# DATA COLLECTION PROCEDURES
# FOR THE
# PHYSICAL HABITAT SIMULATION SYSTEM

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August 1997

# CONTENTS

CONTENTS CONTINUED

# INTRODUCTION

The Physical Habitat Simulation System (PHABSIM) is an integral component of the Instream Flow Incremental Methodology (IFIM). In fact, PHABSIM is so closely identified with the IFIM that many people often get the two confused. However, these are two distinct methodologies.

The purpose of PHABSIM is to develop functional relations between discharge and physical microhabitat for a variety of aquatic resources (Fig. 1). These resources commonly include different life stages or seasonal microhabitat for stream fishes, but microhabitats for species of algae, aquatic insects, crustaceans, mollusks, reptiles, amphibians, and birds have also been simulated successfully using PHABSIM. Furthermore, PHABSIM has been used to quantify the relative values of different stream flows for a variety of recreational activities ranging from kayaking to fly-fishing.

The purpose of the IFIM is to integrate all aspects of an instream flow problem: physical microhabitat, temperature, water quality, hydrology, social and economic issues, reservoir operations, conflicting values systems, feasibility, and risk analysis. Theoretically, the output from the IFIM is a mutually acceptable solution to a multi-faceted water and habitat management problem. PHABSIM is a small but important component in the IFIM.

PHABSIM consists of three components: (1) channel structure, (2) hydraulic simulation, and (3) habitat suitability criteria (Fig. 2). The ***channel structure*** component incorporates all of the fixed channel properties that do not change dynamically with stream flow (although they may change gradually over long time periods). Examples of fixed channel characteristics include the dimensions and cross-sectional configuration of the channel, substrate characteristics and distribution, and the locations of various types of structural cover within the channel.

***Hydraulic properties*** include those variables that change dynamically as a function of discharge: water surface elevations, depths, velocities, wetted perimeters, and surface areas, for example. ***Hydraulic simulation*** programs are used to predict the values of these hydraulic properties at discharges that were not measured.

In combination, the channel structure and hydraulic components generate a computerized "map" of a portion of stream, depicted as a mosaic of stream cells (Fig. 3). At any particular stream flow (discharge), each stream cell has a unique combination of depth, velocity, substrate, and cover. Other properties associated with the cell include its surface area and position within the channel. When another discharge is simulated in the hydraulics program, the depths and velocities in all of the cells change, and in cells near the edge, the surface areas may also change. The net result is that the mosaic will look different as the discharge is changed.

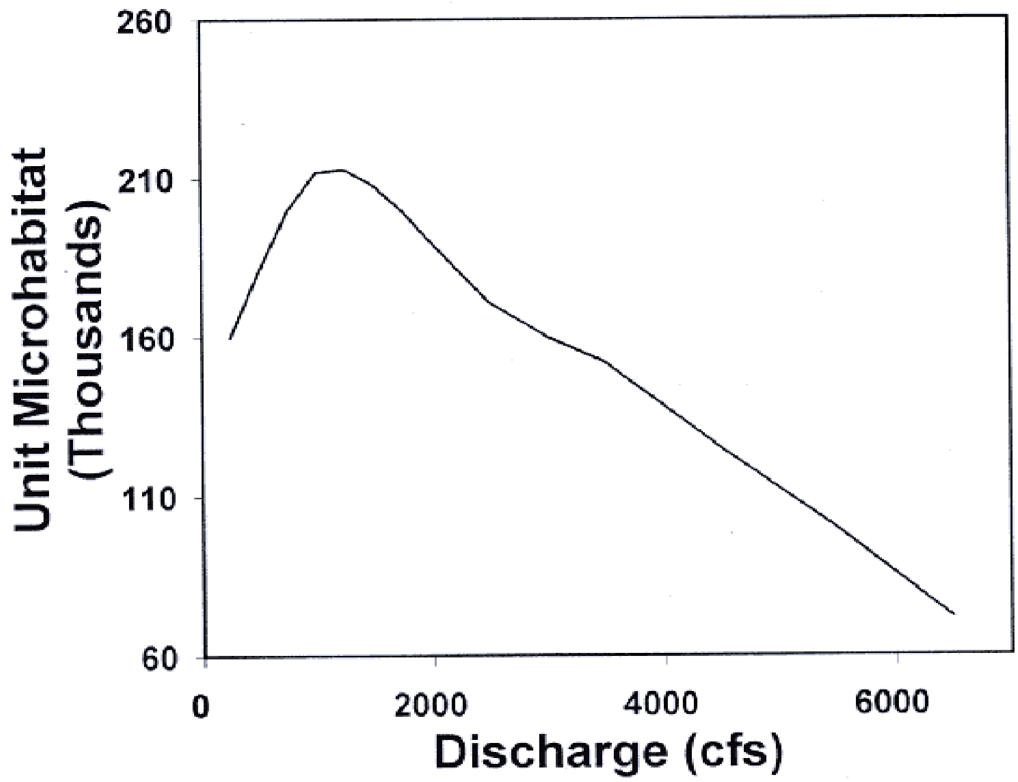



Figure 1. Typical output from PHABSIM: a functional relationship between discharge and microhabitat area. Note that the units of microhabitat are expressed as an area per unit length of stream.

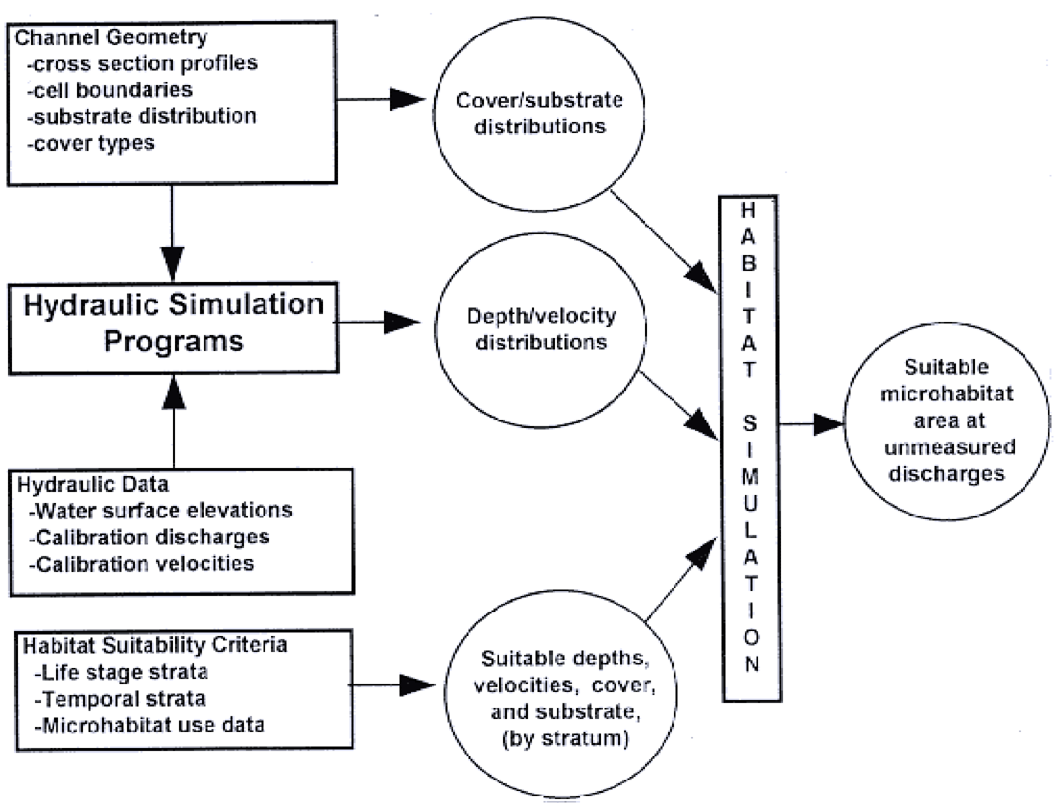



Figure 2. Components, inputs, and flow of information within PHABSIM.

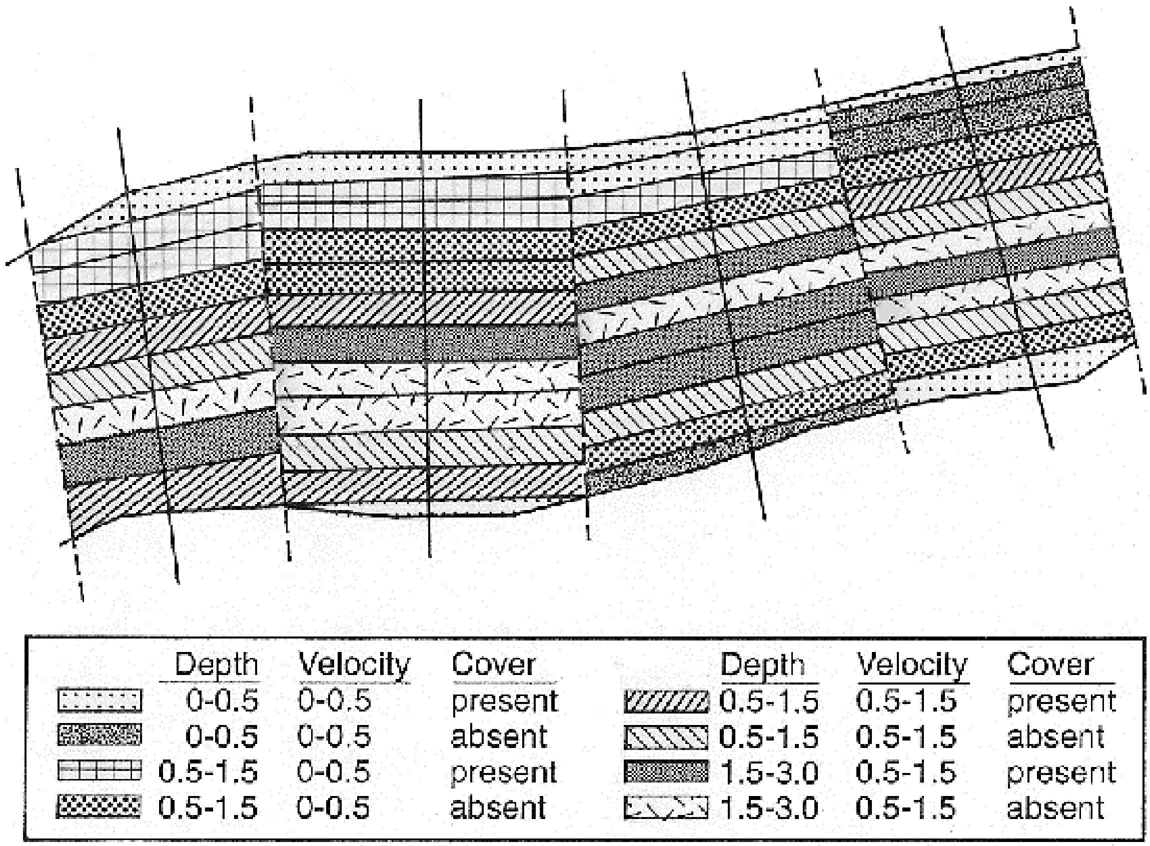



Figure 3. Conceptual depiction of the computerized "map" produced by the channel structure and hydraulic components of PHABSIM. Stream cells are characterized by unique combinations of depth, velocity, substrate and cover at a given discharge.

This computerized "map" provides a picture of what the physical environment looks like at each simulated stream flow. To translate this picture into an estimate of microhabitat, you must determine what ranges of depths and velocities, what types of cover, and which characteristics of the substrate are important to a species or life stage of a species. Collectively, information on the tolerances and preferences of organisms with respect to the hydraulic and structural characteristics of their microhabitats is termed ***habitat suitability criteria (HSC)***. Within PHABSIM, the physical attributes of each stream cell are compared against the habitat suitability criteria to determine the relative value of the cell as microhabitat for a particular organism (Fig. 4). Sometimes, these relative values are expressed as weighting factors, ranging from 0 to 1. When these weighting factors are multiplied by the surface area of the cell, the product is known as ***weighted usable area (WUA)***. The weighted usable areas for all of the cells are then summed to obtain a single weighted usable area for the reach of stream that was simulated.

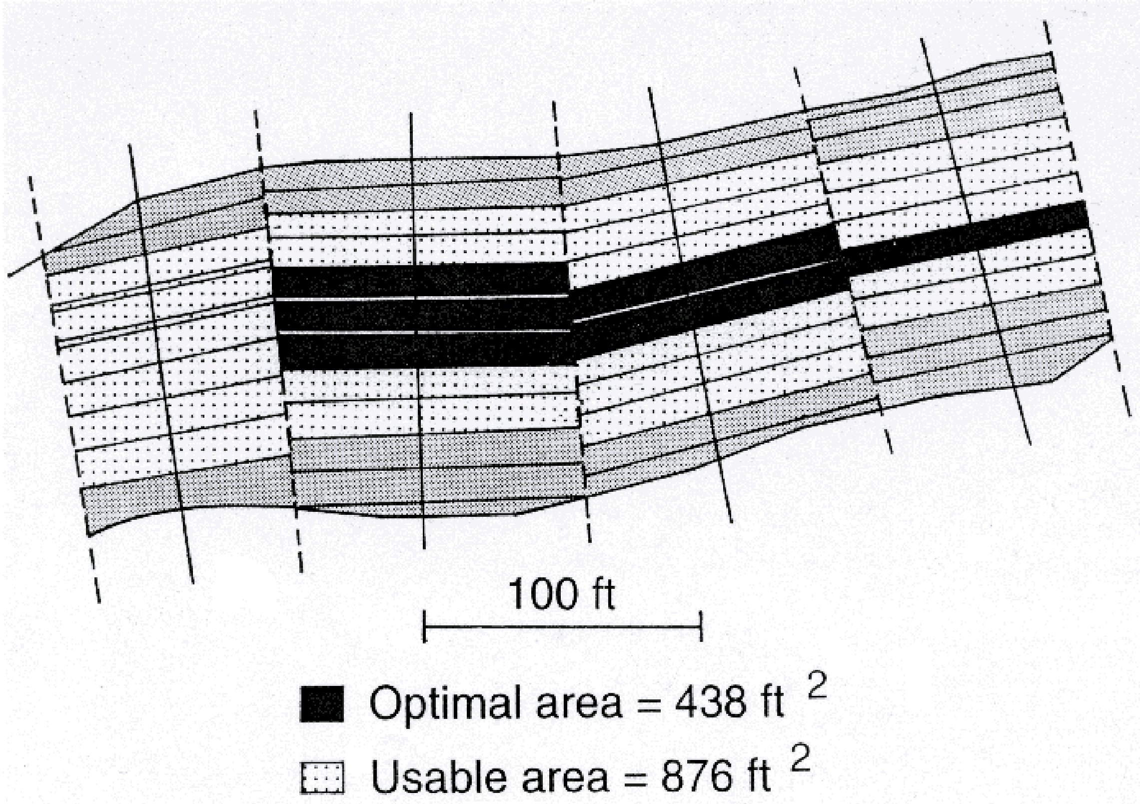



Figure 4. Conceptual depiction of the computerized "map" of physical microhabitat for a life stage of a target species, generated by comparing the physical attributes of each cell with the habitat suitability criteria for the organism.

During the late 1980's, there was a television commercial that admonished car owners to change their oil filters regularly or face an engine overhaul. "Pay me now or pay me later," was the catch-phrase of the commercial, with a strong implication that paying later meant paying more dearly. In many respects, there is a strong analogy between the commercial and data collection for PHABSIM. Well-organized, high quality data greatly facilitate model calibration and quality assurance; PHABSIM novices can often achieve the same high quality output as their more expert counterparts. On the other hand, more sophisticated models and modeling techniques are required to make up for deficiencies in the field data. Therefore, the trade-off is often between an investment in high quality field data (pay now) versus an investment in a PHABSIM modeler with the skill to complete the analysis in spite of the data (pay later).

The purpose of this field techniques manual is to provide you with information, ideas, and experiences of many field practitioners of PHABSIM, so that you can collect the highest quality data possible. The manual also aims to cover all aspects of field work involved in applications of PHABSIM, in a variety of stream settings. Accordingly, individual chapters are organized in approximately the same sequence that should be followed in an application of PHABSIM:

(1) how to test the transferability of habitat suitability criteria,
(2) how to conduct an inventory of mesohabitats in a stream segment,
(3) how to establish a PHABSIM site,
(4) how to collect channel profile data,
(5) how to collect hydrographic and hydraulic data,
(6) how to organize and schedule field work, and
(7) how to prepare data for entry into PHABSIM.

In preparing this document, each of these subjects is initially described in the most general or usual situation. Where special conditions warrant special techniques, the technique is discussed in more detail under the phase of the data collection activity (i.e., you will not see a separate chapter on large rivers, but rather, references in appropriate chapters on how to conduct specific measurements in large rivers).

# Testing Transferability of Habitat Suitability Criteria

Previous users of PHABSIM often have not considered the evaluation of habitat suitability criteria to be an integral part of PHABSIM. We include the subject here for a number of reasons: (1) habitat suitability criteria **are** integral to PHABSIM; (2) field techniques for testing the transferability of criteria are not detailed elsewhere; (3) the collection of site-specific data for PHABSIM may be influenced by the variables specified in the criteria; and most importantly (4) the output from PHABSIM is known to be extremely sensitive to the criteria used in the model.

Transferability is defined as the ability of a set of habitat suitability criteria developed in one stream (the source stream) to correctly distinguish the quality of microhabitat conditions in the stream under investigation (the destination stream). Transferability testing is emphasized in this chapter for three primary reasons. First, tests of transferability are more practical than developing criteria from scratch every time a new study is implemented. It takes approximately one-fourth the effort to test criteria as it does to develop them. Second, the only way to know with certainty that the criteria are appropriate for a particular destination stream is by on-site testing. Professional judgment and group consensus, often used in lieu of a rigorous test of transferability, can never be as definitive as empirical evidence. Third, it is an official policy of the Fish and Wildlife Service (Service) to test criteria before they are used in applications of the IFIM. If the Service is involved in a study (even tangentially), the official line is to test before using.

## THEORY

Consider a PHABSIM site in a destination stream, divided into a grid of equal-sized, internally homogeneous cells as shown in Fig. 5. Because all the cells are the same size, there would be an equal probability of finding a target species in any cell if the organism were randomly distributed within the reach. By applying a set of HSC from a source stream to each cell in the destination stream, a microhabitat quality rating of optimal or usable, and suitable (optimal and usable combined) or unsuitable can be assigned to each cell (Fig. 6). The site is then sampled to determine which cells are occupied by the target species or life stage, and which cells are not (Fig. 7).

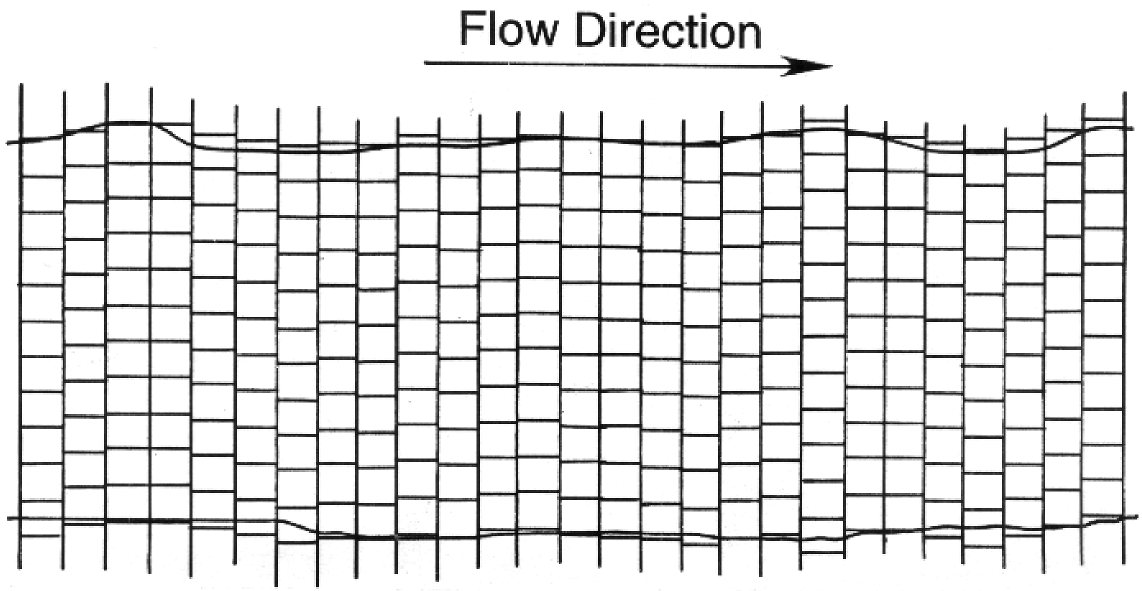



Figure 5. Hypothetical stream reach divided into a grid of equal-sized stream cells.

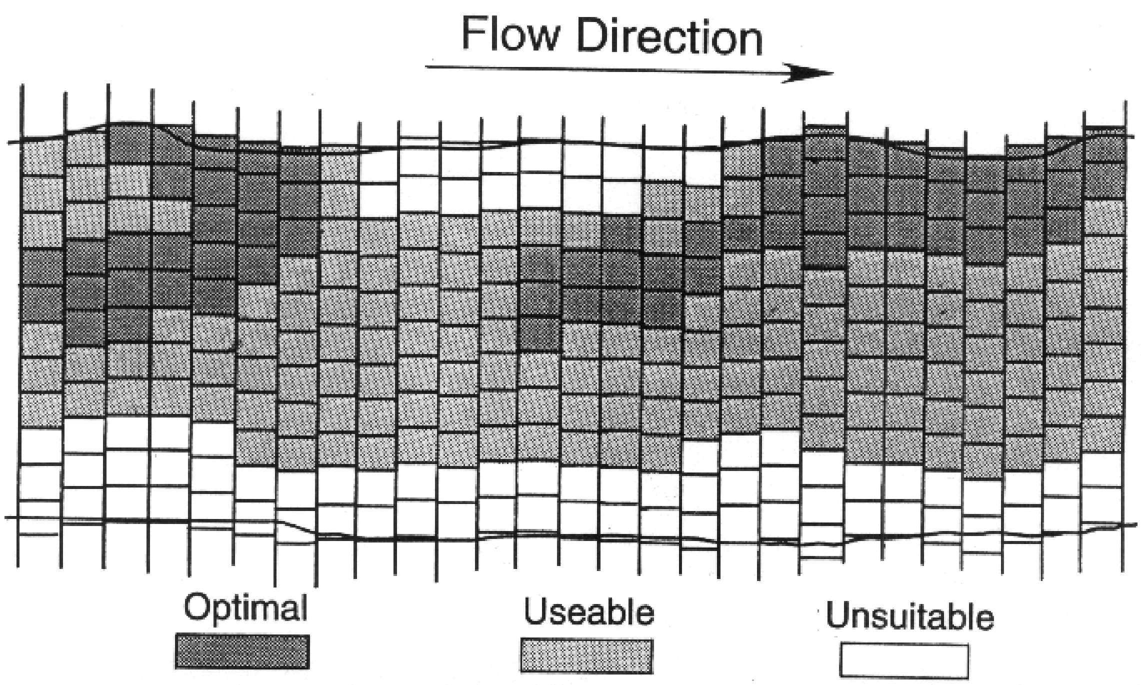



Figure 6. Classification of the stream cells from Figure 5 into optimal, usable, suitable (optimal + usable), and unsuitable categories, based on a set of habitat suitability criteria to be tested.

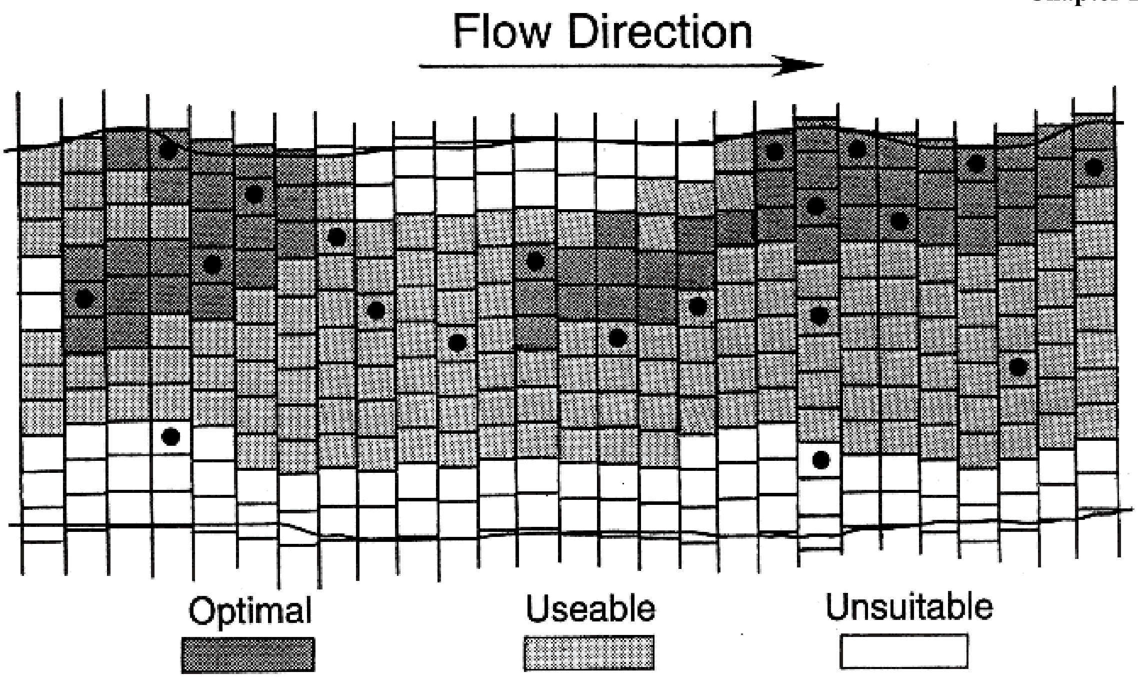



Figure 7. Overlay of locations of target species to determine cell occupancy for the grid of stream cells classified according to a set of habitat suitability criteria being tested.

If the criteria correctly describe the behavior of the target organism in the destination stream, we expect two results: (1) there should be proportionately more fish in optimal cells than in usable cells, and (2) there should be proportionately more fish in suitable cells than in unsuitable cells.

Sixty-five of the cells in Figure 7 were classified as optimal, 144 were classified as usable, and 79 as unsuitable. Eleven of the 65 optimal cells were occupied by the target organism, 7 of the 144 usable cells were occupied, and 2 of the 79 unsuitable cells were occupied. The counts of occupied and unoccupied versus optimal, usable, and unsuitable cells are cross-classified in two ***chi-square contingency tables***. The first table tests the optimal versus usable classification (Fig. 8) and the second one tests the suitable versus unsuitable classification (Fig. 9).

| | **Optimal** | **Usable** | **Total** |
|---|---|---|---|
| **Occupied** | 11 (16.9%) | 7 (4.5%) | 18 |
| **Unoccupied** | 54 | 147 | 201 |
| **Total** | 65 | 154 | 219 |

Figure 8. Contingency table format for one-sided chi-square test of optimal versus usable classifications of microhabitat.

| | Suitable | Unsuitable | Total |
|---|---|---|---|
| **Occupied** | 18 (8.2%) | 2 (2.5%) | 20 |
| **Unoccupied** | 201 | 77 | 278 |
| **Total** | 219 | 79 | 298 |

Figure 9. Contingency table format for one-sided chi-square test of suitable versus unsuitable classifications of microhabitat. The suitable classification is defined as the combined optimal and usable classifications.

A *one-sided chi-square test* (Conover 1971) is used to test for non-random selection of microhabitat conditions by the target organism. The test statistic T is given as:

$$T = \frac{[\sqrt{N}\,(ad - bc)]}{[(a+b)(c+d)(a+c)(b+d)]^{1/2}}$$

where N = the total number of cells,
a = the number of occupied optimal cells,
b = the number of occupied usable cells,
c = the number of unoccupied optimal cells, and
d = the number of unoccupied usable cells, (Thomas and Bovee 1993).

For a test of suitable versus unsuitable habitat suitability classifications,
a = the number of occupied suitable cells,
b = the number of occupied unsuitable cells,
c = the number of unoccupied suitable cells,
d = the number of unoccupied unsuitable cells.

For a set of HSC to be considered transferable, the null hypotheses ($H_{01}$: optimal cells will be occupied in the same proportion as usable cells and $H_{02}$: suitable cells will be occupied in the same proportion as unsuitable cells) should be rejected at the 0.05 level of significance. Rejection of the null hypothesis at this significance level occurs if T $\geq$ 1.6449. From the data presented in Figure 7, and cross-classified in Figures 8 and 9, T = 1.7319 for the suitable versus unsuitable test and T = 3.046787 for the optimal versus usable test. Therefore, we reject both null hypotheses and conclude that the criteria are transferable to the destination stream.

