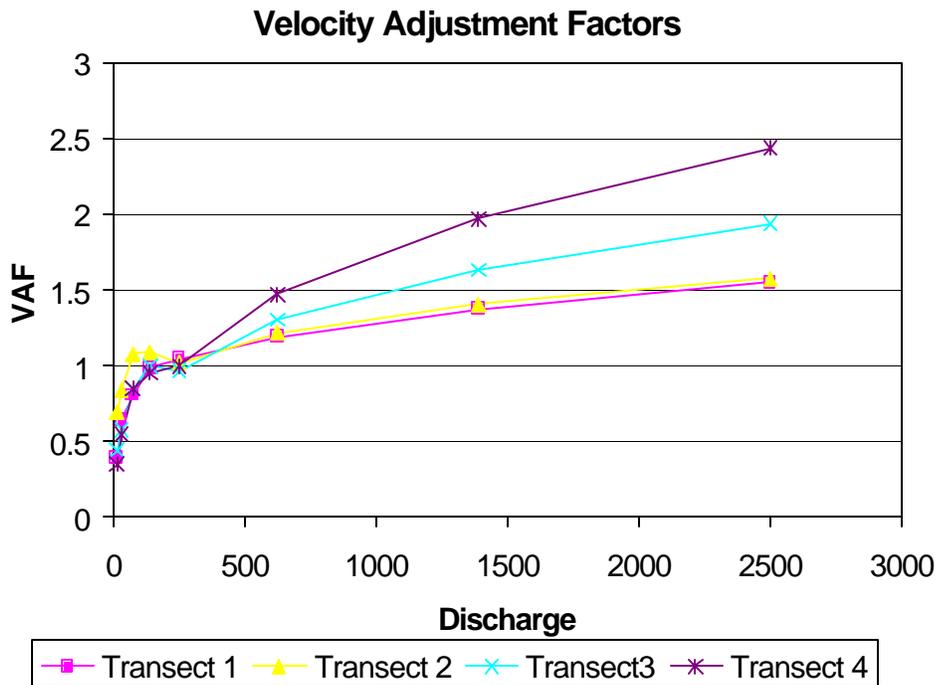
This ratio is then used to adjust individual cell velocities,  $v$ , which also adjusts the computational cell discharges. This adjustment proceeds until the calculated discharge for the cross section equals the requested or simulated discharge. The adjustment of the individual simulated discharges is accomplished with the VAF by adjusting the individual computational cell velocities by the following equation:

$$V_{\text{new}} = v_{\text{initial}} * \text{VAF} \quad (2-30)$$

The use of the VAF in the VELSIM program represents an empirical approach to approximate the role of the RMODs in the WSP program. The relationship shown in Figure 2-15 indicates that at simulated flows lower than the velocity calibration flows, the Manning’s n value derived from the velocity calibration flow will be too low. Since the roughness (i.e., Manning’s n) values used to estimate the velocities are too low, the estimated velocities at each vertical will be too high (see Manning’s equation). This results in a computed trial discharge for the cross section that is greater than the requested simulation discharge and the resulting VAF would be less than 1.0 (see Equation 2-30). Conversely, at simulated discharges greater than the velocity calibration flow, the estimated Manning’s n values will be high and the resulting individual computed cell velocities will be low. This results in a computed trial discharge that is less than

the requested simulation discharge and the VAF will be greater than 1.0. This process suggests that in most cases the relationship between discharge and VAF should be approximately an inverse of the relationship shown in Figure 215 and resemble the example illustrated in Figure 220. Although this general pattern is typical of most cross sections, there are occasions where the VAF versus discharge relationship will not and should not follow this generalized pattern such as when lateral bank vegetation increases the composite roughness at intermediate discharges.

In Figure 2-20, there are two ranges of discharges for which the VAF plot ascends in what appears to be different patterns. The apparent break in the VAF plot at about 250 cms is due to using different calibration sets to produce the velocity template used for velocity simulation. Within the range of discharges for which a particular set of calibration velocity measurements were used to develop the Manning's n template, an ascending VAF relationship indicates the expected outcome of velocity simulation. It should also be noted that the VAF at the calibration flow will not always be equal to 1.0. For example, during the modeling process, the user may have selected the best estimate of discharge for a group of cross sections where the measured variability in computed discharges may have been 15–20%. For any cross section that has a computed discharge based on a set of calibration velocities that is not exactly the same as the best estimate of the discharge, the VAF will deviate from 1.0. The magnitude of the deviation will depend on the magnitude of the deviation between the best estimate of the discharge and the discharge computed using the calibration velocity set.



**Figure 2-20.** Velocity adjustment factors.

It is also reasonable to expect that the VAF relationships for sections with similar cross section geometry will be similar in their functional relationships and the variation between VAF versus discharge relationships will be directly related to the degree of variability in the cross section geometry. As a final note on VAFs, there is no rational basis for judging the “validity” or quality of the hydraulic simulations based strictly on the magnitude of the range in computed VAF values. That is, there is no specific set of envelope values that the VAF should absolutely lie within. It is only an index of the relative change in discharge from the calibration discharge used at the calibration velocity versus the simulated discharge which follows the relationship between roughness and discharge shown in Figure 2-15. The shape of the VAF versus discharge plot is a better indicator of model performance than the VAF magnitude. When a monotonically increasing VAF relation is not obtained, it is not necessarily an indication of model failure. Rather, it simply is an indication that the model calibration and simulation steps should be reviewed. Some channels exhibit non-standard VAF plots even when the models are performing well.

### Significance of Initial Slopes and Manning’s n Values in VELSIM

Note that slope does not appear in the four equations above which describe the computation of velocity and mass balance in the VELSIM program. Also, the slope used in the initial calculation of Manning’s n will not influence the final calculation of the velocity. The slope is important only in being able to compare individual Manning’s n values at cross section verticals from one cross section to another or from one stream to another. The selection of Manning’s n values to add to a data set to control velocity simulations is easier however, if a reasonable estimate of slope is used to calculate roughness from the calibration velocities. The Manning’s n value at this point within the VELSIM program really represents a velocity distribution factor. The user should not be too surprised if individual cell Manning’s n values do not fall within the expected ranges reported in hydraulic roughness tables for cross sections containing a particular substrate characteristic. Handbook values are estimated for whole channel conditions (often for high flow conditions as well) and not for a particular vertical within a cross section.

The role of Manning’s n in VELSIM is important since it functions strictly as a velocity distribution factor and can have an impact on results of the habitat models. In general, since velocities are not measured at previously dry verticals, n values will have to be estimated by the program or supplied (i.e., estimated) by the user. However, the Manning’s n values for velocity distribution are derived in one way or another. Whether they are calculated from observed velocities, estimated for the cell by the VELSIM program when no velocity data is supplied, or supplied by the user, that Manning’s n values are used to calculate the cell velocity for all simulated discharges. This is primary importance when simulating higher flows because, when simulating down from a measured velocity calibration set, the program will have Manning’s n values computed from known velocities at all verticals.

Simulation of higher discharges can, however, lead to problems at the edge of the stream where fringe cells may contain very small cross sectional areas at the calibration discharge. When Manning’s  $n_i$  values for dry cells are not supplied by the user, 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. However, the VELSIM program will occasionally predict unrealistically high velocities on the stream margin (e.g., 20 feet/second!) due to the combination of Manning’s n estimation and application of the VAF to achieve mass balance. Since these areas may be very important to certain life stages of aquatic species being studied, the user should carefully examine the velocity simulation results for these “artifacts” of the computational process during VELSIM calibration. Use the **Cross Section** plot button in **Models/Velocity/Results** to view simulated velocity profiles and the tabular velocity results to determine which cells need to have n values supplied to improve erroneous edge velocities. In these instances or where other factors may warrant, the value of  $n_i$  for dry cells (or wet cells) should be supplied by the user in the **/Edit/Cross Section/Coordinate Data** tab. This is covered in more detail in Laboratory 6 on velocity calibration and simulation.

## Nose Velocities

Much attention has been given to the debate on mean column versus nose velocities (also called focal point velocities) in PHABSIM applications for prediction of available habitat. The HABTAE model offers the user a variety of modeling choices for the computation of nose velocities either based on the 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, to name a few. The application of these techniques however, is limited to those situations where nose velocity habitat suitability curves are available and sufficient field data has been collected to support use of these hydraulic modeling options. Additional descriptions of nose velocity calculations and options are included later in this manual under the HABTAE model program and will not be discussed further here.

### *Control of VELSIM Calibration and Simulation Options*

Much of the utility of the VELSIM program lies in the ability of the user to provide very specific control over all aspects of the computational procedures. The user should review available options for the VELSIM program listed in Table 2-6. This review often results in some confusion for the user to decide 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.

**Table 2-6.** Options in the VELSIM program.

Option description	Action when set to indicated value
Computational details (check box)	Prints the numerical details of the computed velocities and water surface elevations for each simulated discharge to ZOUT. Recommend setting to blank for production runs and checking for calibration runs.
Write ZVAFF (check box)	Writes ZVAFF file containing a summary of the velocity adjustment factors. VAF for flows less than the calibration flows are likely to be less than one. VAF for flows greater than the calibration flows are likely to be greater than one. Contains same information as ZVAFF tab. Recommend leaving blank unless a printed record is needed.
Write CALQ table (check box)	Prints a summary table of the calculated flows.
Use Velocity Adjustment Factor (check box)	Applies the velocity adjustment factor (VAF). If not checked the velocity adjustment will be bypassed. Leave blank if Variable Roughness (see below) is used. Recommend always checking this box. Leaving unchecked is sometimes referred to as “turning off mass balancing”.
Limit Manning’s n (check box and limit cells)	Limits the maximum OR minimum and maximum value of the roughness coefficient (n) used by Manning’s equation in simulating velocities.

**Table 2-6.** Concluded.

Option description	Action when set to indicated value
Use Variable Roughness (check box) and limit cells	Allows user to adjust the roughness in a cell as a function of the depth in a cell (variable roughness). Use to reduce the negative impacts often resulting from too high roughness at the edges in the calibration data set. Use this option with care, as considerable expertise is needed in the application of this option. Judgement is required in choosing a Beta coefficient. The range of values for all but humid tropical channels is from 0.0 to -2.04 with a typical value being in the range of -0.3 to -0.8. The main point here is that the roughness change coefficient (Beta) must be determined by the user. <b>NOTE: <math>n = nc \cdot (d/dc)^{**B}</math>.</b>
Calculate n for Wet Cells (check box)	Allows user to have the program calculate roughness coefficient if roughness values are not supplied, or to supply the roughness coefficient for each cell. Blank = uses n from /Edit/Cross Sections/ Coordinate Data, or calculates n if n not supplied. Checked = uses calculated n for cells with water, n from ../Coordinate Data for dry cells for which n was supplied, and an estimated n for dry cells where n was not supplied.

#### Velocity Adjustment Factor and Mass Balance

*Use Velocity Adjustment Factor:* {tc /14 “Use Velocity Adjustment Factor } This option in essence will allow the user to ignore application of the VAF to achieve a mass balance within the VELSIM model. If this option is not checked, mass balance determined from application of the VAF will be ignored. In most cases, this box should be checked so mass balance will be enforced and the VAF applied.

*Controlling Roughness:* Several options are available to the user to control the way in which the VELSIM program will use roughness.

*Calculate N for Wet Cells* {tc /14 “Calculate N for wet cells}: This option allows the user to control the way in which the VELSIM program will calculate roughness or how it uses the roughness if supplied (i.e., Manning’s n).

If not checked: This option instructs the VELSIM program to use roughness for a cell if it is input in the coordinate data. If n is zero, the VELSIM program will compute the Manning’s n value if a velocity is available, use an adjacent value if available, or use the default value of 0.06.

If checked: This option will result in VELSIM calculating the Manning’s n value for cells that are wet, using Manning’s n if supplied for dry cells, or estimating Manning’s n for dry cells if the Manning’s n value in the cell is 0.

*Limit Manning’s n* {tc /14 “Limit Manning’s n}: This option allows the user to specify the maximum and/or minimum value of the roughness computed with the Manning’s equation during the simulation of velocities. The maximum and/or minimum value is specified in the input cells provided in the /Models/Velocity/Options Window.

If not checked: This will result in no limit on value of the estimated Manning's n value.

If checked: 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.

*Variable roughness coefficient {tc /14 "Variable Roughness Coefficient}*: This option allows the user to adjust the roughness in a cell as a function of depth in a cell. This option can help reduce the negative impacts arising from too high a roughness at edges of the stream calculated at lower discharges that would be expected to become less rough as flow (i.e., depth) increases. NOTE: Leave the Velocity Adjustment Factor box blank or the results will be irrational when using this option.

If not checked: The program will not calculate variable roughness.

If checked: The program will adjust roughness as a function of discharge and requires the user to specify a B exponent in the box provided in the **/Models/Velocity/Options** Window.

The general equation for changing roughness as a function of depth is:

$$N = n_c * (d/d_c)^B \quad (2-31)$$

where: n = depth adjusted Manning's n value for the cell  
n<sub>c</sub> = calibration Manning's n value for the cell  
d = depth of the cell at the current discharge  
d<sub>c</sub> = depth of cell at the calibration discharge  
B = an empirical coefficient in the range from -2.04 to 0.0

The estimation of "B" for use in variable roughness has received little discussion in the literature and only those with an advanced familiarity with hydraulic modeling should consider the use of this option.

## Evaluating Quality of the Hydraulic Modeling

In the preceding sections, the basic theory and steps to achieve the calibration and simulation of both water surface elevations and velocities were presented. This section address some of the more fundamental issues in evaluating the quality of the hydraulic modeling effort. Evaluation of water surface elevations is discussed first followed by a discussion of velocities.

### *Evaluation of Water Surface Modeling*

#### Predicted Versus Observed Water Surface Elevations at the Calibration Flows

Perhaps the most fundamental diagnostic of the quality of hydraulic modeling of the water surface elevations is how close are the predicted and observed water surface elevations at the calibration flows. This leads to the question of how close is close enough? Unfortunately, no readily available answer can be dogmatically stated. In general, the user should attempt to match the observed and predicted water surface elevations with no error, but this represents a case not readily achieved in applied hydraulic modeling. The user will often be faced with trading accuracy at one set of measured calibration flows to achieve a better fit at over the full range of calibration flows. For example, the user may be able to replicate the observed water surface elevation longitudinal profile using WSP at the lowest calibration

flow but no RMOD can be found to achieve an exact match for the high calibration water surface profile. An alternative re-calibration of the WSP model to the high flow may result in replication of the longitudinal profile, but again, no RMOD can be found which adequately replicates the low flow profile. In this instance, the user is likely to use the WSP model which is most accurate nearest to the flow range in which the instream flow questions are likely to be the most contested. As a general guideline, in most applications predicted versus observed water surface calibration errors which are on the order of 0.01–0.02 feet can be achieved. It is not uncommon; however, that a single or a few cross sections may deviate more (e.g., 0.03–0.05 feet or more) depending on the characteristics of the channel geometry, gradient, left versus right bank differences in water surface elevations (remember that only a single value is used for all models). Potentially, a hydraulic control may have been missed during field collection or a hydraulic control is migrating within the channel over the range of discharges collected. It is possible however, to evaluate the application or performance of each of the models and demonstrate that the “best” calibration/model combination achievable with the available data is actually used in the study. It may not be possible to overcome poor model performance with the collection of new or additional data. In such a situation, the degree of uncertainty must be clearly reported and kept in the forefront during the evaluation of study results.

### Longitudinal Profiles of the Water Surface Elevations

A second measure of the quality of the modeling for water surface elevations is the examination of the longitudinal profiles of the water surface elevations over the entire range of simulated discharges. That is, where the cross sections are all measured to a common survey datum, the longitudinal WSL plots can be examined to determine whether or not water “flows uphill”. Such a situation would indicate that the range of simulated discharges should be restricted for the application of that particular WSL model to flow ranges over which the results are consistent (i.e., water flows downhill). In many applications, one or more models (e.g., STGQ and MANSQ) may perform well within the range of the measured calibration discharges but only work well at some reduced range of extrapolated discharges. At these higher discharges of interest, the only WSP model may be adequate and the user can elect to WSP to simulate over all ranges of flows or for only the higher flows where the other models would not be appropriate.

### Valid Ranges of Simulated Discharges

Some individuals have used the absolute range of simulated discharge, that is, how much higher than the highest calibration flow and how much lower than the lowest calibration flow, as a measure of the quality of the simulations. In earlier PHABSIM manuals, ranges of “acceptable” simulations have been reported as 0.4 to 2.5 times the measured discharges. Under some circumstances a range of 0.2 to 1.5 has also been reported. The user should note that, from a functional, algorithmic, or mathematical perspective, **none** of the models (i.e., STGQ, MANSQ, or WSP) are inherently restricted to any range of acceptable simulation limits from a hydraulic perspective. In some applications, very restrictive ranges are required due to channel configuration, model performance and adequacy of the available data, while in others, extremely wide ranges (i.e., 0.1 to 10) are justified by model performance. What constitutes a valid range of simulated discharges in the absence of poor model performance (i.e., “water flowing uphill”, large calibration errors, etc.) is a matter of professional judgement. At present, no rigorous peer reviewed evaluation of WSL simulation limits using any of the hydraulic models for specific types of channels and site specific field conditions has been undertaken. The user is cautioned that a reasoned limit to the reliable range of simulations should be based on model performance given the available data rather than an arbitrary “rule of thumb”.

### *Evaluation of Velocity Modeling*

Perhaps one of the most difficult aspects of evaluating hydraulic simulations involves the evaluation of the velocities. When no calibration velocities are available, it is a matter of professional judgement as to the utility of the velocity distributions based on depth as long as the obvious “errors” such as high velocity artifacts at the stream margins have been corrected. Another potential indication of problems in the simulations would be extremely “odd” VAF relationships which have no rational basis in physical characteristics at a cross section.

In those instances in which a single velocity set has been used in the simulations, it is a matter of professional judgement as to the quality of the simulations, assuming that any erroneous velocity errors have been accounted for. However, if during a review of the channel characteristics for the cross sections it is determined that gross changes in channel geometry occur at some “threshold” water surface elevation (i.e., discharge), then the velocity simulations should be carefully examined to determine if the distribution across the change in channel geometry makes rational sense. This situation often arises where only a single velocity set was collected at a low flow or alternatively at only the high flow and a large “floodplain” type geometry exists. It is unlikely (but not impossible) that a standard application of the single calibration velocity set will reflect the velocity magnitudes and distributions across such a radical change in channel geometry. Modification of the velocity simulations using professional judgement is the only real option if the collection of an additional velocity calibration set(s) cannot be accomplished under the constraints of the project.

In those instances where multiple velocity sets have been collected, the user can easily check the validity of the velocity simulations by comparing the predicted velocities to one or more of the other calibration velocity sets. In the event that the predicted versus observed velocity profiles are not within an acceptable range, then one or more of the other calibration velocity sets should be used for the appropriate range of discharge. Channel geometry changes in this situation can often provide guidance to the analyst for the water surface elevation and hence discharge ranges, that a particular velocity calibration set might be most appropriate. Again, any VAF functional relationship which deviates from the “expected” relationship should have a physical justification based on site-specific characteristics.

## Chapter 3. Habitat Suitability Criteria

### Objectives

This chapter briefly introduces the basic nomenclature and common types of habitat suitability criteria used in PHABSIM. For a more detailed discussion of this subject, the reader is referred to Bovee et al. (1998).

### Laboratories

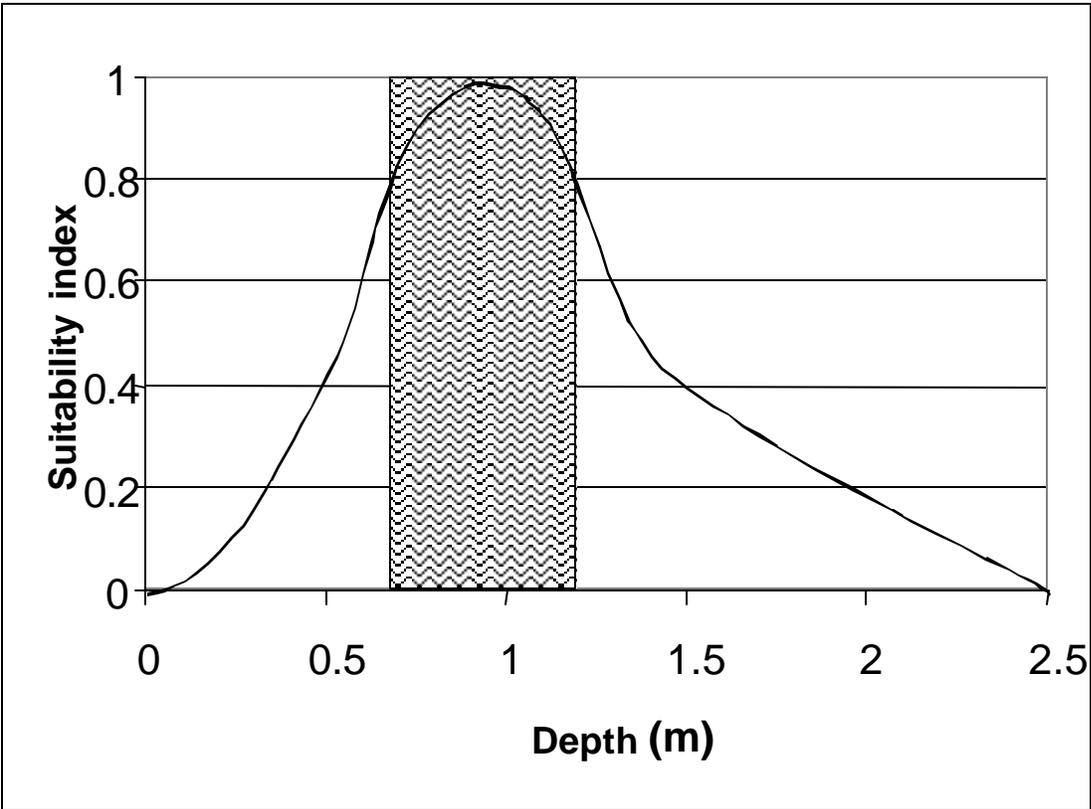
The associated exercise for this material is Laboratory 7. That exercise reviews the HSC numbering convention and the mechanics of managing HSC curve sets within the PHABSIM for Windows environment.

### Introduction

Successful implementation of PHABSIM requires the acquisition of accurate and realistic habitat suitability criteria for the target organism(s) being evaluated. Perhaps more important than accuracy and realism, however, is buy-in from the stakeholders. Because the output from PHABSIM is extremely sensitive to even subtle differences in habitat suitability criteria, establishing the credibility of the criteria can be of utmost importance. Sometimes, establishing credibility requires a scientifically designed study to define a species' habitat characteristics. At other times, the habitat suitability is the result of expert opinion and negotiation. A key concept for PHABSIM analysts is that there is no universal best way to develop habitat suitability criteria. There are many ways to develop criteria, and alternative approaches to using them in PHABSIM, all of which have certain advantages and disadvantages. In simplest terms, criteria can be distinguished by their format and the type of information used to develop them.

### Format

Use of the term format refers to the way that the habitat suitability criteria (HSC) are presented. In practical terms, there are only two viable formats for use in PHABSIM: binary or univariate curve (Figure 3-1). The binary format, shown as a shaded rectangle, brackets a range of a continuous variable (e.g., depth, velocity, distance from shore). Binary criteria act as simple on-off switches: the suitability index for a variable is 1.0 if it falls within the bracket and is 0.0 otherwise. Different ranges can be used to represent distinct categories of microhabitat quality for the target species. For example, a relatively narrow range can define habitat conditions preferred or selected by a life stage or a more all-encompassing range can define conditions the organism will use, but not seek out. Binary criteria can even be used to describe conditions avoided by the target species. In this case, the output from PHABSIM would quantify unsuitable, rather than suitable, microhabitat. **Note:** Binary criteria as used in PHABSIM are really specialized forms of the univariate curve, because vertical lines (e.g., two y-values for a single value of x) are illegal. Separating the x-values at the edges of the rectangle by a razor-thin difference closely approximates binary relations. For example, in Figure 3-1, the minimum usable depth for the binary criteria is 0.65 m. The coordinates entered into PHABSIM would be (0.649, 0.00) and (0.65, 1.00).



**Figure 3-1.** Comparison of binary and univariate curve formats for habitat suitability criteria.

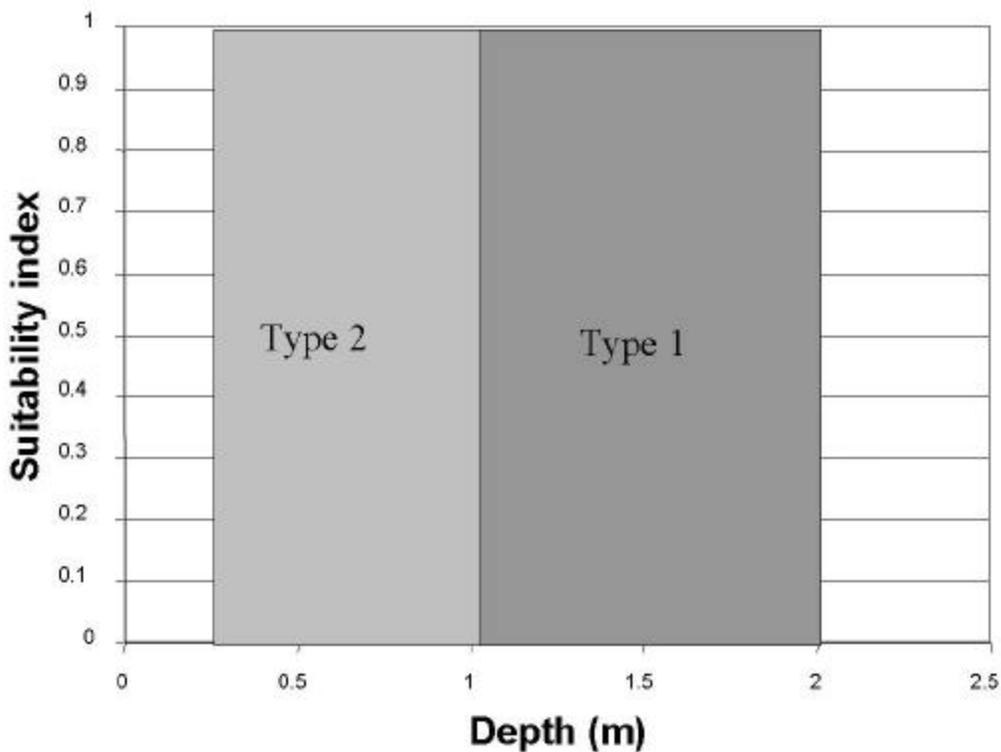
Waters (1976) proposed the use of the univariate curve (Figure 3-1) as a more robust alternative than binary criteria for expressing habitat suitability. Since then, this has become the most familiar criteria format associated with PHABSIM. The tails of the curve are designed to encompass the entire suitable range of a continuous variable, but the narrow peak of the curve represents the optimum. Intuitively, the appeal of the univariate curve is that it is all-inclusive. Credit can be granted for conditions that are of intermediate habitat value, between optimal and barely useful. As popular as it is, however, the univariate curve has its detractors. Morhardt and Mesick (1988) summarized the concerns about univariate curves and the physical habitat generated by PHABSIM as follows:

1. When calculating the composite suitability index, PHABSIM treats variables independently so potentially significant interactions between variables are ignored.
2. Weighted usable area, which results from the use of univariate curves, is an index and cannot be measured directly.
3. Different estimates of weighted usable area can be obtained by using different methods of aggregating the composite suitability index.

Weighted usable area combines elements of habitat quantity and habitat quality. A large area of low-quality habitat can produce the same weighted usable area as a small amount of high-quality habitat.

**Conditional criteria** are used to depict interactions among habitat variables that are known to be biologically important (Bovee 1986). An example of a biologically significant interaction is the use of

deep water as a form of overhead cover by some species of fish. The fish will occupy shallow water areas if overhead cover is present, but will only use deeper areas where cover is absent. This phenomenon can be represented through the use of two sets of criteria: one where overhead cover is present and one where it is absent (Figure 3-2). Presence or absence of cover can be designated in the HSC by clever usage of the channel index (e.g., 1 = no cover and 2 = cover in the cell). Wherever a channel index of 1 is encountered, usable habitat is tallied only for cells with adequate depth according to the deep-water criteria. Where the channel index is 2, usable habitat is accounted using the shallow-water criteria. In the PHABSIM software, this is accomplished by using two sets of HSC, one for deep water and the other for shallow water. The habitat areas for the two simulations are then summed to determine the total habitat, with and without cover. Similarly, surface turbulence can be modeled as a form of overhead cover by using the Froude number (a ratio of potential to kinetic energy) instead of velocity to compute the composite suitability. In this case, cells without overhead cover would be unsuitable unless the Froude number was high enough to indicate surface turbulence. As currently programmed, specialized habitats such as Froude number dependence require review of the computational details in the project.ZOUTn file to extract and sum habitat for the appropriate cells.



**Figure 3-2.** Categorical depth criteria. Type 1 applies to cells that do not contain overhead cover. Type 2 applies to cells with overhead cover.

### HSC Categories

The term category refers to the type of information and data treatment used to generate the criteria. Criteria that are derived from personal experience and professional opinion, or from negotiated definitions are defined as **category I**. These criteria can be developed relatively quickly and at minimal cost,

compared to more data-intensive approaches. Because the criteria are negotiable, obtaining consensus about the criteria may also forestall conflict over their subsequent use in PHABSIM. The principal drawback to category I criteria is that they are based on opinions instead of data. Credibility problems can arise when the criteria are presented to groups that were not involved in the original development process.

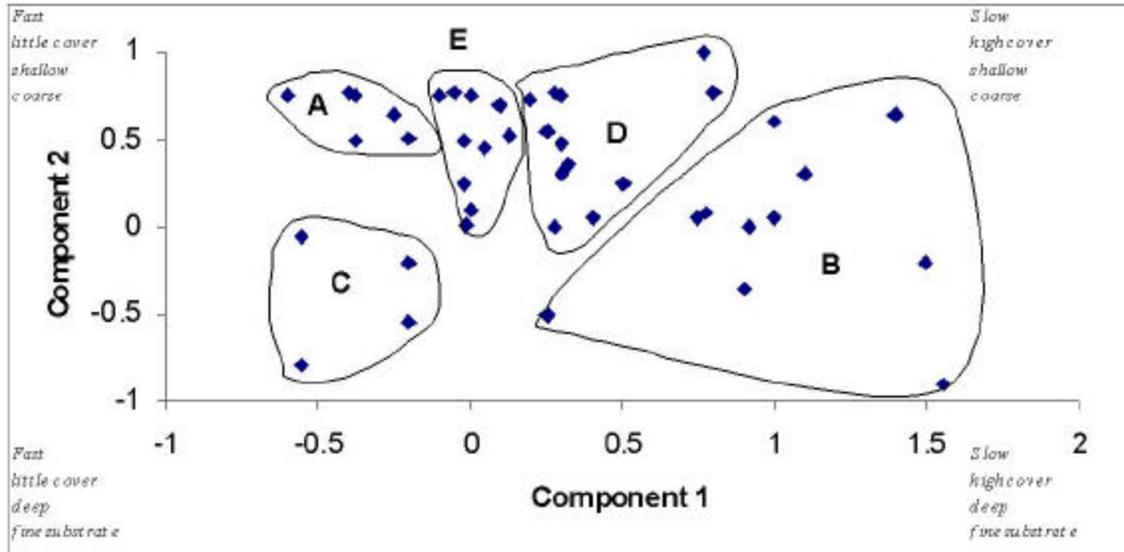
**Category II** criteria are based on frequency distributions of microhabitat attributes measured at locations used by the target species. These criteria are known as **utilization or habitat use functions** because they represent the conditions that were being occupied by the target species when the observations were made. This approach for criteria development dates back to the conceptual precursor of PHABSIM, a planimetric mapping method developed by the Washington Department of Fisheries (Collings, et al., 1972). The **Washington method** was designed to measure the amount of spawning area available to Pacific salmon at various streamflows. Because the methodology was oriented to spawning, criteria development consisted primarily of finding salmon redds and measuring depths and velocities at various locations around them. After a sufficient number of redds were measured, binary criteria were developed to encompass a specified range of the observations.

During the formative years of PHABSIM, the same basic approach for developing habitat suitability criteria was expanded to other species and life stages. One popular sampling method was to use a team of divers to intensively search numerous small reaches of stream to find locations occupied by the target species. At the end of each search, the depth, velocity, cover type, substrate (and other pertinent data) were measured at each occupied location. After measurements had been taken at 100 to 200 locations, the investigator either defined a binary range for the criteria or fit the data to a univariate curve.

Another approach to developing category II criteria is exemplified in the work of Knight, et al. (1991). They used a pre-positioned electrofishing grid to sample randomly selected locations throughout their study area. To take a sample, a grid was positioned at a pre-determined (random) location and left undisturbed for at least 15 minutes to allow fish to resume their normal activities. At the end of the waiting period, fish were collected by electrifying the frame for approximately 20–30 seconds. Immediately after activating the power supply, a seine was placed downstream of the frame so that stunned fish were swept into it. With the power active, one person kicked through the frame to dislodge benthic species. Fish captured at each location were preserved for later identification in the laboratory. Habitat attributes (e.g., depth, substrate type, cover type, and velocity) were measured at the four corners of the frame for each sample, and averaged.

A multivariate analysis of variance (MANOVA) was used to detect differences in habitat composition between samples that contained a particular species and those that did not. Principal components analysis (PCA) was used to illustrate the position of each fish species in habitat space (Figure 3-3). These analyses were used to identify habitat attributes that consistently corresponded to high abundance and diversity of fish species. Variations of this method have also been described by Felley and Hill (1983), Bain, et al. (1988), Scheidegger and Bain, (1995), and Bowen (1996).

The benefit of category II criteria is that they are based on data, not on someone's opinion. However, error can be introduced to these criteria through a **bias of environmental availability**. Manly, et al., (1993) describe this bias in the following way. Even though a resource item is highly favored by a species, it will not be used much if the resource is hard to find. Conversely, less favored resource items will be used in larger proportion if they are the only ones available. In the context of microhabitat utilization, this means that individuals will be forced to use sub-optimal conditions if optimal conditions are unavailable. By observing only the conditions used the most often in a given stream, an investigator could confuse optimal microhabitat with conditions that were merely tolerable.



**Figure 3-3.** Mean species locations in habitat space defined by principal components analysis of pooled data from seven streams in the Alabama River basin. Irregular circles encompass species with similar habitat use (e.g., Group C includes saddleback darter [*Percina vigil*], Alabama hog sucker [*Hypentelium etowanum*], black redhorse [*Moxostoma duquesnei*], and highfin carpsucker [*Carpoides velifer*]). From Knight et al. (1991).

**Category III** criteria are designed to reduce the bias associated with environmental availability. These criteria are also referred to as **electivity or preference functions**. Resource selection refers to the utilization of resources disproportionate to their availability (Manly et al. 1993). For example, suppose that 10% of the stream mesohabitats occur as riffles, but 90% of the target species are found in riffles. Such disproportionate use is interpreted as an active selection on the part of the target organism.

A wide variety of mathematical indexes have been developed to indicate selection, and in some cases, avoidance of various resource units. The index of electivity usually involves a comparison of the proportion of the resource used with the proportion available or unused. [Available includes both used and unused proportions of the resource.] The most familiar index of selection, at least with respect to habitat suitability criteria, has been the forage ratio:

$$E = \frac{U}{A} \quad (3-1)$$

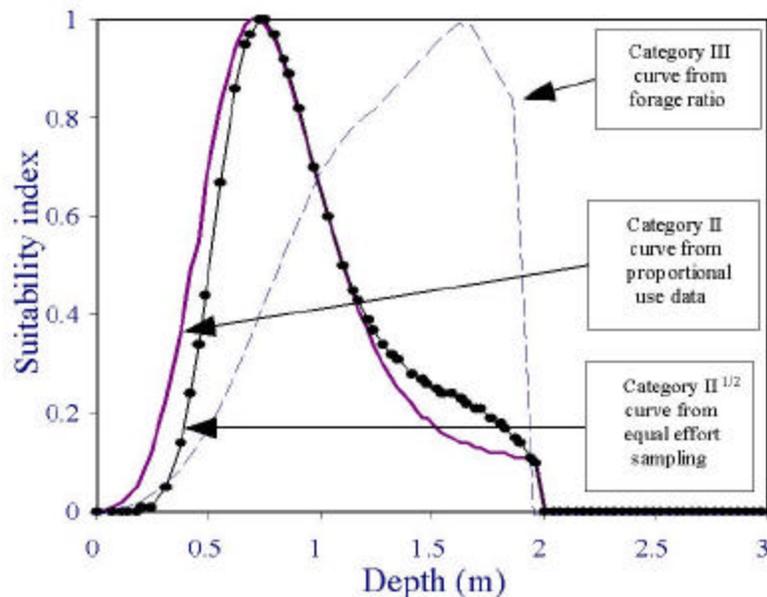
where E is an index of electivity, U is the proportion of used habitat units of category I (for example, depths between 1.0 and 1.5 m), and A is the proportion of habitat units of category I available in the sample.

The use of the forage ratio was promoted as the preferred approach for developing habitat suitability criteria during the mid-1980s (Bovee, 1986). Since then, the method has fallen from favor (Bovee et al., 1998) because the forage ratio can result in an over-correction of the criteria (Figure 3-4). An alternative

approach originates from the definition of preference given by Johnson (1980), who described preference as the likelihood that a resource will be selected if offered on an equal basis with others. Conceptually, the way this definition applies to habitat suitability criteria would be if it were possible to develop criteria in a stream with a perfectly uniform distribution of an infinite variety of microhabitat conditions. According to Johnson's definition, one could determine habitat preference simply by measuring use, because all microhabitat conditions would be equally available. Obviously, streams fitting this description are few and far between (as in non-existent). However, it may be possible to approximate this condition by altering the sampling design when collecting habitat utilization data. Following this strategy, each mesohabitat type would be sampled equally, regardless of its relative abundance in the stream. The premise underlying the concept of **equal-effort sampling** is to equalize the availability of microhabitat conditions within the sampled sub-population, to the extent possible.

### Criteria Verification

Although not a required element for running PHABSIM, criteria verification is always a good idea. Remember that in IFIM, the currency for negotiations is total habitat and alternatives are evaluated by comparison with a baseline. What this means is that habitat does not necessarily have to have a demonstrated biological connection, as long as the currency is meaningful to the stakeholders and decision-makers. For negotiations of low to medium levels of conflict, criteria can be verified simply by obtaining their acceptance among the stakeholders. When it becomes impossible to obtain consensus among the stakeholders, however, it may be necessary to conduct an empirical verification test.



**Figure 3-4.** Comparison of depth suitability curves for active adult brown trout derived from proportional use data (category II), equal effort sampling (category II  $\frac{1}{2}$ ), and forage ratio correction for availability (category III).

If PHABSIM sites are already established, one method to verify the criteria is to measure the standing crop in each site, calculate the habitat availability at the same discharge, and relate the two statistically. This procedure has two advantages. First, a significant correlation is unlikely if the criteria are incorrect, so the chances of committing a Type I error (accepting criteria when they should be rejected) are fairly remote. Second, a significant correlation lends credence to the idea that microhabitat is biologically meaningful. The disadvantages of this procedure are that the correlation may not be significant for reasons other than inaccurate criteria and the results are sensitive to the timing of the surveys. One often overlooked reason for poor correlation is the error associated with the estimate of standing crop. Before getting too excited about a lack of significant correlation, it is a good idea to examine the confidence intervals for the population estimates at each site. You may find that differences in standing crop cannot be quantified reliably enough to perform this type of test. A related problem occurs when trying to validate criteria for sport fish, because places that have good fish habitat also attract fishermen. Sometimes sites with the best and most abundant microhabitat will have the smallest standing crop, simply because all the good habitat may be “fished out.”

Thomas and Bovee (1993) presented a more robust statistical test for criteria verification. This test can be performed without having to establish a PHABSIM site and is less influenced by fishing pressure than the previous method. Also, the results of the Thomas-Bovee method are not dependent on accurate estimates of standing crop. The primary disadvantages of this method are that it requires relatively unbiased habitat use and non-use data. The results are meaningful at the individual level, but not necessarily at the population level. In other words, the criteria may be transferable, in the sense that they describe fish behavior, but there is no guarantee that habitat estimates from the criteria are related to fish numbers.

Under the Thomas-Bovee method, habitat use is determined either by complete census or sampling and a random sample of **unused** habitats is taken. Criteria to be tested are converted from univariate curve to binary format, with the optimum range for a variable defined as having a composite suitability index greater than 0.85. Usable microhabitat is defined as having a composite suitability value between 0.2 and 0.85. Suitable microhabitat is defined as the full range of conditions in which the target organism is observed. Unsuitable microhabitat is defined as all values outside the suitable range. From the criteria, each used and unused location is classified as being optimal or usable, and suitable or unsuitable.

Then, each sampled location is cross-classified (e.g., occupied-optimal, unoccupied-usable) into a 2 x 2 contingency table (Table 3-1). The null hypotheses  $H_{01}$  (optimal locations will be occupied in the same proportion as usable locations) and  $H_{02}$  (suitable locations will be occupied in the same proportion as unsuitable locations) are tested using a one-sided chi-square test (Conover 1980). The test statistic T is given as:

$$T = \frac{\sqrt{N}(ad - bc)}{\sqrt{(a + b)(c + d)(a + c)(b + d)}} \quad (3-2)$$

where N is the total number of measured locations, a is the number of occupied optimal locations, b is the number of occupied usable locations, c is the number of unoccupied optimal locations, and d is the number of unoccupied usable locations. Suitable locations are substituted for optimal locations and unsuitable locations for usable to test classifications of suitable and unsuitable microhabitat.

For a set of criteria to be considered transferable, both null hypotheses should be rejected at the 0.05 level of significance. [Note: The critical value of T at this significance level is 1.6449, and is obtained from the normal distribution table, not from the chi-square distribution. See Conover (1980) for a full discussion.]

## Discussion Items

- In PHABSIM, it is equally important to describe habitat variables used over a broad range as to find narrow habitat preferences. Sometimes, these criteria appear as thresholds, above or below which there is little selection. The empirical frequency distribution of used microhabitat may be artificially narrow, either because the range of available conditions was narrow or because of the method used to fit the criteria to the data. Such artificially narrow criteria can make PHABSIM output unrealistically sensitive to changes in discharge. If this phenomenon is suspected, it should be brought to the attention of the stakeholder group. Modifying a data-based curve on the basis of professional judgement is acceptable, if not encouraged.
- Category I criteria are as valid in an application of IFIM as data-based criteria, if they are supported by a consensus of opinion among the stakeholders. Criteria developed by a committee are often somewhat broader than those based on data, because the ranges of the criteria are often negotiated. In this respect, category I criteria rarely exhibit artificial narrowing, but can be too all-inclusive. If the criteria are too broad, PHABSIM output may be relatively insensitive to changes in discharge.
- The principal components analysis approach presented by Knight et al. (1991) differs most dramatically from the other methods we discussed. A unique advantage of this method is that it can be used to define habitat use guilds and critical habitat types. This allows the analyst to concentrate on only a few key habitat types, rather than analyzing habitat for multiple species and life stages. Furthermore, potential biological connections between the habitat type and the biology of the stream can be quantified through the statistical analysis.
- It may come as a surprise to newcomers to PHABSIM, but it is just as valid to develop habitat suitability criteria for a mesohabitat type as it is for a species. For example, suppose that riffles are considered to be a critical mesohabitat type. A riffle could be defined with binary criteria, as having a depth range between 1 and 75 cm, velocities between 45 and 90 cm/sec, and a gravel/cobble substrate (or other definitions as negotiated among stakeholders). PHABSIM could then be used to determine how much area met those criteria over the range of simulated discharges.
- There is no unbiased way of collecting habitat use data. Every kind of sampling gear or observation technique has some sort of limitation that can result in biased data. For example, even with good visibility, divers are more apt to spot fish in shallow water than in very deep pools. They are also more likely to find active fish than those at rest, because the human eye is attracted to movement. As another example, electrofishing is less effective in deep water, and for safety reasons may be restricted to depths less than 1 m. When evaluating criteria, consider the limitations of the methods used to obtain the data in the context of the source stream from which the data were collected. If you believe that the criteria are unduly biased, refer to the first observation.
- One of the assumptions related to the estimation of resource selection functions is that the variables, which actually influence selection, have been correctly identified and measured. Perhaps the most common misconception about PHABSIM is that the only microhabitat variables that can be used are depth, mean column velocity, and substrate. In fact, PHABSIM can accept a wide range of variables, provided that they are related to the hydraulics or the structural characteristics of the stream. Examples of alternative microhabitat variables include: nose velocity, adjacent velocity (important for feeding stations), cover type, distance to cover, distance from shore, proximity to another habitat type, sheer stress, Froude number, depth-velocity products (important for recreational activities), and depth as a form of cover. Additionally, it is possible to use PHABSIM in conjunction with commercially available spreadsheets to derive alternative habitat indexes, such as habitat diversity. Be aware that

you are not limited to the “default” variables. With a little imagination, it is usually possible to tweak PHABSIM to include microhabitat attributes known to be important to the target species.

## Organization of Habitat Suitability Criteria in PHABSIM

HSC number in PHABSIM for Windows arranges habitat Suitability Criteria (HSC). The HSC numbering convention consists of a four digit species identifier followed by a two digit life stage identifier. Each species and each life stage is also identified by a text description. A typical HSC curve would be identified as follows:

100102      Brown Trout      Fry

The species identifier 1001 is associated with Brown Trout and the life stage identifier 02 is associated with fry. The PHABSIM software organizes HSC selection options and the format of the results from habitat calculations based on this number and text convention. Thus, it is important that each species/life stage have both a unique numerical and text identifier.

One may have different kinds of habitat suitability criteria for the same species in a project. That is, one may have a day time HSC series denoted by 1001 for Brown trout and a night time series denoted by 1101. Following this example, an HSC numerical identifier of 110102 would represent Brown Trout Fry habitat suitability at night. No strict correspondence between numerical identifier and life stage is enforced. Thus a curve number 110126 could be used for nocturnal Brown Trout Fry and the software would process it properly.

Problems can arise, however, if one attempts to assign different text identifiers to the same numerical species identifier and if either the species or life stage text identifiers are left blank. The PHABSIM for Windows interface is looking for consistent association of species text and numerical identifiers across all life stages and for unique life stage names associated with the numerical life stage identifier.

The HSC are entered in PHABSIM as x,y pairs of data to describe univariate relations for the suitability of depth, velocity, channel index, and temperature. Each variable must have an initial ordinate of 0 and a final ordinate of 100. Often, these curves begin with 0,0 and end with 100,0. A typical set of HSC is illustrated in Table 3-2.

**Table 3-2.** Brown trout adult HSC ID number and criteria coordinates.

Brown Trout – Adult			HSC ID Number: 100101		
Velocity	SI	Depth	SI	Channel Index	SI
0.0	0.40	0.0	0.00	0.0	1.00
0.5	1.00	1.0	1.00	1.0	1.00
2.5	0.00	100.0	1.00	9.0	1.00
100.0	0.00			100.0	1.00

From this format, it can be seen that exact binary criteria cannot be represented. Rather, a close approximation is used. For example if binary velocity criteria for adult brook trout consisted of a range from 0.5 to 2.0 ft per second that had a suitability of 1.0 and all other suitability values were 0.0, the representation in PHABSIM might be as follows (Table 3-3).

**Table 3-3.** Representation of binary brook trout adult velocity criteria coordinates.

Velocity	SI
0.00	0.00
0.49	0.00
0.5	1.00
2.0	1.00
2.01	0.0
100.0	0.00

### *Accessing Habitat Suitability Criteria in PHABSIM for Windows*

HSC are entered and managed in the **\Edit\Suitability Curves** window. This window has menu items for **File**, **Edit** and **Curve**. The **File** menu allows for importing existing HSC criteria from text files (PHABSIM Version 2. Curve files) or from other PHABSIM for Windows projects. Thus it is possible to use an existing curve set in a new study by simply importing the old HSC data. Similarly, the import feature makes it possible to create a project with the purpose of maintaining a library of HSC curves and select the desired HSC for each study as needed.

The **Edit** menu allows the user to interactively add new curves, copy curves to new curve ID numbers and species/life stage names and to delete individual curves. One may add a new curve by supplying ID numbers, species/life stage names and the respective HSC coordinates for depth, velocity and channel index. To change from velocity to depth, channel index or temperature, one clicks the appropriate radio button in the **Curve Type** box to the upper right. Click the desired radio button (i.e. depth) and enter the HSC values in the table. Be sure to fill in all HSC tables before exiting. Or, for example, new channel index criteria can be assigned to an existing curve by making a copy of the curve, supplying new identifying information and then entering new coordinate data for the channel index values. The delete function deletes the curve currently displayed in the window.

The **Curve** menu allows selection of the curve displayed in the window by ID number or by moving backward and forward in the list of HSC contained in the project. It also provides for displaying graphs of individual curves or of the four HSC in each curve set.

One can display the individual HSC as they are being entered when adding curves under the **Edit** menu by clicking the **Graph** button located at the lower right of the window. By sizing or dragging the graph window and the Suitability Curve window one can view data as it is being entered and catch data entry errors as they occur. For more complicated HSC graphs, using the zoom feature may enhance viewing of particular portions of the curve. The graph automatically updates when a different curve is selected. As you click the different radio buttons for depth, velocity, etc. the graph changes to that variable.

## **Summary of Chapter 3**

This chapter covered a brief outline of the numerous considerations needed when using HSC in a PHABSIM analysis. Because HSC are often the source of the greatest variability in PHABSIM study

results, it is of utmost importance that consensus as to the form and numerical values of the criteria be achieved among stakeholders **prior** to beginning the actual PHABSIM work. The processes for developing habitat suitability criteria are outside the scope of the PHABSIM for Windows software so the discussion in this chapter is provided as a very brief introduction to the topic. Readers are referred to the various references for more detailed coverage of this topic.

The chapter concludes with a description of the HSC data management capabilities of PHABSIM for windows. In any study, the HSC need to be entered into the PHABSIM project before proceeding to the habitat analysis process. Habitat analysis in its numerous forms is described in Chapter 4.

## **Chapter 4. Habitat Modeling**

### **Objectives**

The objectives of this chapter are to introduce the basic concepts of habitat modeling used within PHABSIM followed by a presentation of the specific computational processes important to the successful application of each habitat model within PHABSIM.

### **Laboratories**

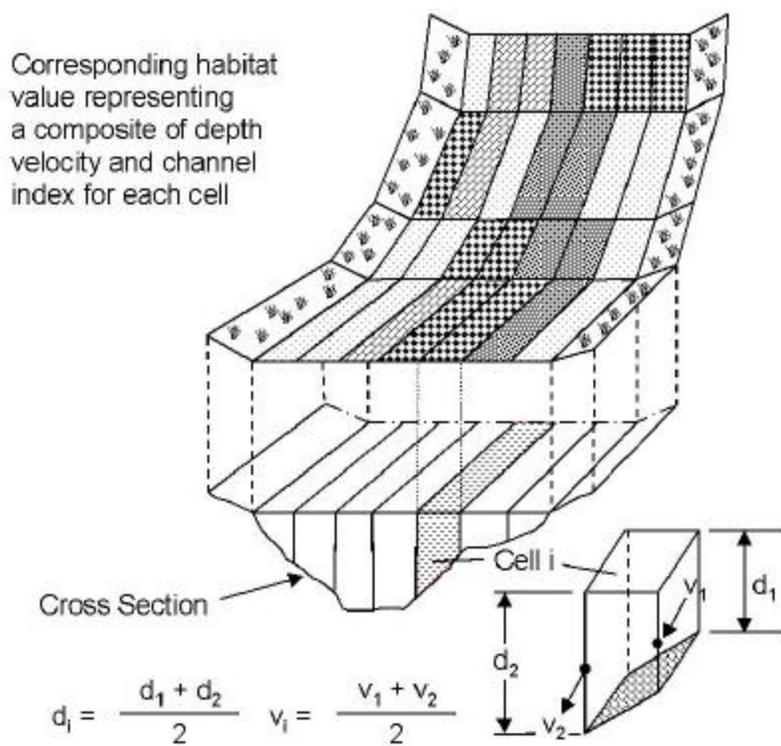
The associated laboratory exercises for this chapter will introduce the specifics of the two average parameter models AVDEPTH and AVPERM in Laboratory 8, general habitat modeling (HABTAE) in Laboratory 9, conditional velocity modeling in Laboratory 10, and finally lateral migration in Laboratory 11.

### **Introduction**

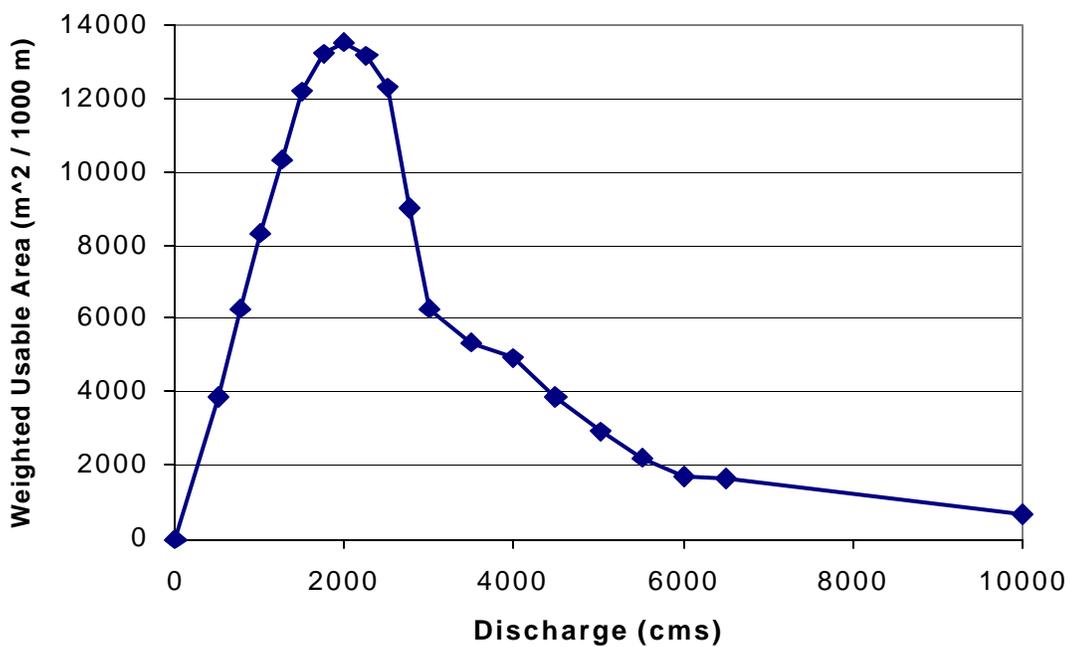
At this point in a PHABSIM analysis, the needed hydraulic model(s) has/have been applied to determine characteristics of the stream in terms of depth and velocity as a function of discharge for the full range of discharges to be considered for the study. In the habitat modeling process, this information is integrated with habitat suitability criteria (HSC) to produce a measure of available physical habitat as a function of discharge.

The general theory behind the habitat modeling programs within PHABSIM 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 reach. The stream reach 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) as illustrated in Figure 4-1. The depth and velocity for each cell is the average of the simulated depth and velocity values obtained from the hydraulic simulation phase of PHABSIM. Depth and velocity attributes vary with simulated changes in discharge, causing changes in the amount and quality of available habitat. The end product of the habitat modeling is a description of habitat area as a function of discharge as illustrated in Figure 1-4 reproduced here as Figure 4-2 for ease of reference.

This habitat-discharge relationship is the basis of further analysis from which fishery and recreation management decisions are developed in IFIM. By linking the habitat-discharge relationship with flow time series data, a habitat time series can also be developed as described in Chapter 5. 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. When combined with a habitat time series, the habitat discharge relation is particularly useful in evaluating potential changes in species composition, because of the associated changes in the hydraulic characteristics of the stream reach as a function of discharge.



**Figure 4-1.** Matrix of habitat cell attributes in a PHABSIM study site.



**Figure 4-2.** Habitat-flow relation for one species/life stage derived from a PHABSIM analysis.

This chapter presents material on how the habitat models view a stream based on the information passed from the hydraulic simulation programs; how the habitat models use the reach lengths, upstream weighting factors, and their linkage to habitat mapping or representative reaches to derive area (or volumes); and the generalized conceptual and analytical approaches used in the habitat models to integrate the hydraulic and suitability curve data to produce the basic metrics of habitat quantity and quality. The chapter concludes with a detailed description of each of the specific habitat models within PHABSIM and the available computational options within each habitat model.

The following section provides a discussion of several ways in which the output from the habitat models can be interpreted and how model results fit within the broader context of ecological assessment of alternate flow regimes.

## Habitat Model Computational Cells

Figure 4-1 shows a generalized representation of a river segment for a series of transects that define a matrix of habitat cells with their associated attributes of depth, velocity and channel index (i.e., substrate and cover). These habitat cells represent the basic computational cells used by the various habitat programs to derive relevant indices of available habitat. This information is obtained from the hydraulic simulation models, as described in Chapter 2. In PHABSIM for Windows, all habitat models view a habitat computational cell the same way. In previous versions of PHABSIM there were two different cell definitions. As noted in Chapter 1, the change to one type of habitat cell definition may affect the computed habitat values when certain conditional habitat options are selected.

As noted above, all habitat programs now represent the habitat computational cells as bounded by the points where verticals were measured in the field. The hydraulic models define a cell as one-half the distance to the next vertical in each direction. Thus, the hydraulic models simulate depths and velocities (shown as  $d_1$ ,  $d_2$ ,  $v_1$  and  $v_2$  in Figure 4-1) at the verticals used in the habitat models.

### *Deriving Habitat Computational Cell Areas and Volumes*

During the discussion of the project data (see Chapter 2), the distance from the previous cross section and upstream weighting factors supplied in **/Edit/Cross Sections** were described. The distance from the previous cross section (or reach length) and the upstream weighting factors (or reach length weighting factors) are used by the habitat models to assign a length to the habitat computational cells in the longitudinal direction for each cross section and, thereby, impart a surface area to each cell. Since the bed elevations are also known, several habitat model options can also be used to derive individual cell volumes and stream bed areas for use in calculating available habitat. A clear understanding of the relationship between the reach lengths and reach length weighting factors is necessary for proper use and interpretation of the habitat modeling results as illustrated in Figure 4-2 and discussed below.

### Representative Reaches

Figure 4-3 illustrates a stream segment in which three cross sections have been used to characterize this “representative” reach. Each cross section was placed in a unique habitat feature as indicated. In Figure 4-3, the reach lengths measured between the left and right bank head pins at each cross section have been indicated, starting at the downstream cross section and moving in an upstream direction. The reach length at the downstream-most cross section by definition is zero (0) since there is no previous cross section and this is the value entered in the **/Edit/Cross Sections/Cross Section Data** field for length for the first cross section.

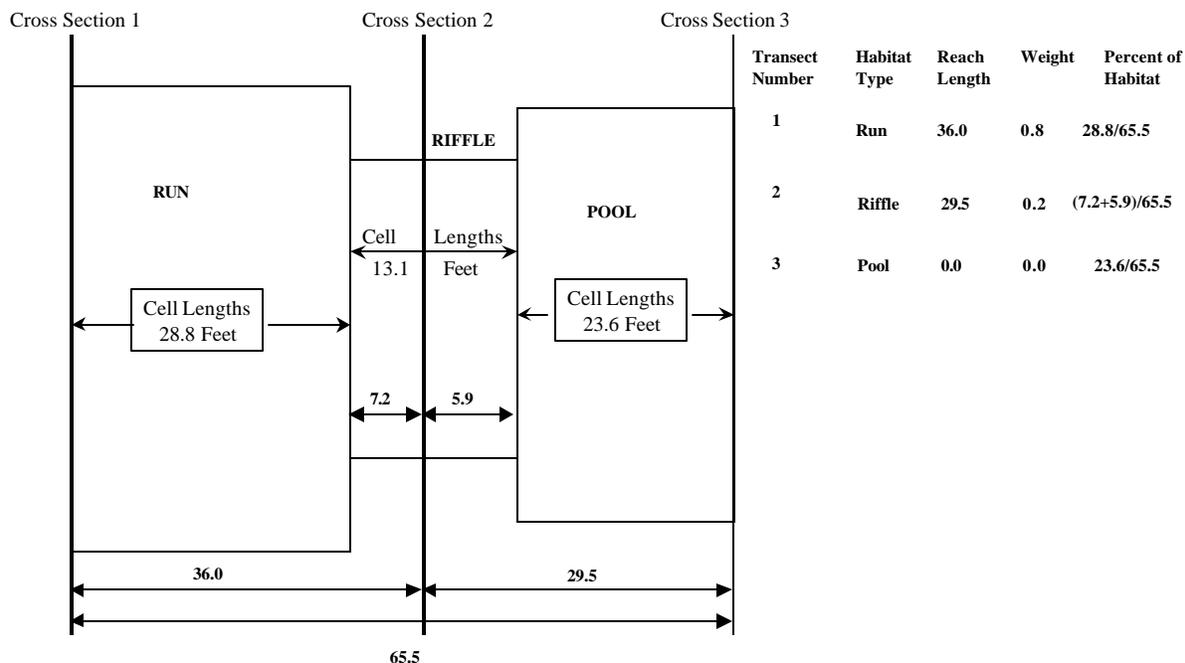


Figure 4-3. Derivation of reach length weighting factors.

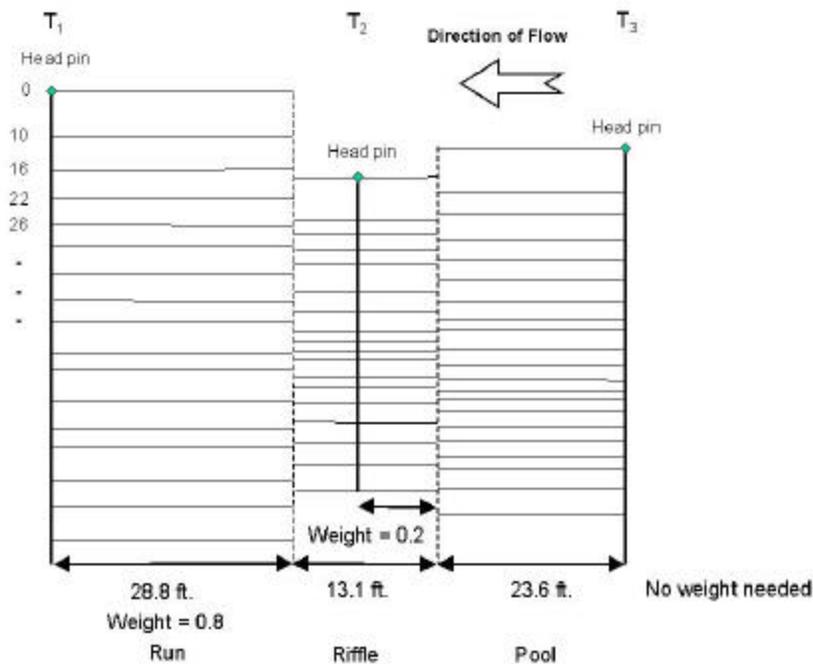
The actual reach lengths entered in **./Cross Section Data/Length** for the remaining cross sections are typically the average of the left and right bank distances measured between adjacent cross section head pins. The reach lengths in this instance define the physical spacing of the cross sections within the reach as plan view rectangles without "bends". Use of the **Left** and **Right Bank Weighting Factors** can accommodate the actual left and right bank distances to preserve the spatial orientation or "bends" is discussed later in this chapter.

The **Reach Length Weighting Factors** (upstream weighting factors) are the values used in the habitat models in conjunction with the reach lengths to derive the longitudinal distance represented by cells at each cross section. In the example illustrated in Figure 4-3 in which a representative reach approach has been undertaken, the investigator would define during field data collection how far in the upstream direction, the attributes represented at the current cross section (i.e., habitat feature) extend toward the next upstream cross section. This upstream weighting factor is entered in the **/Edit/Cross Sections/Cross Section Data** field for **Upstream WF** for that cross section.

For example, the investigator may have decided that the run habitat type represented by the downstream most cross section extends approximately 80% of the average distance upstream to the second cross section located in the riffle. In a similar manner, the investigator may have also decided that the second cross section located in the riffle only represents characteristics approximately 20% of the distance moving upstream to the transect located in the pool. This would result in an upstream weighting factor for the downstream-most cross section having a value of 0.80 and a value of 0.20 at cross section two. Any value between 0.0 and 1.0 may be supplied at the last cross section located in the pool since there is no upstream cross section and the area upstream of the last cross section will not be considered when calculating habitat. The resulting cell lengths for the downstream cross section would therefore be derived by distance calculated from the product of the Reach Length Weighting Factor at Cross Section One (i.e., 0.80) times the Reach Length Distance at Cross Section Two (i.e., 36.0) or  $(0.80 \times 36.0) = 28.8$  feet in Figure 4-3. This implicitly defines a longitudinal distance for cells at the second cross section of 7.2 feet in the downstream direction (i.e.,  $36.0 - 28.8$ ). The remaining longitudinal distance in the upstream direction at cross

section two would be computed by taking the upstream weighting factor at cross section two (i.e., 0.20) and multiplying it by the reach length value entered on the XSEC data line at cross section three (i.e., 29.5 feet) to derive an upstream longitudinal distance of 5.9 feet. The **total** longitudinal distance (e.g. length) of all cells at cross section two is then derived by the addition of these two parts and would yield 13.1 feet for this example. The length of all cells at cross section three is derived by subtracting the upstream distance at cross section two (i.e., 5.9 feet) from the reach length distance entered for cross section three. In this example it would be 29.5–5.9 or 23.6 feet.

Note that the last cross section does not have a contribution of a longitudinal distance in the upstream direction and that the first cross section does not have a length contribution in the downstream direction. Figure 4-4 illustrates the final "internal" representation of the habitat computational cells as defined in the previous example.



**Figure 4-4.** Habitat computational cells represented within the habitat models.

From this approach to cross sections weights, if the upstream weighting factor at cross section two had been specified as 1.0, then cross section three would have no length in the habitat model and, therefore, not contribute to the computation of available habitat. Similarly, if the upstream weighting factor at cross section one had been set to 1.0 and the upstream weighting factor at cross section two had been set to 0.0, then cross section two would have effectively been eliminated from use in the habitat models. The use of reach lengths and, in particular, upstream weighting factors to "eliminate" a cross section or cross sections such as hydraulic controls used for hydraulic simulation purposes only, is easy to accomplish using such an approach.

Changing upstream weighting factors to reflect relative contributions of specific types of habitat and impacts on the overall contribution to habitat availability can also be facilitated using these concepts. The next section illustrates use of the reach lengths and upstream weighting factors to represent stream segments in which specific types of habitats were sampled and which represent the proportions that these specific habitat features occur within a longer stream.

### *Habitat Mapping and the Idealized River Reach Approach*

For illustration purposes, assume that a river segment has been habitat mapped (see Bovee, et al., 1998 and Morhardt, et al., 1983) over some suitable length and it was determined that four distinct habitat types were recognizable and were found to occur in the following proportions based on measured longitudinal distances:

20% pools      60% runs      10% riffles      10% glides

The investigator randomly selected two locales of each habitat type and subsequently collected data from each set of four habitat types and now has successfully modeled the hydraulic conditions at 8 cross sections (i.e., 4 habitat types X 2 cross sections / habitat type). The investigator would now like to conduct habitat modeling at all 8 cross sections such that the weight given the individual cross sections reflects their proportional contribution as measured by the habitat mapping indicated above. Therefore, it is desired that both cross sections in pools total 20%, both cross sections in runs total 60%, both cross sections in riffles will total 10%, and both cross sections in glides total 10%. Because a stratified random sampling procedure was used, all 8 cross sections were collected independently and were spread out over 20 miles of river so the representative reach approach described in the previous section is not an option. The following example is one of several possible approaches which combine reach lengths and upstream weighting factors to weight the relative contribution of each cross section in order to produce the desired habitat mapping weighting in the calculated WUA results.

First, assume that all the transects represent 100% of an idealized river reach or alternatively, consider the idealized river as being 100 feet long. The basic strategy, is to specify reach lengths and upstream weighting factors for each **/Edit/Cross Sections/Cross Section Data** field such that the combination of distance and weights produce the following results: (1) both of the pool transects have a combined total habitat computational cell length of 20 feet (or 20%), (2) runs represent a total of 60 feet, (3) riffles represent 10 feet, and (4) glides represent 10 feet. This approach requires using the STGQ and/or MANSQ programs because these programs treat each cross section independently. Note, WSP can be used to simulate a pool transect provided that the control transect governing the pool is “weighted out” as described above and the pool transect reach length fits into the overall distance weighting scheme. Assuming the investigator has decided to enter the data grouped by habitat type and in the order of the habitats listed above, we only need to specify the appropriate reach lengths and upstream weighting factors at each cross section, which could be accomplished as indicated in Table 4-1.

Note that the “solution” for this example could have been handled in any number of different ways to yield the same basic results. The habitat models will produce an index of habitat availability (i.e., WUA) in units of square feet per 1000 feet of stream and therefore using total distances of 1000 or 10,000 for the total idealized reach will only “scale” the WUA magnitudes by factors of ten. This is different than that obtained from using a representative reach since, in that approach, the actual reach lengths are spatially dependent. If the relative combinations between reach length and weighting factors result in approximately the same relative contributions of specific habitat types sampled, then the functional relationship between habitat and discharge will be nearly the same using either approach.

**Table 4-1.** Example of transect weighting based on reach length and upstream weights to duplicate percentage of habitat types within a study reach.

Transect number	Habitat type	Reach length	Weight	% of habitat
1	Pool	0	1.0	10
2	Pool	10	1.0	10
3	Run	10	1.0	30
4	Run	30	1.0	30
5	Riffle	30	1.0	5
6	Riffle	5	1.0	5
7	Glide	5	0.5	5
8	Glide	10	0.0	5 (from previous remainder)

The “end product” of these efforts within the hydraulic simulations using STGQ or MANSQ is the generation of an array of stream cells representing each cross section as illustrated in Figure 4-1 at each simulated discharge. This “array” of cells and corresponding attributes of depth, velocity, and channel index is passed to the habitat programs and, as indicated above, represent the basic habitat computational cells. The use of these attributes and associated area, volume, or bed area in each cell in conjunction with the HSC curve coordinate data to generate an aggregated index of available habitat is discussed in the next section.

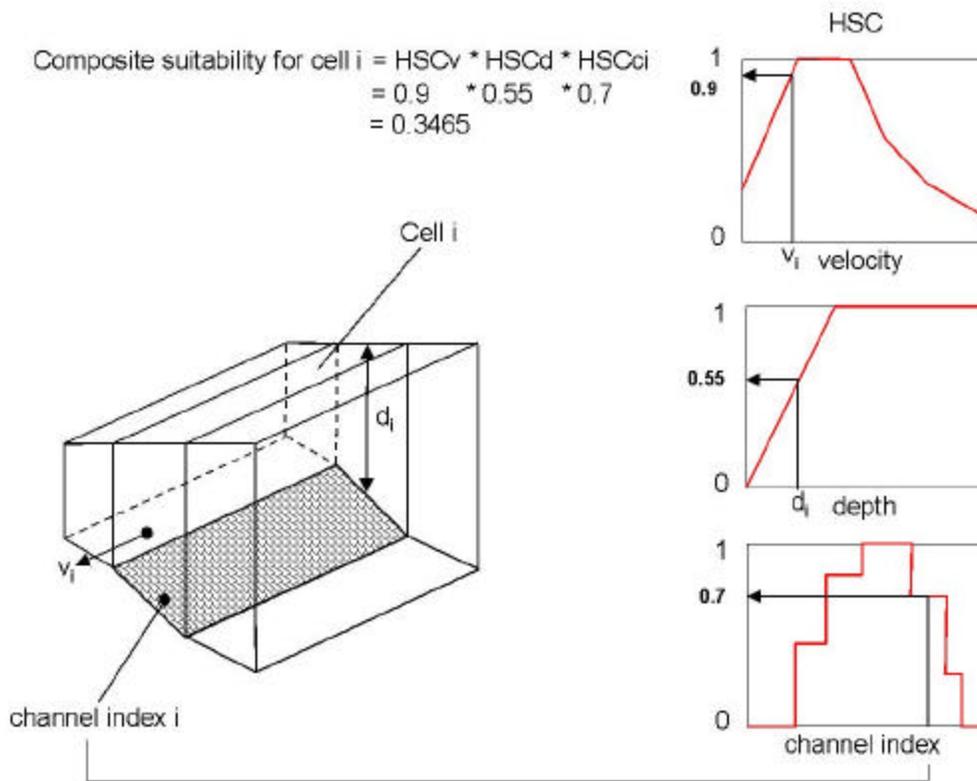
### **Integrating Habitat Suitability Criteria Curves and Computational Cell Attributes**

The habitat models rely on HSC relating hydraulic and channel characteristics to the habitat requirements of fish, other aquatic species, or even recreational activities. These HSC are used to describe the adequacy of various combinations of depth, velocity, and channel index conditions in each (or the adjacent) habitat computational cell to produce an estimate of the quantity and or quality of habitat in terms of surface area, bed area, or volume. As noted earlier, this metric is referred to as Weighted Usable Area (WUA) and has units of square feet per 1,000 linear feet of stream length (regardless of stream width). WUA is computed within the reach at a specific discharge from:

$$WUA = \frac{\sum_{i=1}^n A_i * C_i}{\text{Reachlength (1,000 feet)}} \quad (4-1)$$

where:  $A_i$  = surface area of cell  $i$   
 $C_i$  = combined suitability of cell  $i$  (i.e., composite of depth, velocity and channel index individual suitabilities)

The combined suitability of the cell is derived from the component attributes of each cell (see Figure 4-1) which are evaluated against the species and life stage habitat suitability curve coordinates for each attribute to derive the component suitabilities as illustrated in Figure 4-5. Once the individual component suitabilities have been determined, the user has the option to select several different ways of aggregating them for a cell into a single composite cell suitability.



**Figure 4-5.** Habitat suitability criteria attributes for a habitat cell, showing multiplicative aggregation option.

The most common method is a multiplicative aggregation given by:

$$C_i = V_i * D_i * S_i \quad (4-2)$$

where:  $C_i$  = composite suitability 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

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

$$C_i = \sqrt[3]{V_i * D_i * S_i} \quad (4-3)$$

Third, the most locally limiting individual suitability factor can be selected by setting the composite suitability for the cell based on the minimum of the individual cell factors according to:

$$C_i = \text{Min}(V_i, D_i, S_i) \quad (4-4)$$

Once the composite suitability  $C_i$  has been determined, then the amount of WUA using all cells at this specific discharge is computed according to the following equation:

$$WUA = \sum_{i=1}^n A_i * C_i \quad (4-5)$$

where: WUA = total Weighted Usable Area in stream at specified discharge  
 C<sub>i</sub> = composite suitability for cell i  
 A<sub>i</sub> = vertical view area of cell i ( bed area or volume)

This process is then repeated for all discharges simulated and the functional relationship between habitat and discharge as illustrated in Figure 4-5 is obtained. As will be discussed under the HABEF and HABTAM models, the WUA within a specific cell can also be “adjusted” based on the attributes of adjacent cells such as conditional velocities, or on the difference in attributes of the existing cell when compared over a range of paired conditions.

### **Basic Assumptions in Habitat Modeling**

The habitat programs in general are based on the following assumptions:

1. Individual organisms select the most desirable conditions within a steady state stream but will use less favorable areas as the stream becomes more crowded.
2. Desirable conditions can be adequately represented by habitat suitability criteria curves.
3. Each cell can be evaluated independently.
4. The area weighted arithmetic sum of available habitat (as WUA) in each cell is indicative of total habitat conditions at a specific discharge.
5. Physical habitat (not water quality and/or other factors) is limiting the population size.

It should be emphasized that prediction of habitat as a metric (i.e., WUA) within PHABSIM is made in terms of changes to physical properties of aquatic microhabitat (i.e., velocity, depth, and channel index) and do not directly predict changes in the biomass of organisms. This fact has led to much criticism in the literature when PHABSIM results were applied and interpreted without consideration for other factors such as water quality, temperature, food availability, and fishing mortality. However, a number of studies have shown that there is a positive relationship between the output derived from PHABSIM and observed distribution and abundance of fish (e.g., Jowett, 1992; Railsback et al., 1995; Bovee et al., 1994; Nehring and Anderson, 1993).

HABTAE Flow/Habitat Relations  
RAINBOW TROUT

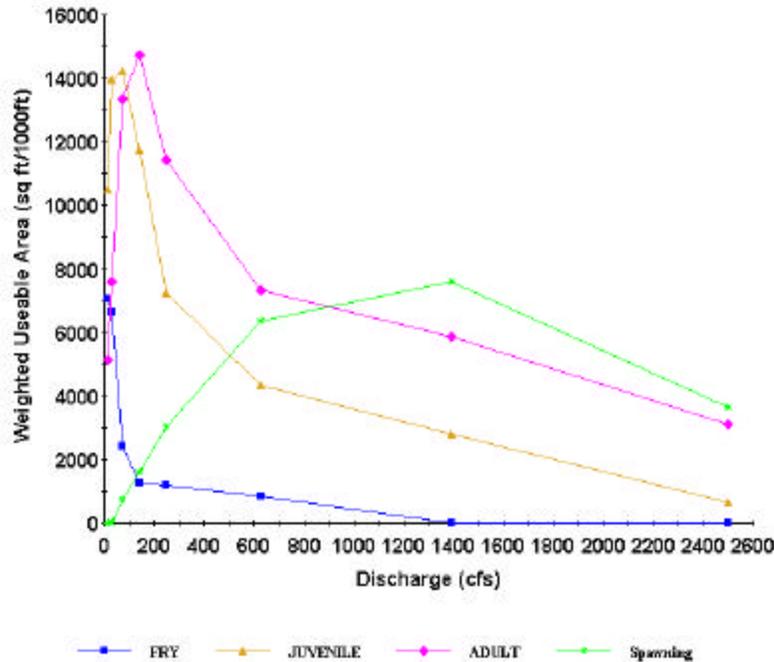


Figure 4-6. Simulated habitat-discharge relation for Rainbow Trout.