Thomas and Bovee (1993) examined the effects of varying sample size on the reliability of the transferability test procedure. A reduction in reliability was identified by an increase in the probability of committing either a type I or type II error. A type I error is committed when a null hypothesis that should have been rejected is accepted. Type II errors result from rejecting a null hypothesis which should have been accepted. Type I errors are considered more critical in IFIM applications because they can result in the acceptance and use of non-transferable criteria in a destination stream. The rejection of criteria that are actually transferable, resulting from type II errors, is inconvenient but not as serious as using the wrong criteria in a study.

Thomas and Bovee (1993) found that the probability of committing a Type I error with this procedure was very small, regardless of sample size, but that Type II errors were common with fewer than about 60 occupied and 200 unoccupied cells. The practical outcome from this analysis was that the stream grid approach is unnecessary. Occupied and unoccupied cells can be determined by more efficient and traditional sampling techniques than the labor-intensive methods used by Thomas and Bovee (1993). Furthermore, the study suggests that testing of habitat suitability criteria can be initiated as soon as the first data become available. If the test results are positive (both nulls rejected) with a sample as small as 15 occupied and 100 unoccupied cells, the probability that the criteria are correct is approximately 90%. Further data collection would be up to the discretion of the investigator, but the result is unlikely to change. If the criteria are correct for the stream, additional data collection will simply reinforce their correctness.

Small initial samples are more likely to produce negative results that would imply that the criteria should be rejected. The incidence of Type II errors in the Thomas/Bovee study rose dramatically when the number of occupied cells was less than 35. Therefore, if a negative result is obtained with an initial sample of 20 occupied and 80 unoccupied cells, there is at least a 50/50 chance that the results will improve with additional sampling. When negative results are still obtained with samples in excess of about 65 occupied and 300 unoccupied cells, however, the criteria are probably not transferable to the destination stream. Additional sampling is not likely to make them transferable.

## IMPLEMENTATION

The greatest (perhaps only) skill involved in conducting microhabitat observations in streams is to locate fish before they locate you. Because fish typically orient themselves into the current, one of the simplest tactics for avoiding detection is to sample in an upstream direction. Fish are superbly equipped with sensory devices, however, so no matter how stealthy you are, the fish probably are aware of your presence. Therefore, the real trick in making unbiased observations of fish locations is to be as non-threatening as possible. Your movements should be slow and deliberate to create as little disturbance as possible. In preparing to conduct a transferability test, you might want to practice your sampling technique on schools of suckers. In our experience, if you can sneak up on a school of suckers without triggering an underwater stampede, you can probably sneak up on anything else.

Underwater observation by snorkeling is widely considered to be the least intrusive technique of observing fish for habitat suitability work. The goal in conducting underwater observations is to achieve total coverage of the area being sampled. Sampling lanes, less than or equal to the underwater sight distance in width, are assigned to individuals in a team of divers. Enough sampling lanes are established to cover the entire width of the stream, or in some cases, a zone within the stream. In relatively slow, shallow water, divers can use rocks and other handholds on the streambed to pull themselves along.

In deeper and faster water, we have found the static-line and drop-line arrangement (Fig. 10) developed by Li (1988) to work very well. Using mountaineering ascenders (Fig. 11) to pull ourselves up the drop-lines, we have successfully sampled areas of streams with surface velocities in excess of 10 ft/sec. **[Safety note: in some of our older publications, you might see a diver attached to the ascender by a chest harness and carabiner. Do not do this! We nearly drowned one of our colleagues with this arrangement several years ago. Attach yourself to the ascender with your hands only.]**

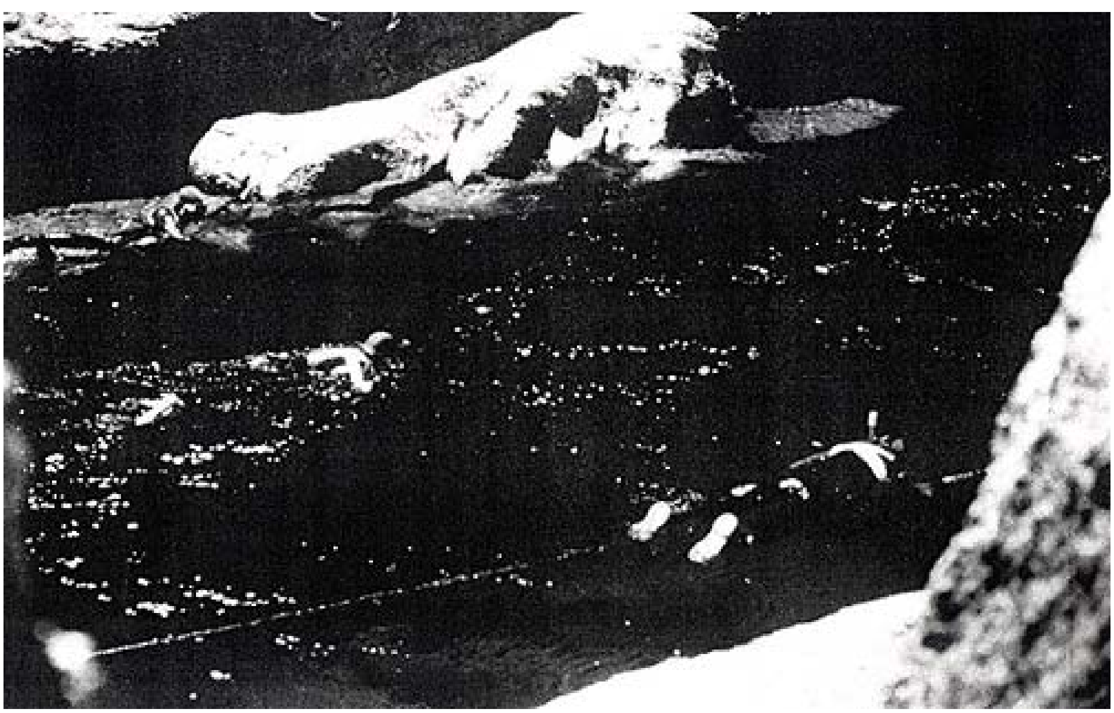


Figure 10. Static/drop-line arrangement used by a team of snorkels to observe fish locations in a deep, fast-moving water.

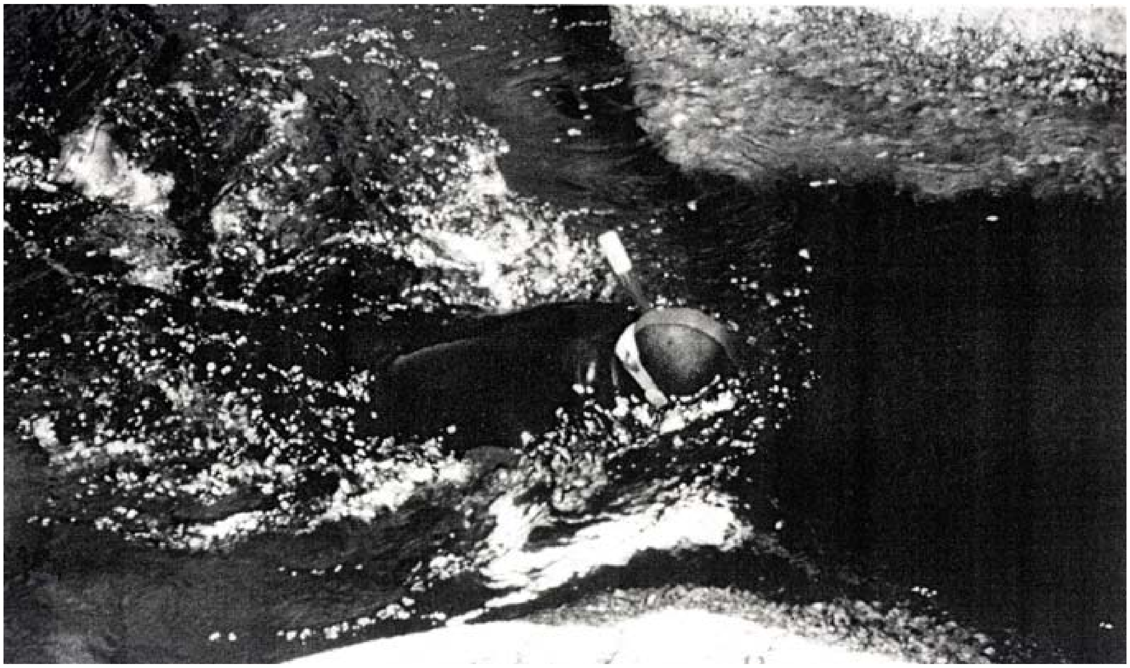


Figure 11. Diver moving against a relatively strong current with the use of a drop-line and mountaineering ascender (visible in diver's right hand).

The dive team should move upstream slowly and deliberately, taking care to stay in line so that a diver in one lane does not disturb fish in a neighbor's lane. When a target organism is observed, its location is marked. For markers, we have used goose decoy weights attached to numbered aluminum tags (Fig. 12). Other investigators have used weighted buoys or floats to mark occupied locations. Data pertaining to the marker, such as tag number, species, life stage, activity, proximity to cover, and cover type, are recorded at each sighting. Some investigators prefer to relay the information to a crew member on shore, whereas others prefer to have the divers record the information on dive slates as they make the observations. At the completion of the dive, the crew returns to each marked location to measure its depth and velocity (see chapter on hydrographic measurements for description of techniques). Markers are not retrieved at this time.

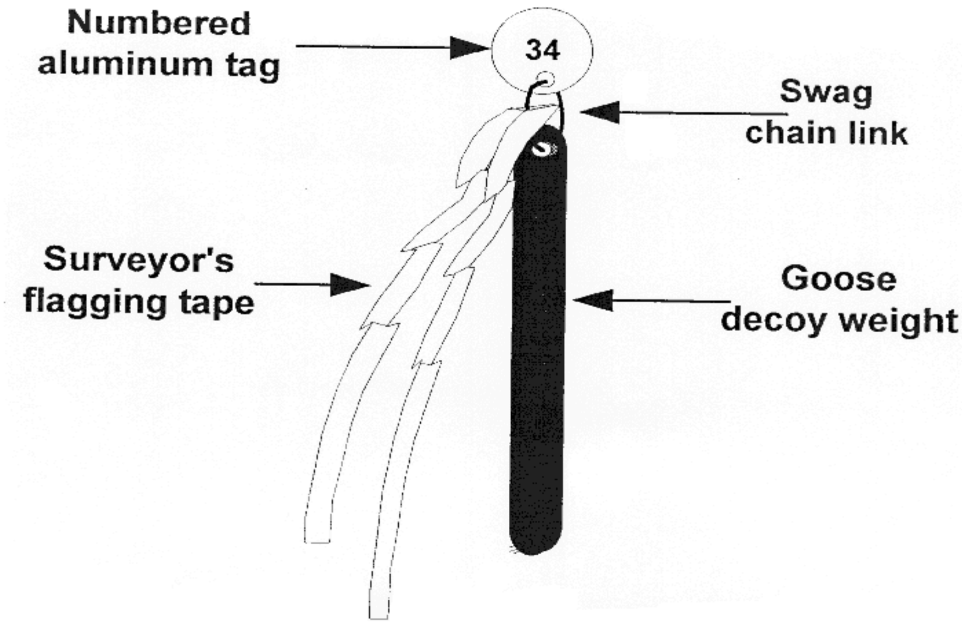



Figure 12. Fish location marker constructed from a goose decoy weight attached to a numbered aluminum tag. Flagging tape is used to re-locate tags at the end of the sampling session.

The next step in the process is to select several unoccupied locations in the dive site for measurement. Figure 13 shows the use of a ***random walk*** sampling design (Bovee 1986) to locate unoccupied sampling points. The location of a sampling point along the longitudinal axis of the stream is determined by selecting a random distance from the bottom of the sample site (identified as a ***transect***). A measurement point along the transect, termed a ***vertical***, is then selected at random. The reason that the markers are not retrieved at the end of the dive is to make certain that no occupied locations are included in the pool of unoccupied locations.

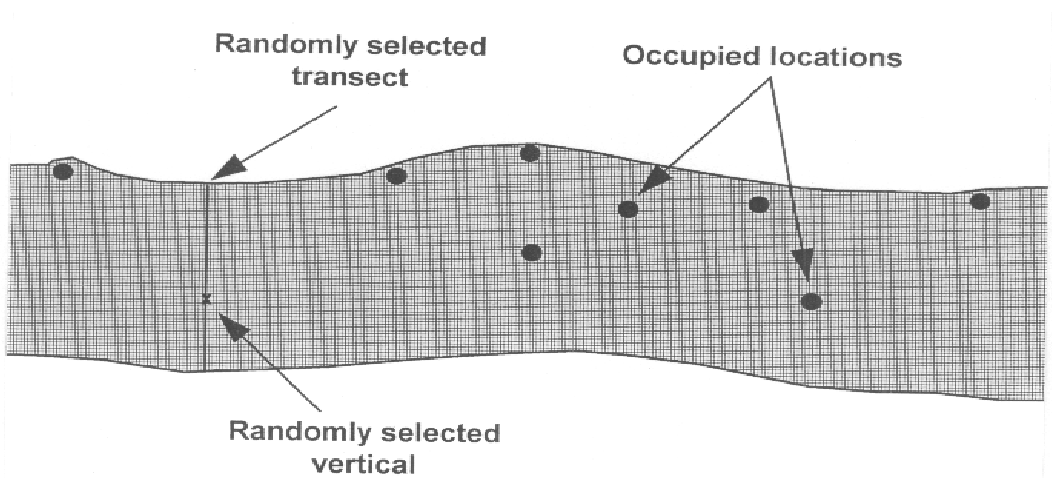



Figure 13. Random walk sampling design, using randomly selected transects and verticals to obtain measurements of unoccupied cells in a reach of stream.

There are no firm guidelines regarding the number of unoccupied locations to measure at each dive site, except that the same number should be sampled at all the sites. The number of unoccupied cells measured at a site should not be based on the number of occupied cells, because doing so may introduce a bias into the test procedure. Some sites may contain more fish because they also have an abundance of optimal or suitable habitat. Relating the number of unoccupied cell measurements to the number of fish observed can result in an overestimation of the availability of optimal or suitable cells. Such an overestimation will result in an unrealistically low value of the test statistic, T, which in turn, could result in a type II error.

Despite its advantages, snorkeling is not without limitations and biases. Restricted visibility due to turbidity is one of the most common limitations encountered by divers. When the underwater sight distance is less than about 4 ft, snorkeling is not a very efficient or practical means of gathering habitat-use data. However, even when visibility is not so severely restricted, it can be a source of bias. If the maximum depth of water is greater than the maximum visibility, there will be a tendency to make more observations in shallow water. This form of bias may be overcome by surface diving, if it can be done with a minimum of disturbance.

Underwater observation also seems to work better for some species and activities than for others. For example, divers can detect active fish more readily than resting fish. The movement of an active fish tends to alert the diver to its presence, whereas resting fish are often cryptic and easily overlooked. For similar reasons, there is a tendency for divers to observe large fish more immediately than small fish. [Note: some species, notably the darters, have an annoying habitat of maintaining just enough distance between themselves and a diver that identification of the species and the actual focal point location of the fish are questionable.]

Electrofishing has been used widely in habitat studies over the past forty years, and its use for this purpose has been praised and condemned. The most serious criticism of electrofishing is that it is too disruptive and intrusive to be of value in habitat-use studies. However, recent advancements in the use of electrofishing gear may counteract some of these deficiencies. Bain et al. (1985) developed a ***pre-positioned electrode*** for habitat-use investigations. The purpose of pre-positioning the electrode is to minimize disturbance associated with a constantly energized, moving electrical field. The anode is positioned at a location to be sampled, left undisturbed for 10 minutes or so, and then energized. As soon as the electrode is energized, a team of dip-netters attack the grid, netting target organisms stunned or immobilized within the shocking grid (Fig. 14).

Figure 14. Dip-netters searching an electrofishing grid for stunned fish in the Deerfield River, Massachusetts. Photo courtesy of M. Bain.

The design of this electrode unit is elegant in its simplicity. A 12-gauge solid copper insulated wire, with the insulation removed at 5-cm intervals is formed into a rectangle (other geometric shapes could also be used as long as the area shocked remained the same) and anchored to the streambed. Power is supplied via an AC generator on shore or mounted in a shocking barge (Fig. 15).

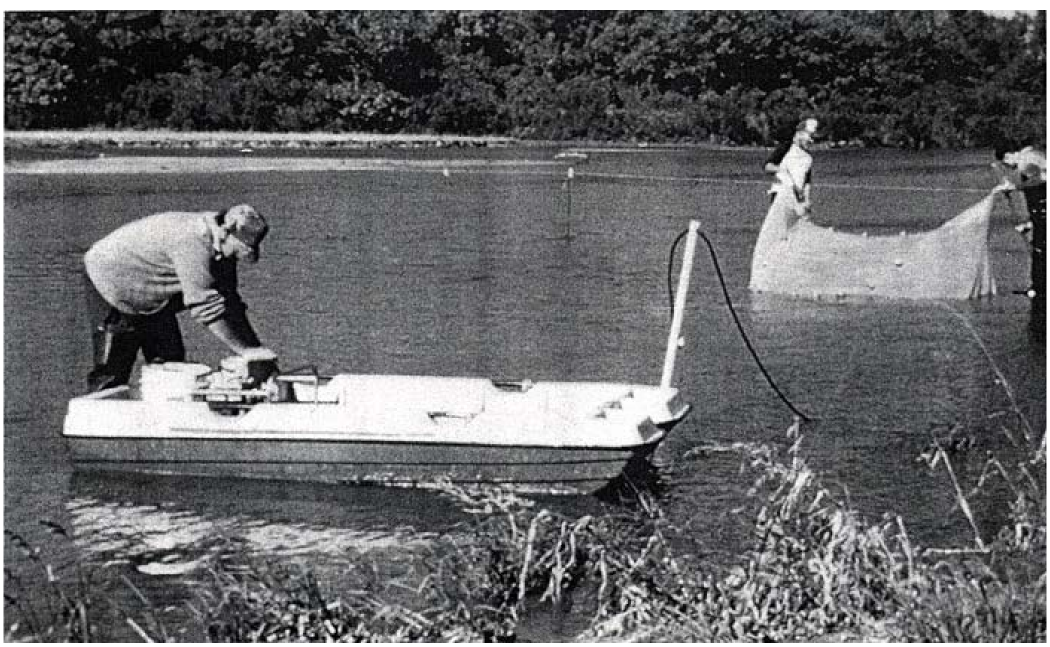


Figure 15. Electrofishing barge used on the Platte River, Nebraska. Note the use of a beach seine to recover stunned fish downstream from the shocking grid. Photo courtesy of M. Bain.

The design illustrated by Bain et al. (1985) suggests that the electrical circuit is completed by connecting the hot lead to one side of the frame and the ground on the other side. In view of the potentially damaging effects of alternating current on fish and the heightened awareness of fisheries scientists to avoiding electrofishing injury, we suggest the following modifications to this design. First, a variable voltage pulsator (VVP) should be connected to the generator to convert the electrical field from AC to pulsed DC. Second, instead of using a single wire loop, we suggest using two parallel straight wires, one as a cathode and the other as the anode (Fig. 16). This design will ensure the greatest field strength between the two wires and will tend to concentrate fish at the anode, making collection easier.

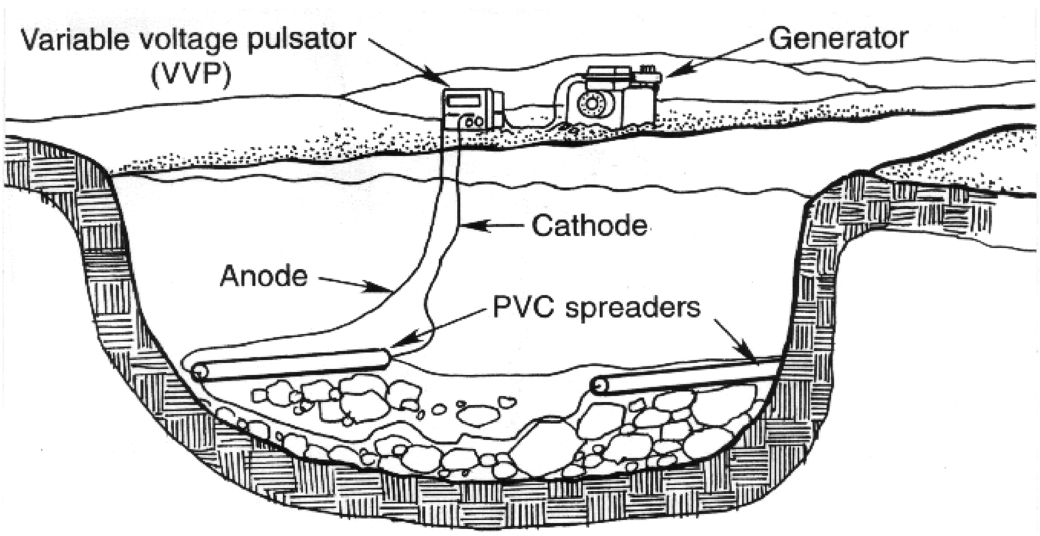



Figure 16. Pre-positioned electrode configurations to convert grid to DC or pulsed DC power source.

The pre-positioned electrode eliminates some of the disturbance associated with electrofishing, but not all of it. Fish located within 10-20 ft of the anode will undoubtedly be disturbed (but may not be immobilized) by the electrical field. The greater source of disturbance, however, results from people splashing around and flailing at the water with dip nets. This disturbance is unrelated to the delivery system for the anode, a realization that has lead to experimentation with a ***mobile anode*** electrofishing system. The primary advantage of the mobile anode over the pre-positioned electrode is a substantial reduction in the amount of time involved in taking a sample.

The unique characteristic of a mobile anode system is that the anode is thrown to a sampling location rather than being pre-positioned in it (Fig. 17). The generator and VVP are carried in the barge, and attached to 150-300 ft of power cord. The anode consists of a looped cable, housed in a length of weighted PVC pipe, connected to the power cord with a waterproof (Turnex®) connector. A three-person crew is recommended for this sampling procedure (we also recommend that crewmembers stay in communication with one another by voice-activated radios). **[Safety note: For reasons of safety, one person should stay at the barge to operate the "deadman" switch that energizes or deactivates the anode.]** This person also records data and keeps track of sampling locations (data recorder). A second crew member should be responsible for delivering the anode to the predetermined sampling location (thrower). The third crewmember acts as the dip-netter. Generally speaking, the sequence of events involved in taking a sample proceeds as follows:

(1) The data recorder identifies the next location to be sampled.
(2) The sampling location is approached from downstream, and the samplers stop 20-30 ft from where the sample is to be taken.
(3) The thrower gathers and coils 20-30 ft of slack power cord, checks the readiness of the dip-netter, and when prepared to sample, signals the data recorder to energize the anode.
(4) The anode is energized.
(5) The anode is thrown in a high arc into the pre-selected sampling location.
(6) As soon as the anode is in the air, the dip-netter moves to the sampling location as quickly as possible, without compromising safety. When properly synchronized, the anode reaches the sampling location a second or so before the dip-netter arrives.
(7) The dip-netter retrieves any target organisms stunned by the anode. After 10 seconds or so, the anode is deactivated.
(8) The dip-netter marks the sample location with a marker tag and relays tag number and occupancy data (unoccupied, or species and life stage if occupied) to the data recorder.

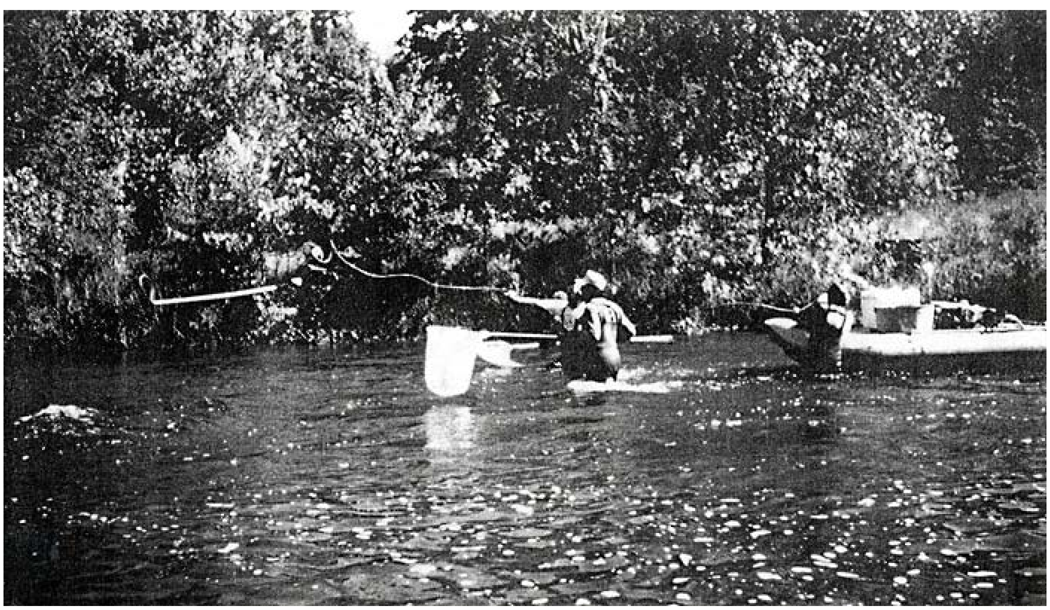


Figure 17. Mobile electrode system used in the Huron River, Michigan to develop habitat suitability criteria for smallmouth bass.

Whenever microhabitat use data are collected by electrofishing, investigators must be acutely aware of the potential for bias. The amount of bias associated with electrofishing can be minimized by: (1) using a recognizable sampling design to avoid the tendency to sample where you think you will find fish, and (2) spacing sample locations sufficiently far apart so that fish are not unduly disturbed by the previous sample. To these ends, we have used the following systematic sampling design with considerable success.

Transects are spaced at equal intervals along the bank, separated by a distance considered to be sufficient to minimize sampling disturbance (Fig. 18). For noisy, high-gradient streams, 50 ft is usually far enough, but in quiet, low-gradient streams, transects should be spaced 100-150 ft apart. Alternating sampling zones are then assigned to each transect: Zone 1 near the right bank, Zone 3 at midstream, and Zone 5 near the left bank. Zones 2 and 4 are spaced approximately one-fourth and three-fourths of the way across the channel. One sampling pattern, called a "double-diamond", connects straight lines of sequential numbers forming an overlapping diamond pattern (Fig. 18).

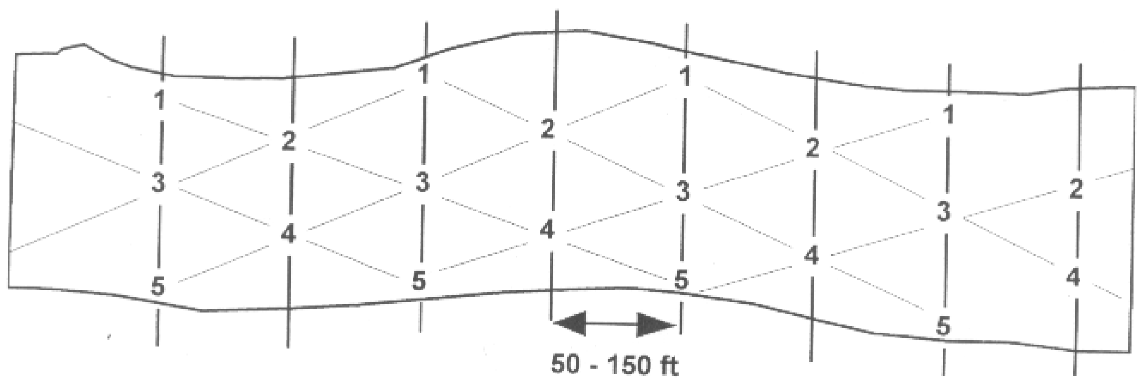



Figure 18. "Double-diamond" sampling pattern designed to prevent data bias and disturbance, using electrofishing or other potentially disturbing sampling techniques.

Figure 19 shows another sampling pattern, called a "two-pass", of the site laid out in Figure 18. The barge is anchored near the center of the reach to be sampled, and the anode is carried downstream the full length of the power cord. On the first pass, Zones 1 and 2 are sampled in an upstream direction. Tags are placed at each location after sampling, and the tag number and catch (species, life stage, or "no catch") is recorded. After the first pass is completed, microhabitat measurements are made at all tag locations, whether the target species was present or absent. By making the measurements after the first pass, fish that might have been disturbed on the opposite side of the river will have had time to settle down and resume normal activities. On the second pass, Zones 3, 4, and 5 are sampled, tagged, and measured. Note that the distance between sampling zones should be about the same as the distance between transects. If the transects were 50 ft apart and the stream was less than 150 wide, some of the sampling zones (specifically Zone 3) would be eliminated.