The typical habitat-discharge relationship provided in Figure 4-6 represents the basic output from the habitat modeling phase of PHABSIM. Note that the goal of habitat time series and related project assessment methods in IFIM 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 evaluate proposed management alternatives. Further, the basic relationship between habitat and discharge, illustrated in Figure 4-6, is not the only analytical capability within PHABSIM for development of an understanding of the “controlling” factors, examination of the quality of total habitat, and evaluation of potential effects of alternative flow regimes. The other habitat simulation and analysis capabilities of PHABSIM are considered in the following section, which highlights the specific computational capabilities of each habitat program, and in the following chapter on applying PHABSIM within the IFIM Framework.

### Habitat Modeling Options in PHABSIM

The following sections present each of the main habitat models, a description of their primary purpose, computational control options and the basics for their application. Table 4-2 provides an overview when a particular model might be used and distinctive options. The use of each of the main habitat models is also covered in the accompanying laboratory exercises as indicated at the beginning of the chapter.

Table 4-2. Habitat model descriptions.

Model	Use when these habitat results are desired	Distinctive options	Other comments
HABTAE	Weighted Usable Area Weighted Usable Volume	Computes WUV and WUBA Prints composite suitability tables	This program has the most

	Weighted Usable Bed Area Usable Habitat Minimum contiguous width Minimum combined suitability Life stage dependent velocity Nose velocities or shear stress Fish can prefer different velocities spatially Conditional velocity gradients	Calculates usable area Computes minimum contiguous width Computes minimum composite suitability factor Different velocity calculations for different life stages Scans velocities in adjacent cells Scans for minimum habitat velocity in adjacent cells	available options for velocity- related habitat simulations
AVDEPTH/AV PERM	Hydraulic parameter based evaluations	Produces hydraulic properties information by cross section or reach	
HABTAM	Show how rapid fluctuations in flow limit fish habitat Lateral migration based on velocity simulations	Computes and prints migration analyses	Limited velocity simulation options
HABEF	Effective habitat modeling Competition analysis Effective spawning Ramping rate analysis	Flow to flow comparisons on a cell by cell basis Life stage versus life stage comparisons performed on a cell-by-cell basis Though this program performs cell by cell calculations, output is for entire reach.	Requires HABTAE or HABTAM results for analyses. (User selects model.)

### *The Average Parameter Model AVDEPTH/AVPERM*

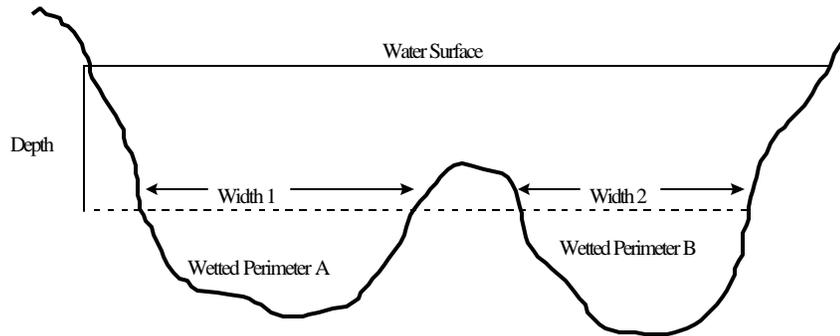
The two general types of habitat modeling in PHABSIM are based on either average conditions in an entire stream channel or on distribution of velocity and depth among field measurement cells (i.e., habitat computational cells) and the nature of the channel in a stream. The average parameter model AVDEPTH/AVPERM calculates wetted width and wetted surface for flows and water surface elevations supplied by the user. It determines width of a stream with water over a depth specified by the user. The average velocity is also calculated.

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 stream area 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. The use of the AVDEPTH/AVPERM program can often provide valuable insights into the functioning of the hydraulic simulations at specific cross sections as well as for reach aggregated results and the associated implications to target species and life stages.

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/AVPERM gives information for each cross section and a summary of the average parameters for a whole reach 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 4-7). The use of wetted width is a special case of WUA habitat modeling in that the weights for habitat computational cells are essentially set to 1.0 for all

velocities, depths, and channel indexes.



$$\text{AVDEPTH} = \text{WIDTH 1} + \text{WIDTH 2}$$

$$\text{AVPERM} = \text{WETTED PERIMETER A} + \text{WETTED PERIMETER B}$$

**Figure 4-7.** Calculation of width and wetted perimeter in AVDEPTH/AVPERM.

#### Running AVDEPTH/AVPERM

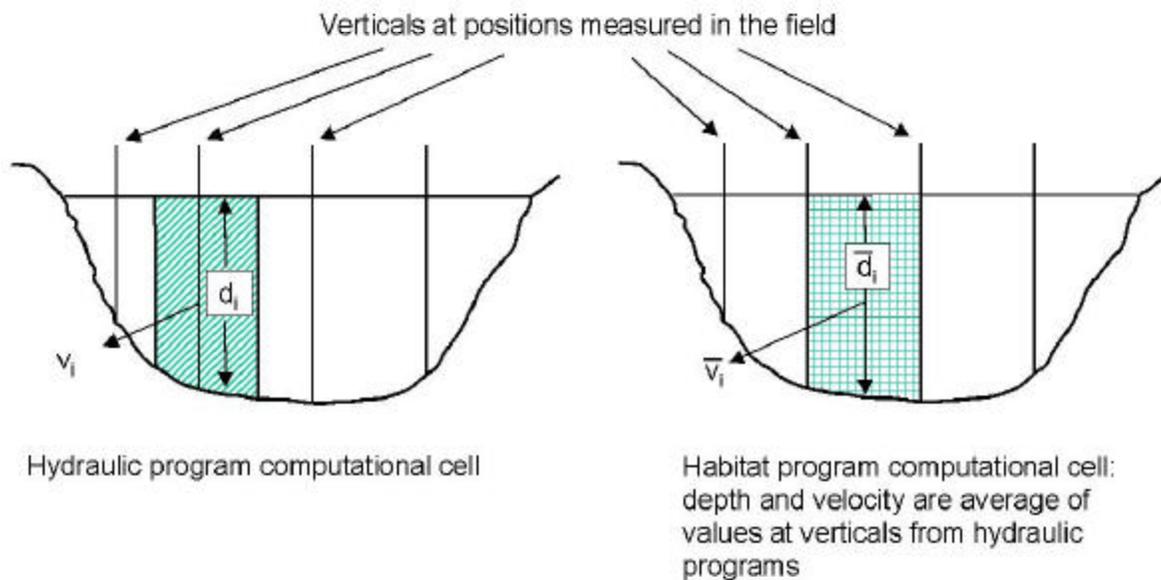
The AVDEPTH/AVPERM program is accessed from the PHABSIM for Windows interface using **/Models/AVDEPTH/AVPERM**. The depths to be evaluated are set in the **../Models/Avdepth/Avperm/Avdepth Avperm input** tab which also contains the run button.

If depths are specified, the AVDEPTH/AVPERM program will calculate the total width of the stream that is as least as deep as the depth(s) specified. Depths are entered in the table provided in the **../AVDEPTH/AVPERM Input** tab.

## The HABTAE Program

The HABTAE program is the main habitat program in PHABSIM for Windows. It calculates WUA (surface or bed) or weighted usable volume (WUV) for a reach or for each cross section. Depending on the options selected to control the computations, output will contain: (1) WUA, (2) usable surface area (UA) (given a user specified minimum value for combined suitabilities), (3) usable volume (UV) and (4) WUV that is the WUA times the water depth. HABTAE now also contains the conditional or adjacent velocity calculations formerly contained in HABTAV. The adjacent velocity calculations in the HABTAE program simulate situations where fish habitat is determined by hydraulic parameters at the fish's location, as well as by velocities near the fish. (See Habitat Calculations Conditioned on Adjacent Velocities below.)

The user is reminded that the cell boundaries in HABTAE are defined as illustrated in Figure 4-8. HABTAE uses the channel index value taken from the X coordinate vertical on the upstream-right (not left) side of the cell. This should be kept in mind when entering data.



**Figure 4-8.** Cell boundaries in the hydraulic and habitat programs in PHABSIM.

The HABTAE program requires that HSC curves for aquatic species or recreational activities be created or imported using the **/Edit/Suitability Curves** menu and successful simulations of water surface profiles and velocity distributions be performed prior to habitat modeling.

### Setting HABTAE Options

The HABTAE program uses the options selected in the following tabs under **/Models/Habtae**: **../Output Options**, **../Computations**, **../Limits**, **../Adjacent Velocity**, and **../Velocity Replacement Options**. HSC data must have been provided in **/Edit/Suitability Curves**, and the appropriate hydraulic programs must have been run. The user must select the HABTAE options prior to running the model. The options in the HABTAE program are summarized in Table 4.3. Note that due to enforcing use of the same habitat cell definition across all habitat programs in PHABSIM for Windows, the options formally in the HABTAV program in the DOS version are now contained in HABTAE.

Conditional velocity simulations within the HABTAE program are controlled by the combination of selected

options for scanning for VLIM and using VLIM and the action to be taken when VLIM is not found. The first option in the /Models/HABTAE/Adjacent Velocity tab directs the program to scan the cross section a user-specified distance out from the cell for which the habitat is being simulated to locate a user-specified velocity in any adjacent cells. If the velocity is found within this distance, the WUA calculated for the cell is multiplied by one (1.0). In other words, the existing cell WUA remains unmodified. Note that the program can be directed to use the limiting velocity as a minimum or maximum limit. If the user-specified velocity is not found, the WUA calculation when VLIM is not found option directs the program to scan 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 (0.0) based on the suitability criteria. The program then searches for a velocity, which is between the initial velocity and the user-specified velocity that is closest to the user-specified velocity and then interpolates the velocity suitability value using the suitability curves and the located velocity. This new suitability value is multiplied by the original WUA to obtain a new amount of WUA for the current cell.

### *Description of Habitat Calculation Options*

Several of the options shown in Table 4-3 are self-explanatory. However, others bear further elaboration to ensure clarity as follows.

#### ZHAQF Options

The **ZHAQF Options** radio buttons in the **Output Options** tab determine the mode of calculation of habitat area. The user may elect to calculate Weighted Usable Area or volume or simply usable area or volume. The weighted usable habitat can be surface area, bed area, or volume. The usable area is all areas with a composite suitability factor greater than 0.001. Volumes are calculated by multiplying weighted cell areas by the depth. Typical PHABSIM applications select “Write WUA or WUV” in the ZHAQF Options portion of the **Output Options** tab and “Calculate WUA for reach” in the **Computations** tab. Note: take care to match WUA or UA in the **Output Options** tab with the option selected in the **Computations** tab.

#### Using Bends

The **Describe Reach Bends** check box in the **Computations** tab allows the length represented by a cross section to vary from cell to cell (also called variable cell length) across the stream (i.e., a bend). The default is to use cells as rectangles in plan view. Most historical PHABSIM applications have used this default. Supplying the additional information for bends allows a more accurate representation of a study site where bends are significant.

When the **Describe Reach Bends** box is checked, the program uses cells as trapezoids based on the length multiplied by left and right bank weights. To use this option, left and right bank weighting factors must be entered in **/Edit/Cross Sections**. Note that the left and right bank weighting factors are multiplied times the cross section length entered in the second column of the cross section data in **/Edit/Cross Sections**. Thus, one bank should have a weight greater than 1.0 and the other should be less than 1.0 to indicate a bend in the stream. When the longitudinal distances between head pins were measured in the field, it is straightforward to find the ratio of left and right bank weights to the cross section length. If these distances are not known, it may be possible to approximate the distances if accurate maps of the study site are available. The check box must be checked and

**Table 4-3.** Options in the HABTAE program.

Option description	Action when set to indicated value, notes
Output Options Tab <b>Write Flow Data</b> (check box) (IOC 3)	Writes the flow related data for each cross section evaluated at each discharge to ZOUT. It also lists the velocity for each cell that has water in it. The data are a rehash of the hydraulic model results. Recommend leaving blank unless a printed record is needed.
Output Options Tab <b>Write Computational Details</b> (check box) (IOC 4)	Writes all the computational details used in determining the weighted usable area, weighted usable bed area, or weighted usable volume to ZOUT. Recommend leaving blank except when details are needed to evaluate the simulation. Strongly recommend using only a few life stages and discharges when using this option.
Output Options Tab <b>Write Cross Section Data</b> (check box) (IOC 2)	Writes cross section data to ZOUT. Output is the same as that contained in <b>/Edit/Cross Sections</b> . Recommend leaving blank unless a printed record is needed.
Output Options Tab <b>ZHAQF Options</b> (radio buttons) (IOC 10)	Determines calculation of habitat area. The weighted usable habitat can be surface or bed area or volume. The usable area is all areas with a composite suitability factor greater than 0.001. Typical applications select “Write WUA or WUV”. Take care to match WUA or WUV with the options selected in the <b>Computations</b> tab.
Output Options Tab <b>Discharges</b> (input table)	User selects which of the discharges used in the hydraulic simulations are to be used for habitat calculations. Default is to use all discharges.
Computations Tab <b>Describe Reach Bends</b> (check box) (IOC 12)	Allows the length to vary from cell to cell (variable cell length) across the stream (i.e., a bend). Default is to use cells as rectangles in plane view. When checked, program uses cells as trapezoids based on the length multiplied by left and right bank weights. To use this option, left and right bank weighting factors must be entered in <b>/Edit/Cross Sections</b> .
Computations Tab <b>Use a Minimum Contiguous Width</b> (check box) (IOC 11)	When checked this directs HABTAE to use a minimum contiguous width. Minimum width (WMIN) values must be supplied for each HSC curve set ID Number (life stage) in the right-hand table in the <b>Velocity Replacement Options</b> tab.
Computations Tab <b>Use Zero CI in Calculations</b> (check box) (IOC 18)	This defines how channel index values of zero (0) are used. If not checked channel index values of zero are converted to 1.0 which effectively removes channel index from the calculation for any cell with a 0.0 CI. When checked, a channel index value of zero is used in the calculation of WUA for that cell. Recommend checking this box.

**Table 4-3.** Continued.

Option description	Action when set to indicated value, notes
Computations Tab <b>Near Shore Habitat Analysis</b> (check box and distance entry box (IOC 22))	Used to define suitable habitat for organisms that require certain combinations of depth and velocity within a given distance of the shoreline. These may be terrestrial as well as aquatic organisms.
Computations Tab <b>WUA Calculations</b> (radio buttons) (IOC 1)	Determines if the WUA, 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.
Computations Tab <b>Habitat Calculations</b> (radio buttons) (IOC 9) These are the typical habitat calculations produced by PHABSIM. Note that the outcome of these calculations is influenced by the other option choices.	Controls how the calculation of habitat area will be made. <b>Standard calculation</b> -- 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. <b>Geometric Mean</b> - $CF = (f(v)*g(d)*h(ci))^{0.333}$ . <b>Lowest Limiting Parameter</b> - $CF = \text{MIN}(f(v), g(d), h(ci))$ .
Limits Tab <b>Velocity Limits</b> (radio buttons) (IOC 15)	Limits the velocities allowed in the habitat simulation calculations. Choices are: No restriction on velocities; Abort if velocities are <0 or >15; and Convert negative velocities and abort if >15.
Limits Tab <b>Minimum Effective Composite            Suitability Factor</b> (radio buttons) (IOC19) Use to prevent very small CF from accumulating a large area of poor habitat.	Sets a minimum composite suitability for each life stage. The minimum value for each life stage is entered in the CFMIN column in the right-hand table in the <b>Velocity Replacement Options</b> tab. When values less than CFMIN are calculated for a cell, the composite suitability for that cell is set to zero.
Velocity Replacement Options Tab <b>CFMIN</b> (column in input table)(IOC19)	Data entry location for minimum effective composite suitability Factor.

**Table 4-3.** Continued.

Option description	Action when set to indicated value, notes
<p>Velocity Replacement Options Tab  <b>Vel Calc</b> (column in input table)                      (IOC14)                      Where various Vel Calc options require additional input parameters, those parameters are supplied in the appropriate columns of the left or right side input tables in the <b>Velocity Replacement Options</b> tab.</p>	<p>0 = Mean column velocity.                      1 = Nose velocity - Empirical equation based a power law equation and user defined coefficients. User supplies the nose depth (<math>D_{nose}</math>) for which a velocity is to be calculated, and the calibration parameters A and B. These values are entered in the right input table.                      2 = Nose velocity - 1/7th power law equation. User supplies nose depth (<math>D_{nose}</math>) in right input table.                      3 = Nose velocity - logarithmic velocity distribution equation. The nose depth and the <math>D_{65}</math> of the bed material are supplied by the user in the right input table (scroll table to display <math>D_{65}</math>).                      4 = Nose velocity - 1/mth power law equation. m is calculated using the equation: <math>m = \frac{c}{n} D^{0.1667}</math>, n is the Manning's roughness coefficient (n), and c is 0.105 for traditional units and 0.128 for metric units. The value of m is determined for each cell. The value of n and the nose depth are supplied in the right input table.                      5 = Nose velocity - 1/mth power law equation. Same as above except m is calculated using the equation <math>m = aD^b</math>. Values for a and b and nose depth are supplied in the right input table.                      6 = Nose velocity - 1/mth power law equation. Same as above except the nose depth (<math>D_{nose}</math>) is measured from the surface. The values for nose depth and n are entered in the right input table.                      7 = Nose velocity = Shear velocity. To calculate the shear stress (<math>\tau</math>), the Manning's roughness must be known. Manning's n is entered in the right input table.</p>
<p><b>Velocity Replacement Options</b> tab  <b>Dnose, a, b, n, D65</b> (columns in input table)</p>	<p>Data entry location for nose depth, a and b coefficients, <math>D_{65}</math> sediment size and Manning's n from above.</p>
<p><b>Velocity Replacement Options</b> tab  <b>Nose Vel</b> (column in input table)                      (IOC16)                      Nose depth is supplied in <math>D_{nose}</math> field of right-hand table.                       Note: If <b>Nose Vel</b> is not set to 0 for a life stage, <b>Vel Calc</b> should also be non-zero.                      Note: For <b>Nose Vel</b> options 1, 2, and 3, <b>Vel Repl</b> should be set to 0.</p>	<p>0 = Given velocities, or nose velocities, (depending on what Vel Calc was set to) are used for habitat simulation.                      1 = Optimum velocities are used for habitat simulation with equal depth from top as from bottom. Nose depth is set by one of two methods: (a) <math>D_{nose}</math> in the right-hand table of the Velocity Replacement Options tab; or (b) if <math>D_{nose}</math> has not been set, nose depth = .1.                      2 = Optimum velocities are used for habitat simulation with unequal depth from top as from bottom.                      3 = Mean velocity in a top cell is used in habitat simulation. The velocity used is the mean velocity found in a cell defined between the surface of the water column and the depth specified in the cell field in the right-hand table in the Velocity Replacement Options tab.</p>

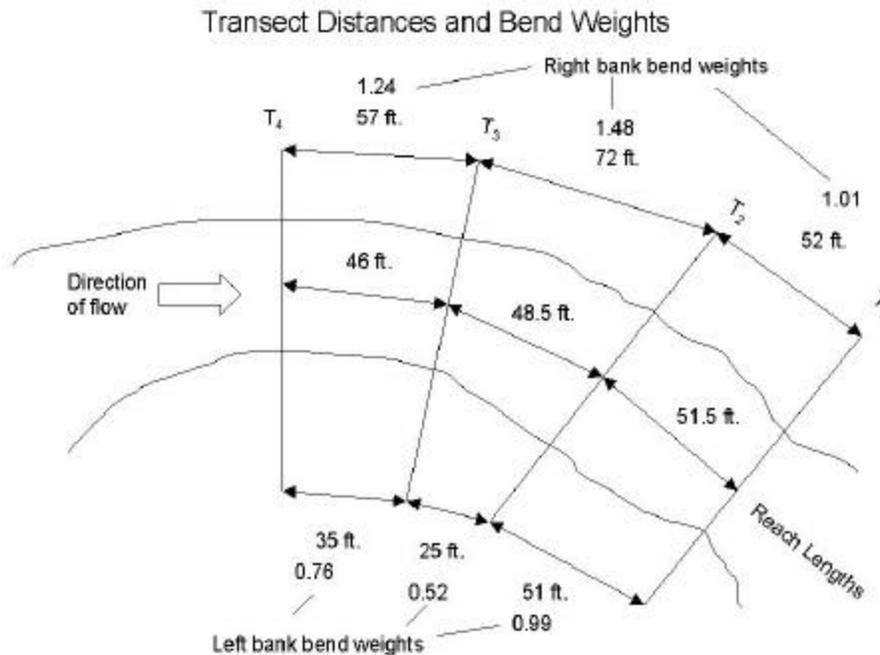
**Table 4-3.** Continued.

Option description	Action when set to indicated value, notes
<p><b>Velocity Replacement Options</b> tab  <b>Vel Repl</b> (column in input table, scroll to view <b>Vel Repl</b> column)(IOC17)</p>	<p>0 = Use given velocity.            1 = Use velocity * depth as velocity.            2 = Use (velocity**2) * depth as velocity            3 = Use Shield's Parameter as velocity.</p>
<p>If <b>Vel Repl</b> is not 0, then <b>Nose Vel</b> must be 0.</p>	<p><math display="block">K_s = \frac{\tau}{D_{65} (S_s - 1) \gamma}</math> where: <math>K_s</math> = Shield's parameter, <math>\tau</math> = shear stress on a bed, <math>D_{65}</math> = size of bed</p>
<p>If <b>Vel Repl</b> is 1 or 2, then <b>Vel Calc</b> must be 0.</p>	<p>surface material at which 65% are smaller, <math>S_s</math> = specific gravity of the bed material, and <math>\gamma</math> = unit weight of water.</p>
<p>If <b>Vel Repl</b> is 3, then <b>Vel Calc</b> must be set to 7 and Manning's n, <math>D_{65}</math> of bed</p>	<p>4 = Use Froude number as velocity.</p>
<p>material, and the specific gravity must be entered in the right-hand table of the <b>Velocity Replacement Options</b> tab. If specific gravity is not specified, 2.65 is used.</p>	<p><math display="block">F_r = \frac{V}{\sqrt{gd}}</math> where: <math>V</math> = velocity, <math>g</math> = acceleration of gravity, and <math>d</math> = depth</p>
<p><b>Velocity Replacement Options</b> tab  <b>Sp. Grav.</b> (column in input table)</p>	<p>Data entry location for specific gravity of the bed material.</p>
<p><b>Velocity Replacement Options</b> tab</p>	<p>Permitted combinations of velocity replacement options are shown in the table at the bottom of the tab. Only the combinations shown can be used.</p>
<p><b>Adjacent Velocity</b> tab            Scan for velocity in adjacent cells (IOC-V 1) (checkbox)</p>	<p>When checked, HABTAE performs adjacent velocity scanning and applies the criteria selected in the <b>Use VLIM as box</b> (below).</p>

**Table 4-3.** Concluded.

Option description	Action when set to indicated value, notes
<p><b>Adjacent Velocity</b> tab  <b>Use VLIM as (IOC-V 1)</b>            (Radio buttons)</p>	<ul style="list-style-type: none"> <li>• <b>Minimum</b> - Scans adjacent cells within a user-defined distance (<b>DIST</b>) for velocity greater than or equal to a user-defined minimum velocity (<b>VLIM</b>). That is, <b>VLIM</b> acts as a lower bound. If found, WUA for current cell = <math>WUA * 1.0</math>.</li> <li>• <b>Minimum</b> - Scans adjacent cells within a user-defined distance (<b>DIST</b>) for velocity greater than or equal to a user-defined minimum velocity (<b>VLIM</b>). That is, <b>VLIM</b> acts as a lower bound. If found, WUA for current cell = <math>WUA * 1.0</math>.</li> <li>• <b>Maximum</b> - Scans adjacent cells within a user-defined distance (<b>DIST</b>) for velocity less than or equal to a user-defined maximum velocity (<b>VLIM</b>). That is, <b>VLIM</b> acts as an upper bound. If found, WUA for current cell = <math>WUA * 1.0</math>.  <b>VLIM, DIST, and V0</b> are supplied in the input table on the <b>Adjacent Velocity</b> tab.</li> </ul>
<p><b>Adjacent Velocity</b> tab            WUA calculation when            VLIM not found (IOC-V 5)            (Radio Buttons)</p>	<ul style="list-style-type: none"> <li>• <b>WUA = 0</b> - If VLIM is not found in adjacent cells, set WUA for current cell to zero.</li> <li>• Scan for initial Velocity (<b>V0</b>) and interpolate – If VLIM is not found in adjacent cells, the program scans a second time for an initial velocity, <b>V0</b>, which is the first velocity where fish habitat is greater than 0. Then it searches for a velocity between <b>V0</b> and <b>VLIM</b> which is closest to <b>VLIM</b> and interpolates a multiplier for the WUA for the current cell between 0.0 and 1.0 based on the velocity found by this process.</li> </ul>
<p><b>Adjacent Velocity</b> tab  <b>Scan distance, velocity limit,</b>  <b>initial velocity</b> (input table with these columns)</p>	<p>Table where <b>DIST, VLIM, and V0</b> are supplied by the user.</p>

the left and right bank weights must be set greater than 1.0 on the long bank and less than 1.0 on the short bank for this option to have an effect. Figure 4-9 illustrates bend weights.



**Figure 4-9.** Illustration of bend weights.

**Note:** In PHABSIM the bend weights act like the upstream reach length weighting factors. That is, they are applied upstream from the cross section. In this example, the left bank bend weight for the third cross section would be calculated from the field data as 35 ft divided by 46 ft. So 0.76 would be entered in the **L Bank WF** field of the **/Edit/Cross Data** tab. When bends are included in the habitat calculation, the final weight applied to habitat cells in the cross section is a composite of the bend weights and the upstream weighting factors for the current and the downstream cross section. This is due to the fact that the habitat cell length for cross section B is a combination of one minus the upstream weighting factor for cross section A times the length from B back to A and the upstream weighting factor for cross section B times the length from C back to B. Refer back to Figure 4-3 of use of upstream weighting factors and reach length.

#### Using Minimum Contiguous Width

If a species requires a minimum amount of continuous habitat across the stream for the habitat to be usable, this option allows the program to enforce that requirement. When checked, this option in the **Computations** tab directs HABTAE to only count habitat in a cell if it is part of an area that has a minimum contiguous width of suitable habitat. Minimum width (WMIN) values must be supplied for each HSC curve set ID Number (life stage) in the right-hand table in the **Velocity Replacement Options** tab.

#### Use of a Zero Channel Index Value

The **Zero CI in Calculations** check box in the **Computations** tab defines how channel index values of zero (0) are used. When PHABSIM was first developed, channel index values of zero were considered to mean that no information was available. This option allows the user to select how a CI of zero is to be treated. If this box is not checked, channel index values of zero are converted to 1.0, which effectively removes channel index from the

calculation. When checked, a channel index value of zero is used in the calculation of WUA for that cell. Care should be taken to ensure that this option reflects the analyst's desired outcome. Recommend checking this box for most applications unless it is known that zero values indicate that channel index is to be ignored.

#### Near Shore Habitats

The **Near Shore Habitat Analysis** check box and distance entry box in the **Computations** tab is used to define suitable habitat for organisms that require certain combinations of depth and velocity within a given distance of the shoreline. These may be terrestrial as well as aquatic organisms. This option was developed to describe habitat for a water snake that required riffle habitat near basking areas on the shore. Other possibilities include riparian bird species that need feeding areas within a certain distance of the shoreline.

To use this option, check the **Near Shore Habitat Analysis** box and supply the distance from shore that habitat will be counted. All cells more than the specified distance from shore will be eliminated from the habitat sum. As the shoreline moves with higher or lower water surface elevations, different cells will fall within the near shore distance and the habitat value will vary according to the depth, velocity, and channel index combinations in those cells. Note the HSC used in this analysis may actually be HSC for the food organisms of the target species; for example the water snake's preferred prey.

#### Weighted Usable Area Calculations and Independent Cross Sections

The **WUA Calculations** radio buttons in the **Computations** tab are used to select the most commonly used calculation schemes in PHABSIM. They determine if WUA, WUV, or weighted usable bed area (WUBA), is to be calculated, and if the WUA, WUV, or WUBA is to be calculated for independent cross sections or for a reach. While the selection of WUA, WUV, or WUBA is straightforward, the use of independent cross section or reach aggregation merits further discussion.

Most PHABSIM applications use aggregation of the WUA by reach and result in one habitat-flow relation for each species/life stage for the entire reach. However, this approach assumes the reach length weighting factors accurately capture the desired weighting for each cross section. If the weighting factors are a concern, or if alternate weighting schemes are to be considered in the analysis, calculating WUA for each cross section independently allows the user to perform other analyses outside of PHABSIM for Windows. When using the independent cross section option, the user is advised to take care in tracking the tables of WUA carefully.

#### The Form of the Habitat Calculation

The **Habitat Calculations** radio buttons in the **Computations** tab direct the form of the habitat calculation. These choices allow the user to select among standard, geometric mean, or minimum parameter calculations. Note that the outcome of these calculations is influenced by the other option choices.

In the standard calculation the combined suitability factor is:

$$(CF) = f(v) * g(d) * h(ci)$$

(4-6)

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 HSC weights and implies synergistic action. It also treats each of the three variables as independent. That is, there are no interaction terms in the multiplication. Optimum habitat only exists if all variables are optimum and low SI values for all three variables can

yield very low WUA values for a cell.

The geometric mean produces a combined suitability using:

$$CF = (f(v) * g(d) * h(ci))^{0.333} \quad (4-7)$$

This technique implies compensatory effects; if two of the three variables are in the near-optimum range, the value of the third variable has less effect, unless it is zero. This option may be selected for organisms that fare well in marginal habitats as long as two of the physical habitat parameters are high.

The lowest limiting parameter approach calculates combined suitability as:

$$CF = \text{MIN} (f(v) * g(d) * h(ci)) \quad (4-8)$$

This approach 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. The user is advised to select the habitat calculation form with care based on the available data on the species of interest and the decision environment in which the PHABSIM results will be used.

#### Velocity Limits and Eddies

The **Velocity Limits** radio buttons on the **Limits** tab allow the user to limit the velocities allowed in the habitat simulation calculations. The choices are: **No restriction on velocities**, **Abort if velocities are <0 or >15**, and **Convert negative velocities and abort if > 15**. MESC strongly recommends selecting the second or third button. If the "No restrictions" option is required for successful habitat simulation runs, there probably was an error in the hydraulic simulation process.

The "Convert negative velocities" option would apply in situations where reverse flow occurs on part of a transect, such as a transect that runs across an eddy. Care should be taken in such situations to select the calibration velocity set that applies to this situation and not to extrapolate reverse flow to discharges where either the eddy has not yet developed or where it has been washed out at higher flows.

#### Minimum Effective Composite Suitability

The **Minimum Effective Composite Suitability Factor (CFMIN)** radio buttons in the **Limits** tab allow the user to prevent very small composite suitabilities from accumulating a large area of poor habitat. This option sets a minimum composite suitability for each life stage. The minimum value for each life stage is entered in the **CFMIN** column in the right-hand table in the **Velocity Replacement Options** tab. When a value less than **CFMIN** is calculated for a cell, the composite suitability for that cell is set to zero.

#### Nose Depth: Empirical Calculation of Velocity at a Given Depth

The **Vel Calc** column in the input table in the **Velocity Replacement Options** tab allows various forms of empirical or assumed vertical velocity distributions to be applied to determining the habitat value based on assuming the organism selects a particular location above the stream bed. This option is particularly useful when the depth-oriented behavior of a particular life stage of a target species is known. Thus, the velocity calculation option varies by HSC curve number as shown in the left-hand table of the **Velocity Replacement Options** tab.

When **Vel Calc** is set to zero (0), only the mean column velocity is used in habitat calculations. This is the default or standard habitat calculation.

When **Vel Calc** is set to 1, nose velocity is calculated using an empirical exponential equation and user-defined coefficients. The user supplies the nose depth ( $D_{nose}$ ) for which a velocity is to be calculated, and the calibration parameters a and b. These values are entered in the right input table. Nose velocity is calculated as:

$$V_n = \bar{V} a \left[ \frac{D_{nose}}{D} \right]^b \quad (4-9)$$

where:  $\bar{V}$  = mean column velocity of the cell, and  $D$  = total depth of the cell.

When **Vel Calc** is set to 2, nose velocity is calculated using the Prandtl-von Karman 1/7th power law equation. User supplies nose depth ( $D_{nose}$ ) in right input table (scroll table to display  $D_{nose}$ ). Nose velocity is calculated as:

$$V_n = \bar{V} (1 + 1/7) \left[ \frac{D_{nose}}{D} \right]^{1/7} \quad (4-10)$$

When **Vel Calc** is set to 3, nose velocity is calculated using a logarithmic velocity equation. The nose depth and the  $D_{65}$  of the bed material are supplied by the user in the right input table (scroll table to display  $D_{65}$ ). The relationship is given as:

$$V_n = \bar{V} \frac{\log(33.2 * d_{nose}/D_{65})}{\log(12.12 * d_{nose}/D_{65})} \quad (4-11)$$

When **Vel Calc** is set to 4, nose velocity is calculated using a 1/mth power law equation. The nose velocity equation used is:

$$V_n = \bar{V} (1 + 1/m) \left[ \frac{D_{nose}}{D} \right]^{1/m} \quad (4-12)$$

and m is calculated using:

$$m = \frac{c}{n} D^{0.1667} \quad (4-13)$$

where: n = Manning's roughness coefficient, and c = 0.105 for traditional units and 0.128 for metric units. The value of m is determined for each cell. The value of n and the nose depth are supplied in the right input table (scroll table as needed to display n).

When **Vel Calc** is set to 5, nose velocity is calculated using the 1/mth power law equation in the same manner as above except m is calculated using:

$$m = aD^b \quad (4-14)$$

Values for a and b and nose depth are supplied in the right input table (scroll table to display  $D_{nose}$ ).

When **Vel Calc** is set to 6, nose velocity is calculated using the 1/mth power law equation in the same manner as above except the nose depth ( $D_{nose}$ ) is measured from the surface. The values for nose depth and n are entered in the right input table (scroll table to display  $D_{nose}$ ).

When **Vel Calc** is set to 7, shear velocity is used for nose velocity. To calculate the shear stress ( $\tau$ ), the Manning's roughness must be known. Manning's n is entered in the right-hand input table (scroll table to display

n). Then:

$$\mu^* = \sqrt{\frac{\tau}{\Delta}} \quad (4-15)$$

where:  $\mu^*$  = shear velocity,  $\tau$  = shear stress on the bed, and  $\Delta$  = density of water.

#### Replacements for Velocity

The **Vel Repl** column in the left input table of the **/HABTAE/Habitat Simulation/Velocity Replacement Options** tab allows the user to make certain replacements for velocity in the velocity calculation algorithm. These replacements enable alternative habitat determinations when sufficient data is available to support their use. All velocity replacement option combinations are subject to the conditions stated at the end of this section.

When using velocity replacements the analyst must take care to ensure that the habitat suitability criteria for velocity reflect the velocity replacement option being used. That is, new HSC must be entered in **/Edit/Suitability Curves** corresponding to the velocity replacements described below. In the option tables in the **Velocity Replacement Options** tab, a different set of velocity calculation options may be supplied for each habitat suitability criteria curve. Thus, an analysis can be performed where most HSC are treated with the standard mean column velocity calculation and certain HSC are used with velocity replacements. This means that the user must be cautious to ensure that the velocity HSC values are Froude number suitability values if **Vel Repl** is set to 4 (see below) for a particular HSC curve set.

When **Vel Repl** is set to 0, the velocity option specified by **Vel Calc** is used.

When **Vel Repl** is set to 1, the product velocity \* depth is used as velocity.

When **Vel Repl** is set to 2, (velocity\*\*2) \* depth is used as velocity.

When **Vel Repl** is set to 3, Shield's Parameter is used as velocity.

Shield's parameter is defined as:

$$K_s = \frac{\tau}{D_{65}(S_s - 1)g} \quad (4-16)$$

where:  $K_s$  = Shield's parameter,  $\tau$  = shear stress on a bed,  $D_{65}$  = size of bed surface material at which 65% are smaller,  $S_s$  = specific gravity of the bed material, and  $\tau$  = unit weight of water. Values for  $D_{65}$  and specific gravity are supplied in the right input table (scroll table as needed to display **D65** and **Sp. Grav.**). If the user does not supply specific gravity, 2.65 is used.

When **Vel Repl** is set to 4, Froude Number is used as velocity. Froude number is defined as:

$$F_r = \frac{V}{\sqrt{gd}} \quad (4-17)$$

where:  $V$  = velocity,  $g$  = acceleration of gravity, and  $d$  = depth.

The following conditions apply to combinations of **Vel Repl** and **Nose Vel**. If **Vel Repl** is not 0, then **Nose Vel** must be 0. If **Vel Repl** is 1 or 2, then **Vel Calc** must be 0. If **Vel Repl** is 3, then **Vel Calc** must be set to 7 and Manning's  $n$ ,  $D_{65}$  of bed material, and the specific gravity must be entered in the right-hand table of the **Velocity Replacement Options** tab. The permitted combinations of **Nose Vel**, **Vel Repl**, and **Vel Calc** are given in a table

at the bottom of the **Velocity Replacement Options** tab.

Nose Depth: Use of “Optimum” Velocities for a Portion of the Water Column

The **Nose Vel** column in the input table in the **Velocity Replacement Options** tab allows the analyst to select the portion of the water column where velocities will be calculated. The velocity calculated in the selected portion of the water column is sometimes referred to as an “optimum” velocity. Note: if **Nose Vel** is not set to 0 for a life stage, **Vel Calc** should also be non-zero. Further, for **Nose Vel** options 1, 2, and 3, **Vel Repl** (see below) should be set to 0.

When **Nose Vel** is set to 0, the simulated mean column velocities, or nose velocities, (depending on what **Vel Calc** was set to) are used for habitat simulation.

When **Nose Vel** is set to 1, optimum velocities are used for habitat simulation with equal depth from top as from bottom as follows: A “top of cell and bottom of cell” are removed from the water column. Within the remaining water column, the velocities in the habitat simulation calculations are optimized, i.e., it is assumed that the fish can move vertically to find the “best velocity” in the remaining water column. This “best velocity” is used with the nose velocity calculated by the selection of **Vel Calc**. If **Vel Calc** = 0, and **Nose Vel** = 1 or 2, the program will calculate nose velocities as if **Vel Calc** = 2. The “optimum (best) velocity” is defined as the velocity that is found within the range of nose depth down from the surface (top) and nose depth up from the bottom that has the highest suitability index value on the HSC relation for that species/life stage. Nose depth is set by one of two methods, (a) **Dnose** in the right-hand table of the **Velocity Replacement Options** tab, or (b) if **Dnose** has not been set, nose depth has a default value of 0.1.

When **Nose Vel** is set to 2, optimum velocities are used for habitat simulation with unequal depth from top as from bottom. The top portion of the cell that is removed is the distance between the water surface and the depth specified in the **Cell** field in the right-hand input table in the **Velocity Replacement Options** tab (scroll the table to find the **Cell** column). The bottom portion of the cell that is removed is defined by the **Dnose** values.

When **Nose Vel** is set to 3, the mean velocity in top portion of each a top cell is used in habitat simulation. The velocity used is the mean velocity found in the region of the cell defined between the surface of the water column and the depth specified in the **Cell** field in the right-hand table in the **Velocity Replacement Options** tab.

## Habitat Calculations Conditioned on Adjacent Velocities

In some situations, fish habitat is determined not only by hydraulic parameters at the fish’s location, but also by velocities near the fish. The adjacent velocity calculations in HABTAE provide a mechanism for lateral scanning of velocity conditions that can be used to evaluate such phenomena as feeding stations. Each cell on a cross section is evaluated for its proximity to desired nearby velocity conditions. The habitat in each cell is included in the total WUA when the desired adjacent velocity conditions are met and excluded when those conditions are not met. The adjacent velocity calculations are controlled by a checkbox that determines if adjacent velocity calculations are to be performed and by combinations of the following menu items in the **Adjacent Velocity** tab. When adjacent velocity scanning is performed, the program starts at the center of the current cell and scans in both directions to find velocities that satisfy the adjacent velocity conditions.

Simulation of a feeding station would take the following form: Velocity HSC for the target species would indicate that habitat was most suitable in the low velocity range expected to be found behind a rock or other cover object. The adjacent velocity criteria would search for a significantly higher velocity within the sight distance of the species using the minimum adjacent velocity criteria (the **Use VLIM as Minimum** radio button in the

../Habtae/Adjacent Velocity tab). For example, if the “feeding” velocity HSC for a species peaked at 0.5 fps, the VLIM value was 2 fps, the search distance was 3 ft and the minimum adjacent velocity criteria caused the program to search for velocities within 3 ft that were greater than 2 fps, the program would sum habitat for only cells that had low velocities within 3 ft of high velocities. The paragraphs below describe how to set up adjacent velocity calculation options.

### *Selecting the Form of the Adjacent Velocity Calculation*

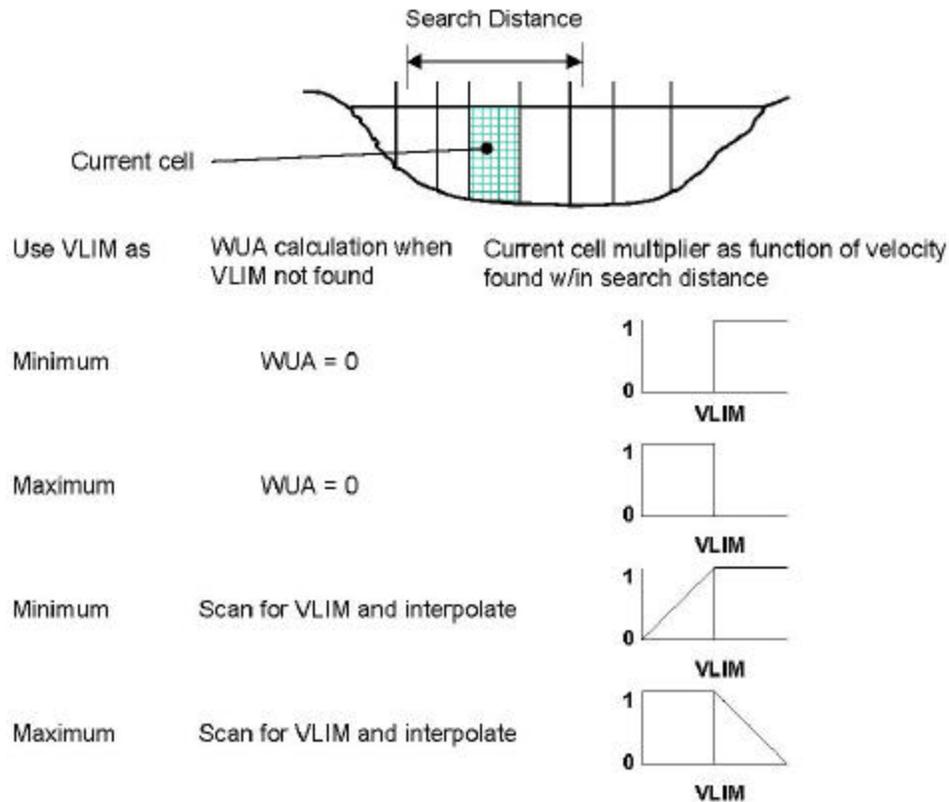
Figure 4-10 shows the computational options within the HABTAE program based on conditional velocity simulations. The options are discussed below.

The **Use VLIM as** radio button selection allows the user to choose if a minimum or maximum adjacent velocity limit is to be scanned for when the **Scan for velocity in adjacent cells** box is checked. When **Minimum** is selected, the program scans adjacent cells within a user-defined distance (**DIST**) for velocity greater than a user-defined velocity value (**VLIM**). That is, the limiting velocity acts as a minimum. If a velocity greater than VLIM is found, WUA for the current cell is retained by multiplying original WUA \* 1.0. When **Maximum** is selected, the program scans adjacent cells within the user-defined distance (**DIST**) for a velocity less than or equal to the user-defined velocity (**VLIM**). If a velocity less than VLIM is found, WUA for the current cell is retained by multiplying WUA \* 1.0.

Cells containing the desired minimum or maximum velocity may not be encountered when evaluating adjacent cells within the scan distance DIST. The **WUA calculation when VLIM not found** options provide for dealing with this situation by either setting the current cell WUA to 0 or by interpolating a scaled value of the WUA when no cell within DIST of the current cell satisfies the VLIM constraint. The **WUA = 0** option directs the program to set the WUA in the current cell to zero if the appropriate minimum or maximum velocity is not found in adjacent cells within the scan distance. The **Scan for initial Velocity (V0) and interpolate** option directs the program to scan adjacent cells a second time using a relaxed velocity limit, **V0**, and searches for the adjacent cell velocity that exceeds (or falls below) **V0** by the greatest amount. The program then interpolates a multiplier for the WUA for the current cell between 0.0 and 1.0 based on the velocity found by this process. The multiplier is calculated as:

$$\text{Mult} = \frac{V_{\text{found}} - V_0}{\text{VLIM} - V_0} \quad (4-18)$$

Then the WUA for the current cell is calculated as the original WUA \* Mult.



**Figure 4-10.** Illustration of adjacent velocity VLIM calculation options in HABTAE.

A caution on the different combinations of adjacent velocity options:

- If **Scan for velocity in adjacent cells** is checked, **Use VLIM as** is set to **Minimum**, the **WUA = 0** radio button is selected, and **V0** is greater than **VLIM**, it is illogical to supply a **V0**. These settings do not have the same result as **VLIM** nor **V0** being found in adjacent cells, hence, **V0** is ignored.
- Similarly, if **Scan for velocity in adjacent cells** is checked, **Use VLIM as** is set to **Maximum**, the **WUA = 0** radio button is selected, and **V0** is less than **VLIM**, it is illogical to supply a **V0**. These settings also result in neither **VLIM** nor **V0** being found in adjacent cells so **V0** is ignored.

*Adjacent Velocity Calculation Example*

While most of the habitat calculation processes are relatively straightforward, the adjacent velocity calculations merit an example to illustrate the process. Assume the adult life stage of a trout species can be assigned a search distance (**DIST**) of 10 ft. and a velocity threshold (**VLIM**) of 2.7 ft. per second. Further, assume the velocity threshold is treated as a lower bound (minimum) such that the purpose of the simulation is to find velocities that are above the minimum within the search distance from each cell. How is the habitat for a cell determined?

Figure 4-11 shows the velocity distribution for cross section 0.0 of the sample study site at a discharge of 139 cfs. Consider the cell spanning from X = 48 feet to X = 50 feet. When VLIM is treated as a lower bound (minimum) the program searches out from each side of the cell over the 10 foot search range shown in the figure. If a velocity above the minimum threshold is found within the search range on either side of the cell, the habitat for that cell is included in the total habitat calculated for the study site. Here, a velocity slightly above the threshold

is found 8 feet from the right side of the cell (at X = 58 feet) and a velocity of nearly 3 fps (feet per second) is found exactly 10 feet from the cell (at X = 60 feet). Thus, the habitat value for X = 48 feet is included in the conditional habitat total. None of the habitat to the left of X = 48 feet was included in the site total because no velocities satisfying the criteria of exceeding VLIM were found within 10 feet of those cells. What will be the last cell on the right to be included in the conditional habitat total?

Table 4-4 contains the cell velocities for cross section 0.0 at 139 cfs and the values found in the **Habitat Results** table of the **/Models/Habtae** window. Note that the first cell counting from the left bank (X = 0.0) where the adjacent velocity weight (**Ad Vel**) becomes 1 is at X = 48, and the last cell is at X = 82. Also note that the velocity 2.72 fps is the first velocity above the threshold value and is located 8 feet from the right side of cell 48-50.

This table illustrates the case where VLIM is used as a lower bound (minimum threshold) and the sought-after velocity is greater than VLIM. If VLIM was used as an upper bound (maximum threshold), which cells would be, included in the adjacent velocity conditioned habitat and which would not? That is, within the search distance, which cells are within 10 feet of velocities less than VLIM? Use Figure 4-11 and Table 4-4 to determine the answer.

### *Evaluating HABTAE Results*

HABTAE program results are accessed on two tabs within the **/Models/HABTAE** window. The **../Habitat Results** tab displays the composite suitability for each wet cell and the **../Zhaqf Results** tab displays the WUA versus discharge relation produced by HABTAE.

In the **../Habitat Results** tab, the user may select the species/life stage, transect, and discharge to display. This allows evaluation of precisely which part of the stream is supplying habitat to each life stage of each species used in the analysis. The **Graph** button in this tab displays a plan view plot of the suitability for the study site. This plot has several interactive selections to display the life stage, discharge, form of habitat output or suitability displayed, etc. Users are encouraged to try all options in this plot to determine which selection best illustrates the habitat feature they wish to display or include in a report. Click the **Refresh** button after making any changes in the plot parameters. A **Print** button is supplied so color copies of the plots can be produced for inclusion in reports.

The **../Zhaqf Results** tab contains the results of the WUA calculation. A plot of WUA versus discharge may be viewed by clicking the **Graph** button. This plot also provides the ability to select the species and life stage(s) to be displayed.

The WUA versus discharge relations produced by HABTAE are the typical output from PHABSIM that are used in instream flow analyses. In many applications, users have ended the analysis at this stage. In an unfortunate number of cases, the discharge producing the highest habitat value has been selected as the recommended instream flow. Such a choice neglects to deal with the feasibility, effectiveness or frequency of occurrence of that flow value. Thus, MESC strongly recommends that users apply PHABSIM in the context of an IFIM study. It is particularly important that habitat time series analysis be performed using the WUA versus discharge relation as a starting point. See Bovee, et al., (1998) for a full development of the IFIM process and how to create and analyze habitat time series.

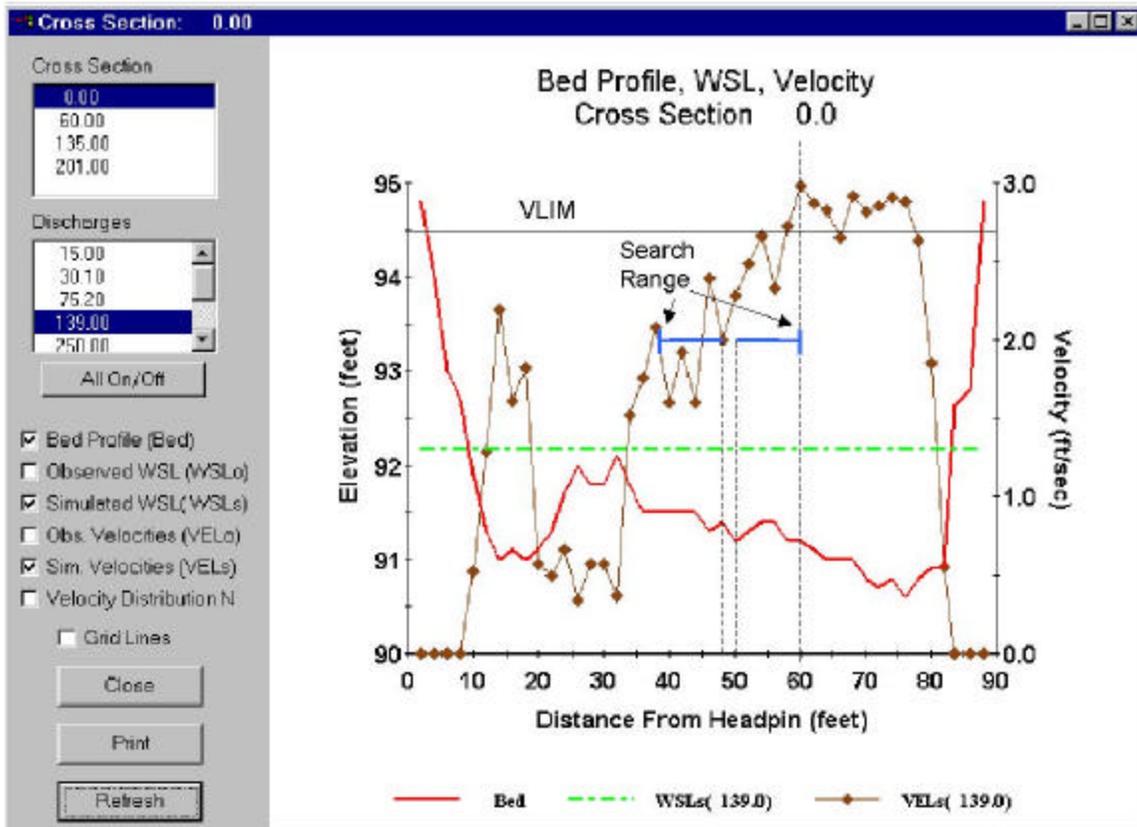


Figure 4-11. Illustration of adjacent velocity calculation.

### *Running HABTAE*

The HABTAE program may be executed by selecting the desired calculation and output options in the various option tabs and clicking the **Run** button in the **Output Options** tab.

## **Lateral Migration Analysis using the HABTAM Program**

The HABTAM program simulates conditions in which fish can migrate laterally within a cross section in order to make use of the available WUA when there is a change in discharge. Note with the revision of cell definition from DOS PHABSIM, the values of hydraulic characteristics (depth, velocity, and channel index) for each cell are the values of the velocity, depth, and channel index at the right vertical looking upstream.

The HABTAM program calculates WUA at each designated flow using the user supplied suitability curve functions for velocity, depth, and channel index and/or other hydraulic properties within each computational cell derived from the VELSIM program. HABTAM assumes that the available WUA at the user-designated starting flow is fully used and then, based on the user-designated maximum allowable migration 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 used. Fish are permitted to migrate only laterally from cell to cell within a cross section.

**Table 4-4.** Cell-by-cell adjacent velocity calculations.

X	Vel	Siv	Sid	Sis	Ad Vel	Factor	Area	WUA
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.72	0.14	1.00	0.00	0.00	21.00	0.00
10	0.53	1.00	0.58	1.00	0.00	0.00	60.00	0.00
12	1.28	1.00	1.00	1.00	0.00	0.00	60.00	0.00
14	2.19	1.00	1.00	1.00	0.00	0.00	60.00	0.00
16	1.61	1.00	1.00	1.00	0.00	0.00	60.00	0.00
18	1.82	1.00	1.00	1.00	0.00	0.00	60.00	0.00
20	0.57	1.00	0.98	1.00	0.00	0.00	60.00	0.00
22	0.50	1.00	0.68	1.00	0.00	0.00	60.00	0.00
24	0.66	1.00	0.33	1.00	0.00	0.00	60.00	0.00
26	0.34	0.95	0.28	1.00	0.00	0.00	60.00	0.00
28	0.57	1.00	0.38	1.00	0.00	0.00	60.00	0.00
30	0.57	0.96	0.23	1.00	0.00	0.00	60.00	0.00
32	0.37	1.00	0.23	1.00	0.00	0.00	60.00	0.00
34	1.52	1.00	0.53	1.00	0.00	0.00	60.00	0.00
36	1.76	1.00	0.68	1.00	0.00	0.00	60.00	0.00
38	2.08	1.00	0.68	1.00	0.00	0.00	60.00	0.00
40	1.60	1.00	0.68	1.00	0.00	0.00	60.00	0.00
42	1.92	1.00	0.68	1.00	0.00	0.00	60.00	0.00
44	1.60	1.00	0.78	1.00	0.00	0.00	60.00	0.00
46	2.40	0.80	0.83	1.00	0.00	0.00	60.00	0.00
48	1.99	0.86	0.88	1.00	1.00	0.76	60.00	45.53
50	2.28	0.62	0.93	1.00	1.00	0.57	60.00	34.48
52	2.48	0.43	0.83	1.00	1.00	0.36	60.00	21.40
54	2.66	0.51	0.78	1.00	1.00	0.40	60.00	23.77
56	2.33	0.48	0.88	1.00	1.00	0.42	60.00	25.17
58	2.72	0.15	0.98	1.00	1.00	0.14	60.00	8.69
60	2.98	0.07	1.00	1.00	1.00	0.07	60.00	4.45
62	2.87	0.15	1.00	1.00	1.00	0.15	60.00	9.10
64	2.83	0.26	1.00	1.00	1.00	0.26	60.00	15.75
66	2.65	0.22	1.00	1.00	1.00	0.22	60.00	13.02
68	2.92	0.13	1.00	1.00	1.00	0.13	60.00	7.85
70	2.82	0.16	1.00	1.00	1.00	0.16	60.00	9.88
72	2.85	0.12	1.00	1.00	1.00	0.12	60.00	7.07
74	2.91	0.10	1.00	1.00	1.00	0.10	60.00	6.15
76	2.88	0.24	1.00	1.00	1.00	0.24	60.00	14.61
78	2.63	0.76	1.00	1.00	1.00	0.76	60.00	45.48
80	1.85	1.00	1.00	1.00	1.00	1.00	60.00	60.00
82	0.56	0.73	0.64	1.00	1.00	0.47	33.10	15.54
83.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The user designates a starting flow, ending flow, and a maximum allowable migration distance for each life stage of each species in the right-hand table of the **/Models/HABTAM/Options** tab. The program looks only at the user-designated starting and ending flows for the migration calculations, and processes each cross section as a separate entity, that is, fish cannot migrate from one cross section to another. Assuming that the stream is saturated with fish at the starting flow (all WUA is occupied) and that the flow is then changed to the ending flow, the program permits the fish to migrate in either direction within the cross section up to the maximum allowable migration 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 used by the fish presently existing in the stream. The results will show that either all the available WUA at the ending flow can be used, or there is an excess of WUA available at the ending flow, which cannot be used because there are not enough fish to use it.

The following assumptions are made for the migration calculations:

1. Fish migration is assumed to begin at the cell boundaries. Thus, when a fish is given a maximum allowable migration distance greater than zero, it is automatically permitted to migrate to adjacent cells. Any distance it might have to travel within its cell of origin is ignored.
2. In situations where the maximum allowable migration distance places a fish exactly 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 migration calculation. Cell widths change with wetting and drying of the extreme edge cells.
4. When a portion of a cell becomes dry at the user-designated ending flow, the fish are not permitted to migrate beyond the dry boundary point.
5. When a given life stage does not or cannot migrate at all, a value of 0.0 should be entered as the maximum allowable migration distance for that life stage. When this occurs, the program will select for the WUA with migration, the minimum of the WUA at the starting flow, and WUA at the ending flow.

Input to the HABTAM program is through the **/Models/HABTAM/Options, ../Computations, ../Migration, and ../Velocity Calculations** tabs. The program uses these previously entered data and simulation results: (1) HSC curves of aquatic species or recreational activities created in **/Edit/Suitability**, (2) hydraulic simulation results from the WSL and velocity modeling stages, and (3) study site layout (weighting) values from **/Edit/Cross Sections/Cross Section Data**.

### *Setting HABTAM Options*

The HABTAM program provides the user with a wide array of computational and output listing capabilities. Control of computations and output listings is accomplished through several check boxes and data entry fields in the various tabs in **/Models/HABTAM** as described below.

HABTAM options are summarized in Table 4-5.

**Table 4-5.** Options in the HABTAM program.

Option description	Action when set to indicated value, notes
<b>Options</b> tab <b>Write Migration Calculation Details</b> (check box)(IOC 1)	Writes details of migration calculations to ZOUT. Use when HABTAM produces unexpected results. Recommend leaving unchecked for most runs.
<b>Options</b> tab <b>Write Cross Section Data</b> (check box)(IOC 2)	Writes cross section data (from <b>/Edit/Cross Sections/Cross Section Data</b> ) to ZOUT. May be used in documenting PHABSIM runs. Recommend leaving unchecked for most applications.
<b>Options</b> tab <b>Write Flow Related Data</b> (check box) (IOC 3)	Writes flow data for each cross section evaluated at each discharge to ZOUT. This also lists the velocity for each cell that is wet. This recapitulates the VELSIM output. Recommend leaving unchecked and using VELSIM output table for documentation of most applications.
<b>Options</b> tab <b>Write Computational Details</b> (check box) (IOC 4)	Writes all the computational details for the weighted usable area calculations to ZPOUT. Recommend leaving unchecked except when HABTAM gives unexpected results and further evaluation is needed. Output is voluminous, so limiting the number of life stages is recommended when using this option.
<b>Options</b> tab <b>Write Criteria Curve Coordinates</b> (check box) (IOC 8)	Writes the coordinates of the HSC curves used in HABTAM analysis to ZOUT. Recommend checking this box.
<b>Options</b> tab <b>Selected Discharges</b> (input table with check boxes)	This table of discharges used in HABTAM calculations has check boxes to select or deselect discharges. Typically, all discharges would be selected. However, for some analyses only a few discharges may be needed.
<b>Options</b> tab <b>Flows for Migration Calculations</b> (input table)	This table allows the user to set up to 25 pairs of starting and ending discharges to be used for migration calculations. The discharges used may be the same as those in the <b>Selected Discharges</b> table. You can <u>copy</u> from Selected Discharges and <u>paste</u> to <b>Flows for Migration Calculations</b> to ensure the same values are used.
<b>Computations</b> tab <b>Use Channel Index Values of Zero in WUA Calculations</b> (check box) (IOC 7)	This defines how channel index values of zero (0) are used. If not checked, channel index values of zero are converted to 1.0 which effectively removes channel index from the calculation for any cell with a 0.0 CI. When checked, a channel index value of zero is used in the calculation of WUA for that cell. Recommend checking.

**Table 4-5.** Continued.

Option description	Action when set to indicated value, notes
<b>Computations</b> tab <b>Describe Reach Bends</b> (check box) (IOC 12)	Allows the length to vary from cell to cell (Variable Cell Length) across the stream (i.e., a bend). Default is to use cells as rectangles in plan view. When checked, program uses cells as trapezoids based on the length multiplied by left and right bank weights. To use this option, left and right bank weighting factors must be entered in <b>/Edit/Cross Sections</b> .
<b>Computations</b> tab <b>Calculate Habitat as % of Total Area</b> (check box) (IOC 10)	Calculates habitat as a % of total area. This output is useful in comparative analyses where different flow pairs are compared for relative impacts of different hydropower flow management alternatives.
<b>Computations</b> tab <b>Habitat Area Calculation</b> (radio buttons) (IOC 9)	Controls how the calculation of WUA will be made. <b>Standard calculation</b> -- 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. <b>Geometric Mean</b> – $CF = (f(v)*g(d)*h(ci))^{0.333}$ . <b>Lowest Limiting Parameter</b> – $CF = \text{MIN} (f(v), g(d), h(ci))$ .
<b>Migration</b> tab <b>Enter Migration Distance for Each Curve ID</b> (input table)	Each HSC identifying number is displayed in the left column of this table. Enter the migration distance for the species/life stage represented by each HSC.
<b>Migration</b> tab <b>Enter up to 25 Additional Migration Distances</b> (input table)	Enter an HSC curve number and additional migration distance for that species/life stage for all species you wish to evaluate different migration capabilities. This option is useful if there is more than one hypothesis about the species' migration capability.
<b>Velocity Calculations</b> tab <b>Cell Velocity Options</b> (radio buttons) (IOC 14)	These options act the same as the <b>Vel Calc</b> options in HABTAE. · <b>Mean column velocity</b> - Uses standard mean column velocity in habitat calculations. · <b>Nose velocity</b> – Uses the 1/7th power law equation. User supplies nose depth ( $D_{nose}$ ) in input table below. Only the needed items will be activated when these options are selected. · <b>Nose velocity user defined coefficients</b> – empirical power law equation and user defined coefficients. User supplies the nose depth ( $D_{nose}$ ) and the calibration parameters a and b. These values are entered in the input table below. · <b>Nose velocity logarithmic velocity distribution</b> - logarithmic velocity distribution equation. The nose depth and the $D_{65}$ of the bed material are supplied by the user in the input table below.
<b>Velocity Calculations</b> tab <b>Scan Adjacent Cells for</b> (radio buttons) (IOC 6)	These options represent the same choices for scanning as for the <b>Cell Velocity Options</b> above.

## Evaluating HABTAM Results

The HABTAM program performs a standard WUA calculation to obtain the cell-by-cell habitat values prior to evaluating migration. Thus, there are three tabs for results. As with the HABTAE model, the **../HABTAM/Habitat Results** and the **../HABTAM/ZHAQF Results** tabs contain cell-by-cell composite suitability and WUA versus discharge values, respectively. The result tables and graphical displays on these tabs act the same as those for HABTAE.

The **../HABTAM/Migration Results** tab is unique to HABTAM. Here the WUA resulting from the constraints of the migration calculations is displayed as an output table and a rotatable 3-dimensional surface plot of the migration results is displayed. Simply stated, the highest point on the plot shows the discharge pair that produces the highest habitat value and the lower valued combinations are easily visualized. For many situations, large flow changes will produce relatively poor migration habitat values and small flow changes will produce relatively good migration habitat. That is, small changes in flow will produce migration habitat values that are near the WUA values obtained for the lower of the two discharges.

When comparing fluctuating flow regimes such as hydropeaking management alternatives, the analyst must take care to recognize that not only the magnitude of the flow change but the frequency with which it occurs, will be a factor in determining which alternative may have the most impact on the aquatic organisms downstream of the dam.

## Running HABTAM

Once all options and starting and ending discharges have been entered for the items covered in Table 4-4, the HABTAM program is run by clicking the **RUN** button on the **../Options** tab. If a minimum set of options have not been selected, the program prompts with warning messages.

## Effective Habitat Analysis using the HABEF Program

The HABEF program calculates physical habitat considering conditions at two stream flows and/or for two life stages or species. The program uses habitat results from either HABTAE or HABTAM as the source of species/life stage habitat information for each cell. The basic equation used in HABTAE for weighted usable area in cell  $i$  ( $wua_i$ ), is given by the equation:

$$wua_i = A_i * CS_i \quad (4-19)$$

where:  $wua_i$  = weighted usable area of computational cell  $i$   
 $CS_i$  = combined suitability of computational cell  $i$   
 $A_i$  = area of computational cell  $i$

HABEF uses  $A_i$  and  $CS_i$  for each computational cell used in the physical habitat simulation performed in HABTAE or HABTAM. The WUA used in HABEF is derived from the normal calculation used in the principal habitat programs and is defined by the equation:

$$WUA = \sum_{i=1}^{ncell} CS_i A_i \quad (4-20)$$

The usable area (UA) can also be computed and is derived from:

$$UA = \sum_{i=1}^{ncell} CS_i A_i \quad (4-21)$$

if  $CS_i \geq 0.001$  then  $CS_i = 1.0$   
if  $CS_i < 0.001$  then  $CS_i = 0.0$

The user can select either of these habitat definitions for the computation of effective habitat during execution of the program by specifying the appropriate options within the **/Models/HABEF/Options** tab as explained below.

In addition to these basic calculations, the HABEF program can be used to conduct a number of analyses in which comparisons of available habitat on a spatial basis can be examined between species or life stages pairs.

The basic computational options for the HABEF program are listed below with a description of each option provided in the **/Models/HABEF/Options** tab.

Union Of Life Stage 1 With Life Stage 2	-	Use two species/life stage HSC
Competition Analysis	-	Use two species/life stage HSC
Stream Flow Variation Analysis (Minimum WUA)	-	Use one species/life stage HSC
Stream Flow Variation Analysis (Maximum WUA)	-	Use one species/life stage HSC
Effective Spawning Analysis	-	Use two species/life stage HSC
Stranding Index Analysis	-	Use one species/life stage HSC

### *Union Analysis*

The first option in HABEF is the Boolean algebraic union of two life stages or species. The WUA results from HABTAE or HABTAM are compared on a cell-by-cell basis for both selected life stages (species/life stage) at all flows in the data set. This may be the union of two life stages of the same species (i.e., fry and juveniles) or it may be the union of two species/life stages (i.e., rainbow and brown trout adults). A union analysis will usually result in a WUA value for the study site for each given stream flow that is greater than the higher of the two independent variables, but less than the sum of the two.

### *Competition Analysis*

Of considerable interest in habitat analyses is the competition of two life stages or two species for the same space. An analysis of habitat competition can be done using Option 3 in HABEF. Most likely, two species will compete for some of the habitat; yet, in other places have the habitat all to themselves (assuming two species are in the stream). In the areas (cells) where direct competition occurs, there are cells where one species/life stage (1) is better suited than the other life stage (2); and other cells where the converse is true. Option 3 gives information on both of these possibilities. It should be noted that this analysis does not explicitly take into account the behavior of either species.

When this option is selected, HABEF first calculates habitat for species/life stage “1” in cells where habitat for the species/life stage “2” is zero. This is combined with the amount of habitat occurring in computational cells where combined suitability is greater than 0.0 for both species but where species “1” has a higher combined suitability value than species “2”. Thus the competition option describes the total WUA for cells where species “1” dominates. The program reports this in the column labeled **WUA 1>2 in 1&2**. The inverse calculation is

simultaneously performed for species “2”.

In interpreting the results, situations where one species clearly has superior habitat conditions to the other (for example, if **WUA 1>2 in 1&2** is two or more times greater than **WUA 2 in 1&2**) it is likely that behavior alone would not allow the species with the less favorable habitat to out-compete the species with the more favorable habitat. When the habitat areas derived in the competition analysis do not significantly favor one species over the other, another form of analysis outside of PHABSIM may be needed to determine the effects of competition in the study reach.

To run this option, the two species to be evaluated are selected in the two input cells on the **/Models/HABEF/Options** tab and the **Competition Analysis** radio button is set, followed by clicking the **Run** button. Changing to the **./Results** tab, the user will find that in addition to the standard WUA result (sum of cell area times composite suitability), the following WUA sums are accumulated under the indicated column heading.

**WUA (1 and 2)** This is a Boolean intersection of all cells where both species have WUA>0. This column contains the sum of the surface area of all cells that have both species with non-zero habitat. That is, as long as both species have more than 0.001 units of habitat, the cell is counted in this sum. This value is an indicator of the total surface area of the stream where competition may occur.

**WUA (1 = 2)** Intersection: This value is a sum of the WUA for only those cells where the WUA values for both species are equal. This column commonly contains zeros.

**WUA (1 in 1&2)** This is the sum of cell WUA values for species 1 for all cells where both species 1 and species 2 have habitat values greater than 0.001. (e.g., this is the Species 1 habitat in potential competition areas.)

**WUA (2 in 1&2)** This column contains the sum of cell WUA for species 2 for all cells where habitat for both species 1 and 2 is greater than 0. This is the species 2 habitat in potential competition areas.

**WUA (1>2 in 1&2)** This is the sum of WUA for species 1 where species 1 WUA is greater than species 2 WUA in potential competition cells.

**WUA (2>1 in 1&2)** This sum is the opposite of the above.

Competition analysis is used to compare the results from a WUA analysis for two species at the same stream flows or for the same species/life stage at all combinations of flows supplied in the **Edit/Discharges** menu. Scroll the results table to display all columns. As with other PHABSIM for Windows results, these may be pasted into a spreadsheet.

### *Stream Flow Variation Analysis*

The purpose of the stream flow variation analysis is to look at available habitat at two flows with both sets of flows varying over a range of discharge. Recall that HABEF output contains all combinations of flows contained in the discharge list. The streamflow variation analysis option allows the analyst to evaluate which variation in flow produces the least or most usable area and Weighted Usable Area. To run this option, the same species/life stage (same HSC curve number) is entered in both input cells on the **/Models/HABEF/Options** tab and the **Streamflow Variation Analysis** radio button is set. The **./Results** tab contains entries for the sum of usable area, WUA and minimum or maximum WUA as noted below.

Maximum and minimum values for specific discharges can be obtained from the diagonal of the streamflow

variation results matrices as the diagonal represents a no-variation case. The minimum and maximum values can be used to compare the state under one condition (flow, species, etc.) for a specific cell to the state with a second condition in the same cell. The **Streamflow Variation Analysis (minimum WUA)** option determines the minimum WUA value compared between each set of discharges for each computational cell, and the **maximum WUA** option does the converse. The summed results represent the aggregate results of those cell-by-cell comparisons.

### *Effective Spawning Analysis*

In effective spawning analysis, an area available for spawning habitat is only included as habitat if suitable conditions continue to exist over the period of incubation. Thus, it may be useful to run this analysis over the range of discharges that are likely to exist during the incubation period. If the lowest discharge that is likely to be encountered is significantly lower than the discharge at which spawning takes place, then a large amount of streambed that was wet at the time of spawning may become dry or freeze during incubation. Such an event may cause the spawned eggs to die.

The results contain all combinations of flows set in the discharge list. The user may wish to select a smaller range when reporting effective spawning results.

When **Effective Spawning Analysis** is selected, the WUA within a computational cell is determined from the relative amount of WUA in the computational cell at the second discharge. If the WUA in the computational cell at the second discharge is greater than the WUA in the computational cell at the first discharge, then the WUA is set to the WUA within the computational cell at the first discharge. If the WUA at the second discharge for the computational cell is 0.0, then the WUA is set to 0.0.

### *Stranding Index Analysis*

When **Stranding Index Analysis** is selected, the program computes an index of the habitat isolated when the flow drops. Basically, the available WUA in a computational cell is determined in the same manner as for effective spawning above. However, the stranding index is then computed according to the equation:

$$\text{Stranding Index} = \left(1.0 - \frac{\sum \text{WUA}_{\text{effective}}}{\sum \text{WUA}_{q1}}\right) * 100.0 \quad (4-22)$$

where:  $\text{WUA}_{\text{effective}}$  = the effective WUA described under Option 7 summed over all computational elements

$\text{WUA}_{q1}$  = the WUA summed over all computational elements at first discharge

When performing stranding index analysis, users are cautioned to carefully check the output and evaluate only those conditions where the flow is dropping.

## **Summary of Chapter 4**

This chapter presented the wide variety of habitat simulation approaches available in the PHABSIM for Windows software. Using commercial spreadsheet software to aggregate variables in ways that are not explicitly handled in PHABSIM can further enhance some analyses. For example, conditions with and without cover can be aggregated by adding the WUA values for a species/life stage with and without cover to obtain a final habitat – discharge relationship that encompasses both conditions. PHABSIM users are encouraged to adapt the analyses they perform to the problem at hand and not to be limited by the specific processes coded in this software. The next

chapter provides some ideas for using PHABSIM in various situations. The ideas and cautions in it are intended as thought provoking examples that can be built upon when using PHABSIM as part of an IFIM-based study.

## **Chapter 5. Interpretation of PHABSIM within IFIM**

### **Objectives**

The objectives of this chapter are to present several approaches to interpreting and using the output from PHABSIM within the context of the Instream Flow Incremental Methodology (IFIM).

### **Laboratories**

No specific laboratory exercises are provided for this material.

### **Introduction**

This chapter presents examples of particular situations and analytical approaches that may occur or be applied within an application of PHABSIM. During the analysis scoping phase of IFIM (see Figure 1-1), the stakeholders involved in an instream flow issue are expected to reach consensus on the type of analysis to be used for the problem, the technology to be applied, and the approaches to interpreting the analytical results. As noted in Chapter 1, an IFIM application may be entirely successful without use of PHABSIM if the issue can best be decided based on criteria other than physical microhabitat. MESC strongly recommends that consensus on these issues (type of analysis, scale of the problem, technology to be used, and interpretation of results) be reached prior to investing time and resources in the study. Doing so has been found to greatly reduce after-the-fact disagreements on methods and interpretations, allowing decision makers to focus on the issue of allocating instream flows.

Once consensus has been reached to use PHABSIM, one of the most challenging aspects in its application is the proper use and interpretation of PHABSIM model results within the IFIM framework. It is important to stress that the basic WUA versus discharge relationships obtained from the habitat modeling process in PHABSIM represent only instantaneous variation of physical habitat with flow and should not be interpreted in the absence of one or more alternative flow regimes for a particular study site. This is why a study employing PHABSIM is not considered to be an IFIM study unless flow and habitat time series including seasonal habitat needs for all life stages are analyzed.

### **Picking the Peak of WUA Curves**

One potential error PHABSIM users commonly make is a “blind” evaluation of the WUA versus discharge function where the instream flow is selected to be the discharge at which the peak (or maximum) WUA value occurs. This can create a number of problems as illustrated by the following example.

In a study, an investigator completed a PHABSIM analysis for a number of target species and life stages. After reviewing the component habitat versus discharge relationships, the investigator selected the most sensitive species and life stage (i.e., habitat in shortest supply) for each month and then recommended an instream flow regime by selecting the flows at the peak of the WUA curve for each month of the year. This seemed a prudent and defensible approach at the time. However, it was found out some time later when the discharge records for the gauge at the study site were examined on a monthly basis, that many of the selected monthly instream flows corresponded to discharges with monthly exceedance values in the ranges between 10–15%. That is, flows greater than or equal to the recommended flows occurred only 10–15% of the time. In essence, the investigator

was claiming that near flood flows were necessary for the recommended instream flows in most months. Unfortunately for this particular investigator, no rational biological justification could be offered in defense of the selected flow regime.

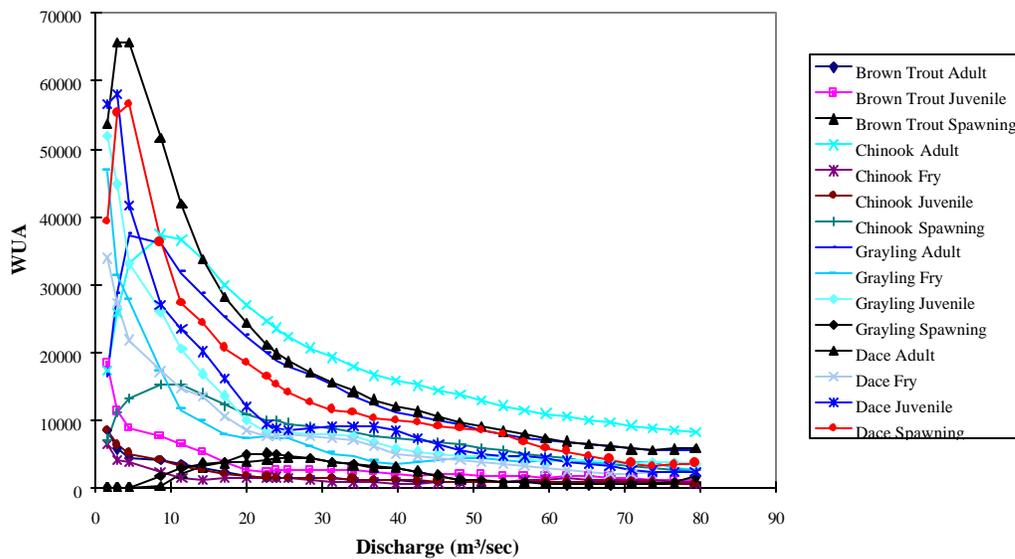
This example is provided to highlight the point that failure to evaluate the feasible flow regime(s) at the site during the evaluation of instream flows can lead to problems in negotiating instream flows and is highly discouraged. There are situations, in which flows greater or lesser than the flow associated with the peak of the WUA curve may make rational sense and perhaps the most critical element of the interpretation process is the rational basis or framework for evaluation of model outputs. IFIM emphasizes creation and analysis of habitat time series as a key component in this framework.

For example, the investigator above could examine the monthly flow duration curves and consider where the median monthly flow (i.e., 50% exceedance) or some other exceedance level lies in relationship to the flow at which optimal habitat conditions exist for a target species and life stage. If the median flow was selected for consideration and is higher than the optimal flow, the investigator may consider allowing some level of abstraction down to the flow at which the optimum habitat occurs. If the median monthly flow falls below the flow at which the optimal habitat occurs, then the investigator can examine the magnitude of habitat or percentage reduction and decide if further reductions would potentially represent any level of adverse conditions. In many cases, this type of approach which requires the investigator to consider the consequences of a particular flow regime in light of the amount and or quality of habitat for one or more exceedance ranges is encouraged and permits the consideration of known life history needs that are not directly reflected in the results of the habitat versus flow relationship derived from PHABSIM.

### **Use of a Most Sensitive Species and Life Stage**

In many instream flow studies, a number of species and life stages are considered to be important for evaluation within PHABSIM at an early stage of the project (i.e., scoping). For example, a stream may contain salmon, brown trout, arctic grayling, and dace. After considerable effort in the selection and application of each of these species and associated life stage suitability index curves for representative life stages, the analyst may obtain a family of WUA versus discharge functions as illustrated in Figure 5-1. For some time periods of the year many, if not most, of these species and life stages may be present in the system. Therefore, the investigator is faced with a difficult task of integrating all these curves in a coherent manner to establish a recommended flow regime.

One approach to integrating multiple WUA relationships is to base the instream flow assessment on the single species and life stage that is most sensitive to changes in flow during a critical period. Alternatively, a particular species and life stage may be considered the most important from a management perspective, such as spawning brown trout in a system where the management goal is a self sustaining wild brown trout population. Flows can then be selected based on this single species and life stage while attempting to minimize potential adverse reductions to other species and life stages. In some situations, a reduction in the primary target species and life stage habitat quantity and quality can be made such that other species and life stages can still retain what are considered adequate levels of habitat availability. This approach is sometimes called a “keystone” or “cornerstone” species analysis.



**Figure 5-1.** Example of WUA vs. discharge relation for a suite of species.

Another approach to the multiple species problem is to apply a two-tiered prioritization process that includes life history stage first, and then species priority. This approach, suggested by Reiser (2001), begins by establishing a list of target species, agreeing on their management priority, and obtaining consensus on the most important life stages of those species at different times of the year. For example spawning habitat may be considered more important than habitat for the adult or juvenile life stages. Then for any given month, if spawning occurs for any of the species, the spawning life stage is given first consideration in the flow analysis. If spawning does not occur for any of the species during that month, go to the next priority life stage for the 1<sup>st</sup>, 2<sup>nd</sup>, etc. species and base the flow analysis for that month on that next selected species/life stage. This approach avoids basing the conclusions of the entire analysis on a single “keystone” species. As with all analyses where priorities are established, consensus is vital to avoid conflict after the analysis is complete.

Some applications are not readily amenable to the use of the most sensitive species or critical species and life stage (i.e., they all are the focus of management objectives). In this instance, a post-analysis guiding approach is sometimes possible.

### Post-analysis Guiding

A post-analysis guiding approach can take on several forms depending on the context of the project and management objectives. One approach that has been used involves the construction of a community level habitat versus flow relationship. A community habitat curve can be constructed using the original habitat versus discharge relationships or by using a set of normalized habitat versus discharge functions. If normalized habitat functions are to be used, the first step is to re-scale each individual species and life stage WUA versus discharge curve to the maximum value of WUA for each species and life stage (i.e., each curve is re-scaled as a percent of the maximum or optimal habitat) as illustrated in Figure 5-2. The investigator can then combine these curves (or the original unscaled curves) using a weighted arithmetic average to produce a single curve as illustrated in

Figure 5-3. The relative weighting factors for a specific critical period for each species and life stage can be selected to represent the management objectives for the system and should be defined during the project-scoping portion of an IFIM analysis.

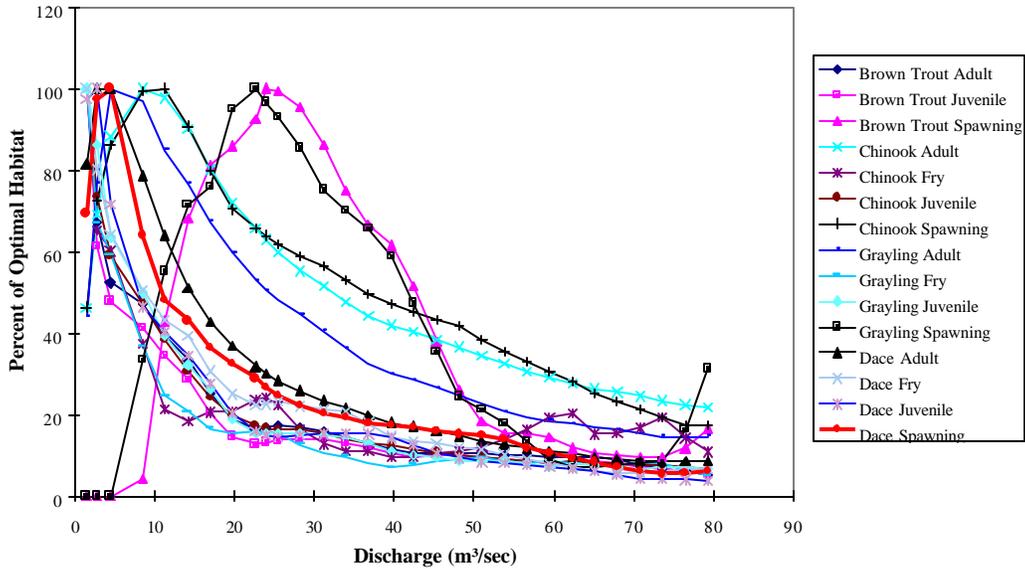


Figure 5-2. Normalized multiple-species WUA relationships.

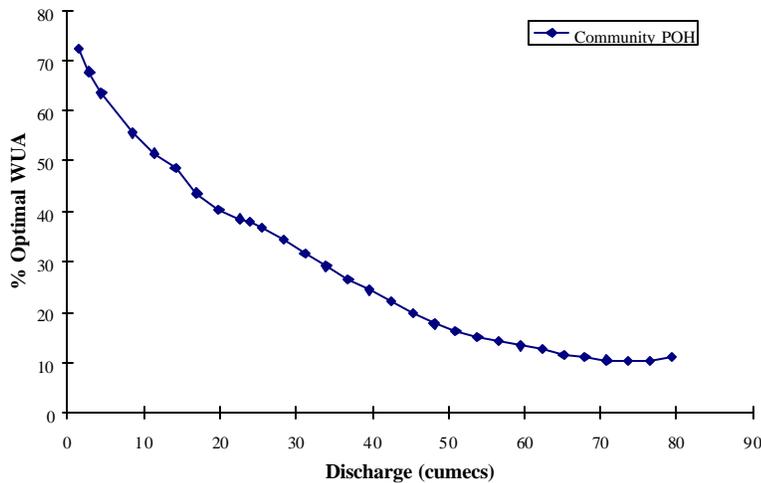


Figure 5-3. Combined community WUA versus discharge relationship.

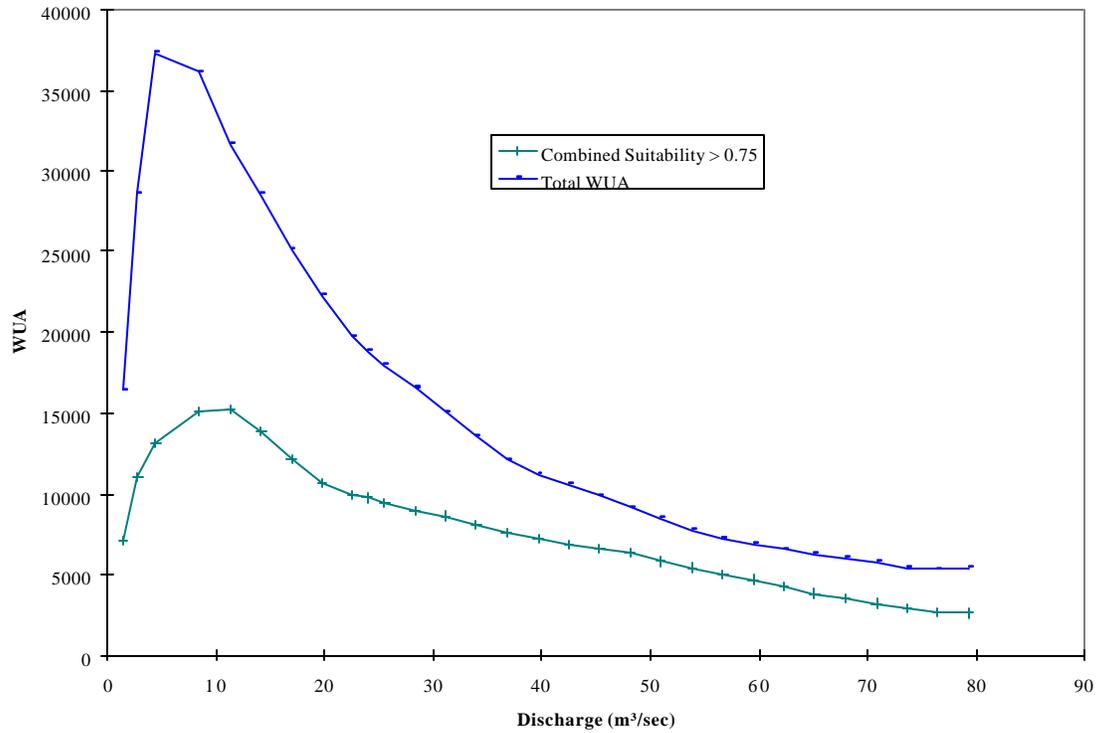
In the analysis scoping stage of IFIM, the stakeholders may choose to develop a community curve for specific periods of the year based on the unique combinations of species and life stages identified by the species periodicity table as discussed previously. It is also possible that the relative weighting factors used to construct the community curves may change between time periods to reflect the relative importance or sensitivity of specific species and life stages during a particular time period. For example, an endangered species may receive a weight of 2.0, while all other species and life stages may receive a weight of 1.0, or spawning may be weighted more than fry during the spawning period. The community curves can be used in subsequent evaluations such as time series and habitat duration analyses. It is strongly advised that individual species and life stage habitat relationships be checked to ensure flow regimes selected provide consistency in the results.

Alternatively, parties to an IFIM application may choose to simplify multiple habitat curves to eliminate very similar or “redundant” WUA versus discharge relationships. In this approach, curves that have the same basic magnitude and functional relationship can either be eliminated or averaged to generate a single curve which in essence represents the guild of species and life stages with similar fundamental relationships between habitat and flow. In some instances, this combining or guilding can be accomplished using normalized habitat functions since many applications focus on relative changes in habitat and not necessarily on the actual magnitude of the habitat change. Similarity in the functional relationships between habitat and discharge for different species and life stages in fact is not uncommon and in a sense is to be expected. For example, fry and juvenile curves for many salmonids actually exhibit very similar habitat requirements, which follow known obligate habitat use for these early life stages. It is also not uncommon for different life stages for different species to use similar habitats. This is reflected in similar HSC curves and thus, similar habitat versus discharge relationships.

The final set of gilded habitat functions can then be used to construct a community level curve as described above, or the most sensitive guild within a critical period may be selected for consideration in further analyses. As mentioned previously, in all cases, habitat-discharge relationships must be evaluated using analysis of habitat time series for feasibility, effectiveness, cost, and risk of failure. The reader is referred to Bovee, et al., (1998) for further development of habitat time series analysis.

## Consideration of Quantity Versus Quality

As discussed in Chapter 4, the basic habitat versus discharge relationship represents an aggregation of the component cell WUA values across all cells at a specific discharge for a given species and life stage. Therefore, the results presented in a habitat-discharge relationship such as Figure 5-1 cannot be directly used to ascertain the difference between a total magnitude of WUA which is represented by all cells having a low suitability, versus a WUA result where a few cells contain high suitability values. For example, a stream may have a total surface area of 100 square feet at a given discharge that is composed of 10 equal area cells (i.e., each cell is 10 square feet). A computed total WUA could be derived from all 10 cells each having a combined suitability of 0.1, giving  $(0.1)(10 \text{ ft}^2)(10 \text{ cells})=10 \text{ ft}^2$  of WUA. Alternatively, nine of the habitat cells could have a combined suitability of 0.0, while the one remaining habitat cell could have a combined suitability of 1.0 giving  $[(0.0)(10 \text{ ft}^2) (9 \text{ cells}) + (1.0)(10 \text{ ft}^2)(1 \text{ cell})] = 10 \text{ ft}^2$  of WUA. Fortunately, PHABSIM includes options to exclude poor quality habitat (see **Minimum Effective Composite Suitability Factor (CFMIN)** in Chapter 4). This is illustrated in Figure 5-4 for composite suitability greater than 0.75 for adult brown trout. As can be seen, the peak of the total WUA curve does not always correspond with the peak of highly suitable habitat conditions. The investigator should carefully consider the biological implications of selecting flows that maximize total WUA versus the consideration of an alternative flow that may maximize the area associated with high quality habitat. It should be remembered that all the techniques described above could be used with high quality habitat versus flow functions in a manner equivalent to using the total WUA curves.



**Figure 5-4.** WUA vs. discharge for cells with composite suitability > 0.75.

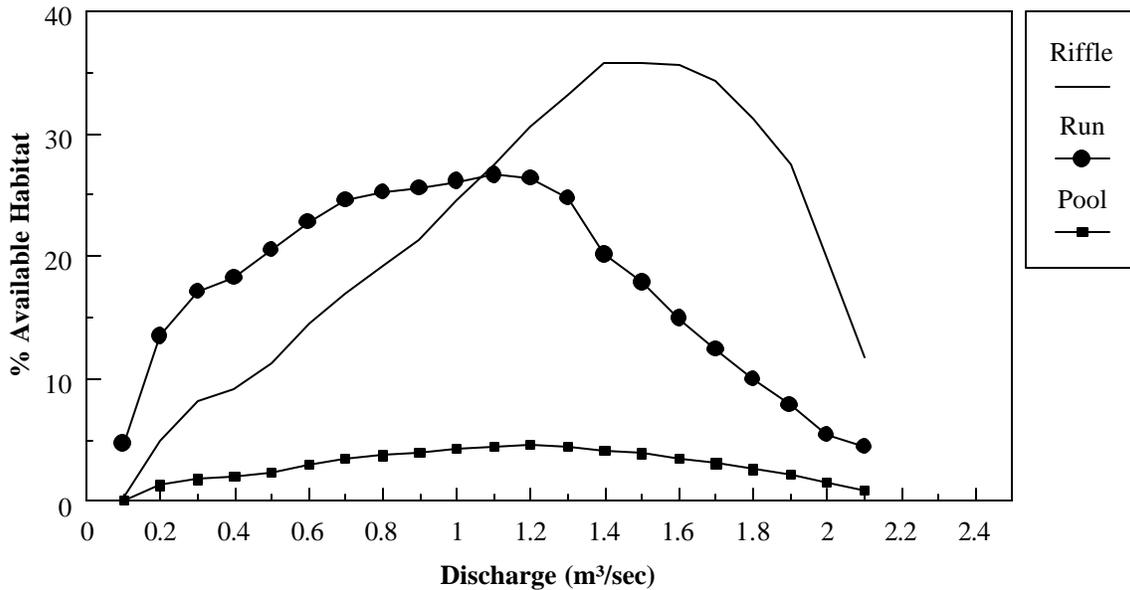
### Evaluation of Mesohabitat-specific Conditions

HABTAE can be used to generate output on a cross section by cross section basis, or for a group of cross sections by selecting pools only versus selecting riffle habitats. Using this sub-sampling approach, the investigator can develop habitat versus flow functions for specific species and life stages on a mesohabitat basis as illustrated in Figure 5-5. This type of analysis can focus the investigation on species and life stage specific sensitivity to particular habitat types that may be important during critical periods of the year. For example, an analysis may focus on riffle type habitats during the spawning season in lieu of other less sensitive life stages and mesohabitats using this approach. This type of analysis can also facilitate the aggregation of mesohabitat versus flow functions into composite WUA versus flow functions when the proportion of habitat types may change as a function of discharge, or where a gross evaluation of habitat improvement works is desired. Such aggregation can easily be accomplished by exporting PHABSIM for Windows results to a spreadsheet.

### Evaluation of Habitat Suitability Criteria

Habitat suitability criteria (HSC) have been an area of considerable controversy in PHABSIM applications since its inception. Recognizing that site-specific HSC may best reflect the habitat utilization of aquatic species, MESC has recommended that either local HSC be developed for PHABSIM applications or that the stakeholders agree on the HSC to be used as part of the analysis scoping process in IFIM.

## Adult Trout in Chalk Streams



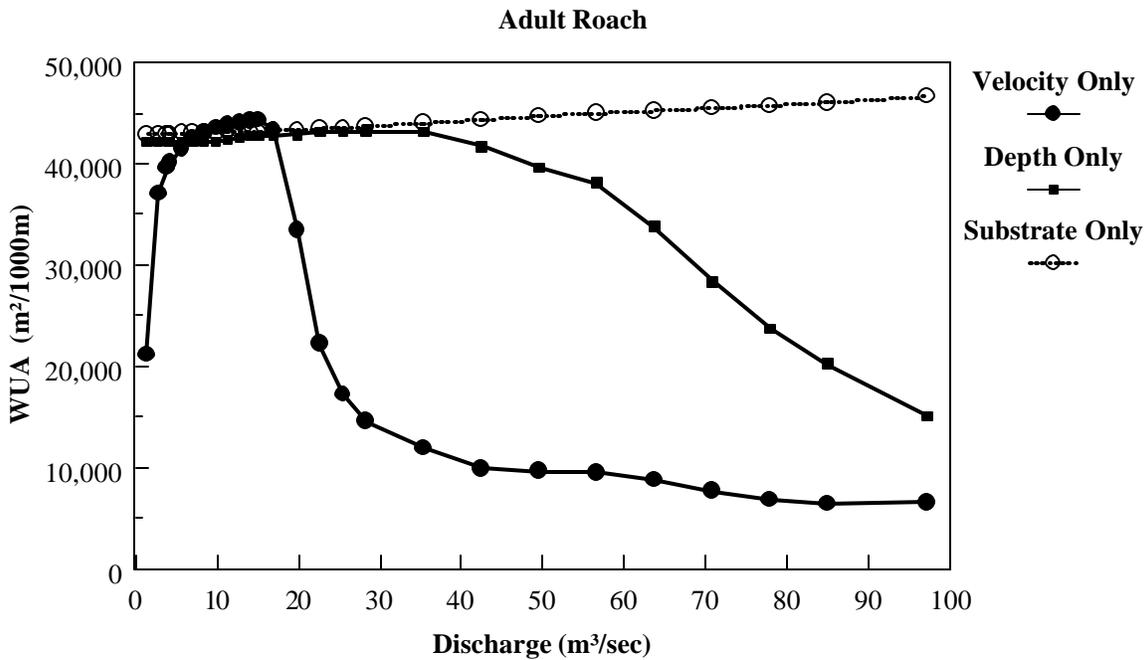
**Figure 5-5.** Habitat-discharge relationships for mesohabitat types.

HSC adopted from the literature or other studies may be evaluated for applicability to the study at hand as shown in this example. The investigator may select a cross section at a specific location in the stream where a known habitat activity, such as spawning, was observed. In this instance, the investigator can examine the spatial distribution of combined suitability values across the cross section to determine if the suitability curves correctly demonstrate suitable habitat conditions at the location of known spawning redds as illustrated in Figure 5-6. Prediction of low combined suitability at the known redd location should cause some concern. A more detailed evaluation of the hydraulic simulations (primarily velocity or channel index) in conjunction with a re-assessment of the suitability curves should be undertaken to ensure the habitat conditions are being properly represented.

### Decomposition of Single Parameter Suitability

In some streams, one or another of the physical habitat parameters may be the source of greatest change in habitat magnitude with a change in flow. An investigator may find that determining which specific suitability factor is contributing to the estimate of total WUA is important. This can be accomplished, for example, by modifying the suitability curves such that only a single parameter such as velocity is retained, while both depth and channel index are set to a 1.0 for all values. This type of analysis can reveal whether depth, velocity or channel index is the controlling factor over specific ranges of discharges as illustrated in Figure 5-7. Note the relative insensitivity to substrate, but great sensitivity to velocity in this example. In addition, when combined with an analysis of mesohabitat, this type of assessment can lend insight to the physical basis for habitat-specific sensitivity to flow for a critical life stage in the target stream.

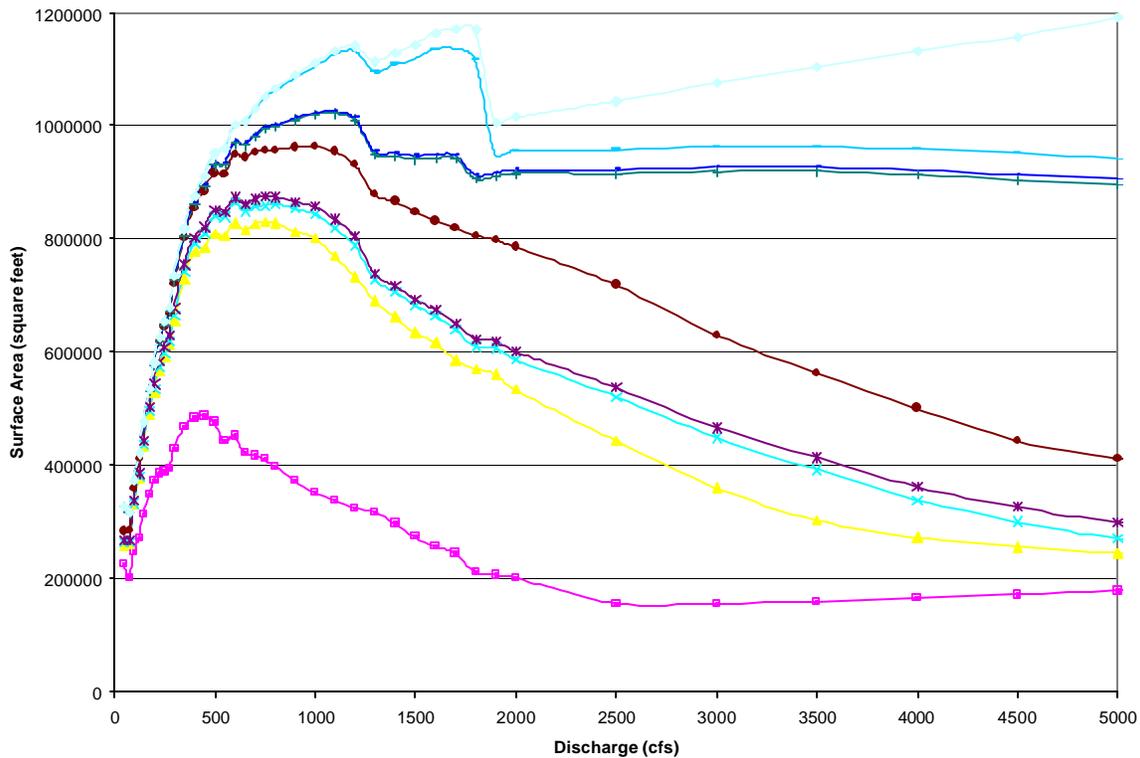




**Figure 5-7.** Single parameter habitat-discharge relationships.

**Table 5-1.** Example of a hypothetical spatial niche indicating component habitat partitioning by resident species/life stages.

		Depth gradient (m)		
		0–0.5	0.5–1.0	≥1.0
Velocity Gradient (m/s)	0–0.5	Brown trout fry Salmon fry Grayling fry Dace fry	Brown trout juvenile Salmon juvenile Dace juvenile Dace adult	Dace adult Winter brown trout adult Winter salmon juvenile
	0.5–1.0	Dace juvenile Dace adult	Grayling juvenile Brown trout adult Salmon juvenile	Grayling adult Brown trout adult Salmon adult
	≥1.0	Dace adult	Salmon spawning	Brown trout adult Salmon spawning



**Figure 5-8.** Example of spatial niche composition versus discharge, each line represents one item in Table 5-1.

It is also possible to use these results to compute a variety of ecologically-based indices such as a diversity index. The diversity index can be computed using the available habitat areas at each flow to produce a habitat diversity versus discharge relationship. The analyst can then examine these relationships in light of specific discharges and the associated amounts of specific areas represented by specific habitat niches or overall habitat diversity. This may lead an investigator to select a discharge or discharge range, which either maximizes the spatial niche of a particular community element(s) or favors a broader range of diversity of available habitats.

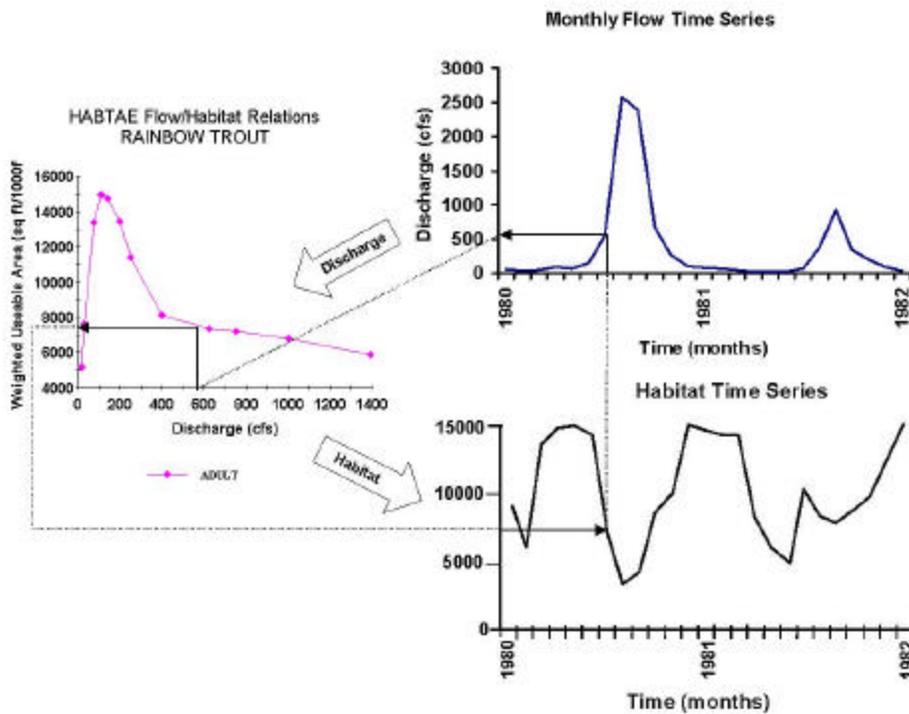
### Habitat Time Series

While not explicitly included in the PHABSIM for Windows software, habitat time series analysis is a key part of an application of IFIM. Because of its importance in IFIM and relationship to PHABSIM results, the following discussion of habitat time series is included in this document.

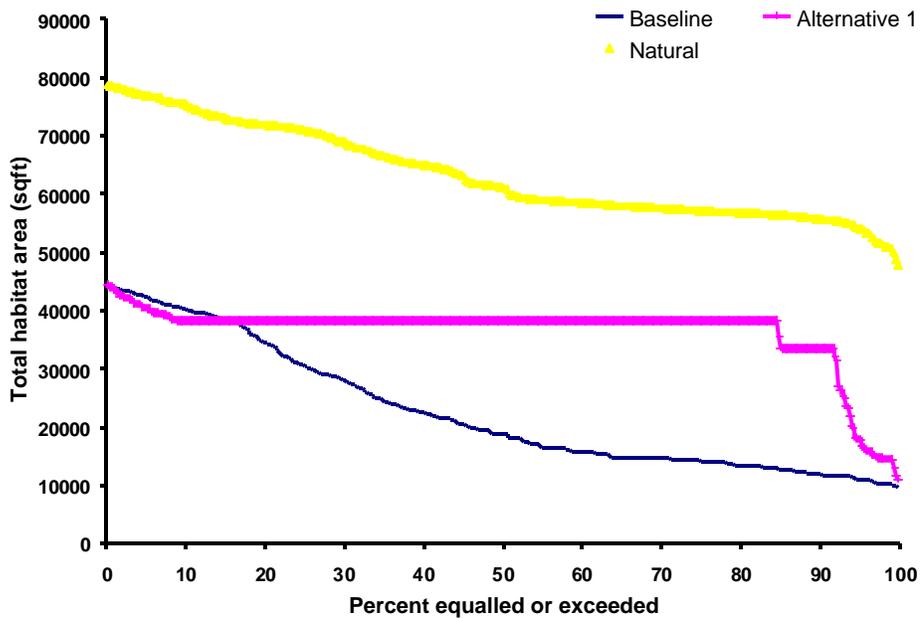
All other factors being equal, it is a reasonable assumption that current populations of fish are dependent on the antecedent history of habitat availability. It is also logical to assume that future population levels will be influenced by the time dependent characteristics of habitat availability. In many instances, it is the time dependent characteristics of habitat occurrence that ultimately may limit a particular life stage and, therefore, control the fishery population. This has often been referred to as a limiting life stage or population bottleneck. An instream flow assessment based on PHABSIM can be used to explore these potential limiting conditions for specific species and life stages through the application of habitat time series. This extension of the basic PHABSIM model results

(the weighted usable area versus discharge curve) to temporal predictions of habitat can be a crucial step in the examination of habitat availability that may influence long-term changes in fish and invertebrate populations. Use of habitat time series in an IFIM analysis is more extensively covered in Bovee, et al., (1998). Habitat time series may be generated using programs in the TSLIB (Time Series LIBrary) group of programs or through use of spreadsheets.

To conduct a habitat time series analysis, the user needs to derive the basic habitat versus flow relationships for target species and life stages and also obtain a baseline and various alternative time series of flow(s) at the study site. The major premise of habitat time series analysis is that habitat is a function of stream flow and that stream flow varies over time. The basic steps to calculate a habitat time series are illustrated in Figure 5-9, where the habitat versus flow function (i.e., WUA vs. discharge) is integrated with the flow at each time step to derive habitat availability at each time step. The habitat time series can then be analyzed to derive a habitat duration curve similar to flow duration curves derived in hydrologic analyses as illustrated in Figure 5-10 and discussed below.



**Figure 5-9.** Generation of a habitat time series.



**Figure 5-10.** Example of habitat duration curves derived from three habitat time series.

In its various forms, time series analysis provides a very valuable method of assessing the impacts of changes in flow regime. The most common approach to this is to generate habitat time series data for a study site both under baseline conditions agreed upon in the analysis scoping phase of IFIM. The flow time series used must incorporate the effects of an abstraction or other alternative flow management regime as illustrated in Figure 5-10. It may also be appropriate to produce habitat time series to show the effects of different levels of human manipulation of the stream. Analysis of these alternatives can take a variety of forms. The following are some of the more common approaches:

1. A simple comparison of the two (or more) sets of habitat time series data can identify periods where the human influence has greater/lesser impacts.
2. Using the above data, the percentage reduction in habitat can be calculated, again to assist in the identification of periods of greater/lesser impacts. (See Bovee, et al., 1998)
3. Mean monthly (or other time interval) habitat levels and mean monthly percentage habitat losses can be calculated to examine more general patterns of habitat change.
4. A combination of these analyses can be used to identify which of the alternative flow regimes being analyzed minimizes potential adverse impacts or provides habitat improvements for critical time periods or life stages to meet habitat management objectives.

Once the habitat time series data sets have been calculated, the user may wish to aggregate values at some appropriate time interval such as using daily time steps aggregated to monthly, seasonal, or even yearly intervals,

in order to examine habitat changes on a different time interval basis. Commonly used summary statistics of habitat time series for any interval of time include:

Mean habitat

Median habitat

Minimum habitat

Maximum/optimum habitat

Index-A: mean of all the habitats between 50% and 90% exceedence, i.e., the majority of the low flow events

Index-B: mean of all habitats between 10% and 90% exceedence

An exceedence statistic e.g., 90, 95-percentile habitat

Number of days below a habitat quantity threshold, or total threshold deficit

Bovee, et al. (1998) contains a full discussion of these indices and their use in negotiating instream flow regimes.

### *Habitat Duration Curves*

Further analysis of habitat time series may be achieved using a variety of techniques developed for river flow analysis. The first example of this is the habitat duration curve (Figure 5-10). A duration curve, whether for flow, habitat, or another instream variable, displays the relationship between the variable and the percentage of time it is exceeded. Duration curves are constructed by sorting the data (time series of flows or habitat values) from highest to lowest, and expressing each data point as a percentage of the total number of values. These methods are of particular use in the analysis of how alternative flow regimes affect habitat available to individual life stages of a species.

Duration curves are particularly useful for assessing the impacts of alternative flow regimes over the complete range of discharges considered for alternative flow scenarios as shown in Figure 5-10 which gives “baseline” (with habitat reduced by an abstraction), “alternative” (a proposed managed flow regime) and “natural” (with natural levels of habitat) duration curves. They are also useful for examining habitat changes due to artificial influences for the time periods identified as critical in the species/life stage periodicity analysis or on a seasonal basis by simply sampling from the appropriate portions of the time series to build the habitat duration curve. It is important to note that the habitat duration curves can only be interpreted as representing the amount of time that a particular magnitude of habitat is equaled or exceeded. Other forms of analysis discussed below must be used if the investigator is interested in determining the amount of time that habitat is continuously below some threshold. In other words, a monthly habitat duration curve may indicate that a given quantity of habitat is equaled or exceeded 90% of the time, but one cannot determine from the flow duration curve if the lowest 10% of habitat availability occurs once every fifth day or for five continuous days. From a biological perspective, differentiation between these two cases may be of critical importance in understanding limiting habitat conditions such as chronic versus acute episodes.

### *Habitat Duration Threshold Analyses*

This technique has been used to characterize periods of flow below a certain threshold habitat value. In a PHABSIM study, it allows the user to assess not only the number of low habitat events but also the duration (length of time) of each low habitat event. For example, habitat may drop below a threshold level for 20 separate days in a year, or it may drop below the same level for a single continuous period of 20 days within a year. These two scenarios would appear the same when plotted on a duration curve but may have very different implications for the target species/life stage in question. In this type of analysis, within an IFIM study, a habitat threshold level must be set by the investigator and the relative importance of both the number and length (i.e., number of time steps) over which habitat is at or below this threshold must be interpreted using the available knowledge of the

target species/life stage in question. An example of this technique illustrating the use of habitat duration threshold analysis is presented in Capra et al. (1995).

### *Choice of Flow Time Series and Baseline Conditions*

In the initial planning stages of an IFIM study using PHABSIM, an important consideration will have been the sources of flow data that are available. When changes in flow regime are to be considered, predictions of historical physical habitat are commonly compared with alternative modeled scenarios that could have occurred over the same historical time period, including the “naturalized” condition. This often requires the development of models to predict the flow regime in the river concerned under the “naturalized” flow conditions, which in itself can form a major part of a study. Some key factors in selecting flow data for use in habitat time series analysis are that the flow data is on a time step appropriate for the issues and target species/life stages in question (e.g., 15 minute flow values may be essential for analysis of the impacts of hydropower schemes), that the flow time series is sufficiently long to allow the production of robust seasonal habitat duration curves and other time-based statistics, and that modeled flow scenarios properly represent anticipated management influences, naturalized flows, or other factors as appropriate.

With regard to periods of record, there are no set guidelines. Each study should be considered on a case-by-case basis. However, if daily flows are available, it is suggested that at least 10 years of flow data be used. If the study is using monthly flow data, then 15 or more years may be required. Shorter or longer time periods may be appropriate, however, given data availability and study objectives.

### *Some Important Factors in Time Series and Duration Curve Analysis*

It is important to note that a habitat duration curve shows exceedence percentiles for values of habitat, ranked from highest to lowest. It does not simply show flow exceedence percentiles mapped to their corresponding habitat values. It is also important to note that there is generally not a continuous increasing relationship between habitat and flow in a habitat versus flow function for a target species/life stage. Instead, habitat often increases with flow up to a maximum at a certain flow, and then habitat values decrease with increasing flow. This phenomenon may result in some portion of the habitat duration curve representing levels of habitat produced under both high and low flow conditions. This is unlike a flow duration curve, where high flows are always associated with low exceedence values. As a result care must be taken when interpreting habitat duration curves - a low habitat availability does not always result from a low flow.

While not detracting from the use of habitat duration curves in the evaluation of the impacts of alternate flow regimes, caution should be exercised in their interpretation. It is possible to overcome these issues by plotting values of flow alongside habitat duration curves so that the analyst can see which flows are producing a given habitat exceedence level. Alternatively, the analyst may confine the period of analysis either by restricting it to certain time periods of the year, when flows are lowest, or simply by not calculating habitat exceedence percentiles for flows above the peak in the WUA versus discharge curve. It should also be remembered that duration curves do not give information about the temporal distribution of low flow or habitat events, i.e., whether they occur together or separately. Other techniques such as a habitat/flow threshold analysis, as outlined above, should be considered for this purpose.

## **Integration of Channel Maintenance and Sediment Transport**

One of the more important aspects of an ecologically sound flow regime is the recognition that the long-term ecological function of a stream or river corridor requires that the physical processes that form and maintain a channel must be protected. There are numerous examples where sediment transport has been either severely

reduced, such as below a dam, or significantly increased, such as runoff from a watershed that has been intensively mined or burned in a forest fire. In these situations, the channel will react to the change in the sediment dynamics and either degrade or aggrade differentially along its longitudinal gradient. In some instances, a well-defined river channel will become highly braided, in other circumstances the opposite effect has been observed. This problem, of course, is not confined solely to changes in the sediment supply since alterations in the flow regime, such as seasonally maintained low flows or abstraction of the high flow component for reservoir storage, can result in changes to the dynamic equilibrium between the flow and sediment transport. This can, in turn, result in changes to channel structure and habitat composition as well as changes in the dynamics of the streamside or riparian vegetation.

PHABSIM for Windows does not contain models of sediment dynamics. To include sediment issues in an IFIM application, other models and expertise must be brought to the problem. Appendix 4 contains a brief discussion of some of the issues to consider when including channel maintenance in an instream flow analysis.

## **Summary of Chapter 5**

This chapter covered numerous ideas for application of PHABSIM to various analysis situations. These items are intended as thought provoking examples to encourage PHABSIM users to adapt the analysis to the situations they may encounter in practice. This section concludes the PHABSIM for Windows user's manual.

## Appendix 1. Glossary of Terms and Program Names

### Terminology

The following terms and their definitions are provided to help the reader understand some of the specialized vocabulary utilized throughout PHABSIM in the description of open channel hydraulics, suitability curves, and habitat modeling.

**AREA, CONVEYANCE:** Cross-sectional area of a stream perpendicular to the flow.

**AREA, CROSS-SECTIONAL:** The area of the cross section containing water, perpendicular to the direction of flow. (Units: square feet or square meters).

**AREA, USABLE:** The surface area of a stream that can be used by an aquatic organism. (Units: square feet or square meters).

**AREA, WEIGHTED USABLE (WUA):** The surface area of a stream weighted by its suitability to an aquatic organism. (Units: square feet or square meters).

**AREA, WEIGHTED USABLE BED (WUBA):** The bed area of a stream weighted by its suitability to an aquatic organism. (Units: square feet or square meters).

**BACKWATER:** (1) A region of a stream where the water surface level is governed by a downstream control (Hence the term step-backwater is applied to the WSP model, see below.). (2) An off-shoot from the main channel with little flow and where the water surface elevation is maintained by conditions in the main channel.

**BANKFUL WIDTH:** See Width, Bankful.

**BETA COEFFICIENT:** (1) A coefficient used to represent the change in Manning's roughness with discharge or hydraulic radius. (2) Ratio of the bed shear stress to the resisting forces of the bed-material (Shield's Parameter).

**CELL:** As used in PHABSIM, an increment of width of a stream channel weighted for its relative importance by a length to give an area. Defined by verticals.

**CELL FACTORS:** See Factors, Cell.

**CHANNEL INDEX:** A suitability index to the channel characteristics, usually substrate or cover.

**CHANNEL ROUGHNESS:** A coefficient of resistance to flow caused by particle or vegetative friction and channel features such as bends and constrictions.

**CHANNEL WIDTH:** See Width, Channel.

**COMPOSITE SUITABILITY OF USE FACTOR:** See Factors, Cell.

**CONVEYANCE, FACTOR:** See Factor, Conveyance.

**COVER:** Areas of shelter in a stream channel that provide aquatic organisms protection from predators and/or a place in which to rest and conserve energy due to a reduction in the force of the current or visual isolation, e.g., pools, undercut banks, boulders, water depth, surface turbulence, etc.

**CRITICAL FLOW:** See Flow, Sub-Critical and Super-Critical.

**CROSS SECTION:** A section across a stream channel that is perpendicular to the direction of the flow. Sometimes called a transect.

**CURVES, PREFERENCE:** The criteria used to weight an area as to its worth for a specific aquatic organism. The organism prefers certain conditions.

**CURVES, SUITABILITY-OF-USE (SI):** Same as Preference Curves except the concept of the suitability of the conditions for a specific organism is stressed.

**CURVES, USABILITY:** Same as Preference Curves except the concept of usability of the conditions for a specific organism is stressed.

**DATUM:** Any numerical or geometrical quantity or set of such quantities that may serve as a reference or base for other quantities. An agreed standard point or plane of stated elevation, noted by permanent bench marks on some solid immovable structure, from which elevations are measured, or to which they are referred.

**DEPTH:** The vertical distance from a point on the bed to the water surface.

**DEPTH, HYDRAULIC:** Equivalent to mean or average depth.

**DEPTH, MEAN:** The cross section area divided by the surface width.

**DEPTH, THALWEG:** The vertical distance of the lowest point of a channel cross section to the water surface, i.e., maximum depth of cross section.

**DISCHARGE:** The rate of flow, or volume of water flowing in a given stream at a given place and within a given period of time, expressed as cubic feet per second (cfs) in traditional (English) units.

**FACTOR, CELL:** Also referred to as Composite Suitability of Use Factor. The function of velocity (v), depth (d), and the channel index (CI) used to weight an area of stream for its value as habitat. The term is defined within the context of specific habitat models in Chapter 5.

**FACTOR, CONVEYANCE:** In uniform flow situations, the area available to transport water is directly proportional to Q. The Conveyance Factor (K) is the relationship between the channel and flow characteristics. The equation in traditional units is:

$$K = \frac{1.49}{n} AR^{2/3}$$

The discharge can then be defined in terms of K by:

$$Q = \sqrt{SK}$$

where: A = area  
R = hydraulic radius  
n = Manning's roughness  
Q = discharge  
K = conveyance Factor  
S = slope

**FLOW:** The movement of a stream of water and/or other mobile substances from place to place; discharge; total quantity carried by a stream.

**FLOW, STEADY and UNSTEADY:** Flow in an open channel is said to be steady if the depth of flow does not change or can be assumed constant over a specified time interval. The flow is unsteady if the depth changes with time.

**FLOW, SUB-CRITICAL and SUPER-CRITICAL:** In any body of moving water both inertial and gravity forces are acting on the water body. The effect of gravity on the state of flow is represented by the ratio between inertial and gravity forces, i.e., Froude Number.

If the Froude Number is less than unity, gravity forces predominate, so the flow has low velocity and is described as tranquil or streaming. If the Froude Number is greater than unity, the effects of inertia are more pronounced, so the flow has high velocity and is described as shooting, rapid, or torrential. When the Froude Number is equal to unity, flow is defined as critical.

Most instream flow studies are concerned primarily with the sub-critical state of flow, although hydraulic simulations for certain recreational activities may deal with super-critical states of flow that are difficult to model.

**FLOW, UNIFORM and VARIED:** Uniform flow means that the depth of flow is the same at every section of the channel. Thus, the hydraulic, energy, and bottom slopes are parallel. If the flow is varied, the depth of flow changes along the length of the channel. Varied flow is classified as either rapidly or gradually varied, depending on the distance within which the change in depth occurs. Rapidly varied flow is manifest in an abrupt change in depth, resulting in hydraulic jumps, hydraulic drops, and related phenomena. The criterion for uniform or varied flow is change in depth with respect to space.

**FROUDE NUMBER:** A dimensionless number used as an index to characterize the type of flow in a hydraulic structure that has the force of gravity (as the only force producing motion) in conjunction with the resisting force of inertia. As used in this document the Froude Number is:

$$F_R = \frac{V}{\sqrt{gd}}$$

where:  $F_R$  = Froude Number  
V = mean column velocity  
g = acceleration of gravity  
d = depth of the water

**GRADIENT:** The rate of change of any characteristic per unit of length. See Slope.

**HEAD PIN:** The terminal points in a cross section. Usually marked by something (a "pin") pounded into the ground. By convention, the first head pin is on the left-bank looking upstream.

**HEIGHT OF INSTRUMENT:** The elevation of the sight plane through a level. Level measurements are measured downward from this plane.

**HYDRAULIC GEOMETRY:** The dimensions of certain stream features with respect to both the wetted and unwetted portions of the channel.

**HYDRAULIC RADIUS:** Ratio of the cross-sectional area to the wetted perimeter,  $R = A/P$ . For relatively wide shallow channels,  $R$  approximates the hydraulic depth.

**IFIM:** The Instream Flow Incremental Methodology. (See Bovee, et al., 1998 and Stalnaker, et al., 1995)

**LIFE STAGE:** An arbitrary classification of the age of an organism into stages related to body morphology and reproductive potential, e.g., "middle age" for man and "fry" for fish.

**MACROHABITAT:** Habitat conditions in a reach of river controlling longitudinal distribution of aquatic organisms.

**MANNING'S EQUATION:** An empirical formula for the calculation of velocity in a channel. The equation in traditional units is:

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

**MANNING'S ROUGHNESS or MANNING'S n:** A factor used when computing the average velocity of flow of water in a channel that represents the effect of roughness of the confining material upon the energy losses in the flowing water. Also referred to as "n" or roughness coefficient.

**MICROHABITAT:** Habitat small area (cell) of a river controlling specific locations or home ranges.

**MEAN DEPTH:** See Depth, Mean.

**PHABSIM:** (pronounced P-HAB-SIM) - the Physical Habitat Simulation System. Computes a relationship between streamflow and physical habitat for various life stages of an aquatic organism or a recreational activity. PHABSIM is a component of IFIM; PHABSIM is not IFIM.

**PHYSICAL HABITAT:** The place where a population lives and its surroundings as defined by physical conditions, most commonly depth, velocity, and channel conditions such as substrate and cover objects.

**PROFILE or PROFILE, LONGITUDINAL:** (1) In open channel hydraulics, it is a plot of water surface elevation against channel distance and/or bottom elevation. (2) A line of elevations along a river usually following the thalweg. Most often includes the bed and water surface elevations.

**PROFILE, TRANSVERSE:** Same as a cross section.

**RATING CURVE:** A curve that expresses graphically the relation between mutually dependent quantities, e.g., a curve showing the relation between gage height (or stage) and discharge of a stream.

**REACH:** A comparatively short length of a stream, channel, or shore. The actual length is defined by the purpose of the study.

**REACH LENGTH:** The length of a section or piece of a river.

**REYNOLDS' NUMBER - FLUID:** A dimensionless number relating to the flowing force of the water to the viscous forces. It is calculated using the equation:

$$Re = \frac{V * d}{\nu}$$

where:  $R_e$  = Reynolds number  
 $\nu$  = Kinematic viscosity of water  
 $V$  = mean velocity  
 $d$  = depth of the water

**REYNOLDS' NUMBER - GRAIN ( $R_*$ ):** A dimensionless number used as an index to characterize the relative importance of active forces on the streambed to the viscous forces in the fluid. It is calculated using the equation:

$$R_* = \frac{\tau_* D}{\nu}$$

where:  $\tau_*$  = Shear velocity (see Velocity, Shear below)  
 $D$  = is a characteristic particle size  
 $\nu$  = Kinematic viscosity of water

**RIFFLE:** Shallow rapids in an open stream where the water surface is broken into waves by obstructions wholly or partly submerged.

**ROUGHNESS COEFFICIENT:** See Manning's Roughness.

**SEGMENT:** Relatively homogeneous section of a stream composed of two or more reaches.

**SHEAR STRESS, BED:** The stress on the river bed caused by the flowing water.

**SHIELD'S PARAMETER  $\beta$ :** Ratio of the Bed Shear Stress to the resisting forces of the bed-material:

$$\beta = \frac{\tau D}{(\gamma_s - \gamma) D} = \frac{RS}{(S_s - 1)D}$$

where:  $J$  = bed shear stress  
 $\gamma_s$  = unit weight of bed material  
 $\gamma$  = unit weight of water  
 $D$  = bed material size  
 $S_s$  = specific gravity of bed material  
 $R$  = hydraulic radius  
 $S$  = slope

The terms  $K_s$ ,  $\vartheta^*$  are also used for the Shield's Parameter and  $D$  may be the mean size of the surface layer or the  $D_{65}$  of the surface area ( $D_{65}$  is where 65% of the particles are finer).

**SLOPE:** The inclination or gradient from the horizontal of a line or surface. The degree of inclination can be expressed as a ratio, such as 1:25, indicating one unit rise in 25 units of horizontal distance or as 0.04 length per length. Sometimes also expressed as feet per mile.

**SLOPE, BOTTOM:** The change in the average elevations of the bed between two cross sections, divided by the distance between them.

**SLOPE, ENERGY:** Change in total energy (potential and kinetic) available at a point. Usually approximated as the change between the cross section divided by the distance between cross sections.

**SLOPE, HYDRAULIC:** The change in elevation of the water surface between two cross sections, divided by the distance between the cross sections.

**SLOPE, THALWEG:** The change in the elevation of the bed, measured at the points of maximum depth, divided by the distance between cross sections.

**SLOPE, WATER SURFACE:** The slope of the water surface at a point and is usually approximated as the difference in water surface elevations at two points divided by the distance along the flow path between the points.

**STAGE:** The elevation, or vertical distance of the water surface above a datum (a plane of known or arbitrary elevation).

**STAGE OF ZERO FLOW (SZF):** The water surface elevation at a cross section when the flow reaches zero. This is either the lowest point of the bed or the pool water surface when no flow occurs (i.e., a downstream low bed point acts as the pool water surface control).

**STEADY FLOW:** See Flow, Steady and Unsteady.

**STREAMBED:** The bottom of the stream channel; may be wet or dry.

**STREAM WIDTH:** See Width, Stream.

**SUB-CRITICAL FLOW:** See Flow, Sub-Critical and Super-Critical.

**SUBSTRATE:** The material on the bottom of the stream channel, e.g., rocks, vegetation, etc.

**SUPER-CRITICAL FLOW:** See Flow, Sub-Critical and Super-Critical.

**THALWEG:** The longitudinal line connecting points of minimum bed elevation along the stream course.

**TOE WIDTH:** See Width, Toe

**TOP WIDTH:** See Width, Top.

**TRANSECT:** Same as cross section.

**UNIFORM FLOW:** See Flow, Uniform and Varied.

**UNSTEADY FLOW:** See Flow, Steady and Unsteady.

**USABLE AREA:** See Area, Usable.

**VARIED FLOW:** See Flow, Uniform and Varied.

**VELOCITY:** The time rate of motion; the distance traveled divided by the time required to travel that distance.

**VELOCITY, ADJACENT:** A velocity in a cell near the cell being considered.

**VELOCITY, MEAN:** The mean velocity may represent either a cell or a cross section. It is calculated as:

$$Q = \frac{V}{A}$$

where: Q = the discharge in the cross section or cell

A = the area of the cross section or cell.

**VELOCITY, MEAN COLUMN:** The velocity averaged from the top to the bottom of a stream. Usually measured at 6/10 depth or an average of values measured at 2/10 and 8/10 of the depth when the depth is greater than 2.5 ft.

$$\bar{V} = \frac{1}{d} \int_0^d v * dy$$

where:  $\bar{V}$  = the mean column velocity

v = the point velocity

dy = small increment of depth dy thick

d = total depth

**VELOCITY, NOSE:** The velocity at the point where a fish is located. This is the point velocity expressed in terms of an organism.

**VELOCITY, POINT:** The velocity at a depth in the stream.

**VELOCITY, SHEAR:** The square root of the bed shear stress divided by the density of the water and has the dimension of length/time:

$$\mu_* = \sqrt{\frac{t_*}{\rho}} = \sqrt{\frac{t_*}{\rho/g}}$$

where:  $u_*$  = shear velocity

$J_*$  = shear stress on the bed

$\rho$  = density of water

**VELOCITY ADJUSTMENT FACTOR (VAF):** The ratio of the discharge for which velocities are being simulated to the sum of simulating cell velocities times cell areas:

$$VAF = \frac{Q_{\text{target}}}{\sum_{i=1}^n v_i a_i}$$

where: Q = target discharge (Discharged to be simulated)  
 $v_i$  = cell velocity  
 $a_i$  = cell area  
n = number of wet cells

**VELOCITY CALIBRATION ERROR (VCE):** The error calculated for the relationship  $v = aQ^b$  and is calculated as:

$$VCE = \sum_{i=1}^n \frac{\bar{v} - v}{v}$$

where:  $\bar{v}$  = estimated velocity  
 $v$  = measured velocity  
n = number of velocity discharge pairs used to determine coefficients a and b.

**VERTICAL:** As used in PHABSIM, sample locations across a cross section.

**WATER SURFACE ELEVATION (WSL):** The elevation of the water's surface in relation to an arbitrary datum.

**WATER TRANSPORT PARAMETER (WTP):** As used in PHABSIM, the Water Transport Parameter is expressed in traditional units by the equation:

$$WTP = \frac{1.49}{n} \sqrt{S}$$

where: S = the energy slope  
n = Manning's roughness

**WEIGHTED USABLE AREA (WUA):** See Area, Weighted Usable.

**WEIGHTED USABLE BED AREA (WUBA):** See Area, Weighted Usable Bed.

**WEIGHTED USABLE VOLUME (WUV):** The volume of a stream weighted for its worth as habitat.

**WEIGHTING FACTOR:** The value that weights a surface area or volume area as to its worth as habitat.

**WETTED PERIMETER:** The distance along the bottom and sides of a channel cross section in contact with water. Roughly equal to the width plus two times the mean depth.

**WETTED WIDTH:** See Width, Wetted.

**WIDTH:** The distance across a channel at the water surface measured normal to flow.

**WIDTH, BANKFUL:** The width of the stream just before the flow overtops the channel.

**WIDTH, CHANNEL:** An arbitrary width based on what the observer sees as a channel.

**WIDTH, STREAM:** Either the same as the channel width or the width of the wetted stream.

**WIDTH, TOE:** The width of the base of a trapezoidal channel.

**WIDTH, TOP:** The width of the wetted area of flow across a stream channel.

**WIDTH, WETTED:** The width of the stream with water in it.

## Program Names

**STGQ:** The STGQ model uses a stage-discharge relationship (rating curve) to calculate water surface elevations at each cross section. In the stage-discharge relationship and its simulation, each cross section is independent of all others in the data set. The basic computational procedure is conducted by performing a log-log regression between observed stage and discharge pairs at each cross section. The resulting regression equation is then used to estimate water surface elevations at all flows of interest.

**MANSQ:** The MANSQ program utilizes Manning's equation to calculate water surface elevations on a cross section by cross section basis and therefore treats each cross section as independent. Model calibration is accomplished by a trial and error procedure to select a  $\beta$  coefficient that minimizes the error between observed and simulated water surface elevations at all measured discharges.

**WSP:** The Water Surface Profile (WSP) program uses a standard step-backwater method to determine water surface elevations on a cross section by cross section basis. The WSP program requires that all cross sections being analyzed in a given model run be related to each other in terms of survey controls and sequence upstream. That is, each cross section's hydraulic characteristics in terms of bed geometry and water surface elevations are measured from a common datum. The model is initially calibrated to a measured longitudinal profile of water surface elevations by adjusting Manning's roughness, first for the entire study site and then at each cross section. Manning's roughness is then adjusted for subsequent measured longitudinal water surface profiles at other discharges by setting the roughness modifiers used within the model. This approach requires all hydraulic controls within the modeled study site are represented by cross sections.

**VELSIM:** The VELSIM program is the principal tool used to simulate the velocity distributions within a cross section over the required range of discharges (i.e., the mean column velocity in each wetted cell in a study cross section at each simulation discharge). The technique relies on an empirical set of velocity observations (i.e., measured velocities) that act as a template to distribute velocities across a channel by solving for the 'n' in Manning's equation (in this context 'n' acts as a roughness distribution factor across the channel). The channel is divided into cells and the velocity calculated for each of these cells. The usual practice is to use one set of velocities as a template for simulating velocities for a particular range of discharges. When more than one set of empirical velocity measurements is available, a commensurate number of flow ranges can be simulated with different velocity templates. The program can be used when no velocity measurements are available. In this situation, velocity will be distributed across the cross section as a function of flow depth.

**HABTAE:** The primary habitat simulation program in PHABSIM. Options within **HABTAE** allow the user to select habitat calculation assuming the condition within a cell establishes the worth of the

habitat in the cell. Adjacent cell conditions (for example a “feeding station”) are also included in **HABTAE**. Assuming the condition in a cell simulates conditional velocity considerations plus the velocity in adjacent cells or at another location nearby establishes the worth of the habitat in the cell. The **HABTAE** program also allows habitat to be determined in terms of volume (instead of the surface area), and provides a method for determining the habitat conditions at each cross section as well as the aggregate for a study site.

**HABEF:** Effective habitat analysis in PHABSIM is used to determine availability of physical habitat considering two flows; in other words, the HABit that remains EEffective when two flows are of importance. This situation often arises, for example, in the evaluation of reducing flows during the spawning period and subsequent incubation period or in hydro-peaking operations that have a daily minimum and maximum flow. In the case of spawning and incubation analyses, the spawning area at a cross section is not ‘effective’ unless the incubation period flow regime maintains the habitat in a suitable condition for the eggs to hatch.

**HABTAM:** The second effective habitat model is the **HABTAM** program. In **HABTAM** the species can move from cell to cell cross each transect over a range of starting and ending discharges. In this model, effective habitat is defined as the habitat that remains usable when the species is forced to move due to flow fluctuations.

**AVDEPTH/AVPERM:** The average parameter model, **AVDEPTH /AVPERM**, calculates a variety of hydraulic characteristics for each cross section in addition to a study site average view. These include wetted width, wetted perimeter, and wetted surface area, cross sectional area, mean channel velocity, and average depths. They can also be utilized to determine the width of a stream with water that is over some arbitrary depth(s) specified by the user. These programs provide a wealth of information at a cross section or a study site level aggregate and should be examined in most applications.

**CALCF4:** This utility program calculates a water transport (or conveyance) parameter (WTP) for each cross section. The program uses Manning’s equation at each cross section to calculate the WTP for each water surface elevation, develops power relationships between WTP’s, area and maximum depth, discharge and width, velocity, and average depth. The exponent (B) in the WTP regression equation between discharge and the channel conveyance factor or WTP for each cross section is an excellent initial estimate for the  $\beta$  coefficient for each transect in the MANSQ program.

**SLOP34:** A utility program that provides thalweg values, water surface elevations, and slopes in the following four tables: water surface elevation, water surface slope, energy grade line elevation and energy grade line slope.

**LSTWLF:** Utility program that calculates and displays the Froude number and mean channel velocities for each cross section and each flow.

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## Appendix 3. ProjView

ProjView is a utility program included with the PHABSIM for Windows installation that allows the user to export the binary project files to a text format. It is intended that ProjView aid the user in recovery from software/hardware errors with the minimal amount of lost data as possible.

Output from ProjView is either a set of text files that can be viewed and edited, or a set of PHABSIM for Windows project files. Exported text files and their contents are:

Project.txt	-	General project information
Xsec.txt	-	Cross section specific data
Point.txt	-	Point specific data
Index.txt	-	Indexes points to cross sections
Cal.txt	-	Calibration data
Options.txt	-	PHABSIM option selections
Curves.txt	-	Suitability index curves

The exported text format files have, for the most part, a very specific format in order for the “build” options to function properly. Any editing of text files MUST follow the formats listed below.

There are two “build” options, Build and Build/Clean. The Build option builds new project files for only those checked in the selection box. The Build/Clean option performs a complete project build. As such, it requires an export of all files, with the exception of the Options file. In addition, the Build/Clean option rebuilds the Options file with default settings. This option should be used if errors to the options file would take longer to edit than it would take to reset options in PHABSIM for Windows.

### Some Conventions and Comments

Lines indicated by {Note: }, {Format: }, or underlining are informational lines on format and are not part of the actual file.

Lines ending in \ are longer than the paper width and are continued on the next line. These form a single line in the text file.

Lines followed by a vertical “. . .” indicate lines missing to conserve space. Missing lines are of the same format, and the total number of lines for the section will be included in a {Note: }.

Where there are multiple data values on a single line, the positioning is important. Single data values on a line do not require specific spacing, except that when following text, there should be a space between the text and the data. Blank lines in a file should not be removed.

Where appropriate, comments are added on how errors have been repaired. Please note that, during the PHABSIM development process, it was only necessary to edit the Options file to fix corrupt datasets. Generally, it best to edit the existing file, using correct data lines as a template. When unsure about format, run ProjView on a good project and use the resulting files as templates.

**Note:** ProjView exports data in the order that it is stored in the project files. This is not necessarily the order in which it is displayed by PHABSIM for Windows.

## Project File

The Project File contains general information about the project; name, units, discharges, etc., plus some information specific to the velocity model (N limits and beta). Discharges listed in Options File data records should match the discharges in the Project File. Likewise,

### Sample File

```
Project: wintest
Units : English
N MIN: 0.000 N MAX: 0.000 BETA: 0.000
Number of calibration sets: 3
XSEC ID LIST 4
  0.000 60.000 135.000 201.000
CALIBRATIONS FLOWS 3
  75.200
  139.000
  250.000
SIMULATIONS FLOWS 4
  15.000
  30.100
  625.000
  1250.000
```

## Point File

The Point File contains information related to each coordinate point. There is a single coordinate point per line and point IDs should match those listed in the Point Index File. Velocity values for calibration sets not used should be entered as -99.990.

### Sample File

{Format: Values are ID, X, Y, Z, CI, N, units, and velocities for nine calibration sets. Note that -99.99 is used for no data.

```
123456712345678.12312345678.12312345678.12312.1231.123451231234.123\
\1234.1231234.1231234.1231234.1231234.1231234.1231234.1231234.123}
  1      2.000      0.000      94.800 6.0000.00000 0 -99.990\
\ -99.990 -99.990 -99.990 -99.990 -99.990 -99.990 -99.990 -99.990
  2      4.000      0.000      94.000 6.0000.00000 0 -99.990\
\ -99.990 -99.990 -99.990 -99.990 -99.990 -99.990 -99.990 -99.990
  3      6.000      0.000      93.000 6.0000.00000 0 -99.990\
\ -99.990 -99.990 -99.990 -99.990 -99.990 -99.990 -99.990 -99.990
  4      8.000      0.000      92.700 6.0000.00000 0 -99.990\
\ -99.990 -99.990 -99.990 -99.990 -99.990 -99.990 -99.990 -99.990
  5     10.000      0.000      91.900 6.0000.00000 0  0.900\
\  0.000  0.000 -99.990 -99.990 -99.990 -99.990 -99.990 -99.990
```

{Note: There is a line for each coordinate point.}

```

    154      68.000      201.000      96.000 7.0000.00000  0 -99.990\
\ -99.990 -99.990 -99.990 -99.990 -99.990 -99.990 -99.990 -99.990

```

## Index File

The Index File lists which coordinate points belong to specific cross section. Coordinate Ids in the list should match coordinate Ids in the Point File.

### Sample File

{Format: There are 10 indices/line at 5 spaces allocated for each point index.}

```

XSEC:      0.000      NUMBER OF POINTS: 44
  1   2   3   4   5   6   7   8   9  10
 11  12  13  14  15  16  17  18  19  20
 21  22  23  24  25  26  27  28  29  30
 31  32  33  34  35  36  37  38  39  40
 41  42  43  44

```

.

{Note: There is a block for each cross section. There should be a blank line between each block.}

.

```

XSEC:      201.000      NUMBER OF POINTS: 32
 123 124 125 126 127 128 129 130 131 132
 133 134 135 136 137 138 139 140 141 142
 143 144 145 146 147 148 149 150 151 152
 153 154

```

## Xsec File

The Xsec File contains information specific to each cross section. Cross section Ids should match those in the Project File and the number of points should match the Index File.

### Sample File

{Format: Values are, in order ID, distance, upstream weight, left bank weight, right bank weight, SZF, thalweg, N, beta, slope, and number of points.

```

123456.123 123456.123 123456.123 12.123 12.123 1234.123 1234.123 / /123.123
1.123 12.12345 1234}
  0.000      0.000      0.500  1.000  1.000  90.600  90.600 /
/  0.000 0.000  0.00400  44
  60.000      60.000      0.500  1.000  1.000  90.600  90.600 /
/  0.000 0.000  0.00320  41
 135.000      75.000      0.500  1.000  1.000  90.600  90.500 /
/  0.000 0.000  0.00230  37
 201.000      66.000      0.500  1.000  1.000  90.600  89.800 /
/  0.000 0.000  0.00230  32

```

## Cal File

The Cal File lists information specific to calibration data sets. There is one record for each cross section/calibration set pair. Cross section Ids should match Ids in previous files, and the number of calibration sets is given in the Project File.

### Sample File

{Format: Values are Cross section, cal set ID, best estimate discharge, local discharge, left bank WSL, right bank WSL, user supplied WSL.

12345.123	1234	12345.123	12345.123	1234.123	1234.123	1234.123
0.000	1	250.000	240.000	0.000	0.000	92.670
0.000	2	139.000	124.000	0.000	0.000	92.180
0.000	3	75.200	55.200	0.000	0.000	91.900
60.000	1	250.000	265.000	0.000	0.000	92.950
60.000	2	139.000	129.000	0.000	0.000	92.420
60.000	3	75.200	61.400	0.000	0.000	92.080
135.000	1	250.000	252.000	0.000	0.000	92.970
135.000	2	139.000	137.000	0.000	0.000	92.590
135.000	3	75.200	86.700	0.000	0.000	92.250
201.000	1	250.000	249.000	0.000	0.000	93.100
201.000	2	139.000	99.000	0.000	0.000	92.740
201.000	3	75.200	80.400	0.000	0.000	92.360

## Curves File

The Curve File contains the suitability index curve information. The number of curves in the file should match the number of curves listed in the Options File.

Each curve has an ID line, a species line, and a stage line. The next line is a header line followed by the number of coordinate pairs for velocity, depth, channel index, and temperature, respectively. Note that PHABSIM for Windows does not use temperature data.

Following the suitability curve point counts are the data points. Points are listed as X/Y pairs with each value using 8 spaces with 3 decimal points (8.3 format.) There are 6 X/Y pairs per line with each curve (i.e., velocity, depth, etc.) starting on a new line. Thus, a curve with 7 coordinate pairs would have 6 on the first line, 1 on the second, and the next curve would start on the third.

### Sample File

Number of curves: 3

ID: 21112

Species: RAINBOW TROUT

Stage: FRY

VEL	DEP	CI	TEM				
4	8	8	0				
0.000	1.000	0.100	1.000	0.500	0.000	100.000	0.000
0.000	0.000	0.100	0.100	0.200	1.000	0.500	1.000 /
/ 1.000	0.500	1.250	0.300				
3.000	0.000	100.000	0.000				
0.000	0.000	1.000	1.000	2.000	1.000	4.000	1.000 /

```

/ 6.000 1.000 8.000 1.000
  9.000 1.000 100.000 0.000
ID: 21114
Species: RAINBOW TROUT
Stage: JUVENILE
  VEL    DEP    CI    TEM
    5     4     8     0
  0.000 1.000 1.200 1.000 1.600 0.250 2.600 0.000 / /100.000
0.000
  0.000 0.000 0.400 0.000 0.700 1.000 100.000 1.000
  0.000 0.000 1.000 1.000 2.000 0.500 6.000 0.500 /
/ 7.000 1.000 8.000 1.000
  9.000 0.000 100.000 0.000
ID: 21115
Species: RAINBOW TROUT
Stage: ADULT
  VEL    DEP    CI    TEM
    4     4     8     0
  0.000 1.000 1.500 1.000 3.000 0.000 100.000 0.000
  0.000 0.000 1.000 0.200 1.600 1.000 100.000 1.000
  0.000 0.000 1.000 1.000 2.000 0.700 6.000 0.700 /
/ 7.000 1.000 8.000 1.000
  9.000 0.000 100.000 0.000

```

## Options File

The Options File stores all user selections from the PHABSIM for Windows dialogs. All cross section IDs, discharges, calibration set IDs, and suitability curve IDs listed in the various sections of the Options File must match the respective value in the other files.

### Example Problem Fixes

*General:* Often, a quick scan of the file will reveal problems. They usually appear as values of 0 or something like 128723746109238787654. Check the category and edit for the appropriate data.

*Problem:* The WSL method grid shows error cells (colored red) that appear whenever the project is reopened.

*Solution:* Check the section titled “Selected WSL Models:” and make sure every cross section/discharge combination is there and has correct method value (1 through 7 based on the dialog radio button) and a correct WSL, if needed.

*Problem:* Velocity calibration set assignments appear as zero when that is not the desired assignment.

*Solution:* Check the “VELOCITY XSEC/Q Calibration Set Assignments:” section for the appropriate cross section/discharge combinations. With the correct records, the use flag should be no less than 0 and no greater than the number of calibration sets.

**Note:** This problem can occur with the “WSL XSEC/Q Calibration Set Assignments” also; however, the use flag is not as straight forward. Once the correct records are in place it is best to set the use flag to 0 (all off) or 65535 (all on), and adjust the settings in PHABSIM.

*Problem:* Selected life stages for the habitat programs do not stay selected when reopening a saved project.

*Solution:* Check that the “NUMBER OF CURVES:” is correct.

### Sample File

```
NUMBER OF CROSS SECTIONS: 4
NUMBER OF CALIBRATION SETS: 3
NUMBER OF DISCHARGES: 7
NUMBER OF CURVES: 8
WSP option values:
  0 0 1 0
MANSQ option values:
  1 0 0 0 0 0 0 0
STGQ option values:
  4 3 1
VELOCITY option values:
  1 1 0 0 1 0 0 0
HABTAE option values:
  1 0 0 0 0 0 0 0 0 1 0 0 0 0
Near Shore Distance: 0.000000
HABTAM option values:
  0 0 0 0 0 0 0 0 0 0 0 0 0 0
AVDEPTH/AVPERM Depths: 5
  0.100 0.250 0.500 0.750 1.000
{Note: If there are no depths, the preceding line is blank.}
HABTAM Migration Flow Pairs:
  0.000 0.000
  0.0 0.000
{Note: There are 25 total lines here.}
.
.
.
  0.000 0.000
  0.000 0.000
HABTAM Factors for Nose Velocity Calculation
Dn: 0.0000 A: 0.0000 B: 0.0000 D65: 0.0000
STGQ Cross Section Option Flags:
  xsec ID  cID  QT  WT  SZF
    0.000  1  2  4  1
    0.000  2  2  4  1
    0.000  3  2  4  1
   60.000  1  2  4  1
   60.000  2  2  4  1
   60.000  3  2  4  1
  135.000  1  2  4  1
  135.000  2  2  4  1
  135.000  3  2  4  1
  201.000  1  2  4  1
  201.000  2  2  4  1
  201.000  3  2  4  1
MANSQ Cross Section Options:
  xsec ID  cID  QT  beta
    0.000  0  0  0.0000
   60.000  0  0  0.0000
```

```

135.000  0  0  0.0000
201.000  0  0  0.0000

```

Selected WSL Models:

```

XSEC:    0.000  Q:    15.000  Method:  1  User WSL:    0.000
XSEC:    0.000  Q:    30.100  Method:  1  User WSL:    0.000
XSEC:    0.000  Q:    75.200  Method:  1  User WSL:    0.000
XSEC:    0.000  Q:   139.000  Method:  1  User WSL:    0.000
XSEC:    0.000  Q:   250.000  Method:  1  User WSL:    0.000
XSEC:    0.000  Q:   625.000  Method:  1  User WSL:    0.000
XSEC:    0.000  Q:  1250.000  Method:  1  User WSL:    0.000

```

. {Note: One line for each cross section/discharge pair.}

```

XSEC:    201.000  Q:  1250.000  Method:  1  User WSL:    0.000

```

WSL XSEC/Q Calibration Set Assignments:

```

XSEC:    0.000  Q:    15.000  Use: 65535
XSEC:    0.000  Q:    30.100  Use: 65535
XSEC:    0.000  Q:    75.200  Use: 65535
XSEC:    0.000  Q:   139.000  Use: 65535
XSEC:    0.000  Q:   250.000  Use: 65535
XSEC:    0.000  Q:   625.000  Use: 65535
XSEC:    0.000  Q:  1250.000  Use: 65535

```

. {Note: One line for each cross section/discharge pair.}

```

XSEC:    201.000  Q:  1250.000  Use: 65535

```

VELOCITY XSEC/Q Calibration Set Assignments:

```

XSEC:    0.000  Q:    15.000  Use: 1
XSEC:    0.000  Q:    30.100  Use: 1
XSEC:    0.000  Q:    75.200  Use: 1
XSEC:    0.000  Q:   139.000  Use: 2
XSEC:    0.000  Q:   250.000  Use: 3
XSEC:    0.000  Q:   625.000  Use: 3
XSEC:    0.000  Q:  1250.000  Use: 3

```

. {Note: One line for each cross section/discharge pair.}

```

XSEC:    201.000  Q:  1250.000  Use: 3

```

VELOCITY Calculation options for Habitat Analysis

```

sprintf(line,"%8d %2d %2d %2d %2d %8.3f %8.3f %8.3f %8.3f
%8.3f %8.3f %8.3f %8.3f %8.3f\n",
        l.ID,l.selected,l.velcalc,l.nosevel,l.velrepl,l.wmin,l.cfmin,l.Dn,
        l.A,l.B,l.N,l.D65,l.spg,l.CELL);

```

ID	s	v	n	r	wmin	cfmin	Dn	A	B	/
/	N		D65		SPG	CELL				
12345678	12	12	12	12	1234.123	1234.123	1234.123	1234.123	1234.123	1234.123/
/1234.123	1234.123	1234.123	1234.123	1234.123						
11300	1	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000/
/	0.000		0.000		2.650	0.000				
11301	1	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000/
/	0.000		0.000		2.650	0.000				

. {Note: One line for each curve ID.}

```

21115  1  0  0  0  0.000  0.000  0.000  0.000  0.000/

```

/	0.000	0.000	2.650	0.000
ID	dist	vlim	vo	
11300	0.000	0.000	0.000	
11301	0.000	0.000	0.000	
11302	0.000	0.000	0.000	
11303	0.000	0.000	0.000	
11304	0.000	0.000	0.000	
21112	0.000	0.000	0.000	
21114	0.000	0.000	0.000	
21115	0.000	0.000	0.000	

Maximum Migration Distances

11300	5.000
11301	5.000
11302	10.000
11303	0.000
11304	0.000
21112	0.000
21114	0.000
21115	0.000

Additional migration distance cards: 2

11301	10.000
11302	15.000

Velocity regression records: 12

0.000	1	1
0.000	2	1
0.000	3	1
60.000	1	1
60.000	2	1
60.000	3	1
135.000	1	1
135.000	2	1
135.000	3	1
201.000	1	1
201.000	2	1
201.000	3	1

## Appendix 4. Integration of Channel Maintenance and Sediment Transport

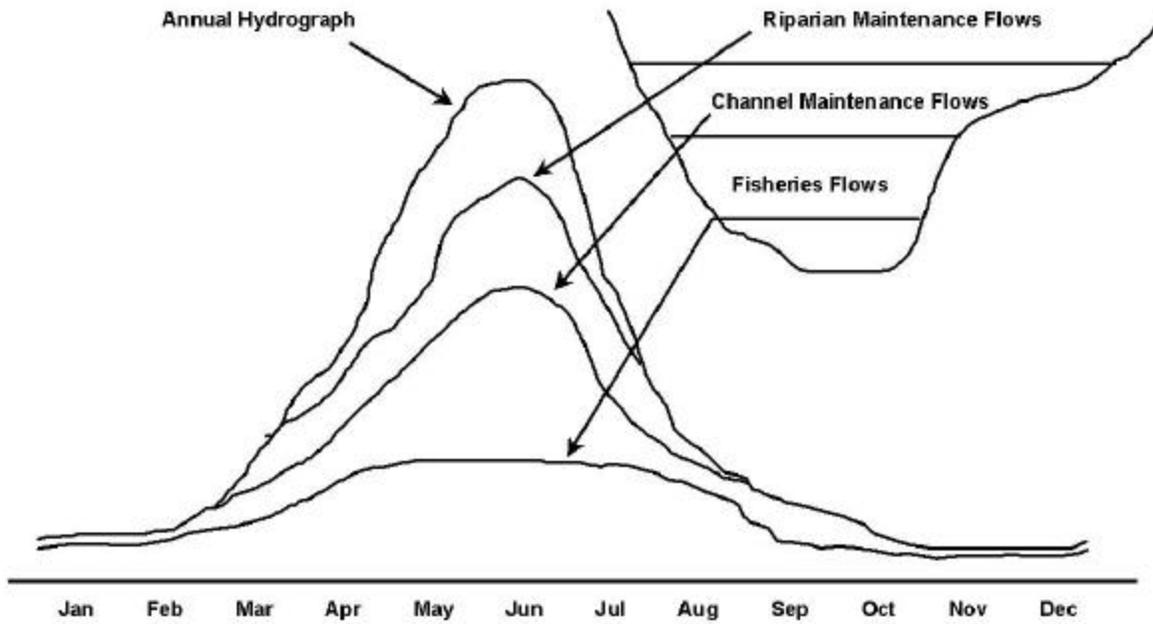
One of the more important aspects of an ecologically sound flow regime is the recognition that the long-term ecological function of a stream or river corridor requires that the physical processes that form and maintain a channel must be protected. There are numerous examples where sediment transport has been either severely reduced, such as below a dam, or significantly increased, such as runoff from a watershed that has been intensively mined or burned in a forest fire. In these situations, the channel will react to the change in the sediment dynamics and either degrade or aggrade differentially along its longitudinal gradient. In some instances, a well-defined river channel will become highly braided, in other circumstances the opposite effect has been observed. This problem, of course, is not confined solely to changes in the sediment supply since alterations in the flow regime, such as seasonally maintained low flows or abstraction of the high flow component for reservoir storage, can result in changes to the dynamic equilibrium between the flow and sediment transport. This can, in turn, result in changes to channel structure and habitat composition as well as changes in the dynamics of the streamside or riparian vegetation.