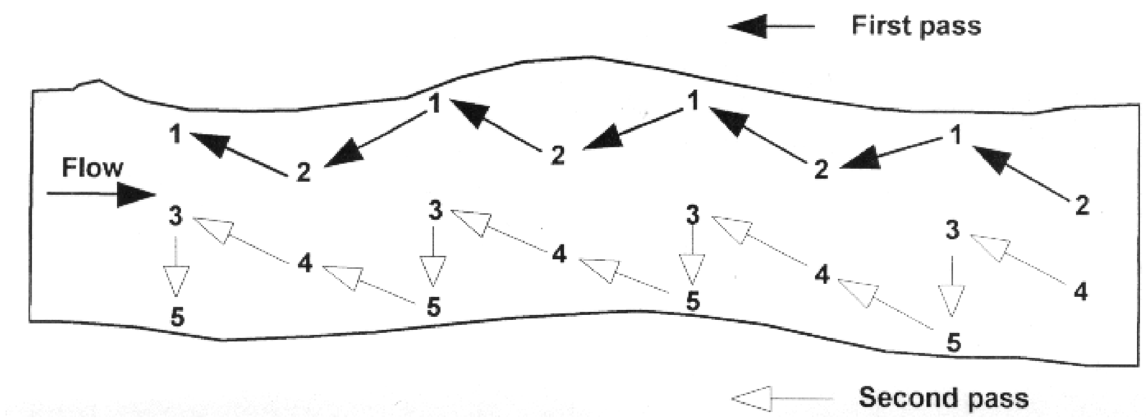



Figure 19. Two-pass sampling of the reach of stream illustrated in the double-diamond sampling design of Figure 18.

This sampling design attempts to accomplish two goals. First, a rough balance is struck between the number of near-shore and off-shore samples. This is necessary to achieve a fair test, especially for species that are oriented to near-shore or mid-channel microhabitat types. Second, an adequate distance is maintained between samples to avoid disturbance problems. Any other sampling design that incorporates the same features (a random walk would probably work quite well) could be substituted.

Unfortunately, the utility of either the pre-positioned electrode or mobile anode technique may be limited to relatively shallow water. Boat-deployed mobile anodes have been used for many years in conjunction with population estimates, but we are unaware of anyone who has attempted to use a similar arrangement to test the transferability of habitat suitability criteria. Theoretically, there is no reason to believe that boat shocking with a mobile anode would not work. However, we know that electrofishing efficiency drops off dramatically in more than about 6 ft of water. Whether a sampling crew could unobtrusively approach and sample a location while in a boat under power is unknown.

If the target species is relatively common, and the destination stream can be sampled efficiently, it should be possible to obtain enough data to test transferability for a given set of habitat suitability criteria in a week or two. However, the criteria to be tested are often seasonal (e.g., spawning, young-of-year), so it is advisable to reserve a full year to complete the tests for all seasonal stratifications.

In some cases, the abundance of the target species will be so low, or the river so difficult to sample, that the methods described in this chapter will not be feasible. Before giving up on transferability testing, however, other compatible approaches should be considered. For example, could you use radiotelemetry to determine occupied locations, and then randomly pick some unoccupied locations to collect the data for the contingency tables? Could you test the criteria in another stream, similar to the one you are working on, but with a larger population of the target species?

If you cannot figure out how to collect the data for a ransferability test, two alternatives should be considered. A roundtable peer-review of the criteria might be a workable solution if a critical mass of experts, knowledgeable about the habitat requirements of the target species, can be assembled. However, where the species is rare and knowledge about its habitat requirements even rarer, participants in a study should be prepared to shut down the IFIM assembly line. Such species are likely to be central to the stakeholders in a IFIM analysis. This being the case, it would be a better investment of time and money to attain a good understanding of the species' requirements and tolerances than to proceed blindly through the rest of an IFIM analysis.

## SUMMARY

- Results from PHABSIM are extremely sensitive to the accuracy of habitat suitability criteria used in the model. Model outcomes can be reversed simply by using a different set of criteria.
- Because microhabitat use by a species may vary from stream to stream, the transferability of habitat suitability criteria should be tested in the destination stream prior to using the criteria in a PHABSIM analysis.
- Criteria can be tested by sampling for the target species in the destination stream, and cross-classifying occupied and unoccupied locations in a $^2$ contingency table. If the criteria correctly describe microhabitat selection in the destination stream, proportionately more optimal than usable locations should be occupied. Similarly, proportionately more suitable than unsuitable locations should be occupied.
- Whenever possible, the preferred technique for obtaining cell occupancy data is by snorkeling. Sampling should be conducted in an upstream direction to approach fish unobtrusively. The static/drop-line system allows divers to sample areas of deep or fast water.
- Snorkeling observations can be biased by visibility, and the size and activity of the fish being observed. Some species are inherently difficult to observe by diving because of their tendency to leap-frog ahead of the diver.
- Electrofishing can be used to gather cell occupancy data provided that: (1) a recognizable sampling design is used, and (2) care is taken to minimize disturbance during sampling.

# Representing the Stream Segment

The ***stream segment*** is the basic habitat accounting unit of the IFIM, a first order subdivision of the study area. Stream segments are relatively long sections of stream, typified by a geographically homogeneous flow regime. The discharge at the top of a segment is about the same as at the bottom (±10% or so). The overall channel geomorphology (slope, sinuosity, channel pattern and structure, geology, and land use) is also usually consistent within segment boundaries. The flow regime, however, is the primary determinant of segments.

Within a segment, there can be several habitat-related subdivisions: reaches, mesohabitats, and microhabitats. A ***reach*** is typically about an order of magnitude longer than the width of the channel (commonly 10-15 channel widths), and contains many or all of the meso- and microhabitat types present in the entire segment. A ***mesohabitat type*** usually has a length of about the same magnitude as the width. Mesohabitat types are commonly delineated by localized slope, channel shape, and structure. Riffles, runs, glides, shoals, pools, pocket waters, and divided channels are features commonly ascribed to mesohabitat types. It is also common practice to stratify mesohabitats into even finer subdivisions (e.g., low, medium, and high gradient riffles or shallow, moderate, or deep pools). ***Microhabitats***, are usually shorter than one channel width, and represent a relatively homogeneous area of about the size scale utilized by an individual fish. Tree-snags, undercut banks, the tail-outs of pools, mid-channel gravel bars, and velocity shelters behind boulders are all examples of channel sub-units at the microhabitat scale.

This chapter discusses sampling strategies that can be used to define and determine the proportions of mesohabitat types, so that all of the measured channel units collectively represent the segment. The next chapter discusses how to sample microhabitats within a channel unit such that the mesohabitat type is accurately represented.

## SAMPLING STRATEGIES

Over the past fifteen years, two very different strategies have evolved for the representation of a segment: representative reaches and mesohabitat typing (habitat mapping). A **representative reach** is approximately 10-15 channel widths in length, and assumed to contain essentially all of the mesohabitat types of the segment. The proportions of the mesohabitat types in the representative reach are also assumed to be the same as their proportions in the segment. ***Mesohabitat typing*** involves the definition and explicit inventory of the proportions of mesohabitats in a segment (Morhardt et al. 1983). This approach was developed when investigators tried to establish representative reaches in streams where mesohabitat types appeared to occur randomly and inconsistently throughout the segment.  The haphazard arrangement and proportioning of mesohabitat types in these streams lead Morhardt et al. (1983) to question the validity of the representative reach in these streams.

## Representative Reaches

The underlying premise of the representative reach is that mesohabitat types (i.e., riffles and pools at the simplest level of resolution) tend to occur in a somewhat repetitive pattern.  This concept was derived from Leopold et al. (1964) who noted that riffles tend to be spaced about 7-10 channel widths apart in alluvial streams. The reasoning behind the representative reach was that each major mesohabitat type should be represented at least once in a relatively long reach of stream (e.g., 10-15 channel widths).  Because of the repetitive nature of alluvial channels, the assumption that all (or at least most) of the segment's mesohabitat types could be represented in a single reach was not so far-fetched.  Likewise, the assumption of similar proportionalities between the representative reach and the segment was supported by the uniformity of spacing suggested by Leopold et al. (1964).

Figure 20 shows a portion of an alluvial section of the Cache la Poudre River, near LaPorte, Colorado.

A surprising number and variety of streams in the United States actually conform fairly well to the explicit criteria of the representative reach. Figure 20 shows a portion of an alluvial section of the Cache la Poudre River, near LaPorte, Colorado. The spacing of riffles and pools is remarkably similar throughout this section of river. Where such repetition and regularity in mesohabitat distribution is exhibited, the representative reach approach is preferred over mesohabitat typing because the proportions of the various mesohabitat types can be measured directly. Generally speaking, the criteria for a representative reach will be best met in alluvial streams. However, representative reaches may not be the best way to describe all alluvial streams, but may be valid in some reaches of bedrock-controlled or colluvial channels.

Bovee (1982) discussed three different techniques for selecting a representative reach: systematic, random, and stratified-random sampling. All three of these surveying techniques require a topographic map of the segment. **Systematic sampling** is the easiest approach, and is recommended for segments exhibiting a gradation in slope or channel shape from the top of the segment to the bottom. The segment is divided into thirds (Fig. 21) and two representative reaches are established at the division points.

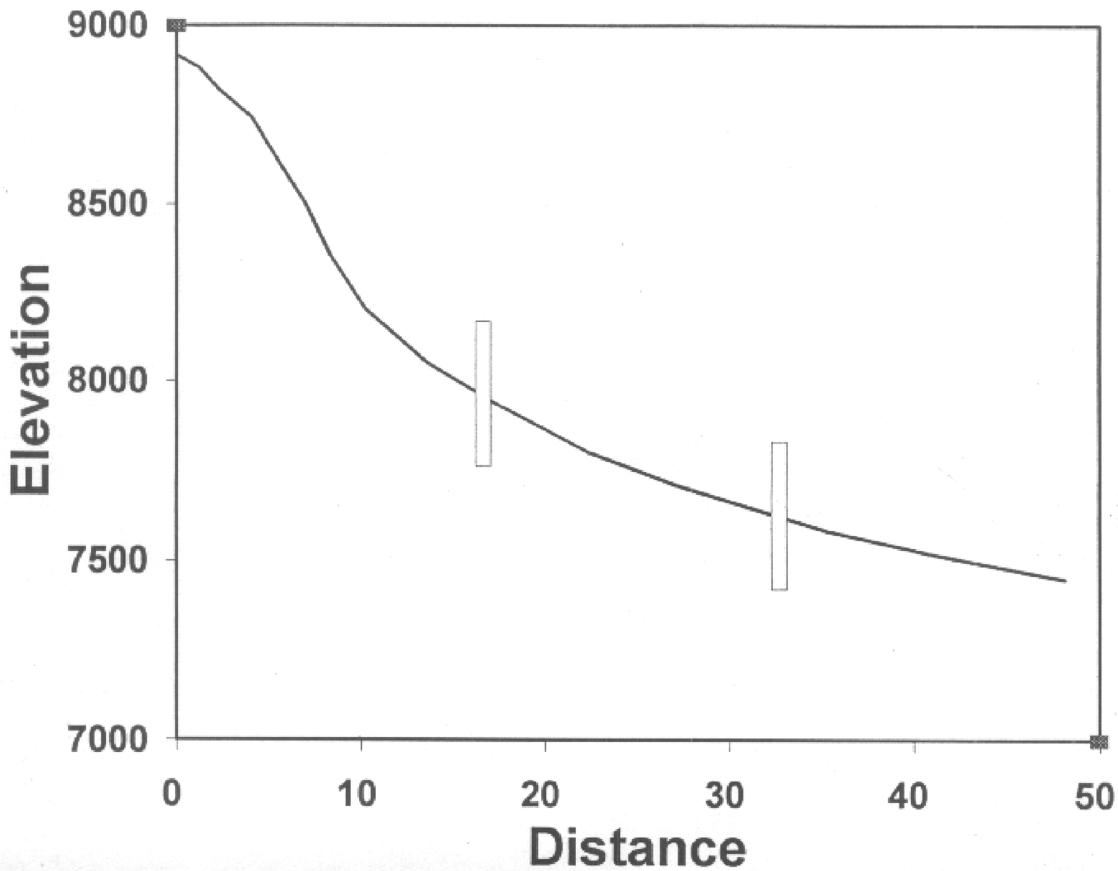



Figure 21. Determination of the locations of representative reaches by systematic sampling in a segment exhibiting a uniform change in gradient from top to bottom.

A representative reach can be selected at random in the following manner. First, determine the average channel (bank-to-bank) width and multiply by a factor of 10 to 15. A factor of 10-12 is recommended for simple riffle-pool sequences (e.g., Fig. 20), and a factor of 12-15 is recommended for meandering or divided channels. The channel width times its appropriate multiplier equals the approximate length of a representative reach. On a topographic map, locate the segment and mark off and number candidate reach lengths between segment boundaries (Fig. 22). Reaches containing bridge crossings or channelized sections should be eliminated from the sampling population, unless they are characteristic of much of the segment. Using a random number generator, select four to six candidate reaches for further inspection.

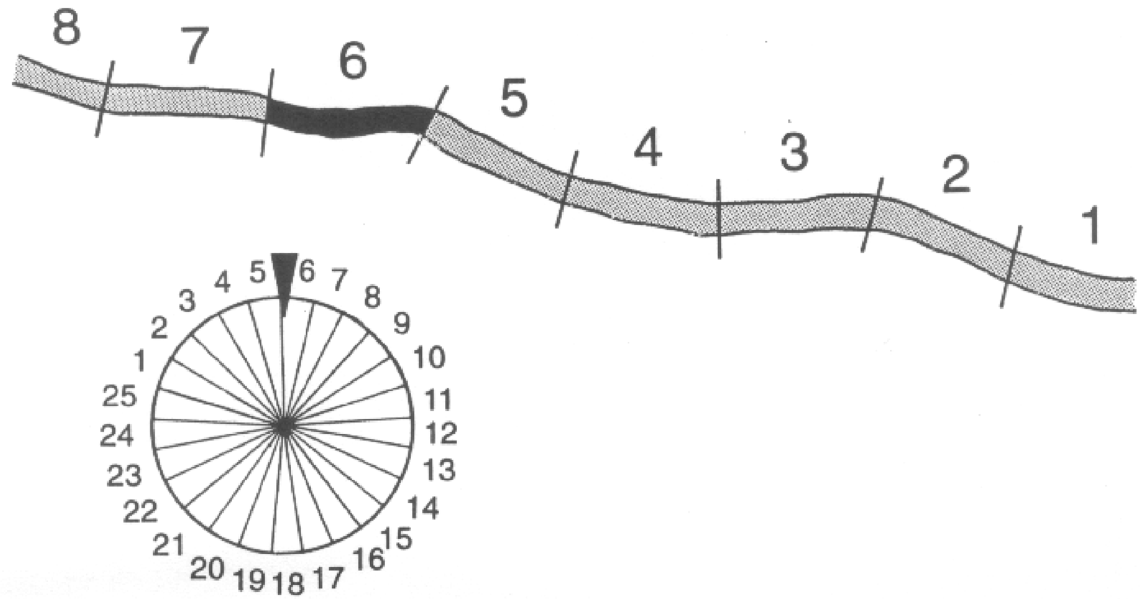



Figure 22. Selection of a candidate representative reach by random sampling. Each candidate reach is 10 times the channel width. The small "wheel-of-fortune" represents a random number generator.

Under the stratified-random sampling strategy (also known as explicit zonation) the segment is essentially subdivided into two or more smaller segments. Such stratification may be appropriate if a segment was defined exclusively on the basis of flow regime, but an abrupt change in channel pattern and structure occurs midway through a segment. In reality, the stratification establishes two segments instead of one, ensuring that measurements will be taken in both channel types. This outcome is not guaranteed by pure random sampling. Once the new strata have been defined, representative reaches are selected systematically or randomly from the two new segments according to the procedures discussed previously.

Prior to about 1982, representative reaches were often chosen more on the basis of access and logistics than by the representativeness of the site. Whether systematic, random, or stratified-random, a sampling procedure of some sort forces the investigator to seriously evaluate the representativeness of potential study sites. After selecting four to six candidate reaches, the investigator should visually inspect all of them. If they are all very similar, a representative reach can be established where access is easiest (and landowner permission is granted). However, if there are differences among reaches that are apparent from a visual inspection, it may be necessary to conduct measurements in two or three of them. If they are sufficiently different to justify using all six candidate sites, perhaps you should consider mesohabitat typing.

# Mesohabitat Typing

Mesohabitat typing may actually be an extreme example of the stratified-random sampling approach for selecting a representative reach. Under the paradigm of habitat mapping, as developed by Morhardt et al. (1983), the mesohabitat becomes the unit of stratification. The principles of mesohabitat typing are summarized as:

(1) mesohabitat types are defined for the stream under investigation.

(2) an on-site inventory is conducted to determine the proportion of the segment represented by each mesohabitat type.

(3) transects are established to represent the mesohabitat type rather than the segment.

(4) transects in each mesohabitat type are weighted according to the proportion of the mesohabitat type in the segment.

(5) the segment is represented by all of the transects from all of the mesohabitat types, combined into a single data set (see "Preparing for Data Entry").

### *Classifying Mesohabitat Types*

Mesohabitat typing has achieved a high level of popularity and support over the past 10 years or so. Unfortunately, defining and identifying different mesohabitat types is often easier said than done. [Note: Defining mesohabitat types will immediately distinguish between the lumpers and the splitters on your crew. The lumpers will typically describe three mesohabitat types: riffles, pools, and miscellaneous. Serious splitters may not find two of any type in the entire segment.]

Numerous habitat classification systems (Fig. 23) are available for use in mesohabitat typing (Pennak 1979; Cobb and Clark 1981; Bisson et al. 1982; Frissell et al. 1986; McCain et al. 1989; Hawkins et al. 1993). With regard to habitat classifications, Balon (1982) appropriately stated that the nomenclature of a science is not as important as clearly understood definitions of terms. In other words, it should not matter how mesohabitats are named in a particular study, as long as the definitions are unequivocal and adhered to religiously. In fact, it might be advisable to name habitat types by letters of the alphabet or by colors, simply to avoid preconceptions and biases that investigators might bring along from previous studies. Habitat classification systems should be used as models, rather than as absolutes, and the definitions should be tailored to your own application.

Whatever the definitions, you should conduct a "dry-run" on the segment before conducting the mesohabitat inventory. It is almost inevitable that the classification system will contain ambiguities or vagueness when you try to apply it in the field. You might also encounter habitat types that are not described at all. It is better to discover and rectify these weaknesses before the inventory is conducted.

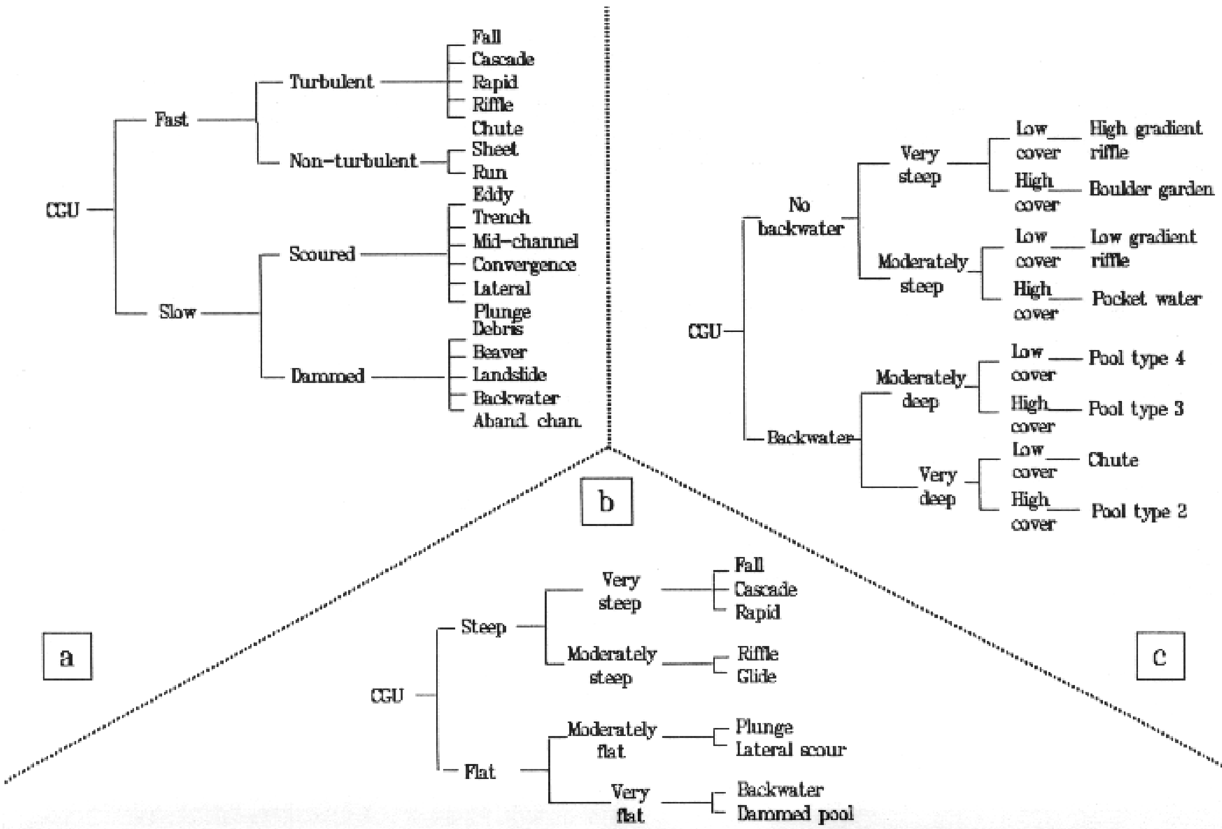



Figure 23. Hierarchical habitat-type classification systems: (a) from Hawkins et al. (1993), (b) from Frissell et al. (1986), (c) from Thomas and Bovee (1993). (The abbreviation CGU refers to "Channel Geomorphic Unit," which is equivalent to mesohabitat types as used in this manuscript).

### *Conducting Mesohabitat Inventories*

Mesohabitat inventories are conducted to determine the proportion of each mesohabitat type in a segment. Surveys can be conducted in several different ways, depending on the size and number of segments to be inventoried. Total-coverage surveys, which inventory all the mesohabitat types in a segment, are usually conducted in segments less than five miles in total length. Random-sample surveys are typically conducted in segments ranging from five to about 25 miles in length.

For segments longer than 25 miles, a stratified-random survey might be warranted.

In addition to differences in sampling design, different methods can be used to determine proportions in a segment or a sample thereof. Using the ***cumulative-lengths approach*** (Fig. 24), the length of each mesohabitat type is measured with a tape, hip-chain, range finder, or other distance-measuring device. The proportion of a particular mesohabitat type in a segment is calculated as the cumulative length of all like mesohabitat types, divided by the total length of the segment that was surveyed.

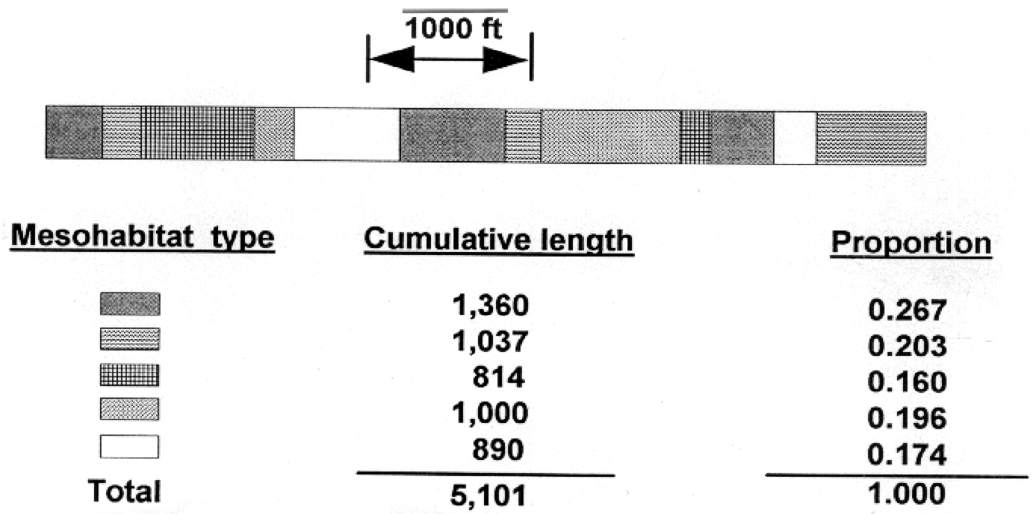
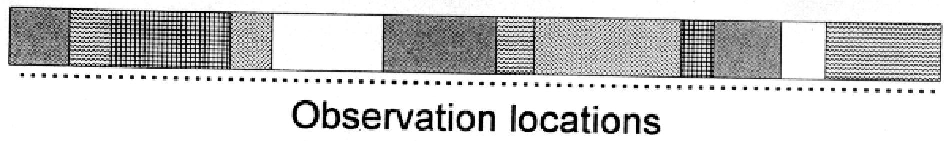



Figure 24. Cumulative-lengths approach for determining the proportions of different mesohabitat types in a sampled portion of a segment.

Although the cumulative-lengths approach is most commonly implemented by walking and chaining distances, we have used a similar technique by floating the study area in a canoe (Bovee et al. 1994). We marked each break from one mesohabitat type to another on a 7½ minute U.S. Geological Survey (U.S.G.S.) quadrangle map, and later used a map wheel to determine the lengths of each mesohabitat unit. By extension, the same approach could be used with aerial photographs or airborne videography, provided that you can determine the scale and you can identify mesohabitat units from the air.

The ***cumulative-frequency approach*** (Fig. 25) is based on a systematic or random sampling design. Rather than measuring the length of each mesohabitat unit, the investigator makes an observation of the mesohabitat type present at pre-determined intervals along the stream. The number of "hits" in each mesohabitat unit is tallied, and divided by the total number of observations in the segment or sample to obtain proportions. Generally speaking, this approach is slightly less accurate than the cumulative-lengths method, but it is considerably quicker and easier.




| Mesohabitat type | Cumulative frequency | Proportion |
|---|---|---|
| | 21 | 0.250 |
| | 17 | 0.202 |
| | 14 | 0.167 |
| | 17 | 0.202 |
| | 15 | 0.179 |
| Total | 84 | 1.000 |

Figure 25. Cumulate-frequency approach for determining the proportions of different mesohabitat types in a sampled portion of a segment.

Systematic sampling, using the same number of paces along the streambank between observations, is a convenient way to conduct a cumulative-frequency inventory. A good rule of thumb is to use a pacing interval approximately equal to the bank-to-bank width of the channel. For most streams, this will give you 5-10 observation points between mesohabitat types.

The cumulative-frequency method can also be used in conjunction with aerial photographs or airborne videography, with the same caveats pertaining to the cumulative-lengths method. This is not such a good technique to implement from a canoe or drift boat, because the distance traveled during a constant interval of time will change as a function of the velocity of the stream. However, if airborne videography can be used on a stream, you can systematically sample the videotape. Each frame of videotape is time-coded, which means that you can specify a time interval (e.g., 30.00 seconds), stop the tape at the appropriate frame, identify the mesohabitat type, and tally just as you would if you had walked the banks. This is an extremely efficient way to inventory mesohabitats over long distances.

## SUMMARY

- Segments are represented by a hierarchy of subdivision units. Reaches are large subdivisions, typically 10-15 channel widths in length. Mesohabitats are short sections of stream having unique and identifiable characteristics that distinguish them from other mesohabitat types. Microhabitats are less than a channel width in length and are distinguished by relatively homogeneous conditions of depth, velocity, substrate, and cover.
- Microhabitat measurements are made along transects, which represent mesohabitat types. Collectively, all the mesohabitat types represent

the segment.