It has only been in the last decade that the importance of the physical and biological processes that maintain the interconnection between a channel and the adjacent floodplain has come into focus as a critical element of ecologically sound flows. Unfortunately, no consistent methodology has yet to be put forward dealing with what is now recognized as the three critical elements of ecologically sound flows: fishery flows, channel maintenance flows, and riparian maintenance flows. These different flow regimes are illustrated in Figure A4-1. It is important to understand that the latter two types of flow are basically related to the ability of the channel to process sediment loads and to provide adequate hydrologic connections between the stream course and the dependent riparian vegetation over some meaningful temporal domain.

We have already dealt with the use of PHABSIM as a tool to assist in the determination of the fisheries flow component of ecologically sound flows. PHABSIM analyses are well suited to examine the changes in physical habitat over flow ranges where the habitat mosaic is relatively static (i.e., after the physical and biological processes associated with channel or riparian flows have done their work within the channel). We now recognize that PHABSIM typically provides only a partial picture of the ecological flow needs and that during the higher flow periods we must turn to other methods for determination of appropriate flows during these periods (i.e., use the IFIM framework). This includes conducting analyses to determine flow regimes that maintain the channel characteristics from a physical perspective, independent of microhabitat. Identifying channel maintenance flow regimes helps to ensure that those microhabitats upon which the fish are dependent for their existence are formed or maintained during short high flow events.

In order to examine which flow patterns are needed to maintain an ecologically functioning stream system, the analyst needs to recognize that flowing water (timing, duration and magnitude) erodes, transports, and deposits sediment as well as controls the types and growth patterns of vegetation species in generally predictable ways. The temporal distribution of the magnitude and duration of flows interacts with the resident geology, topography, and vegetation to ultimately determine to form and condition of the mesoscale and microhabitat distribution of habitat upon which fish and other aquatic organisms are dependent for their living space. Alteration of the flood flow regime in a river can ultimately result in loss of side channel habitats, changes in riparian species and distribution, and alteration of the ratio of pools to riffles. Therefore, these factors need to be carefully considered in any analysis of altered flow regimes and are not restricted to the high flow component. Seasonal reductions in flow at artificially low sustained

levels can also result in the accumulation of fine sediments that are deleterious to successful spawning and egg incubation of many species.



**Figure A4-1.** Elements of the hydrograph to consider when describing an ecologically sound flow regime.

In order to examine which flow patterns are needed to maintain an ecologically functioning stream system, the analyst needs to recognize that flowing water (timing, duration and magnitude) erodes, transports, and deposits sediment as well as controls the types and growth patterns of vegetation species in generally predictable ways. The temporal distribution of the magnitude and duration of flows interacts with the resident geology, topography, and vegetation to ultimately determine to form and condition of the mesoscale and microhabitat distribution of habitat upon which fish and other aquatic organisms are dependent for their living space. Alteration of the flood flow regime in a river can ultimately result in loss of side channel habitats, changes in riparian species and distribution, and alteration of the ratio of pools to riffles. Therefore, these factors need to be carefully considered in any analysis of altered flow regimes and are not restricted to the high flow component. Seasonal reductions in flow at artificially low sustained levels can also result in the accumulation of fine sediments that are deleterious to successful spawning and egg incubation of many species.

Maintenance of stream and river ecosystems hinges on the determination of flow regimes that protect the physical processes, which in turn influence the biological processes within the stream or river. This results in the concept of multiple flow regimes that target specific elements of the flow such as fisheries, channel maintenance, and riparian maintenance flows.

### *Channel Maintenance Flows*

Channel maintenance (or fish habitat maintenance) flows represent that portion of the hydrograph that is high enough to prevent vegetation growth within the active channel and remove sediment. The active channel can be characterized as that elevation within the channel associated with bank-full flows and is typically indicated by flat areas of alluvial deposits and the line of perennial vegetation that makes a well-defined margin along a stream or river corridor. Although a fairly wide range of flows are associated with bank-full discharges across different river systems, flows associated with a return period of approximately 1.5 years have been identified as an average value for these types of flows. Some investigators have also determined that the bulk of sediment transport on an annual budget occurs at intermediate flow ranges and that the most effective discharge in terms of long-term sediment budgets is nearly equivalent to the discharge at bank-full. These studies indicate bank-full flows are an important hydrological benchmark that is related to the flows, which are critical to maintaining the shape of alluvial channels and therefore, the mesohabitats upon which they are dependent.

Site-specific studies that measure the bank full discharge directly or are modeled from observations of the elevations of riparian and sediment deposition areas can be undertaken as an integral part of an IFIM application. Once the magnitude of the bank full flow has been determined, it can be used in conjunction with other information to determine this part of an ecologically acceptable flow regime. Other considerations of these higher flows relate to how the timing of the reduction of the high flows may be impacted by a project. For example, a rapid reduction in high flows has been observed to result in an increased sediment flow to rivers from bank failure due to rapid loss of hydrostatic pressure in the banks.

In some instream flow studies, the anthropogenic reduction in the high flows have been constrained to no more than a 10% reduction from the previous peak daily flow in order to minimize these types of secondary effects. Although not developed from a rigorous analytical procedure, these flow reduction criteria were derived from an examination of the long-term historical daily hydrographs for a number of similar river types and selecting a flow reduction range at the upper limit of observed natural processes. Most natural high flows do not decrease this rapidly and a more stringent requirement may be warranted. Reducing the duration of the peak flows may in fact impair some channel forming processes as well as impacting riparian species seeding and growth dynamics that are tied to these characteristic patterns in flow reductions. It should also be apparent that a careful examination of the flow reduction pattern should be considered in light of not only the riparian vegetation needs but also to minimize potential impacts associated with fish stranding if appropriate. Utilization of the PHABSIM cross section geometries in association with water surface elevation modeling can provide some insights to appropriate flow reductions over specific flow magnitude ranges.

### *Riparian Maintenance Flows*

As with most conceptual tenants of instream flows, to date no universally accepted or recognized methods have been developed for the determination of flow quantity or duration needed to maintain riparian habitats and associated flood plains. In this context we take riparian flows as those not only necessary for the riparian vegetation immediately adjacent to the active channel but also side channels, oxbow lakes, wetlands, swamps, and ponds. Often these types of habitats are only seasonally connected to the main river channel but in turn may represent critical breeding or rearing areas for many fish species and in fact are necessary for successful completion of their life cycles. In addition, the overall importance of these types of habitats in terms of the general ecological diversity and function of a river corridor cannot be overstated.

Existing methods concentrate on modeling flows at which the water surface elevations inundate the flood plain where these riparian features are present within the affected study reaches. As with the channel maintenance flows, these site-specific issues and features can be identified during the scoping, fieldwork, and analysis phases of an IFIM application by making the appropriate cross section geometry measurements and extending them as necessary to pick up critical elevation features. The investigator is still left with determining the seasonal and duration aspects of these flows and inclusion of a riparian and terrestrial wildlife biologist when planning the analysis is strongly recommended for studies in which these types of issues are deemed important.

*Including Sediment Analysis for Medium to Low Flow Issues*

As a final note, we strongly encourage investigators to consider sediment transport as part of the overall instream flow assessment. Characterization of the various sediment size distributions within the study stream can permit simple calculations of the flow at which various size fractions can be moved. This would permit the investigator to determine, for example, in a stream where a significant proportion of the sediment load during medium to low flows is sand or silt, whether or not a proposed flow reduction would be expected to result in conditions in which these size fractions would no longer be transported. This would imply that deposition of these materials in slower water areas of the reach would occur and allow the investigator to evaluate the potential impacts on egg incubation and potential changes in invertebrate community structure associated with the changes in channel substrate characteristics.

# Laboratory 1. Using the PHABSIM for Windows Interface

## Introduction

The PHABSIM Windows interface considers all hydraulic and habitat simulation work planned for a study site to be one "project". All data entry, selection of simulation options, output option selection, and viewing of results takes place within the project. The purpose of Laboratory 1 is to familiarize the user with use of the interface to build a PHABSIM project data set.

## Using the Menu System

The general steps to use the interface consist of creating a new project or opening an existing project; importing, entering, or changing data; entering or changing run options; running programs; viewing intermediate and final results; saving the project files; and capturing results in a format for creating reports. In the laboratory exercises, each of those steps is presented in the following format:

**\Main Menu\Next Menu\Next Menu or Tab**: followed by instructions.

For example, to enter cross section coordinate data for the second cross section, the user clicks on Edit, followed by clicking Cross Sections, followed by selecting the second cross section, followed by clicking the Coordinate Data tab, and then entering data in the spreadsheet-like interface. That sequence of operations is noted in the documentation as:

**\Edit\Cross Sections\Number\Coordinate Data**: Enter x, z, channel index, n (if known), VelSet1, VelSet2, ....

The actions are:

Move mouse to **Edit** item in the main menu, click.

Move mouse to **Cross Sections** tab, click.

Move mouse to the gray **box showing number 2** in the left column, click.

Move mouse to **Coordinate Data** tab, click.

Enter data in the spreadsheet-like interface as described below.

Abbreviated notation, for example **..\Coordinate Data**, is used in some places to abbreviate **\Edit\Cross Sections\Number\Coordinate Data** when moving within the same set of tabs or menus.

This notation convention is used through out the Laboratory exercises. If you find the notation is too terse or confusing, click on the first item that comes to mind and see what happens. Until the data entries or option selections are changed, you are merely viewing different portions of the interface so you can click on each successive item in this notation and follow where it leads.

To gain familiarity with the interface, we will begin by loading an existing project and navigating through the interface to get a feel of the process. First open the project:

## Step 1. Open a Project

**\File\Open Project:** Navigate the Windows File Menu to \If310\Newlabs\Lab01 and double click on the file Lab1.phb

## Step 2. Enter and Edit Cross Section Data

Data can be entered and viewed in the Edit area. Look at the cross section data in the Sampl1 project by:

### **\Edit\Cross Sections\Cross Section Data**

Note that the data set contains four cross sections. For each cross section, the following information has been entered.

**ID** – The cross section identifier. *In PHABSIM for Windows we always use the distance from the downstream cross section as the identifier. This allows a cumulative upstream distance to be calculated and displayed as the Y ordinate in the coordinate data tab.*

**Length** – the cross section length or the distance from the downstream cross section. Length is used to calculate the y (cumulative distance) value. Cross sections are sorted by the cross section ID in ascending order.

**Upstream WF** – the weight assigned to this cross section. That is, the fraction of distance upstream it represents.

**L Bank WF** – the left bank weight for a bend.

**R Bank WF** – the right bank weight for a bend. If these are equal, there is no bend.

**SZF** – stage of zero flow.

**N** – Manning's n value for the cross section.

**Beta/D50** – beta exponent for use in the MANSQ program, if applicable, or median substrate particle size in mm.

**Slope** – energy slope at the cross section. Typically estimated as the water surface slope.

To edit or view individual cross sections use:

### **\Edit\Cross Sections\Coordinate Data**

Under this tab, the cross section currently highlighted under **Edit\Cross Sections\Cross Section Data** will be displayed. Cross section ID is shown above the table and the number of points on the cross section is also displayed. To view the cross section profile, click the **Graph** button. You may drag the graph and Cross Section Data windows by their top bars so both can be viewed simultaneously. To view a different cross section, return to the **Cross Section Data** tab and click on a different cross section. The highlighted region will change. Return to the **Coordinate Data** tab and the graph will update.

The **\Edit\Cross Sections\Calibration Data** tab allows entry of data for left and right bank water surface elevations, the user-determined (or “given”) water surface elevation, the “best estimate” discharge for the site, and the discharge measured at that cross section. As with the coordinate data, cross sections are selected in the **Cross Section Data** tab prior to viewing the **Calibration Data** tab for that cross section.

### *Entering and Editing Suitability Curves*

Now that you have seen how to navigate around the cross section editing menu, take a look at the **\Edit\Suitability Curves** menu. You will find a similar set of menus and tabs there. Look at the data entry and display area for habitat suitability curves using:

#### **\Edit\Suitability Curves**

The **\ Edit\Suitability Curves\File** menu item allows you to create a new curve, import an existing curve file from another project, copy curve files, and save curve files. The **\Edit\Suitability Curves\Curve** menu item allows you to choose which curve in a suitability curve set is displayed in the data entry box. For example: by selecting **..\Curve>Select by ID** you can view a list of all HSC curve sets currently entered into this project and select a particular curve for viewing. Individual curves for depth, velocity, channel index, or temperature are selected using the **Curve Type** buttons to the right. **\Edit\Suitability Curves\Graph** allows you to display a graph of the selected curve values displayed in the SI curve-editing box. These graphs can be scaled for a better view. See Chapter 1 for use of the mouse button graphing features in PHABSIM for Windows.

The **\Edit\Suitability Curves\Curve\Display All Curves** menu item displays the four HSC curves in one window.

### *Entering and Editing Simulation Discharges*

This simple dialog allows you to start with a small number of simulated discharges to be used in calibrating the hydraulic models, then add additional discharges for final simulation runs. For calibration when comparing observed with simulated conditions, the calibration discharges have been entered as simulation discharges by default. They cannot be removed and will appear in all simulations you run. The calibration discharges are shown in gray and any other discharges you enter will be shown with a white background.

To add discharges to this list, either place the cursor on the next highest discharge and press the Insert key on the keyboard or, to add a discharge higher than the highest shown, place the cursor on the last discharge and press the down arrow. Either of these actions will provide a new row with a discharge of 0. You simply type the desired discharge value in the highlighted cell.

### **Step 3. Running the Models**

The **\Models** menu is where you set-up and run the various models. Here hydraulic simulation is divided into water surface and velocity simulation and habitat simulation includes the Habtae, Habtam, and Habef models. Also included here is a combined Avdepth\Avperm model. Each model contains a **Run** button that is clicked after all of the model input parameters are selected.

Further instructions in running the models are contained in the remainder of the laboratory exercises.

#### Step 4. Close and Save the Project

To prepare for the next laboratory exercises, please close this project using:

##### \File\Close Project

If you had made any changes to your project, they would be saved now. The system will prompt you to save your project if changes have been made. In general it is a good idea to frequently use:

##### \File\Save Project

You may wish to save the project periodically to ensure you can recover from a mistake or a computer glitch.

#### Step 5. Manipulating PHABSIM for Windows Graphics

PHABSIM for Windows uses a third-party graphics package that allows the graphs displayed by clicking the various graphics buttons described in the labs and manual to be scaled, translated, zoomed and, in some cases, rotated. The following examples illustrate each of those functions.

*Scaling (Figures L1-1 and L1-2):*

- Press Ctrl and hold down both mouse buttons
- Move mouse down to increase the chart's size
- Move mouse up to decrease the chart's size

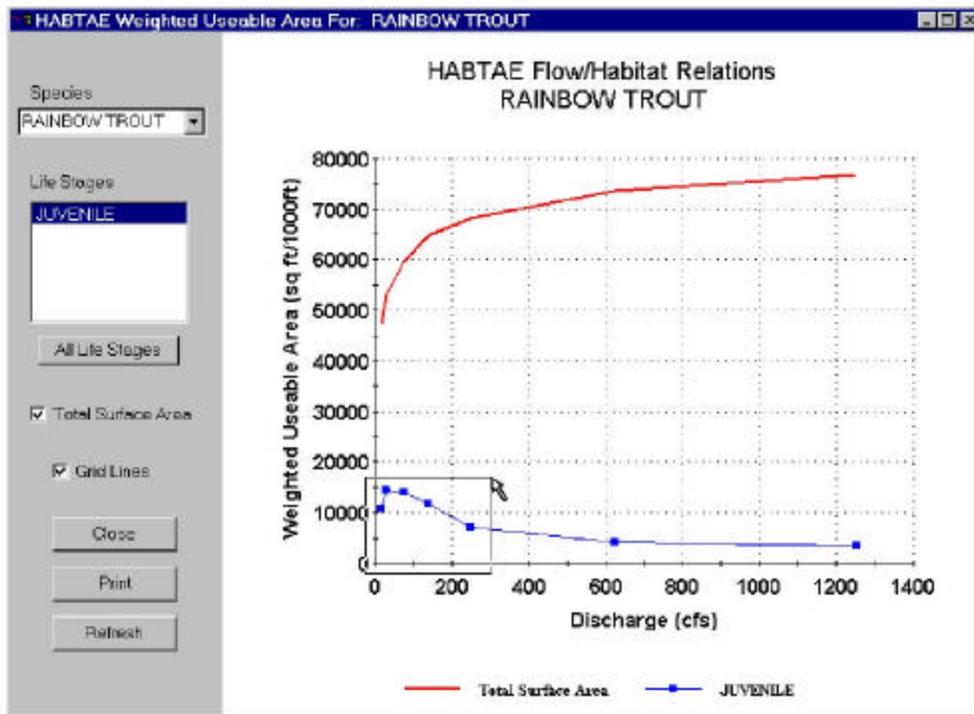


Figure L1-1. Original image.

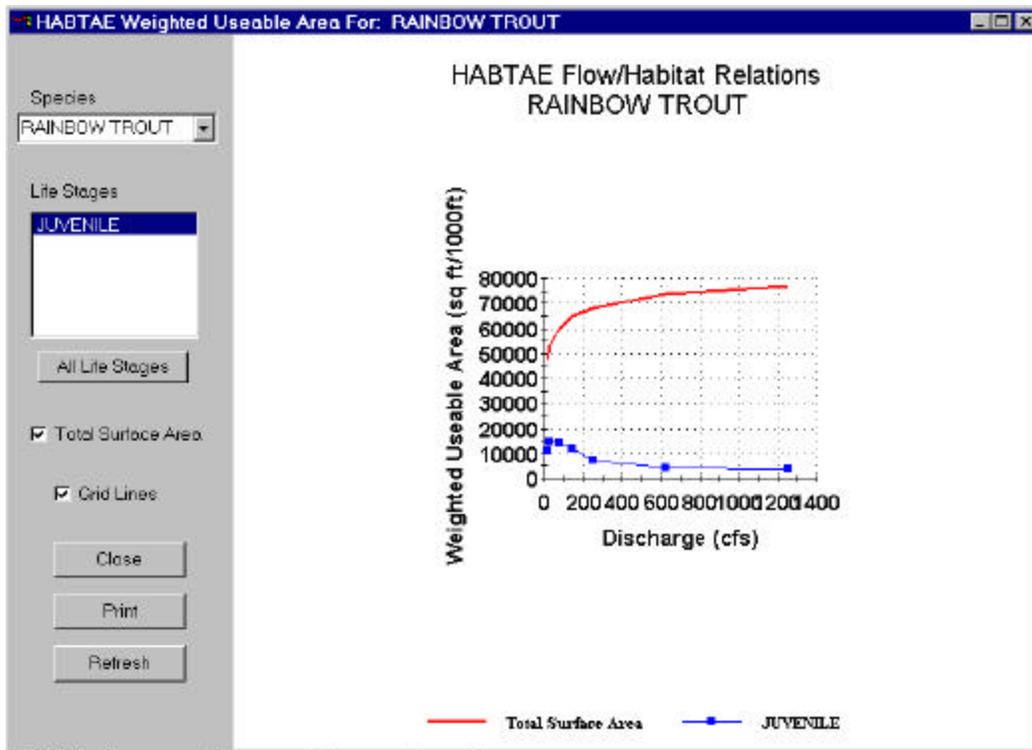


Figure L1-2. Scaled view.

#### Translation (Figure L1-3)

- Press Shift and hold down both mouse buttons
- Move mouse to shift the chart

#### Zooming

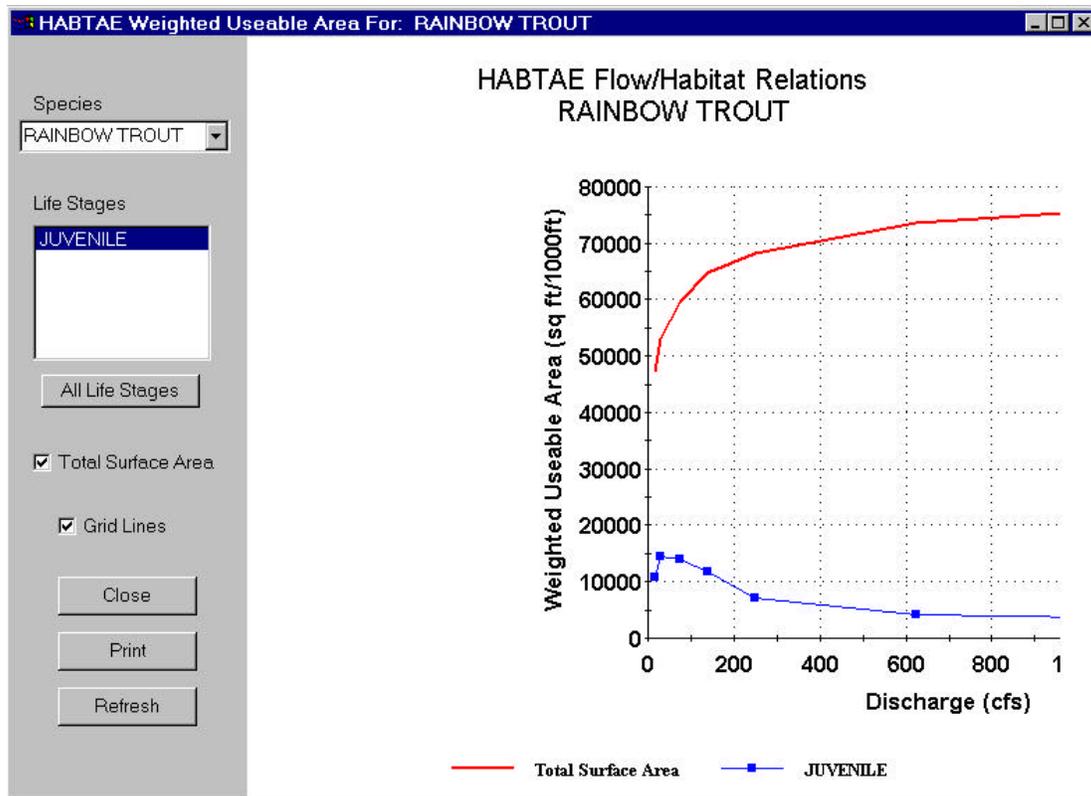
##### Axis Zoom

- Press Shift and hold down the left mouse button
- Move mouse to select the area to Zoom into (a box will be drawn around the area) then release the button

Axis zoom is illustrated in Figures L1-4 and L1-5.

Graphics Zoom does not retain axes, otherwise, same as Axis Zoom

- Press Ctrl and hold down the left mouse button
- Move mouse to select the area to Zoom into and release button



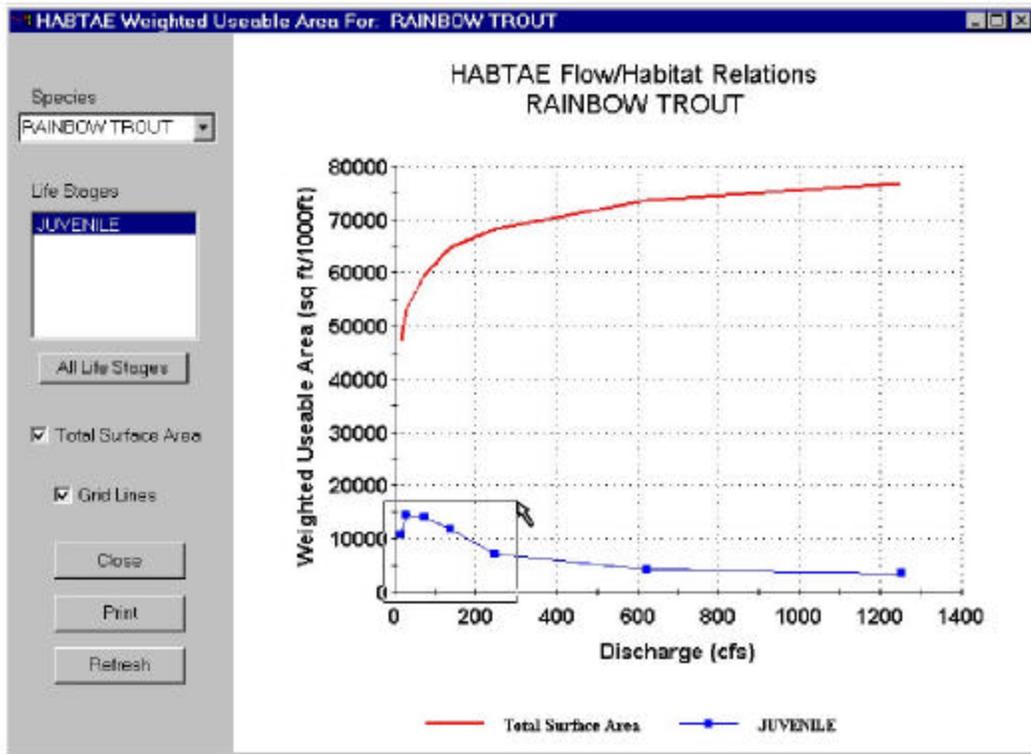
**Figure L1-3.** Translated image.

*Rotation (3-D charts only, Figures L-6 and L-7)*

- Hold down both mouse buttons
- Move mouse left and right to change the rotation angle
- Move mouse up and down to change the inclination angle

*Return to Default Position (Fig. L1-8)*

- Press "r"
- All interactive scaling, translation, and zooming is removed



**Figure L1-4.** Selecting a region to enlarge. Hold Shift and Left Mouse button, drag box to desired area.

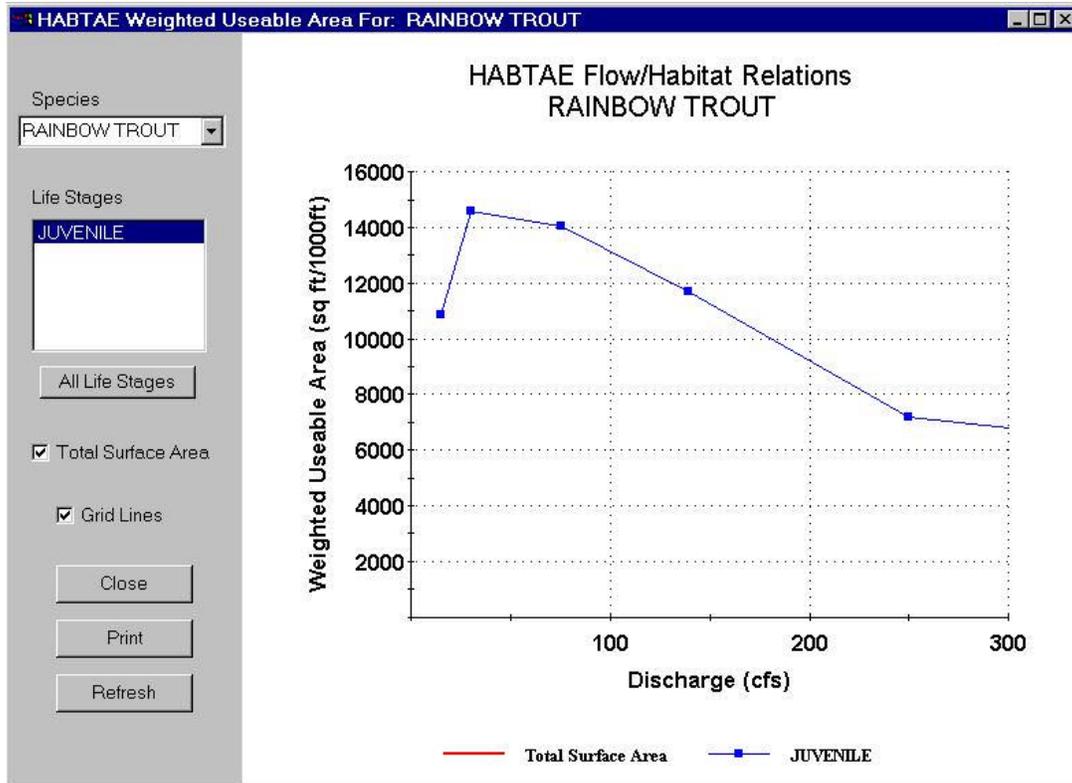


Figure L1-5. Zoomed view appears when mouse button is released.

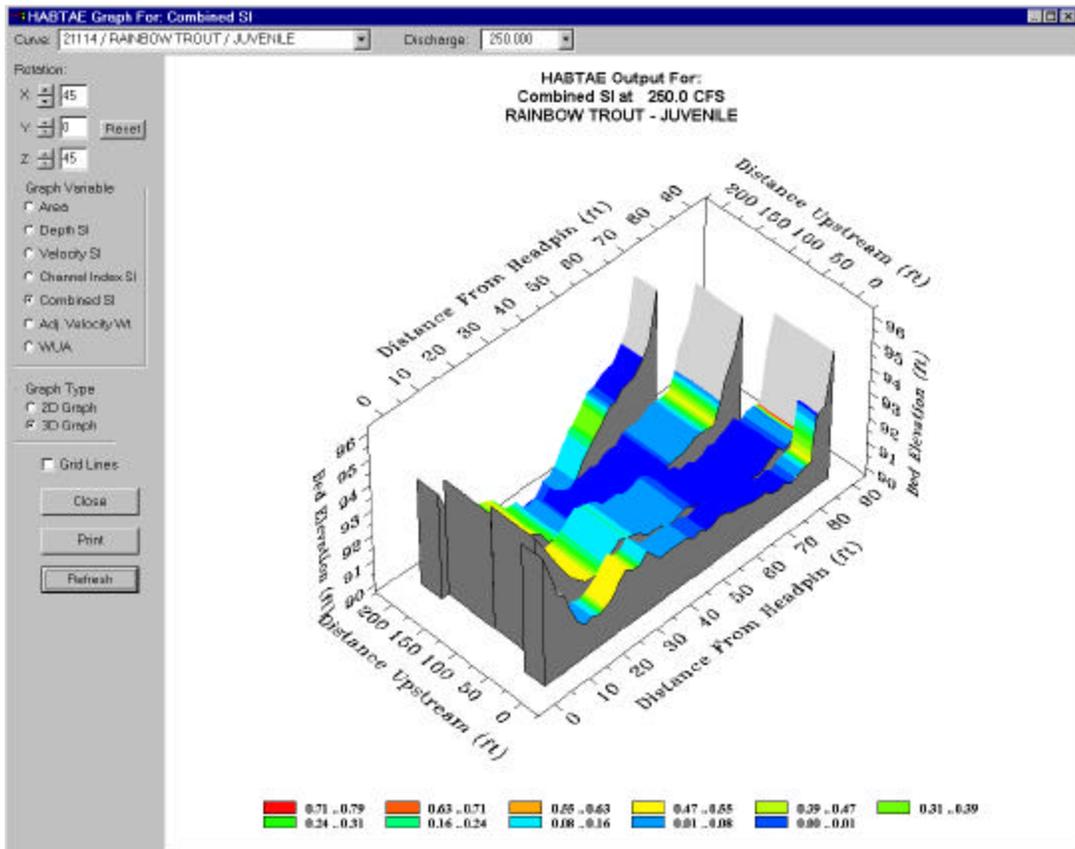


Figure L1-6. Default position of 3-D chart.

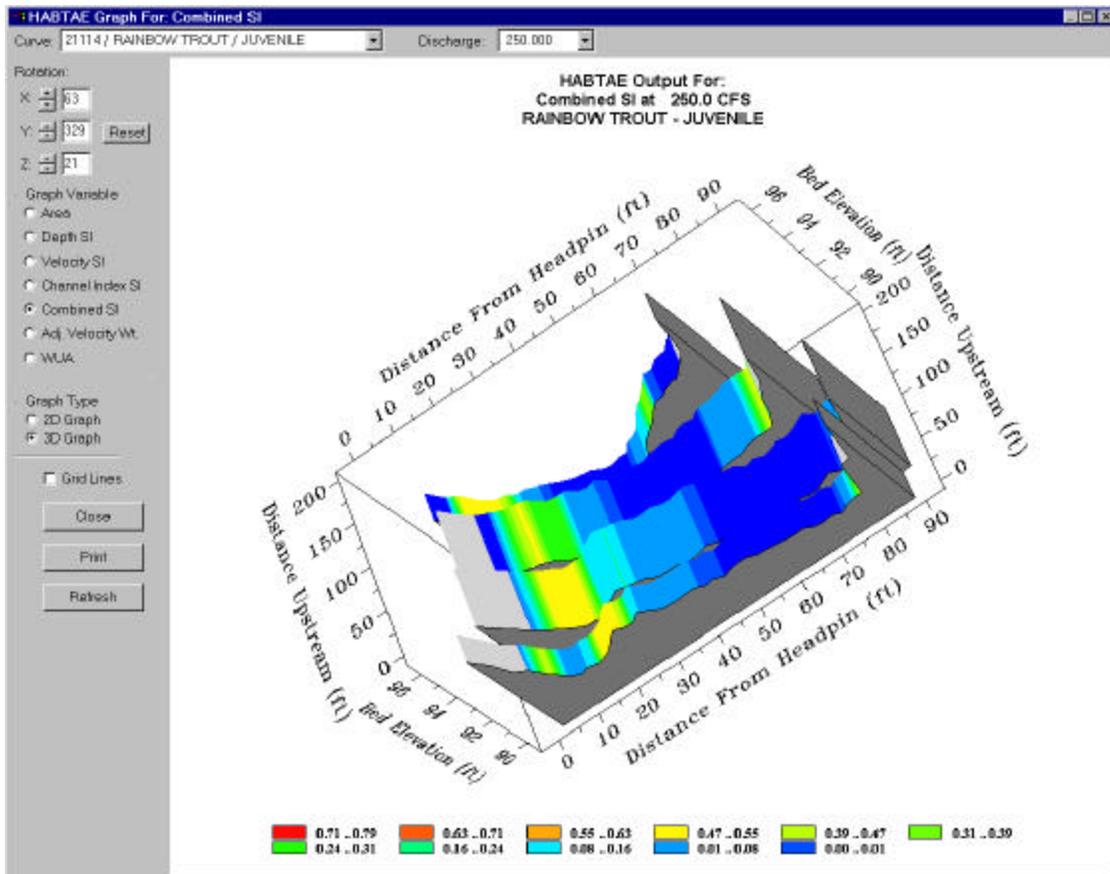


Figure L1-7. Rotated 3-D chart.

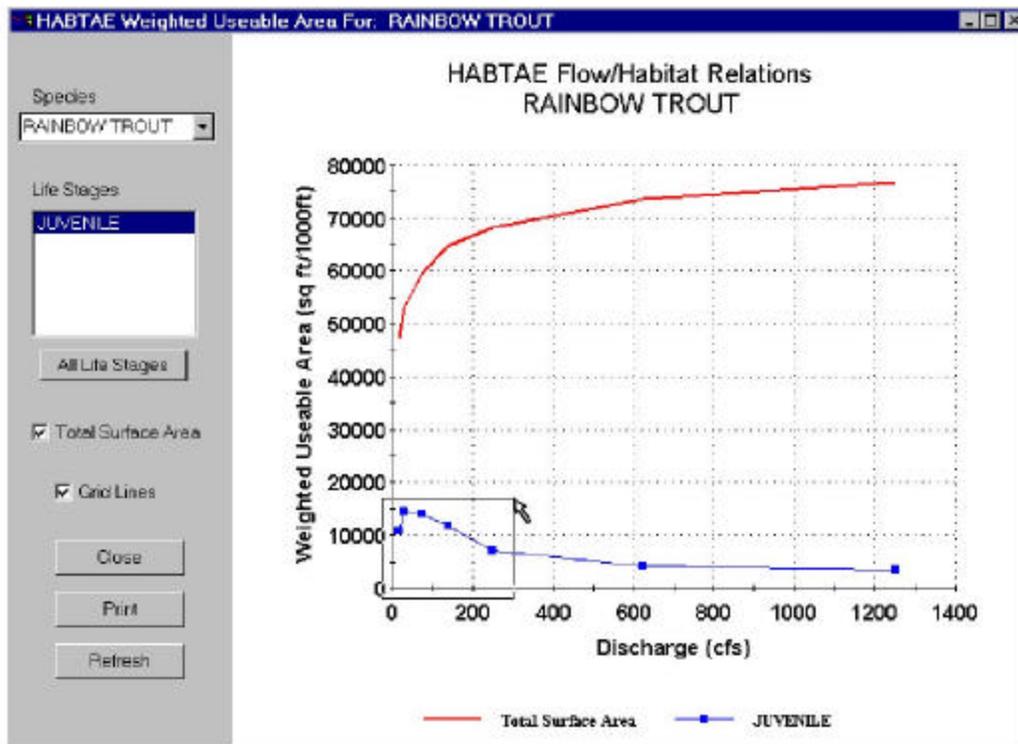


Figure L1-8. Press “r” o keyboard to return to original view.

## A Strategy for Using PHABSIM for Windows

PHABSIM for Windows was designed to be used in combination with other Windows features to allow a large degree of flexibility in the PHABSIM analysis. The following suggestions constitute a strategy for using Windows to the maximum advantage while doing a PHABSIM analysis.

### *Monitor Adjustments*

We have found it is most convenient to adjust your monitor to display the maximum number of pixels that can comfortably viewed. Current generation 17- inch monitors can reliably display 1024 x 768 pixels with font sizes in the range of normal printed text. If you can comfortably use 1280 x 1024 pixels you will find additional utility in being able to position various windows on the desktop for convenient use. The minimum resolution monitor that can be used with PHABSIM for Windows is 800 x 600 pixels. You may find that a 19-inch monitor operating at 1280 by 1024 pixels facilitates the analysis by allowing multiple windows to be open simultaneously.

### *Location of the Working Directory*

PHABSIM for Windows places the sample files in **C:\My Documents\Phabsim\Sample1** and **..\Sample2**. This location was chosen solely because most computers using Microsoft Windows will have

a My Documents directory on the C: drive. You may place your working directory for any project in the desired location at project creation. This may be accomplished by creating the directory using the **Browse** feature in the **\File\Open Project** dialog or by creating the directory prior to running PHABSIM for Windows using Windows Explorer. Place the working directory in a location that is relevant to your project and easy to remember.

### *The PHABSIM Window*

The main program window need not be maintained at its full size. The primary purpose of the main window is to provide the top-level menu items in the menu bar. Thus, after a project is opened, the main PHABSIM window may be sized so only the menu bar or the text in the project description is displayed. This opens up space on the desktop without losing any of the main menu functionality. Drag the lower right corner of the window to resize it.

### *Displaying Graphs*

Many of the plots of input data or model results display values that are either entered or displayed using various interactive tables in the PHABSIM for Windows interface. It is often convenient to drag the graph window to the lower right of the screen and drag the data entry or program option window to the upper right so at least portions of the data table may be viewed at the same time as the graph. Graph windows may be resized by dragging their corners.

### *The Desktop*

We have found that it is very convenient to place icons on the desktop for PHABSIM, Projview (a PHABSIM file translation utility), Notepad, and Wordpad (also called Write). It is also convenient to have an icon for your spreadsheet program to provide ease of starting the spreadsheet by simply double clicking the icon.

A convenient way to capture PHABSIM for Windows graphics (other than printing them) for use in other documents is to use the Print Screen feature of Windows and paste the graphic into Microsoft Paint. Thus, placing an icon for Paint on the desktop may also be convenient.

PHABSIM for Windows produces numerous files that can provide ancillary information during the course of the analysis. It is convenient to have Windows Explorer running while using PHABSIM so those files may be accessed by simple drag and drop actions from Windows Explorer to the other programs noted here that are placed on the desktop.

### *Auxiliary Programs*

#### Spreadsheet Program

Though PHABSIM for Windows contains numerous automatically generated plots that can be used to display both input data and the results produced by the various models within the program, the plotting package can only display results from the current analysis. Thus, when the user wishes to compare results of different analyses, it is necessary to export those results to a different medium using cut and paste operations. We have found it very convenient to create spreadsheets for this purpose. Later lab exercises use spreadsheets to calculate differences between model results based on different model options and to display those different results graphically. When spreadsheets are used in conjunction with PHABSIM for

Windows, the spreadsheet files should be saved with the PHABSIM files and should become part of the analysis record.

### Notepad

While applying PHABSIM to a study site, numerous decisions are made regarding program options, data issues, and alternative approaches to describing habitat for the site. It is very difficult to recall each decision after the study is done. Thus, we suggest that the user create a Notepad file with a name like "Projectlog.txt" and keep a diary of the progress of the analysis including any problems encountered, the program options selected, and especially why they were selected, and any other pertinent information that will allow later defense of the study. For example, such a log file would be a good place to keep track of calibration error statistics and notes as to why a particular calibration was deemed satisfactory.

### Windows Explorer and Wordpad

In addition to the results tables provided in the PHABSIM for Windows interface, the program produces numbered *projectname.ZOUTxx* files that contain computational details and other numerical results from running the models. Viewing these files facilitates some portions of the analysis. It is convenient to be able to "drag and drop" the numbered ZOUTxx files from Windows Explorer to Notepad for viewing. Some of the files will be too large for Notepad, but Wordpad will be able to display them. Further, Wordpad provides more formatting control, when portions of the ZOUT files are to be inserted in reports, than Notepad.

### Use Strategy

When doing a PHABSIM analysis, the strategy we have found most convenient is to open and minimize the following programs and files:

- Notepad, open the log file
- Spreadsheet, open data comparison or error tracking file(s)
- Windows Explorer, move to the working directory so you can drag and drop conveniently

The minimized programs will show as buttons on the task bar at the bottom of the screen. Click on the appropriate button to access them. Remember to save your log, PHABSIM and spreadsheet files often during the course of the analysis. Such a strategy will prevent data loss due to the occasional inevitable mistake.

## Laboratory 2. Building a PHABSIM Project

### Objective

The objective of this laboratory is to cover the use of PHABSIM for Windows to create a PHABSIM project file. PHABSIM for Windows will be used to create an example project file and the project will be reviewed for errors.

**Data Files Used:** Data.xls

### Introduction

In typical PHABSIM applications, the user will likely have a number of cross sections where the hydraulic characteristics of the river channel have been measured at one or more discharges. In this laboratory, we have provided data collected at four cross sections from the Fryingpan River, where water surface elevations and velocities have been measured at three calibration discharges. All the hydraulic data necessary to create a complete PHABSIM project file have been summarized in tabular form by cross section and provided in Tables L1-1 to L1-4 at the end of this lab. Information about reach lengths, Stage of Zero Flow (SZF), upstream weighting factors, reach length, slope, best estimate of the discharge, and measured discharge at each calibration flow is located at the top of each tabular summary. The remaining data in the table lists the x-distance, bed elevation, channel index, and observed velocities at each of the calibration flows.

The laboratory illustrates use of **\Edit\Cross sections** to enter the data for the four cross sections. Two complete PHABSIM project data files containing these calibration data have already been created (SAMPLE1.PRJ and SAMPLE2.PRJ) as example data files. SAMPLE1.PRJ contains data entry only, while SAMPLE2.PRJ has been run through the habitat simulation stage. Both projects are included on the PHABSIM distribution disks. Proceed through the steps in order. If you run out of time to enter all the data described below, you can use SAMPLE1 to navigate the various menus and view diagnostic plots. A separate set of worked laboratory exercise project files is provided for each lab. The location of those files will vary depending on the computer system used for class instruction.

#### Step 1. Create a New Data Set

Now that you understand the basic PHABSIM for Windows navigation process from Lab 01, you are ready to open a new project and enter data.

For ease of reference these instructions will use the Project name MYLAB02.

**\File\Open Project:** Enter a project name in the **Project folder name** box. Then type a description of the project in the **Project Description** box. (The description is limited to 256 characters.) Next use the **Browse** button to navigate the Windows file tree to where you want the new folder to be stored. PHABSIM for Windows will create a directory and a set of files with the project name. For this lab, enter the new project name (i.e., MYLAB02) in the file name box, enter an appropriate description in the project description box, then click **Browse** and navigate to \F310\Laboratories, and click **OK**. (See Figures L2-1, L2-1, and L2-3.)

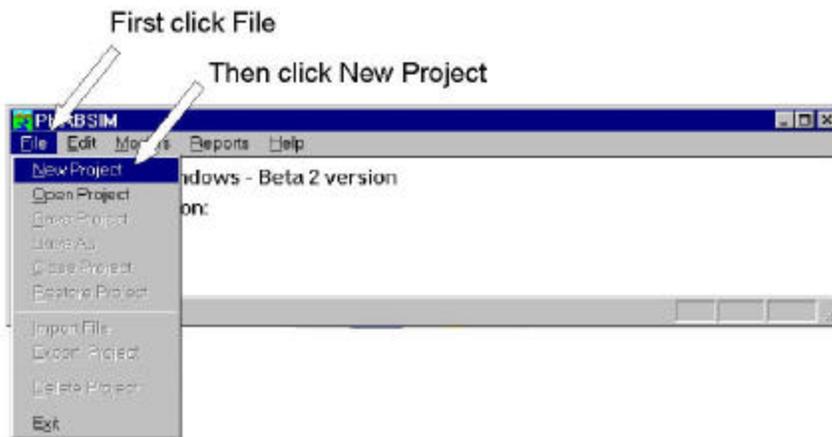
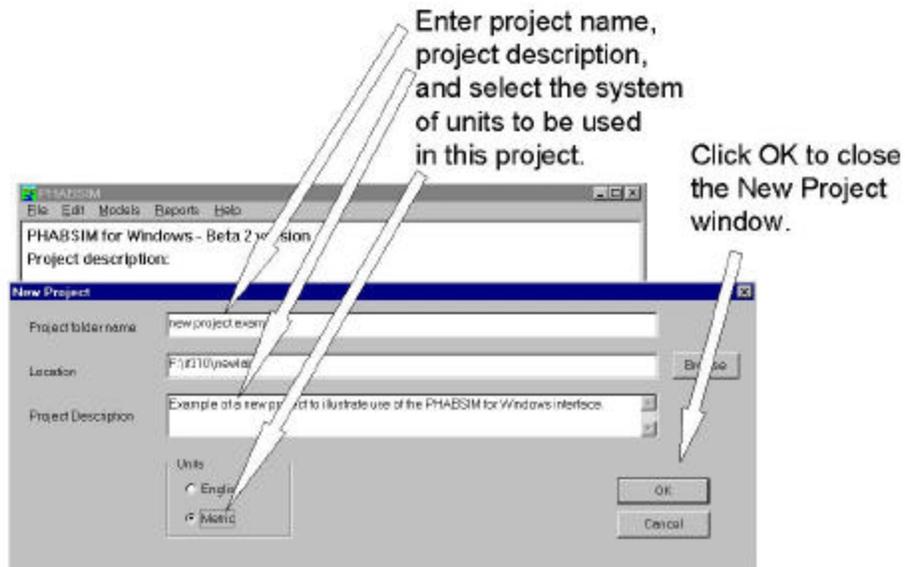


Figure L2-1. Opening a new project.



Figure L2-2. Assigning a folder location.



**Figure L2-3.** Entering project name and description.

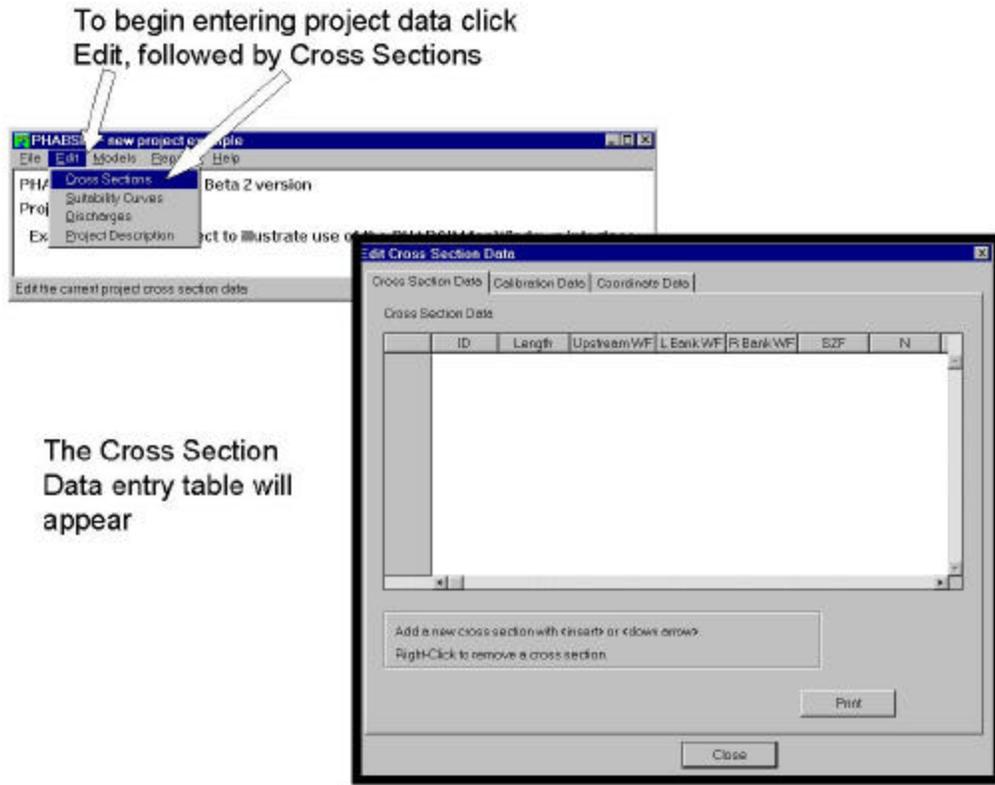
An example of a project description might be:

“Fryingpan River 3 miles downstream from Reudi Reservoir. High flow data collected May 10, 1999, mid flow data collected July 10, 1999, and low flow data collected Aug. 23, 1999. By name, name, and name.”

You can revise the project description from the Edit menu using **\Edit\Project Data**. This allows adding short notes on the status of the analysis as the process progresses.

## **Step 2. Enter Project Hydraulic Data for Lab02**

To build a project’s data set, click the **\Edit** menu item. You are presented with choices of **Cross Sections**, **Suitability Curves**, and **Discharges**. You can enter and change data for each of these categories by selecting the corresponding menu item. However, you must begin with **Edit\Cross Sections\Cross Section Data** and enter the cross section data for at least one transect (cross section) prior to entering calibration data or coordinate data as shown in Figure L2-4. The **Edit\Cross Sections** dialog contains three tabs for **Cross Section Data**, **Calibration Data**, and **Coordinate Data**. The **Cross Section Data** tab is displayed by default.

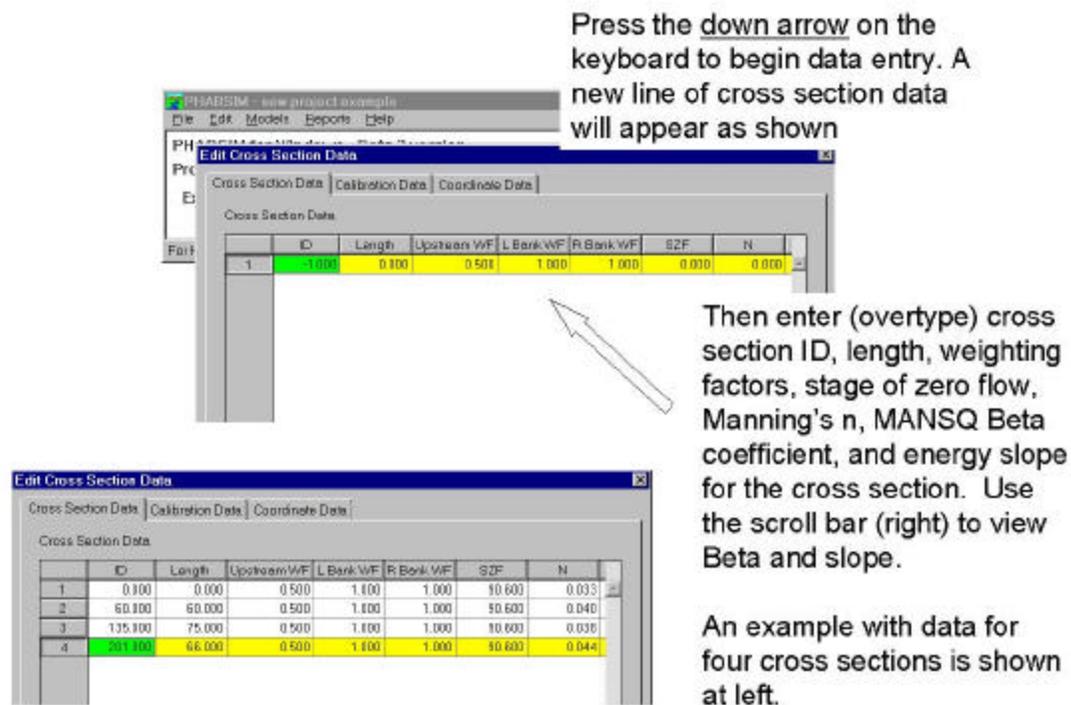


**Figure L2-4.** Preparing to enter cross section data.

To create a new cross section, in the **..\Cross Section Data** tab, use the down arrow. A row of cells appears with a cross section ID number of “-1.00”. For each cross section, enter the id for the cross section by typing the cross section ID from Table L2-1 over the -1.00 entry. Move the highlight cursor to the right with the right arrow and enter the reach length. Continue moving to the right and enter the upstream weighting factor, the bend weights for the Left Bank and Right Bank, the stage of zero flow (SZF), Manning’s n value (if known), Beta coefficient for MANSQ (if known), and the energy slope. Values for Manning’s n and beta can be left unchanged for now. You would enter those values when using the WSP or MANSQ models later in the analysis. Your data for the first transect should now contain the following values.

ID	-	0.0
Length	-	0.0
Upstream WT	-	0.0
Left Wt	-	1.0
Right Wt	-	1.0
SZF	-	90.60
N	-	0.0
Beta	-	0.0
Slope	-	0.0040

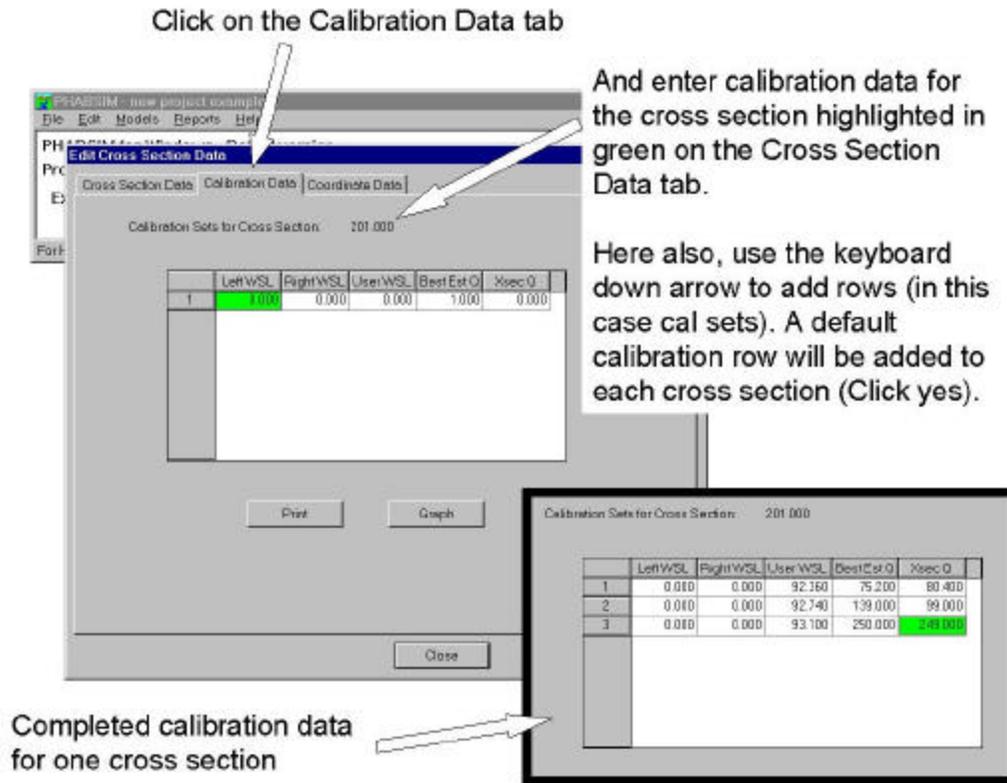
Complete the cross section data table as shown in Figure L2-5. Scroll right to include beta and slope values.



**Figure L2-5.** Entering cross section data.

Next, click on the cross section ID 0.00 line and proceed to the **Calibration Data** tab (Fig. L2-6). Enter data for either left and right bank water surface elevations, or a single “user” selected water surface elevation, the user-determined or “given” discharge for the study site, and the measured discharge for the current transect. Enter these items for each calibration discharge (matching each VEL set) for this study. Return to **Cross Section** tab to change to the next cross section ID.

Note that the best estimate discharge must be a unique value (duplicates are not allowed). After you enter calibration data and exit the calibration data tab, the table sorts in ascending order on the **Best Estimate Q** values.



**Figure L2-6.** Entering calibration data.

**Coordinate Data** tab. Here you will find a difference from historical PHABSIM data entry in that there are values for X, Y, and Z. The inclusion of three dimensions is in anticipation of the ability to import GIS or spatially referenced data in the future. For now, enter the total distance upstream from the first transect as Y. Thus, X represents distance across the transect from the head pin, Y represents the distance upstream from the first transect (also referred to as Stationing), and Z represents the vertical distance above the datum selected for the study site. The program calculates Y values and those cells have a gray background.

From the data in sheet xsec01 enter the x-distance in column X, the distance upstream from the first transect in column Y, and the elevation in column Z. Channel index and individual Manning's n values for each cell are entered in the columns labeled CI and N. Calibration velocity sets are entered in the **Vel @discharge** columns. Enter the coordinate and velocity data from Table L2-1. The coordinate data entry process is shown in Figure L2-7. When you have finished, proceed to the **..Cross Section Data** tab, select the next cross section and repeat the Calibration Data and Coordinate Data entry steps.

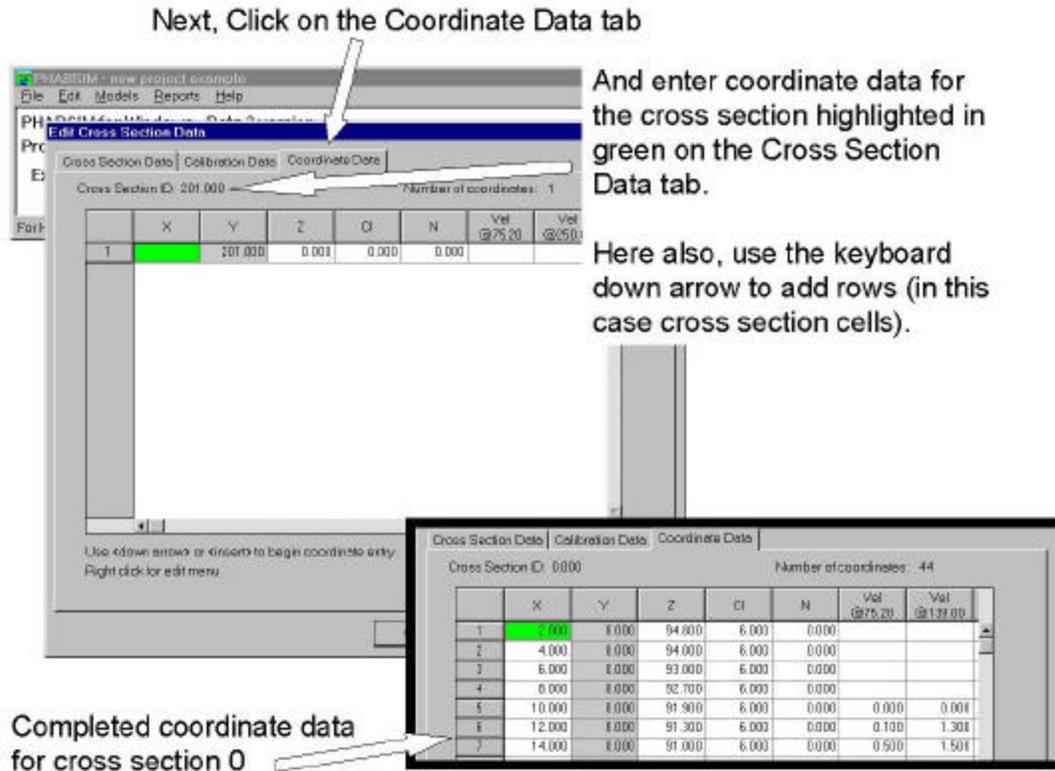


Figure L2-7. Coordinate data entry.

These steps would normally be repeated for all transects in the study. At that point, you have entered the basic hydraulic data for the study site. In this lab, we will also learn how to input coordinate data from a spreadsheet using Windows copy and paste functions for the third and fourth cross sections in this project.

#### Entering Coordinate Data by Copy and Paste from a Spreadsheet

PHABSIM for Windows allows entry of certain parts of the project data using Windows copy and paste operations. The third party data entry software has some quirks that must be accommodated to enable the copy and paste features. The next steps demonstrate how to paste coordinate data from a spreadsheet into PHABSIM for Windows.

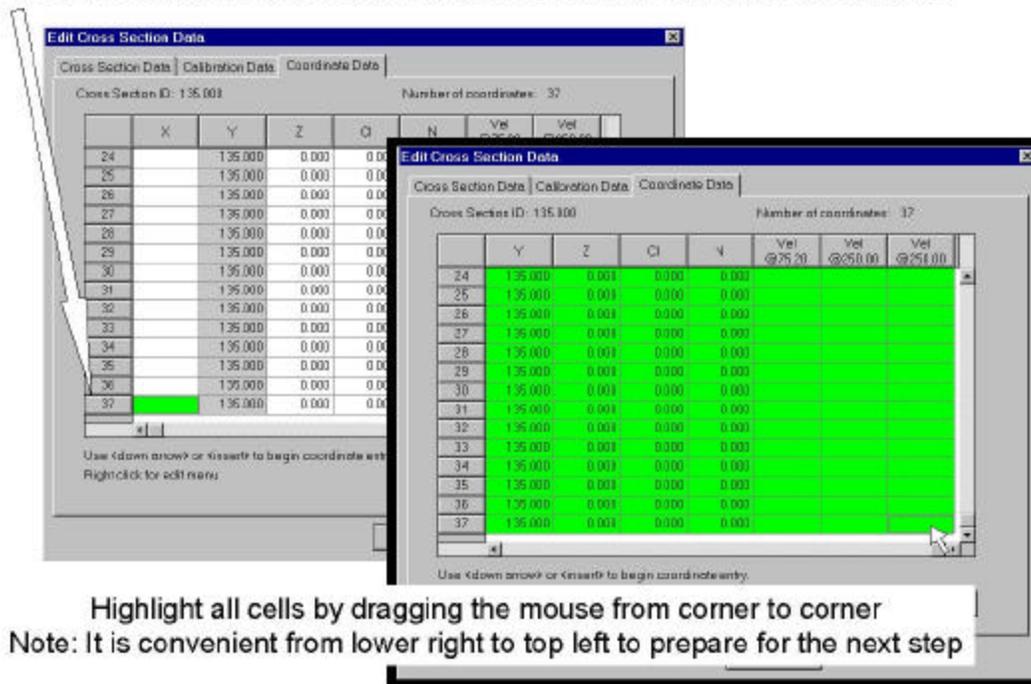
Move to the **Calibration Data** tab for cross section 135. Enter (type) the calibration data contained in Table L2-1. Now move to the **Coordinate Data** tab for cross section 135.

Start your spreadsheet software and open the spreadsheet named Mylab02.xls. Move to the worksheet labeled XSEC135. There you will find a block of cells containing the X, Y, Z, channel index, Manning's n, and calibration velocity data for this cross section. Using the row index at the left, determine the number of rows of data in the transect. Highlight this block of cells and execute the Windows Copy command to copy those values into the Windows clipboard.

Return to PHABSIM for Windows using a mouse click in that window.

Using the **Insert** or **Down Arrow** key, insert the number of rows of data (not row numbers) found in the **Coordinate Data** tab worksheet. (If you insert too many rows, right click and select **Remove Row** as many times as needed. Then, using the left mouse button, **Drag** the cursor from the lower left (last X, last vel) corner of the worksheet to the upper left, being sure to include the calibration velocity set columns. That entire area should now be highlighted. Next, **Right Click** and select **Fill** from the pop-up menu. The entire area will be filled with 0.00. Finally, move to the upper left corner of the coordinate data entry area again. **Right Click**, and select **Paste** from the pop-up menu. The highlighted coordinate data area will be filled with the data from the spreadsheet. This process is shown in Figures L2-8 through L2-10.

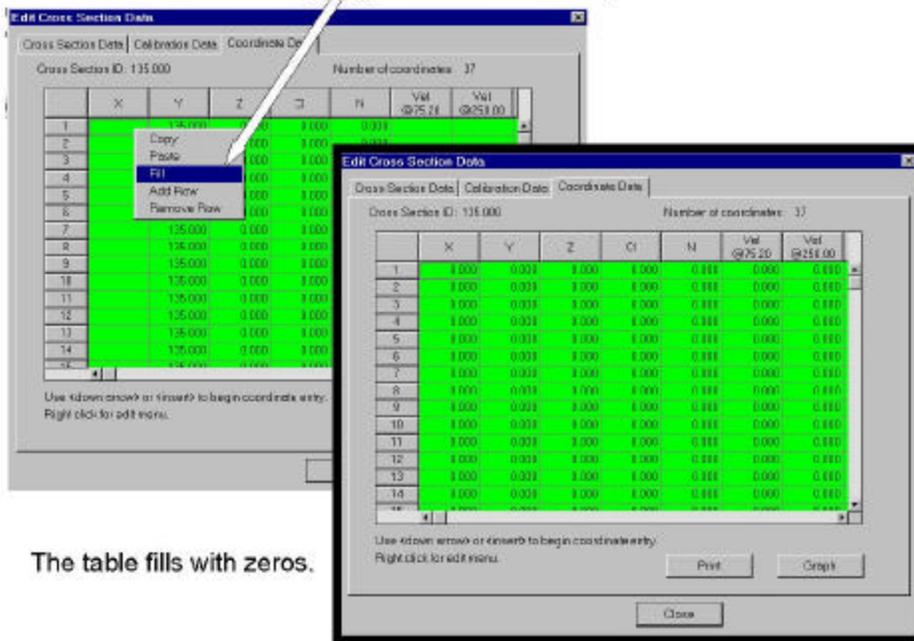
Press the down arrow key until sufficient coordinate data rows are inserted



**Figure L2-8.** Opening and blocking coordinate data tab rows.

Due to the nature of the data entry grid software, calibration velocity cells that were blank in the spreadsheet now have zeros. Delete those zeros using the **Delete** key so the data set follows the convention that a blank velocity means the cell was dry and a velocity of 0.0 means the cell had standing water. Compare the PHABSIM for Windows data entry sheet with Mylab02.xls to ensure all of the required velocity cells are changed to blank. Column Y may change during this cut and paste operation, but it will revert to the calculated value the next time you open this tab.

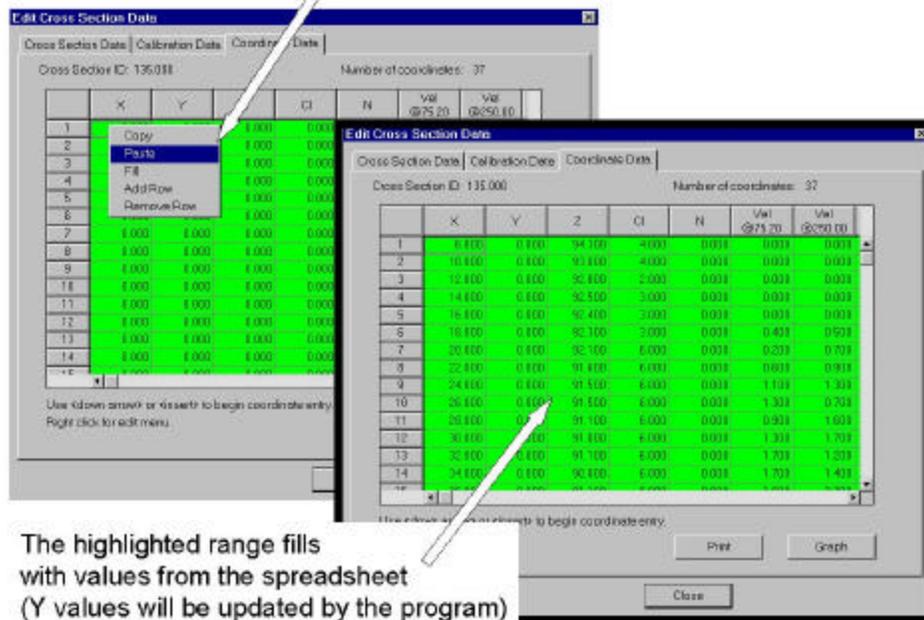
Fill all cells with zeros using: Right Click and selecting Fill



The table fills with zeros.

Figure L2-9. Filling the coordinate data table with zeros.

Block and copy the coordinate data from your spreadsheet, Move to cell X1, Right Click and select Paste



The highlighted range fills with values from the spreadsheet (Y values will be updated by the program)

Figure L2-10. Pasting coordinate data from a spreadsheet.

Repeat these operations (Calibration and Coordinate Data) for cross section 201.

### Step 3. Enter Suitability Data for Lab02

Click **\Edit\Suitability Curves** and you are presented with a dialog box where habitat suitability of use curve (HSC) data can be entered for all species of interest for the study. Begin by using **..\Suitability Curves\Edit\Add Curve** and entering the curve ID number and the species and life stage descriptions from the HSC sheet in the Mylab02 spreadsheet in the boxes provided. Note that curve ID numbers should be five or more digits to capture species and life stage coding. Then click **OK**. A table for entry of the Velocity curve information is displayed by default.

The same **Insert** key convention to create a new line used with coordinate data entry applies. You may also copy and paste HSC curves into PHABSIM for Windows using the conventions described for coordinate data above. You must type the species, life stage, and HSC number, but the coordinate data can be entered using copy/paste operations.

Enter the HSC data for velocity by copy and paste or by typing.

To switch to the Depth, Channel Index, or Temperature HSC curves, click the appropriate button in the Curve Type box at the upper right and enter the HSC data by paste or typing as above.

Repeat this process beginning with **..\Add Curve** for all HSC curve sets in the HSC sheet.

Enter Simulation Discharges for Lab01

This step may be performed now or after the hydraulic models have been calibrated. To avoid excessive output during the calibration process, the user would typically select to run the full range of simulation discharges toward the end of the hydraulic model calibration process. Those selections will be made in the WSL and Velsim windows in later lab exercises. We will enter a small number of additional discharges here to illustrate the process.

Select **\Edit\Discharges** to display the Simulation Discharges window. The user-defined calibration best estimated discharges (75.2, 139.0, and 250.0 cfs) are shaded in gray. They are automatically entered in the Discharge column. Note that they are marked “cal” in the Type column. Click on the first of these discharges and press the **Insert** key. A new cell with a value of 0.00 will appear. Enter a value of 15.0. Repeat this process with Insert (before the calibration discharges) or the Down arrow (after one or more calibration discharges) to enter the values of 60.0, 625.0, and 1250.0. Click the Close button to end discharge data entry.

You have now finished the basic data entry process. Save your project using **\File\Save Project**.

One more key data entry step remains, that of entering Suitability-of-use criteria (SI curves). This topic will be covered in Laboratory 7.

### Step 4. Evaluate Diagnostic Plots

The quality of any modeling exercise begins with correct data entry. PHABSIM for Windows contains several means of viewing plots of the entered data for quality control. A longitudinal plot of the observed water surface elevations can be obtained using **\Reports\Graphs\Longitudinal Profile** and checking the Observed WSL box. Selecting **\Edit\Cross Sections\Coordinate Data** and clicking the graph button can view cross section geometry plots. The cross section profile is displayed for the cross section currently selected in **\Edit\Cross**

**Sections\Cross Section Data.** To view different cross sections, return to the ..\Cross Section Data tab and select the desired cross section, then return to the ..\Coordinate Data tab. Combined plots of velocities, water surface elevations and bed geometry can be obtained using \Reports\Graphs\Bed Profile with WSL\Velocities and checking the Observed WSL and Observed Velocity boxes. You may wish to toggle on or off various calibration discharges for clarity.

### Step 5. Quality Assurance

As noted earlier, a longitudinal plot of the observed water surface elevations can be obtained using \Reports\Graphs\Longitudinal Profile and checking the Observed WSL box. Cross section geometry plots can be obtained by selecting \Reports\Graphs\Bed Profile with WSL\Velocities and checking the Observed WSL and Observed Velocity boxes.

First, look at the longitudinal profile using \Reports\Graphs\Longitudinal Profile, and then the cross section profiles for each transect using \Reports\Graphs\Bed Profile with WSL\Velocities. In the cross section profile plots, select the cross section and discharge to be viewed in the tables to the left of the plot and click **Refresh**. Examining the longitudinal profile of the water surface elevations and thalweg depths in conjunction with the cross section profiles for these data should indicate cross section 0.0 is a riffle (or channel control) and that cross section 201 is in a pool. This is shown by the increased depths at cross section 201 (see longitudinal profile) as well as the more parabolic shape of the cross section profile at station 201.

**Note** in Table L2-1, the velocity values at verticals from 1.0 to 4.0 and vertical 44 have been left blank, since these verticals were out of the water at each of the calibration discharges.

In general it is a good idea to examine the longitudinal and cross section plots and note any areas that appear unusual. Are there any characteristics of this data set that merit further attention? **Hint:** look at the three velocity profiles for cross section 201. Look carefully at the shape of the velocity profiles and at the stream margins. Do you see anything that does not make sense? Are the longitudinal water surface profiles (look at longitudinal plot) consistent? If there are any questions, you can refer to the original field notes, consult with the crew members or look for other means (assistance of a hydraulic engineer or hydrologist, for example) to resolve inconsistencies.

**Table L2-1.** Data for cross section 0.0.

Cross Section	0						
SZF	90.6						
Upstream Weight	Left Wt	0.5	Right Wt	0.5			
Reach Length	Left Dist	0.0	Right Dist	0.0			
Slope	0.004						
Manning's n	0.03						
Beta	0.2						
Calibration Data							
	Left WSL	Right WSL	WSL	BestEstQ	Xsec Q		
	0.0	0.0	91.9	75.2	55.2		
	0.0	0.0	92.18	139	124		
	0.0	0.0	92.67	250	240		
X	Y	Z	Ci	N	VelSet 1	VelSet 2	VelSet 3
2	0	94.8	6	0			
4	0	94	6	0			
6	0	93	6	0			
8	0	92.7	6	0			
10	0	91.9	6	0	0.00	0.00	0.90
12	0	91.3	6	0	0.10	1.30	1.50
14	0	91	6	0	0.50	1.50	2.40
16	0	91.1	6	0	0.50	1.70	1.80
18	0	91	6	0	0.2	1.40	2.00
20	0	91.1	6	0	0.00	0.30	1.00
22	0	91.3	5	0	0.00	0.30	0.80
24	0	91.7	5	0	0.00	0.30	0.50
26	0	92	6	0	0.00	0.50	1.30
28	0	91.8	6	0	0.00	0.90	0.60
30	0	91.8	6	0	0.00	1.30	1.80
32	0	92.1	6	0	0.00	1.00	1.20
34	0	91.8	6	0	0.50	1.80	2.30
36	0	91.5	6	0	0.60	1.60	2.20
38	0	91.5	6	0	0.60	1.60	2.60
40	0	91.5	6	0	0.90	1.30	2.00
42	0	91.5	6	0	0.60	1.40	2.40
44	0	91.5	6	0	1.10	1.10	2.00
46	0	91.3	6	0	0.60	1.40	2.80
48	0	91.4	6	0	0.60	1.80	2.40
50	0	91.2	6	0	1.00	2.30	2.60
52	0	91.3	6	0	1.20	2.50	2.90
54	0	91.4	6	0	1.60	2.40	3.20
56	0	91.4	6	0	1.50	2.60	2.80

**Table L2-1.** Concluded.

X VelSet 3	Y	Z	Ci	N	VelSet 1	VelSet 2	
58	0	91.2	6	0	1.70	2.60	3.10
60	0	91.2	6	0	1.90	1.80	3.40
62	0	91.1	6	0	1.90	2.60	3.20
64	0	91	6.3	0	1.60	2.30	3.10
66	0	91	6.3	0	1.70	2.40	2.90
68	0	91	6	0	1.50	2.90	3.20
70	0	90.8	6	0	2.00	2.20	3.00
72	0	90.7	6	0	1.50	2.50	3.00
74	0	90.8	6	0	1.90	2.50	3.10
76	0	90.6	6	0	2.00	2.60	3.00
78	0	90.8	6	0	1.70	2.30	2.80
80	0	90.9	6	0	1.50	2.00	2.00
82	0	90.9	6	0	1.50	1.70	0.60
83.5	0	92.64	6	0	1.00	1.70	1.10
86	0	92.8	6	0	0.00	0.80	0.00
88	0	94.8	6	0			

**Table L2-2.** Data for cross section 60.0.

Cross Section	0					
SZF	90.6					
Upstream Weight	Left Wt	0.5	Right Wt	0.5		
Reach Length	Left Dist	0.0	Right Dist	0.0		
Slope	0.004					
Manning's n	0.03					
Beta	0.2					
Calibration Data						
	Left WSL	Right WSL	WSL	BestEstQ	Xsec Q	
	0.0	0.0	91.9	75.2	55.2	
	0.0	0.0	92.18	139	124	
	0.0	0.0	92.67	250	240	
X	Y	Z	Ci	N	VelSet 1	VelSet 2
VelSet 3						
6	60	94.6	4	0		
12.3	60	92.9	4	0		
14	60	92.5	4	0		0.00
16	60	92.1	4	0	0.40	0.00
18	60	91.8	4	0	0.80	0.60
20	60	91.5	4	0	0.40	0.80
22	60	91.5	4	0	0.30	0.70
24	60	91.5	6	0	0.10	0.70
26	60	91.8	6	0	0.90	0.70
28	60	92	6	0	0.00	1.50
30	60	92.2	6	0	0.30	1.00
32	60	92.1	6	0	0.00	0.90
34	60	92	6	0	0.70	0.50
36	60	91.9	6	0	0.60	1.80
38	60	91.6	6	0	0.80	1.80
40	60	91.6	6	0	0.60	1.30
42	60	91.6	6	0	0.80	1.20
44	60	91.4	6	0	0.50	1.60
46	60	91.4	6	0	1.20	1.80
48	60	91.5	6	0	0.70	1.70
50	60	91.6	6	0	1.30	1.70
52	60	91.4	6	0	1.80	1.70
54	60	91.4	6	0	1.60	2.20
56	60	91.3	7	0	0.70	2.40
58	60	91.1	6	0	1.90	2.00
60	60	91	6	0	1.60	2.10
62	60	90.7	6	0	1.40	1.70
64	60	90.8	6	0	1.90	2.40

**Table L-2.** Concluded.

---

X VelSet 3	Y	Z	Ci	N	VelSet 1	VelSet 2	
66	60	90.6	6	0	1.90	2.30	3.20
68	60	90.7	6	0	1.90	2.50	3.10
70	60	90.9	6	0	1.70	2.40	3.10
72	60	90.8	6	0	1.70	2.30	3.00
74	60	90.9	6	0	1.80	2.40	3.10
76	60	91.1	6	0	1.80	2.50	2.60
78	60	91.3	6	0	1.50	1.80	3.00
80	60	91	6	0	0.00	2.00	3.10
82	60	91.2	6	0	0.00	1.90	2.60
84	60	91.2	7	0	0.00	0.30	0.00
86	60	91.1	7	0	1.50	0.00	0.00
88	60	93	7	0	1.00	0.15	2.00
90	60	94.4	6	0			0.60

---

**Table L2-3.** Data for cross section 135.0.

Cross Section	135					
SZF	90.6					
Upstream Weight	Left Wt	0.5	Right Wt	0.5		
Reach Length	Left Dist	75	Right Dist	75		
Slope	0.023					
Manning's n	0.03					
Beta	0.2					
Calibration Data						
	Left WSL	Right WSL	WSL	BestEstQ	Xsec Q	
	0.0	0.0	92.25	75.2	86.7	
	0.0	0.0	92.59	139	137	
	0.0	0.0	92.97	250	252	
<hr/>						
X	Y	Z	Ci	N	VelSet 1	VelSet 2
VelSet 3						
<hr/>						
6	135	94.3	4	0		
10	135	93	4	0		
12	135	92.8	2	0		0.00
14	135	92.5	3	0		0.00
16	135	92.4	3	0	0.40	0.00
18	135	92.3	3	0	0.80	0.50
20	135	92.1	6	0	0.40	0.70
22	135	91.6	6	0	0.20	0.90
24	135	91.5	6	0	0.60	1.30
26	135	91.5	6	0	1.10	0.70
28	135	91.1	6	0	1.30	1.60
30	135	91	6	0	0.90	1.70
32	135	91.1	6	0	1.30	1.20
34	135	90.8	6	0	1.70	1.40
36	135	91.1	6	0	1.70	2.30
38	135	90.8	6	0	1.60	1.30
40	135	90.6	6	0	2.10	2.30
42	135	90.5	6	0	1.80	3.00
44	135	90.7	6	0	1.50	1.80
46	135	90.7	6	0	1.90	2.20
48	135	90.8	6	0	1.60	2.70
50	135	90.7	6	0	2.00	2.30
52	135	90.9	6	0	1.60	2.00
54	135	91	6	0	1.90	2.30
56	135	90.9	6	0	1.60	2.00
58	135	91.2	6	0	1.60	1.40

**Table L-3.** Concluded.

---

X VelSet 3	Y	Z	Ci	N	VelSet 1	VelSet 2	
60	135	91.3	6	0	1.60	2.00	2.70
62	135	91.3	6	0	1.30	1.70	2.20
64	135	91.4	6	0	1.30	1.50	2.20
66	135	91.6	6	0	1.00	1.40	2.40
68	135	91.6	6	0	1.10	0.80	2.00
70	135	91.6	6	0	0.30	0.80	2.10
72	135	91.6	6	0	0.00	0.60	0.90
74	135	92.3	6	0	1.80	0.30	0.00
75	135	93	6	0	1.80	1.80	3.00
78	135	93.9	6	0	1.50	2.00	3.10
80	135	95.2	6	0	0.00	1.90	2.60

---

**Table L2-4.** Data for cross section 201.0.

Cross Section	201					
SZF	90.6					
Upstream Weight	Left Wt	0.5		Right Wt	0.5	
Reach Length	Left Dist	66		Right Dist	66	
Slope	0.023					
Manning's n	0.03					
Beta	0.2					
Calibration Data						
	Left WSL	Right WSL	WSL	BestEstQ	Xsec Q	
	0.0	0.0	92.36	75.2	80.4	
	0.0	0.0	92.74	139	99	
	0.0	0.0	93.1	250	249	
X	Y	Z	Ci	N	VelSet 1	VelSet 2
VelSet 3						
4	201	93.9	6	0		
6	201	93.1	6	0		0.00
8	201	92.8	6	0		0.00
10	201	92	6	0	0.00	0.00
12	201	91.6	6	0	0.30	0.00
14	201	91.5	6	0	0.40	0.30
16	201	91.2	6	0	0.50	0.40
18	201	91.2	6	0	0.50	0.50
20	201	91	6	0	0.60	0.60
22	201	90.8	6	0	0.70	0.80
24	201	90.5	6	0	0.80	0.90
26	201	90.3	6	0	0.90	1.50
28	201	90.2	6	0	1.10	1.50
30	201	90.1	6	0	1.20	1.90
32	201	89.9	6	0	1.50	2.30
34	201	89.8	6	0	1.60	2.40
36	201	89.9	6	0	1.90	1.80
38	201	89.9	6	0	1.90	1.60
40	201	90.3	6	0	1.50	1.00
42	201	90.4	6	0	1.30	0.90
44	201	90.7	6	0	1.80	0.70
46	201	91.3	6	0	1.40	0.70
48	201	91.6	6	0	1.10	0.40
50	201	91.9	6	0	0.60	0.20
52	201	92.3	6	0	0.40	0.00
54	201	92.7	6	0	1.60	0.00
56	201	92.7	6	0	1.60	0.00

**Table L2-4.** Concluded.

---

X VelSet 3	Y	Z	Ci	N	VelSet 1	VelSet 2	
58	201	93	6	0	1.30	1.70	0.00
60	201	93.1	6	0	1.30	1.50	0.00
61	201	93.1	6	0	1.00	1.40	0.00
66	201	94.1	7	0	1.10	0.80	2.00
68	201	96	7	0	0.30	0.80	2.10

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## Laboratory 3. Water Surface Modeling Using A Stage-Discharge Approach

### Objective

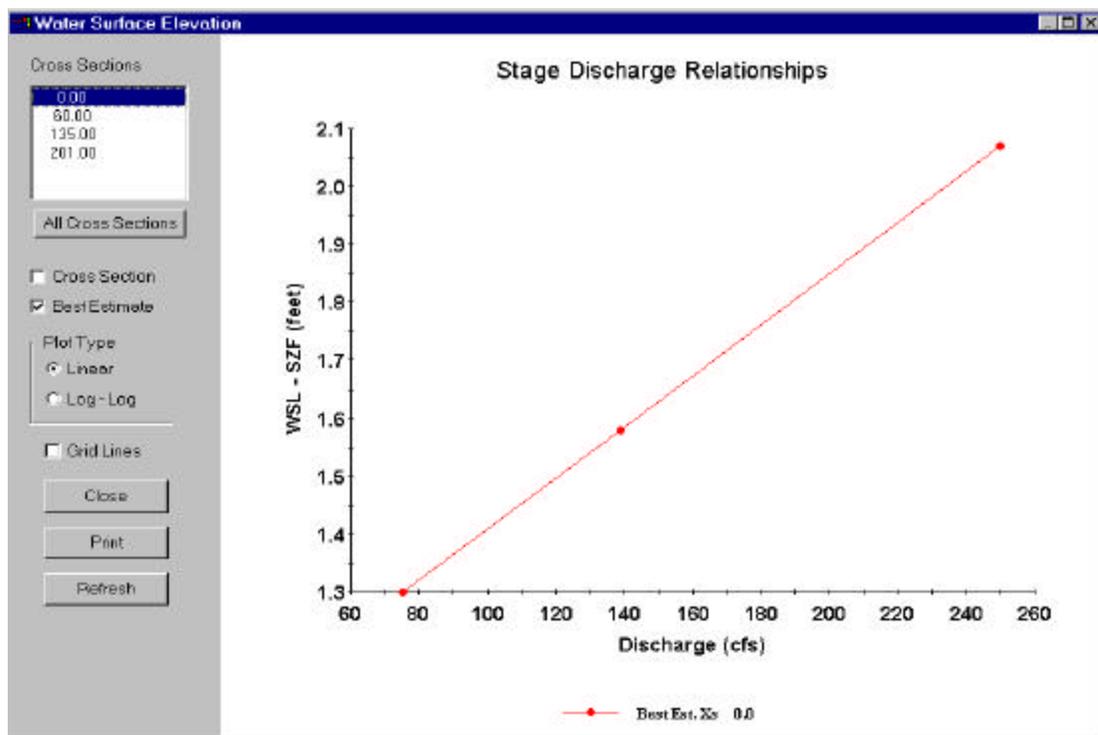
The objective of this laboratory is to demonstrate modeling water surface elevations based on a stage-discharge regression approach. The reader will be introduced to the use of the STGQ program within PHABSIM for this purpose. The general theory of stage-discharge modeling using a regression approach is covered in the manual in Chapter 3.

**Program Used:** STGQ

**Project File Used:** C:\My Documents\Phabsim\Laboratories\Lab3.phb

### Introduction

The purpose of this laboratory is to introduce stage-discharge regression modeling in PHABSIM using the STGQ model. Recall from the lecture material that under most circumstances an investigator will obtain measured water surface elevations at a specific cross section at three or more flows, which is illustrated in Figure L3-1 for cross section 0.0 for the Fryngpan River (see Laboratory 1 or access \Models\WSL\STGQ Options\Stage Discharge Graph in the Lab3 project).



**Figure L3-1.** A stage-discharge relationship.

As discussed in Chapter 3, the relationship between stage (i.e. water surface elevation) and discharge can often be represented at a cross section in a channel by the following equation:

$$(L3-1) \quad (WSL - SZF) = a Q^b$$

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 = coefficient derived from measured values of discharge and stage

Note that the SZF is included in Equation L3-1 since the stage-discharge relationship at a channel cross section is a function of the SZF at that specific location as discussed in Chapter 3. The SZF is used within the STGQ program and should be included whenever using alternative stage-discharge regressions. Equation L3-1 can be transformed to a linear relationship between stage and discharge by taking the  $\log_{10}$  of the equation, which yields:

$$\log_{10} (WSL - SZF) = \log_{10}(a) + b * \log_{10} (Q) \quad (L3-2)$$

Given at least three sets of measured stage-discharge data at a cross section, a simple linear regression can then be performed using Equation L3-2 to determine the constant and coefficient and the resulting regression equation can be used to predict stage over a desired range of discharges. The effectiveness of this modeling approach for the simulation of water surface elevations is not only a function of the observed data, but also the channel geometry and relative difference in the slopes of the regression lines between adjacent cross sections (see Chapter 3 of the manual).

In regression-based modeling, the primary modeling choices involve the selection of the appropriate calibration discharges (i.e., best estimate of discharge versus cross section specific [or “local”] discharges), determination of an appropriate SZF, and selection of the calibration water surface elevations. In this laboratory, the best estimate of the discharge and average water surface elevations will be used in the regressions. The SZF has also been determined based on the thalweg bed elevations at each cross section following the procedure outlined in Chapter 3 of the Manual.

Figure L3-2 contains the log of the water surface elevations (minus SZF) versus the log of the discharges (best estimate) for all four of the cross sections for the Fryngpan River. This figure is provided to assist in an understanding of the laboratory data and in the interpretation of the laboratory results.

Now proceed through the laboratory steps in the given order.

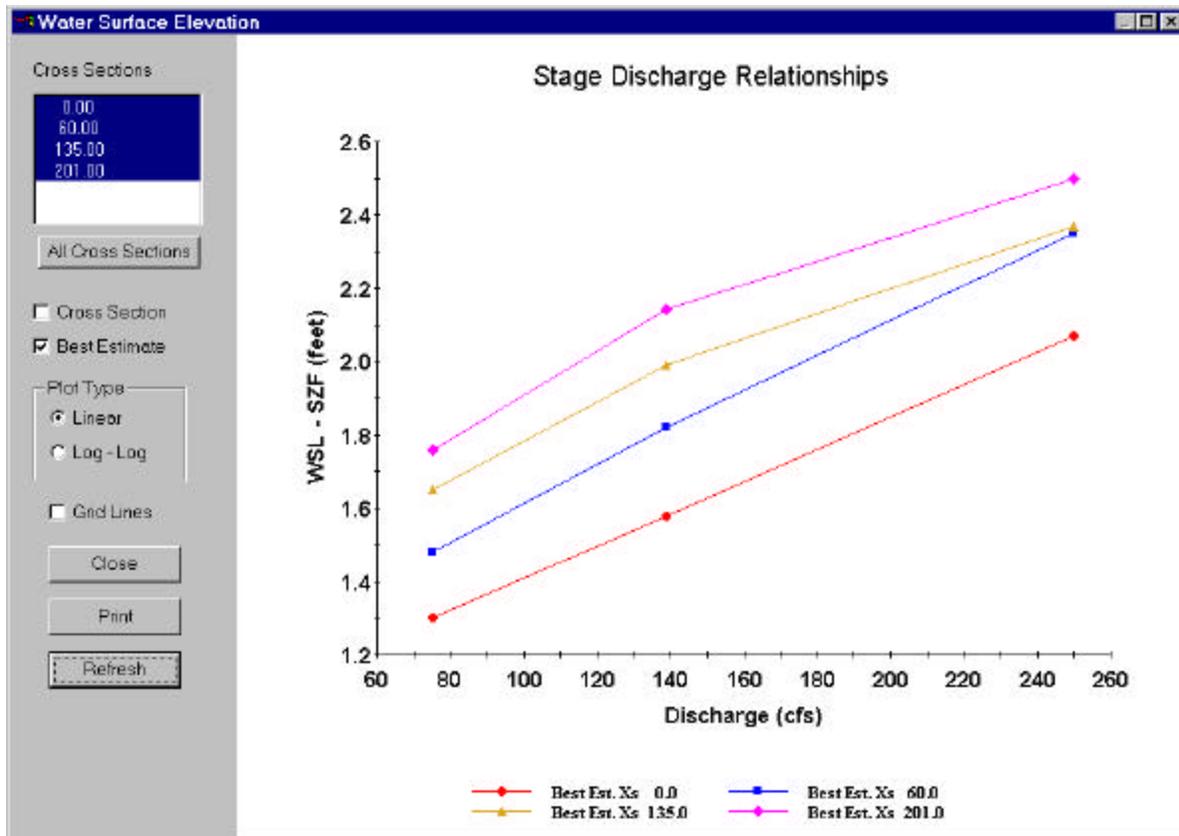


Figure L3-2. Stage-discharge relationship for four cross sections.

### Step 1. Selection and Setup of STGQ Water Surface Simulation Model

The complete project data set for the Fryingpan River is supplied with the PHABSIM distribution disks and is named SAMPLE1.phb.

Begin by starting PHABSIM and opening the SAMPLE1 project. Select **Models\WSL**. The **Water Surface Elevation Simulation** window opens and the **Output Options** tab is displayed by default. In this window the user can select which of the discharges supplied earlier are to be used at the current stage of the simulation process. For example, while calibrating the hydraulic models, it is suggested to use only the calibration discharges. Thus, the check boxes in the **Use** column should be toggled so only the “cal” discharges are checked. When doing a final production run, all discharges would be checked. In this lab, we are running a small number of discharges, so leave this set at **Use All**.

In this window, you may also choose to overwrite the ZOUT (results output) files. If you chose not to overwrite ZOUT, successive runs of the models in PHABSIM append their results to ZOUT. This can result in a very large file, but may be necessary when working on a particularly difficult simulation. You may select **Overwrite ZOUT File** for this lab by clicking on the box or the **Overwrite ZOUT File** text so a check mark appears.

Next, click on the **STGQ Options** tab. Examine the options (see Chapter 3) and make sure that you understand which options are being used. In particular, note the Discharge (IOC Option 5) has been set to “Best Est Q” for all

calibration sets for all transects. This instructs STGQ to use the first “best-estimate” discharge in the stage-discharge regressions. Setting the items in the Discharge column to **Xsec Q** will use the discharge measured at that cross section in the stage-discharge regression. This is not necessarily equivalent to the best estimated discharge for the reach at that calibration flow, but may provide a better fit to the observed water surface elevation for individual cross sections under some conditions.

Also note that the project has seven simulation flows ranging from 15.0 to 1250.0 cfs, which represent a range of discharges both lower and higher than the three calibration, flows of 75.2, 139.0, and 250.0 (see Laboratory 1). The higher and lower discharges allow an evaluation of model performance over a simulated range of discharges that is needed for the final habitat-discharge relation.

## Step 2. Obtain the Calibration Water Surface Elevation and Discharge Data

Select **Edit\Cross Sections\Calibration Data** to find the calibration data sets for the first cross section (i.e., cross section 0.0) and note the three calibration flows and their observed water surface elevations.

The three calibration flows (best estimate of discharge as well as the actual measured discharge at this cross section for each calibration set) and the corresponding water surface elevations from the CAL lines are:

Cross section 0.0	Best Est. Q	Meas. Q.	Water Surface Elevation
CAL1	75.2	55.2	91.90
CAL2	139.0	124.0	92.18
CAL3	250.0	240.0	92.67

Find and record the water surface elevations, discharges, and SZF for all cross sections in Table L3-1 by first clicking on the **Cross Section Data** tab, and on the next desired cross section, then the **Calibration Data** tab. Once you have recorded the data in Table L3-1, choose cancel and return to the **Models\WSL\STGQ Options** tab.

**Table L3-1.** Calibration information for the Fryingpan River.

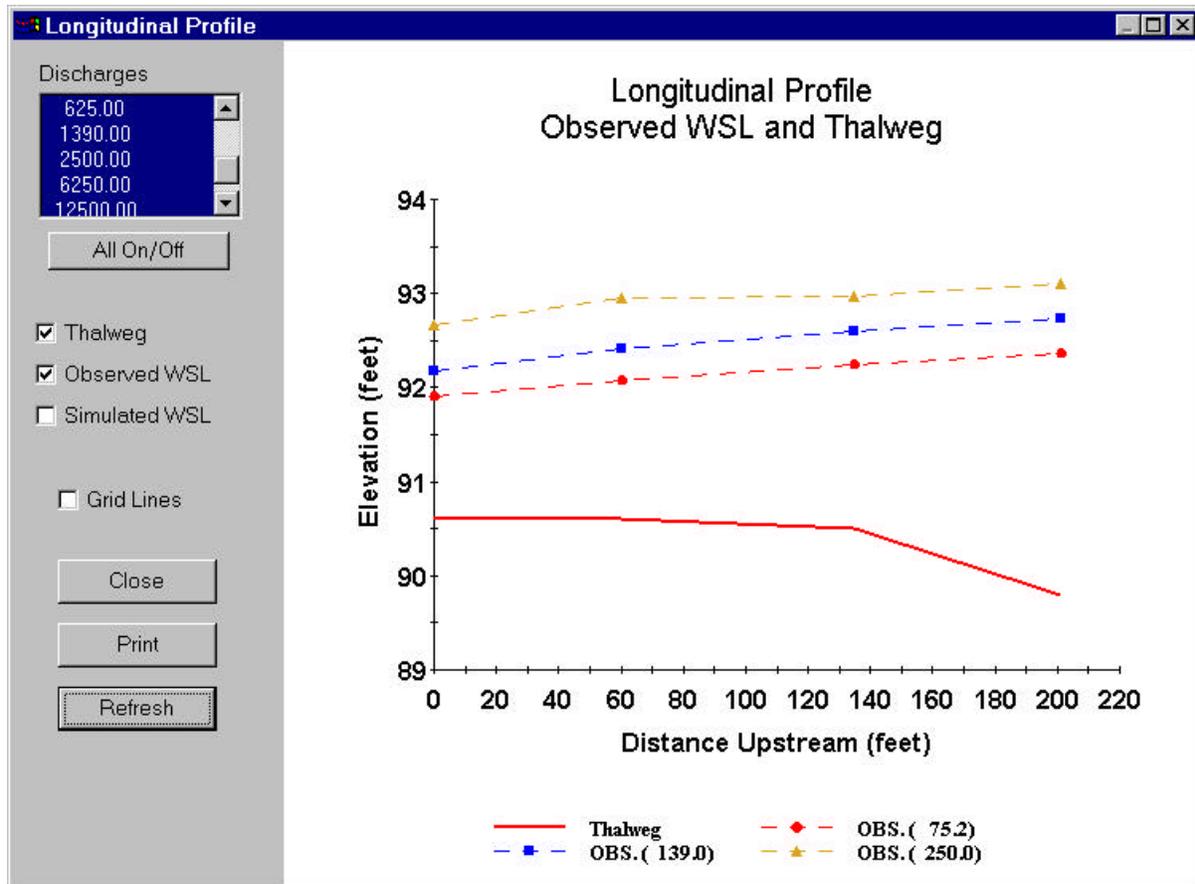
Cross section	Best estimated Q	Measured Q	Water surface elevation
0.0 (SZF = 90.6)	75.2	55.2	91.90
	139.0	124.0	92.18
	250.0	240.0	92.67
60.0 (SZF = _____)	75.2		
	139.0		
	250.0		
135.0 (SZF = _____)	75.2		
	139.0		
	250.0		
201.0 (SZF = _____)	75.2		
	139.0		
	250.0		

In this example, the best estimate of the discharge was determined from an examination of the measured

discharges at each cross section. In some applications, the best estimate of the discharge could have been derived from a gage within the reach or from the average of a selected number of the measured transects where conditions for obtaining good flow estimates was possible.

### Step 3. Examination of the Stage-Discharge Relationships

The summary data in Table L3-1 was used to create a plot of the observed longitudinal water surface elevations versus discharge for the calibration data and a plot of the log of the discharge versus the log of the (WSL-SZF) (see Figures L3-1 and L3-2).



**Figure L3-3.** Observed water surface profiles.

First, it should be apparent from the plot of the longitudinal profile of the calibration data (Figure L3-3) that at the high calibration flow, a flattening of the water surface elevation is apparent at the middle two cross sections. This may be indicative of a backwater effect at this discharge. Although backwater effects can be pronounced more often at low flows due to riffle type habitats, channel constrictions can produce this effect at higher discharges. We do not know (since we did not collect this data) what is actually occurring.

Examining the plot of the log-log relationship between WSL-SZF and discharge shows that the observed data for

cross sections 60 and 135 have almost identical WSL values at the high calibration discharge (see Figure L3-2). This should indicate that using a regression approach (i.e., stage-discharge with STGQ) may be problematic at high simulated discharges since the regression lines will likely >cross over= each other. This will be explored in more detail in this laboratory.

#### Step 4. Running the Stage-Discharge Regression

Running the STGQ model to perform stage-discharge regression modeling is basically an automated process once the appropriate data have been entered and model options have been selected.

Select **Models\WSL\STGQ Options** and ensure that the **SZF** box is checked for each cal set for each transect (the default). In rare instances removing the check mark can be used to set the SZF used in the calculations to zero. You will not encounter such a situation in this class. Click the **Write Computational Details** check box so the program produces a file called ZOUT containing the computational results. Once you have experience with PHABSIM, this file can be omitted during the calibration process. It is often a good idea to turn on this option when doing production runs in case an “at the time” record is needed for documenting or defending the study.

Next click the **Assign Cal Sets** button. Select each transect using the dialog box in the upper left and ensure that there is a check for each cal set for each applicable discharge. Selecting **All On** means that the WSL for all discharges will be simulated using all cal sets in the regression model. Under various circumstances of data quality or channel configuration it may be desirable to use only a portion of the available cal sets for a given discharge at a particular cross section. Note: you may have more than three Cal sets, but only certain ones may apply to specific cross sections. That selection is made in the **Assign Cal Sets** table.

In PHABSIM for Windows it is possible to use different water surface elevation models for different transects at different discharges. Therefore, you must specify which model is being used for each transect/discharge combination. Clicking the Method tab and selecting a method from the list on the right and clicking the appropriate position in the cross section discharge table accomplish this. For this laboratory exercise, click **STGQ** and then click **Set All**. This tells PHABSIM for Windows that the STGQ model will be applied to all combinations.

Now you are ready to run the STGQ program. Simply click the **Run** button at the bottom right. When the model has finished running a “WSL Simulation Completed” message will be displayed. To view the results, click **OK** and then click the **Results** tab.

In the **Results** tab window you will see a table of water surface elevations for each transect – discharge combination. Plots of the water surface elevation results can be viewed by clicking either the **Cross Section** or **Longitudinal** buttons at the bottom.

#### Step 5. Evaluation of the Stage-Discharge Model Results

At this point, we are interested in determining how well the regression approach is working as a model for use in simulations of water surface elevations. Figure L3-4 contains simulated water surface profiles derived from the stage-discharge relations for the four cross sections.

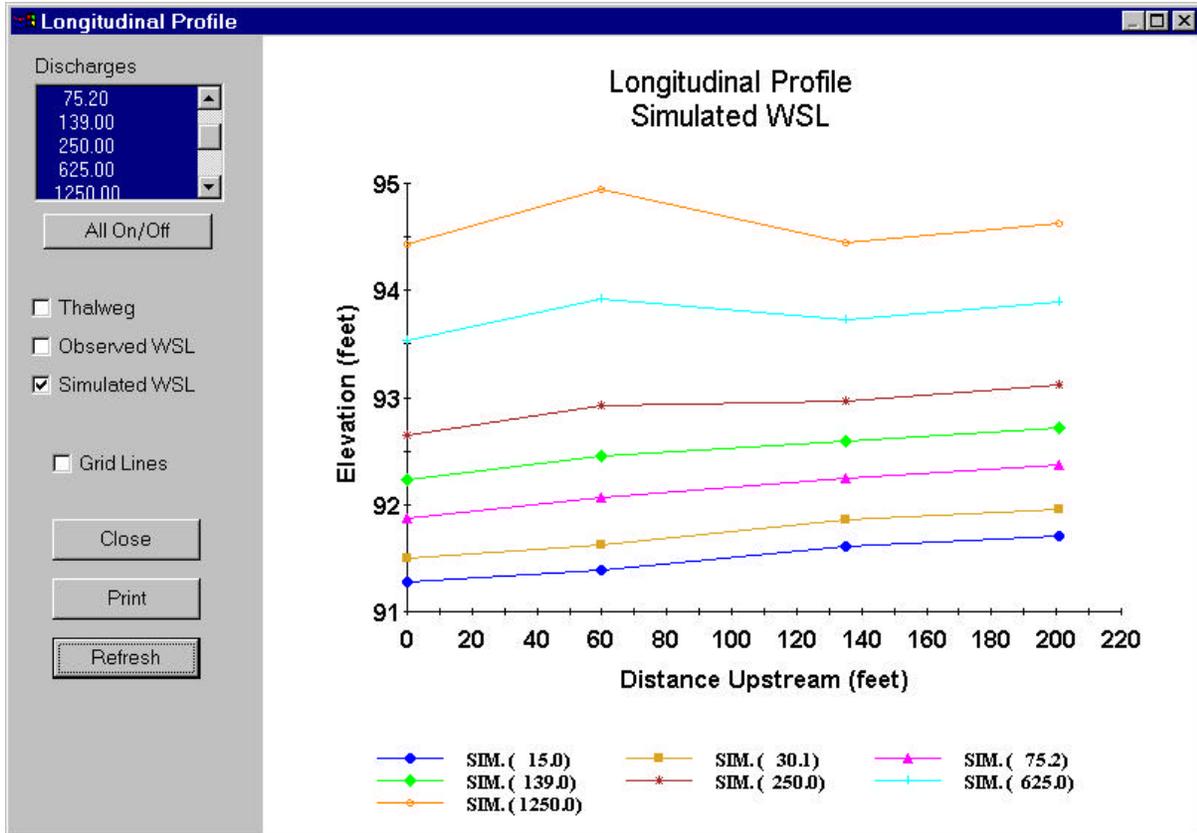


Figure L3-4. Water surface profiles simulated with STGQ.

Click the **Longitudinal** button to view a plot of the water surface profiles for each discharge as simulated by STGQ. Remove checks from the Thalweg and Observed WSL boxes to arrive at Figure L3-4. The top line in this graph (i.e., labeled SIM.(1250.0)) represents the predicted water surface elevation at a discharge of 1,250 cfs. The predicted water surface elevations at each cross section are derived from each cross section's regression equation based on the three sets of calibration data. At this discharge, water appears to be flowing downhill from right to left in this figure. Note that at 1,250 and 625 cfs, water is >flowing uphill= from cross section 135 to 60. These results are irrational from a physical standpoint and indicate that the regression models are not appropriate at higher discharges for this data set. In reviewing the simulation results for **1250.0** cfs, it should be apparent that the >water flowing uphill= between cross section 135 and 60 is >worse= than that observed at 625 cfs. This suggests that the further you extrapolate above the highest observed discharge (250 cfs) the more error in estimated water surface elevation you will have.

At this point, we only know that somewhere between 250 and 625 cfs, the stage-discharge regression approach >breaks down=. If we wanted to better define where the model no longer works properly, we could add additional QARD flows to our data set, such as 275, 300, 325, etc., up to 625 and rerun the STGQ model. Examination of the output would show the specific flow range at which water begins to >run uphill=.

Based on our examination of the plotted longitudinal profiles and the previous examination of the observed calibration data we can more easily understand how these irrational results can be generated by the regression modeling approach.

The STGQ program performs the regression analysis at each cross section independently. Although the  $r^2$  for the regressions at each cross section are  $> 0.99$ , the difference in slope for each regression equation results in predicted water surface elevations which **cross** at simulated discharges just above the highest calibration flow. This should be expected given the observed relationships between discharge and water surface elevations shown in Figure L3-2, where the observed water surface elevations at cross sections 60.0 and 135.0 are very close and tend to **>converge=** over the range of observed discharges.

The modeling results would indicate that the stage-discharge modeling approach may be valid at simulated discharges up to our highest measured data (i.e., 250 cfs) but that an alternative modeling approach for higher simulated flows will be needed. In Laboratory 4, the MANSQ model will be used, while Laboratory 5 will employ the WSP model to deal with this phenomena.

### Step 6. Explore STGQ Regression Modeling Options

This section of the laboratory is optional and intended to be completed at your convenience.

As indicated previously in the laboratory, the user can select which of the cal set discharges to use in the regression modeling with STGQ. In the previous laboratory steps, the stage-discharge regressions were conducted using the best estimate of the discharge by setting the **Discharge (IOC 5)** column to **>Best Est Q'** for all cross sections and cal sets. This forced STGQ to use the best estimate of the discharge in the regression computations. In this step of the laboratory, we will set these values to **"Xsec Q"** so that the regressions are performed using the calculated discharges at each cross section at each calibration flow.

If you are not in the **\Models\WSL** window, move there now. Click the **STGQ Options** tab and click on the first entry **"Best Est Q"**. Next, click on the small wedge arrow **▼** to the right of the cell and then click **"Xsec Q"**. Repeat this for all cal sets for all transects.

To ensure the PHABSIM for Windows interface recognized the change, go to the **Methods** tab and then click **STGQ** and click any one of the transect – discharge cells to ensure the **Apply** button becomes active. Then click the **Apply** button and view results as before.

What you should find is that the **>error=** values in the regression equations have remained the same or increased and that regression modeling of these data with discharges measured at each cross section instead of a best estimate of discharge does not eliminate the irrational results of simulated water surface elevations at flows higher than our high flow calibration data set. Using the computed discharges for each cross section can, and often will, result in poorer linear relationships using Equation L3-2. This type of variability between cross sections using computed discharges is not atypical when field data has been collected in a variety of fisheries habitats which are poor in terms of obtaining a **>best estimate=** of the discharge for hydraulic modeling.

As a final wrap-up to this laboratory, go to the **STGQ** tab and reset all of the discharges to Best Est Q. Then go to the **Methods** tab, ensure that **STGQ** is marked and click **Select All**. Click **Run**, go to results, and view the longitudinal plot. Zoom on the calibration discharges (hold Shift and drag a box with the mouse and release the mouse button) and print the plot for later reference.

## Laboratory 4. Water Surface Modeling Using the MANSQ Model

### Objective

The objective of this laboratory is to demonstrate the technique of modeling water surface elevations based on using Manning's equation (i.e., the MANSQ model). The general theory for the MANSQ program is covered in the manual within Chapter 2.

**Programs Used:** MANSQ

**Project Files Used:** Lab4.phb

### Introduction

The MANSQ model can be used to simulate the stage-discharge relationship for individual cross sections. The model assumes that flow variations caused by changes in channel configuration are negligible (i.e., minimal backwater effects). The application of the MANSQ model in pools can be problematic since pools are generally created by backwater effects of a downstream hydraulic control. The MANSQ model assumes that each cross section is independent of all other cross sections during calibration and simulations. Therefore, the longitudinal profile of the simulated water surface elevations should always be checked to assess overall model performance.

At a computational level, the MANSQ model uses Manning's equation in the form:

$$Q = \left[ \frac{1.49}{n} * S^{1/2} \right] * A * R^{2/3} \quad (L4-1)$$

which is simplified to:

$$Q = KAR^{2/3} \quad (L4-2)$$

The value of K is determined from a single measured discharge-water surface elevation data set and the measured channel geometry at a cross section. The program then uses additional calibration data sets (i.e. discharges and water surface elevations) to solve one of the following two equations selected by the user:

$$K = K_o \left( \frac{Q}{Q_o} \right)^b \quad (L4-3)$$

$$K = K_o \left( \frac{R}{R_o} \right)^b \quad (L4-4)$$

where: subscript  $\geq 0$  refers to calibration values

**b** is a coefficient supplied by the user for each cross section

Calibration of the model is accomplished by selecting an initial calibration discharge to compute  $K_b$ , and then employing a trial and error procedure for selecting a value of  $b$  that minimizes the error between observed and predicted water surface elevations for the remaining calibration data sets. Typical values of  $b$  range from 0.0 to 0.6 in most channels and as noted in Chapter 2. The steps in this laboratory represent a suggested order for MANSQ analysis.

### Step 1. Obtain an Initial Estimate of $b$

Begin by initially setting that the  $b$  value for each transect in **\Edit\Cross Sections\Cross Section Data** to 0.2. This is an arbitrary default value derived from taking the median value for a large number of study sites. Final  $b$  values will be determined by observing the results of simulating water surface elevations with MANSQ.

In this step, the CALCF4 program will be used to obtain an initial estimate of  $b$ . Run the CALCF4 program by clicking **\Models\CALCF4**. The results will be automatically displayed to the screen. Scroll down the file and locate the conveyance factor (CFAC) regression equation for cross section 0.0. Alternatively, use the Notepad editor to search for “CFAC” in the current ZOUTx file.

The exponent of the CFAC regression equation represents an excellent initial estimate for  $b$  and is -0.003 for cross section 0.0. Continue through the output listing to locate and record the CFAC regression exponents at the three remaining cross sections. Record these values in Table L4-1.

Note that the CFAC regression exponent at cross section 0.0 is negative. Under most circumstances, the use of negative  $b$  values is not expected since this would imply that roughness would be increasing with discharge. In typical applications of MANSQ, a negative  $b$  would be rounded up to 0.0 for use in the model.

**Table L4-1.** CFAC regression exponents for each cross section.

Cross section	CFAC exponent
0.0	-0.003
60.0	
139.0	
201.0	

Once the remaining CFAC exponents have been entered in Table L4-1, exit Notepad if you have been using it to find the CFAC exponents and return to **\Models\WSL\MANSQ** in PHABSIM for Windows.

The MANSQ program requires a calibration flow and water surface elevation at each cross section in addition to the initial estimate of  $b$ . These data are derived from the calibration data sets entered in **\Edit\Cross Sections\Calibration Data** for each cross section. For this laboratory, the high flow calibration data at each cross section will be used as our initial calibration flow for MANSQ.

**Table L4-2.** Calibration discharges and water surface elevations for the Fryingpan River from MANSQ using 250 cfs (Cal Set 3) as the calibration discharge.

Calibration Q	Cross section 0	Cross section 60	Cross section 135	Cross section 201
75.2	91.90	92.08	92.25	92.36
139	92.18	92.42	92.59	92.74
250	92.67	95.95	92.97	93.10

**NOTE:** You may choose either the high, medium or low flow calibration data sets (or any combination for specific cross sections). However, selection of the calibration discharge should be considered of the flow ranges most critical to the study. Remember, MANSQ will  $\text{return} =$  the observed water surface elevation at the calibration flow and the  $\text{error} =$  between predicted and observed water surface elevations at the other calibration discharges will be a function of the field data and selection of appropriate  $b = s$ . We will select  $b = s$  to minimize the error between observed and predicted WSL at each transect.

## Step 2. Running the MANSQ Model and Evaluating Results

Select the **\Models\WSL\MANSQ** tab and note the options available in the MANSQ program and review the options that have been set. For this laboratory exercise, the default options will suffice. However, advanced users may wish to consider the alternative ratios of flow conditions given in equations L4-3 and L4-4, and other MANSQ options.

Next, click on the **Methods** tab and click **MANSQ** followed by **Set All**. This assigns MANSQ as the model to be applied to all cross sections at all discharges. Now click **Run**.

Since we have chosen the high calibration flow (i.e., 250 cfs) MANSQ will always return the observed water surface elevations for this flow at each cross section. We need to evaluate the predicted water surface elevation at each cross section for the medium (139 cfs) and low (75.2) calibration flows.

The **Results** tab contains a table of predicted water surface at each of the simulated discharges for each cross section. Click the **Print** button to obtain a copy of this table for later use. Click the **Longitudinal** button to view a plot of the longitudinal profile for all discharges. Click the check boxes for **Observed WSL** and **Simulated WSL**. Note the wild divergence of the WSLs at transects 135 and 201. The steep water surface elevation at high flows is unrealistic for a pool. In addition, the water surface elevation at the lowest discharges runs uphill. Our initial  $b$  values are not working too well.

Compare the predicted water surface elevations at 139 cfs and 75.2 cfs for each cross section against the observed water surface elevations for these calibration flows. It is apparent that an initial estimate of  $b$  of 0.2 results in a prediction of the water surface elevations at cross sections 0 and 60 that are too low, while this same  $b$  results in a prediction of water surface elevations at cross sections 135 and 201 which are too high at the high discharges and too low at the low discharges.

This means that  $b$  coefficients at all cross sections need to be adjusted in order to obtain better agreement

between observed and predicted water surface elevations.

**Table L4-3.** MANSQ calibration table.

X-Sec 0	Obs-WSL	$\beta:0.20$	$\beta:0.02$	$\beta:$	$\beta:$	$\beta:$	$\beta:$	$\beta:0.00$
250 cfs	92.67	92.43						
139 cfs	92.18	92.15						
75.2 cfs	91.90	91.90						
X-Sec 60	Obs-WSL	$\beta:0.20$	$\beta:0.02$	$\beta:$	$\beta:$	$\beta:$	$\beta:$	$\beta:0.00$
250 cfs	92.95	92.68						
139 cfs	92.42	92.35						
75.2 cfs	92.08	92.08						
X-Sec 135	Obs-WSL	$\beta:0.20$	$\beta:0.02$	$\beta:$	$\beta:$	$\beta:$	$\beta:$	$\beta:0.32$
250 cfs	92.97	93.12						
139 cfs	92.59	92.66						
75.2 cfs	92.25	92.25						
X-Sec 201	Obs-WSL	$\beta:0.04$	$\beta:0.02$	$\beta:$	$\beta:$	$\beta:$	$\beta:$	$\beta:0.51$
250 cfs	93.1	93.68						
139 cfs	92.74	92.99						
75.2 cfs	92.36	91.36						

### Step 3. Trial and Error Calibration of MANSQ by Adjusting $b$ at Each Cross Section

You have now obtained an initial solution of the water surface profile using MANSQ but some adjustment is needed. Return to **Edit\Cross Sections** and change the  $b$  coefficient from 0.20 to 0.02. Make this same change to the  $b$  value at cross sections 60 to 201. Note that these new estimates of  $b$  have been entered in Table L4-3.

Click **OK** to exit **Edit\Cross Sections** and save the file changes. Return to **\Models\WSL\Methods**, check that the MANSQ method is selected, and click **Set All** again. When the program has finished, click **OK** and **Results** as before.

Compare the Results table displayed on the screen to the one you printed earlier. What happened to the predictions for the water surface elevations when we increased or decreased **b** at the cross sections?

You should find that increasing **b** will result in predicted water surface elevations which increase for discharges above the calibration discharge, while decreasing **b** results in the predicted water surface elevations decreasing. The opposite will be true below the calibration discharge.

Return to **\Edit\Cross Sections** and change the **b** values for each cross section to induce the needed change in WSL at each transect to match the calibration discharges. Record these values in Table L4-3. Remember to use a **b** value of 0.00 instead of negative values for any cross section. Save these changes and re-run the MANSQ program and record the new predictions for the water surface elevations at each cross section for the medium and low calibration flows in Table L4-3. How close are the predictions of water surface elevations?

Based on these results, make adjustments to the **b** values as necessary. Your strategy should be to minimize the error between predicted and observed WSLs at both the 139 cfs and 75.2 cfs calibration flows for each cross section (you cannot get them both to be exact) by selecting the 'best' **b** for each cross section. Remember, MANSQ treats each cross section independently, so if you get a particular cross section to work, you no longer have to adjust the **b** value at the cross section while continuing your calibration efforts at other cross sections. You should make several trial runs during the lab in your quest for the best fit; however, due to class time limitations, the final calibration **b** values are provided in Table L4-3.

#### **Step 4. MANSQ Final Calibration Run and Hydraulic Diagnostics**

Up to this point we have focused on the calibration discharges and have not dealt with the WSL for the other discharges in the data set. The particular **b** values entered at the far right in Table L4-3 generally result in a maximum error between observed and predicted water surface elevations at the calibration flows, which range between 0.00 and 0.06 feet. This magnitude of difference is on par with the results obtained from the stage-discharge regression approach covered in Laboratory 3. However, we still need to check the effectiveness of the hydraulic simulations further by looking at the longitudinal profile of the water surface elevations at all simulated discharges.

View the longitudinal plot in **\Models\WSL\Results** again. Expand to full screen using the Windows maximize button for the graph window. It is useful to print this graph and label it MANSQ final for later reference.

The thalweg depths for each cross section are displayed as the bottom line with the x-axis indicating the distance between each cross section moving in an upstream direction. The top line in this graph represents the water surface elevation at a discharge of 1250 cfs. Using the key at the bottom of the plot, the other discharges can be identified by their line and symbol combinations. To aid in viewing simulated water surface profiles only, the **Observed WSL** check box can be left blank (click to remove check).

The predicted water surface elevations at each cross section are derived from the MANSQ model based on the calibrated **b**'s. At this discharge, water appears to be flowing downhill for some cross sections and uphill for others.

Note that at the simulated discharge of 625 cfs, water is 'flowing uphill' between cross sections 3 and 2. Although excellent agreement can be obtained with MANSQ for the calibration data, the simulated water surface elevations at discharges greater than 250 cfs are irrational.

At this point, we know that somewhere between 250 and 625 cfs, the MANSQ model 'breaks down' in a similar fashion to the results obtained using the IFG4 model in Laboratory 3. The reason behind the production of

irrational results with MANSQ for this data is basically similar to the reasons discussed in Laboratory 3 using IFG4. In MANSQ, the  $b$  value represents the exponent in a power law relationship (see Equations L4-3 and L4-4) that approximately tracks the changes in Manning's  $n$  over a range of discharges. Therefore,  $b$  acts as the 'slope' factor for the relationship between water surface elevation and discharge. Since the measured water surface elevations at cross sections 60 and 135 are very similar at the high calibration flows (see Table L4-2), the best fit relationship derived from matching the water surface elevations at the two lower calibration flows causes the predicted water surface elevations to cross over at simulated discharges above 250 cfs.

At this point, an alternative modeling approach for the simulation of discharges greater than our high flow calibration (i.e., 250 cfs) should be considered. Given the nature of these data, modeling options within MANSQ are not likely to improve the simulation results (i.e., use of Equation L4-4 rather than Equation L4-3). Given the results already examined in Laboratory 3 using IFG4, the WSP model would be the next step and is examined in Laboratory 5.

## Laboratory 5. Water Surface Modeling Using the WSP Model

### Objective

The objective of this laboratory is to demonstrate the technique of modeling water surface elevations based on the step-back water method as implemented in the WSP model. We will cover the steps of finding an overall Manning's n value that is a "best fit" for the study site, adjusting n values to capture localized roughness differences at each transect, and specifying roughness modifiers to accommodate the change in n value as a function of discharge. The general theory for the WSP program is covered in the manual in Chapter 3.

**Programs Used:** WSP

**Project File Used:** Lab5.phb

### Introduction

The WSP model is a water surface profile program that is used to predict how the longitudinal profile of the water surface elevation changes over a range of simulated discharges. The initial objective in the calibration of the model is to use a trial-and-error procedure to select Manning's n coefficients at each cross section, which will replicate the longitudinal profile of the water surface elevations at this single calibration flow. This requires that the bed geometry elevations and water surface elevations have been measured to a common benchmark or elevation datum (i.e., the cross sections are 'dependent' and connected). We first attempt to find a global value (or overall channel roughness value) for n that is applied at each cross section to produce a "least error fit" of the water surface elevation profile to the observed data for one discharge. We then vary Manning's n for each cross section (within reasonable limits) to achieve a reasonably close fit between observed and predicted water surface elevations. Finally, we use a trial-and-error procedure to select main channel and overbank roughness modifiers that produce the best fit between observed and predicted water surface profiles for all remaining calibration flows. The relationship between the calibrated roughness modifiers and discharge is then used to develop either a regression equation or a good linear approximation, from which we can estimate the appropriate roughness modifiers for all simulation discharges of interest.

WSP requires a starting water surface elevation or energy slope as an initial condition. We have already found stage-discharge relationships using a regression approach (i.e., STGQ) and by calibrating MANSQ for the downstream cross section. To provide WSP with the needed initial condition, the user selects the combination of starting conditions based on using the water surface elevation derived from STGQ or MANSQ in the **\Models\WSL\Methods** tab by clicking on **..\WSP\STGQ supplies initial WSL** or **..\WSP\MANSQ supplies initial WSL** or **..\WSP\User supplies initial WSL**. The two combined WSP\XX options take the starting water surface elevation from one of those models and supplies it to WSP. The WSP\User option allows the user to set this value manually. The **..\User supplies WSL (no model run)** option allows users to import WSL values for the entire study area and discharge range from an outside source.

In this laboratory, we will select the high flow calibration data as the starting point in the calibration of the WSP model. In particular, we are interested in determining if this modeling approach can overcome the problem with simulated water surface elevations at higher discharges encountered when using a stage-discharge regression (i.e., STGQ in Laboratory 3) or the MANSQ model (Laboratory 4). The laboratory also provides a discussion of the implications of using a different initial calibration flow and resulting impacts to simulated water surface elevations. The given steps represent a suggested order for WSP analysis.

### **Step 1. Prepare Data and Select Options to Run the WSP Program**

We begin by setting the same initial Manning's n roughness value for all cross sections. Start PHABSIM for Windows and load Lab5.phb. Select **\Models\WSL\WSP Options** and note that a Manning's n value of 0.030 has been entered for all cross sections.

WSP requires that the water surface elevations at the down stream cross section for each discharge are supplied to the model as boundary conditions. For discharges of 75.2, 139, and 250 cfs we know the actual observed water surface elevations at the down stream most cross section (i.e., cross section 0.0). However, the water surface elevations for the remaining four discharges are not known. To resolve this issue, we use STGQ or MANSQ to obtain water surface elevations for the downstream cross section. From Labs 2 and 3 we know that STGQ produces a slightly better fit between observed and simulated water surface elevations at cross section 0. Thus, we will use STGQ as the source of starting water surface elevations.

Move to **\Models\WSL\Methods** and first select **WSP** (click the radio button) followed by **Set All**. This saves clicking on each element of the table separately. Now select the **..\WSP\STGQ** radio button and click in the cross section 0.0 row for each discharge. (Be sure and scroll the table so all cross section 0.0 entries for all cross sections are filled with WSP-S. This sets all initial conditions to use the WSL from STGQ and applies WSP to all cross sections at all discharges.

We have the measured water surface elevations for the three calibration discharges. Will they be different than those predicted by STGQ? To ensure the best precision in calibrating WSP, it is wise to use the known values as the initial conditions. For the three calibration discharges, select **..\WSP\User supplies initial WSL** and click the cross section 0.0 entry for each discharge and enter the starting WSL from the data. You have already entered this data as part of the calibration data sets, but to allow for improved estimates of the starting WSL, you must enter it here also.

In the **\Models\WSL\WSP Options** tab, there is a table for entering roughness modifiers (RMODs) for each discharge. The RMODs are used by WSP to adjust the Manning's n values derived in the initial calibration of the longitudinal water surface profiles to account for changes in roughness as a function of discharge. The default value for the RMODs is '1', so initially there is no variation in Manning's n with discharge. These values are modified by the user as needed to obtain a reasonable fit between observed and simulated water surface profiles.

For this exercise, we will use the high discharge as our reference discharge. This is generally a good practice when using WSP as calibration residual errors tend to compress (get smaller) as one simulates downward using backwater type models. As trial values, set the roughness modifiers for 139 cfs and 75.2 cfs to 1.1 and 1.2, respectively. These are strictly trial values so you can start by leaving them at 1.0 if you wish.

## Step 2. Run the WSP Program and Determine the Initial Water Surface Elevation Predictions

Click the **Run** button now to run the combined STGQ (at cross section 0.0) and WSP (at all cross sections) model. A message window will indicate when the WSL simulation is completed. Click **OK** to clear this window.

Select the **\Models\WSL\Results** tab or **\Reports** and click on the longitudinal plot option. Select **Observed** and **Simulated WSL** followed by **Refresh**. Zoom on the three calibration discharges by holding down the **Shift** key, moving the mouse to the lower left corner of the region you wish to zoom, holding the **left** mouse button and dragging to the upper right corner of the zoom area. Then release the mouse button and the plot will zoom to that area. Note that **\Models\WSL\Results** contains a table of water surface elevation information for all cross sections and all discharges. In this case, it has seven entries in each row corresponding to the seven discharges we have directed the model to simulate. Note, for example, that the predicted water surface elevation associated with the 250 cfs calibration flow at cross section 201 is 92.936.

How do the simulated values compare with the observed values? Note from the plot that at all three calibration discharges the simulated water surface profile falls considerably below the observed profile. An adjustment to Manning's  $n$  is needed. The table in the **\Models\WSL\Results** tab can display the observed, simulated, and difference in water surface elevation at the calibration flows by clicking the **Cal Comparison** radio button. This is useful to display numerical values for the differences seen in the plot.

## Step 3. Calibrate WSP for the Longitudinal Water Surface Profile at 250 cfs

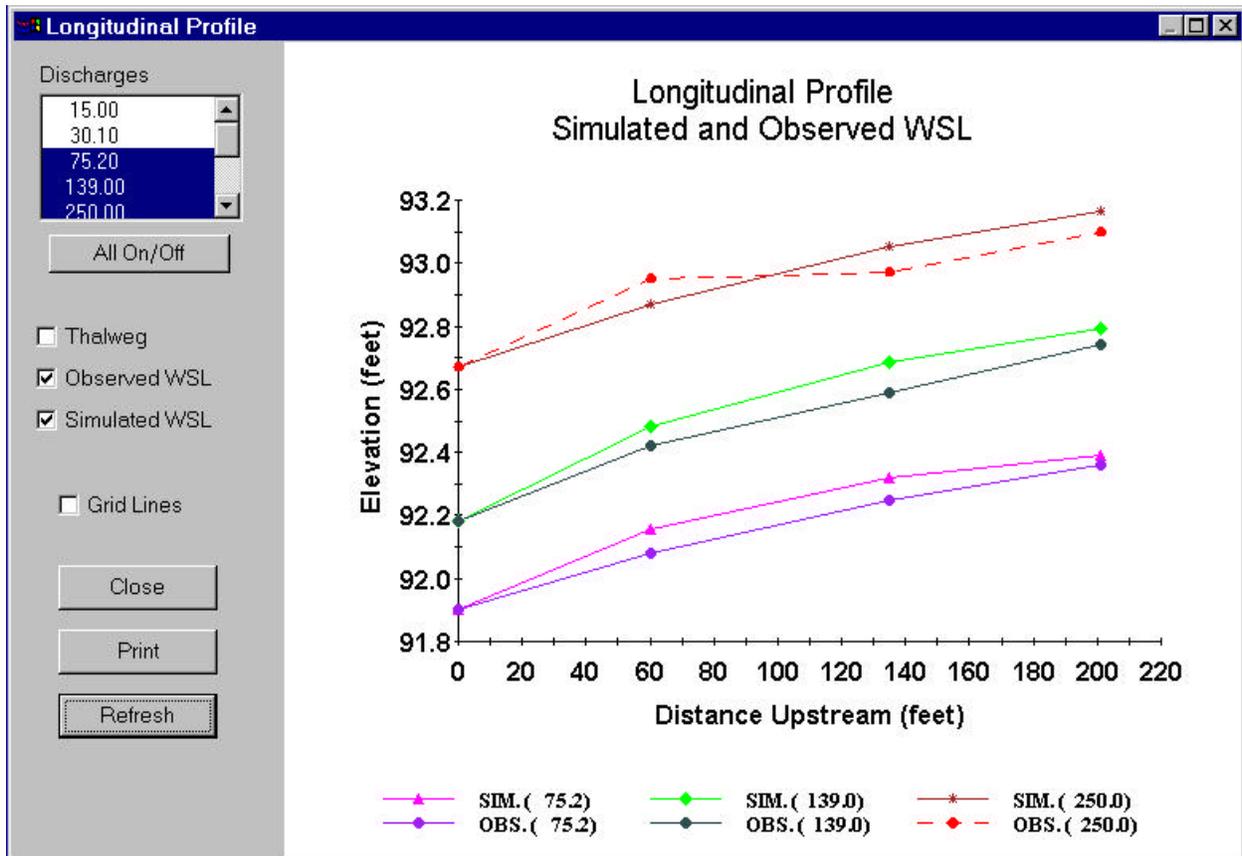
For the calibration process it is useful to prepare a table such as Table L5-1 to record successive iterations of the Manning's  $n$  adjustment process. The first estimate of the water surface elevation at cross section 60 at 250 cfs recorded in Table L5-1 shows that the predicted WSL is low by 0.185 feet. The calibration strategy will be first to change the Manning's  $n$  values at all cross sections simultaneously to get the predicted water surface elevation at all cross sections for our chosen discharge of 250 cfs to fit through the observed values for all cross sections in a reasonable manner. Generally, we would like the simulated values to fit the observed values as closely as possible. We expect some values to be high and some to be low at this stage. Go back to **\Models\WSL\WSP Options** and raise the Manning's  $n$  to a new, higher value for all cross sections (.045 is suggested). Remember, raising  $n$  increases roughness will thus raise the simulated water surface profile.

Return to **Models\WSL\WSP Options** and make sure the roughness modifier for a discharge of 250 cfs has a value of 1.0. Then click the **Run** button to run the model. Repeat this process of setting Manning's  $n$ , running the model, and viewing results until you have achieved a satisfactory fit between the simulated and observed water surface profile for the 250 cfs discharge.

Figure L5-1 shows the plot resulting from raising Manning's  $n$  to 0.45 at all cross sections. Display this plot by clicking the Longitudinal button in the **..\WSL\Results** tab.

**Table L5-1.** WSP calibration table for Manning's n.

X-sec 60	N: 0.030	N: 0.045	N:	N:	N:	N:	N:
WSL = 92.95	92.74						
Xsec 135							
WSL = 92.97							
X-sec 20							
WSL = 93.10							



**Figure L5-1.** Water surface profiles resulting from Manning's n = 0.045.

Increasing the Manning's n from 0.030 to 0.045 raised the water surface profile at all cross sections. Note that the elevation for 250 cfs at cross section 60 changed from 92.765 feet to 92.871 feet. Is this close enough? What about the 250 cfs WSL at the other transects? In this case they are higher than the observed values by 0.081 ft. for transect 135 and 0.066 ft. for transect 201. This would appear to satisfy the criteria of using a single n value to get the best fit through the data. However, we have a dilemma. Notice cross section 60 at 250 cfs. This is the only place where there is a pronounced rise in observed WSL above the values being predicted by WSP. Also notice that, at the other calibration flows, the predicted water surface profile lies above that of the calibration data. Examination of the cross section shapes, the thalweg profile, or relative transect location does not reveal a clear reason for the high observed value at cross section 60. The channel index codes in this study are based on bed material size. There are a few CI values of 7, but the predominant value is 6. The predominant value at cross section 0 is also 6. So, while the bed at cross section 60 may be slightly rougher than at cross section 0, there is no compelling reason to increase roughness above that at cross section 0.

In this particular situation, we may suspect an error in measurement at the high discharge. Following this assumption, we adjust the n values such that the simulated 250 cfs water surface profile closely matches the observed values at the upstream two transects. To accomplish this, reduce the n values in **Edit\Cross Sections** and re-run WSP until good agreement is reached. As you make those adjustments, record n and WSL in Table L5-1. Agreement will occur near  $n = 0.041$  at all cross sections.

With global  $n = 0.041$ , the WSL is 0.109 ft. low at cross section 60, 0.032 ft. high at 135, and 0.005 ft. low at 201. The 0.109 ft. difference seems large. What kind of error may have occurred when the measurements were made? One possible scenario is that the water surface was recorded 0.1 ft. higher than reality. Let us use that assumption and determine which further local adjustments to n should be made to reach a WSL of 92.85 ft. instead of 92.95 ft.

Local adjustments to n are best made in pairs stepping upstream. The Manning's n at the first cross section is changed concurrently with the value at cross section 60.0 since the predicted water surface at cross section 60 is dependent on the initial roughness at the down stream cross section as well as at cross section 60. Changing both Manning's n values also reduces the chance of obtaining unrealistic Manning's n values at upstream cross sections during the calibration process. To reach 92.85, we must raise n at the first two cross sections. Try a value of 0.042.

Go to **\Models\WSL\WSP Options** and enter 0.042 for the first two transects. Then set the roughness modifiers to 1.0 for 250 cfs, 1.1 for 139 cfs, and 1.2 for 75.2 cfs, if you have not already done so, and click **Run**. Look at the table and longitudinal plot in **..\Results**. Note that while the elevation for 250 cfs at cross section 60 has now reached 92.848, the elevations upstream have increased. To get those values back down to within 0.02 ft. of the observed values will require low n values for cross sections 60 and 135. It is possible to set the n value at cross section 0.0 high enough that even a low n value at cross section 60 will produce an elevation of 92.85. However, there is no evidence in this stream that radical changes in n are justified. Thus, the global value of 0.041 appears to be a reasonable best fit value that causes the simulated water surface profile at the selected discharge (250 cfs) to "bracket" the observed values.

Set the n values back to 0.041 for all cross sections and re-run. Now look at the water surface profile (longitudinal) plot. Note that the observed water surface profiles for the three calibration flows appear to arch up in the center and become flatter at cross section 201. This suggests that there is a legitimate increase in roughness between cross sections 135 and 201. Try modifying the n values for those cross sections to obtain a better overall fit for the 250 cfs water surface profile. Be sure to record both the Manning's n values and associated predictions of the water surface elevations in Table L5-1. An approximate rule of thumb is that no more than a 5% – 15% change in n values should occur between transects in an alluvial stream unless there is a topographic or geologic phenomenon to consider. For example, if large car-sized boulders densely filled a short section of stream, large changes in n would be anticipated. That does not appear to be the situation here.

It is important to avoid varying n values merely for the purpose of obtaining an exact fit of the simulated to observed water surface profile. When n values vary substantially between transects, the reliability of extrapolating to higher or lower discharges may be affected. Generally, n represents the combined roughness of the bed particle size and bed form (dunes, for example) that resists the flow of water. Additional losses, such as expansion or contraction losses, are handled to varying degrees within the WSP model. In some circumstances, adjustments to n may be used to ensure such losses are fully represented.

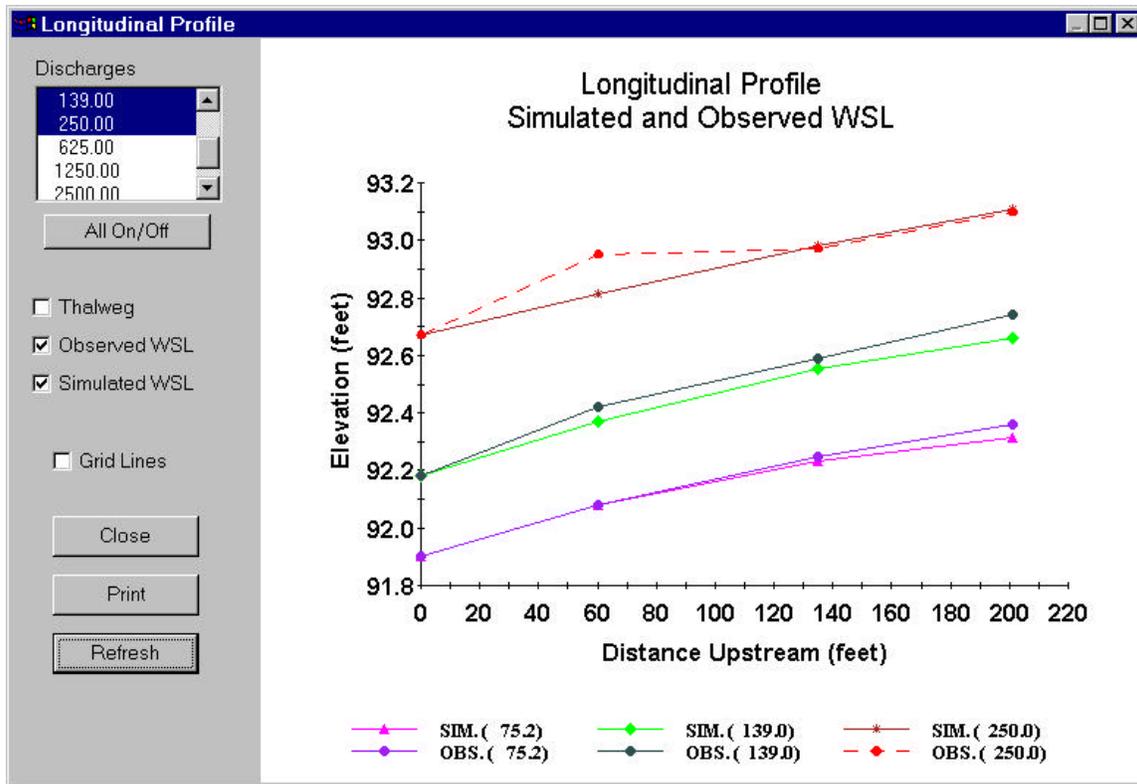
#### **Step 4. Calibration of Roughness Modifiers for Remaining Calibration Data**

Now that Manning's n values have been selected to approximately reproduce the water surface profile at the high (250 cfs) calibration flow, the next calibration step involves using a trial-and-error procedure to select RMODs at the remaining calibration flows which most closely reproduce the longitudinal water surface profiles at those discharges. Since WSP treats each simulated discharge independently, calibration of the RMOD for the remaining two calibration flows can occur at the same time. The RMODs represent constants that change the magnitude of the Manning's n values at each cross section while simulating discharges. The RMOD for the calibration flow must therefore be 1.0 and the RMODs at other flows will be either higher or lower than 1.0 depending on whether these discharges are higher or lower than the initial calibration flow. Why?

Recall from Chapter 2 in the manual that roughness or resistance to flow decreases with increasing discharge. Conversely, the roughness should increase as flows are reduced. Since the high calibration flow (i.e., 250 cfs) was used for the initial calibration of the WSP model, the calibrated Manning's n values alone will be too low to correctly predict the water surface elevations at the 139 cfs and 75.2 cfs calibration flows. Therefore, the RMODs at these remaining two calibration flows will need to be greater than 1.0. Think this through and reread Chapter 3 if it is still unclear why. This is why we assigned arbitrary RMODs of 1.1 and 1.2 to the 139 cfs and 75.2 cfs discharges earlier.

Select **\Models\WSL\WSP Options** to display the RMOD table. Set the RMOD values for 139 cfs and 75.2 cfs to 1.1 and 1.2, respectively if they are not already so set. Then select **..\Results** and display the longitudinal plot. Select both **Observed** and **Simulated** water surface elevations and **Refresh** to display them. It is convenient to drag the plot to the lower right of the screen so you can view both the PHABSIM window and plot window simultaneously. In the plot window, magnify (zoom) the area of water surface profiles for the calibration discharges. Now click the **Run** button to run the models. Click **OK** when the program has finished and click the **Refresh** button in the plot window. Where do the simulated water surface profiles for 75.2 and 139 cfs lie in relation to the observed profiles? Are they high or low? Return to the WSP Options tab.

Figure L5-2 shows the predicted versus observed longitudinal water surface profiles at the three calibration flows based on our existing RMODs.



**Figure L5-2.** Water surface profiles with RMODs of 1.0, 1.1, and 1.2.

This figure illustrates several key factors in the calibration of WSP using RMODs. It should be apparent that the predicted longitudinal profiles for the calibration discharges at 139 cfs and 75.2 cfs 'mimic' the pattern of the water surface profile at the initial calibration flow of 250 cfs. This should be expected since the only effect that the roughness modifiers have in the simulation is to change the magnitude of the Manning's n values and therefore, the relative differences between the individual cross section Manning's n values are retained at the other simulated discharges.

In Figure L5-2 (or by viewing `\Models\WSL\Results\longitudinal`) you can see that the simulated water surface profiles for 139 and 75.2 cfs are generally lower than the observed profiles for those discharges. Do not close the graph window, merely click on the PHABSIM window to move back to it. Remembering that increased roughness will raise a backwater curve, enter new values for the roughness modifiers for 139 and 75.2 cfs in the `\Models\WSL\WSP Options RMOD` table. Click **Run** to re-run the models, click **OK** when the simulation is done and click the **Refresh** button to see the results in the longitudinal profile graph. Continue changing the RMOD values until you achieve the best overall fit at the discharges of 139 and 75.2 cfs. You may record your iterations of this process in Table L5-2.

It should also be noted that if either the 75.2 cfs or 139 cfs flow was selected as the initial calibration discharge, a close agreement between predicted and observed water surface elevations at the other flows would be achieved with the right RMOD. This would be expected given the similarity in the shape of the longitudinal water surface profiles at both of these discharges. However, neither of these lower calibration flows would be expected to achieve close agreement at all cross sections at the high calibration flow given the difference in the observed longitudinal profile at 250 cfs. This should reinforce the concept that

you should carefully consider which initial calibration flow to select, or that you should use multiple calibration flows to see which is best. This determination should be made in light of both model performance and flow ranges of interest in the study.

Staying within the 5%–15% guideline described earlier, try making final small changes to the n values for all cross sections and to the RMODs to best fit all three water surface profiles from cross section 0 to cross section 201. Observe the **diff** column in the **Cal Comparison** table and try to find a set of n values and RMODs that result in not more than a 0.02 ft. difference at all cross sections and discharges. This final step ensures that all observed water surface profile data has been used to achieve the final calibration of WSP over all calibration discharges and over all cross sections. Table L5-3 gives one possible final calibration of n values and RMODs. Other combinations of n and RMOD may give a similar range of WSL calibration errors.

**Table L5-2.** WSP RMOD calibration table.

Calibration Q = 75.2	X-Sec - 60.0	X-Sec - 135.0	X-Sec 201.0
Target WSL	92.08	92.25	92.36
RMOD: 1.20	92.20	92.23	92.30
RMOD: 1.			
RMOD:			
RMOD:			
RMOD: 1.28			
Calibration Q = 139.0	X-Sec - 60.0	X-Sec - 135.0	X-Sec 201.0
Target WSL	92.42	92.59	92.74
RMOD: 1.10	92.51	92.54	92.64
RMOD: 1.			
RMOD:			
RMOD:			
RMOD: 1.22			

**Table L5-3.** A possible WSP calibration.

Cross section	n value	Discharge	RMOD
0.0	0.038	75.2	1.28
60.0	0.038	139	1.23
135.0	0.043	250	1.00
201.0	0.043		

Laboratories 3 and 4 demonstrated that neither the stage-discharge or MANSQ models were able to simulate rational (water flowing downhill) profiles at the high discharge range. Let us assume that the current WSP model calibration results are the best that can be achieved and move to the next step in the calibration process.

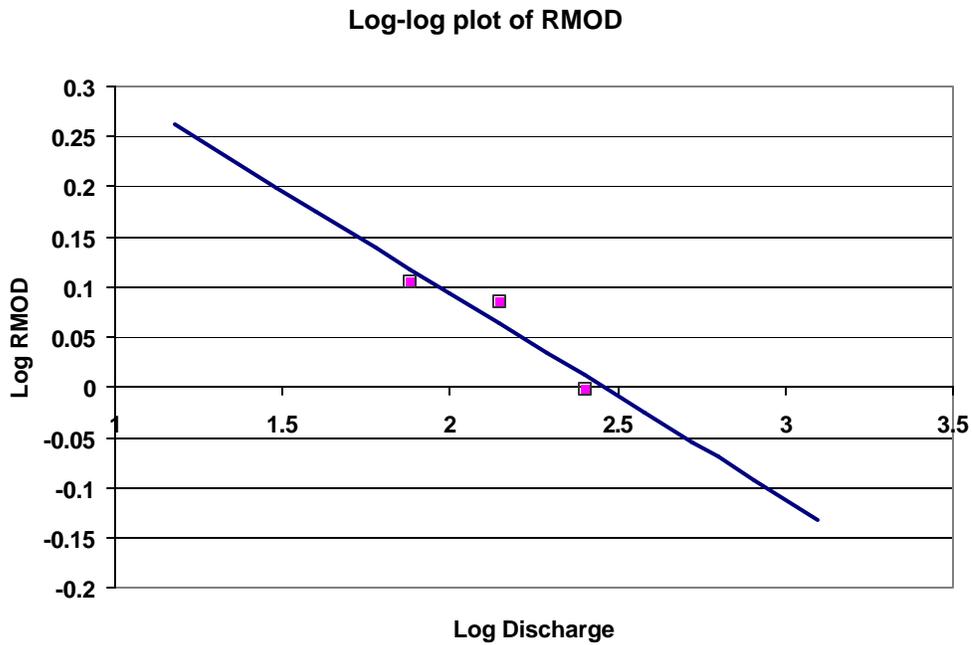
#### **Step 5. Estimate the Roughness Modifiers for all Desired Simulation Discharges**

Assuming that our final calibration effort for RMODs listed in Table L5-2 represents the best compromise in matching the predicted and observed water surface profiles at the medium and low calibration discharges, the next step will involve trial-and-error approximation of a linear log-log relation between n and discharge or development of a regression between the  $\log_{10}$  of the discharges and  $\log_{10}$  of the RMOD values. The resulting regression equation or approximated relation will then be used to estimate the roughness modifiers for all remaining discharges to be simulated in WSP (i.e., 15.0, 30.1, 625.0, and 1250.0). The log regression is easily accomplished with a spreadsheet program.

Figure L5-3 shows the log-log linear regression results for the relationship between discharge and roughness modifiers obtained using a spreadsheet program. The equation is:

$$\text{Log}_{10}\text{RMOD} = -0.2045*\text{log}_{10}\text{Discharge} + 0.502 \quad (5-1)$$

This regression equation was used to generate the estimated roughness modifiers listed in Table L5-4 for the remaining simulation flows to be used in the laboratory. Note that the  $\log_{10}$  of the discharge must be used in the equation and that the result is the  $\text{Log}_{10}$  of the roughness modifier. Therefore, the correct RMOD estimate is derived by exponentiating the result from the regression equation as the 'x' in  $10^x$ .



**Figure L5-3.** Log-log plot of RMOD and discharge.

**Table L5-4.** Estimated RMOD values at simulation discharges.

Simulation discharge	Estimated RMOD
15.0	1.83
30.1	1.58
625.0	.852
1,250.0	.739

Enter these values in the RMOD table in the **WSP Options** tab and click the **Run** button. We now have a water surface profile for each discharge based on the WSP model. The resulting profiles can be viewed using **..\Results\longitudinal**. If you have not already done so, include the remaining target discharges in the simulation by moving to **..\Output Options**, placing a check in all check boxes, and re-running the simulation.

The log-log linear RMOD versus discharge relationship can be visually approximated by trial-and-error by plotting that relationship in PHABSIM for Windows. In the WSP Options tab, click the **Roughness Modifier Graph** button and the **log-log** radio button. Prior to setting RMOD values for the simulation discharges, the graph will look something like Figure L5-4.

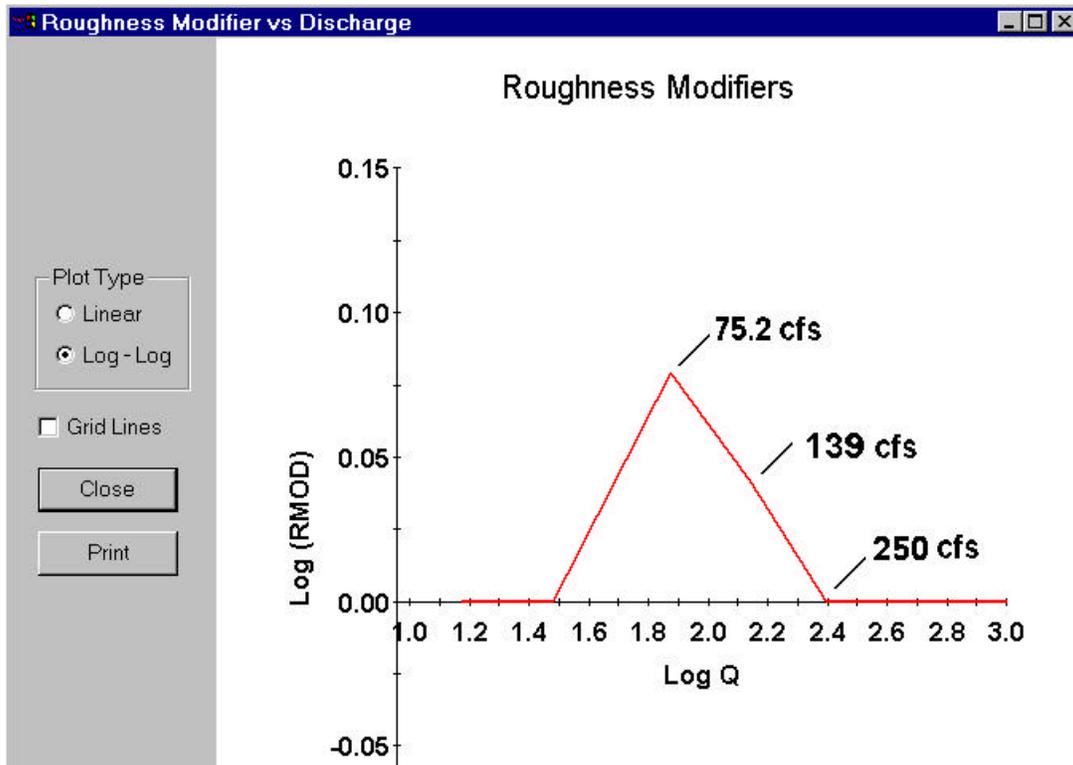


Figure L5-4. Roughness modifier graph.

This plot shows the initial RMODS of 1.0 ( $\log_{10}$  of 1 is 0.0) for all simulation discharges and  $\log_{10}$  of 1.2, 1.1, and 1.0 for 75.2 cfs, 139 cfs, and 250 cfs respectively. By displaying this plot and the RMOD table in the **..WSP Options** tab simultaneously, the user can quickly build a linear RMOD vs. discharge relationship visually. While not as precise as the regression approach, this is often an adequate approximation for estimating RMOD values.

### Step 6. Evaluate the Hydraulic Simulations

In order to check the effectiveness of the hydraulic simulations, we examine the longitudinal profile and calibration error of the water surface elevations for all our simulated data. In particular, the performance of WSP at the high-simulated discharges is of interest, since neither STGQ nor MANSQ were able to produce rational results above our high calibration flow of 250 cfs.

Zoom in on the water surface profiles for 625 cfs and 1250 cfs in **..Results\Longitudinal**. Compared to the STGQ and MANSQ results these profiles show water running downhill at the high discharges. The WSP model produces rational results for the high-simulated flows. This would suggest that the WSP model could be used for simulations above the highest calibration flow (i.e., above 250 cfs).

Now zoom in on the water surface profiles for 15 cfs and 30 cfs. Do these results also look rational? It does appear that a weak pool is produced by backwater from cross sections 0.0 and 60. Neither of those sections shows clear evidence of being a strong control. More likely, control is the result of the overall resistance of the channel between those two sections. This condition is often referred to as channel control and helps explain the observed and simulated water surface profiles seen here.

You may compare the water surface profiles developed using WSP and STGQ by starting another copy of PHABSIM and loading the lab03 SAMPLE data set. Longitudinal plots for both data sets can be displayed on the screen at once by sizing windows appropriately. Do not try to load two copies of the same project.

Based on these results, the WSP simulated water surface elevations will be used for the subsequent steps in the laboratory exercises.

A final note: We ignored the water surface elevation at cross section 60 for 250 cfs and assumed it was a measurement error. What if it was not a measurement error? What would need to be done differently in this WSP calibration to achieve the “best” simulation? Specifically, could we stay within the 5%-15% change in ‘n’ guideline? Could the maximum water surface simulation error be held to  $\forall$  0.02 ft.? How would the RMODs change?

To explore these questions you can make a copy of the project at the present stage using **\File\Save As** and re-calibrate assuming that the cross section 60 value is correct.

## Laboratory 6. Velocity Modeling – VELSIM

### Objectives

The objectives of this laboratory are to explore various methods for velocity modeling within PHABSIM using the VELSIM program and to introduce the basic techniques for evaluation of the effectiveness of velocity simulations.

**Programs Used:** VELSIM, WSP

**Data Files Used:** Lab6.phb

### Introduction

In this laboratory, different empirical approaches to simulating velocities are examined. Recall from Chapter 2 of the manual, that VELSIM can use specific velocity calibration sets for specific ranges of discharges, and a conveyance area-based velocity distribution can be developed when no calibration velocities are available. The 'best' approach can only be determined by evaluating a combination of available data, model performance, and objectives of the particular study.