- A representative reach is defined as a subunit of the segment, approximately 10-15 channel widths in length, and containing essentially all of the mesohabitat types of the segment. The proportions of the mesohabitat types in the representative reach are also assumed to be the same as their proportions in the segment.
- The use of representative reaches to describe a segment is most appropriate in streams that exhibit a cyclic and regular repetition of mesohabitat types.
- Mesohabitat typing, or habitat mapping, is an alternative to representative reaches, and is most appropriate in streams exhibiting a random and irregular distribution of mesohabitat types. Mesohabitat typing consists of a two-step process of defining mesohabitat types and conducting an inventory to determine the proportions of the various types of mesohabitats in the segment.
- Widely-accepted, standardized stream habitat classification systems do not exist, although several existing systems can be used as models. Consistency in definitions is considered to be more important than the actual terminology or nomenclature used in developing a classification system.
- Mesohabitat inventories are conducted using the cumulative-lengths or cumulative frequency method. The cumulative-frequency method is generally quicker and easier, but slightly less accurate than the cumulative-lengths method. Both methods can be applied remotely (i.e., from aerial photography or videography) provided that mesohabitat types can be identified, and the data are at a constant, definable, scale.

# Establishing PHABSIM Sites

A geographical hierarchy is used to represent a study area in PHABSIM (Fig. 26). In the previous chapter, we discussed how a study area is represented by one or more segments, and that each segment is described by one or more representative reaches or mesohabitat types. Representative reaches and mesohabitat types are represented by PHABSIM study sites. Study sites are divided up into longitudinal stream cells and transects. Transects are subdivided by lateral stream cells and verticals.

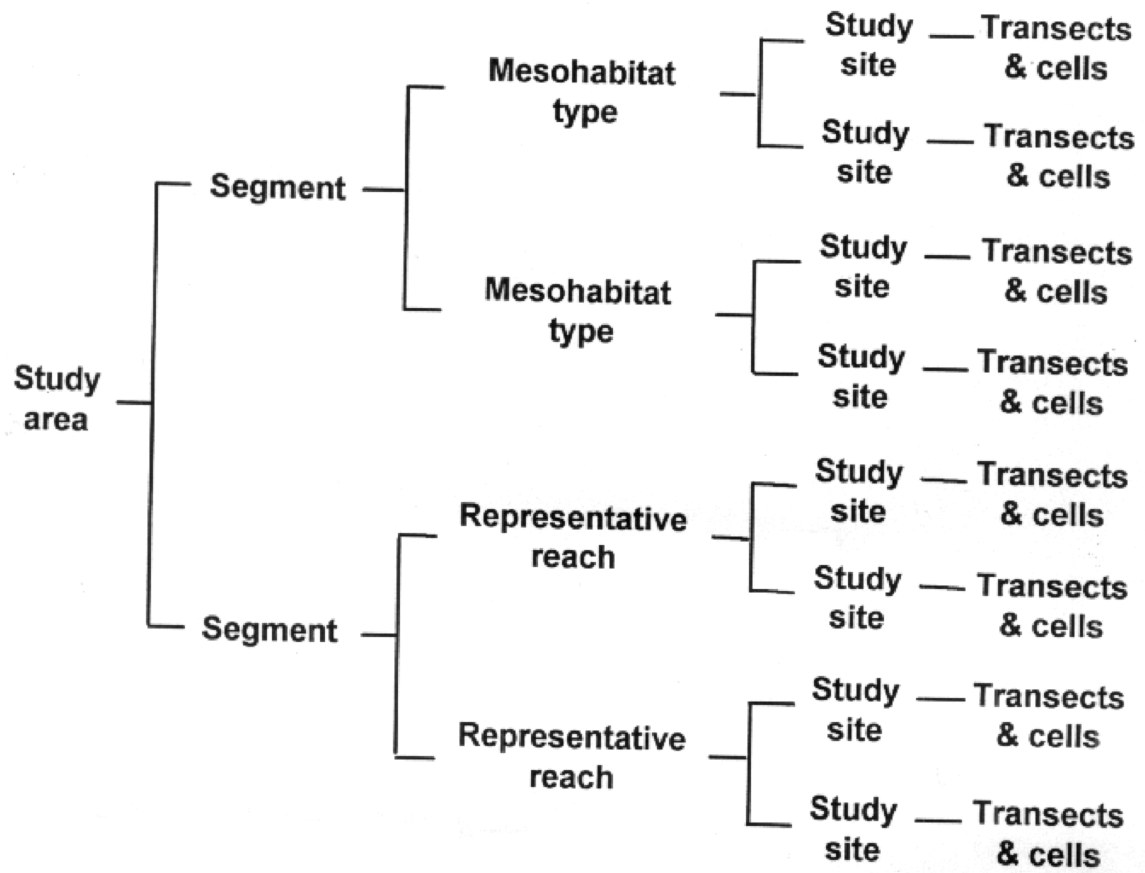



Figure 26. Hierarchy of geographical subdivisions used in the IFIM to represent a study area.

A ***PHABSIM study site*** is a self-contained microhabitat simulation unit, whether it describes a representative reach or an individual mesohabitat type. Representative reaches and mesohabitat types can be somewhat vague and abstract concepts, but the properties of a PHABSIM site are concrete. PHABSIM sites have upper and lower boundaries to define where they begin and where they end. Transects are permanently located for the duration of the study and any litigation that might follow. Elevations within the site are all connected to a common reference elevation.

This chapter discusses how to establish a PHABSIM site to describe

a representative reach or mesohabitat type. The procedures for setting up a site are virtually the same, regardless of what mesohabitat type you are interested in describing:
(1) Upper and lower site boundaries are delineated,
(2) the site is subdivided longitudinally by streams cells and transects,
(3) horizontal control is established, and
(4) vertical control is established.

## Upper and Lower Site Boundaries

One of the conventions of PHABSIM is that all simulations proceed in an upstream direction. According to this convention, the site starts at its lower boundary and ends at its upper boundary. Generally speaking, the location of the lower site boundary is a more critical consideration than the placement of the upper boundary.

Hydraulic simulation models are used extensively in PHABSIM. The foremost constraint of these models is that the water surface elevation at the first transect must be known for any discharge to be simulated, or you must be able to predict the water surface elevation accurately. These conditions are best met at features of channels known as ***hydraulic controls***, A hydraulic control can be thought of as a constriction in the channel, either horizontally or vertically. The constriction causes a reduction in cross-sectional area, which creates a bottleneck to stream flow. Effectively, water piles up at the bottleneck, resulting in a backwater effect in the upstream direction.

The crest of a riffle is one of the most common types of vertical constriction encountered in natural streams. In a meandering stream, the riffle often forms as a crossing-bar in the straight section between meander bends. Where channels are divided by a depositional island, there will usually be a V-shaped control that converges at the head of the island. Other types of vertical constrictions include submerged logs, bedrock outcroppings, log jams, boulder fields, beaver dams, and weirs. Vertical constrictions are often most effective as hydraulic controls at low-to-moderate discharges.

It is noteworthy that transects for hydraulic controls are a requirement for hydraulic simulation models only. Microhabitat simulations may or may not include transects for hydraulic controls. In representative reaches, it is common to treat hydraulic controls as part of the microhabitat mosaic; controls are often excluded when the mesohabitat typing approach is used.

Horizontal constrictions are often more effective as hydraulic controls at high discharges. Just as it is hard to detect the presence of a riffle during a flood, it may be difficult to locate channel constrictions at low flows. However, you should be alert to any feature that causes an abrupt narrowing in the channel. Bedrock outcrops and knickpoints are often obvious places where the channel suddenly becomes more narrow. However, the same effect can be caused much more subtly by point bars, tree snags, or encroaching riparian vegetation.

An important, and often frustrating, aspect of a hydraulic control is that the dominance of the control can shift with changing discharge. This phenomenon is called a ***variable backwater effect***, and is especially common in low gradient streams. At low flow, the hydraulic control may be the crest of a riffle, located conveniently near where the study site begins. At high flow, however, the control might be an abandoned mill dam, a mile downstream from the study site. In this situation, the lower site boundary would normally be placed at the riffle. An additional transect would then be tied in to the site at the mill dam, unless the logistics for doing so become overwhelming. If the lower hydraulic control cannot be incorporated into the data for the site, the next best alternative is to measure a few extra water surface elevations at the high flows. As long as you can determine the water surface at the first transect at our site, it does not matter how you get it. Anticipating variable backwaters, however, is an important step in ensuring that you get water surface elevations one way or another.

You will normally have a little lee-way in the selection of PHABSIM study sites, so in addition to accessibility, you should also consider the characteristics of the hydraulic control at the site. As a general guideline, it is advantageous if the hydraulic control is well-defined, stable, and most importantly, straight and perpendicular to the channel. Remember, you will be measuring across the stream along a straight-line transect. If the control is diagonal to the channel, the transect must also be placed diagonal to the channel. Some controls are horseshoe-shaped, which makes it nearly impossible to follow the transect and the control simultaneously. The quality of the control is not the sole deciding factor in selecting one site over another, but if two sites are otherwise nearly identical, pick the one with the best hydraulic control.

The upper boundary to the study site should be placed where the mesohabitat type or the representative reach ends. This is a more subjective and less critical decision than the location and characteristics of the downstream control. In most mesohabitat types, it will be fairly obvious where the upstream boundary should go. In representative reaches, Bovee (1982) recommended the inclusion of two full riffle-pool (or meander bend-crossing bar) sequences. If the first transect is at the top of the first riffle, the last transect should be at the top of the second riffle.

## LAYING OUT THE SITE

According to the geographical hierarchy illustrated in Figure 26, the site represents one or more mesohabitat types that describe a segment. In turn, a site is depicted by a series of longitudinal cells that are represented by transects. The paradigm of the geographical hierarchy is valuable in making sense out of site layout, because it is important to remember what you are trying to do. If the site is described in too much detail (e.g., with too many cells and transects), it may be infeasible to measure replicate sites. Consequently, the site may be described very well, but the mesohabitat type represented poorly. However, if the site is described in too little detail, important microhabitats will be missed and the mesohabitat type will not be well-represented. It may not matter how many replicates are taken, if the biologically important microhabitat areas are not included in a site description.

Some investigators approach site layout as though they were measuring the microhabitat for an individual species. This approach may be somewhat misleading because it is unlikely that the microhabitat requirements of all of the life stages of all of the species to be analyzed are well-known. Consequently, the site will be described for the species and life stage the investigator knows the most about.

In reality, when we describe a PHABSIM site, we should really describe the river. It is just as important to quantify what is <u>not</u> microhabitat as it is to quantify what <u>is</u> microhabitat for the species under investigation. Stratified-random sampling is well suited for establishing PHABSIM sites, because discrete areas of microhabitat can be designated as sampling strata. In the jargon of PHABSIM, a discrete area of microhabitat is defined as a longitudinal stream cell. If cells are so defined, it should not matter where the transect is placed in the cell. For convenience, I usually put the transect in the middle of the cell, but purists are free to select the transect location at random if they wish.

The real trick to the placement of stream cells is to locate them according to the most random microhabitat variable in the stream. Most of the time, this variable is cover. If stream cells are set up to describe the distribution of cover objects, you will probably describe the distributions of depths, velocities, and substrate types quite adequately. Figure 27 illustrates this approach to the placement of stream cells. Stream cell 1 was placed to describe a large tree snag along the bank. Stream cell 2 incorporates an undercut bank, a scour pool on the outside of the meander bend, and a gravel bar on the inside of the bend. Stream cell 3 is homogeneous in that it contains no cover at all. The only noteworthy habitat feature within cell 3 is the continuation of the gravel bar from cell 2. A random scattering of boulders typifies cell 4.

Arguably, the site depicted in Figure 27 could have been subdivided differently. For example, stream cell 1 might be subdivided at the end of the gravel bar, so that one cell contained a gravel bar and the other did not. The boundary between stream cells 3 and 4 might be moved downstream (or another small cell added) so that all of cell 3 contained a portion of the gravel bar. What typically happens during site layout is that non-homogeneous components, such as the gravel bar, will occur in some of the cells. Unfortunately, there are only two ways to deal with non-homogeneity within a cell: either subdivide the cell or compromise the non-homogeneity (if a transect is placed in the middle of cell 1, it will capture some of the gravel bar, but not all of it). Remember the paradigm! If you describe the site too well, you may not describe the mesohabitat type very well at all.

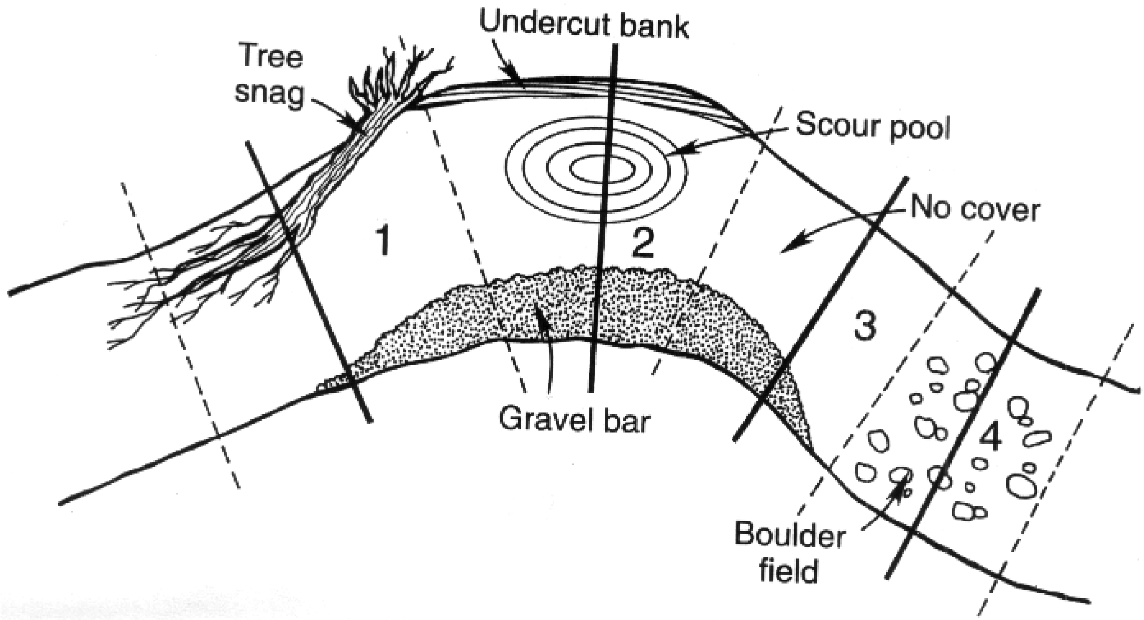



Figure 27. Establishment of cell boundaries according to the distribution of various cover types (including no cover) in a PHABSIM study site.

Other problems in cell definition can arise in sites where cover is essentially non-existent, or where it is broadly distributed. In sites without appreciable cover, the depth distribution is probably the easiest feature on which to define cells. You can usually identify three cells in a pool, for example: the tail-out at the bottom, the belly (deepest portion), and the head at the top. If the site is totally featureless, having no cover and a uniform depth distribution, then the entire site can be treated as a single cell.

If there is a tendency to define sites without cover with very few cells, the opposite can occur in sites with abundant cover. Among the most complex of these sites are mesohabitat types we classify as ***pocket waters***, which are essentially low gradient riffles with an abundance of large boulders scattered randomly throughout. Scour pools and low-velocity pockets form around individual boulders, providing an extremely patchy, heterogeneous environment. Generally speaking, it takes three cells to describe the microhabitat surrounding a single boulder, one in front, one in back, and one over the top. Describing each individual boulder in a pocket water is impractical, if not impossible.

Fortunately, from the perspective of cell definition, the presence of abundant and widely distributed cover is equivalent to the no-cover scenario. No matter where a transect is placed, it will go in front of some boulders, in back of others, over the tops of some, and will traverse parts of the channel where there are no boulders.

If sites are established with random or systematically-placed transects, each transect is a sample and represents 1/n of the site, where n is the number of transects. In contrast, each cell (and transect) represents a portion of the site equal to the ratio between the cell length and the site length, when cells are established by stratification (Fig. 27). This is an important distinction in preparing a PHABSIM site. For sites established with random or systematically-placed transects, it is unnecessary to place cell boundaries or measure the lengths of individual cells. In contrast, sites that are stratified into cells require placement of cell boundaries and measurements of both cell lengths and distances between transects.

**So Many Transects, So Little Time**

One of the most frequent technical assistance requests we receive is for help in scoping out budgets and time schedules for study plans. Inevitably, the question arises, "So, how many transects do I need and how should I put them in?" Our stock answer of "That depends," while true, is not very satisfying to people who are trying to determine a reasonable scope of work and a budget. The question of "how many transects" is tricky. How many transects to do what? If your goal is to ascertain the precise distribution of every combination of microhabitats within a mesohabitat type, you will need many transects. However, a more reasonable goal might be to reproduce with a few transects, the WUA-discharge relationship that you would have obtained using many transects. To this end, a simple sensitivity analysis was conducted on a pocket water mesohabitat type in the Cache la Poudre River in Colorado. As part of another study (Thomas and Bovee 1993), we had placed 20 uniformly-spaced transects in a 200 ft study site. A discharge versus weighted usable area function was developed for adult rainbow trout, using all 20 transects. The WUA-discharge function for the pocket water, developed from all of the transects in the site was considered to be the best estimate of the true WUA-discharge function for the site. For the first experiment, I selected five transects at random to compare results with those obtained using 20 transects (Fig. 28 a). The WUA functions for some of the individual transects (1, 6, and 10) were quite similar to the one for all transects, but two of the transects (16 and 19) were very different. I used five different draws of 3-transect combinations for the second experiment (Fig. 28 b). The first three draws were random combinations, whereas the second two were systematic. The results using a combination of three transects were similar to the results using all the transects, and the sampling strategy (random vs. systematic) did not seem to make much difference.

I repeated experiment 2 with random and systematic combinations of five transects (Fig. 28 c), which resulted in slightly greater similarities among the combinations. Experiment 4 (Fig. 28 d) consisted of taking 3- and 5-transect combinations in clusters from the bottom, middle, and top of the study site, to replicate what can sometimes happen with random sampling. In this particular mesohabitat site, the results from the two clusters in the middle (both the 3-transect and 5-transect) were fairly close to those obtained from all transects. WUA was overestimated from the downstream clusters and underestimated from those near the top of the site. [Note: With the exception of experiment 4, each of these experiments was repeated 500 times. The results given here are representative of the collective experiments.] These results may not be universal, but from my experiences with pocket waters, they are probably representative. The sensitivity analysis suggests that a pocket water mesohabitat type can be accurately described with three to five transects. Transect locations can be picked randomly or systematically, but care should be taken to avoid clustering transects at one end of the mesohabitat site or the other.

## Establishing Horizontal Control

Horizontal control means that relative the locations of transects and cell boundaries are known. In the simplest sense, horizontal control is determined by the lengths of individual stream cells and the distances between transects. For a variety of reasons, however, it is often necessary to determine the actual positions of cell boundaries and transects relative to one another. The most common medium for depicting the relative positions of site subdivisions is on a scale planimetric map of the site.

Cell boundaries are generally more transient than transects. This is because transects are revisited often during a study, but cell boundaries are usually measured only one time. Once the various lengths of the cells have been determined and associated with a transect, cell boundaries are essentially disposable. These differences in longevity are reflected in the way the two types of site subdivisions are marked. Cell boundaries are usually delineated simply by tying flagging tape in the vegetation along the channel margin. Transects are usually marked by ***headpins*** and ***tailpins***, pieces of permanently marked rebar or fence posts. If extreme longevity is desired in a site, transects may be marked by a concrete monument.

Although it might seem elementary, one of the most important procedures in setting up a site is to number cell boundaries and transects as they are established. This is best accomplished with a crew of at least two people, one on each bank and both in constant communication with one another. When a headpin is driven in on one side of the river, it is crucial for it to have a mate on the other side. Flagging and numbering pins as you go will save you from ending up with 20 pins on one side of the river and 18 on the other side. [Note: If several transects connect to a common pin, such as at the inside of a meander bend, mark the pin with the numbers of all shared transects.]

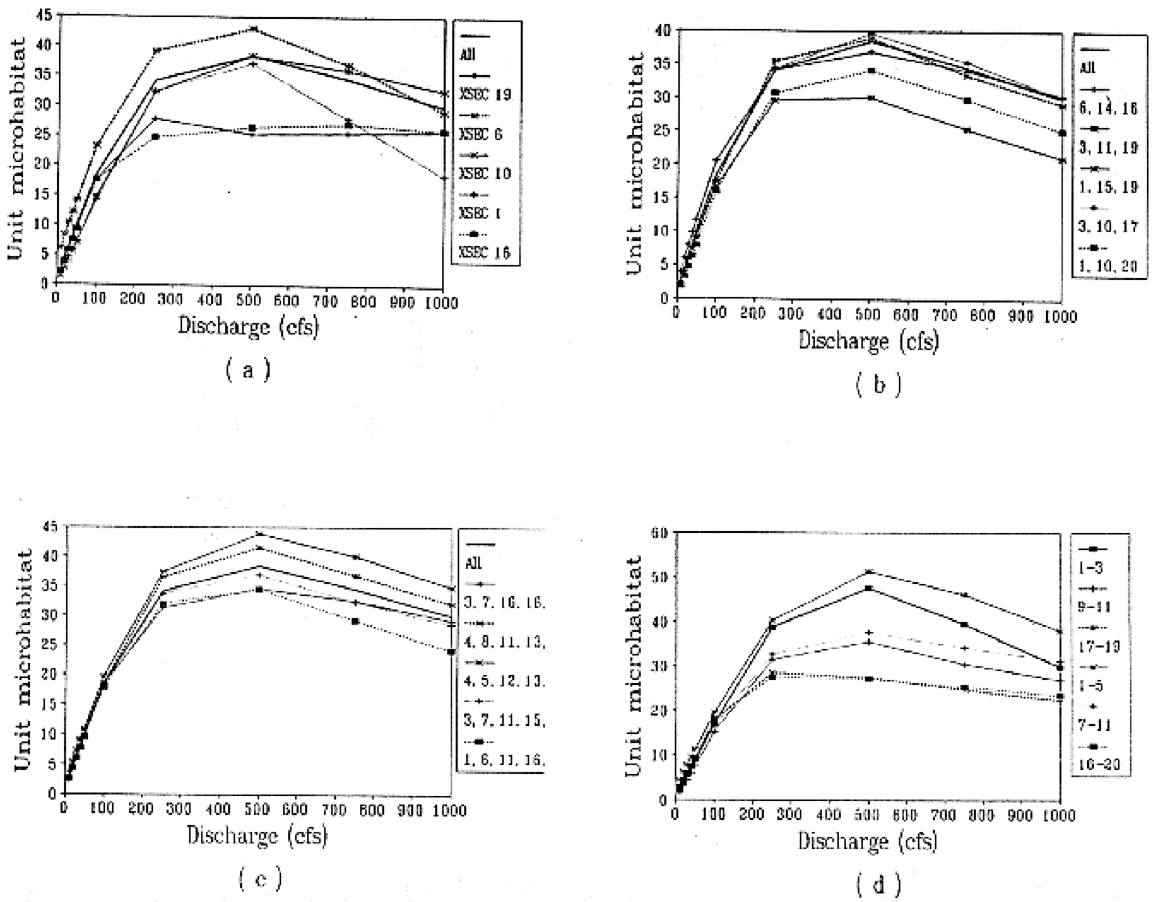



Figure 28. Sensitivity of PHABSIM to transect density and sampling strategies in a complex "pocket water" mesohabitat type. Results compare WUA vs. discharge functions for adult rainbow trout, using 20 transects with results from: (a) individual, randomly selected transects; (b) random and systematically selected groups of three transects; (c) random and systematically selected groups of five transects; and (d) three and five transects, clustered at the bottom, middle, and top of the site.

The degree to which horizontal control is maintained is highly discretionary among principal investigators. The only horizontally-related data required by PHABSIM is the distance between transects and the relative lengths of the cells associated with each transect. Drawing a scale planimetric map can be time-consuming, and is not strictly needed for any of the PHABSIM models. However, there are other reasons for establishing horizontal control more formally than simply measuring distances between transects. First, PHABSIM sites are sometimes vulnerable to vandalism. If you have a good map of your site, you can reconstruct every transect and cell boundary if only two pins remain undisturbed in the site. Second, cell lengths and distances between transects in some streams can be determined more accurately (and more easily) from a map than from direct measurements in the channel. Third, high quality site maps are often useful figures to be included in reports and professional papers.

### ***Direct Measurements of Cell and Inter-transect Lengths***

The simplest data requirements for PHABSIM involve the distances between transects, and the lengths of stream represented by each longitudinal stream cell. These measurements are usually relatively easy to make in small streams, where the distances between cell boundaries or transects are small enough to be measured with a tape. Generally, this restriction applies to streams where cell boundaries and transects are less than 300 ft apart. If the line-of-sight between transects is relatively unobstructed, it may be possible to use an electronic distance meter (EDM) to measure distances up to a mile or so. If the cell lengths and inter-transect distances are greater than 300 ft or the unrestricted line-of-sight is less than 300 ft, you should probably consider mapping the site.

### ***Data for Site Mapping***

The procedures for developing a site map are based on the principle of triangulation, whereby the location of an unknown point is determined using the unknown point and two known points as vertices of a triangle (Fig. 29). If the locations of two points are known, the location of a third point can be determined by: (1) measuring the angles between the two known points and the third point, (2) measuring the lengths of arcs between the two known points and the third point, or (3) measuring an angle and an arc length from one of the known points to the third point. Although the first method is as acceptable as the other two methods, we tend to use methods 2 and 3 most often in site mapping.

In the vernacular of PHABSIM, the measurement of arcs from two known points to an unknown point (method 2) is called the ***diagonals method***. The measurement of an angle and an arc length from a known point (method 3) is called the ***range and bearing method***. It is noteworthy that all three methods are interchangeable in a site survey. Use the method that is the quickest and easiest for a particular measurement.

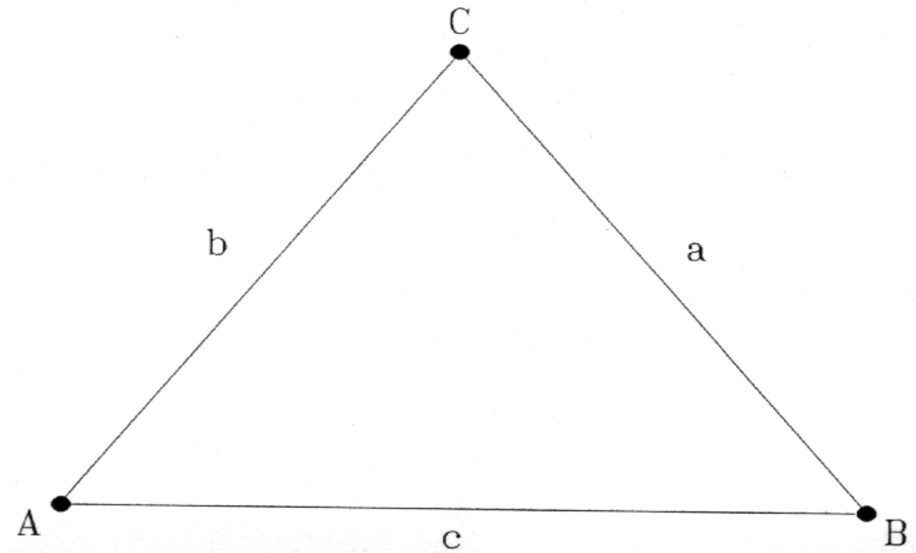
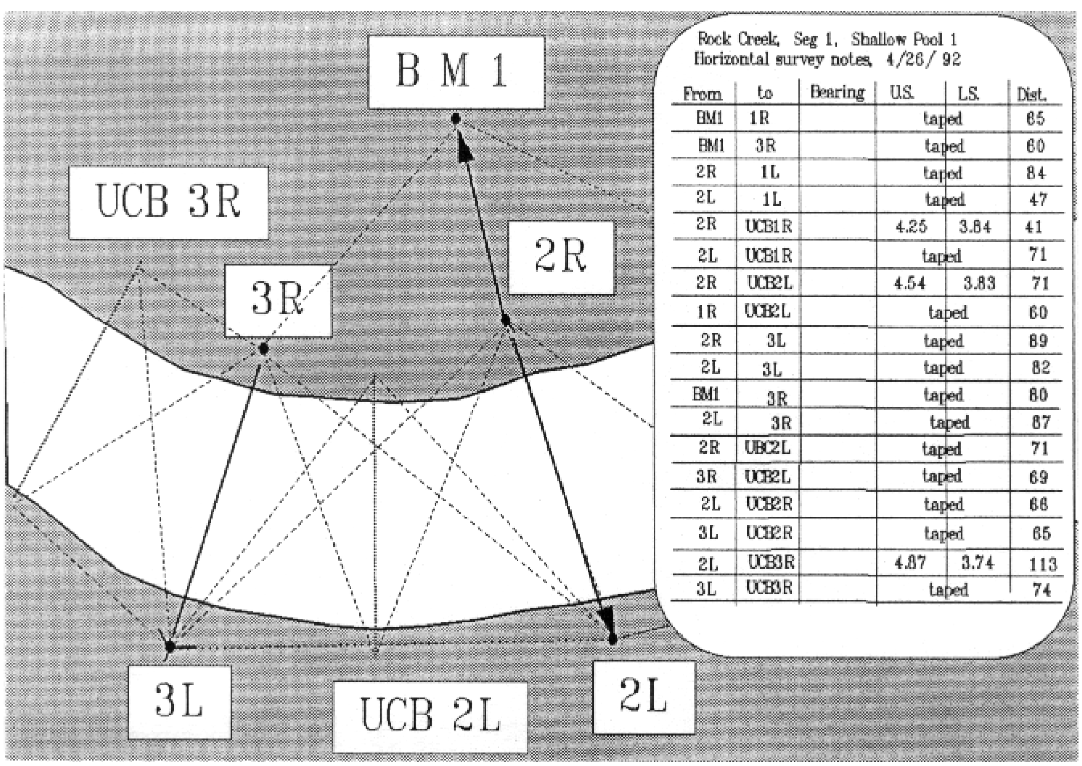



Figure 29. Methods of triangulating the position of an unknown point from two known points: (1) measuring angles ABC and BAC, (2) measuring sides a and b, (3) and measuring one angle and one side, such as angle ABC and side a.

**Diagonals Method**: A ***diagonal*** is defined as the cross-channel distance to a headpin on one transect to the tailpin on another (or from a transect to a cell boundary, Figure 30). For the purposes of triangulation, one of the distances could be from headpin to tailpin on the same transect with no appreciable loss in accuracy.




Rock Creek, Seg 1, Shallow Pool 1
Horizontal survey notes, 4/26/ 92

| From | to | Bearing | U.S. | L.S. | Dist. |
|---|---|---|---|---|---|
| BM1 | 1R | | taped | | 65 |
| BM1 | 3R | | taped | | 60 |
| 2R | 1L | | taped | | 84 |
| 2L | 1L | | taped | | 47 |
| 2R | UCB1R | | 4.25 | 3.84 | 41 |
| 2L | UCB1R | | taped | | 71 |
| 2R | UCB2L | | 4.54 | 3.83 | 71 |
| 1R | UCB2L | | taped | | 60 |
| 2R | 3L | | taped | | 89 |
| 2L | 3L | | taped | | 82 |
| BM1 | 3R | | taped | | 80 |
| 2L | 3R | | taped | | 87 |
| 2R | UBC2L | | taped | | 71 |
| 3R | UCB2L | | taped | | 69 |
| 2L | UCB2R | | taped | | 66 |
| 3L | UCB2R | | taped | | 65 |
| 2L | UCB3R | | 4.87 | 3.74 | 113 |
| 3L | UCB3R | | taped | | 74 |

Figure 30. Site map and example field notes for horizontal control established by diagonals.

One important point to remember about diagonals is that you <u>must</u>

have two independent distance measurements to every pin or cell boundary in the site. This can get a little complicated sometimes, so it is helpful to set up your field book like the example shown in Figure 30. In this example, all of the measurements **to** a pin (e.g., 1L, 3R) or cell boundary (e.g., UCB2R) are written as pairs. The measurements do not necessarily have to be taken in this order, but by pairing them, you can substantially cut down the chances of missing a measurement. This is critical, because if you lose a point that is a reference to other points on your map, the map cannot be completed.

You may notice the column headings U.S. and L.S. on the example field book in Figure 30. These data refer to upper stadia and lower stadia, a handy alternative method for measuring distances. A tape often becomes impractical when diagonals are over about 150 ft long, or traverse through a lot of brush. Stadia measurements are made using a surveyor's level and a level rod. Most surveying levels are equipped with two small horizontal cross hairs, above and below the main horizontal cross hair (Fig. 31). The distance between the telescope and the rod is found by subtracting the lower stadia reading from the upper reading and multiplying by a stadia constant (usually 100). Stadia measurements are only accurate to about the nearest foot, but that is usually close enough for the types of distances measured during a horizontal survey.

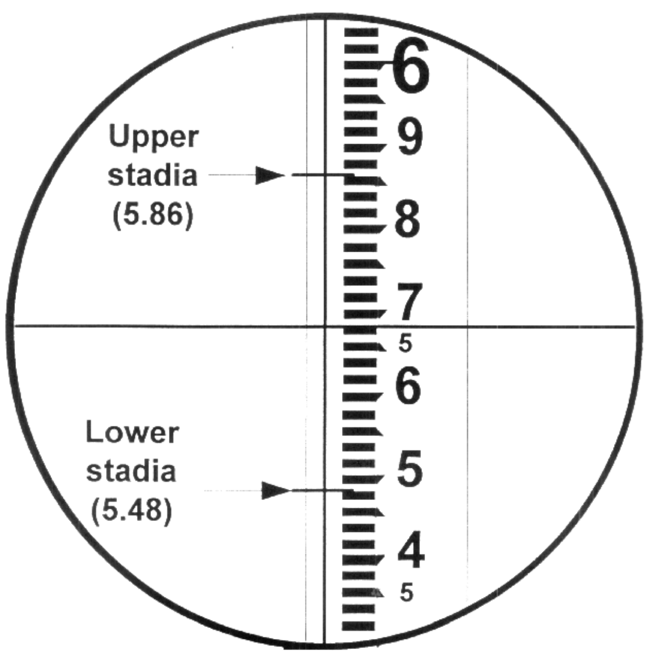


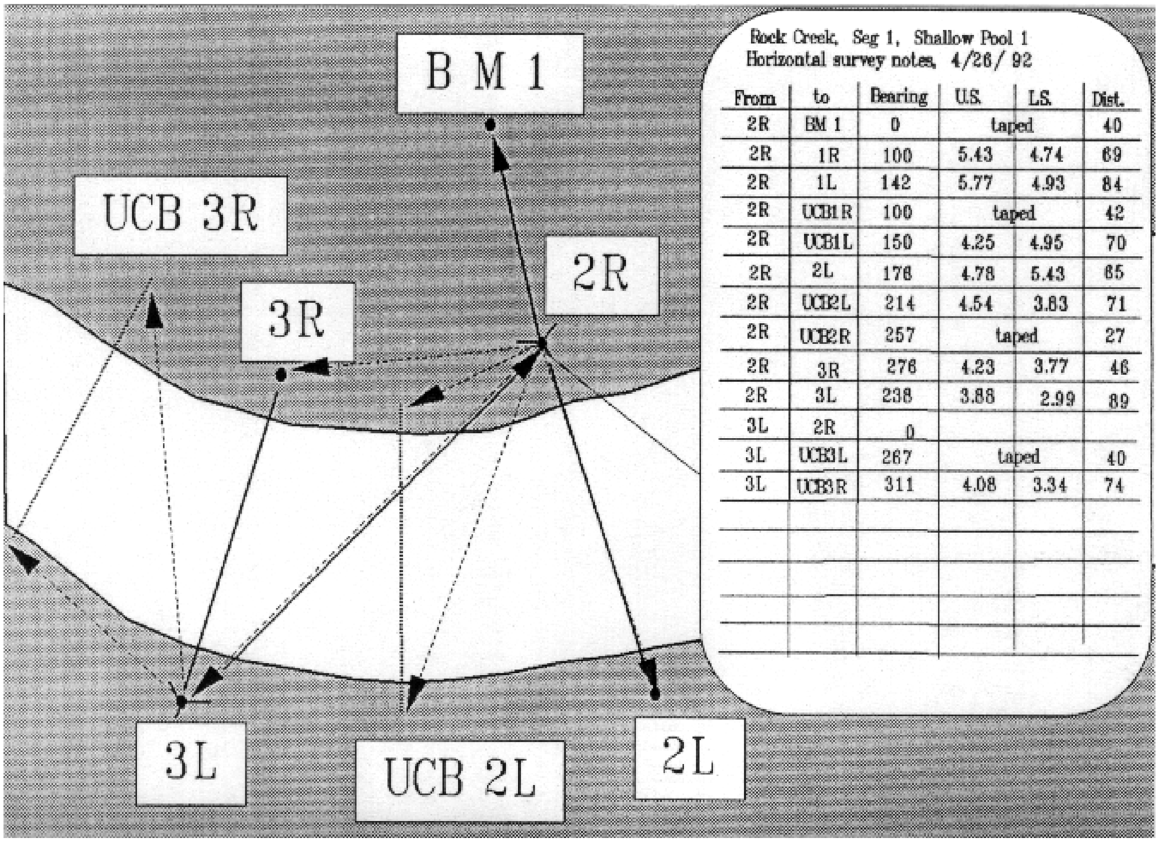

Figure 31. View of the stadia hairs through a level, on a level rod 38 feet away from the telescope. The distance between the telescope and the rod is found by subtracting the lower stadia reading (5.48) from the upper (5.86) and multiplying by 100.

When using stadia, be sure that the level and the rod are in the same units of measurement. Most levels and rods in the United States are in English units (feet and hundredths). Occasionally, however, you will run across a metric level or a metric rod, which work well as long as both are in the same measurement. Strange results will transpire if a metric level is used with an English rod, or vice versa. They will work together, but you will have to derive your own stadia constant. [Note: the stadia markers in a metric level are much closer to the central cross-hair than in an English level. You should be able to tell the difference between metric and English rods without much difficulty.]

**Range and Bearing Method:** As the name suggests, the **range and bearing** method is based on a measured angle and a distance from a known point to determine the location of an unknown point. The use of a surveying instrument capable of measuring horizontal angles is essential for this method. Transits, plane-tables, theodolites, and total stations are specifically designed for measuring horizontal angles. These instruments come equipped with a 360 compass dial (either analog or digital) that can be locked onto a zero or true North bearing. Subsequent angle measurements can be made with extremely high accuracy (for some of the new electronic instruments, angles are accurate to the nearest 3seconds). Generally speaking, levels are not very accurate instruments for measuring horizontal angles. In fact, many levels are even not equipped with a compass dial. Those that do have compass dials are usually accurate only to about ½ degree, and sometimes the dials cannot be locked down.

The basic procedure for surveying a site by range and bearing is illustrated in Figure 32. Perhaps the easiest way to describe this technique is to imagine the site as a huge piece of graph paper. The surveying instrument is equivalent to a 360 protractor, and the stadia and taping equipment are the same as rulers. The first step in using a protractor is to center it over a point, and line up the 0 reference line with another point on the paper. This initial alignment is known as the ***zero azimuth.*** In Figure 32, the instrument was set up over station 2R (center of protractor) and sighted to BM 1. When BM 1 was lined up in the cross-hairs of the instrument, the zero azimuth was set by turning the compass dial to 0 . The distance between BM 1 and station 2R (40 ft) was subsequently measured with a tape, and entered on the first line in the field notes along with the zero azimuth.

The first sighting in Figure 32 that is not obscured by the sample field book is from station 2R to station 2L (about mid-way down the page). When this shot was taken, the rod operator placed the leveling rod on top of the pin for station 2L. Without changing the position of the compass dial (i.e., without changing the zero bearing), the level operator swiveled the instrument around until the cross-hairs again lined up with the rod. A new azimuth (176 ) was read from the compass dial and entered on the data line "From 2R To 2L." The distance between station 2R and station 2L was determined by stadia.




| From | to | Bearing | U.S. | L.S. | Dist. |
|---|---|---|---|---|---|
| 2R | BM 1 | 0 | taped | | 40 |
| 2R | 1R | 100 | 5.43 | 4.74 | 69 |
| 2R | 1L | 142 | 5.77 | 4.93 | 84 |
| 2R | UCB1R | 100 | taped | | 42 |
| 2R | UCB1L | 150 | 4.25 | 4.95 | 70 |
| 2R | 2L | 178 | 4.78 | 5.43 | 65 |
| 2R | UCB2L | 214 | 4.54 | 3.83 | 71 |
| 2R | UCB2R | 257 | taped | | 27 |
| 2R | 3R | 276 | 4.23 | 3.77 | 46 |
| 2R | 3L | 238 | 3.88 | 2.99 | 89 |
| 3L | 2R | 0 | | | |
| 3L | UCB3L | 267 | taped | | 40 |
| 3L | UCB3R | 311 | 4.08 | 3.34 | 74 |

Figure 32. Site map and example field notes for a horizontal site survey conducted using the range and bearing method.

The center of the protractor remained at station 2R for a number of readings: to both upper cell boundaries for cell 2 and to the head- and tailpins for transect 3. However, it was necessary to move the instrument to complete the measurements to the upper cell boundaries for cell 3. At the left side of Figure 32, notice the new instrument position indicated at station 3L, and the double line between stations 2R and 3L. The dotted line from station 2R to 3L indicates the original range and bearing measured <u>from</u> station 2R <u>to</u> station 3L. The solid line from station 3L back to 2R is used to establish a new zero-bearing. Essentially, we have centered the protractor over a new point and have lined up the 0 reference with another known point on the drawing. Once a new zero bearing was established, ranges and bearings to UCB 3R and UCB 3L were measured from station 3L.

## ESTABLISHING VERTICAL CONTROL

A "computer picture" of the cross-section for each transect must be developed for PHABSIM's hydraulic models. This picture is generated as a series of x and y coordinate pairs, where x is a distance and y is an elevation. Because the hydraulic characteristics at one transect are often influenced by the hydraulics of an adjacent transect, all of the transects must be related in elevation to a common reference elevation, known as a ***datum***. It is possible to describe the shape of a cross-section simply by measuring the depth at intervals across a transect. However, it would be impossible to determine whether transect 2 was lower than transect 6 (or by how much), or to calculate the hydraulic slope from transect 1 to transect 5 unless the elevations of all of the transects are referenced to the same datum. Establishing ***vertical control*** in a site refers to the process by which all locations in the site are related to a common datum.

The procedure used to establish vertical control is known as ***differential leveling***, which gets its name from the process of determining the elevations of unknown points by measuring the vertical distance (difference) between the point and a horizontal line of known elevation. As the name of the procedure implies, a level is the most appropriate instrument for conducting this type of survey, although satisfactory results can also be obtained with theodolites, electronic transits, and total stations. Levels, however, are designed specifically for differential leveling and offer the best overall combination of economy, accuracy, and versatility. They are also easiest to explain with regard to establishing vertical control at a site.

The use of headpins, tailpins, or other monuments to mark the positions of transects was mentioned in the discussion of establishing horizontal control. The monuments used to establish vertical control are known as ***benchmarks***. Every PHABSIM site, regardless of size, should have at least two benchmarks: the elevations of all secondary benchmarks related by differential leveling to that of the primary benchmark. In very long or brushy sites, there may be many benchmarks, but usually there will be fewer benchmarks than transects.

Compared to a headpin, which is supposed to be semi-permanent, benchmarks should be virtually indestructible. As a general rule, headpins should not be used as benchmarks because they are too susceptible to being disturbed. Examples of typical benchmarks used in PHABSIM sites include:

(1) spikes driven into trees or tree roots (leaving about ½ in. of nail exposed),

(2) lag bolts screwed into trees or tree roots (leaving only the hex-head exposed),

(3) steel fence posts or long pieces of rebar driven flush to the ground (or with only an inch or two protruding from the ground),

(4) rebar or 1 in. pipe driven into the ground and immersed in concrete, or

(5) chiseled or spray-painted marks on boulders or concrete abutments.

Naturally, U.S.G.S. benchmarks are perfectly acceptable if they are conveniently located close to a site. U.S.G.S. benchmarks are all referenced to Mean Sea Level as their datum, which is generally unnecessary for PHABSIM sites. In fact, it is most convenient (and conventional) to assign an arbitrary elevation of 100.00 ft above datum to the primary benchmark for each site.

After installation of the primary and at least one secondary benchmark, the first step in differential leveling is to set up the instrument and determine the elevation of a level line of sight, relative to the primary benchmark. The elevation of the horizontal line of sight is known variously as the **H**eight of **I**nstrument, the HI, or the Instrument Height. The measurement taken to determine the Height of Instrument is known as a ***backsight*** (Fig. 33), so-called because the level operator is looking back in his or her notes to a known elevation (in this case, the elevation of the primary benchmark). To take the backsight, the rod operator stands the rod vertically ( or "plumbs" the rod) on top of the benchmark. Once the rod is properly placed, the level operator reads the backsight to the nearest 0.01 ft This reading is recorded under the column labeled BS(+) in the field book, and the Height of Instrument (HI) is calculated by <u>adding</u> the backsight to the known elevation.

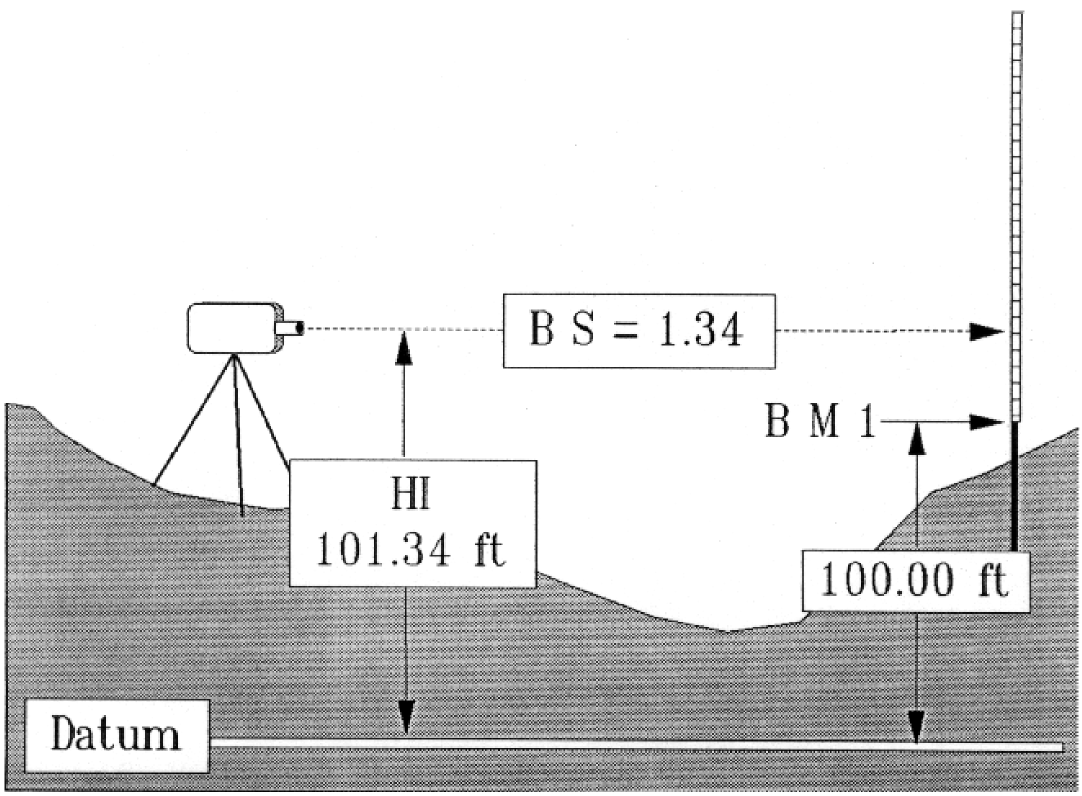



Figure 33. Differential leveling concepts: the backsight (BS). The height of instrument (HI = 101.34) was determined by adding the backsight (BS = 1.34) to a known elevation (BM 1 = 100.00). In this case, the elevation of BM 1 was assigned arbitrarily as 100.00 ft., a common practice in PHABSIM field studies.

The next step in the procedure is to determine the elevation of other benchmarks relative to the primary benchmark, without moving the level. This measurement is known as a ***foresight*** (Fig. 34). The rod operator moves to a secondary benchmark, confirms the location, and plumbs the rod. The foresight is taken to the nearest 0.01 ft, and recorded under the column FS(-) in the field book. The elevation of the secondary benchmark is determined by subtracting the foresight from the HI.

Foresights can be taken from a single location as long as the rod can be seen without moving the instrument. Sometimes, however, it becomes necessary to move the instrument in order to carry the elevation farther through the study site. The process by which the instrument is moved, while carrying the elevation forward, is called a ***turn*** and the point around which the instrument is moved is called a ***turning point***. Turns can seem a little daunting at first, but they are really fairly simple:

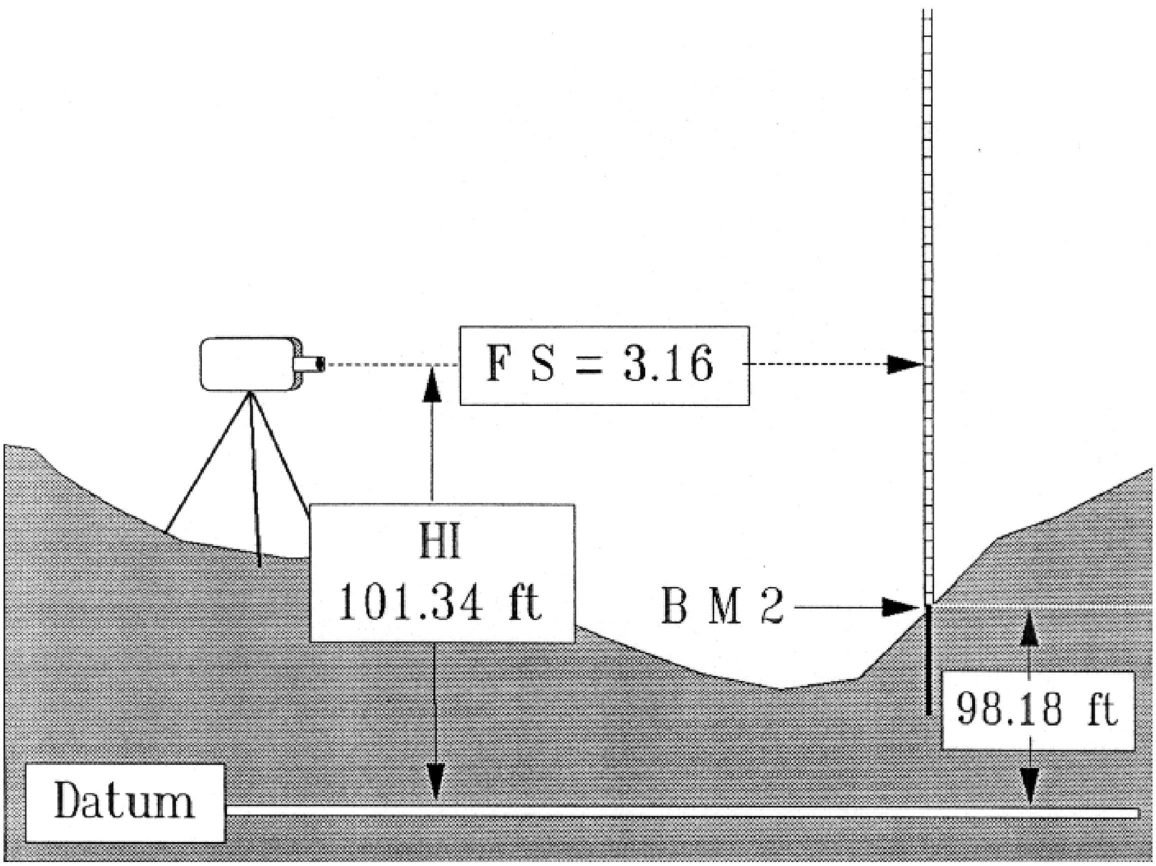



Figure 34. Differential leveling concepts: the foresight. The elevation of BM 2 (98.18) wass determined by subtracting the foresight (FS = 3.16) from the instrument height (HI=101.34).

(1) a foresight is taken to the turning point (often a secondary benchmark) to establish its elevation,
(2) the instrument is moved to a position where the turning point and the next benchmark can both be seen,

(3) the instrument is leveled at the new location, and
(4) a backsight taken to the turning point to establish a new height of instrument (Fig. 35).

Once you have practiced a little, you will find that turning is much easier than the alternative of bushwhacking a line of sight through all the trees and vegetation that obstructs your view.

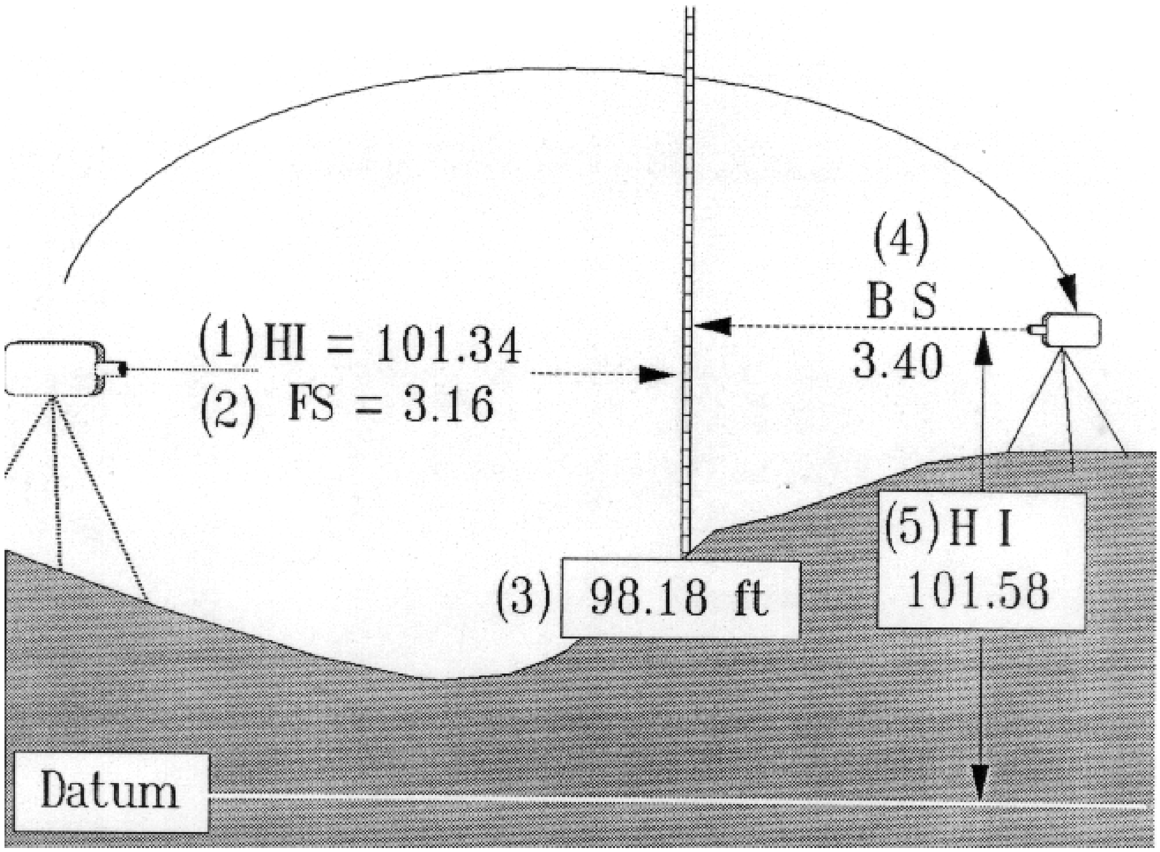



Figure 35. Differential leveling concepts: turning points. BM 2 (elevation = 98.18) was used as the turning point. A backsight (BS = 3.40) was taken to BM 2 from the new instrument location, and added to the elevation of BM 2 to determine the new instrument height (HI = 101.58).

The number of benchmarks needed in a study site is dictated by the length of the site and the amount of vegetation or other hindrances to a clean line of sight. The purpose of placing additional benchmarks is to allow a backsight to a known elevation from virtually anywhere in the site. In very short sites, the purpose of the secondary benchmark is to provide a back-up in the event that the primary benchmark is disturbed or destroyed.

The completion of the vertical control at a site involves conducting a ***level loop***. When the last secondary benchmark in the site is surveyed, the last benchmark is used as a turning point, and a complete survey is repeated in reverse (Fig. 36). The purpose of the level loop is to check for errors made during the initial survey. The final measurement in a level loop is a foresight back to the primary benchmark. If there are no errors (or they cancel themselves out perfectly), you should calculate the same elevation for the primary benchmark that you started with. However, unless the site is very small, some error is expected. As long as the final elevation is within acceptable limits, the level loop is said to have been ***closed***. The acceptable limits for PHABSIM surveys are determined from the equation:

$$e = 0.05\sqrt{L}$$

where e = the acceptable error, and
L = the length of the level loop in miles.