This laboratory explores several different velocity set combinations and simulation control options within VELSIM to help the user understand the effects and consequences of selecting a particular velocity calibration data set and modeling option(s) within VELSIM. The laboratory is also intended to demonstrate the implications of selecting a particular water surface elevation model and subsequent effects during the simulation of velocities in VELSIM. The overall objective of velocity calibration and simulation is to pick the best combination of calibration velocity(s) and simulation options to represent the velocity profiles at each cross section over the range of simulated flows. The steps in this lab provide a good sequence for velocity simulation.

#### Step 1. Evaluate Observed Velocity Profiles

Prior to beginning the modeling efforts, examine the observed velocity profiles at each cross section for all three calibration flows provided in Figures L6-1 through L6-4. The velocity profiles between different cross section geometries are highly variable as would be expected. Also note, however, that the velocity patterns at specific cross sections are 'generally' similar at all three calibration flows, but differences in the location of high versus low velocities and changes in the transverse patterns of velocities between the different calibration flows are also evident.

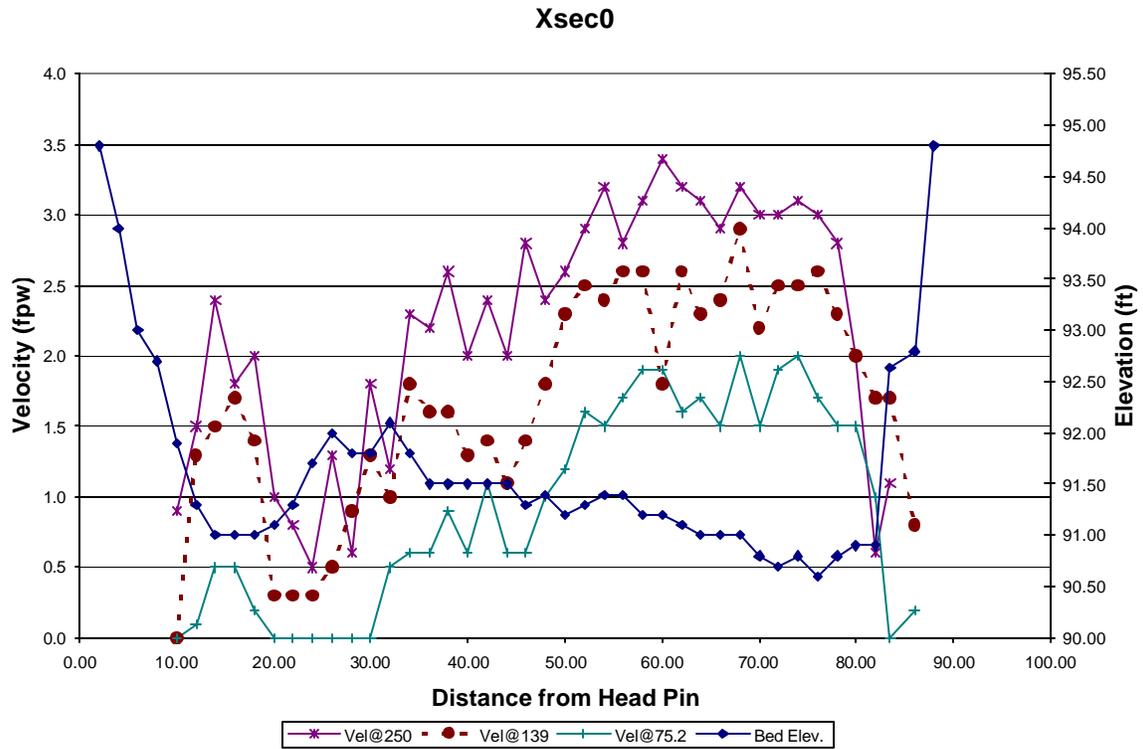


Figure L6-1. Observed velocity distribution for cross section 0.0.

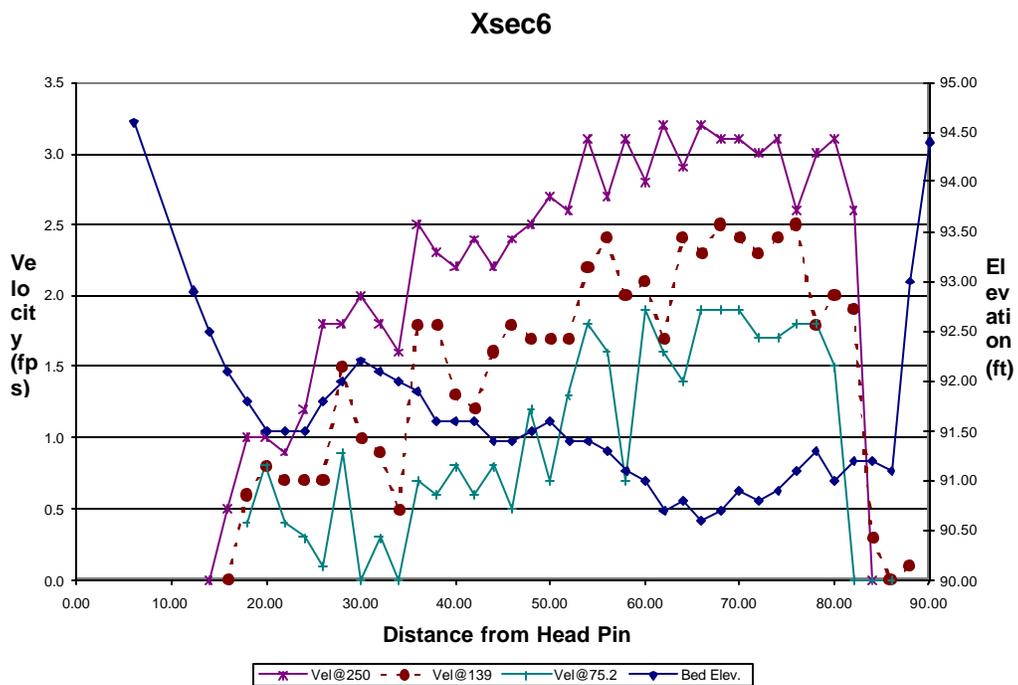
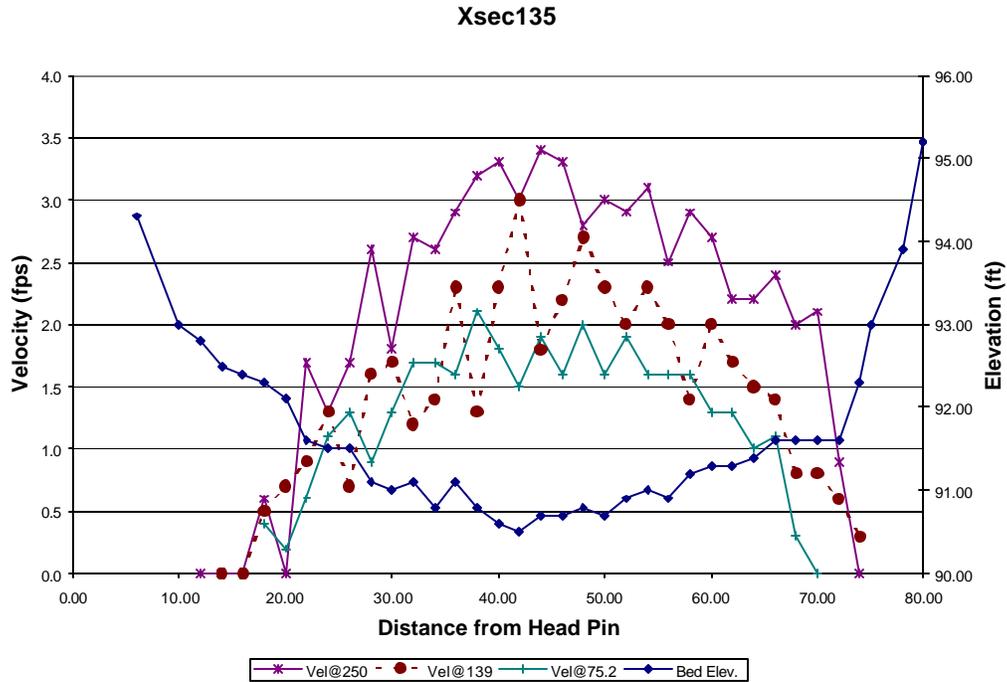
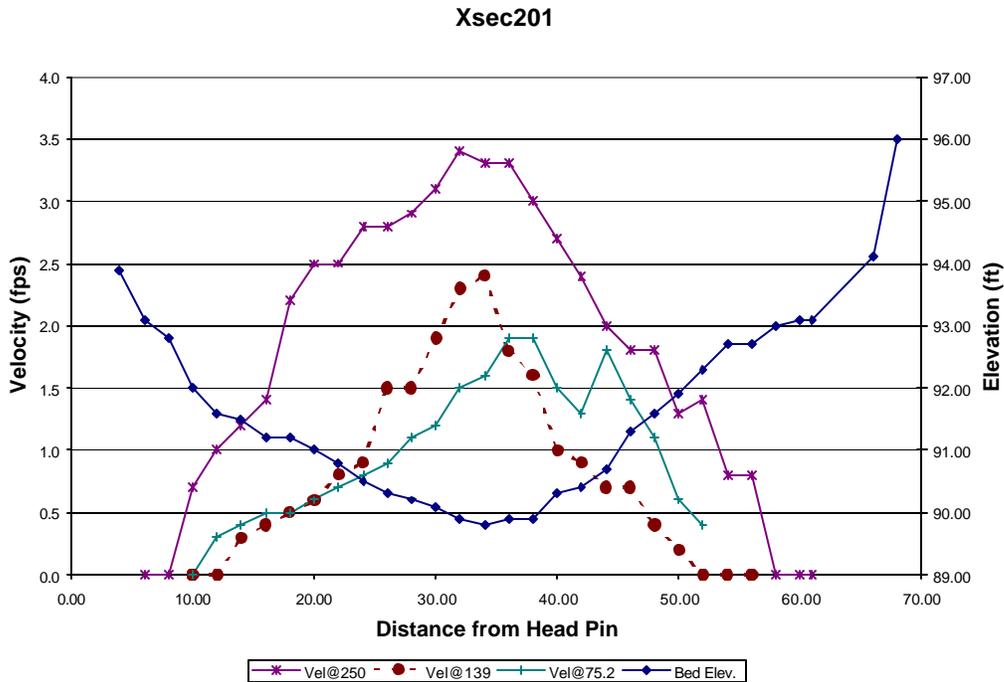


Figure L6-2. Observed velocity distribution for cross section 60.0.



**Figure L6-3.** Observed velocity distribution for cross section 135.0.



**Figure L6-4.** Observed velocity distribution for cross section 201.0.

## Step 2. Assign Velocity Calibration Sets for Simulation of Velocities

Go to \Models\Velocity Simulation\Velocity Calibration Set Assignments and assign velocity sets as shown in Table L6-1.

**Table L6-1.** Initial velocity set assignments.

Transect		Discharges						
15	30	75.2	139	250	625	1,250		
0	1	1	1	1	1	1	1	1
60	1	1	1	1	1	1	1	1
135	1	1	1	1	1	1	1	1
201	1	1	1	1	1	1	1	1

Assigning velocity set 1 to all cross sections and discharges tells the program to use the low calibration discharge velocity distribution as the template for simulating discharges across the entire flow range of the study. Later we will reset some or all of these values and compare the different velocity simulation results to obtain a final set of assigned calibration sets to use for each transect and discharge combination in this table.

We can now simulate velocities for all discharges at all cross sections using the low flow calibration set as the velocity distribution template. Remember that water surface elevations (WSLs) were previously established using the WSP program.

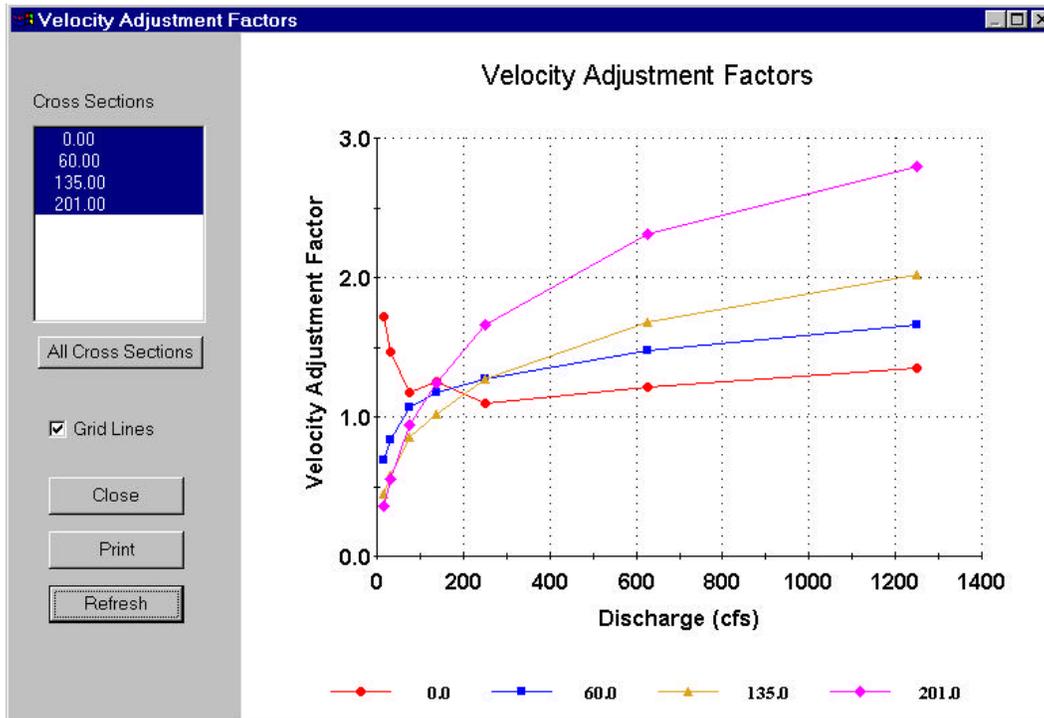
## Step 3. Velocity Simulations Based on Different Velocity Calibration Data Sets

Begin by simulating velocities using the low discharge calibration set as the velocity distribution template. To do this, click the **Run** button. When the VELSIM program has completed its execution. A small message box will announce velocity simulation is finished. Click **OK**.

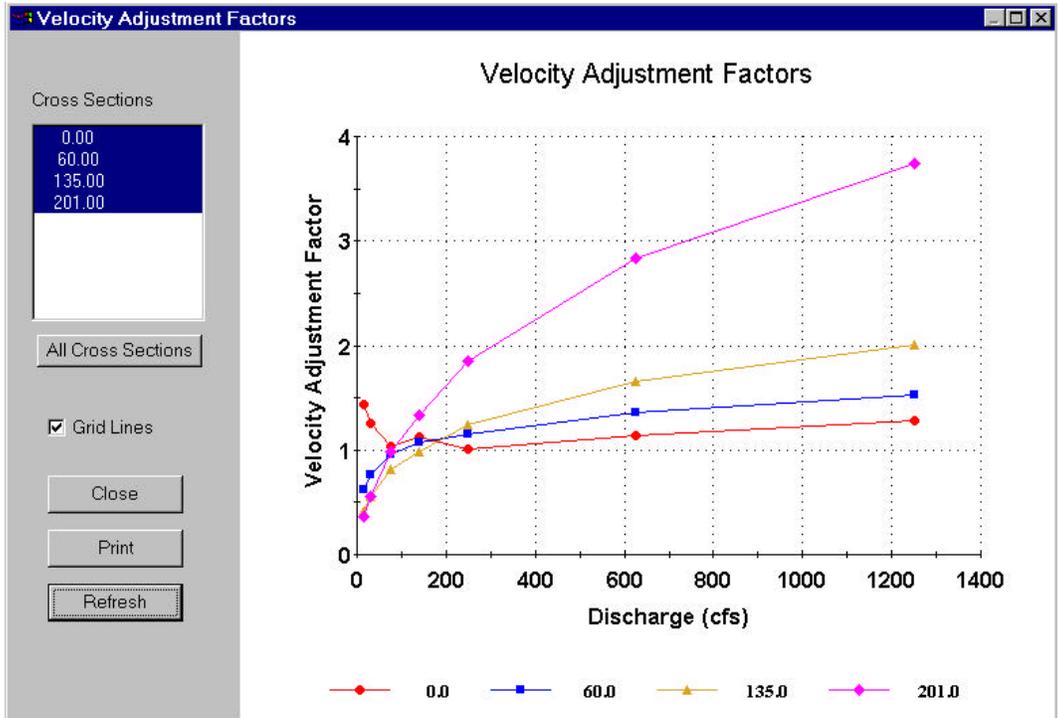
Now click the **Results** tab and the **Cross section** button at its bottom to display cross sectional plots. Click on 75.2 in the discharges table to display results for 75.2 cfs for cross section 0. Click the check boxes such that a check shows in all four boxes for **Observed WSL, Simulated WSL, Observed Velocities, and Simulated Velocities**. Now click the **Refresh** button. The graph should look like Figure L6-10. To view it better, use the Windows maximize button in the upper right corner of the graph window. You can now visually compare the observed and simulated velocities at a discharge of 75.2 cfs for cross section 0 based on using the 75.2 cfs calibration set as the velocity distribution template. Click on cross section 60 in the box at the top left of the window and then the **Refresh** button. The graph changes to display the WSL and velocity data and simulation results for cross section 60 at 75.2 cfs. In the classroom situation, it would take too long for each student to make printed copies of all of the plots of observed and to simulate velocities based on different templates, so the results of using calibration set 1, calibration set 2, and calibration set 3 for all cross sections at all discharges are given in Figures L6-10 through L6-45 at the end of this laboratory.

A cursory examination of these figures shows that the best fit occurs when the simulated discharge is equal to the calibration set discharge. So it seems reasonable to use Cal Set 1 for discharges less than or

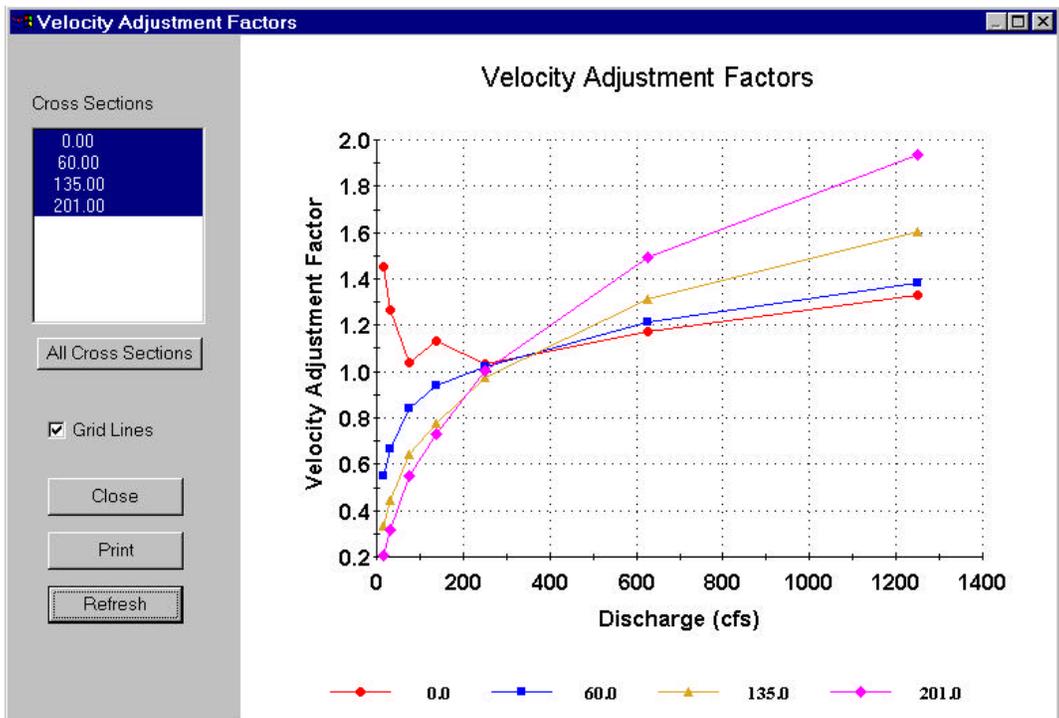
equal to 75.2 cfs, Cal Set 2 for 139 cfs, and Cal Set 3 for discharges greater than or equal to 250 cfs. Try assigning calibration sets in that order and run the model again. Figures L6-5 to L6-8 contain the VAF relationships for the four velocity template runs. These results will be compared in the next section.



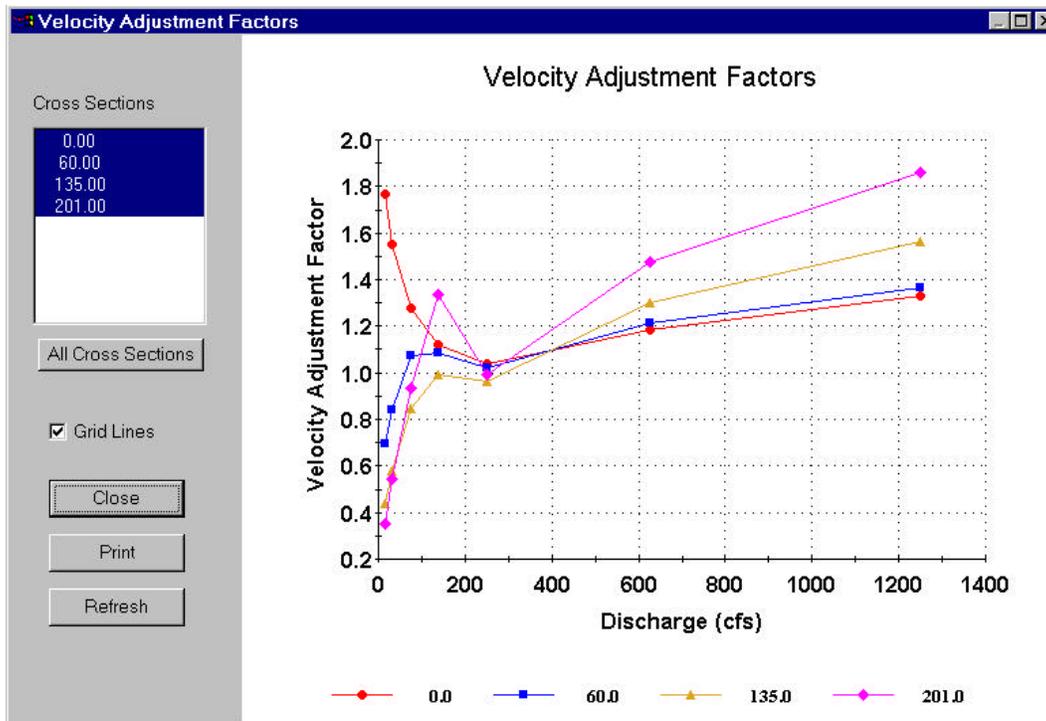
**Figure L6-5.** Velocity adjustment factor for calibration flow of 75.2 cfs.



**Figure L6-6.** Velocity adjustment factor for calibration flow of 139 cfs.



**Figure L6-7.** Velocity adjustment factor for calibration flow of 250 cfs.



**Figure L6-8.** Velocity adjustment factor for mixed calibration flow sets.

#### Step 4. Examine the VAF Relationships and Velocity Profiles

We will first examine the VAF relationships for each of the four simulations. Remember, velocity predictions at a simulated discharge are a function of the Manning's  $n$  derived from the calibration velocities at a single calibration flow. Also recall that VELSIM uses the VAF to maintain mass balance between simulated and computed discharges. Since roughness decreases with increasing discharge, VAF's below the calibration flow should generally be less than 1.0 and greater than 1.0 for flows above the velocity calibration flows. The degree to which the VAF departs from 1.0 at the velocity calibration flow is a function of the difference between the calculated discharge and the 'best estimate of the discharge' as well as the difference between predicted and observed water surface elevations (see Chapter 2 in the manual).

In Figure L6-5 (where the 75.2 cfs calibration set was used to simulate all discharges), all the VAF relationships except at cross section 0 follow the expected pattern. The relationship at cross section 0 'suggests' that roughness is decreasing with as the discharge decreases below 139 cfs, which is counter to expected results. The remaining cross sections appear to behave 'normally'.

The VAF relationships for all four simulations are shown in Figures L6-5 to L6-8. We can learn several things by comparing these figures.

First, it should be apparent that the use of a single velocity calibration set results in VAF relationships, which are more 'typical' of expected results for all but cross section 0. Use of a mix of all three velocity sets produces an irregularity between 75.2 and 250 cfs for all but cross section 0. Though the VAF traces appear to have a break in slope at either 75.2 cfs or 139 cfs and drop to the value at 250 cfs, they do

appear to be ascending with increased discharge within each range of simulation, e.g. 0.0 – 75.2 cfs and above 250 cfs. As only one discharge was simulated using the 139 cfs template, we do not know if this will hold true for the 139 cfs calibration set without running additional discharges. What do the other VAF plot suggest?

Note the magnitude of the velocity adjustment factors using the four different approaches. These results show that the choice of a particular velocity calibration data set can impact both the magnitude and functional relationship of the VAF's. As might be expected, since the WSP modeled water surface elevations were used for these simulations, the VAF relationship for the high flow velocity set is 'best behaved' over all ranges of simulated discharges. The results at cross section 0 would suggest that either alternative velocity simulation options in VELSIM should be attempted, that an alternative water elevation modeling approach may be required, that a combination of the two may be warranted, or that the channel conditions warrant further study.

Although an examination of the VAF relationships helps in the general diagnostics of the velocity simulations, an examination of the actual predicted velocities for each vertical for all cross sections at all simulated discharges must be undertaken to critically evaluate the simulation results. Actual velocity predictions should receive more emphasis than 'strict' adherence to an expected pattern of the VAF relationships in evaluation of the effectiveness of the velocity simulations.

A careful examination of the results shown in Figures 10 – 45 should reveal several key points about this particular data set and VELSIM velocity simulations in general. First, the predicted velocities at a given calibration flow using that calibration flow velocity set do not exactly reproduce the observed velocities. The velocities measured at each cross section do not necessarily result in a computed discharge equal to the best estimate of the discharge or calibration discharge. Thus, the predicted velocities are adjusted by the computed VAF to maintain mass balance between the simulated flow and computed flow at the cross section (see Chapter 3 in the manual).

The second thing to note is that at a given calibration flow, using that calibration flow velocity set results in some computational cells at the stream margin that have predicted velocities where none were observed. This is due to the discrepancy in the observed and predicted water surface elevations at each cross section and possible errors in the original data.

It should also be apparent that the velocity pattern at the calibration flow used in the simulation is 'replicated' at all simulation flows. This can result in relatively large discrepancies between observed and simulated velocities when using for example a low velocity calibration set to simulate high flows or vice versa. This can often occur when the velocity profiles change dramatically between discharges due to channel geometry heterogeneity, especially due to unobserved conditions upstream of the transect.

Collection of a single high flow velocity data set for use in modeling should be carefully evaluated based on complexity of the channel geometry at specific cross sections. If significant changes in velocity profiles are expected over different ranges of discharge of interest in a study, additional velocity data sets should be collected.

The results also suggest that simulation of velocities higher than an observed calibration velocity data set can be problematic at some cross sections since VELSIM must 'guess' at a Manning's n value for computational cells where no observed velocities have been provided at the velocity calibration flow.

The simulation results for cross section 201.0 also demonstrate the influence of water surface modeling on the predictions of velocities with VELSIM. Go to **Results\Graphs\Longitudinal Profile** and zoom in on the region encompassing the three calibration discharges. Note that at cross section 201.0 the WSP

model is slightly under-predicting the water surface elevation at the 139.0 cfs and 75.2 cfs calibration flows. Now view **Results\Graphs\Cross Section** and select cross section 201, discharge 75.2 cfs, observed and simulated WSL and velocities. At 75.2 cfs VELSIM predicts slightly slower water at the cross section but one cell on the left bank shows a simulated velocity of 0.236 fps where the calibration velocity was 0.0. This provides enough conveyance to slightly lower the other velocities. At 139 cfs, however, the simulated velocities are significantly higher than the observed velocities. The simulated water surface elevation is 0.001 ft higher than the observed value, not a significant difference. Yet, the velocities are slightly higher. Why? Noting the calibration data, we find that the local discharge was 249 cfs, but the best estimate discharge is 250 cfs. Thus, a VAF slightly greater than 1.0 was needed to achieve mass balance resulting in a very slight increase in velocities in spite of the slightly higher WSL.

In general, improving the water surface elevation predictions for any cross section at the calibration flows would bring the simulated cross sectional areas closer to the observed values. This would therefore reduce the VAF adjustments and result in a better match between observed and predicted velocities at the lower calibration flows. This can be seen the results at the 250 cfs calibration flow which identically match the calibration velocities over most of the cross section. Try simulating additional discharges that match the local discharges measured at cross sections 60 and 135. Do the simulated velocity results match the observed values better?

The final water surface elevation simulation using WSP allowed a very large difference (0.137 ft.) between the observed and predicted water surface elevation at cross section 60 for the 250 cfs discharge. This was based on the assumption that an error of at least 0.10 ft. had been made in the water surface measurement at that discharge. In spite of the large difference in water surface elevation, the simulated velocities are only slightly lower than the observed velocities. Two cells at the right of the channel, which have significant simulated velocities when the measured velocities were zero, explain the lower velocities. The overall close agreement in simulated and observed velocities further supports the assumption of a water surface elevation measurement error.

No single velocity calibration set is guaranteed to work at all ranges of simulated discharges at all cross sections. The 3-calibration data set approach would appear to represent the best compromise at all cross sections for all flow ranges. Selection of an appropriate velocity set(s) should be carefully considered in light of model performance and study objectives. These results should reinforce the importance of accurate water surface elevation modeling prior to undertaking the velocity modeling in VELSIM. A critical examination of the velocity modeling can also be used to revise water surface modeling approaches (for example, what to do with cross section 60) based on the effectiveness of the velocity predictions at specific ranges of discharge of importance to a particular study.

#### **Step 5. Revise Water Surface Elevations at Discharges below 250 cfs Based on MANSQ**

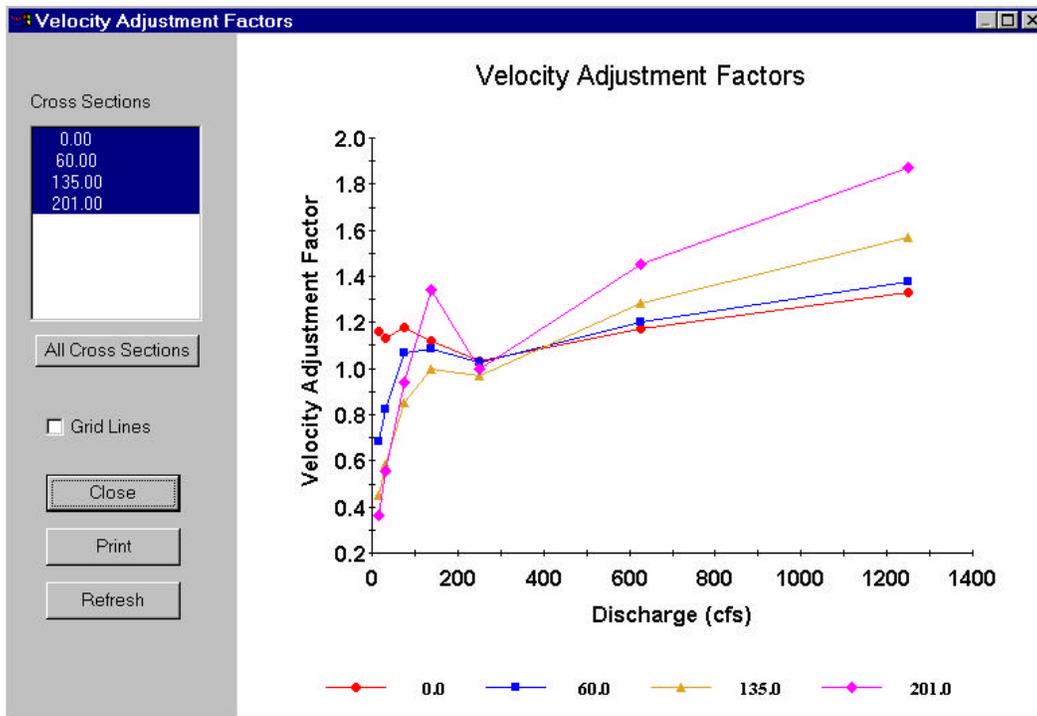
The water surface elevation modeling conducted in Laboratories 3, 4, and 5 indicated that either the VELSIM or MANSQ model matched the observed water surface elevations at the medium and low calibration flows. In this step of the laboratory, the WSL data for each cross section will be updated to use the water surface elevation predictions derived from the MANSQ model for all simulation flows below 250 cfs. Table L6-2 lists the water surface elevations for each cross section that will be used for this part of the laboratory.

**Table L6-2.** MANSQ derived water surface elevations for each cross section.

Discharge	Cross Section			
	0.0	60.0	135.0	201.0
15.0	91.37	91.46	91.68	91.67
30.1	91.57	91.70	91.88	91.94
75.2	91.90	92.08	92.25	92.36
139.0	92.21	92.43	92.59	92.71

Go to **\Models\WSL\Method** and set the starting combination for the WSP backwater at cross section 0.0 for discharges of 75.2 and 139 cfs to WSP-MANSQ and **Run** the selection.

Now go to **\Models\Velocity** and click **Run** to re-run the velocity simulation using the new elevations derived from using MANSQ as the starting point in the WSP backwater calculation. Compare the VAF relationship in Figure L6-9 with Figure L6-8. Updating the WSLs at the lower discharge ranges (i.e., below 250 cfs) improves the VAF relationship at cross section 0.0 by reducing the variation above a VAF value of 1.0 even though it does not result in transforming the VAF curve into the desired shape.



**Figure L6-9.** Velocity adjustment factors using MANSQ for low flow starting WSLs.

Based on these simulation results, the user would likely conclude that if only one calibration set is to be used, the high velocity calibration data set could be used for all ranges of simulated discharges. Alternatively, the user could also use each velocity calibration data set over a specific range of simulated discharges such as the high velocity calibration set for all flows greater than 250 cfs and for flows down

to a discharge of 139 cfs. The 139 cfs velocity calibration data set could then be used to model flow down to 75.2 cfs and then use the 75.2 cfs velocity calibration data set for all lower simulated discharges. The choice of modeling strategy is a matter of professional judgment based on the quality of the available data. The goal is to produce a simulated velocity distribution that is as near as possible to that which occurs in the stream. A carefully kept set of analysis notes explaining why a particular strategy was selected is strongly advised. PHABSIM for Windows maintains a **History.project name** text file that records the order of model runs. This file can be periodically copied to another file and annotated as a means of tracking the analysis.

#### Step 6. Use of the NMAX Option in VELSIM to Control Velocity Simulations

One of the ways to control velocity simulations in VELSIM is to restrict the magnitudes of the estimated Manning's n values. This can be accomplished by using the NMAX or NMIN options. Restriction of Manning's n values can often improve velocity simulations in computational cells at the margin of the stream where velocity calibration data does not exist (i.e., verticals in the channel above the highest velocity calibration data set). Since velocity simulations at the stream margins can be controlled, the velocity predictions at all other verticals are also affected due to the interaction of conveyance and the VAF's.

Selection of a limit on Manning's n, whether a maximum or minimum, is a matter of professional judgment. One rational approach is to examine the calculated Manning's n values at computational cells along the margins of each cross section for each calibration flow and select a Manning's n which is an 'average' of these values. Alternative approaches include the estimation of a Manning's n value using handbook values (see Chapter 3 in the manual) based on substrate characteristics. It should be noted that use of an NMAX and/or an NMIN applies to all computational cells at all cross sections at all flows when running VELSIM. Therefore, in those instances where substrate characteristics vary dramatically between cross sections, separate VELSIM data files containing only selected cross sections may be necessary. In this laboratory, the NMAX constraint will be applied to the entire data set over all ranges of simulated discharges.

Go to **\Models\Velocity\Options** and check the box labeled **Limit Manning's n**. Enter an NMAX value of 0.035 and click the **Run** button. Then view the VAF relation by clicking the **ZVAFF** tab and its **Graph** button.

It is apparent the constraint of Manning's n values to a maximum of 0.035 has resulted in a reduction in the magnitudes of the VAF's at all cross sections. This would be expected since lowering the upper limit on estimated Manning's n should result in higher velocity predictions. This in turn should decrease the VAF that is derived from the ratio of simulated discharge over computed discharge. A comparison of predicted Manning's n and velocities at the first 25 computational cells at cross section 135 at 15 cfs clearly illustrates the effect of NMAX on velocity modeling (Table L6-3).

**Table L6-3.** Comparison of Manning’s n and velocity predictions at cross section 135.0 at 15.0 cfs.

Cell	NMAX = 0.035		No NAMX	
	Manning’s n	Velocity	Manning’s n	Velocity
8	0.035	0.09	0.052	0.07
9	0.035	0.19	0.071	0.11
10	0.035	0.19	0.054	0.14
11	0.035	0.44	0.042	0.43
12	0.035	0.49	0.063	0.32
13	0.035	0.44	0.04	0.45
14	0.035	0.59	0.046	0.52
15	0.035	0.44	0.037	0.48
16	0.035	0.59	0.038	0.64
17	0.035	0.68	0.039	0.72
18	0.035	0.72	0.044	0.68
19	0.035	0.64	0.036	0.71
20	0.035	0.64	0.038	0.69
21	0.035	0.59	0.043	0.56
22	0.035	0.64	0.041	0.63
23	0.035	0.54	0.040	0.55
24	0.035	0.49	0.036	0.56
25	0.035	0.54	0.047	0.48

The overall pattern of velocities generated by limiting Manning’s n needs to be considered before accepting the improved VAF relation as the best velocity simulation outcome that can be obtained for velocity simulation. Using **Models\Velocity\Results\Cross section**, look at the velocity patterns obtained for each cross section at the three calibration discharges. How well do they match? Do you think that limiting Manning’s n has improved the overall velocity simulation across all transects over the full range of discharges?

At this point in the analysis, users would need to determine from the context of their particular application which set of velocity simulation options and results is best over what target flow ranges in choosing the appropriate velocity modeling approach. In some applications it may be desirable to use simulation results that minimize the error between measured and observed velocities over the full range of simulations. In other situations, the investigator may choose to use each single velocity calibration set only over a specific range of discharges. This is often the case where velocity patterns vary dramatically across cross section geometries as discussed in Chapter 2 of the manual.

**Step 7. Specifying n values for Problem Areas**

Look through Figures L6-10 to L6-45 for those cases where simulated discharge is equal to the calibration discharge. Note that some edge conditions are not well simulated due to being dry at the observed discharge. Table L6-4 contains a summary of the diagnostic conditions revealed by those figures. Some data errors can be seen and some velocity simulation problems stand out.

**Table L6-4.** Summary of data and simulation diagnostic conditions.

Sim Q	X-sec	Cal Q	Figure	
75.2	0	75.2	L6-10	Simulated velocity anomaly between 18 and 30, non-zero observed velocity in dry area on right bank
75.2	60	75.2	L6-13	Zero observed velocities in deep area near right bank
75.2	135	75.2	L6-16	Zero observed velocity in wet cell near right bank
75.2	201	75.2	L6-19	Zero observed velocity in wet cell near left bank
139	0	139	L6-23	Non-zero observed velocity in dry area on right bank
139	60	139	L6-26	Zero observed velocity in wet cell near both banks
139	135	139	L6-29	Zero observed velocities in wet cells near left bank, n may be too low near left bank
139	201	139	L6-32	Zero observed velocity in wet cells near both banks, VAF scaling very clear
250	0	250	L6-36	Observed velocity values reversed at right bank?
250	60	250	L6-39	Zero observed velocities in deep area near right bank
250	135	250	L6-42	n appears low at edge on left bank (sim velocity > obs velocity), odd velocities at 18 and 20
250	201	250	L6-45	n appears low at edge on both banks (sim velocity > obs velocity)

In **\Edit\Cross Sections\Coordinate Data** you can set Manning's n values for specific cells on each cross section. After examining how VELSIM handles edges (or other parts of the channel) automatically, you may wish to enter n values for specific cells and rerun the velocity simulation. Roughness values set for specific cells apply at all discharges so you must take care that a good n value for one condition does not perturb the results for other discharges. Try setting n values on the left bank of cross section 201 for 250 cfs, rerun the simulation, and see how velocity values are affected at all flows.

The user is encouraged to try additional velocity simulation options within VELSIM (e.g., placing specific Manning's n values at specific verticals or using the NMIN option). Examine the effects on the velocity simulations in terms of both the VAF relationships and observed versus predicted velocity distributions at each cross section. Remember that water surface simulations for each cross section affect the velocity simulations. In some cases water surface errors can be the main contributing factors for discrepancies between observed and predicted velocities.

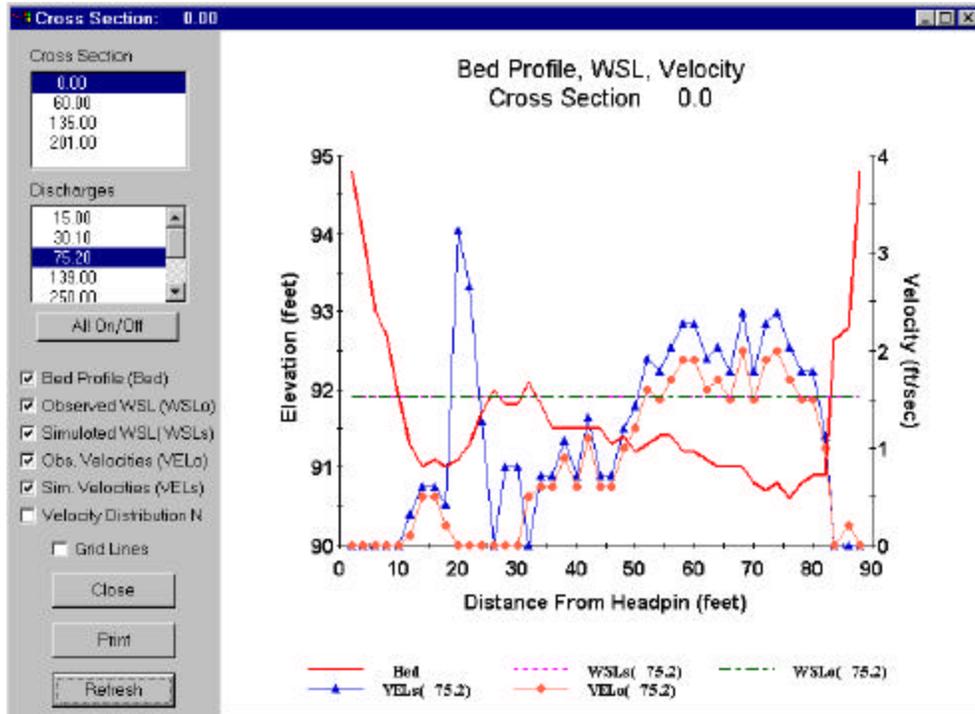


Figure L6-10. Simulated and observed velocity profile for 75.2 cfs at Xsec 0, Cal Set 75.2.

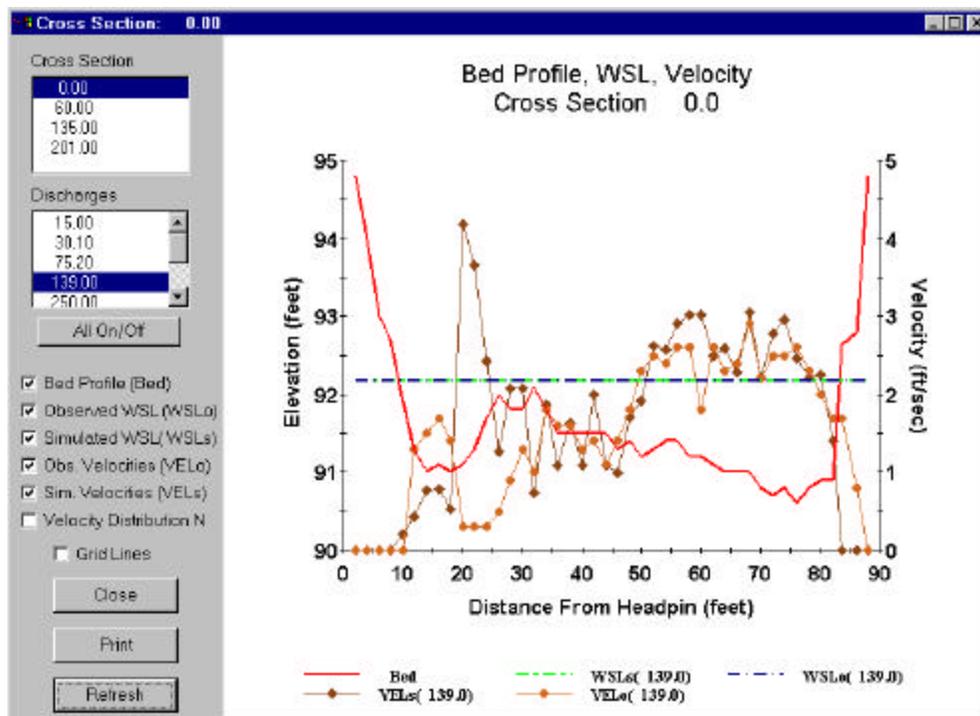


Figure L6-11. Simulated and observed velocity profile for 139 cfs at Xsec 0, Cal Set 75.2.

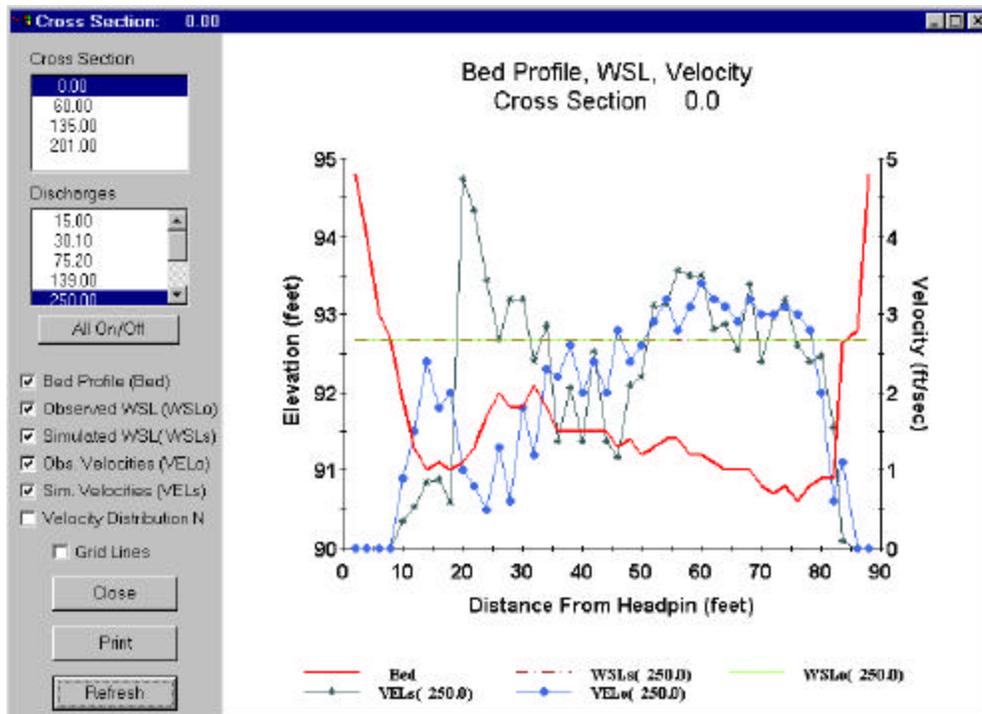


Figure L6-12. Simulated and observed velocity profile for 250 cfs at Xsec 0, Cal Set 75.2.

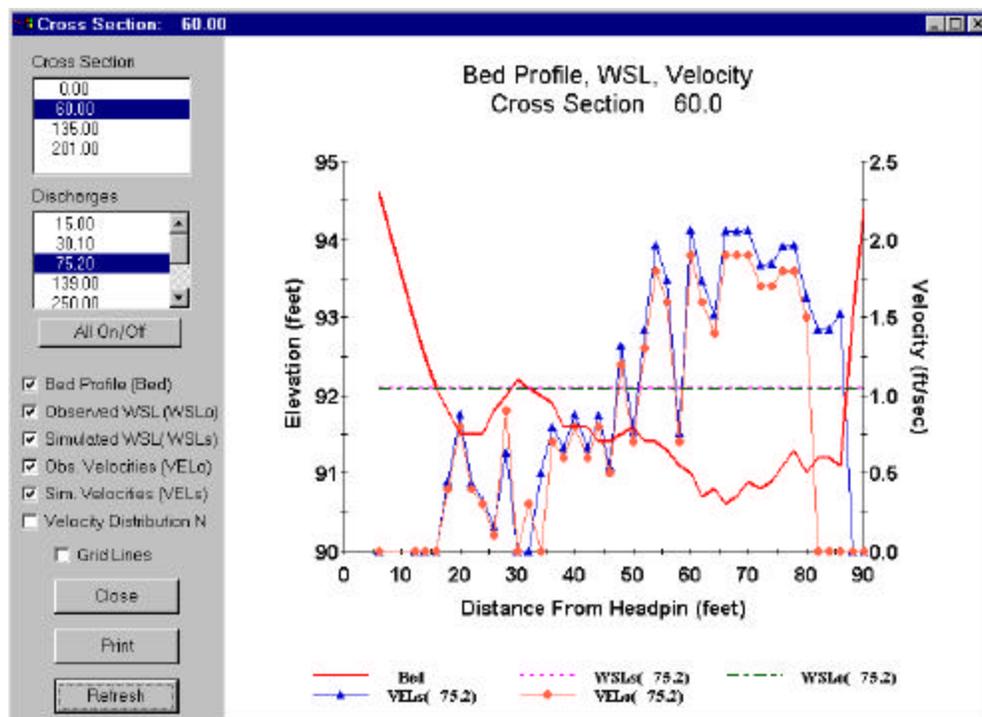


Figure L6-13. Simulated and observed velocity profile for 75.2 cfs at Xsec 60, Cal Set 75.2.

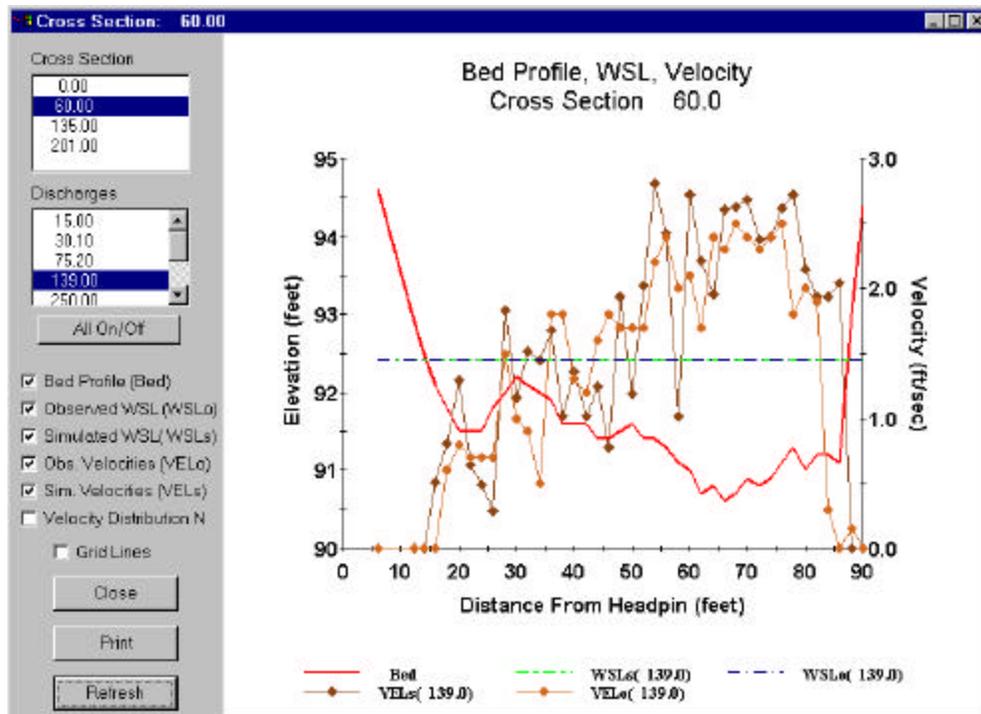


Figure L6-14. Simulated and observed velocity profile for 139 cfs at Xsec 60, Cal Set 75.2.

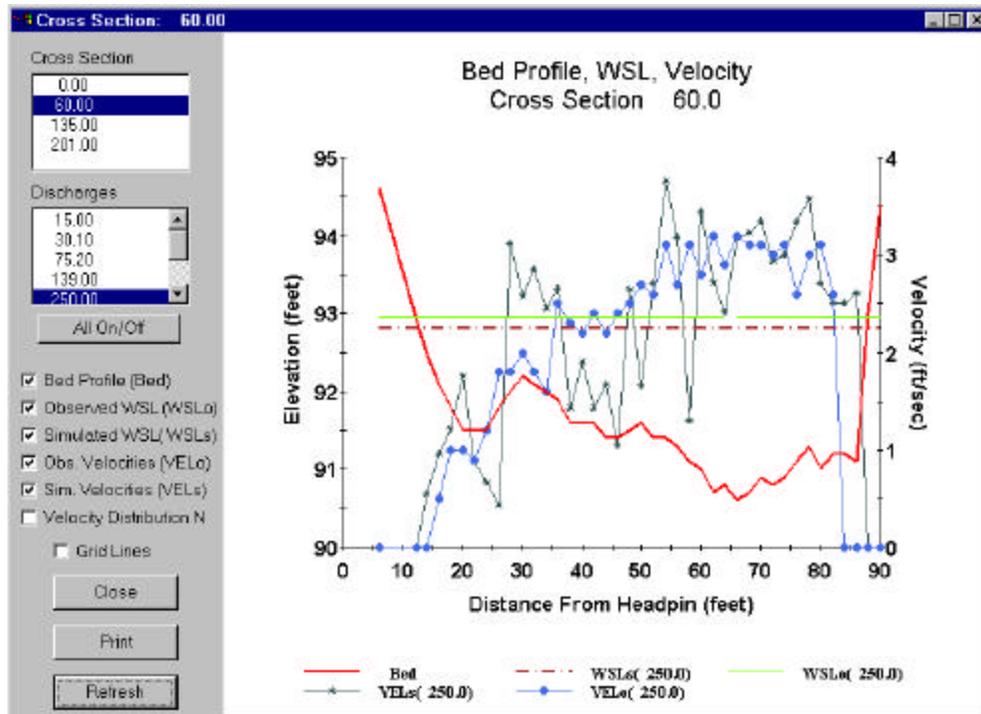


Figure L6-15. Simulated and observed velocity profile for 250 cfs at Xsec 60, Cal Set 75.2.

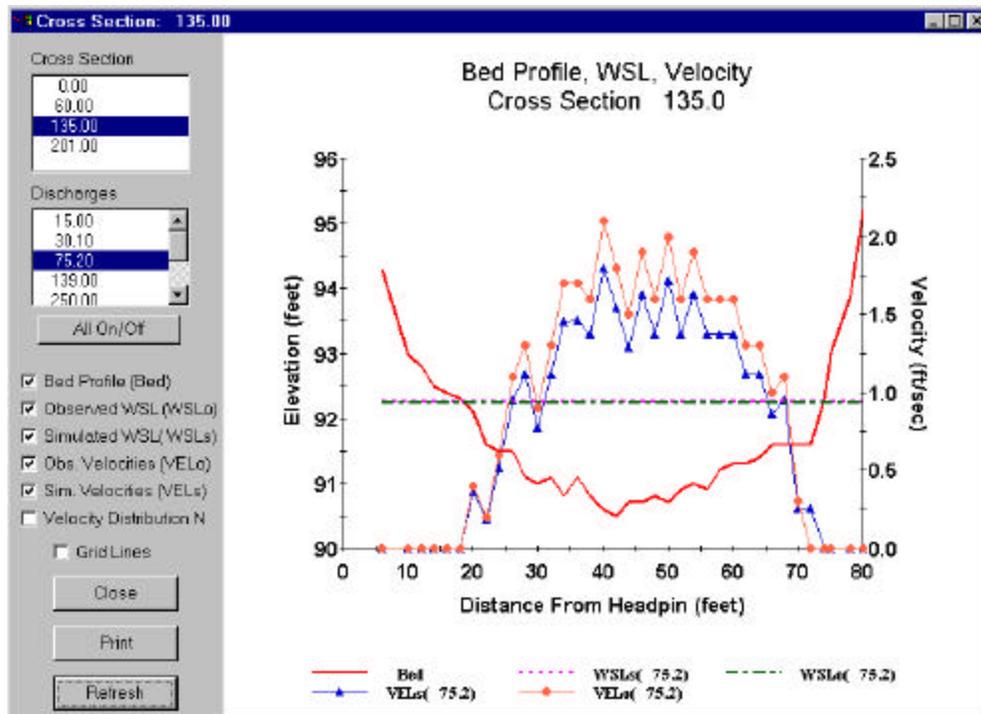


Figure L6-16. Simulated and observed velocity profile for 75.2 cfs at Xsec 135, Cal Set 75.2.

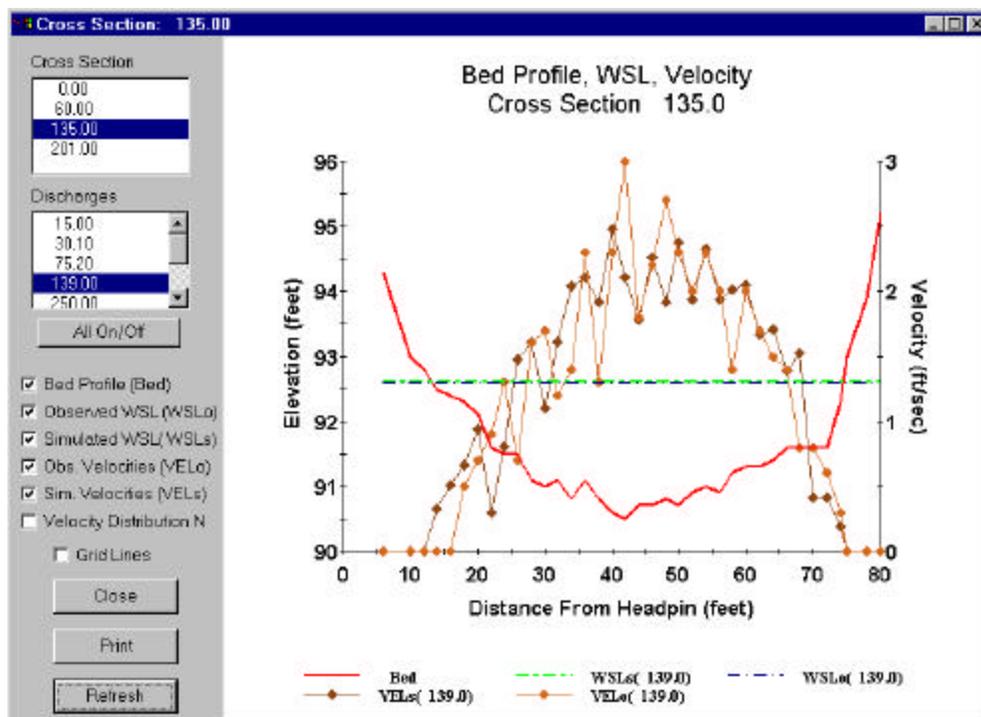


Figure L6-17. Simulated and observed velocity profile for 139 cfs at Xsec 135, Cal Set 75.2.

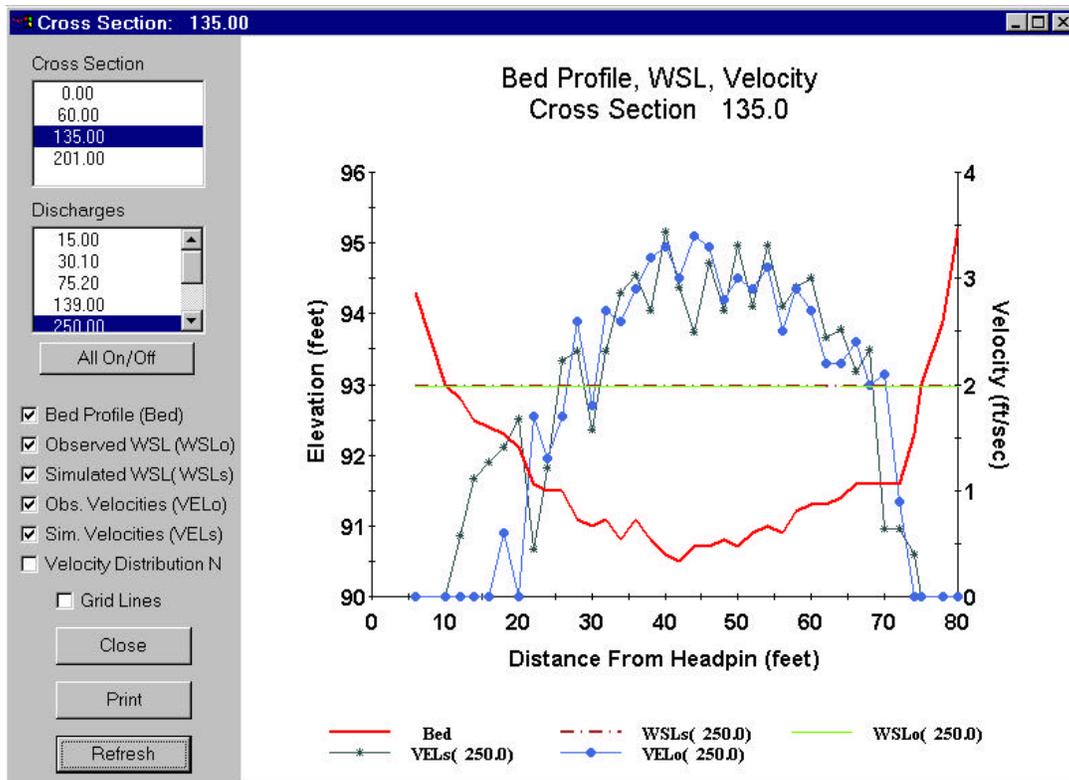


Figure L6-18. Simulated and observed velocity profile for 250 cfs at Xsec 135, Cal Set 75.2.

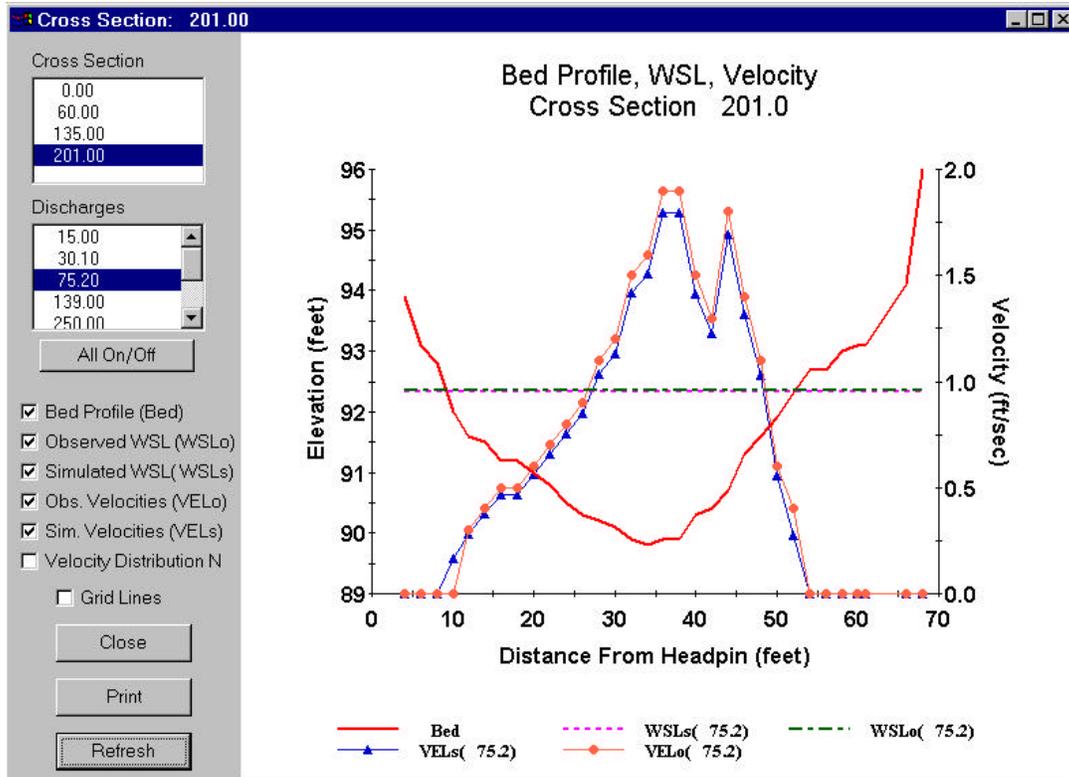


Figure L6-19. Simulated and observed velocity profile for 75.2 cfs at Xsec 201, Cal Set 75.2.

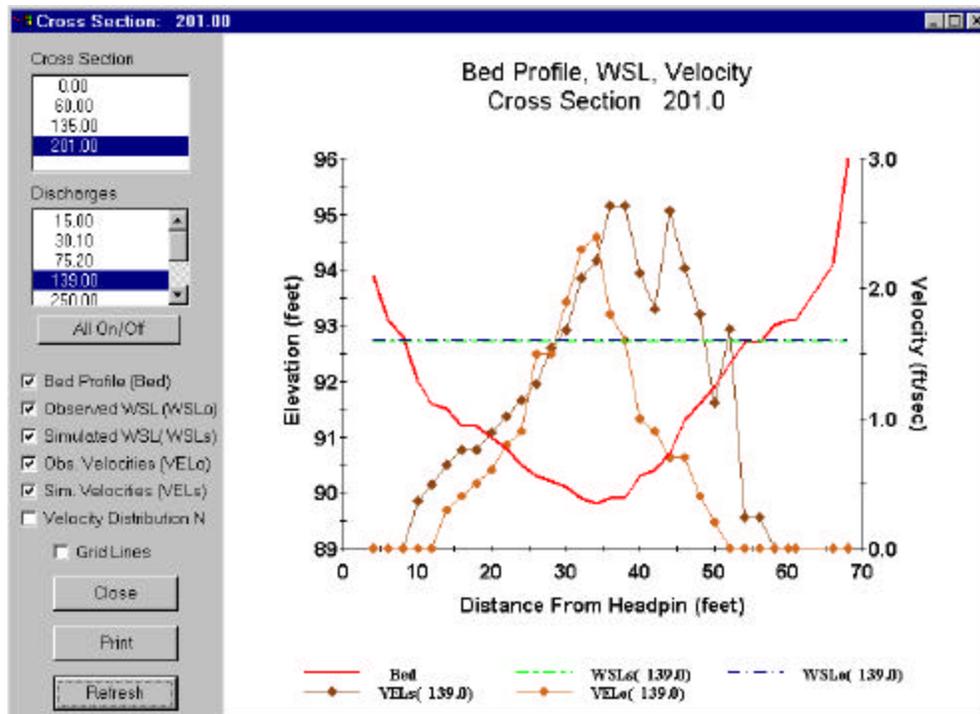


Figure L6-20. Simulated and observed velocity profile for 139 cfs at Xsec 201, Cal Set 75.2.

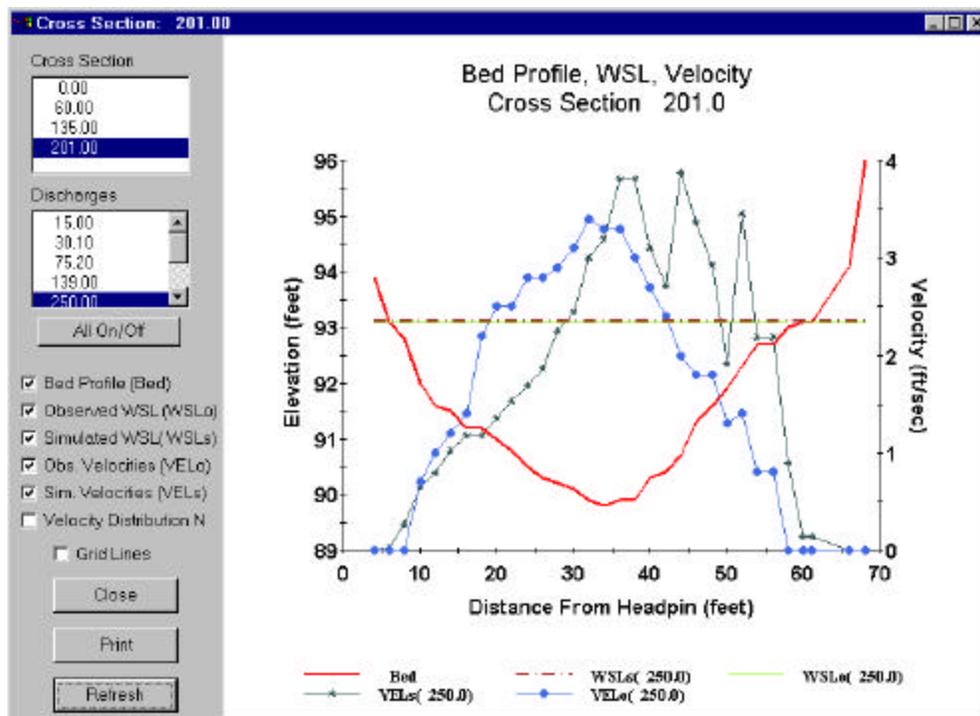


Figure L6-21. Simulated and observed velocity profile for 250 cfs at Xsec 201, Cal Set 75.2.

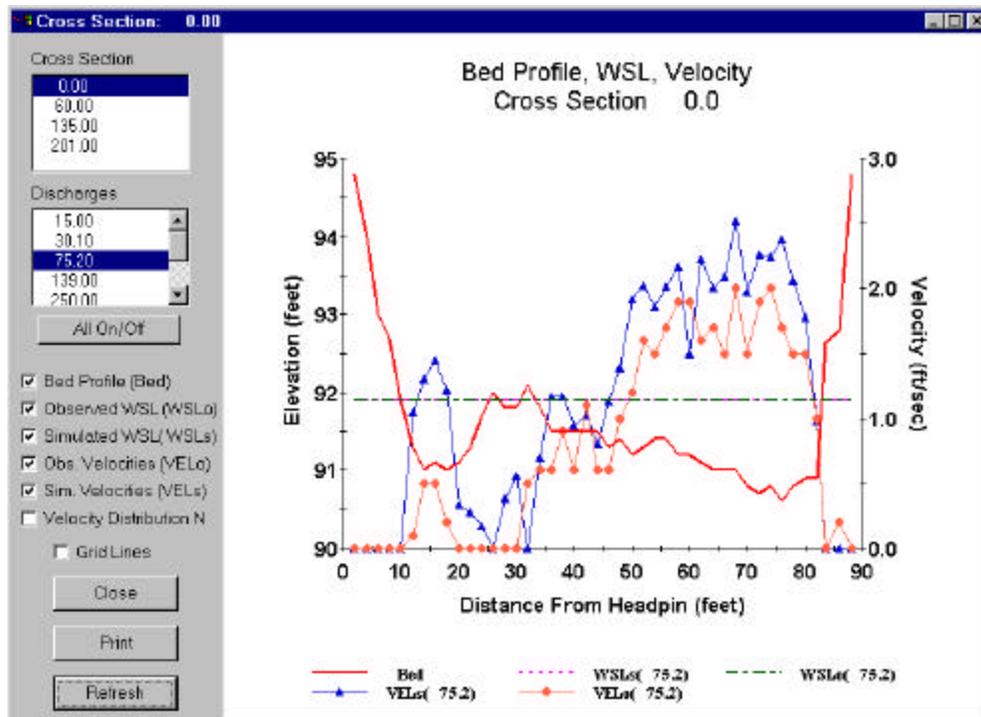


Figure L6-22. Simulated and observed velocity profile for 75.2 cfs at Xsec 0, Cal Set 139.

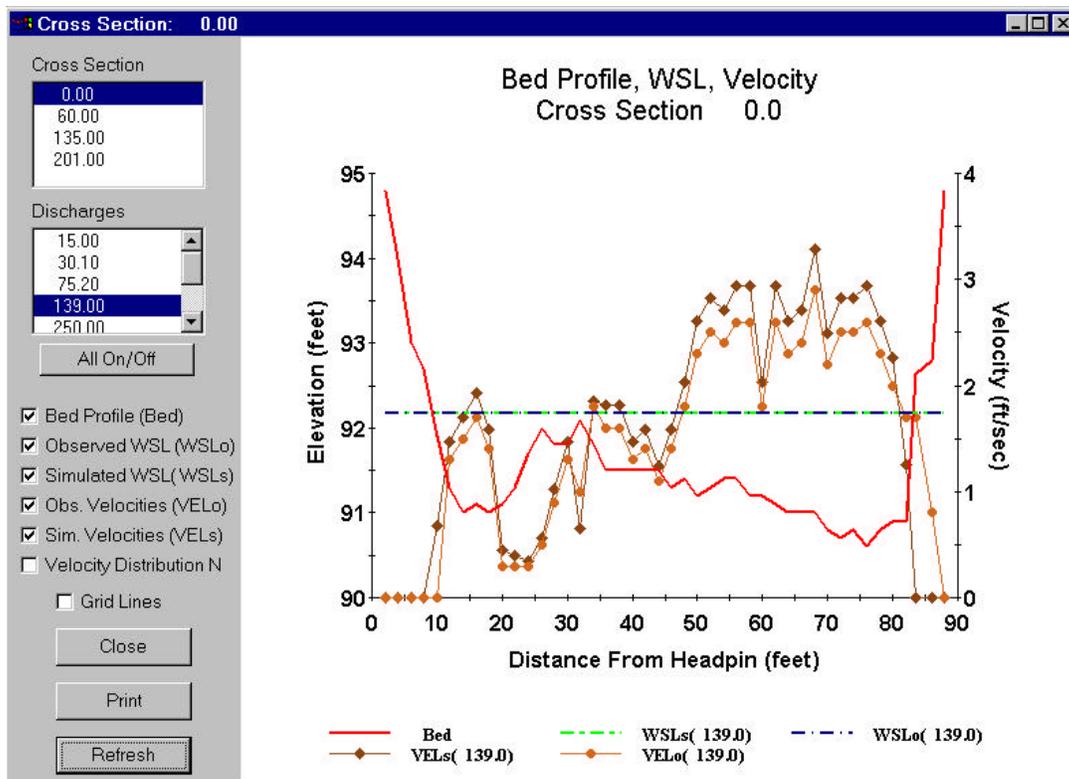


Figure L6-23. Simulated and observed velocity profile for 139 cfs at Xsec 0, Cal Set 139.

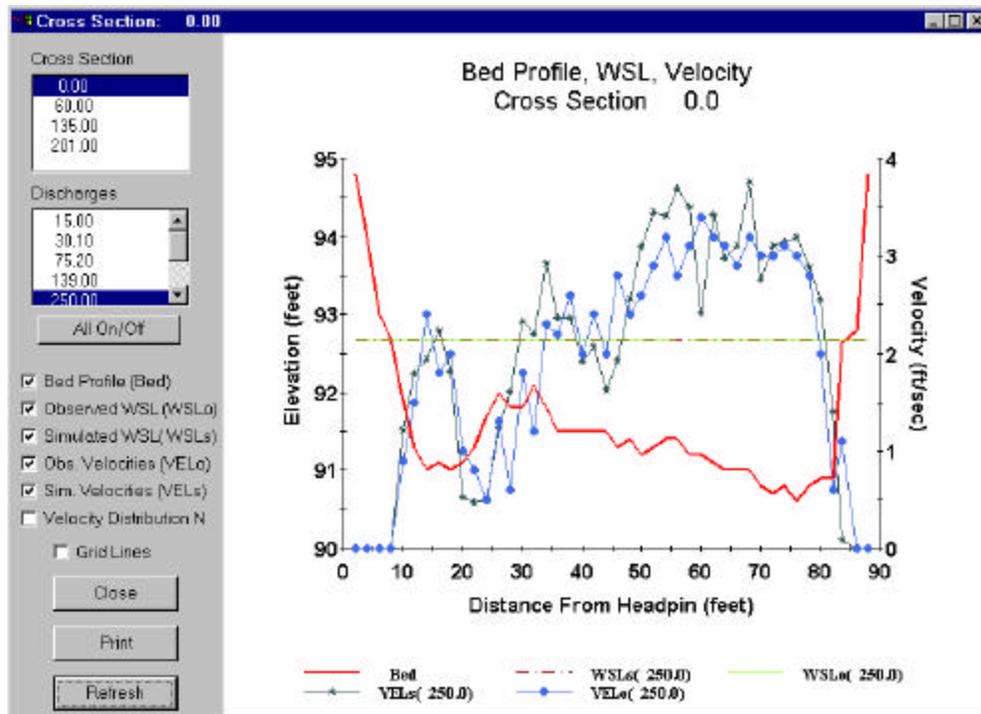


Figure L6-24. Simulated and observed velocity profile for 250 cfs at Xsec 0, Cal Set 139.

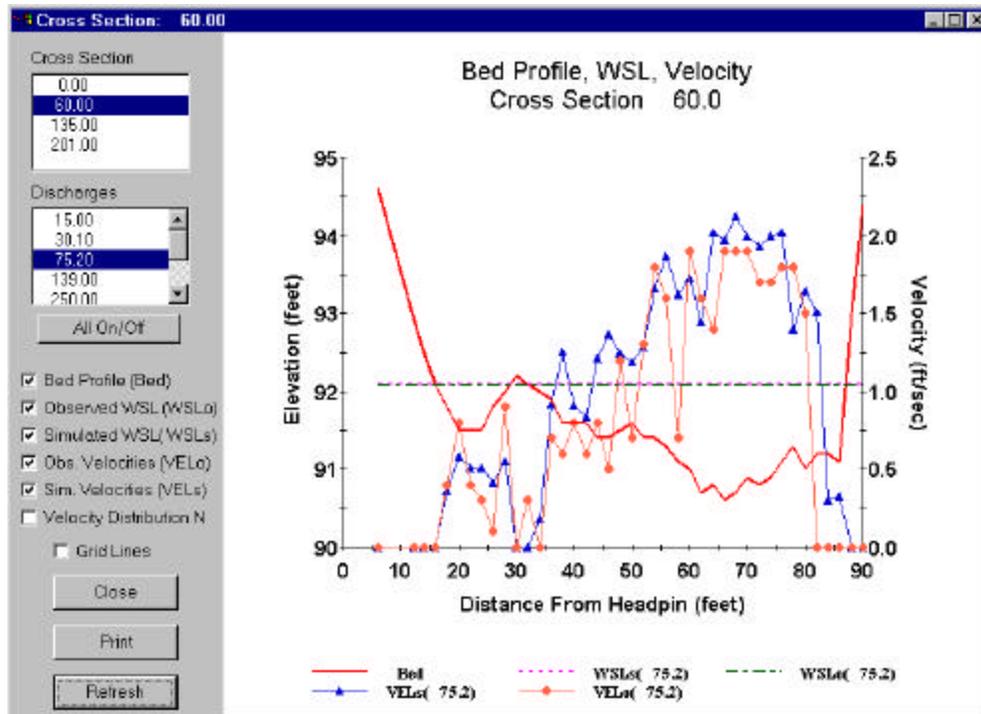


Figure L6-25. Simulated and observed velocity profile for 75.2 cfs at Xsec 60, Cal Set 139.