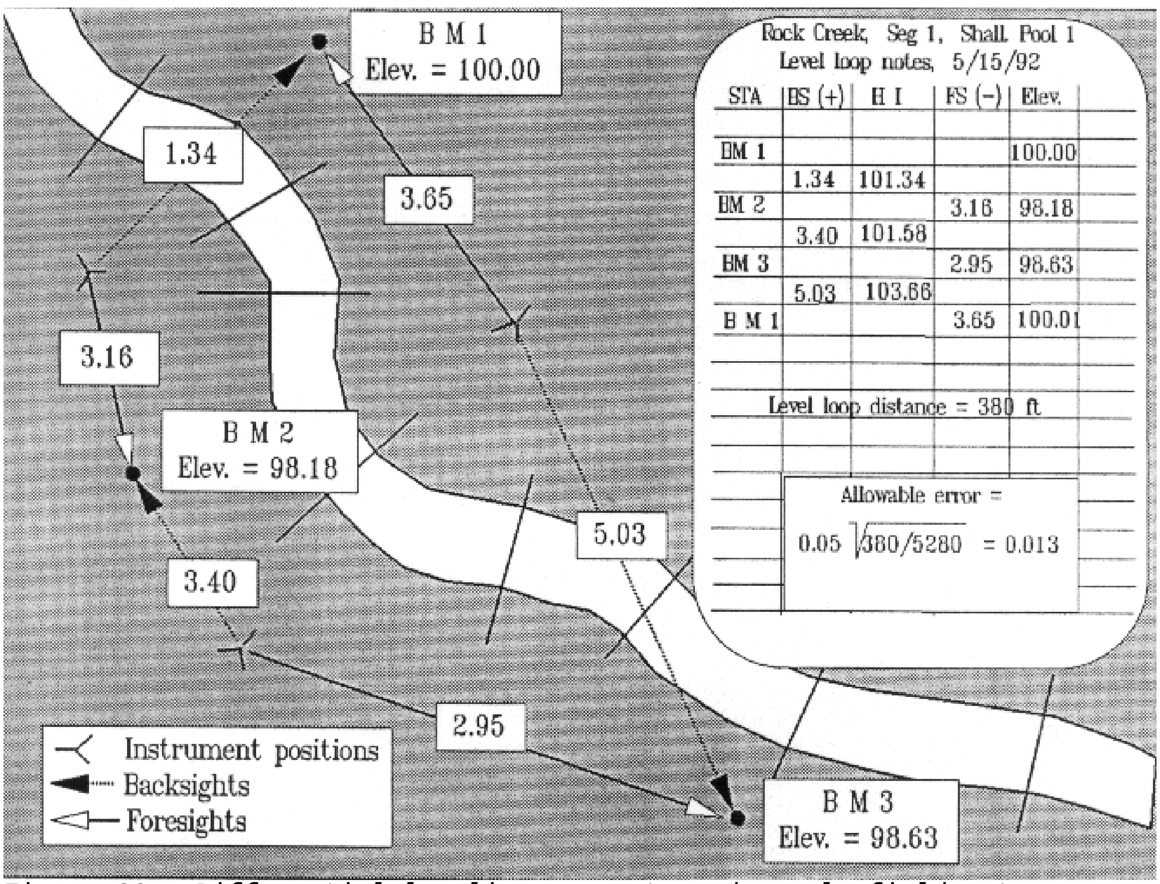



Figure 36. Differential leveling concepts and sample field notes: the level loop. Note the protocol of skipping lines between foresights and backsights. Following this protocol, there is no mistaking the order in which the readings were made. Also note calculation of allowable closure error near the bottom of the page.

***Differential Leveling Tips***

**Operating the rod.** During a survey, the rod operator has two critical duties: (1) to know exactly where the rod is being placed, and (2) to hold the rod as plumb as possible while the shot is taken.

- One of the most common errors made by rod operators is getting lost. Benchmarks (and other monuments) should be marked so that you do not have to assume where you are. Read the tag on the benchmark.
- When conducting a level loop, you want the elevation of the benchmark, not the ground next to it. Beginners often make the mistake of setting the rod on the ground instead of on top of the benchmark.
- Plumb that rod! An easy way to plumb the rod is to rock it back and forth along the line of sight of the level. The smallest reading through the level will occur when the rod is vertical. As the rod leans toward or away from the level, the reading will be higher.

**Operating the level.** Here are some tricks you might find helpful when operating the level:

- If possible, figure out which way you will be shooting the most and point one leg of the tripod in that direction. That way, you can stand between two legs rather than straddling a single leg.
- If at all possible, use an auto-level. These have three leveling screws instead of four (found on engineer's levels). Auto-levels are much easier and quicker to relevel than other types of levels. This can be important when you have to make a lot of turns.
- There are two focusing knobs on a level. The big knob on the side of the telescope is the objective lens focus. This helps you focus on whatever it is you are trying to look at. The eye-piece focus is the little knurled widget surrounding the part you look through. If you can see the rod all right, but can not make out the cross-hairs, you need to adjust the eye-piece focus.

**Reading the level.** Now that the instrument is "on-the-level" here are some things to consider when taking readings:

- Keep the rod operator informed at all times. If you are taking a reading, let the rod operator know when you begin, and when you are finished. Because good communication is so essential, I highly recommend the use of voice-activated, headset two-way radios.
- Confirm your shots. Reading one of the stadia marks instead of the cross-hair (the one in the middle) will wreck your level loop, and the farther the rod is from the instrument, the worse it will be wrecked. Be careful when taking a reading on a rod that is fairly close, because your eye will want to read the big red number for the whole foot <u>above</u> the central cross-hair. This

error will be a lot more obvious than reading a stadia marker, because you will be off by exactly 1 ft. Another source of error is reversing numbers when you record them (i.e., you read 5.46 but write down 5.64). After making and recording the reading, take a 10-second break and then re-read the rod.

- If possible, try not to survey during summer. The best time to do this kind of work is from late autumn to early spring when all of the vegetation has lost its foliage. It is much easier to sight through branches and twigs than it is through leaves.

**Recording data.** Here are just a few comments on taking notes and recording data:

- Penmanship counts. If you have trouble reading your own handwriting, you may want to have someone else record data for you.
- Organization counts. Look at the way the field book is set up in Figure 36. By skipping lines between backsights/HI's and foresights/elevations, you will know the order in which measurements were completed. If there is a problem closing your level loop, this organization may help you isolate the probable cause.
- Neatness counts. Start off with high quality field books or data forms that will withstand getting wet (because they will get wet). Write in pencil or indelible ink. Do not erase in the field book. Mark out errors with a single pencil stroke and neatly write in the correction. This is especially important if there is any chance that the case you are working on will go to litigation.
- Establish a chain of custody for the data. By the time you fill a field book with data, it will be worth a lot more than when it was empty. The last thing you want to do is lose it. Develop a habit of always turning the book over to the same person, and putting the book in the same place (e.g., in a specially marked box, ammo can, glove box, or briefcase), at the end of the day.

***Electronic Instruments***

Before leaving the subject of horizontal and vertical surveys of study sites, it is appropriate to discuss some of the newly emerging technology that can be applied to the data collection techniques involved in horizontal and vertical surveys. Although there are many choices in electronic instrumentation, the most versatile, self-contained unit is known as a total station.

Total stations operate under a substantially different principle from levels, transits, and theodolites. Foresights and backsights are not read as vertical distances from a horizontal line as they are with a level. Instead, the instrument is focused on a high-precision prism (target), and the time it takes for a laser beam to travel to the prism and back is converted into a distance. This **slope distance** is the hypotenuse of a right triangle, formed between a horizontal line of sight from the instrument and a vertical line to the prism (Fig. 37). The vertical distance from the horizontal line of sight is calculated as the sine of the interior angle, measured by the instrument, times the length of the hypotenuse (Fig. 37). The horizontal distance (b) is found as the cosine of the angle times the hypotenuse distance.

Total stations introduce capabilities that unavailable with a conventional level and rod. One of the primary advantages of these instruments is that measurements do not rely on numbers read from a leveling rod. Shots of over 300 ft are about the limit with a level, but turns spanning 2,000 ft can be accomplished relatively easily with a total station. The principal source of error with a total station usually involves aiming the instrument at a prism that seems microscopic at distances of a quarter to half a mile away. For this reason, we recommend taking several (4-6) independent shots and averaging them.

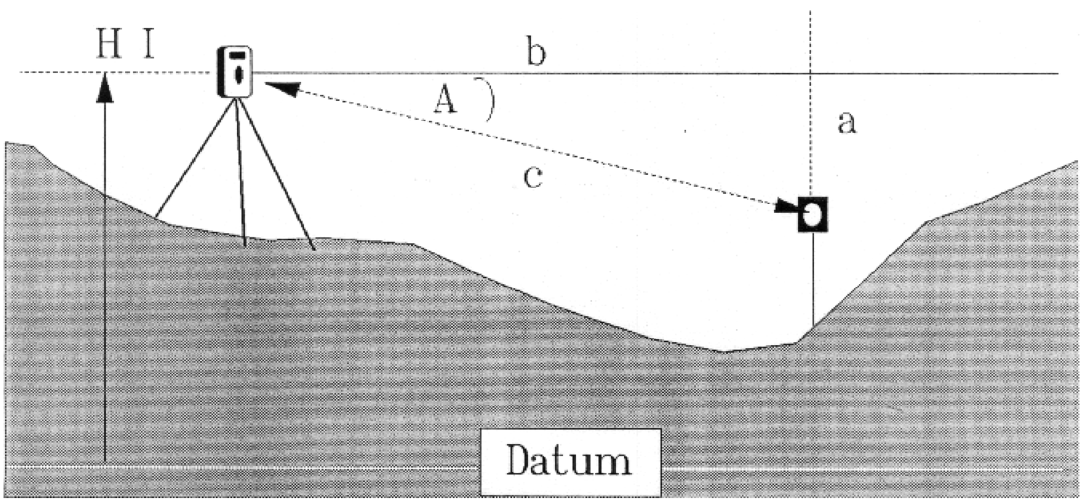



Figure 37. Operating principles of a total station for measuring horizontal and vertical distances. The vertical distance a = c sin A, and the horizontal distance b = c cos A.

Another attractive feature of the total station is that measurements can be made when the target is higher than the instrument. One of the more serious limitations of a level is that the instrument must always be higher than the elevation of the target. This restriction means that levels must nearly always be located up on the streambank, where visibility is usually the most limited. If there is a convenient spot to set up in the middle of the river, a total station can be positioned there with no problem or loss of accuracy.

One potential source of confusion when using a total station is that the rules for differential leveling are reversed. Using a level, backsights are always added and foresights subtracted. Backsights are subtracted with a total station, and foresights are added. The reason for the rule change is that the vertical distance from the horizontal line of sight is recorded as a negative if the target is lower than the instrument. If a negative foresight is subtracted from the HI, the elevation will come out higher than the instrument (clearly a mistake if you know what to look for...not so obvious if you do not). It may be necessary for you to develop your own convention to deal with vertical angles. One of the easiest ways to avoid confusion is to label columns in your field book as BS (-) and FS (+) whenever you are using a total station for differential leveling.

The possibility of confusion can be exacerbated by total stations equipped with internal data loggers. It is your responsibility to understand what data are being logged by the instrument, and further, to ensure that it is the right information. For that reason, I recommend that for the first few months you record data in a field book, as well as in the data logger. That way you will never lose the data, you will always know what it means, and eventually you may begin to trust the most expensive part of your instrument.

### ***Global Positioning Systems (GPS)***

The use of Global Positioning Systems in instream flow studies is on the rise, especially in large river applications. As the quality and accuracy of GPS units rise, and their costs decrease, we expect this trend to continue well into the future. Usually, GPS is used to locate positions on the earth (x,y data) for such purposes as mesohabitat typing or site mapping. However, survey-grade GPS is sufficiently accurate (but pricey) for obtaining elevation (x, y, z) data compatible with PHABSIM.

There are three basic ingredients to a Global Positioning System: a constellation of broadcasting satellites, a ground control system, and a navigation set (e.g., a receiver commonly called a rover). Broadcase satellites orbit the earth twice a day at a distance of 22,000 miles. Your assignment is to calculate how fast each satellite is traveling.

GPS navigation is based on the principle of satellite ranging and triangulation (Rockwell Avionics 1996). Satellite ranging involves determining the distance from the satellite to the receiver, which is accomplished by measuring the travel time of the signal. The distance to each satellite is represented by the GPS receiver as a sphere. The point at which the spheres intersect (Figure 38) is the location of the receiver. The concept is simple, but the programming probably did require a rocket scientist.

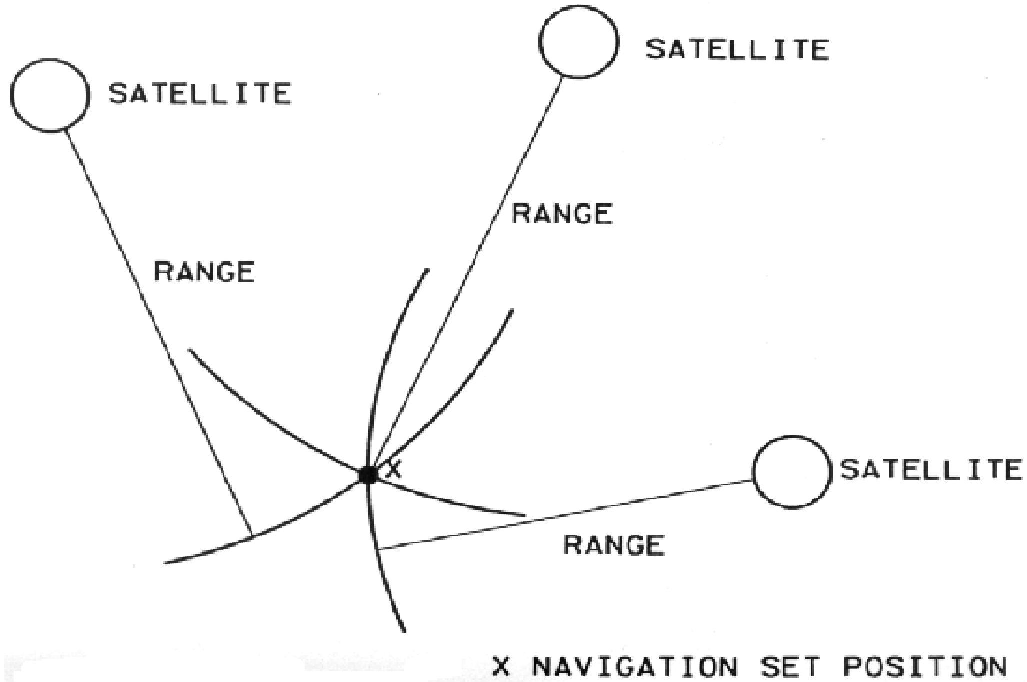


Figure 38. Concept of satellite ranging used to locate position of a GPS receiver.

Each satellite broadcasts two spread-spectrum radio signals, C/A (for coarse/acquisition) and P (for precision). Each signal is modulated with a unique code sequence and a navigation data message. The code sequence allows the receiver to identify each satellite from which it receives a signal. The navigation data messages contains information about the location and status of the satellite, and importantly, a “handover” word. The handover word is used to switch from C/A code to P code, a process known as selective availability. GPS satellites provide two levels of navigation services: Standard Positioning Services (SPS) and Precise Positioning Services (PPS). SPS information contains built-in errors that limit the accuracy of the receiver. This is a security technique called selective availability. A GPS that you buy from a sporting goods store will only be accurate to about 100 meters, because it only receives SPS data. For mapping, we want PPS data because we can obtain highly accurate positional data from it (x,y accuracy of 1-4 meters depending on the unit). Essentially, selective availability (and other security tricks) is analogous to throwing a nasty curve ball to the GPS in order to thwart anyone trying to use it as a targeting device. Unfortunately, the same curve balls also affect innocent PHABSIM users in the field.

The most common solution to overcome positional errors (whether deliberately introduced or inherent in the system) is to employ differential correction. Scattered all across the U.S. are **base stations** which continuously monitor the satellite signals. The location of the base station is precisely known. Differential correction involves comparing the known location of the base station with where the

GPS said it was, for each signal sent by the satellites. For example, if the base station position at time t was determined by GPS to be 10 m due north of its actual position, the differential correction would be 10 m due south for the same time step (each second). GPS users can obtain the differential correction records from each base station, and using the software that generally accompanies the GPS receiver, the rover locations can often be corrected to an error of less than a meter. The amount of residual error is a function of the distance from the rover to the base station (should generally be kept less than about 250 miles).

Real-time differential correction is also available in certain parts of the country. This involves the broadcasting of the second-by-second base station correction over an FM radio band. A small receiver is tied into the rover and as the corrections are received, the rover positions are corrected instantaneously. This service is commercially available through a subscription and purchase/lease of the FM receiver and differential correction software. The only significant problem we have encountered with real-time differential correction is working at sites that are out of range of the FM radio signal.

The accuracy of rover positions is also determined by the signal strength and configuration of the satellite constellation. For a 2-D fix on a location, the rover must be able to receive signals from at least three satellites. For a 3-D location, four satellites are required. The accuracy of either type of position is best when the broadcasting satellites are widely separated in the constellation, and worst when they are all clustered in the same part of the sky. If you are working in the open, your rover will usually select among several satellites (or you can manually select them) to give you the highest accuracy constellation. However, when you move the rover to the base of a cliff, and into the depths of a canyon, or under a heavy tree canopy, the number of satellites available to your rover will drastically, and sometimes catastrophically, decrease. In some situations, you will not even be able to access enough satellites to calculate a position. In other situations, your GPS will tell you that you are in Wyoming even though you know you are in North Dakota. This type of error cannot be corrected by differential correction. Fortunately, PDOP (Positional Dilution of Precision) error is typically displayed on the rover unit, so it is possible to refrain from collecting highly inaccurate data. Often, the best solution to a bad satellite configuration is simply to move a little bit or wait until it improves. Sometimes, accuracy will improve substantially by moving the rover a few feet, extending an antenna, or waiting five to ten minutes for more satellites to come into view of the rover.

## SUMMARY

- Establishing a PHABSIM study site consists of four activities: (1) defining the lower and upper site boundaries; (2) subdividing the site into homogeneous, longitudinal stream cells; (3) establishing horizontal control; and (4) establishing vertical control.
- The lower site boundary is usually defined by a hydraulic control, especially in representative reaches and in pool mesohabitat types. A hydraulic control is a feature in the channel that creates a backwater effect that is transmitted upstream. Vertical constrictions, such as the crests of riffles, are more effective as hydraulic controls at low discharges; lateral constrictions are more effective at high discharges. When the dominance of a control changes as a function of discharge, the stream is said to be affected by a variable backwater.
- When final selections of potential study sites are being made, it is wise to consider the quality of the hydraulic control for the site. Ideally, low-flow controls should be relatively straight and perpendicular to the channel. Sites should never be selected on the condition of their hydraulic controls alone, but if two sites are otherwise identical, the one with the best control should be selected.
- Sites are subdivided in longitudinal, relatively homogeneous stream cells that outline unique areas of microhabitat within the representative reach or mesohabitat type. The recommended approach for establishing stream cells is to identify homogeneous areas of stream on the basis of cover objects, except in sites having very little or very much cover. In these sites, transects may be placed randomly or systematically, but care should be taken to avoid clustering transects in any particular location within the habitat type.
- The minimum amount of horizontally-related data that is required in PHABSIM is the distance between transects, and the relative lengths of stream cells defining a site. However, developing horizontal control of the site by constructing a scale planimetric map is often recommended because: (1) the site can be reconstructed in the event of a catastrophic event or vandalism, (2) measuring cell lengths and inter-transect distances is often easier and more accurate from a map, and (3) the map is a useful addition to reports or professional papers.
- Data for site maps are obtained through horizontal surveys and triangulation. The most common triangulation techniques include the diagonals method and range and bearing techniques. The diagonals method uses paired distances from two (or more) known points to an unknown point. Distances are commonly measured by taping, stadia

measurements, or electronic distance meters. The range and bearing technique is based on an angle of deviation from a known zero-bearing and the distance from the apex of the angle to the unknown point.

- All of the elevations in a site must be referenced to a common datum. This process involves the installation of multiple permanent benchmarks in the sight and relating their elevations by differential leveling. A level loop is conducted as a quality assurance measure to ensure the accuracy of the elevations.
- Electronic instruments, such as total stations, measure the angle and distance between the instrument and a reflecting prism, and use trigonometric functions to calculate elevations and horizontal distances. Because these instruments do not rely on the ability of the human eye to read numbers on a leveling rod, they are capable of making highly accurate measurements over very long distances.

# CROSS-SECTIONAL PROFILE DATA

In PHABSIM, the channel ***cross-section*** is described as a series of x and y coordinates, called ***verticals***. Each vertical is typically described by: (1) a distance from a known point across the channel; (2) the elevation of the ground at that distance; and (3) information describing characteristics of the substrate and cover. In contrast to the longitudinal stream cell boundaries established during transect placement, verticals divide the channel laterally. This chapter describes how to collect typical cross-section profile data, including the coordinate data, substrate descriptions, and cover classifications. Also discussed are modified procedures for floodplains and river corridors, undercut banks, and large rivers.

## MODEL CONVENTIONS

The same channel profile data are collected for all of the PHABSIM microhabitat simulation programs, but the basic procedures and conventions vary somewhat among programs. For the most part, the differences among programs affect the way cell boundaries are defined across the cross-section, which in turn, may affect the way profile data are collected. In the programs HABTAT and HABTAE, the verticals delineate the edges of the lateral stream cells, as illustrated in Figure 39. Cover and substrate descriptors apply to structural features of the channel, located between the verticals.

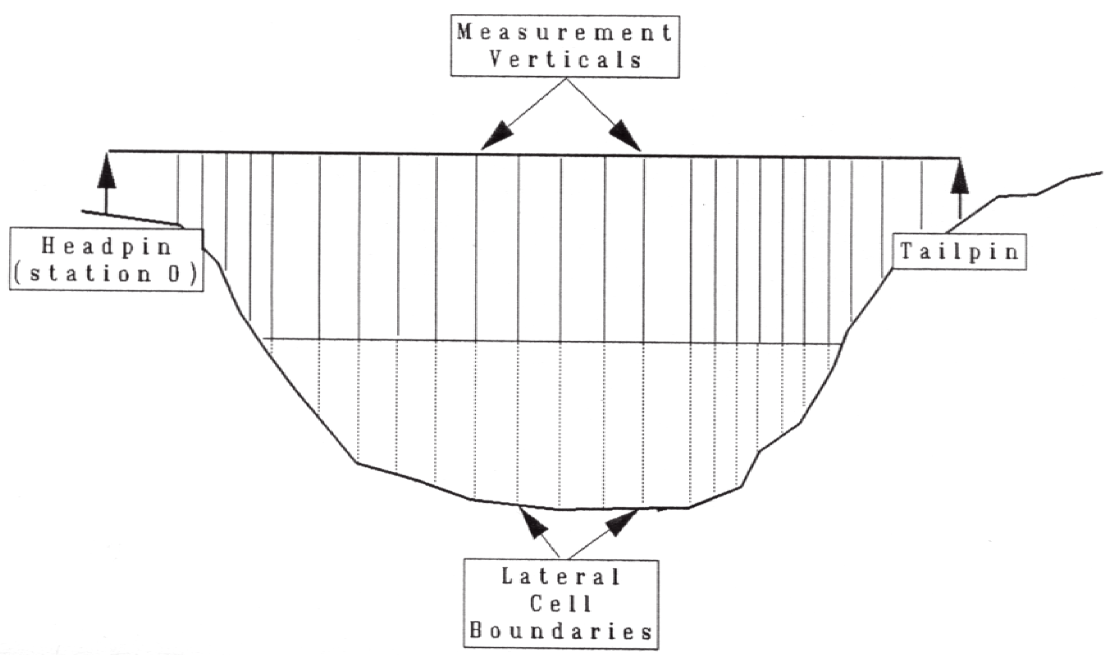



Figure 39. Conventions relating x,y coordinates and lateral cell boundaries for a cross-sectional profile in the PHABSIM programs HABTAT and HABTAE.

The programs HABTAV and HABTAM treat the vertical as the center of the cell (Fig. 40). In these programs, the cell boundaries are established halfway back to the previous vertical and halfway forward to the next. Unless the cells are the same width, however, some verticals will not be located in the exact center of the cell. As the widths of adjacent cells become more disparate, the location of the vertical in the cell will become more off-center. As with HABTAT and HABTAE, the substrate and cover information recorded for a vertical applies to the whole cell. However, it is worth remembering that for HABTAV and HABTAM, the vertical is somewhere in the middle of the cell, not on its edge. Although this may sound confusing, data collection problems with the two systems can be minimized by using many small, equally-spaced verticals to describe the cross-section. In most streams, we recommend 30-40 verticals to describe the bank-to-bank portion of the cross-section.

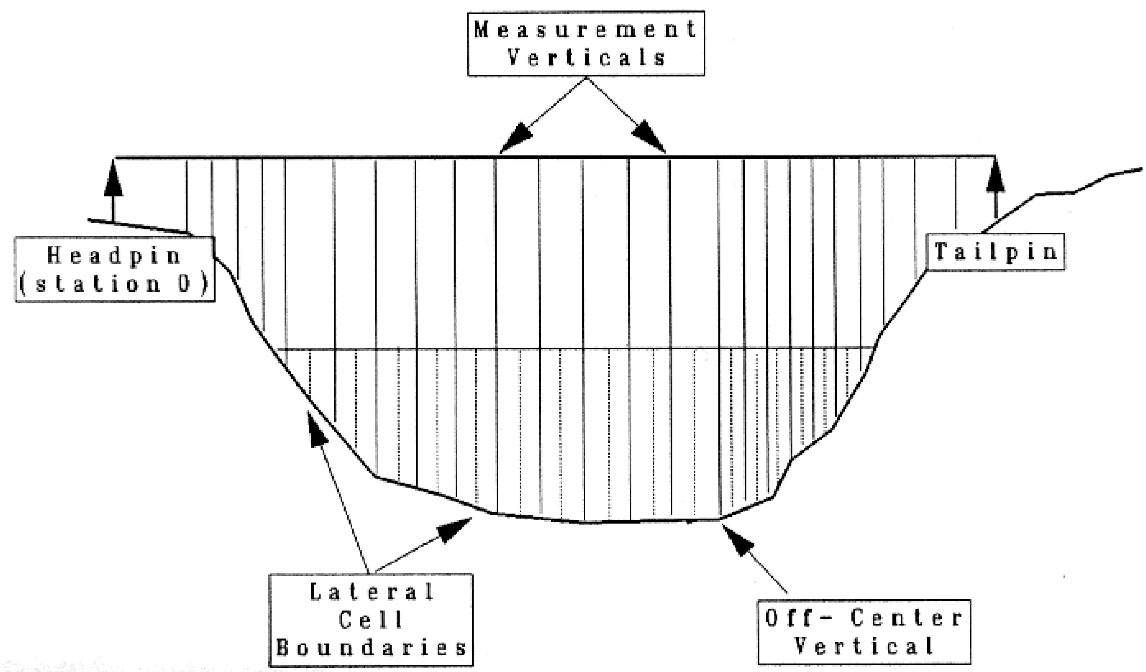



Figure 40. Conventions relating x and y coordinates with lateral cell boundaries for a cross-;sectional profile in the PHABSIM programs HABTAM and HABTAV. Notice that the verticals are off-center when cells are not the same width.

Another convention in measuring cross-sections is to locate x-coordinate zero (0) on the left streambank looking upstream. Normally left and right banks are identified looking downstream, especially by canoeists, kayakers, and rafters. However, some of PHABSIM's hydraulic simulation programs require data to be entered from downstream to upstream. This restriction has made it necessary for us to institutionalize the convention of viewing the stream in an upstream direction.  Because we enter data from left to right, zero is placed on the left bank looking upstream.  Placing zero on the right bank does not automatically create problems, but data entered this way will depict the channel in mirror-image.

## COORDINATE DATA

For streams of small to moderate size (e.g., less than about 200 ft wide), the following sequence of activities relating to measurement of the cross-section should be followed:

(1)  A tape or tagline is strung from the headpin (on the left bank) to the tailpin (right bank).

(2)  The level is set up in a convenient location where the full length of the transect can be seen and a backsight can be taken to a known elevation (i.e., a benchmark).

Rock Creek, Seg 1, Shallow Pool # 2, XSEC 3
7/15/92 1020 h BS to BM1 = 4.33
BM1 = 100, 00, HI = 104.33

| STA | FS | Elev. | Cov | Sub | Emb. |
|---|---|---|---|---|---|
| 0 | 3.9 | 100.4 | NC | Silt | 1.0 |
| 2 | 4.1 | 100.2 | NC | Silt | 1.0 |
| 4 | 4..4 | 99.9 | NC | Silt | 1.0 |
| 6 | 4.5 | 99.8 | NC | Silt | 1.0 |
| 7.9 | 4.6 | 99.7 | NC | Silt | 1.0 |
| 8 | 6.5 | 97.8 | UCB | MG | .5 |
| 9.5 (w e) | 7.1 | 97.2 | UCB | MG | .25 |
| 10 | 7.5 | 96.8 | LOGS | Sand | 1.0 |
| 12 | 7.7 | 96.6 | LOGS | Sand | 1.0 |
| 14 | 7.9 | 96.4 | LOGS | Sand | 1.0 |
| 16 | 8.2 | 96.1 | BLDR | MG | .25 |
| 18 | 8.3 | 96.0 | NC | MG | .25 |
| 20 | 8.4 | 95.9 | NC | SC | 0 |
| 22 | 8.4 | 95.9 | COBL | SC | 0 |
| 24 | 8.2 | 96.1 | BLDR | SC | 0 |
| 26 | 8.0 | 96.3 | NC | | |
| 30 | 7.9 | | | | |
| 32 | | | | | |

Figure 41.  Example layout of a field book for recording channel profile data.

(3)  The Height of Instrument (HI) is determined by reading a backsight to a previously-established benchmark.  The backsight reading, the benchmark number, the benchmark elevation, and the height of instrument should be recorded **at the top of <u>each</u> page of cross-section profile data** as illustrated in Figure 41.

(4)  Starting at the zero point, the rod operator reports the x-

coordinate distance (termed the ***station*** and abbreviated as STA in the field book) to the data recorder, and holds the rod still and plumb for the level operator. (The level operator and the data recorder are often the same person.)
(5) A foresight is read to the nearest 0.1 ft and recorded as illustrated in Figure 41. (Note: Ground elevations are measured to the nearest 0.1 ft, water surface elevations to the nearest 0.01 ft).
(6) The rod operator reports substrate and cover information to the data recorder. When the data recorder confirms that all the information for the vertical is complete, the rod operator proceeds to the next vertical, where the sequence is repeated

Regarding the field notes in Figure 41, note the information contained in the heading for each page: stream and reach ID, date, time, transect number, backsight, reference elevation, and height of instrument. These data should be recorded at the top of each page for a new transect. Continuation pages should identify the reach, transect number, and date, and indicate that the data continue from a previous page or pages.

***Floodplains***

If the stream has a floodplain, it should be measured routinely as a functional part of the river channel. In many streams, we have found that high flows are as important as low flows in regulating populations of fish (Nehring and Anderson 1993, Bovee et al. 1994). When inundated, the floodplain offers a large area of relatively slow, shallow water, often with an abundance of complex woody cover, that can serve as a refuge for a wide variety of fish species and life stages. In fact, some fishes are floodplain spawners that rely on flooding events to perpetuate their species. The floodplain also allows water to spread out at high flows, which tends to moderate main channel velocities during flood events.

Like most aspects of field work related to PHABSIM, the inclusion of a floodplain in the analysis requires that you plan ahead. You must determine whether the stream actually has a floodplain, and if it does, how far it extends away from the active channel. In some parts of the country, just figuring out where the active floodplain ends can be quite an endeavor in itself. Often, the active floodplain will merge with a terrace or grade into a less-frequently inundated floodplain.

It is convenient to mark the locations of transects with headpins and tailpins placed fairly close to the edge of the bank. It is also convenient to designate "zero distance" as the location of the headpin on the left streambank. When the headpin is assigned as the zero point, the stations for the left bank floodplain should be entered into the field book as negative distances, as illustrated in Figure 42.

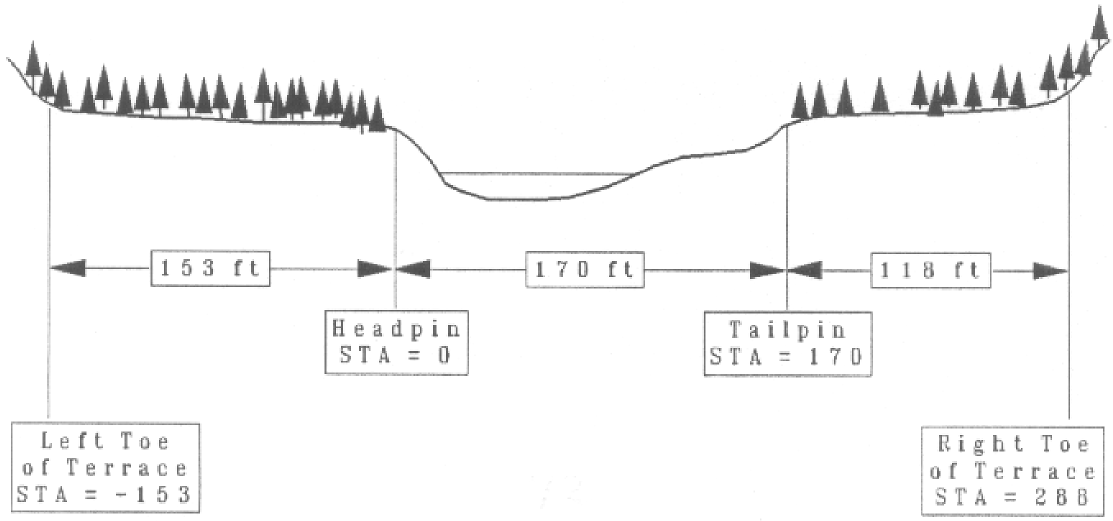



Figure 42. Typical configuration and approach for measuring channel profiles with floodplains.

If the left-side floodplain is more than 100 ft wide, it may become necessary to re-number the distances along the transect, with a new zero point at the toe of the terrace. However, it is usually better to make this correction in the office rather than in the field.
For example, in Figure 41, the station at the left toe of the terrace is measured back from the headpin and recorded as -153 in the field book. During preparation for data entry, the left toe of the terrace will be re-numbered as zero, and 153 ft. added to all stations along the transect, and ending at the right toe of the terrace.

### ***Undercut Banks***

Like floodplains, the first act in measuring an undercut bank is determining its presence. Generally, several verticals on the top of the bank will have been measured before the rod operator arrives at the undercut. If the left bank is undercut, the data recorder should leave <u>three</u> spaces in the field book after the last top-of-bank entry. The next entry will be made in the <u>third</u> space, representing the distance and elevation of the vertical at the inside (streamside) edge of the bank (Fig. 43). [Note: This vertical is assigned as the cover designator for an undercut bank.]

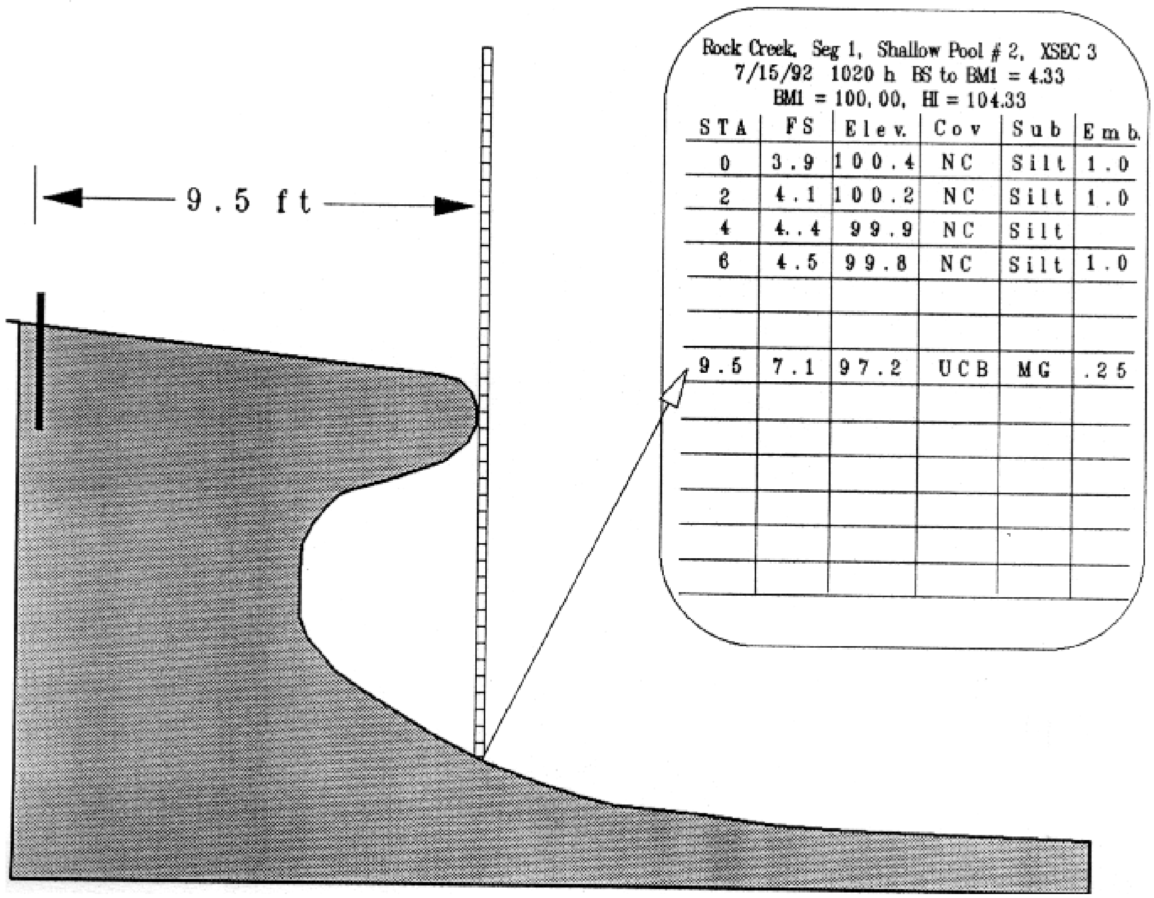



Figure 43. First vertical measured for an undercut bank on the left side of the stream, and corresponding data entry position in the field book.

Next, the rod operator probes back beneath the undercut to determine the average distance from the outer edge to the backside of the undercut. This distance is subtracted from the x-coordinate for the outer edge of the undercut and recorded in the <u>second</u> blank space reserved in the field book (Fig. 44). The rod operator then estimates an elevation for the vertical located at the backside of the undercut (away from the stream). The easiest way to make this estimate is to assign the back of the undercut the same elevation as the front. A more accurate technique is to insert a board or other flat object into the undercut, level the object as well as possible, and set the level rod on top of it for the elevation reading.

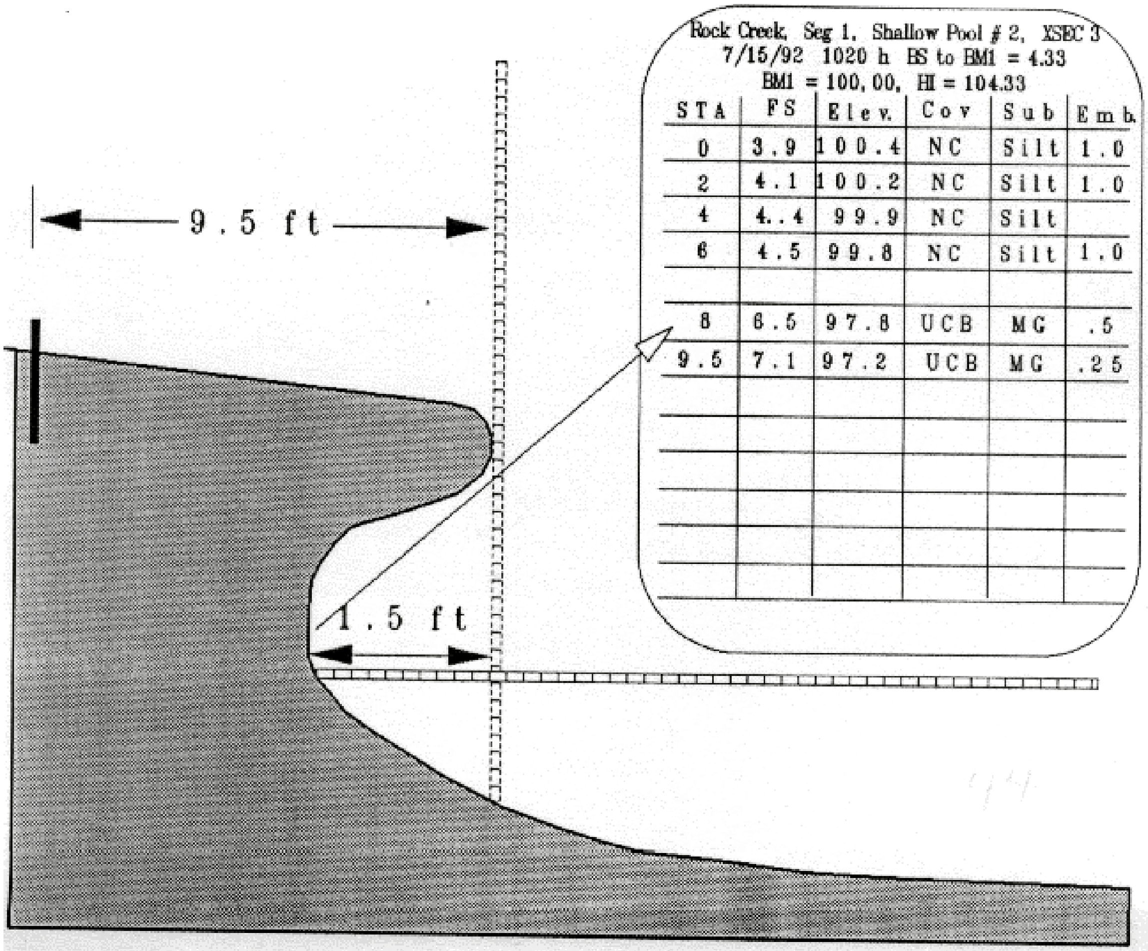



Figure 44. Second vertical measured for an undercut bank on the left side of the stream, and corresponding data entry position in the field book.

The final coordinate point for the undercut is determined by subtracting 0.1 ft from the x-coordinate distance for the vertical at the backside of the undercut, finding that distance on the tape, and measuring the elevation on the top of the bank at that station. These data are recorded in the first blank space reserved in the field book. Undercut banks on the right-hand side of the stream are measured following the same basic sequence, but you do not have to plan ahead so much.

The true configuration of an undercut bank can only be approximated in PHABSIM, mainly because each x-coordinate is allowed only one elevation (and vertical lines are prohibited). The procedure we have described above results in a distorted representation of the true undercut, but because undercut banks are such important microhabitat features, however, we feel that a distortion is better than no representation at all.

***Large Rivers***

For PHABSIM work, we start classifying rivers as large when part or all of the work must be done out of a boat. Because differential leveling is highly accurate, it is the preferred technique for measuring ground elevations, but it becomes infeasible in deep, fast water. The switch from wading to the use of a boats usually occurs when the depth exceeds about 4 ft, or when the depth multiplied by the velocity results in a number greater than about 10 or 12. Although it is possible to operate a level rod from the front of a boat, it becomes more difficult as the depth and velocity increase. When the depth-velocity product exceeds a factor of about 20, it is nearly impossible to operate a level rod from a boat.

As a consequence of the problems associated with differential leveling in large rivers, ground elevations are commonly determined by ***sounding***. Sounding is a two-step operation. First, the water surface elevation is determined for a transect by differential leveling. Then, bed elevations are found by subtracting the depths measured at verticals from the water surface elevation. Sounding is analogous to differential leveling in that the water surface elevation is akin to an instrument height and the depths are equivalent to foresights. The above-water portions of the transect, as well as submerged portions too shallow for soundings, are measured by differential leveling. This can cause some problems in record keeping in that both sets of survey data are referenced to the same datum, but two different reference elevations (the HI and the water surface elevation) are used in the calculation of bed elevations (Fig. 45).

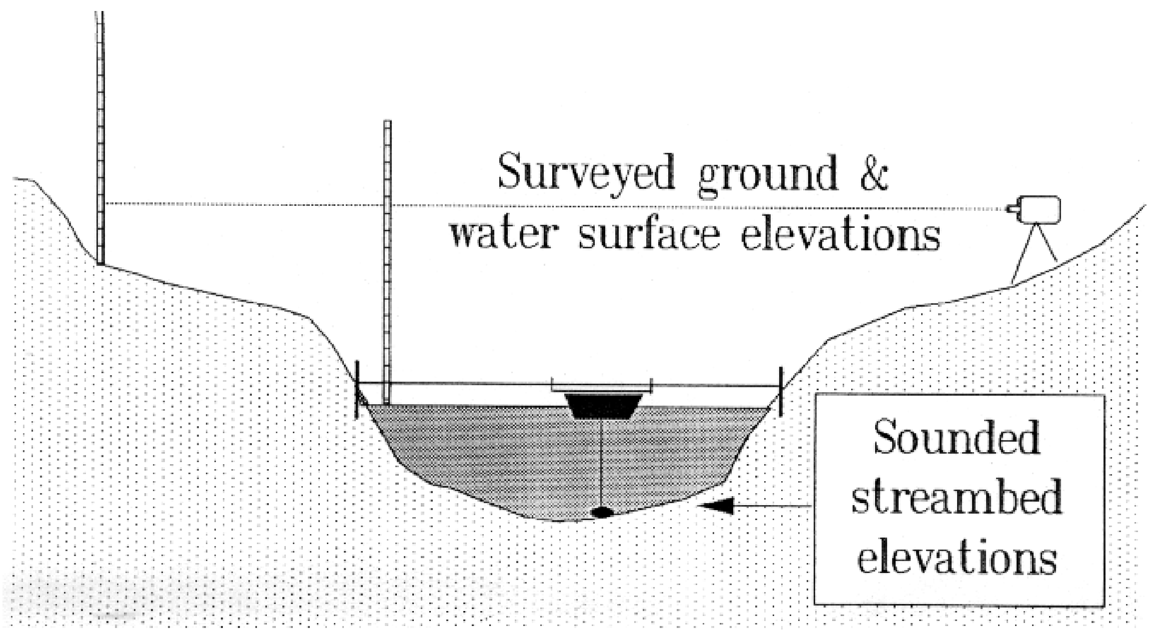



Figure 45. Measurement of a cross-sectional profile using a combination of differential leveling and sounding techniques.

There are two basic approaches to making sounding measurements across large, deep channels. The first method, called the **fixed line-fixed point**, utilizes a static-line across the channel to hold a boat in position on the transect. The second technique, known as the **floating line-floating point** system, does not use a static line.

Whenever possible, we prefer to use the **fixed line-fixed point** system because it affords greater stability and accuracy. As the name suggests, the fixed-line refers to a cable strung tightly between two on-shore deadmen (Fig. 46). The fixed-point refers to the fact that the boat can be locked in place on the cable.

Figure 46. Free end of static line attached to a tree with a wire rope grip and tightened with a hand-winch (come-along).

Over the years, we have used a variety of fixed-point systems. The one we like the best is the boat outfit developed for stream gaging applications by the Water Resources Division of the U.S. Geological Survey (Fig. 47). The complete boat rig consists of a crosspiece that clamps or bolts to the gunwales of the boat and a boom that extends off the bow. The crosspiece end brackets attach to the cable by means of two guide rollers on each bracket (Fig. 48). This design allows for nearly instantaneous detachment from the cable in case of an emergency, a highly desirable safety feature. By simply pulling the rope connecting the roller latches on the end brackets, the guide rollers fall forward and release the boat from the cable.

Figure 47.  Boat rigged for hydrographic measurements, attached to static line.

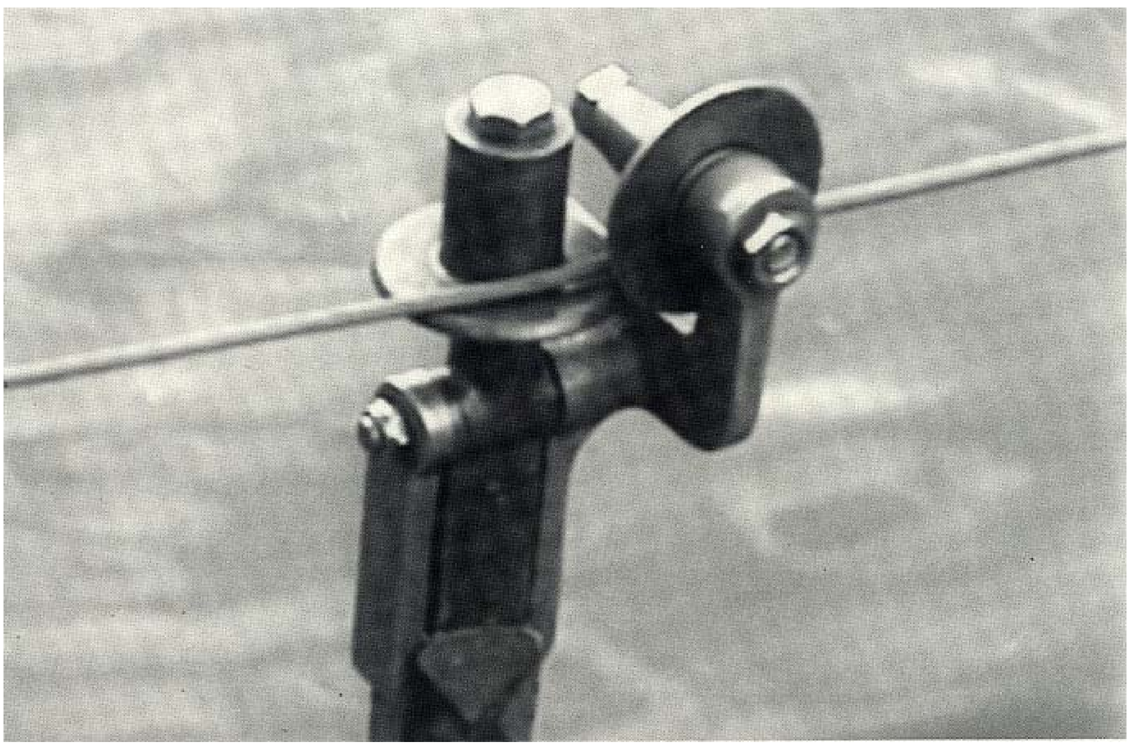


Figure 48.  Close-up of the end bracket of crosspiece assembly, in its attached position.

The third piece of equipment attached to the crosspiece is a cable clamp (Fig. 49).  When the boat is positioned at a measurement location, it can be clamped in place so that it does not slide back and forth along the cable.  Like the guide rollers, the cable clamp disconnects from the cable when the cross-rope is pulled.

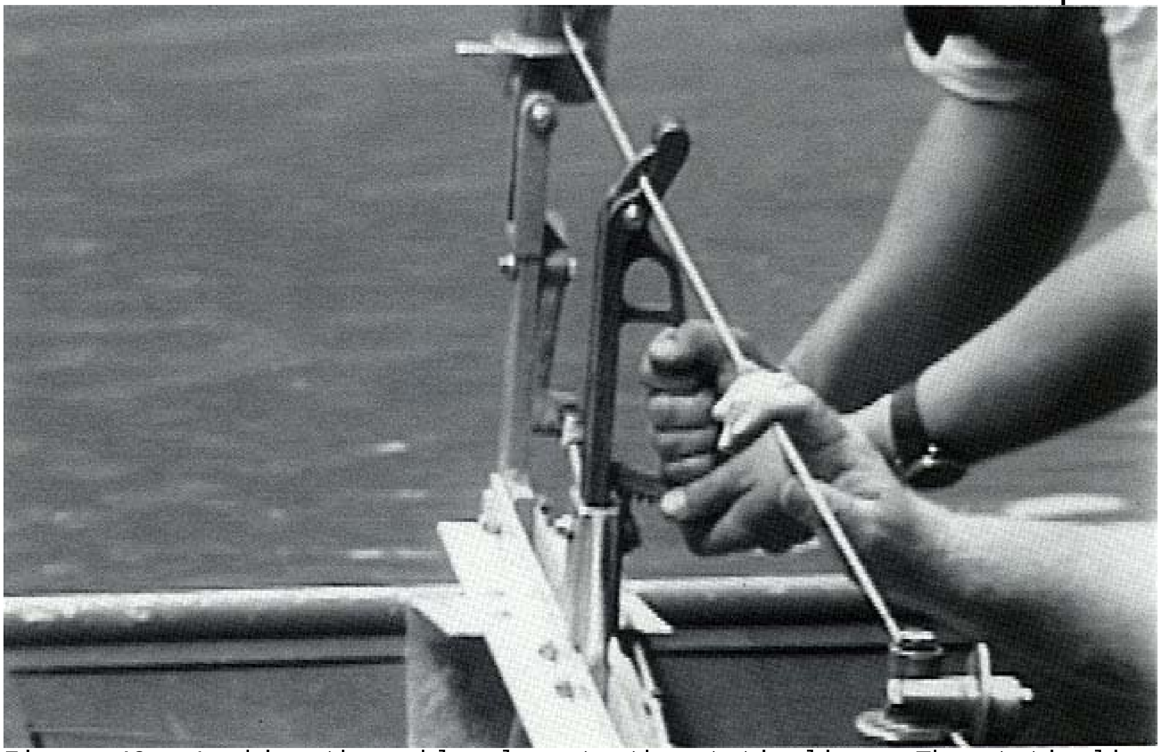


Figure 49. Locking the cable clamp to the static line. The static line is pinched between the jaws of the clamp, which in turn is locked by a "tab-and-notch" apparatus near the base of the clamp.

The retractable boom is mounted parallel to the centerline of the boat by attaching it to the crosspiece and extending it over the bow of the boat (Fig 50). A reel seat is provided on the interior end of the boom, for attaching an A, B, or E-type sounding reel. These sounding reels hold varying lengths of stainless steel, reverse-lay cable with an insulated center conductor. The main differences among the various types of sounding reels are:

(1) A-reels have to be manually operated, whereas the other types can be fitted for power operation.

(2) A-reels are not equipped with clutches, which allow the reel drum to turn without moving the handle. The other reels come with clutch assemblies.

(3) A-reels can hold 80 ft, B-reels 144 ft, and E-reels up to 200 ft of sounding cable.

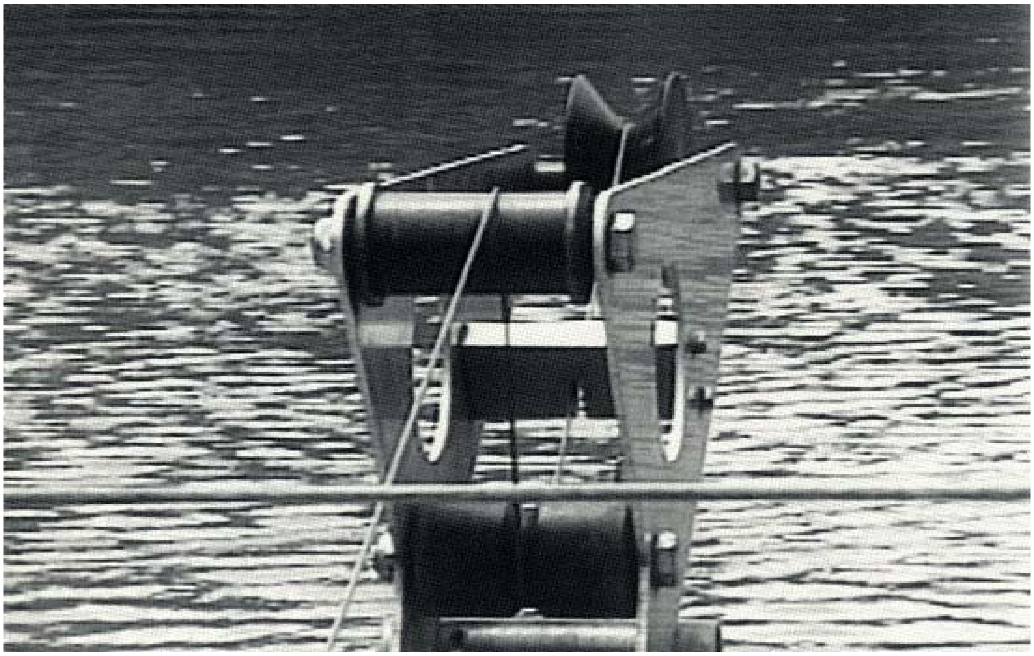


Figure 50. Nosepiece of extendable boom. The static line is in the foreground and the sounding cable is rigged over the upper nosepiece roller. This rigging of the sounding cable over the boom pulleys prevents entanglement of the nosepiece with the static line in the event of an emergency release.

***New Cable Materials Make Life Easier***

Since about 1985, the U.S.G.S. and other cable suppliers have offered static lines made of nylon-sheathed Kevlar® rather than the traditional beaded, stainless steel cable used in the past. The Kevlar® cables are highly recommended. One of the primary advantages of Kevlar® is that it floats. Steel cables sink while you are stringing them across the channel, and eventually tie half-hitches around anything sticking up above the streambed. Untangling steel cable from boulders and logs on the channel floor is not only time consuming, it can be dangerous. Another advantage of Kevlar® is that in an emergency, it can be cut with a pocket knife (although we try to restrain ourselves with regard to what constitutes an emergency). Stainless steel cable can barely be cut with a cable cutter.