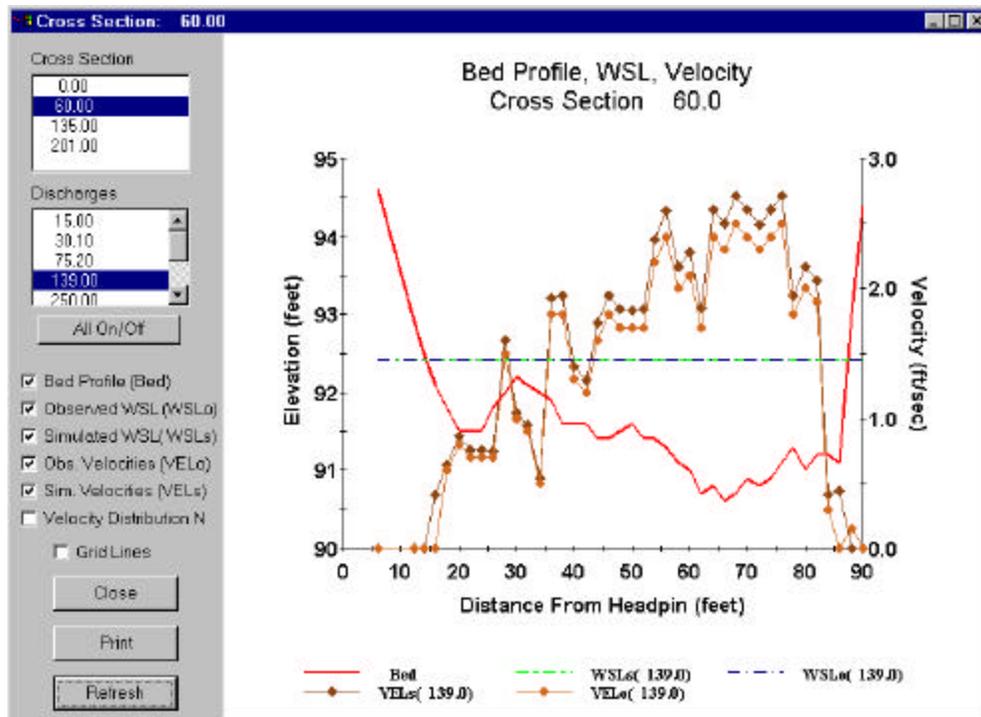


Figure L6-26. Simulated and observed velocity profile for 139 cfs at Xsec 60, Cal Set 139.

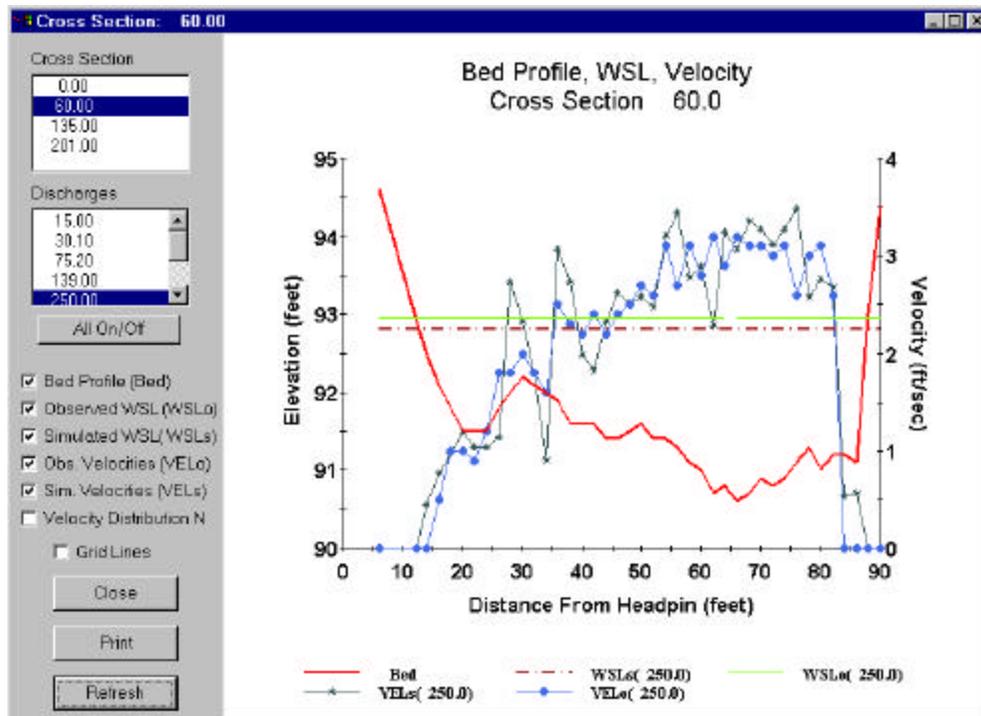


Figure L6-27. Simulated and observed velocity profile for 250 cfs at Xsec 60, Cal Set 139.

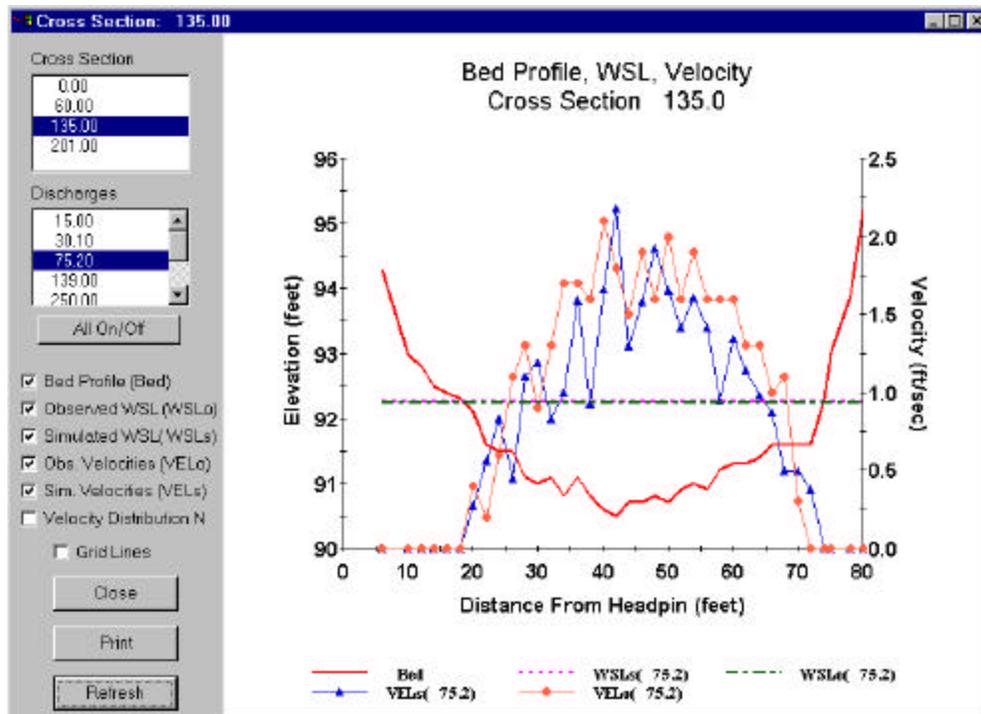


Figure L6-28. Simulated and observed velocity profile for 75.2 cfs at Xsec 135, Cal Set 139.

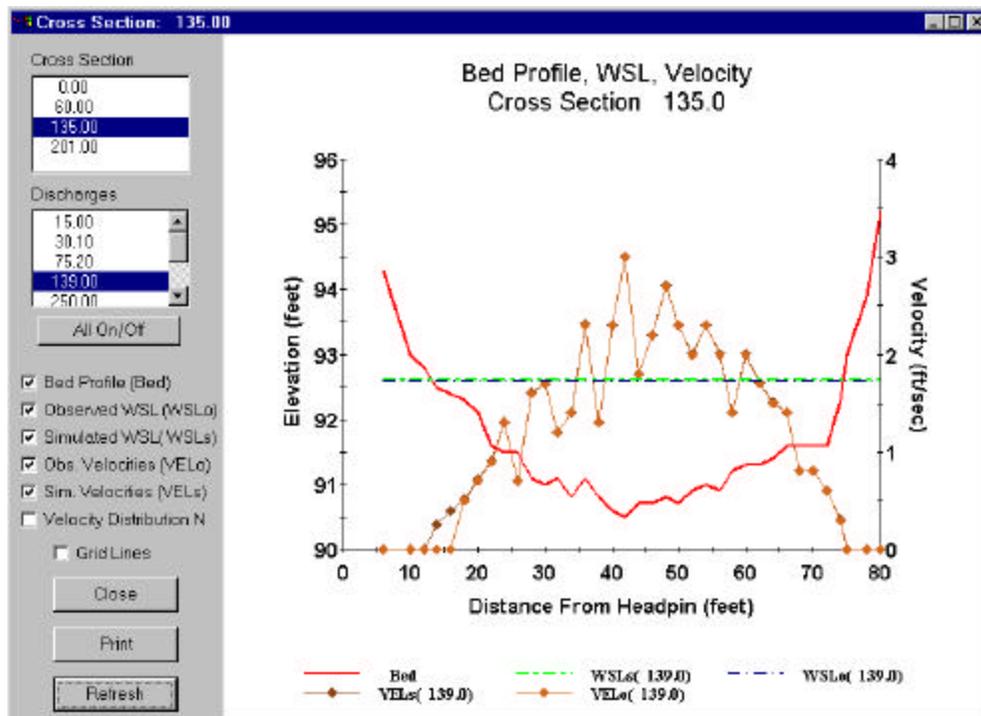


Figure L6-29. Simulated and observed velocity profile for 139 cfs at Xsec 135, Cal Set 139.

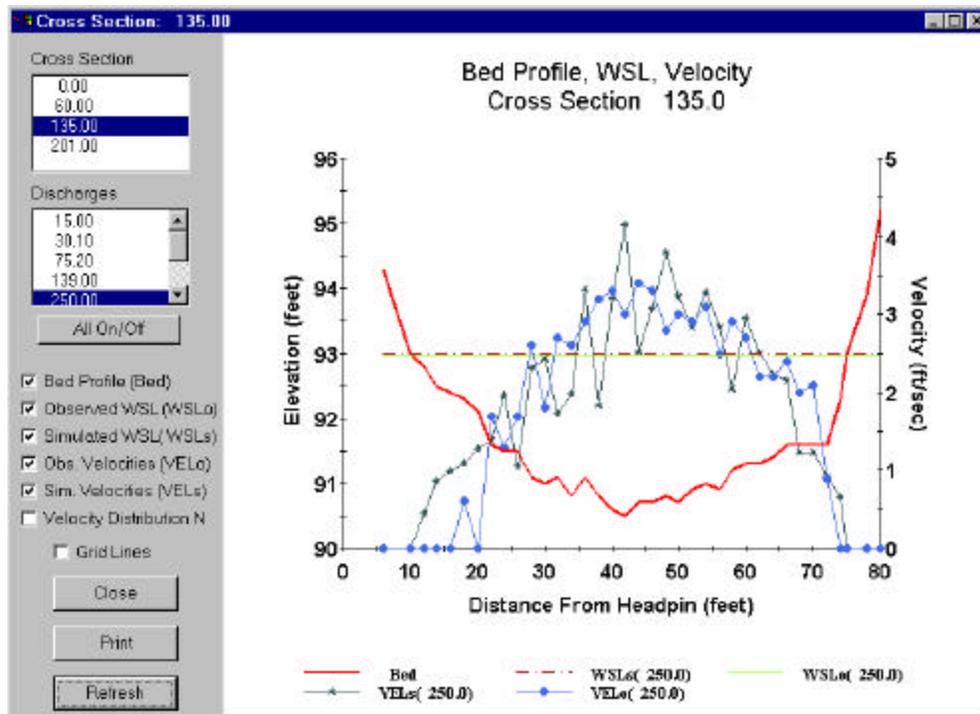


Figure L6-30. Simulated and observed velocity profile for 250 cfs at Xsec 135, Cal Set 139.

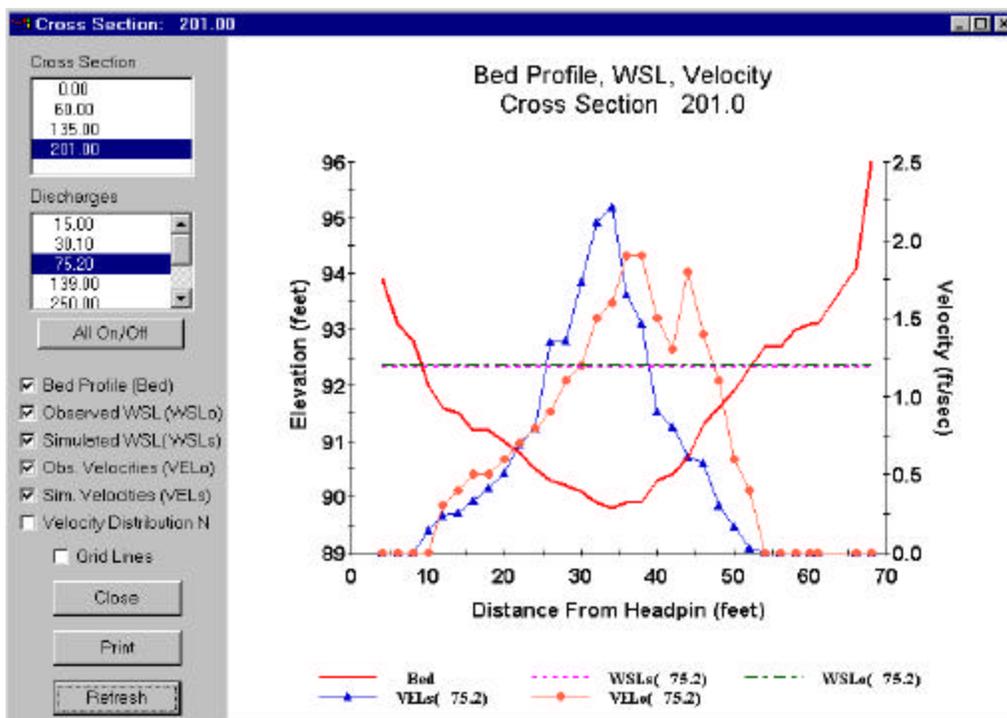


Figure L6-31. Simulated and observed velocity profile for 75.2 cfs at Xsec 201, Cal Set 139.

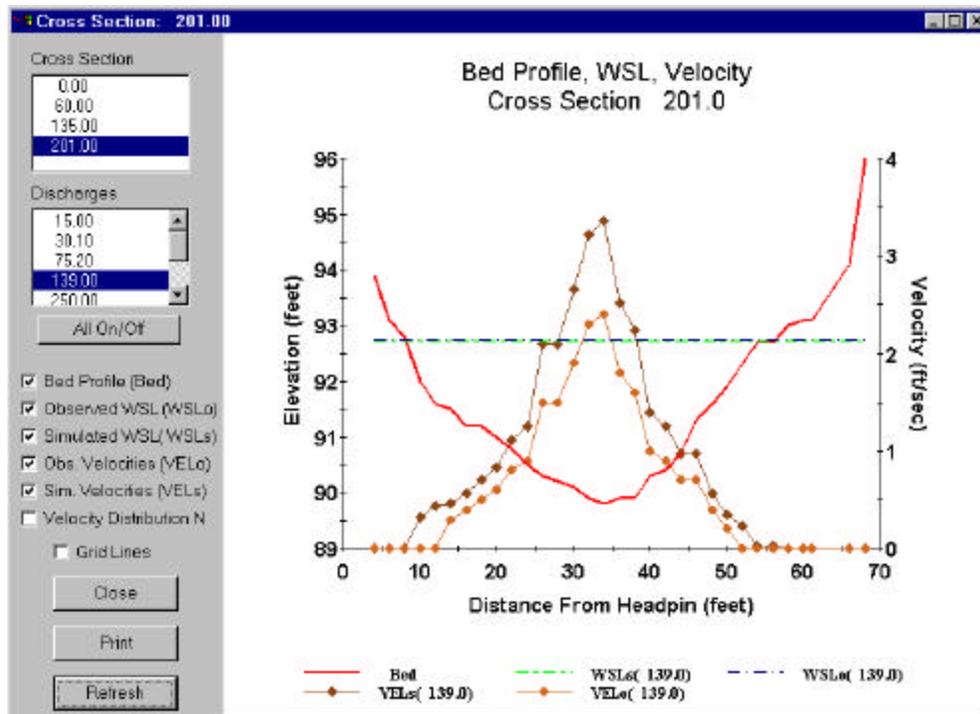


Figure L6-32. Simulated and observed velocity profile for 139 cfs at Xsec 201, Cal Set 139.

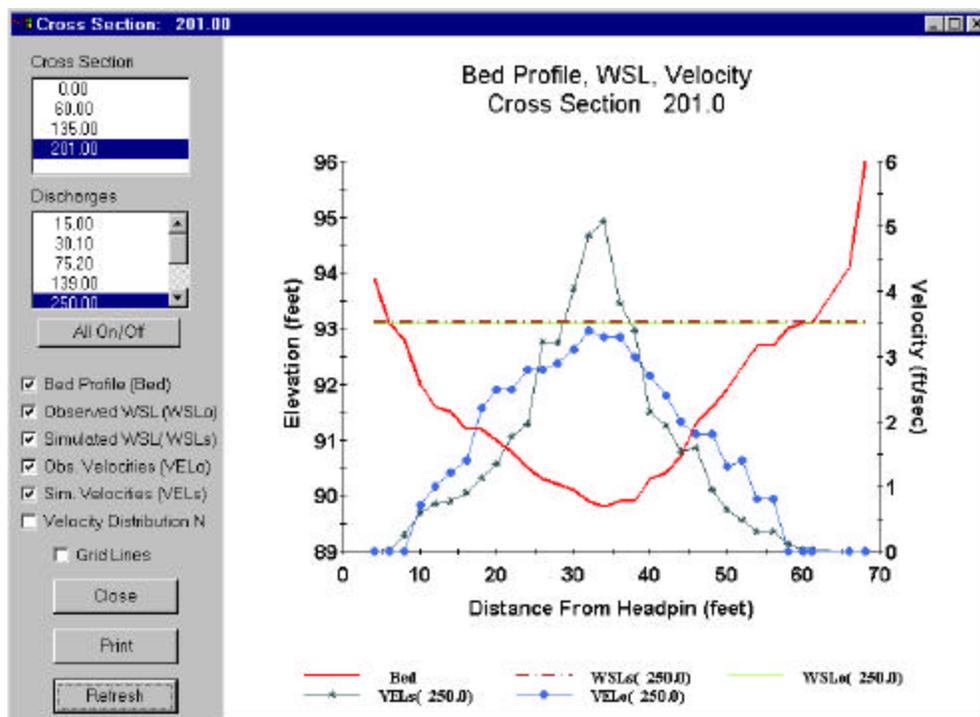


Figure L6-33. Simulated and observed velocity profile for 250 cfs at Xsec 201, Cal Set 139.

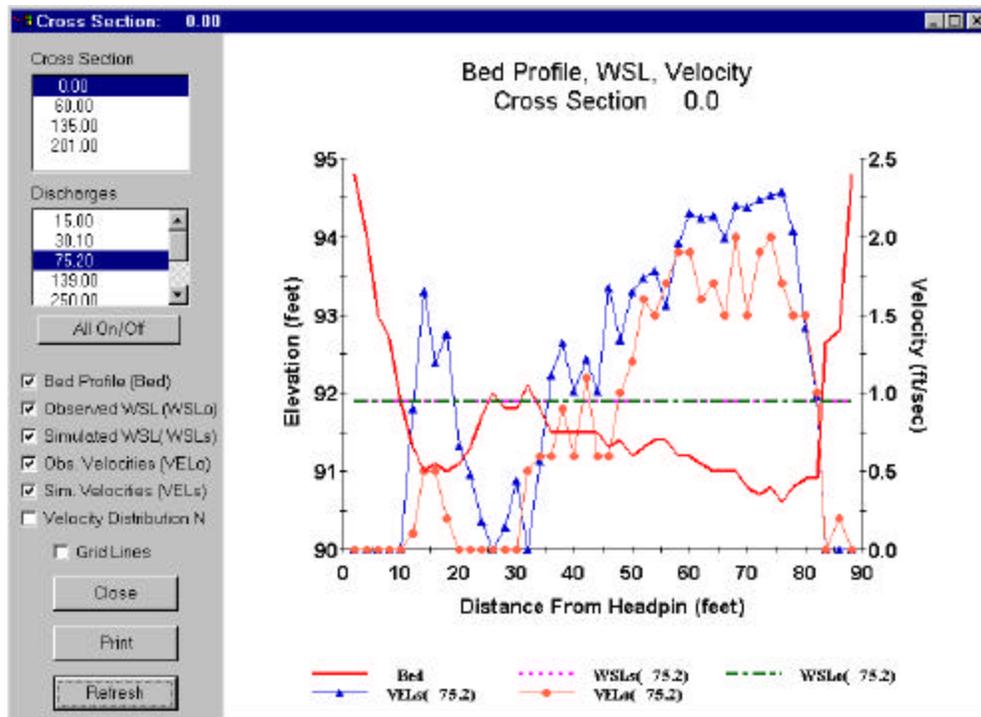


Figure L6-34. Simulated and observed velocity profile for 75.2 cfs at Xsec 0, Cal Set 250.

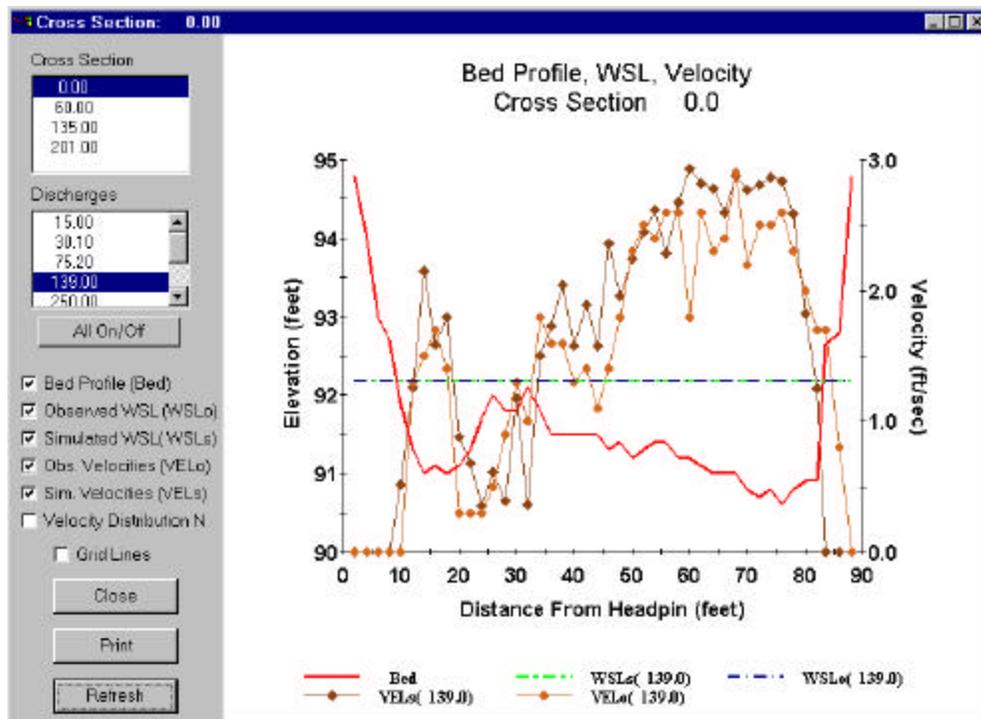


Figure L6-35. Simulated and observed velocity profile for 139 cfs at Xsec 0, Cal Set 250.

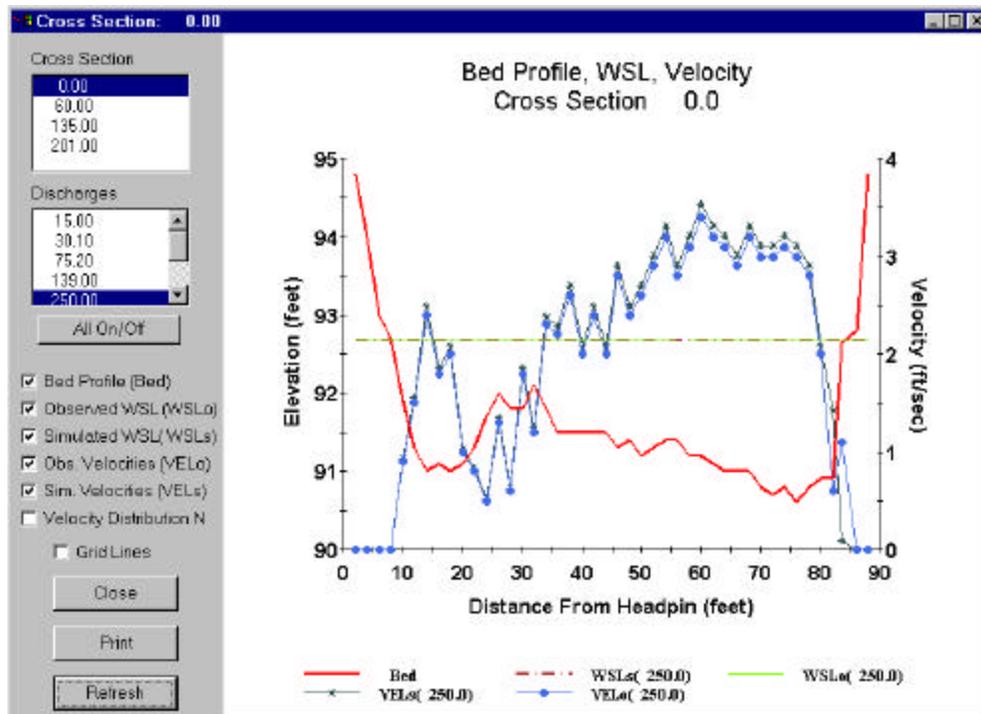


Figure L6-36. Simulated and observed velocity profile for 250 cfs at Xsec 0, Cal Set 250.

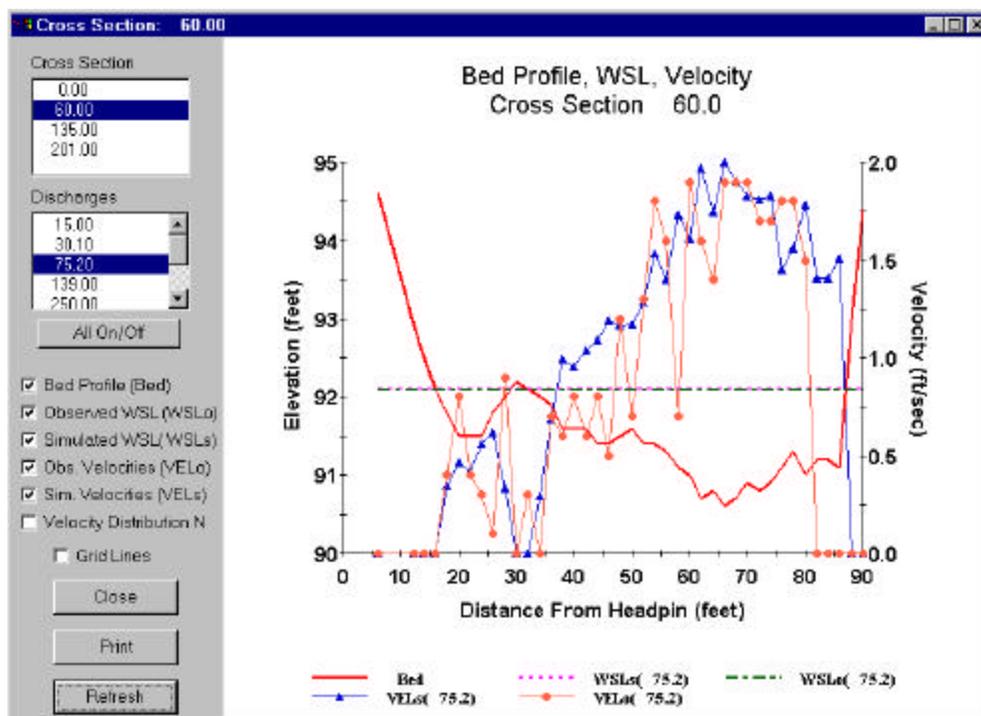


Figure L6-37. Simulated and observed velocity profile for 75.2 cfs at Xsec 60, Cal Set 250.

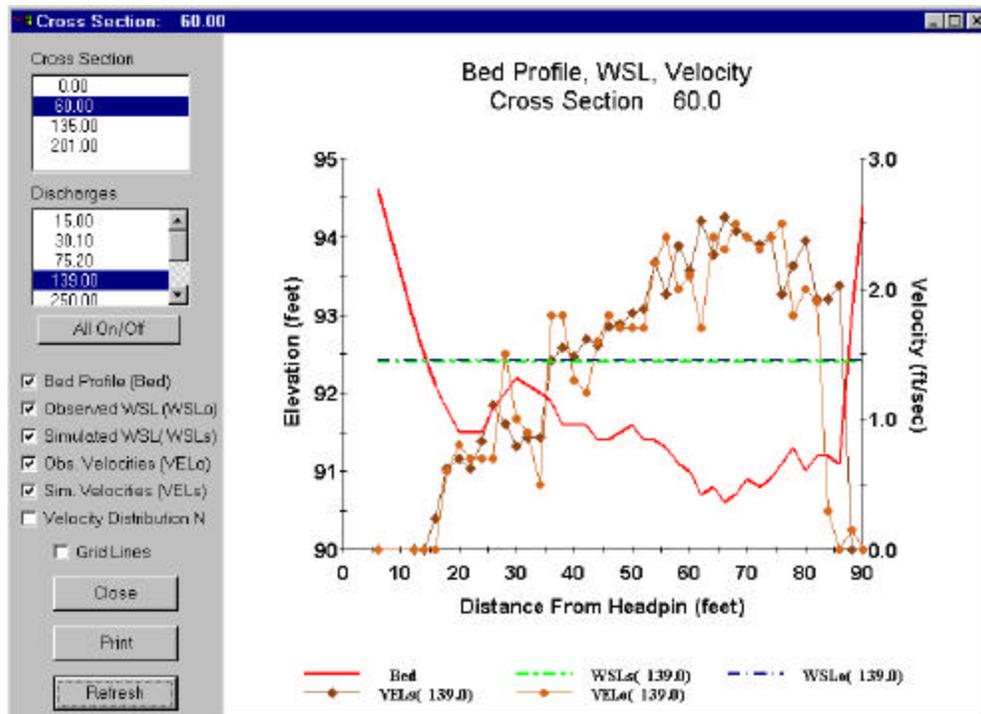


Figure L6-38. Simulated and observed velocity profile for 139 cfs at Xsec 60, Cal Set 250.

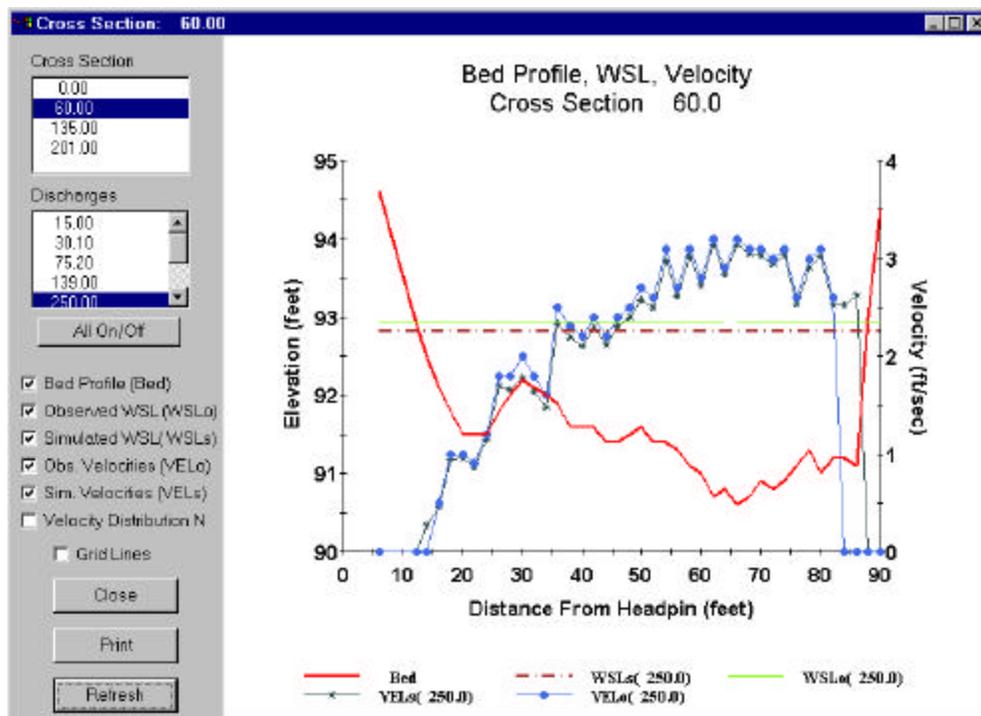


Figure L6-39. Simulated and observed velocity profile for 250 cfs at Xsec 60, Cal Set 250.

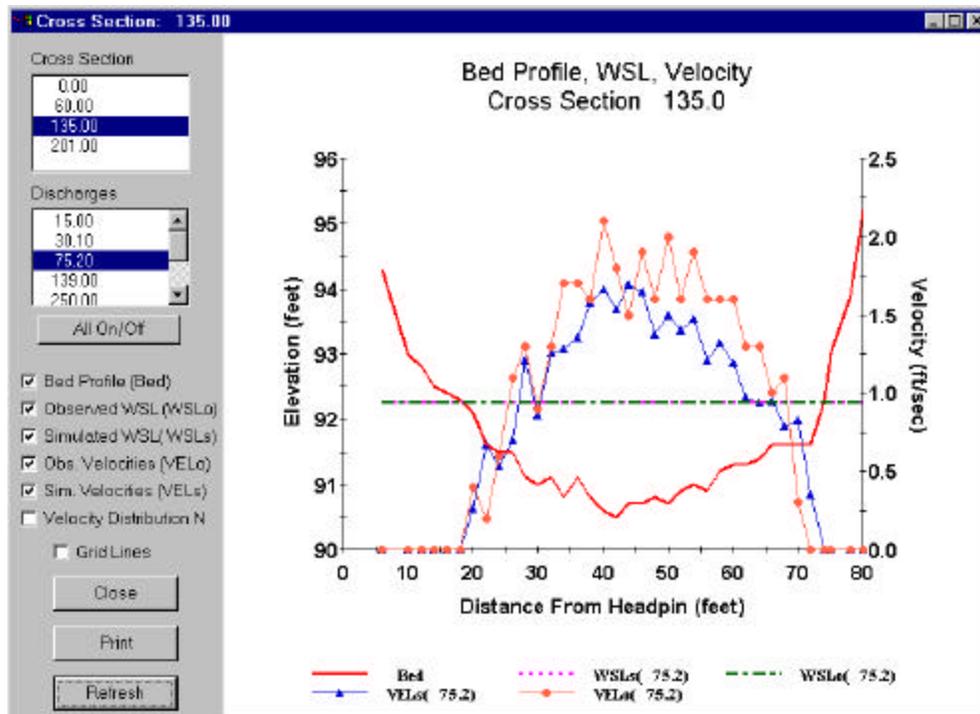


Figure L6-40. Simulated and observed velocity profile for 75.2 cfs at Xsec 135, Cal Set 250.

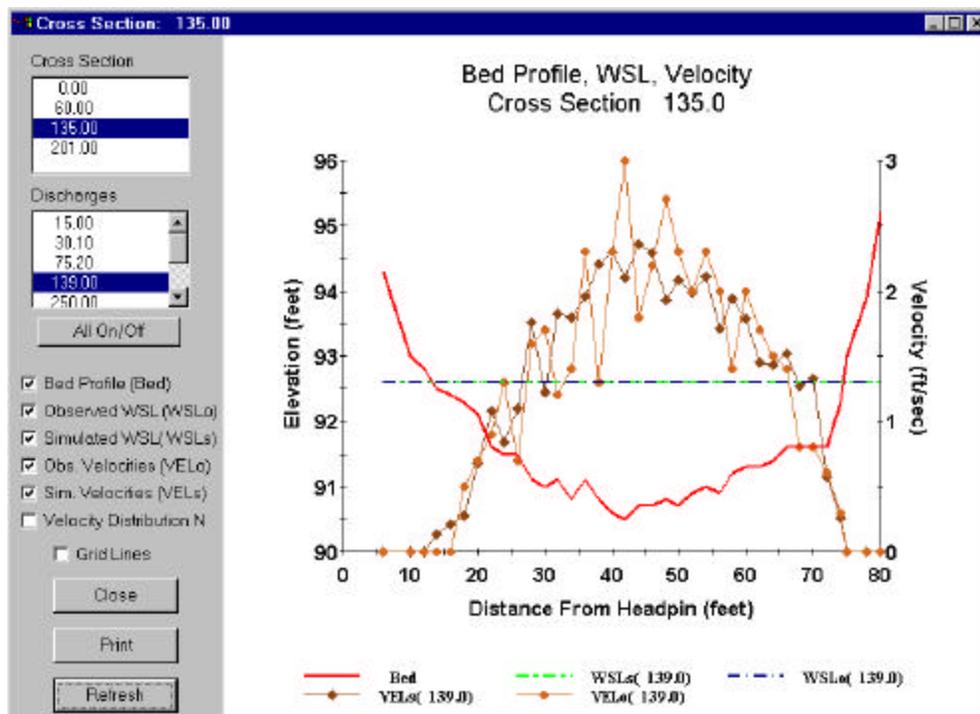


Figure L6-41. Simulated and observed velocity profile for 139 cfs at Xsec 135, Cal Set 250.

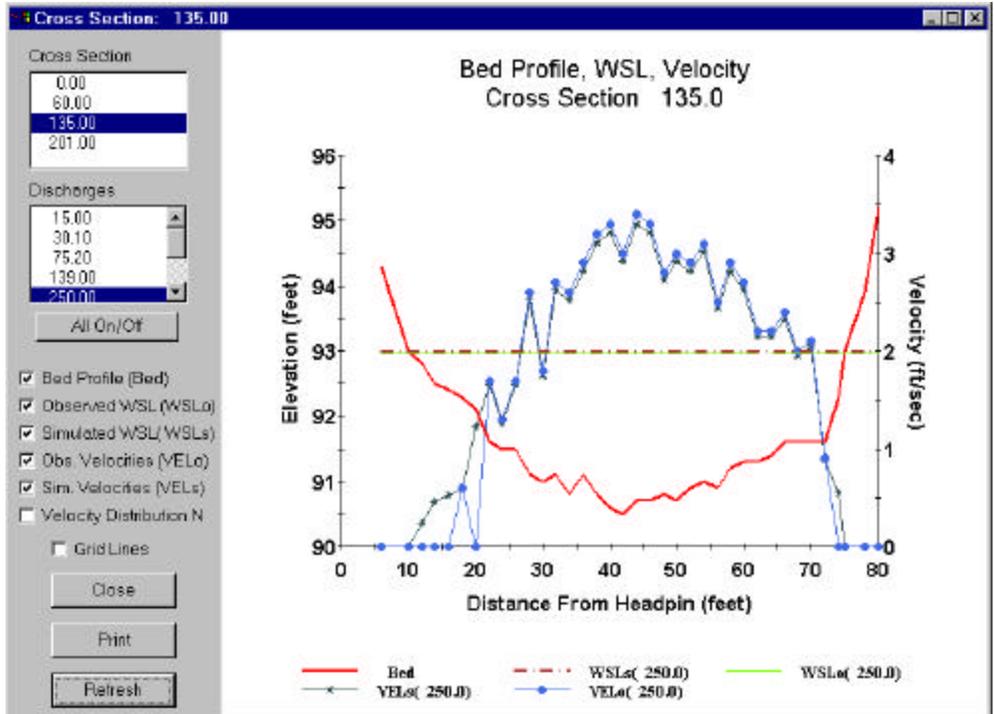


Figure L6-42. Simulated and observed velocity profile for 250 cfs at Xsec 135, Cal Set 250.

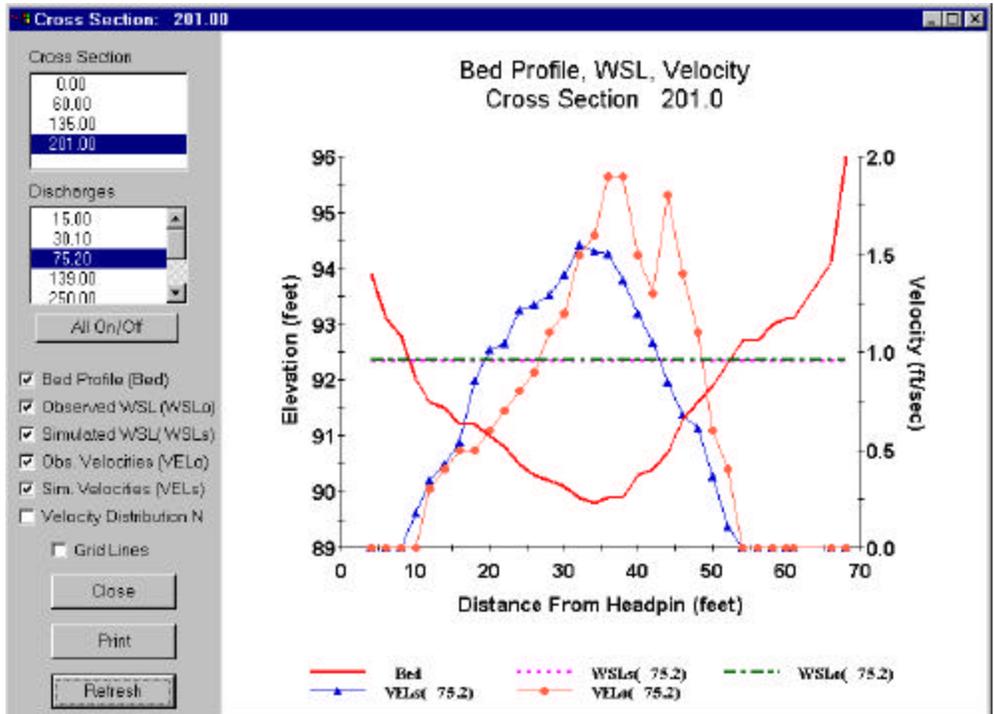


Figure L6-43. Simulated and observed velocity profile for 75.2 cfs at Xsec 201, Cal Set 250.

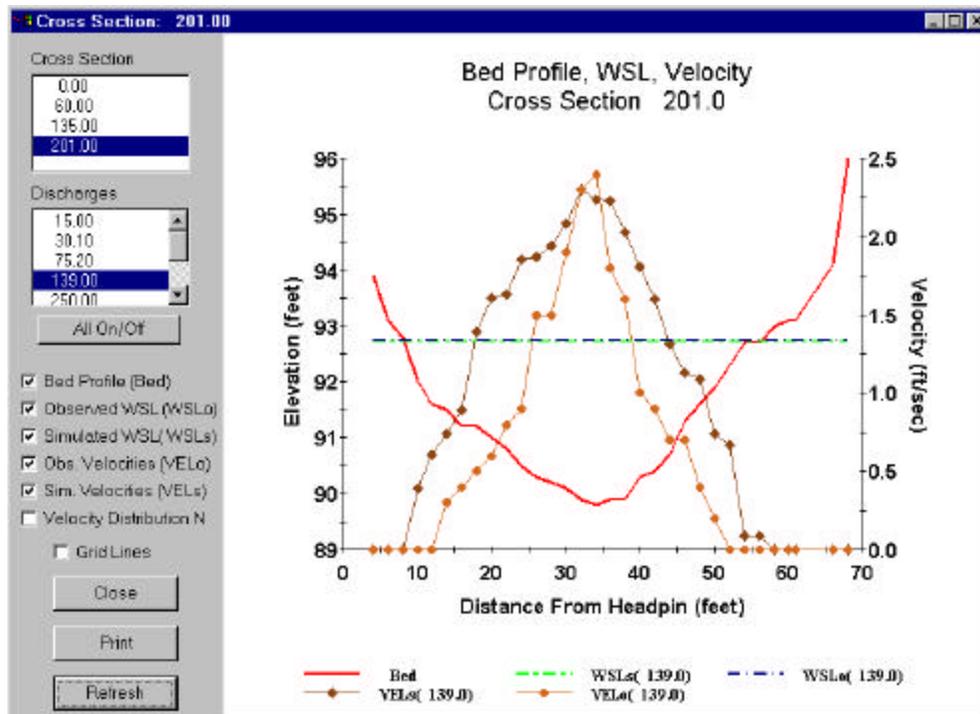


Figure L6-44. Simulated and observed velocity profile for 139 cfs at Xsec 201, Cal Set 250.

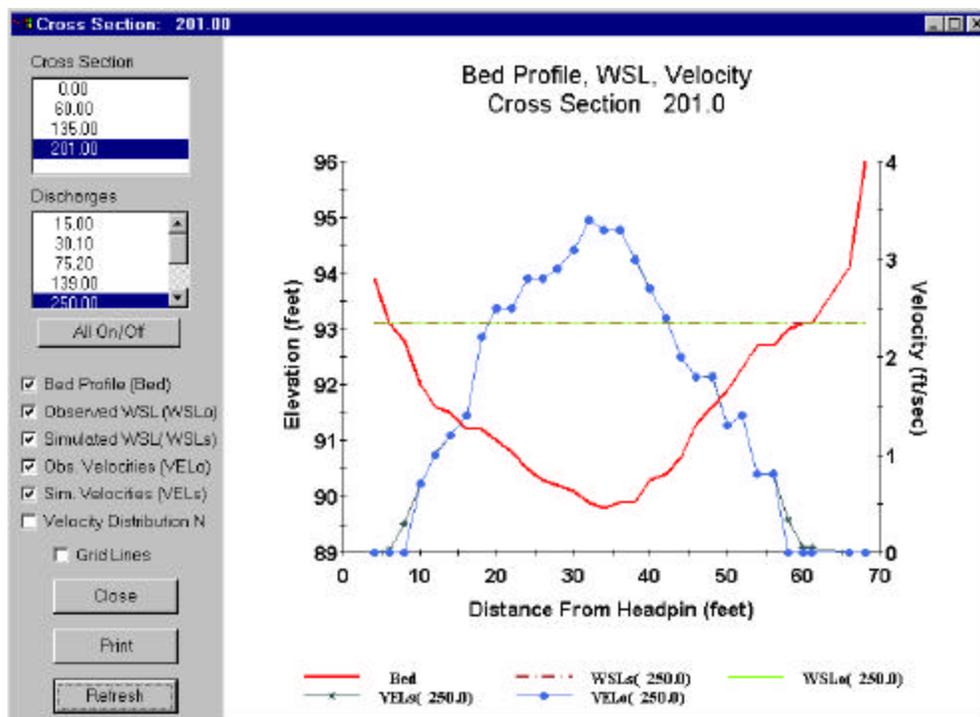


Figure L6-45. Simulated and observed velocity profile for 250 cfs at Xsec 201, Cal Set 250.

## Laboratory 7. Habitat Suitability Criteria in PHABSIM

### Objective

The objective of this laboratory is to introduce the use of habitat suitability criteria (HSC) within the PHABSIM for Windows system. The laboratory will illustrate the method used to input HSC for use within PHABSIM and examine several of the available criteria maintenance programs.

**Data Files Used:** Lab7.phb, Curvlib.phb

### Introduction

The principal means by which PHABSIM integrates biological information for habitat modeling purposes is through the use of HSC (sometimes referred to as suitability-of-use criteria) within the various habitat models. The laboratory will not deal with the specifics of HSC development. However, the various means by which HSC can be entered and manipulated within PHABSIM will be examined. See Bovee et al. (1998) for a detailed description of HSC and their development.

In PHABSIM, HSC data are created, edited, and stored in the **\Edit\Suitability Curves** section of the program. These data contain the HSC coordinate data for species and life stages in terms of depth, velocity, channel index, and temperature.

HSCs for a particular species and life stage are typically grouped into three sets of HSC data representing the relationships between depth, velocity, and channel index and their corresponding suitability values.

In PHABSIM, HSC data are referenced by HSC numbers. Although these HSC numbers can be arbitrarily assigned within any PHABSIM project file, the structure of the numbers does control the format of the output results from the habitat programs as will be discussed later in this lab. The steps in this lab are designed to build basic skill in using HSC w/in PHABSIM.

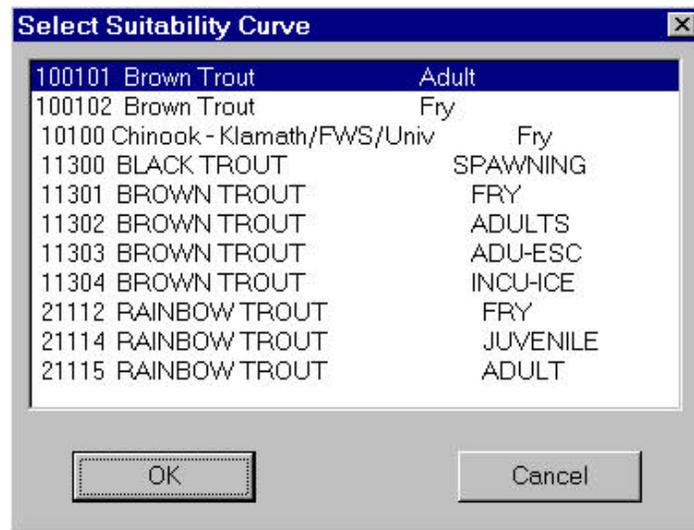
#### Step 1. HSC Numbering

HSC numbering within PHABSIM allows the user to organize HSC curves by species groups. The basic format for HSC numbering is:

xxxxyy

The first four digits (i.e., xxxx) denote the >species=, while the last two digits (i.e., yy) denote the >life stage=. Figure L7-1 contains a list of habitat suitability criteria for use in a particular study. This list is obtained by clicking **\Edit\Suitability Curves\Curves>Select by ID**.

The **Graph** button in the **\Edit\Suitability Curves** window allows you to view individual habitat suitability criteria graphically. To view all HSC for a species/life stage, select **Display All Graphs** in the **\Edit\Suitability Curves\Curves** menu. Figure L7-2 shows an example of the resulting plot. Note that there are no temperature HSC values in this curve set for Black Trout.



**Figure L7-1.** List of suitability curves showing species and life stage numbering.

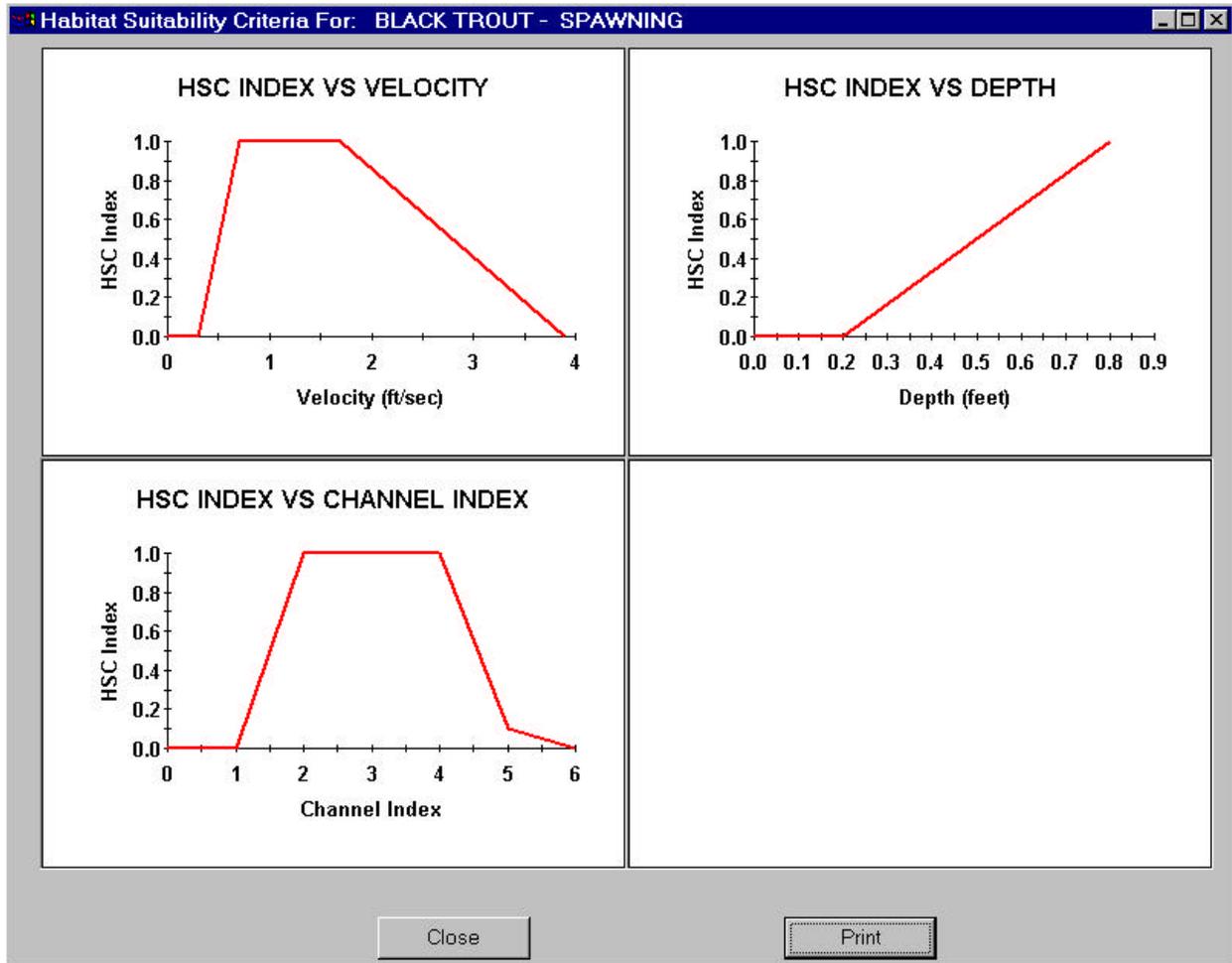
Note that each HSC set (i.e., velocity, depth, and channel index) is associated with a unique HSC number for each species and life stage. In the example above, the user should identify that Rainbow Trout Fry has a HSC number of 21112. HSC number 21114, on the other hand, identifies the Rainbow Trout Juvenile curve set. Be sure you recognize how this follows the numbering convention described above.

## Step 2: HSC Data Structure in PHABSIM

Move to **\Edit\Suitability Curves** in the SAMPLE.phb project and click **Select\By ID**. This displays a list (as in Figure L7-1) of the HSC curves that have been entered in the sample project including curve number, species, and life stage. New curves are entered by clicking the **\Edit \Suitability Curves\File** menu item, selecting **New Curve**, then filling in the boxes for Curve number, Species, and Life stage. Enter the HSC values in the table shown in that window (the first table is velocity). To change from velocity to depth, channel index or temperature, click the appropriate radio button in the **Curve Type** box to the upper right. Click the desired radio button (i.e., depth) and enter the HSC values in the table. Be sure to fill in all HSC tables before exiting. Habitat suitability criteria are discussed in Chapter 3 of the manual. Remember the PHABSIM convention that all HSC curves must begin at 0 and end at 100. In most situations the starting and starting values will be 0.0, 0.0 and ending values will be 100.0, 0.0. When might this not be the case?

In the suitability curve-editing portion of our Sample project, select Rainbow Trout Fry and note that the first velocity coordinate point at a velocity of 0.0 has a suitability value of 1.00. Note the last value. Again, failure to include the coordinate points with 100 for all curve sets will result in an error message indicating that the 100 value has not been entered. You cannot exit HSC data entry until all curves have final values of 100.

While in the **\Edit\Suitability Curves** window, each HSC set can be viewed graphically by clicking the **Graph** button. For Rainbow Trout fry, the HSC value of velocity descends from 1.0 at a velocity of 0.0 to 0.0 at a velocity of 0.5. For more complicated HSC graphs, using the zoom feature may enhance viewing of particular portions of the curve. The graph automatically updates when a different curve is selected. For example: click **Graph** and drag the plot to the lower right so the **Curve** box with radio buttons is revealed. Then click the **Depth** (or any other) radio button. The graph will update to show the depth curve at the same degree of zoom that was previously selected.



**Figure L7-2.** An example of displaying all HSC for a selected species and life stage.

When you are finished entering or viewing HSC curves, click **OK** to exit the **\Edit\Suitability Curves** window.

### Step 3. Building HSC Libraries

The **\Edit\Suitability Curves** section of PHABSIM can be used for entering HSC data to create a set of HSC curves. Users of PHABSIM Version 2.0 (DOS) will recall the term FISHCRV libraries applied to such HSC sets. Table L7-1 lists HSC coordinate data for Brown Trout adult and fry for velocity, depth, and channel index which will be used to construct HSC data. The HSC numbers for each species and life stage are also indicated in this table.

**Table L7-1.** Brown trout adult and fry HSC ID numbers and criteria coordinates.

Brown Trout - Adult		HSC ID Number: 100101			
Velocity	SI	Depth	SI	Channel Index	SI
0.0	0.40	0.0	0.00	0.0	1.00
0.5	1.00	1.0	1.00	1.0	1.00
2.5	0.00	100.0	1.00	9.0	1.00
100.0	0.00			100.0	1.00

Brown Trout – Fry		HSC ID Number: 100102			
Velocity	SI	Depth	SI	Channel Index	SI
0.0	1.00	0.0	0.00	0.0	1.00
0.5	0.78	0.1	0.11	1.0	1.00
1.0	0.19	0.5	1.00	9.0	1.00
1.5	0.04	1.6	1.00	100.0	1.00
2.0	0.01	2.4	0.29		
2.5	0.01	3.2	0.13		
3.0	0.00	4.1	0.04		
100.0	0.00	4.9	0.02		
		5.7	0.01		
		7.3	0.01		
		8.2	0.00		
		100.0	0.00		

Enter these HSC in the SAMPLE data set using **\File\New Curve** in the **Suitability Curves** Window. Examine the newly created HSC sets using the **Graph** feature. When finished, go back to the main menu and save the project.

The HSC in this project can now be used in other projects by importing the HSC data. In the **\Edit\Suitability Curves** window the ability to import from an existing project is found under **\File\Import\From Existing Project**. One may also import FISHCRV format text files prepared in DOS PHABSIM version 2 format using the **Import From Text File** menu item. You will be prompted to select which curves to import.

Thus, it is possible to create a project with the sole purpose of containing a library of HSC curves and import the desired HSC for each specific study from this library as needed. Try creating a new project and importing the HSC from this revised Lab7 project. Give the new project the name “New Curves”. The “New Curves” project could become a library of curves by importing or building successive HSC data sets as described above. Note that any individual curve can be selected from the source project and placed in the receiving project as long as the curve ID numbers are unique.

## Laboratory 8. AVDEPTH and AVPERM Models

### Objective

The objective of this laboratory is to introduce the user to the hydraulic parameter based model AVDEPTH/AVPERM. This concatenated name is retained for familiarity with past versions of the PHABSIM system. The laboratory will demonstrate the use of this model as well as illustrating the type of model outputs generated.

**Programs Used:** AVDEPTH\ AVPERM

**Data Files Used:** Lab8.phb

### Introduction

The AVDEPTH \AVPERM model characterizes a study site channel in terms of hydraulic properties at each cross section. The AVDEPTH/AVPERM model can be used to characterize a stream in terms of a qualified wetted perimeter at each simulated discharge . The wetted perimeter can be reported for areas at least as deep as up to five user-specified depths . The output is provided for each cross section as well as for reach-aggregated results . In addition, the program produces summary output of average channel velocity, hydraulic depth, hydraulic radius, wetted width, wetted perimeter, Froude number, wading parameter, drag parameter, and cross sectional area . The wading parameter is calculated as the product of the depth times the velocity and can be used as an index of safe wading conditions at a cross section. The drag parameter is computed as the velocity squared times the depth.

The AVDEPTH/AVPERM model requires that the simulated hydraulic properties for use within the model have been generated by one of the hydraulic models (i.e., STGQ, MANSQ, or WSP). At least one of those models must have been run prior to use of AVDEPTH/AVPERM.

#### Simulate the Hydraulic Properties within the River

Ensure that the SAMPLE2.phb project file is available in the current working directory before starting the laboratory. At this point, STGQ, WSP, and VELSIM have been run in previous labs so the needed depth and velocity information is contained in the project database.

#### Run the Model and Examine the Output

Move to \Models\AVDEPTH/AVPERM and note the table for input of depth increments to be used in AVDEPTH/AVPERM. For this exercise, the five depth increments of 0.5, 1.0, 1.5, 2.0, and 2.5 ft. will be used. If the user does not supply any depths, the program computes the summary parameters based on all available depths at a cross section. Results are viewed in the **Average Parameters** and **Depth Parameters** tabs. Scroll these tables to see all entries. As with all PHABSIM for Windows output tables, these can be copied by dragging the mouse from the upper left to lower right corner, right clicking, and selecting copy from the pop-up menu. Figure L8-1 provides a partial Average Parameter and Depth Parameter table listing. Average parameters for the entire reach are available in text output only; click the **Text File** button to obtain this output. Figure L8-2 shows a reach level summary table produced by AVDEPTH/AVPERM.

Average Parameters												
XSEC	Q	WSL	Ave. Vel	Hyd. Depth	Hyd. Radius	Wetted Width	Wetted Perimeter	Froude No.	Drag Param.	Wading Parm.	Flow Factor	C/S Area
0	15	91.37	1.03	0.33	0.33	44.05	44.39	0.32	0.35	0.34	2.17	14.54
0	30.1	91.57	1.21	0.42	0.42	59.29	59.79	0.33	0.62	0.51	2.18	24.83
0	75.2	91.90	1.65	0.67	0.66	68.53	69.29	0.36	1.81	1.10	2.18	45.58
0	139	92.18	2.11	0.89	0.88	73.80	74.79	0.39	3.98	1.88	2.30	65.76
0	250	92.67	2.44	1.35	1.33	75.89	77.19	0.37	8.05	3.29	2.02	102.34
0	625	93.53	3.66	2.09	2.05	81.78	83.53	0.45	27.94	7.64	2.27	170.95
0	1250	94.44	5.07	2.91	2.83	84.73	87.06	0.52	74.73	14.75	2.53	246.74
60	15	91.59	0.71	0.43	0.43	49.25	49.61	0.19	0.22	0.30	1.25	21.15
60	30.1	91.78	0.95	0.55	0.55	57.67	58.14	0.22	0.49	0.52	1.42	31.79
.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.
201	625	93.98	4.07	2.50	2.46	61.41	62.27	0.45	41.45	10.18	2.23	153.46
201	1250	94.87	5.99	3.32	3.26	62.81	63.98	0.58	119.31	19.90	2.73	208.52
Depth Parameters												
Widths and continuous widths at depth greater than												
XSEC	Q	Wetted Width	0.5	0.5 (cont)	1	1 (cont)	1.5	1.5 (cont)	2	2 (cont)		
0	15	44.05	10.16	10.16	0.00	0.00	0.00	0.00	0.00	0.00		
0	30.1	59.29	24.21	19.55	0.00	0.00	0.00	0.00	0.00	0.00		
0	75.2	68.53	46.26	35.43	11.00	11.00	0.00	0.00	0.00	0.00		
0	139	73.80	61.04	47.87	29.84	21.84	1.60	1.60	0.00	0.00		
0	250	75.89	73.77	73.77	60.88	47.80	29.47	21.63	1.40	1.40		
0	625	81.78	80.28	80.28	74.97	74.97	72.32	50.48	58.61	46.72		
0	1250	84.73	83.01	83.01	81.51	81.51	79.72	79.72	74.67	74.67		
60	15	49.25	19.15	17.67	0.00	0.00	0.00	0.00	0.00	0.00		
60	30.1	57.67	29.68	21.62	6.78	4.62	0.00	0.00	0.00	0.00		
60	75.2	67.97	49.74	36.50	19.57	17.94	0.00	0.00	0.00	0.00		
.	.	.	.	.	.	.	.	.	.	.		
.	.	.	.	.	.	.	.	.	.	.		
.	.	.	.	.	.	.	.	.	.	.		
201	625	61.41	57.87	57.87	51.10	51.10	44.12	44.12	40.33	40.33		
201	1250	62.81	62.28	62.28	60.75	60.75	57.00	57.00	49.55	49.55		

Figure L8-1. Partial average parameter and depth parameter tables from AVDEPTH/AVPERM.

Summary of Average Parameters for Whole Reach										
Discharge	Wetted		Widths with depth greater than:					Depth	C/S Area	Velocity
	Perimeter	Width	0.500	1.000	1.500	2.000				
15.00	47.33	47.03	23.53	5.26	1.99	0.00	0.57	26.6	0.56	
30.10	53.47	53.08	32.17	12.13	2.95	1.13	0.70	37.1	0.81	
75.20	60.13	59.59	47.91	24.57	7.48	2.51	0.94	56.0	1.34	
139.00	65.49	64.81	55.16	40.40	19.95	4.61	1.18	76.2	1.82	
250.00	69.16	68.30	63.67	53.90	34.10	14.75	1.51	103.2	2.42	
625.00	74.84	73.64	70.85	66.66	61.52	51.99	2.23	164.1	3.81	
1250.00	78.40	76.84	75.36	73.11	70.24	65.87	3.02	232.2	5.38	

Figure L8-2. Whole study site average parameter table from AVDEPTH/AVPERM.

The summary table in Figure L8-1 shows the stream width at each of the simulated discharges at cross section 0.0, followed by the total width of the stream (i.e., the SUM column) with a depth greater than 1.0, as well as the maximum contiguous width with depths greater than 1.0. These summaries are repeated for each of the depths specified by the user in the **AVDEPTH/AVPERM input** tab. Use the scroll bars to view all of the output in the **Average Parameters** and **Depth Parameters** tables.

The final output summary at the bottom of the file (see Figure L8-2) contains this same information for depths aggregated over the entire study reach. The user should note that the AVDEPTH/AVPERM model computes the reach-aggregated results using the cross section weighting factors assigned in **\Edit\Cross Sections**. Therefore, changing the weighting given to particular cross sections will change the summary results displayed in this table.

## Laboratory 9. The HABTAE Model

### Objective

The objective of this laboratory is to introduce the HABTAE model for calculating available habitat quantity and quality. The lab will explore several commonly used modeling options as well as demonstrate the sensitivity of habitat model predictions to different approaches taken in the hydraulic modeling phase of PHABSIM.

**Programs Used:** HABTAE

**Data Files Used:** Lab9.phb

### Introduction

The HABTAE program allows integration of biological requirements of target species and life stages, represented in the form of Habitat Suitability Criteria (HSC), with hydraulic simulation results. This integration generates a number of indices of available habitat quantity and quality. These include weighted usable area, bed area, and volume. These results can be computed for each cross section, as well as for aggregated summaries at the study site level. A description of the calculations used in the HABTAE program can be found in Chapter 4 of the manual.

In this lab, we assume that water surface profile modeling has been finished and quality controlled so the VELSIM program will be used for all hydraulic simulations. However, several different modeling approaches for simulation of velocities will be explored to examine the impact on calculated available habitat. The lab is divided into several steps, which address a specific computational aspect or evaluation of HABTAE model sensitivity to different modeling options. The principal sections of the lab are:

- a. Aggregation Method for Computing Combined Suitability
- b. Computing Habitat for Cross Sections versus Reaches
- c. Calculation of Habitat Quality
- d. Effects of Velocity Simulations on weighted usable area (WUA) Results

The user is encouraged to examine the full range of computational capabilities for the HABTAE model contained in Chapter 4 of the manual and explore use of the options not covered in this lab manual. An effective way to determine whether a particular option has value to the user for a given problem is to run the HABTAE model with 'standard' or 'default' settings and then compare the computational detail listings in the output with other selected options. This is often the best way to determine how or what the program is actually calculating and whether or not a particular option is appropriate for the problem you are attempting to solve.

#### Compare Aggregation Methods for Computing Combined Suitability

In this section of the lab, three computational methods by which the HABTAE program combines individual suitability for depth, velocity, and channel index within a cell to derive WUA will be examined. The three approaches include multiplicative, geometric mean, and limiting value methods (see manual Chapter 4). Make sure that the requisite data files listed above have been copied to the current working directory prior to beginning the laboratory. The following steps proceed in the general order of a habitat analysis.

#### Step 1. Generate Hydraulic Characteristics for Selected Stream Flows using VELSIM

The Lab9.phb project contains the results of simulating water surface profile and velocity distributions for the sample study site. You may want to compare the results you obtained at the end of the previous laboratory with these results.

To determine if the Lab9 project is ready for this next step, go to **\Reports\Graphs** and view the longitudinal profile for all discharges. Then view the velocity distribution for the simulated and observed discharges at each cross section. When you have determined that these are the correct profiles, you can assume the project now contains the necessary hydraulic and channel geometry property information needed to proceed with this laboratory.

## Step 2. Select Species and Life Stages

Prior to setting the HABTAE options, the target species and life stages to be used in the analysis must be determined. Specifically, HSC identification numbers must be selected or input to PHABSIM. Go to **\Edit\Suitability Curves>Select\By ID** to view a list of all of the HSC curve sets that have been loaded into the project thus far. Locate the HSC ID numbers for Bull Trout fry, juvenile, adult, and spawning life stages (i.e., 100101, 100102, 100103, and 100104). If Bull Trout HSC has not been loaded, you may load them now by importing them from an old PHABSIM format FISHCRV file. You will find FISHCRV.LAB in the working directory.

## Step 3. Set the HABTAE Options

Next go to the HABTAE computational options tab at **\Models\Habtae\Computations**. Note that **Habitat Calculations** (old IOC Option 9) has been set to **Standard Calculation** so multiplicative combination of depth, velocity, and channel index HSC values for each computational cell will be the form of the WUA calculation. This option will be changed in subsequent HABTAE model runs as part of the laboratory to examine effects of different suitability aggregation techniques on WUA predictions. Note that WUA Calculations are set to **Calculate WUA for Reach**. Also note that **Use Zero CI in calculations** (IOC 18) has been selected so that a channel index code of '0' will match the associated HSC curve coordinate data of '0' for channel index.

Next go to the **\Models\Habtae\Limits** tab and select **No restrictions on velocities** to allow the HABTAE program to run if it encounters negative velocities or velocities that are greater than 15 feet/second.

Finish setting options by going to the **..\Life Stages** tab and clicking on each HSC curve set ID number you wish to use in the habitat simulation. Select the 4 life stages of Bull Trout (i.e., 100101, 100102, 100103, and 100104) by clicking on each of them to highlight the Bull Trout entries.

## Step 4. Run the HABTAE Program and Examine Output

Click the **Run** button in the **..\Output Options** tab to run HABTAE. Move to the **..\Results** tab where you will find tabular values indicating the combined suitability for each cell. Select the **Discharge** and **Result** you want to view and the table will update automatically. You may view a color graph of the habitat suitability distributed over the study site for the selected result by clicking on **Graph**.

Next move to the **..\ZHAQF Results** tab to review tabulated WUA values calculated for the study site. As in the velocity and WSL sections, the results may be viewed by clicking on the **Graph** button. The relative differences in magnitude and shape of the WUA versus discharge curves for these life stages are a result of the habitat calculated from the HSC curves in response to the hydraulic properties at each discharge. The program also

writes to a numbered ZOUT file as illustrated in Figure L9-1.

These summary tables are aggregated totals for all cross sections. This information is repeated for each life stage in the numbered ZOUT file produced by running HABTAE. To view this table, check the filename.history file for the number of the ZOUT file produced by the last HABTAE run and open the ZOUT with a text editor.

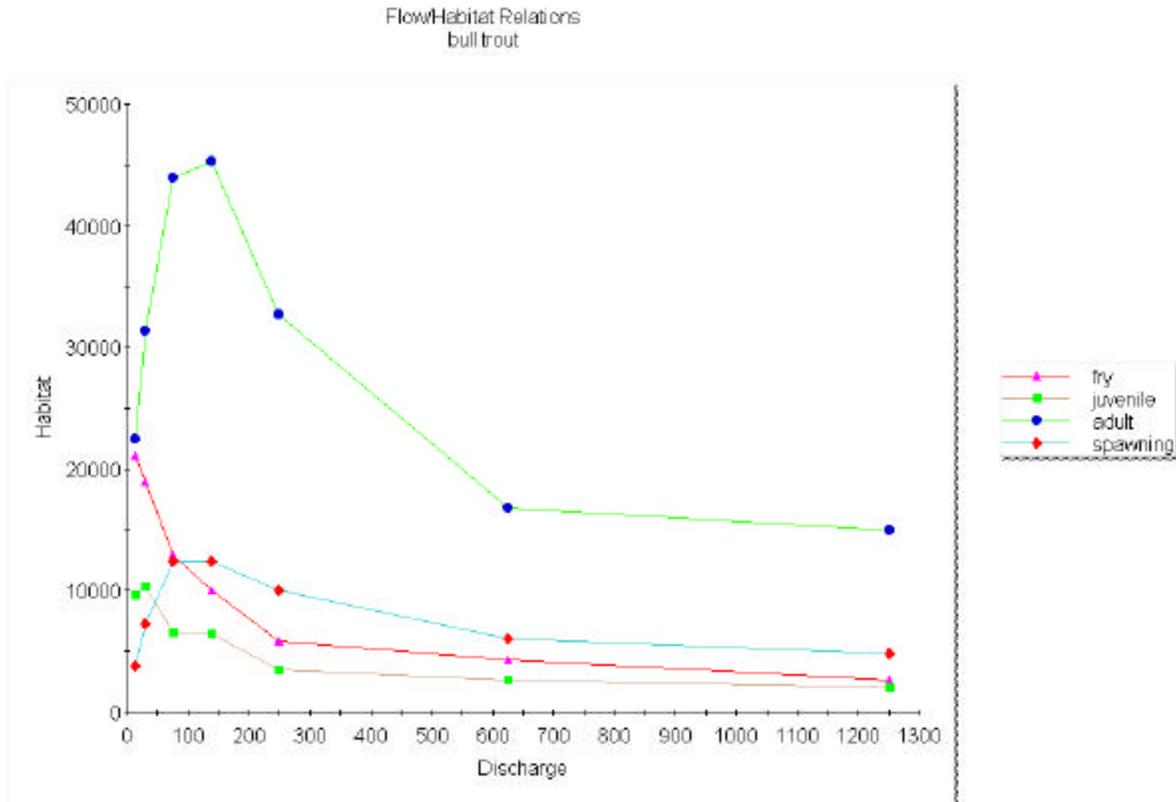
To easily view the ZOUTxx file, move to Windows Explorer and the working directory for your study. Then drag and drop the latest ZOUTxx file on to the Wordpad icon on the desktop. Highlight all text in the file and set the font size to 8 pt for ease of viewing the text without scrolling the lines.

The tabular listing in the **..\Zhaqf Results** tab contains a tabular summary of total WUA for each species and life stage at each discharge. Clicking the check box marked **Include total area** will add a column for total surface area at each discharge. A list box for **Species** is provided so analysis results for different species can be displayed sequentially. Note that all life stages for Bull Trout are given in one table due to the format of HSC curve numbers used in the FISHCRV.LAB data file (i.e., 100101, 100102, 100103, etc.). If these HSC curve numbers had been 100001, 200001, 300001, 400001, then output for each life stage would have been displayed as a separate species.

As would be expected from the differences in HSC curves for different life stages, the WUA versus discharge plot found using the **..\Zhaqf Results\Graphs** button shows that adults have the most habitat overall, and that as flows increase, fry and juvenile habitat availability tends to decrease (See Figure L9-2). This should make intuitive sense because velocities are increasing within the main channel areas, which makes these areas increasingly unsuitable for life stages with less swimming ability. Once this plot has been examined, return to the **..\Zhaqf Results** and click **Print** to produce a copy (or copy and paste the table to a spreadsheet) of your Bull Trout results using multiplicative combination of HSC criteria. Label this copy “Standard Multiplicative WUA Results”.

SPECIES - Bull Trout		LIFE STAGE - fry				CURVE ID - 100101	
DISCHARGE	MEAN VELOCITY	SURFACE AREA	USABLE AREA	WEIGHTED AREA	TOTAL VOLUME	PERCENT USABLE	PERCENT WUA
15.0	0.58	45875	45875	20377	25781	100.00	44.42
30.1	0.83	51623	51623	18667	36085	100.00	36.16
75.2	1.34	59655	59632	13379	56130	99.96	22.43
139.0	1.82	64821	63239	10087	76351	97.56	15.56
250.0	2.42	68318	50356	6095	103291	73.71	8.92
625.0	3.81	73636	23755	4301	164026	32.26	5.8
1250.0	5.40	76806	17925	2744	231270	23.34	3.57
UNITS: TRADITIONAL		VELOCITY TERM - MEAN			CFMIN = 0.00		

**Figure L9-1.** Aggregate habitat results for Bull Trout fry life stage at each of the simulated discharges.



**Figure L9-2.** Multiplicative WUA values for Bull Trout.

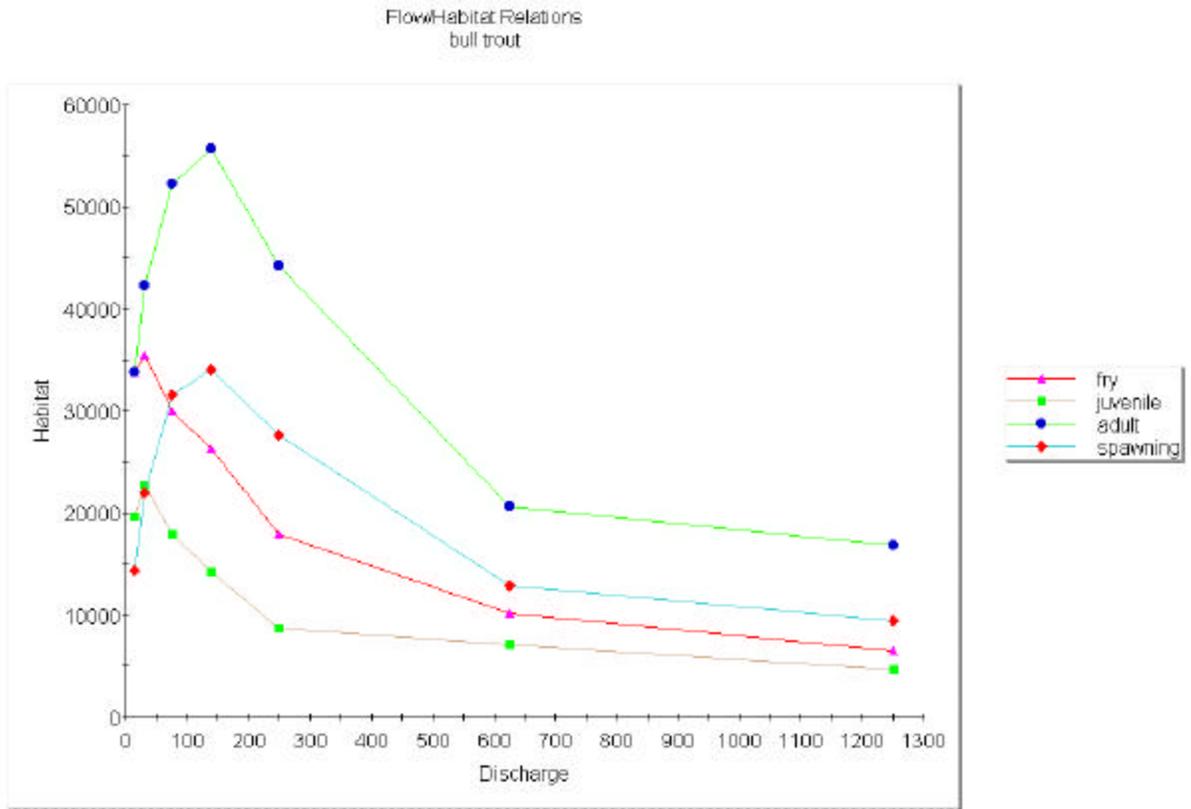
### Step 5. Compare the Effect of Various Combined Suitability Values on Habitat Predictions

Changing the manner in which the HABTAE program computes combined suitability for each computational cell has the potential to change resulting predictions of WUA. In previous habitat simulations, WUA was computed using the multiplicative approach. In this step, the HABTAE program will use the geometric mean.

Go to the **\Models\Habtae\Computations** tab and click **Geometric Mean**; then move to the **..\Output Options** tab and click **Run**. The results of this simulation are shown in Figure L9-3.

Comparing Figures L9-2 and L9-3 clearly demonstrates that the magnitude of WUA predictions change but in general the shape of the functional relationship in the WUA curves has remained essentially the same using both simulation options. The increased magnitude of WUA predictions should make sense since the geometric mean “compensates” for a single low suitability factor in a computational cell if the remaining two suitability factors are high. This should increase WUA values overall.

Finally, go to the **..\Computations** tab and click **Lowest Limiting Factor**; and again click **Run** in the **..\Output Options** tab. The results of this simulation are shown in Figure L9-4.



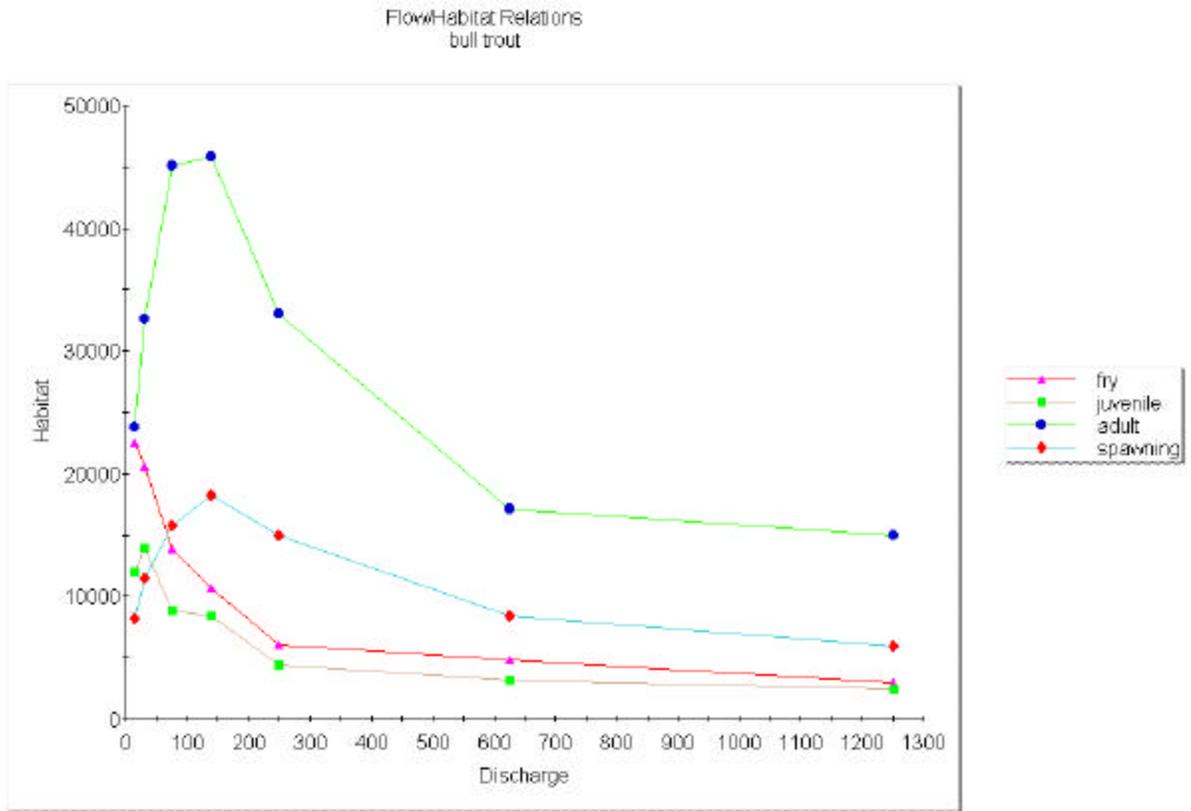
**Figure L9-3.** Geometric mean WUA values for Bull Trout.

A comparison of all three simulation results illustrates several interesting patterns. The geometric mean always produces more habitat than either the multiplicative or limiting factor method as would be expected. The limiting factor approach is always greater than the multiplicative method. These differences are an interplay between estimated hydraulic properties from hydraulic modeling and the functional form of species and life stage HSC curves.

The user should carefully consider which option or combination of options to use when estimating habitat. Each of the computational approaches tells the user something different that, when interpreted in the context of the biology of the target species and life stages, may help in the evaluation of flow regimes.

### Computing Habitat for Cross Sections versus Reaches

The HABTAE program can be used to calculate WUA, weighted usable volume, or weighted usable bed area either for an entire reach or individual cross sections. This is accomplished by selecting the appropriate item for **WUA Calculations** in the **..Computations** tab. In the next step of the laboratory, the HABTAE program will be used to produce results for each cross section. The analysis of habitat at particular cross sections can identify not only the amount contributed to total WUA by each habitat area but can also be used to focus your study on specific critical habitats.



**Figure L9-4.** Lowest limiting factor WUA for Bull Trout.

### Step 6. Change Habitat Options to Produce Cross Section Output

In the **..\Computations** tab, set **WUA Calculations** to **Calculate WUA for Independent XSEC** and set **Habitat Calculations** to **Standard Calculation**. Then click **Run** in the **..\Output Options** tab.

Using this option in HABTAE will generate summary tables for each species and life stage for each cross section. These tables are only contained in the ZOUT file created after running this HABTAE option. View the latest numbered ZOUTxx file using Wordpad and scroll down through the output to examine these results. When finished, exit Wordpad and return to the HABTAE program in PHABSIM for Windows. In the output (see Figure L9-5), you will find terms for weighted width and percent WUA. These terms are provided because each cross section is treated independently and therefore, there is no longitudinal direction over which to compute area of the computational cells.

This option in HABTAE is particularly useful for understanding how predicted habitat changes for a given species and life stage within specific types of mesoscale habitats. This may be important when considering impacts of alternative flow regimes on spawning habitat in riffles or over wintering habitats in pools, for example.

```

SPECIES - bull trout
LIFE STAGE - fry
UNITS: TRADITIONAL      VELOCITY TERM - MEAN
CFMIN = 0.00

CROSS SECTION 0.000000

```

DISCHARGE	WATER SURFACE ELEVATION	MEAN VELOCITY	SURFACE WIDTH	USABLE WIDTH	WEIGHTED WIDTH	C/S AREA	PERCENT USABLE	PERCENT WUA
15.0	91.28	1.38	37.25	37.25	3.64	10.85	100.00	9.78
30.1	91.49	1.47	50.07	50.07	8.28	20.42	100.00	16.53
75.2	91.90	1.65	68.53	68.53	13.78	45.58	100.00	20.11
139.0	92.18	2.11	73.80	69.80	7.87	65.76	94.58	10.66
250.0	92.67	2.44	75.89	47.89	7.40	102.34	63.11	9.75
625.0	93.53	3.66	81.78	27.78	4.92	170.95	33.97	6.02

**Figure L9-5.** Excerpt of habitat results for individual cross sections.

## Evaluation of Habitat Quality

All HABTAE program runs to this point in the laboratory have estimated total WUA. For a given discharge the program may indicate that of a total stream surface area of 100 ft<sup>2</sup> that there are 10 ft<sup>2</sup> of WUA. WUA could be composed of a single 10 ft<sup>2</sup> area with a combined suitability of 1.0 with the remaining 90 ft<sup>2</sup> of habitat having a combined suitability of 0.0. Alternatively, all 100 ft<sup>2</sup> of stream may have a combined suitability of 0.1. In both cases, total WUA would be 10 ft<sup>2</sup>. In this section of the lab, the HABTAE program will be used to set a threshold on the magnitude of combined suitability to compute the amount of “high quality” habitat at each discharge.

### Step 7. Calculate Habitat With Minimum Combined Suitability Factors

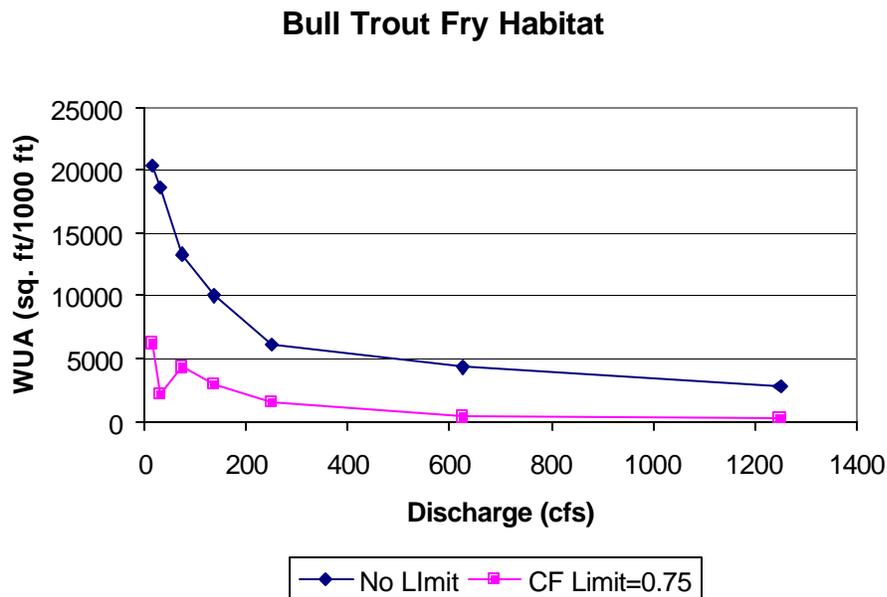
Go to the **..Limits** tab and click **Specify minimum factor by life stage** in the **Minimum Effective Composite Suitability Factor (IOC 19)** box. Then move to the **..Velocity Replacement Options** tab and enter the minimum composite suitability factor value you will accept in the CFMIN column for each life stage HSC number shown. For this laboratory, use 0.75 for all life stages. Then click **Run** in the **..Output Options** tab.

The results for total WUA and “high quality” habitat can be compared for each species and life stage. In the **..ZHAQF Results** tab, click the **Graph** button, select Bull Trout Fry and click the **Refresh** button. Figure L9-6 displays the results for Bull Trout fry where the line labeled No Limit is total WUA and the line labeled CF Limit = 0.75 is WUA with a combined suitability greater than 0.75. Making two runs of HABTAE with and without composite suitability factor limits and copying the results to a spreadsheet produced this figure. The Bull Trout Fry graph in PHABSIM for Windows should look like the CF Limit = 0.75 line in Figure L9-6.

Note the apparent decline in WUA at 30.2 cfs (the second discharge) compared to 15.0 and 75.2 cfs. By clicking the Graph button in **..Habitat Results** you can view a plot of composite suitability for all cells in the study site. The color key allows visual evaluation of which cells have more than 0.75 combined suitability. At 30.2 cfs, only cross section 201 has a significant amount of Bull Trout fry habitat. Whereas at either 15.0 or 75.2 cfs, at least one other cross section has relatively large amounts of fry habitat with a combined suitability of 0.75 or greater. At these low flows, large relative changes in habitat may occur with changes in flow as highly suitable areas become wetted and those same areas develop high velocities at greater flows.

Display the results for the remaining life stages of Bull Trout in both the **..Habitat Results** and **..ZHAQF**

**Results** tabs. Note that for this particular data set, high quality habitat is contributing to less than half of the total WUA over all ranges of discharge for all life stages. However, this is not always the case. In some instances, the amount of high quality habitat may make up only a small proportion of total available habitat over certain ranges of flows while dominating total available habitat at others. It is also not uncommon that the discharge at which high quality habitat is maximized may be different than the discharge at which total habitat is maximized. This type of analysis with HABTAE permits evaluation of tradeoffs between flows that may sacrifice total habitat to maximize high quality habitat at an alternative discharge.



**Figure L9-6.** Bull Trout fry habitat with and without composite suitability limits.

### Evaluate the Effects of Velocity Simulations on WUA Results

To illustrate the effects of hydraulic simulations on computation of available habitat, this part of the laboratory will use four different calibration\simulation velocity data sets as input to HABTAE for the production of WUA. Setting a total of four different velocity simulation options and generating WUA for each of the resulting velocity distributions will accomplish this. We will simulate velocities using the high flow velocity calibration data set, the medium flow velocity calibration data set , the low flow velocity calibration data set, and the discharge range distributed set as templates. We currently have modeled velocities using the low flow velocity set as the template from 15 –75.2 cfs, the mid-flow velocity set for 139 cfs, and the high flow velocity set for 250 cfs and up. So we will begin there.

### Step 8. Select different CAL sets within the VELSIM Program and Compute WUA with HABTAE for each

## Velocity Template

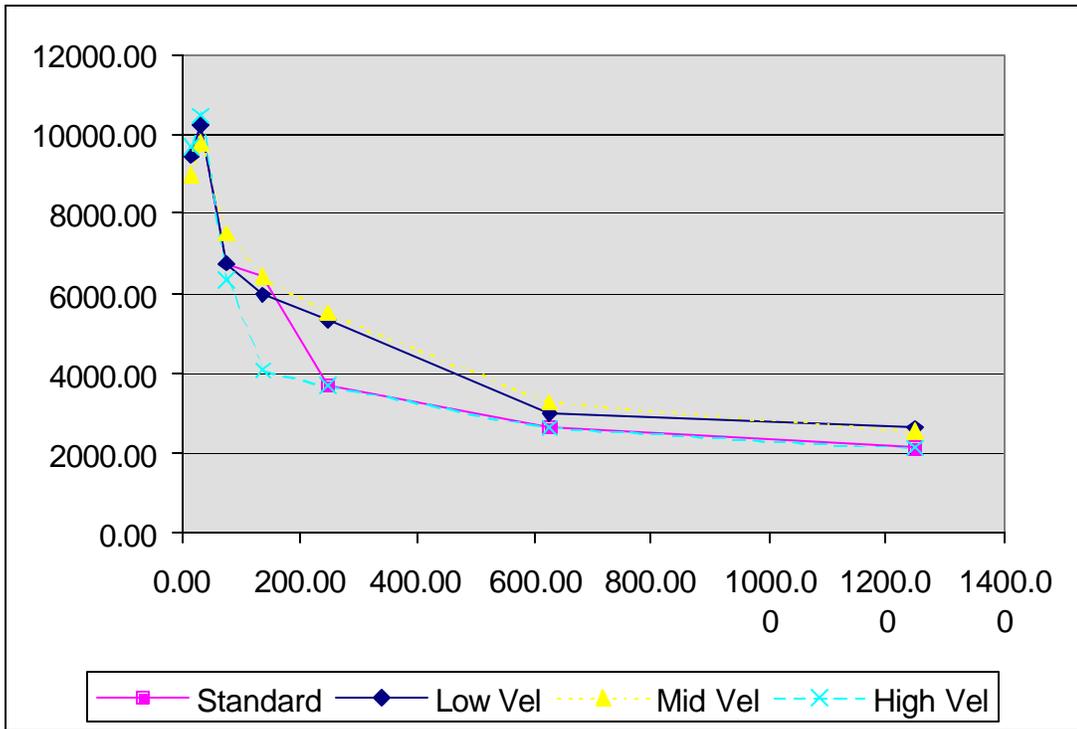
Set HABTAE to produce standard WUA for the entire study site by setting **No limiting factor specified** on the **LIMITS** tab and **Calculate WUA for Reach** and **Standard Calculation** on the **Computations** tab. Click **Run**, go to **Zhaqf Results**, and **Print** the table. Alternatively, you may copy the table into a spreadsheet. (Do not forget to enter the column and row headings.) Label the printed copy or spreadsheet block, “Combined Velocity Templates”. Save the project using **\File\Save Project** before proceeding. We will come back to this project in the next lab so it is important to save the file now.

Next, go to **\Models\Velocity Simulation\Velocity Calibration Set Assignments** and set all combinations of discharge and cross section to 1. This will assign the low velocity set as the template for all velocity simulations. Click **Run** followed by **OK** to exit the velocity simulation window. Save this project under a new name using **\File\Save As**. Give the project the name “Lowvel” and ensure it is located in a directory subordinate to the working directory “Lab9”.

In **\Models\HABTAE**, click **Run** (you have already set all the options). Go to the **Zhaqf Results** tab and print the table of WUA values. Label this copy or spreadsheet block “Low Velocity Template”.

Repeat this process by setting all combinations of discharge and cross section to velocity calibration set 2 and then 3 with appropriate labels for middle and high velocity calibration set on the printed (or copied and pasted) tables of weighted usable area. Save the projects under new names using **\File\Save As**. Name the projects “Midvel” and “Highvel”, and ensure they are located in directories subordinate to the working directory “Lab9”. You should now have four sets of habitat results and four projects located in separate directories.

Examining the four sets of results for Bull Trout juveniles shown in Figure L9-7 shows convincing evidence that the choice of velocity calibration data set can impact the relationship between WUA and discharge over at least part of the flow range. Results for different species and life stage HSC relationships and different hydraulic calibration data can produce similar or widely differing results. The user needs to carefully consider her (his) choice of calibration data sets, HSC, and modeling options when applying PHABSIM. It is up to the investigator to justify the choice of options and data used in the context of the particular instream flow assessment. Usually these choices are made based on goodness-of-fit, reasonableness, and study objectives.



**Figure L9-7.** Bull Trout juvenile habitat produced by four different velocity set templates.

## Laboratory 10. Conditional (Adjacent) Velocity Habitat Simulations

### Objective

The objective of this laboratory is to introduce calculation of habitat based on adjacent or “conditional” velocities using the HABTAE model.

**Programs Used:** HABTAE, Excel

**Data Files Used:** Lab10.phb, highvel.phb, midvel.phb, lowvel.phb, adjvelhab.xls

### Introduction

In addition to “standard” Weighted Usable Area calculations, the HABTAE program allows the user to generate available habitat where adjacent velocity conditions are combined with the habitat suitability criteria to determine habitat worth.

In this lab, the VELSIM program will be used for all velocity distribution simulations using four different velocity simulations to explore the impact on calculation of available habitat within HABTAE. To facilitate presentation of the material, the lab has been broken into several sections, which address a specific computational aspect or evaluation of model sensitivity with HABTAE. The principal activities of the lab are:

- Creation and Modification of HABTAE Options Control Files for Simulations
- Conditional Velocity Simulations
- Generation of Hydraulic Properties using Different Velocity Simulation Approaches
- Conditional Velocity Simulations with Different Velocity Modeling Approaches

The user is encouraged to examine the complete listing of computational capabilities for the HABTAE model contained in Chapter 5 of the manual and explore use of computational options not covered in this lab exercise. The best way to determine whether a particular option has value to the user for a given problem is to run the HABTAE model with 'standard' or 'default' settings and then compare computational detail listings in the output with other selected options. The laboratory is presented in 7 steps that lead you through the conditional velocity analysis process.

#### Step 1. Run HABTAE with Standard Options

In the **..\Output Options** tab, set the following items:

- Click the **Write Computational Details** check box to cause computational details to be printed to the next numbered ZOUT file.
- Click the **Write WUA or WUV** radio button in the **ZHAQF Options** box to write WUA calculation results to the ZOUT file.
- Click the **Write Flow Data** check box so the ZOUT file will also contain the flow data used to generate these habitat results.

In the **Computations** tab, set the following items:

- Click the **Use Zero CI in Calculations** check box, as channel index values of zero should calculate as zero.
- Click the **Calculate WUA for Reach** radio button in the **WUA Calculations** box to produce aggregated weighted usable area as the final habitat result.
- Click the **Standard Calculation** radio button in the **Habitat Calculations** box to ensure that the “standard” multiplicative calculation of composite suitability is performed.

In the **Life Stages** tab scroll the table and click on each of the four life stages of Bull Trout. For this exercise, do not include any other species. Only the four Bull Trout lines should be highlighted. Make a note of the HSC numbers for each life stage as you will use them later.

Return to the **\Models\Velocity Simulation\Velocity Set Assignments** window and check that Cal Set 3 has been assigned to all discharges at all cross sections. If this has not been done, do it now and rerun the velocity simulation.

These settings prepare the HABTAE model to perform the standard habitat calculation for four life stages of Bull Trout. In the **..Output Options** tab, click the **Run** button. Move to the **ZHAQF Results** tab. On the Windows Desktop, start Microsoft Excel (or your preferred spreadsheet package) and open the file *adjvelhab.xls*. Drag the mouse from the upper left to the lower right corner of the ZHAQF Results table, right click, and select **Copy**. Move to Excel and paste to the first block of values starting at cell A9. This places the “standard” habitat calculation results in the spreadsheet.

## Step 2. Select HABTAE Options for a Minimum Adjacent Velocity Limit Calculation

In the **Adjacent Velocity** tab, set the following items:

- In the **Use VLIM as** box, click the **Minimum** radio button to search for a velocity that is greater than or equal to the velocity you will define below as VLIM. That is, VLIM is set to act as a lower (minimum) bound.
- In the **WUA Calculation when VLIM not found** box, click **WUA = 0** to cause no WUA to be calculated in the current computational cell if the user-defined minimum velocity is not found within a user specified distance.

Enter scan distances and threshold velocities to be used for each species and life stage in the **Dist** and **VLIM** columns of the table in the **Scan distance, velocity limit, and initial velocity** box. These values are entered next to the appropriate HSC curve ID numbers for Bull Trout; 100101 for fry; 100102 for adult; 100103 for juvenile; and 100104 for spawning. (Scroll the table using the scroll bar until the needed HSC curve numbers are displayed.)

For the purposes of this lab exercise, enter a restrictive scan distance (Dist) for fry (5 feet), a larger distance for juveniles and adults (10 feet), and zero distance for the spawning life stage to simulate immobility of incubating eggs in the analysis. It is incumbent on the investigator to determine an appropriate distance to scan for particular species and life stages when using the adjacent velocity calculations in the HABTAE program.

Similarly, enter a different threshold velocity (VLIM) value for fry (0.5 fps) and adults (1.0 fps), and the same

value for juvenile and spawning (1.5 fps). The choice of limiting velocity is again a matter of professional judgement. Examining the HSC curves for velocity can often provide insight as well as searching published literature on sustained swimming speeds or related life history information. The values chosen in this laboratory are for illustrative purposes only.

In the **Velocity Replacement Options** tab, leave all values set to zero as only mean column velocity is being considered and no nose velocity issues are being explored at this point. It is possible, however, to base adjacent velocity calculations on nose velocities as long as you have habitat suitability criteria that reflect nose velocity, search distance and velocity limit information that is appropriate to such a calculation. Little research has been done in this area so such information may be scarce.

This sets up the Adjacent Velocity as Minimum Limit calculation for four life stages of Bull Trout. In the **Output Options** tab, click the **Run** button. Move to the **ZHAQF Results** tab. On the Windows desktop, start Microsoft Excel (or your preferred spreadsheet package) and open the file `adjvelhab.xls`. Drag the mouse from the upper left to lower right corners of the ZHAQF Results table, right click, and select **Copy**. Move to Excel and paste to the first block of values starting at cell A21. This places the “VLIM is Minimum” habitat calculation results in the spreadsheet.

### Step 3. Run HABTAE With a Maximum Adjacent Velocity Limit

In the **Adjacent Velocity** tab set the following items:

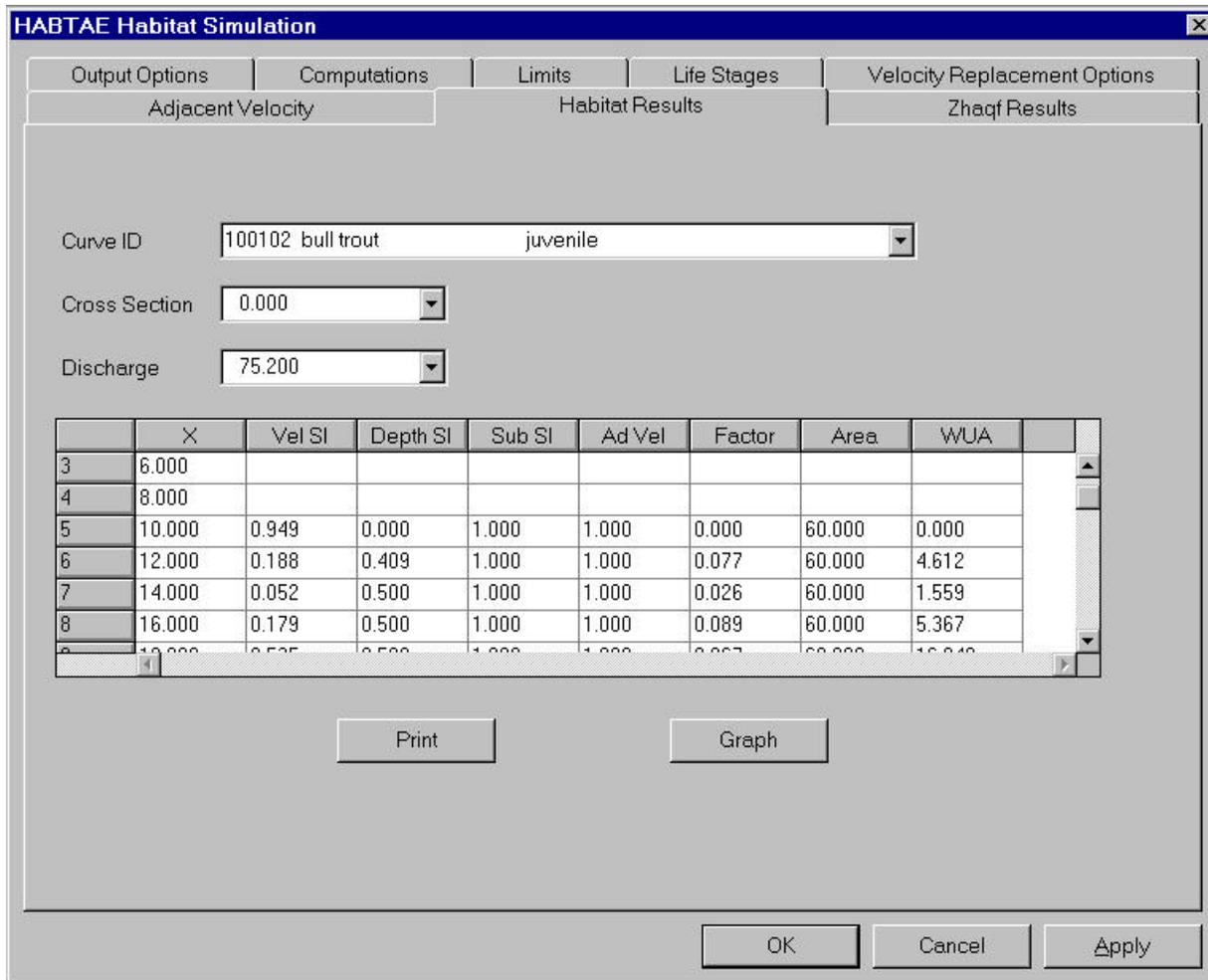
- In the **Use VLIM as** box, click the **Maximum** radio button to search for velocity less than or equal to the velocity you will define below as VLIM. That is, VLIM is set to act as an upper (maximum) bound.

Leave all other options the same as in Step 2 above. Click the Run button as above and copy and paste the habitat results into the spreadsheet at cell A33. This places the “VLIM is Maximum” habitat calculation results in the spreadsheet.

### Step 4. Compare Standard and Adjacent (Conditional) Velocity Simulations

This section of the laboratory will compare HABTAE habitat predictions based on both maximum and minimum threshold conditional velocity simulations. In the previous steps, results have been generated using the standard habitat calculation, conditional velocity simulation using a minimum threshold, and conditional velocity simulation using a maximum threshold. In each instance high flow calibration velocity simulation results from VELSIM were used.

To begin this evaluation, move to the **Habitat Results** tab. There you will find dialog boxes for Curve ID, Cross Section and Discharge. Clicking the triangular down arrow at the right of each box displays a menu of the options available for **Curve ID**. Select 100101 Bull Trout fry. For **Cross Section**, select 0.000, and for **Discharge** select 139.0 cfs. The table now displays the velocity suitability index value (VEL SI), the Depth SI, the channel index suitability value (Sub SI), the adjacent velocity suitability factor (Ad Vel), the combined suitability factor for each cell (Factor), the cell area and the cell weighted usable area (WUA). A separate table of results will be displayed for each combination of Curve ID, Cross Section, and Discharge selected as shown in Figure L10-1.



**Figure L10-1.** Habitat results table.

This table may be copied by dragging the mouse from the upper left to lower right corner, right clicking and selecting copy in the menu provided. The table may then be pasted to a spreadsheet or report as needed. Table headings are not included in the copy operation, so it is often useful to prepare a spreadsheet containing the headings as a template to receive this information.

The habitat results may be graphically viewed by clicking the **Graph** button. Both plan view and 3-D rotatable graphics are provided. The graphical display gives an indication of where on each transect the most suitable conditions exist. At the top of the graph window, dialog boxes similar to the **Habitat Results** tab allow the user to select which **Curve ID** and **Discharge** are to be viewed. Click **Refresh** to update the plot when each menu change is made.

Note the areas of high quality Bull Trout fry habitat at 139 cfs. Red is used for the highest value range. You can see that the highest composite suitability is less than 1.0. Why is this?

Now select 15 cfs and click **Refresh**. What differences do you see between this view and the 139 cfs view? Reduce the size of this graph window by dragging a corner so you can see the HABTAE window, but leave the graph window open for later use.

In the HABTAE Habitat Simulation window, go to the ZHAQF Results tab and click the graph button. In the Species dialog box select Bull Trout fry. Note the shape of the habitat-discharge relationship. Resize both this and the Habitat Results graph window so both can be viewed on screen at the same time. (On smaller monitors, it may be necessary to overlap the two graph windows and alternately click them to bring one or the other to the foreground or you may find it convenient to print the **ZHAQF** plot.)

While viewing the **ZHAQF** plot, select (and refresh) each discharge in the **Habitat Results** graph. How do the composite suitability values explain the resulting ZHAQF plot?

Note that at the lower discharges, the area of fry habitat occupies much of the stream bed. However, at the higher discharges, fry habitat is relegated to the stream margins. As the flow increases, the number of cross sections with suitable fry habitat at the stream edges decreases and the amount of area represented as high quality habitat (i.e., displays in red) decreases. Figures L10-2 to L10-4 illustrate the difference between the standard, minimum and maximum limit habitat for one discharge.

Note the loss of habitat at the fourth cross section (168 to 201 ft upstream) between the standard and “minimum” adjacent velocity calculations. This accounts for the lower conditioned habitat value at 15 cfs seen in the habitat flow relation displayed at the upper right. Also note that the fourth cross section has a large area of good habitat under the conditions of the “maximum” calculation. When the limiting velocity (VLIM) is treated as a lower bound (minimum) no cells are found within the search distance with velocities higher than VLIM at the fourth cross section. Thus, the final weighting factor is zero due to the adjacent velocity condition. In contrast, when VLIM is treated as an upper bound (maximum), there are ample cells with velocities lower than the limit and the habitat at the fourth cross section at 15 cfs is substantially the same as the standard calculation.

You can use the graphical display to determine the cause of the trend toward less fry habitat at higher discharges by selecting from the **Depth SI**, **Velocity SI**, and **Channel Index SI** radio buttons in the **Habitat Results** plot. If you select the Depth SI button and click refresh while displaying habitat results for 250 cfs, you will see a large area of the stream turn red. Thus, it is unlikely that Depth is the limiting factor. However, if you select Velocity SI, the plot shows minor changes from the composite suitability plot. Thus, it appears that velocity is the limiting factor that causes the fry suitability to decline with increasing discharge. This is true for the standard and both conditional velocity calculations. Why?

Now that we have considered how the habitat suitability for depth and velocity influences the shape of the habitat-discharge relation, we are ready to compare the three adjacent velocity limit approaches chosen earlier. Return to the [adjhabvel.xls](#) spreadsheet and note the graphs displayed to the right of the data entry area. (If you did not have time to complete this portion of the lab, a worked example is contained in Sheet 2 of the spreadsheet.)

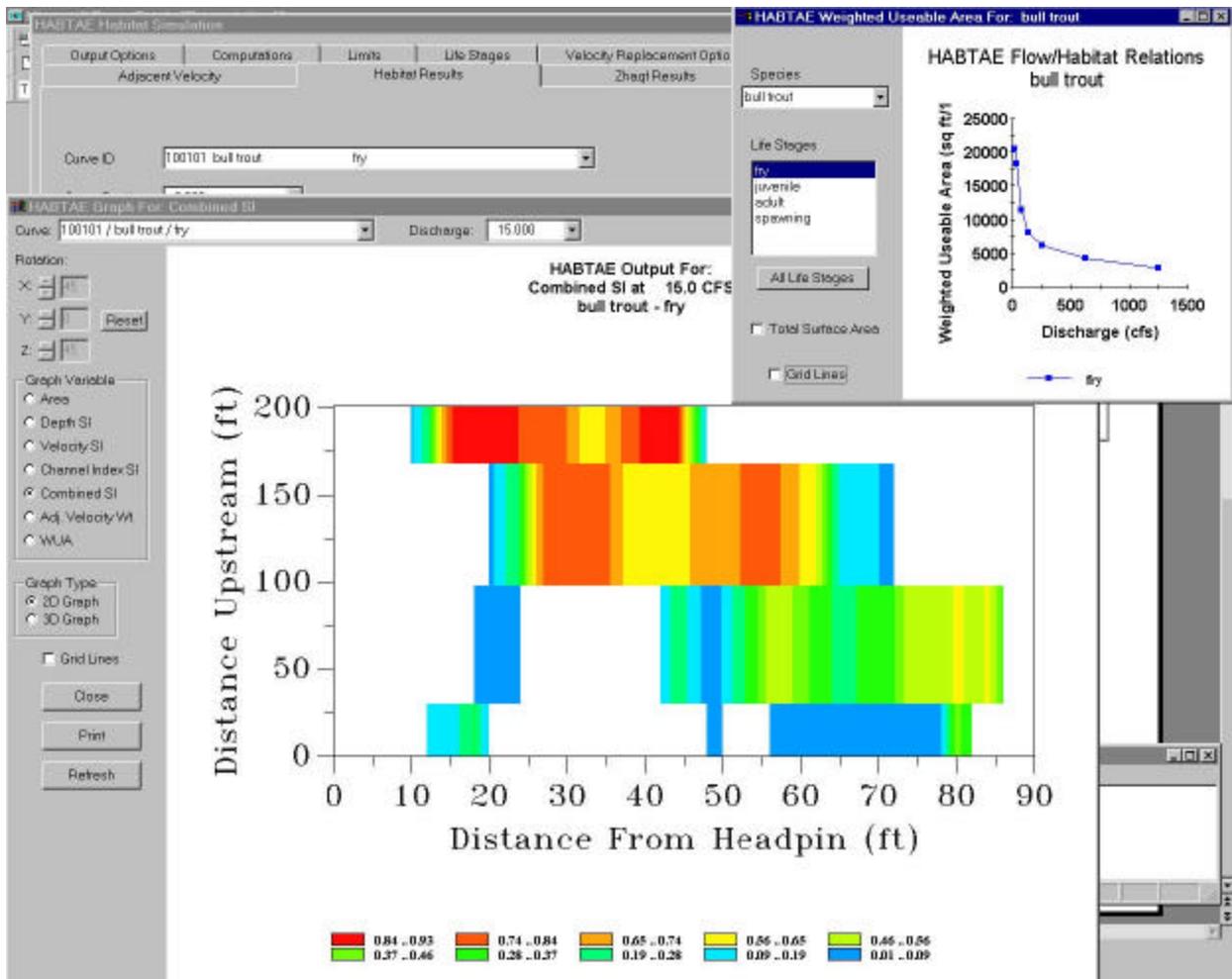


Figure L10-2. Bull trout fry habitat plan view, standard calculation.

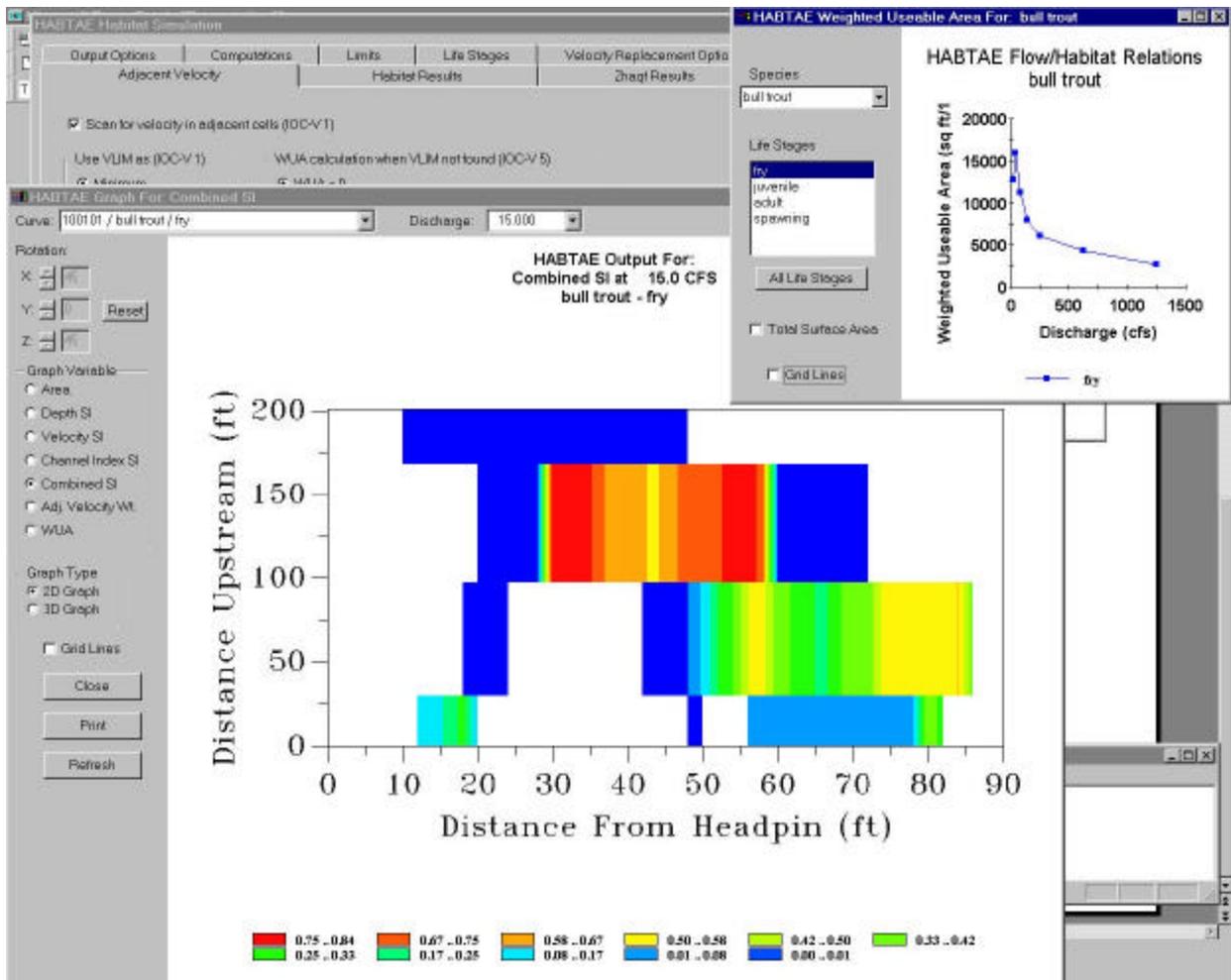
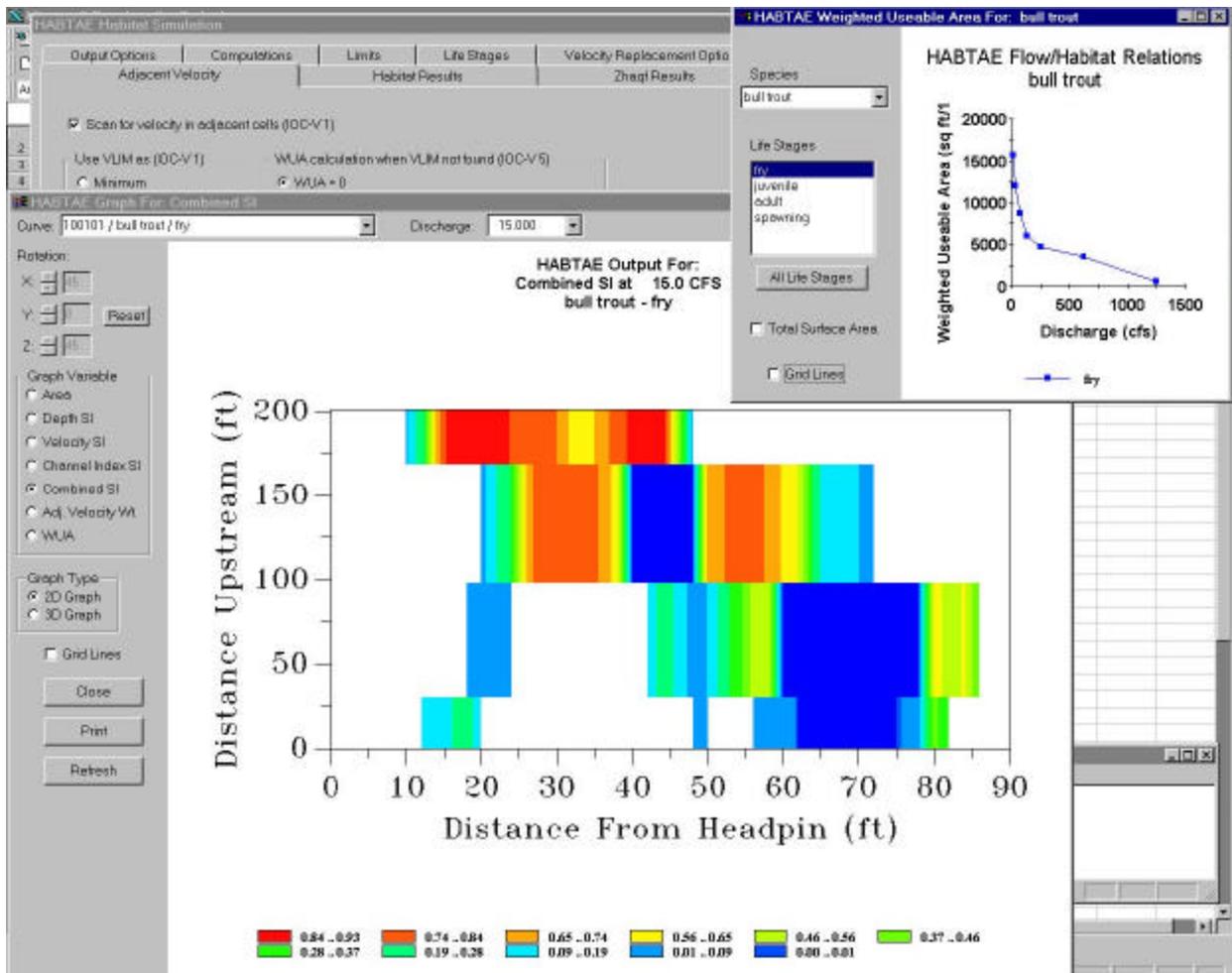


Figure L10-3. Bull trout fry habitat plan view, minimum adjacent velocity calculation.



**Figure L10-4.** Bull trout fry habitat plan view, maximum adjacent velocity calculation.

These examples should demonstrate that for part of the flow range some life stages were not affected by use of conditional velocity simulations based on the criteria specified for either the maximum or minimum thresholds in conjunction with the user-specified scanning distances. The greatest impact on WUA across the entire range of discharges was obtained for the spawning life stage. Note that spawning was the only life stage where scan distance was set to >0'. The combination of threshold velocity and scan distances using the minimum threshold gave similar results to the standard velocity simulations for all life stages except spawning. This suggests that for most flows, HABTAE was able to find a velocity value above the threshold velocity within the specified scan distance for these life stages. This was not true at the very lowest discharges, but it is reasonable that fewer high velocity cells would be encountered at the very lowest flows.

Conversely, using the maximum threshold, there were more instances where HABTAE was not able to find a velocity that was less than the specified maximum (upper bound) within the scan distance for fry, adult, and spawning. Therefore WUA totals were reduced compared to the standard velocity simulations. Refer to the adjacent velocity calculation example in Chapter 4 of the manual if you have questions about the effect of these conditional velocity simulations. Again, the spawning life stage was most strongly affected due largely to the zero scan distance.

The degree to which conditional velocity simulations will affect WUA relationships will be a function of the form of the HSC curve for velocity, velocity limits specified, and the scanning distance supplied by the user. These factors will also result in either greater or lesser changes between target species and life stages. It is the responsibility of the investigator to justify his (her) choice of modeling options and, in particular, choice of velocity limits and scanning distances used for the species and life stages involved in each project analysis.

### Step 5. Effects of Changing Threshold Velocities

To better illustrate the ideas discussed above, move to the **Adjacent Velocity** tab and change **VLIM** for Bull Trout juvenile and adult to 4.0 feet/second and select the **Minimum** radio button in the **Use VLIM as** box. From the comparison of simulation results in Step 4, relatively small differences between minimum and standard velocity simulations were obtained for juvenile and adult Bull Trout. To generate results for the higher VLIM, move to the **Output Options** tab and **Run** the simulation, then move to the **ZHAQF Results** tab and view the graph. Select Juvenile and Adult life stages only. You may also copy and paste the ZHAQF table into the adjvelhab.xls spreadsheet in the space identified as REVISED VLIM FOR JUVENILE AND ADULT, row 50.

By viewing the graphs to the right of the data table, it is apparent that setting the minimum threshold to a higher value has dramatically altered simulation results for both of these life stages. In fact, at lower discharges the results would indicate that velocities greater than 4.0 feet/second simply do not exist in the channel. Why? Confirm this is true by reviewing the velocity distribution plots for the lower discharges in either **\Models\Velocity Simulation\Results\Cross Section** or **\Reports\Graphs\Bed Profile with WSL/Velocities**. You should find there are no velocities greater than 4.0 fps until a discharge of 650 cfs is simulated.

The fact that WUA for Bull Trout juvenile (and adult) is 0.0 at discharges 250 cfs and below, means that HABTAE was unable to locate velocities greater than 4.0 feet/second within the given scan distance for each computational cell. Therefore set the computational cell WUA to zero (i.e. in **..\HabtAE\Adjacent Velocity** the **WUA = 0** button was selected in the **WUA calculation when VLIM not found** box.) At simulated discharges of 650 cfs and 1,250 cfs, hydraulic predictions are generating velocities in at least some computational cells that are greater than 4.0 feet/second and, therefore, a small amount of conditional WUA is predicted for these life stages.

### Step 6. Generation of Hydraulic Properties using Different Velocity Simulation Approaches

You have already run the VELSIM program to produce the four velocity simulation alternatives that will be used in this lab. For convenience, you will find them in the Sample folder as noted in Table L10-1 below:

**Table L10-1.** Project names for different velocity simulation options.

Directory	Project name	Contents
Sample	Sample.phb	Three velocity calibration sets applied to three flow ranges
Sample/highvel	highvel.phb	High flow calibration velocity set used for all flows
Sample/midvel	midvel.phb	Medium flow calibration velocity set used for all flows
Sample/lowvel	lowvel.phb	Low flow calibration velocity set used for all flows

To use any of these projects in PHABSIM for Windows, use **\File\Open Project** and move to the desired project directory using **Browse**. Once in that directory, the file *projectname.phb* will be visible in the Open File dialog box. Double click the project file to open the project.

In previous laboratory steps, effects of different conditional velocity simulation approaches were examined to

compare the HABTAE habitat predictions using these options. In this step, the effect of different hydraulic simulation approaches on conditional velocity simulations using a minimum threshold approach will be compared. First we will examine the effect of using the “best” velocity simulation by applying each of the three calibration velocity sets to their appropriate range of discharges.

Return to the **\Models\Velocity Simulation\Velocity Calibration Set Assignments** tab and assign the appropriate cal set 1 to all discharges up to 75.2 cfs and cal set 2 to 139 cfs. Run the velocity simulation again by clicking the **Run** button in the **..\Options** tab. Then move to the **\Models\Habtae\Adjacent Velocity** tab and remove the check from the **Scan for velocity in adjacent cells** check box. Click the **Run** button in the **..\Output Options** tab. Move to the **ZHAQF Results** tab and copy the Results table for Bull Trout. Paste these results into the range beginning at row 72 in the adjhabvel.xls spreadsheet.

Compare the results of the standard habitat calculation for bull trout juveniles and adults (using the three cal set velocity simulation) to the standard habitat calculation using a single cal set. Are the results significant? How might this change in velocity simulation affect the outcome of any decision being based on the habitat analysis?

What effect does use of three cal sets have on adjacent velocity calculations? To examine this, move to the **\Models\Habtae\Adjacent Velocity** tab and check the **Scan for velocity in adjacent cells** check box. Click the **Run** button in the **..\Output Options** tab. Move to the **ZHAQF Results** tab and copy the results table for bull trout. Paste these results into the range beginning at row 91 in the adjhabvel.xls spreadsheet.

Again, compare the results using the graphs provided. Comparing these results with the results generated earlier using a single cal set, you can see that the effect of the adjacent velocity condition is greater at low flows in both sets of results. For this particular data set, it appears that the habitat results are more strongly influenced by the adjacent velocity condition than by the choice of velocity calibration set.

What about the first decision you made in the hydraulic modeling process, the choice of hydraulic model? The results obtained to this point were based on the “best” water surface results we could obtain by combining models at the control and across the pool. To examine the sensitivity of the habitat simulation process to choice of water surface model, we will run the WSL simulation using STGQ for all combinations of cross section and discharge.

Return to the **\Models\WSL\Methods** tab, select the **STGQ** radio button, and click the **Select All** button followed by the **Run** button. Move to the **..\Velocity Simulation** window and click the **Run** button in the **Options** tab. Next, move to the **\Models\Habtae\Output Options** tab and click the **Run** button there. Move to the **ZHAQF Results** tab and copy the Results table for Bull Trout. Paste the results into the space provided in row 113 of the adjvelhab.xls spreadsheet.

Comparing the graphs in spreadsheet you will again find that the choice of hydraulic simulation option has less effect than the choice of adjacent velocity calculation.

At least two conclusions can be drawn from this exercise. First, in the particular circumstances of this study site, the choice of hydraulic simulation has less influence than the choice of adjacent velocity conditions for Bull Trout adult and juvenile. This may not be true for all study sites or all HSC. (You may wish to create spreadsheet graphs for the other life stages to see if they are more or less affected by these choices.) Second, use of the adjacent velocity simulation can be a good tool to help determine which ranges of flow produce substantial and/or insignificant amounts of habitat when adjacent conditions are important. This information may be very useful in the instream flow decision arena.

When using conditional velocity based habitat simulation, it is especially important to ensure that the various adjacent velocity conditions used have a strong biological basis. The IFIM process emphasizes obtaining

agreement among stakeholders as to the form of the analysis prior to beginning the PHABSIM application. This ensures that the critical questions about use of habitat simulation options such as conditional velocity are asked before the analysis begins.

### **Step 7. Including Adjacent Velocity Conditions That Lie Just Outside The Search Distance**

As a final step in this laboratory, the **Scan for initial velocity (VO) and interpolate** radio button in the **..\Habtae\Adjacent Velocity** tab will be checked to cause the program to interpolate a weight for suitable habitat if the threshold velocity is not found within the user-specified scanning distance. In previous simulations, the **WUA = 0** radio button was checked, which caused the WUA to be set to 0.0 if the threshold velocity was not found. Choosing the interpolation option directs the program to locate a velocity that is closest to the threshold velocity and less/greater than the user specified velocity ( $V_o$ ) within the scanning distance. The program then interpolates a 'combined suitability' between 0.0 and 1.0 to modify WUA in the computational cell rather than setting it to 0.0. Whether the program finds a suitable velocity which is less than ( $VLIM$  acts as a maximum) or greater than ( $VLIM$  acts as a minimum)  $V_o$  is determined by the option selected in the **Use VLIM as** box.

In PHABSIM for Windows, move to the **\Models\Habtae\Adjacent Velocity** tab and enter  $V_o$  values of 0.4, 0.5, 1.0, 1.0 for bull trout fry, juvenile, adult, and spawning life stages, respectively, in the input table. Set **VLIM** to act as a minimum, select **Scan for initial velocity (VO) and interpolate**, and be sure that the **Scan for adjacent velocity** box is still checked. Move back to the **Output Options** tab and click **Run**. Copy and paste the ZHAQF table to row 137 of the **adjvelhab.xls** spreadsheet.

Note that  $V_o$  values have been entered for each life stage to be analyzed and, in this particular application, the values are less than the  $VLIM$  values since the minimum threshold option is being used in the simulations. Remember the minimum threshold option directs the program to look for values greater than  $VLIM$  so a relaxed  $V_o$  must be less than  $VLIM$  to make sense. Refer to the example in Chapter 4 of the manual if you have questions about this.

Plots of the **Scan for initial velocity (VO) and interpolate** and the **WUA = 0** options for adult and juvenile Bull Trout are included in the spreadsheet at row 130. The results for all life stages show slightly greater habitat over part of the range of discharges with the **Scan for initial velocity (VO) and interpolate** option compared to the **WUA = 0** option. This is a result of including the additional interpolated WUA that had weighting factors assigned between  $VLIM$  and  $V_o$  when the interpolation option was selected.

# Laboratory 11. Habitat Modeling - HABTAM

## Objective

The objective of this laboratory is to illustrate the use of the HABTAM program where the investigator wishes to examine available habitat at two different flows and the species and life stage of interest can migrate laterally within a cross section.

**Programs Used:** . HABTAM

**Data Files Used:** Lab11.phb

## Introduction

The HABTAM program is used to simulate conditions at a cross section where fish are allowed to migrate laterally to find suitable habitat when two separate flows are compared. The user supplies a starting flow, an ending flow, and an appropriate maximum migration distance. The program will compute the WUA for each pair of discharges and compute the amount of WUA that is used at the ending flow assuming that all the WUA (i.e., habitat) at the starting flow was used. The program can also be used with a maximum allowable migration distance of 0.0, which might be appropriate for incubation life stages or benthic invertebrates. In this latter case, the program will compute the minimum of the WUA of the starting or ending flow. The use of the HABTAM program should not be confused with “migration” analyses within a reach or river segment, since only lateral migration on a given cross section is considered in the HABTAM program. PHABSIM for Windows does not contain any reach or river segment migration analytical capabilities.

The required hydraulic and channel properties information for this lab has already been generated in previous exercises. We will use the Lab11 project that contains three calibration sets assigned to their representative discharge ranges as the starting point for this lab. The laboratory implements the following processes four steps:

- Ensure the best WSL and velocity simulations have been performed
- Set HABTAM Options
- Simulate habitat using HABTAM

### Step 1. Open the Lab11 Project

Use **/File/Open** to move to the lab11 working directory and open the lab11 project file. You now have the sample project as it was at the end of Lab 6 with the velocity distribution determined by three velocity templates applied to three ranges of flow.

For later use, it is a good idea to open the project and make a note of the curve ID numbers and which life stage and species they represent. Table L11-1 contains the curve ID numbers in the project. Note that some have three digits for the species ID number.

**Table L11-1.** HSC ID numbers and life stages provided in the sample project.

Curve number	Species	Life stage
11300	Brown Trout	Spawning
11301	Brown Trout	Fry
11302	Brown Trout	Adult
11303	Brown Trout	Adult-escapement
11304	Brown Trout	Incubation-ice formation
21112	Rainbow Trout	Fry
21114	Rainbow Trout	Juvenile
21115	Rainbow Trout	Adult
100101	Bull Trout	Fry
100102	Bull Trout	Juvenile
100103	Bull Trout	Adult
100104	Bull Trout	Spawning
500101	Brook Trout	Adult
500102	Brook Trout	Juvenile
500103	Brook Trout	Fry
500104	Brook Trout	Spawning

## Step 2. Set HABTAM Options

Go to **/Models/HABTAM/Options** and put a check in the boxes for **Write migration calculation details**, **Write cross section data**, **Write flow related data**, and **Write computational details**. Selecting these options will allow the examination of the computational details in the output file listing to better understand how the HABTAM program functions. Check that **Velocity Calculation Options** in the **Velocity Calculations** tab is set to **Mean column velocity** because the HSC curves used in the laboratory are based on mean column velocities. The remaining options can be left in their default condition. We recommend you compare the defaults with the option choices for a full understanding of the choices available in HABTAM.

Next, go to the **Migration** tab. Here you will find a table containing all species/life stages for which HSC have been entered in this project. You can supply the allowable migration distance for each life stage. For this lab we will use Brown Trout spawning, fry, and adults, HSC curve numbers 11300, 11301, and 11302. Enter migration distances of 0.0 for spawning, 5 for fry, and 15 for adults. Note that a distance of 0.0 is entered for spawning since incubating eggs cannot migrate.

In the **Options** tab you can enter starting and ending discharge pairs representing the range of flow to be considered in the analysis. In an actual application, you would enter flow ranges relevant to the purpose of your study. For example, the range of high and low flows due to a hydropeaking operation. For this lab, enter three sets of flow pairs: 15, 30, 75.2, 139, 250 versus 625; 15, 30, 75.2, 139, 250 versus 1,250 and 1,250 versus 15, 30, 75.2, 139, and 250. That is, enter a starting flow of 15 and an ending flow of 625. In the next row, enter a starting flow of 30 and an ending flow of 625, etc. For the third set, enter a starting flow of 1,250 and an ending flow of 15. Continue similar entries until finished.

### Step 3. Simulate Habitat Using HABTAM

With these options selected, click the **Run** button. When the program finishes click **OK** and go to the **Migration Results** tab. There you will find a table of WUA values that reflect the amount of habitat area that was available to an organism that could migrate the specified distance when the flow changed over the ranges shown on the table axes. The **Graph** button provides 2- and 3-dimensional plots of the results. The entries in the **Migrations Results** table represent the habitat area derived for the species/life stage shown in the **Curve – species/life stage** box and the distance shown in the **Migration Distance** box. You may scroll through the possible entries for those boxes to view the results for all life stages and migration distances set in the options. For example, to view the table or graph for Brown Trout adults, scroll the species box to Brown Trout adults and the migration distance box to 15 ft. (We only specified a single entry of 15 feet for them earlier, so you must select that distance to fill the table with the Brown Trout Adult results.)

The ZOUTn file contains the selected output items and can be viewed using Wordpad. The Zout file contains computational detail summary tables for each cross section, a summary table output listing for the selected life stages for each set of paired flows for each cross section in sequence, and, following the final flow pair computational summary table for the current life stage, HABTAM provides reach level summary tables.

Examine the **Migration Results** tab summary table listing shown in Table L11-2 that contains the pairwise flow comparisons for each life stage. It should be apparent from these results that the order of the paired flows can make a difference on program results. This should make sense since the initial flow is being compared to the ending flow and the actual difference is a function of not only the user-specified migration distance but also the combined suitability of available habitat cells at the ending discharge. Note that for both the adult and spawning life stages the “habitat used” areas are identical for these two sets of flow comparisons. For spawning, a migration distance of 0.0 should, by definition, produce the same result. In the case of adults, it is apparent that a migration distance of 15 feet is large enough to allow access to most, if not all, of the cross sections’ computational cells between the changes in discharge. Now select the spawning life stage and 0 migration distance. What kind of changes do you see in comparison to the adult migration habitat?

**Table L11-2.** HABTAM weighted usable area results for Brown Trout adults for the study site with 15 feet search distance.

Starting discharge	Ending discharge						
	15	30.1	75.2	139	250	625	1250
15	0	0	0	0	0	2,080.99	451.24
30.1	0	0	0	0	0	2,930.99	1,107.54
75.2	0	0	0	0	0	3,886.65	2,185.41
139	0	0	0	0	0	5,167.13	3,645.41
250	0	0	0	0	0	6,624.82	4,622.36
1250	223.98	545.69	972.18	2,336.49	3,380.58	0	0

Two- and 3-dimensional plots of the migration-based weighted usable area can be viewed by clicking the **Graph** button. The 3-D plot can be rotated for better viewing by holding down both mouse buttons and moving the mouse. It takes some trial-and-error experimentation to get familiar with the movement mechanism. Try it, and see.

The ZHAQF output from HABTAM contains the reach level summary results of WUA and can be accessed at the **ZHAQF Results** tab.

#### Step 4. Influence of Migration Distance on HABTAM Model Predictions

To illustrate the sensitivity of the HABTAM model to proper choices of migration distance, this step of the laboratory will alter the migration distance used for fry, juvenile, and adult life stages and compare the resulting computations at the 139 cfs and 15 cfs flow combinations. Change the migration distance for fry and adults to 3 feet and 25 feet respectively. The results of this change for Brown Trout adults are shown in Table L11-3.

What effect did changing the migration distances have on fry and adult life stages compared to the previous habitat simulations?

It should be apparent that sensitivity in model predictions occurs over a range of migration distance between 0.0 and some upper threshold that is dependent on the shape of the HSC criteria and, therefore, different for different species and life stages. The selection of an appropriate migration distance is a matter of professional judgment. Remember, this migration distance only applies to computational cells at a given cross section.

**Table L11-3.** HABTAM weighted usable area results for Brown Trout adults for the study site with 25 feet search distance.

Starting discharge	Ending discharge						
	15	30.1	75.2	139	250	625	1,250
15	0	0	0	0	0	3,266.24	1,396.92
30.1	0	0	0	0	0	3,540.05	2,227.93
75.2	0	0	0	0	0	4,072.22	2,720.29
139	0	0	0	0	0	5,729.13	4,263.98
250	0	0	0	0	0	6,624.82	4,688.58
1,250	552.11	585.30	1,040.32	2,798.86	3,446.80	0	0

## Laboratory 12. Habitat Modeling - HABEF

### Objective

The objective of this laboratory is to illustrate use of the HABEF program for simulation of effective habitat for each of six options available to the user. The HABEF program can be used to examine differences between available habitat for a given species and life stage at different flows or comparisons between different species and life stages at a specific flow.

**Programs Used:** HABTAE, HABEF

**Project Used:** Lab12.phb

### Introduction

The HABEF program can be used to examine a number of relationships between habitat conditions at two stream flows and/or for two life stages at a specific discharge. In this laboratory, each of the six computational options available within the HABEF program will be examined.

In the HABEF program different hydraulic property arrangements can be used depending on the option selected. The HABEF program will compute two different indices of habitat. The first is WUA, which is derived from the combined suitability factor computed by the initial habitat simulation program. (You must have run HABTAE or HABTAM prior to using HABEF.) The second index, UA (usable area) is derived from the sum of computational cell areas where the combined suitability in the computational cell is  $>0.001$ . Usable areas can be considered to be a measure of the area where all of the HSC variables have suitability that is marginally greater than zero. Can you explain why this may not be the same as the wetted surface area of the stream?

The six steps in this laboratory guide the student through these basic options of the HABEF program:

- Union of Life Stage 1 with Life Stage 2
- Stream Flow Variation Analysis (Minimum WUA)
- Competition Analysis
- Stream Flow Variation Analysis (Maximum WUA)
- Effective Spawning Analysis
- Stranding Index Analysis

#### Step 1. Ensure Needed Hydraulic And Habitat Model Results Have Been Run

Habitat analysis results from HABTAE or HABTAM are required prior to executing HABEF. Open the Lab12.phb project in the Lab12 directory and note that **WUA Results** exist for Rainbow Trout adult. This indicates one or the other of these programs has produced results earlier. If you are uncertain which program was used, check the **Habitat Results** table. In this case, the **Habitat Results** table in the HABTAM window is filled with [NULL] entries while the table in the HABTAE window has numerical values. Hence, HABTAE was run.

## Step 2. Set Appropriate Simulation Options and Run HABTAE Model

This step is provided as an example of the actions you would perform when the initial modeling steps have not yet been performed. For this laboratory, you may go directly to Step 3 as the HABTAE model has been run and the needed result files are already in the Lab12 folder.

Move to the HABTAE program window by clicking **/Models/HABTAE**. Go to the **Life Stages** tab and click as many life stages on or off until only the Brown Trout adult and Rainbow Trout adult (or other desired) life stages remain. Click the **Run** button to run the model. You will now have habitat results for adult Brown and Rainbow trout.

At this point, two files have been created in the Lab12 directory containing computational cell details at each cross section for each simulated discharge for each of the species and life stages used in the simulation. Those files have the naming convention: Projectname.HSCnr(e or m). The habitat suitability criteria number (HSCnr) is used to identify species and life stage contained in each particular results file. The suffix 'e' or 'm' indicates whether the files were produced by HABTAE or HABTAM, respectively. The HABEF program uses these files for cell-by-cell computations. In this case, they should be named Lab12.11302e and Lab12.21115e, respectively, for Brown and Rainbow trout adult results produced by HABTAE.

## Step 3. HABEF Simulations for Union (Option 1) and Competition (Option 3) Analyses

The HABEF program will now be used to simulate the union of two life stages and competition between two species. In the union analysis for two species and life stages (Option 1) HABEF computes total weighted usable area represented by combined habitat of the two species or life stages. The total habitat quantity computed at a specific discharge will always be greater than or equal to the highest amount for a single species or life stage but always less than or equal to the sum of the two habitat totals. Why is this? In answering this question, consider adding the largest WUA value regardless of species in each cell to the HABEF union sum. If species/life stage "a" has the dominant WUA in all cells and there are no cells where the species/life stage "b" alone has WUA greater than zero, then the WUA reported by HABEF will be equal to the WUA for species/life stage "a". If both species/life stages dominate in some cells, the sum will be greater than the sum for species/life stage "a" alone. Will this general statement still be true for two species/life stages that use very different habitats with little or no overlap?

The analysis of competition (Option 3) computes the amount of habitat for a particular species or life stage for two conditions. First, it calculates habitat for species/life stage "a" in cells where habitat for the species/life stage "b" is zero. This is combined with the amount of habitat occurring in computational cells where combined suitability is greater than 0.0 for both species but where species "a" has a higher combined suitability value than species "b". Thus, the competition option describes the total WUA for cells where a species dominates.

Select **/Models/HABEF** and enter a descriptive name for the comparison being run in the **Job Title** text entry box. This name will be used to label all output tables (both text files and on-screen). In the species/life stage 1 text entry box, click the down arrow button to the right and select Brown Trout adult. In the second text entry box, click the down arrow and select Rainbow Trout adult, then click the **Union of life stage 1 with life stage 2** radio button. Note that this assigns Brown Trout adults to species/life stage 1 and Rainbow Trout adults to species/life stage 2. Finally, click the **Run** button and view the **Results** tab. You may also produce a named HABEF results file using the **Text File** button in the **Results** tab and view it using Wordpad. PHABSIM for Windows does not retain subsequent sets of results in the database, so it is convenient to create result text files for

each run to allow later comparison when numerous HABEF options are generated in the course of an analysis. It is also wise to change the job title for each run to avoid later confusion among options where the numerical results are similar.

The table in the **Results** tab contains a summary for each life stage at each discharge of their respective UA and WUA values and the WUA associated with the union of the two life stages. Note that the WUA associated with the union of two life stages is less than the total WUA if the two life stages had been simply added together at a given flow. A comparison of the Total Area column (i.e., total stream surface area) and the respective UA columns for each life stage shows that at discharges below 139 cfs all computational cells have a combined suitability greater than 0.001. Why is this?

Table L12-1 contains an example of the union analysis output table. Click the **Graph** button at the bottom of the HABEF **Results** tab to view graphical results.

**Table L12-1.** HABEF output for union analysis.

Q	Area	UA(1)	WUA(1)	UA(2)	WUA(2)	WUA(1 or 2)
15.0	40,049.24	9,164.18	2,926.54	40,049.24	3,986.22	4,869.38
30.1	51,654.74	18,582.09	5,291.70	51,654.74	6,036.19	7,512.03
75.2	59,558.40	34,597.02	9,434.51	59,558.40	12,864.07	14,397.67
139.0	64,810.89	50,776.12	10,796.20	64,482.53	14,374.42	16,641.56
250.0	68,096.85	59,678.32	8,980.34	52,992.38	11,189.20	13,551.44
625.0	74,003.04	68,891.79	7,471.48	25,375.71	9,357.60	11,691.81
1,250.0	77,031.06	45,363.88	6,732.50	20,628.08	8,537.55	10,091.42

You can see that the total amount of WUA in the union of two species is greater than that for either individual species WUA and less than their sum would be. You may wish to view the graph of results and print it for later reference.

Next, the HABEF program will be run again with the same input data but will be used to compute effective habitat based on selection of the competition analysis option.

Go to the HABEF **Options** tab and select the **Competition analysis** radio button. Make sure that the first input file is ZHCF1 and the second file is ZHCF2, as in the previous example. Change the **Job Title** to indicate the next results are for the competition analysis. Click the **Run** button and move to the **Results** tab.

Table L12-2 shows output from the competition analysis. Note that the HABEF output is different when selecting competition analysis versus union analysis (Table L12-1). The program shows summary results at each simulation discharge in terms of total stream area, UA and WUA where each species has the only suitable habitat. Summary output is also provided for amount of usable area for both species and area associated with habitat conditions where each species is dominant (i.e., combined suitability for species “1” is greater than the combined suitability for species “2”). The program also computes the amount of habitat area with equal worth for both species as noted earlier.

**Table L12-2.** HABEF output for competition analysis.

Q	Area	UA(1)	WUA(1)	UA(2)	WUA(2)	WUA(1 or 2)	WUA(1 = 2)	WUA(1 in 1&2)	WUA(2 in 1&2)	WUA (1>2 in 1&2)	WUA (2>1 in 1&2)
15.0	40049.24	0.00	0.00	30885.06	1626.35	9164.18	0.00	2926.54	2359.87	2031.87	1211.16
30.1	51654.74	0.00	0.00	33072.66	1669.93	18582.09	0.00	5291.70	4366.26	3412.54	2429.57
75.2	59558.40	0.00	0.00	24961.39	1550.70	34597.02	0.00	9434.51	11313.37	3527.26	9319.71
139.0	64810.89	328.36	25.04	14034.77	788.40	50447.76	0.00	10771.16	13586.02	4400.39	11427.72
250.0	68096.85	15104.48	1041.23	8418.54	497.36	44573.84	0.00	7939.11	10691.84	3722.10	8290.75
625.0	74003.04	48626.87	1861.00	5110.79	356.60	20264.93	0.00	5610.48	9001.00	1328.08	8146.12
1250.0	77031.06	25641.79	660.65	905.99	65.11	19722.09	0.00	6071.85	8472.44	1883.55	7482.10

The competition results for 15.0 and 30.1 cfs show Brown Trout adults have more suitable habitat at the low flow range. However, from 75.2 cfs and up, Rainbows have significantly more habitat than Browns.

The dominance of Rainbow Trout adult habitat at higher discharges is related to their tolerance for lower depth as reflected in the depth HSC reaching 1.0 at a lower depth for Rainbows than for Browns. Go back and check the HSC to confirm this. For the 15 and 30.1 cfs discharges, Rainbow Trout adults have between 50% and 70% as much habitat as Brown Trout adults. However, from 75.2 cfs and up, the Rainbow habitat is three or more times as abundant as Brown habitat. Assuming the HSC have been verified to accurately describe behavior of the two species, from these results can you conclude that higher flows favor Rainbow Trout adults? How would the results be affected if the depth HSC for each species had a  $\pm 25\%$  error and the full range of the uncertainty was considered in the analysis?

#### **Step 4. Streamflow Variation Minimum and Maximum Analysis**

Streamflow variation analysis for minimum and maximum WUA in HABEF can be used to explore which species and life stage has either the maximum or minimum WUA at each discharge on a computational cell-by-cell basis. When HABEF minimum variation is selected, the composite suitability factor used to compute WUA for a computational cell is the minimum composite suitability value in that computational cell in each of the two species/life stages being compared. The maximum streamflow variation HABEF option is identical except that the maximum composite suitability from the computational cell within the two ZHCF files is used to compute WUA.

Make sure that the first species/life stage you wish to consider is entered in the first dialog box and the second species/life stage is in the second box. Select the **Streamflow Variation Analysis (minimum WUA)** radio button, change the job title to indicate minimum WUA analysis, and click the **Run** button to execute the HABEF program. Move to the Results tab to view the output. You may wish to save the results for later comparison, click the **Save** button to do so.

For comparison, perform a maximum streamflow variation analysis. Enter a job title indicating maximum WUA, click the **Streamflow Variation Analysis (maximum WUA)** radio button, and click **Run**. Again, click the **Results** tab to review results.

A comparison of these streamflow variation results with the previous minimum analysis shows a marked difference in the relationship between minimum or maximum WUA and discharge. The minimum WUA analysis declines as discharge increases, while maximum WUA increases then decreases with flow.

When these results have been examined, return to the HABEF window.

#### **Step 5. Effective Spawning Analysis Using HABEF**

HABEF effective spawning analysis allows an investigator to examine the effects of flow alterations on spawning and incubation life stages. The program computes effective spawning habitat based on the concept that available habitat at an initial (spawning) discharge must also be available at the second (incubation) discharge. In this analysis, the HABEF program computes combined suitability in a computational cell at the starting and ending discharges (i.e., for each set of paired discharges in respective HABTAE or HABTAM results). If composite suitability at the second discharge is greater than 0.0, then the composite suitability factor for that computational cell at the first or starting discharge remains unchanged and WUA for that computational cell is added to the total for the cross section and, hence, the reach. Simply put, if the spawning area maintains minimal incubation conditions (stays wet with needed velocity) then the spawning area is accumulated in the total. However, if the composite suitability factor at the second discharge is 0.0, then suitability at the first discharge is set to 0.0 and that amount of available habitat is 'removed' from the total at the cross section. This is similar to using the

minimum streamflow analysis option but differs in that WUA at the first flow is dependent on the analysis of the second flow.

To make this example of effective spawning more realistic, new results using Bull Trout spawning HSC will be generated with the HABTAE program.

Return to **/Models/HABTAE**, move to the **Life Stages** tab and click all of the Brown and Rainbow Trout life stages to turn them off. Now click the four Bull Trout life stages to turn them on. Click **Run** and return to the HABEF program when HABTAE is finished.

Change the job title to indicate you are performing an effective spawning analysis and select Bull Trout spawning in both species/life stage dialog boxes. Then click **Run** and move to the **Results** tab. Click the **Graph** button to view the results. Which combination of discharges produces the greatest effective spawning habitat values? Which produce the lowest values?

The plot also shows that if the starting flow is 1250.0 cfs and flows are reduced, the amount of effective spawning habitat is substantially reduced at 250.0 cfs and non-existent below 75.2 cfs. As the starting and ending flow difference is reduced, the effective spawning is less affected as would be expected (Why?). It should also be apparent that starting at a lower flow such as 75.2 and ending at a higher flow such as 139.0 cfs has less impact on effective spawning (Why?). If you have difficulty reading the 3-dimensional plot, return to the results table and examine it in drawing your conclusion.

#### **Step 6. Stranding Index Analysis Using HABEF**

Stranding analysis with the HABEF program employs essentially the same computational logic as described above for effective spawning analysis. The composite suitability of a computational cell at the second flow must be greater than 0.0 for composite suitability of the computational cell at the first flow to contribute to effective WUA. Thus, when evaluating stranding, one should only compare flow pairs that show a decrease in discharge. For this analysis, the same species and life stage is selected in both dialog boxes on the **/HABEF/Options** tab. Typically, the selected life stage would be one that has only a small capacity to move with changes in discharge, though the analysis can be conducted for any life stage.

While a stranding analysis will not be run in the laboratory due to time considerations, the following general approach can be used for all life stages. To ensure that the analysis is focusing on available depth alone, you can create a new set of suitability curves for stranding. To do so, make copies of the HSC in the **/Edit/Suitability Curves** window and edit suitability curve coordinates for velocity and channel index, setting all suitability values are 1.0. There is no need to change the number of coordinate pairs. Change depth suitability curve coordinates for depth such that depth suitability is 0.0 below some threshold (e.g., 0.5 feet) and then change the remaining depth SI values to 1.0.

Save these changes and run the new HSC in the HABTAE program. Then move to the HABEF program and run the stranding index analysis using the same HSC in both dialog boxes. The results will show the chance of stranding when depth for that species/life stage drops below the selected threshold value.