A sounding weight and current meter assembly are attached to the free end of the cable (Fig. 51), and the meter's electrical connections are attached to the insulated center wire (see further discussion on current meters in the next chapter). As the sounding weight is lowered to the stream, the depth is indicated on a gage (Fig. 52) that measures the amount of cable unwound from the reel.

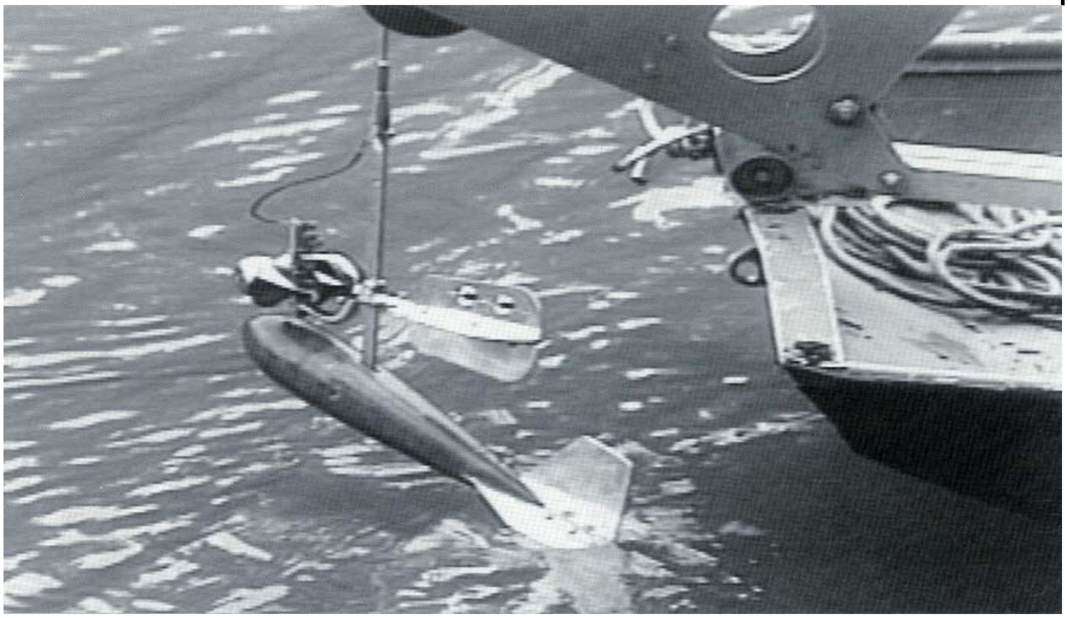


Figure 51. Sounding weight and current meter suspended from the nosepiece of the adjustable boom.

The previously-described suspension gear works equally well with ***floating line-floating point*** systems. The most noticeable difference between fixed-line and floating-line systems is that the latter does not incorporate the use of cross-channel cables and attachment gear. Much of what we know about sounding measurements made from a floating line-floating point system has evolved from stream gaging techniques employed by the U.S. Geological Survey on the Yukon River in Alaska. Normally, the U.S.G.S. conducts its stream gaging activities on large rivers from bridges. However, owing to the remoteness and lack of river crossings on large Alaskan rivers, such as the Yukon, the U.S.G.S has resorted to the same type of boat-mounted equipment we use for PHABSIM work.

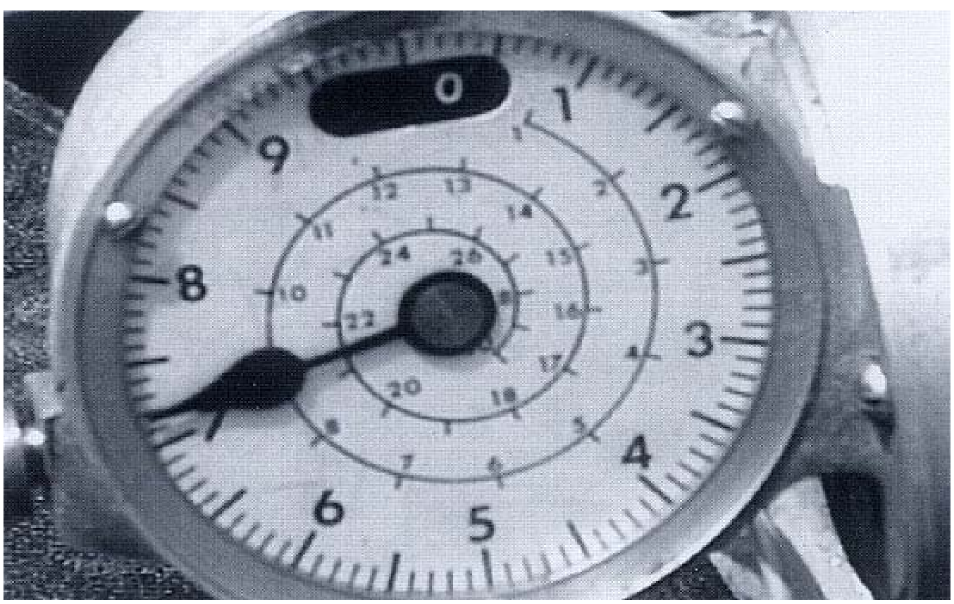


Figure 52. Depth gage mounted on an A-55 sounding reel, indicating a depth of 7.2 feet. The spiral gage on the inner part of the dial is

used to set the current meter at a position 80% of the distance down from the surface (see explanation under stream gaging).

Conducting profile measurements without the benefit of a cable presents two fundamental problems: (1) staying on line and (2) determining the distance from the headpin. Fortunately, neither problem is insurmountable. The transect (floating line) is marked by two monuments on each bank, one white and one orange (or other highly visible contrasting color), as illustrated in Figure 53. It is important for all four monuments to be aligned perfectly with the transect, so they are commonly installed with the use of surveying gear. The boat operator uses the motor to maintain position such that the orange monuments cannot be seen behind the white monuments. If either of the orange monuments can be seen, the boat is off-line. Once the pilot has established the position of the boat on-transect, the distance between the headpin and the boat is measured using a total station or electronic distance meter (we have also successfully used the navigation functions of a real-time GPS to measure distance from the zero point).

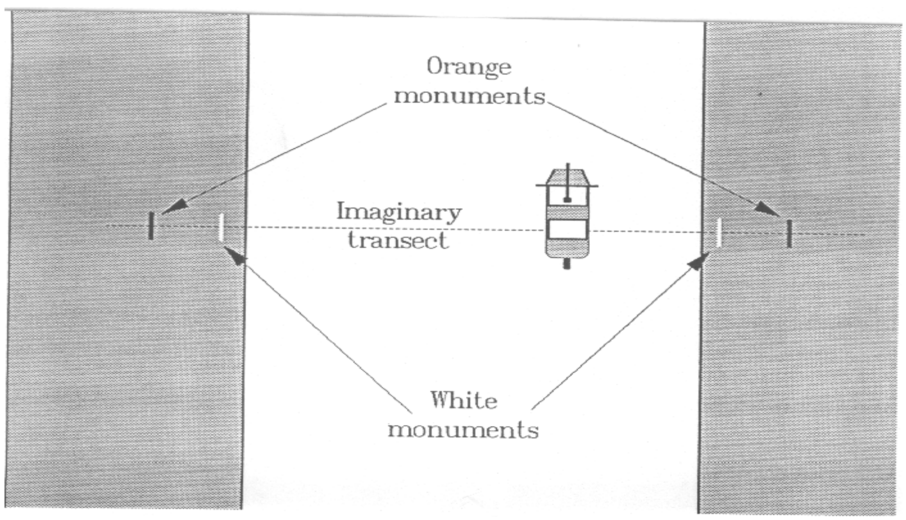


Figure 53. In-line monuments used to maintain position on a transect, using a floating line-floating point sounding technique.

## SUBSTRATE AND COVER DESCRIPTORS

In PHABSIM, substrate and cover are both described as ***channel index*** variables, usually structural features that do not change directly and immediately as a function of stream flow (as opposed to depth and velocity, for example). Sometimes, channel index variables are used somewhat interchangeably in that the substrate can sometimes be used as cover (e.g., boulders used as velocity shelters) and cover can be used as substrate (e.g., submerged logs serving as attachment surfaces for aquatic invertebrates). It is important to keep this distinction in mind, because the same object might be recorded in the field book twice: once as cover and once as substrate.

### ***Recording Channel Index Codes***

One of PHABSIM's more noteworthy limitations is the necessity to translate channel descriptors into a numerical code for entry into the system. It is possible to devise some fairly elaborate numerical coding systems to depict complex combinations of channel materials and objects. Bovee (1986) modified the substrate classification system developed by Platts et al. (1983), to include substrate types, organic detritus, aquatic vegetation, and bedrock (Table 1). This numerical coding system may be more detailed than necessary for some studies, but can be simplified by combining similar classes of materials. In like fashion, cover descriptors can vary from simple presence-absence systems, to highly detailed and complex descriptions of structural cover.

Brusven (1977) devised a system by which various elements of the substrate matrix can be reduced to a 3-part numerical code. The Brusven index consists of an index for the dominant particle size, an index for the subdominant particle size, and an index describing the relative degree of embeddedness of the substrate matrix. ***Embeddedness*** describes the percentage of fine materials in the substrate matrix or the degree to which the dominant particle size is embedded in the subdominant particle size. The index for the dominant particle size is recorded as the first two integers in the code, the subdominant index as the last two integers, and embeddedness is expressed as a decimal. Using the numeric coding system from Table 1, a mixture of small cobbles and medium gravel, 50% embedded in fines could be expressed as 1209.5 (12 for small cobbles, 09 for medium gravel, and .5 for 50% embeddedness).

Channel materials can be described in tremendous detail, often greater than warranted by our understanding of the biological significance of such detail. There is no point in describing the percent embeddedness of the substrate if all you know about the target species is that it spawns over gravel. Conversely, a simplistic channel index that only accounts for dominant particle size would be inefficient if a combination of characteristics were needed to provide biologically suitable conditions.

The level of detail appropriate for describing channel characteristics in the field is dictated by the level of detail in the habitat suitability criteria for the target species. This is why we recommend that you have the appropriate criteria (tested for transferability) in-hand before you ever go to the field. We realize, however, that it may be necessary to collect PHABSIM data concurrently with, or even prior to, the verification of habitat suitability criteria. Where the criteria have not been verified prior to collection of PHABSIM data, it is better to err on the side of too much detail rather than too little. Complex descriptions can be simplified, but simple descriptions cannot be made more detailed.

There are several schools of thought with regard to recording channel index information in the data book. One philosophy is to have everyone on the field crew memorize and use the numerical coding systems for both cover and substrate. Channel indexes can be reported individually (cover, substrate) or as a combination (cover and substrate), but are always reported as a number. A lot of information can be packed into a small space when this approach is used. However, memorizing and reporting the numeric codes is not generally recommended because it can be a source of systematic error. The preferred approach is for the rod operator to verbally describe the cover and substrate characteristics at each vertical. The descriptors are abbreviated (e.g., SC equals small cobble) and entered into separate columns for cover type, dominant particle size, subdominant particle size, percent embeddedness. The conversion to numerical channel index codes is performed in the office. The primary advantage of this system is that no one needs to memorize the coding system. Consequently, there is little chance of recording a code for boulders when the substrate was really gravel.

Table 1. Generalized substrate classes and associated number codes expanded from Platts et al. (1983) to include vegetation and bedrock groups.

| **Number code** | **Class name** | **Size range (mm)** |
|---|---|---|
| 01 | Organic detritus (logs, branches, leaf litter)[a] | NA |
| 02 | Vascular plants | NA |
| 03 | Periphyton | NA |
| 04 | Clay | 0.00024 - 0.004 |
| 05 | Silt | 0.004 - 0.062 |
| 06 | Sand | 0.062 - 2.0 |
| 07 | Very fine gravel | 2 - 4 |
| 08 | Fine gravel | 4 - 8 |
| 09 | Medium gravel | 8 - 16 |
| 10 | Coarse gravel | 16 - 32 |
| 11 | Very course gravel | 32 - 64 |
| 12 | Small cobble | 64 - 128 |
| 13 | Large cobble | 128 - 256 |
| 14 | Small boulder | 256 - 512 |
| 15 | Medium boulder | 512 - 1,024 |
| 16 | Large boulder | >1,024 |
| 17 | Bedrock - flat, unfractured | NA |
| 18 | Bedrock - flat, fractured | NA |
| 19 | Bedrock - tilted, unfractured | NA |
| 20 | Bedrock - tilted, fractured | NA |

[a]Optional subdivisions.

***Obtaining Channel Index Data in Turbid Water***

Reduced visibility is a major hindrance in the description of channel index variables, especially substrate. For this reason, it is common practice to describe these channel properties at very low flows. When the discharge is low, large expanses of the cross-section may be exposed and visibility is often better. In small clear streams, the substrate can often be observed with the naked eye and no specialized equipment is needed. Where the streambed is obscured by surface turbulence or excessive depth, visibility can be improved through the use of a viewbox. A viewbox can be easily constructed by cutting the bottom out of a bucket, and gluing in a piece of plexiglas with silicone sealant (Fig. 54). When pressed into the water, the viewbox acts like a giant dive mask and can often provide a remarkably good view of the streambed.

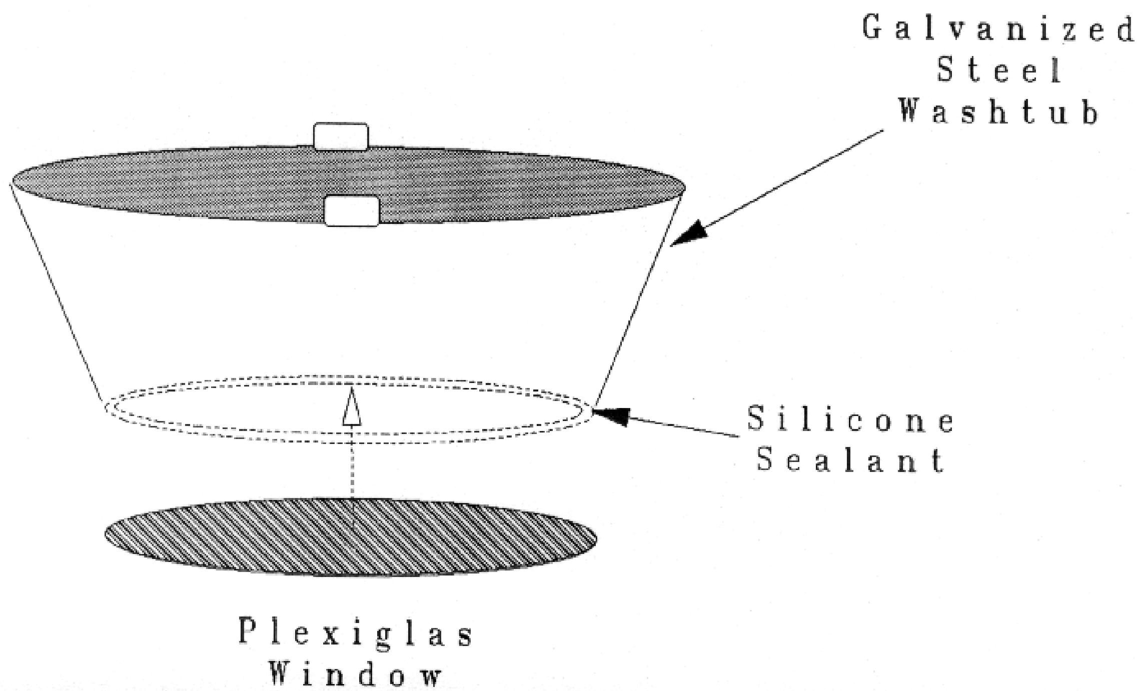



Figure 54. Viewbox for observation of the substrate and in-channel cover objects when the visibility is reduced by surface turbulence or excessive depths.

When visibility is poor but the water is not totally opaque, one of the more promising technologies for observing the streambed is an underwater video camera. Some of these units are as small as a deck of cards and have their own light sources. They can be suspended on a solid rod or from U.S.G.S. cable-suspension sounding gear, either of which can be easily operated from a boat. The camera is connected to a small monitor or to a VCR unit with a length of fiber-optic cable. Because the camera can be suspended nearly to the bottom, it is possible to get a glimpse of the streambed even with visibility as low as 1 ft.

When turbidity is so high that the water is essentially opaque, obtaining a detailed description of substrate characteristics is not easy. Depending on the desired level of detail, however, several alternatives are available. Any good echo sounder will produce an echo signature that can be translated, with appropriate ground truth data, into a relatively coarse substrate classification. So-called scientific echo sounders are designed to be able to record individual pings for subsequent post-processing to determine substrate types. Most scientific echo sounders, however, were designed for use in the ocean, so the shallow depths encountered in a river can cause problems. With our sounder, for example, we are unable to perform bottom typing in less than one meter of water. Fortunately, it is fairly easy to determine substrate in shallower water by probing with a dowel or leveling rod. Side-scanning sonar may be useful in obtaining a low-resolution view of the streambed on a large scale. The level of detail capable with affordable (i.e., not obtained from the military or the CIA) side-scan sonar units is low, but good enough to distinguish big objects from little ones. Side-scan sonar is probably best used to examine the streambed for cover objects rather than for a substrate description.

## SUMMARY

- Channel cross-sections are described as a series of x and y coordinates, called verticals. Channel profile data associated with each vertical include a horizontal distance from a zero point, an elevation relative to a known datum, and descriptions of the cover and substrate in the cell represented by the vertical.
- Verticals divide the channel into lateral stream cells. Cell boundaries and verticals are coincidental in HABTAT and HABTAE, but cell boundaries are located at the midway points between verticals in HABTAV and HABTAM.
- It is a convention in PHABSIM to designate left and right streambanks, looking upstream. It is also conventional to designate zero horizontal distance to the headpin on the left streambank.
- Ground elevations are measured to the nearest 0.1 ft, and water surface elevations are measured to the nearest 0.01 ft
- Horizontal stations on floodplains are measured as negative distances to the left of the headpin and as positive cumulative distances to the right of the tailpin.
- If the left-side floodplain is less than 100 ft wide, negative distances can be entered directly into PHABSIM programs. If the left-side floodplain is greater than 100 ft wide, the horizontal distances must be re-stationed. This correction should be done in the office, not in the field.
- Undercut banks are measured by: (1) determining the horizontal

distance and elevation at the interior (stream) side of the undercut, (2) estimating the average distance from the interior side of the undercut to its exterior (back) side, (3) estimating an elevation for the backside of the undercut, and (4) measuring the top-of-bank elevation at a station 0.1 ft beyond the back side of the under cut.

- The depiction of undercut banks in PHABSIM is distorted because the overhang can not be included in the cross section coordinates. However, because of the biological importance of undercut banks, a distortion is preferable to omitting these features entirely.
- Structural features of substrate and cover are entered into PHABSIM as a numerical channel index code. Although it is possible to develop complex coding systems, the level of detail in channel index codes should be consistent with the habitat suitability criteria for the target species. It is advisable to record cover and substrate information in abbreviated form in the field book, and translate the abbreviations to a numerical code prior to data entry.
- Reduced visibility is a major problem in describing substrate in deep water. Generally, substrate can be described by touch in shallow water, and cover objects are usually large enough to be identified without direct visual contact. Viewboxes and underwater video cameras may be helpful in describing substrate characteristics where visibility is poor but the streambed is not totally obscured. Where visibility is zero, and depths exceed one meter, a high quality echo sounder can produce an echogram that can be translated into a coarse substrate classification.

# HYDROGRAPHIC AND HYDRAULIC DATA

***Hydraulic variables*** change instantaneously with discharge and include current velocity, depth, water surface elevation, cross-sectional area, top width, and wetted perimeter. Many of these hydraulic variables can be calculated from a limited number of empirical measurements. Consequently data collection is concentrated in three specific areas: (1) collecting calibration data for velocity-prediction models (2) developing relations between discharge and water surface elevations, and (3) calibrating relations between stage and discharge at a semi-permanent gaging station. This chapter describes the following equipment and techniques used to collect hydraulic data for PHABSIM:

(1) stream gaging equipment and procedures,
(2) measurement of water surface elevations, and
(3) installation of gaging stations at PHABSIM sites.

## STREAM GAGING

Data collection procedures used to calculate discharge and those used to calibrate PHABSIM's velocity-prediction models are essentially identical. The primary difference between the two types of measurements is in their locations. Stream gaging for discharge calculations is usually performed at a single transect for several different stream flows. Stream gaging for velocity calibrations are made at all of the transects in a site (sometimes excluding the hydraulic control), but commonly at only one or two stream flows. The ideal cross-section for a discharge calculation is relatively wide, shallow, and uniform; often the antithesis of good fish habitat.

Stream gaging data consist of measurements of widths, depths, and velocities at intervals across a transect. Although the measurements of widths and depths are comparable to the measurements for the cross-sectional profile, they are not always the same, nor do they always require the same equipment. The following sections describe techniques for measuring three variables of stream gaging: width, depth, and velocity. Similarities and differences between stream gaging and cross-sectional profile data is discussed where appropriate.

### *Width Measurements*

Stream gaging verticals commonly correspond exactly with those measured for the cross-sectional profile, and therefore, require essentially the same equipment. For small, wadeable streams (up to about 200 ft wide), the preferred measuring instruments are measuring tapes or taglines.

The choice between measuring tapes or taglines is largely a matter of personal preference, because their advantages and disadvantages are somewhat diametrical. Tapes are constructed of stainless steel, fiberglass, or plastic-clad steel, taglines from PVC-clad polypropylene rope or stainless steel cables. The primary trade-offs among the various equipment choices boil down to differences in strength, convenience, and versatility.

Tapes are housed on a reel, whereas taglines often end up as a wad or a series of knots by the end of the day. However, taglines are generally more versatile; they can be tied off on branches or headpins without compromising their strength. Because tying a knot in a tape is the first step in breaking it, the use of tapes also implies the use of chaining pins and tape clamps to secure the ends. Steel tapes and cables are very strong, but are hard on hands if gloves are not worn. Fiberglass tapes are convenient and relatively versatile, but not very strong. If you are working in a very windy area, taglines may be favored because flat tapes tend to develop a low frequency harmonic vibration in the wind. This oscillating motion, if strong enough, will quickly snap even the strongest steel tape. Because of their cylindrical shape, taglines do not develop such strong oscillations in windy conditions. For spans of over 200 ft, we recommend the use of Kevlar® cables, described previously under the fixed line-fixed point system.

As with the cross-sectional profile data, distances across the transect are recorded from the headpin. In fact, these distances are normally recorded as the stations (STA) for the cross-section. The only additional data recorded for hydraulic calculations are the stations at water's edge on both sides of the stream. However, a separate column is set up in the field book for the calculation of cell widths, that are used in subsequent calculations of discharge.

### *Depth Measurements*

Although the use of sounding equipment for measuring depths from a boat is a common practice, in many studies, depths and velocities are measured by wading. The standard piece of equipment for this measurement is the ***top-setting wading rod*** (Fig. 55). This rod has a hexagonal stock, graduated in 0.1 ft increments for measuring depth with double marks every 0.5 ft and a triple mark at each whole foot increment. Metric rods are usually have a single mark at each centimeter and a double mark at each decimeter. The top-setting wading rod gets its name from the ability of the user to set the meter at the appropriate depth automatically, without removing the rod or meter from the water.

Top-set rods are available in even-foot lengths between 4-10 ft, but the 4-ft wading rod is by far the most popular. Six-ft rods are handy where the water depth is between 4-5 ft: too deep for a 4-ft rod, but not deep enough to justify using a boat. For normal usage, however, a 6-ft rod is a little too long. The 8-ft and 10-ft rods generally take two people to operate: one to maneuver the bottom of the rod into position (usually by diving) and one to run the equipment at the top of the rod. Rods of this length are nearly impossible to operate in water shallow enough for wading, so they cannot really be considered to be wading rods.

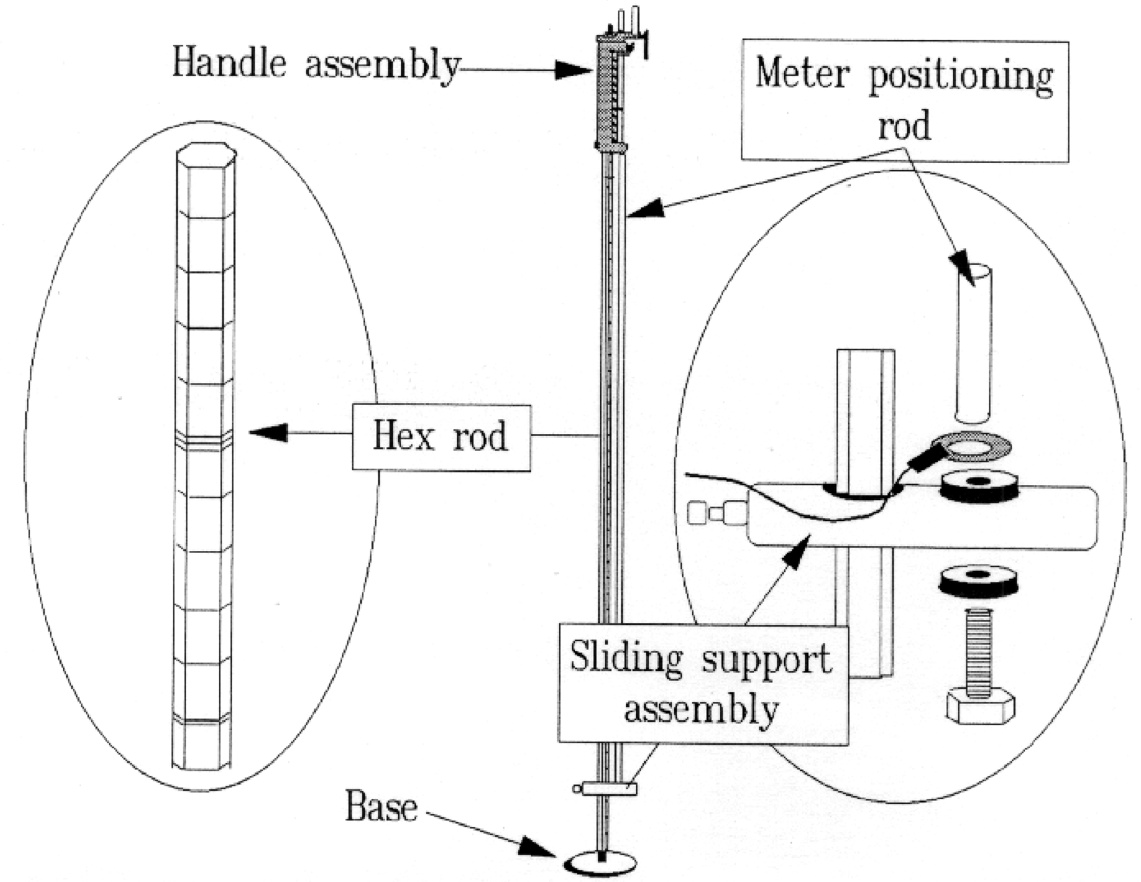



Figure 55. Parts of a top-setting wading rod. Exploded views show the markings for depth measurements on the hex rod and the insulated assembly of the sliding support.

Although fairly simple in appearance, the top-setting wading rod is a sophisticated piece of equipment. The sliding support (Fig. 55) is designed to mount a Price-AA or pygmy current meter, but many other types of commercially-available meters can be affixed to the support. Unlike other types of meters, however, all of the electrical connections between the rod and Price-AA or pygmy meters are internal. This means that the span between the meter and the instrumentation, connected by an unprotected wire, is short and easily repairable. The largest source of problems with some meters is the excessive amount of wiring associated their operation.

Another attractive feature of the top-set wading rod is that it allows easy positioning of the current meter for measurements of the mean column velocity. In depths less than 2.5 ft, the mean column velocity is measured at 60% of the distance down from the surface. Where the depth exceeds 2.5 ft, measurements at 20% and 80% of the distance from the surface are averaged to obtain a mean column velocity. The top-set wading rod is designed to position the current meter at these settings by operating a meter-positioning rod at the top of the rod.

The meter-positioning rod is graduated in 1-ft increments from 0 to 8. The aluminum handle at the top of the rod is graduated at every 0.1 ft. By aligning these two marks, the meter will be placed at a vertical distance 60% from the surface of the water. For example, if the depth is 2.4 ft, the "2" on the meter positioning rod is aligned with the "4" on the handle (Fig. 56). In this position, the meter will be centered at 0.96 ft, exactly 60% down from the surface.

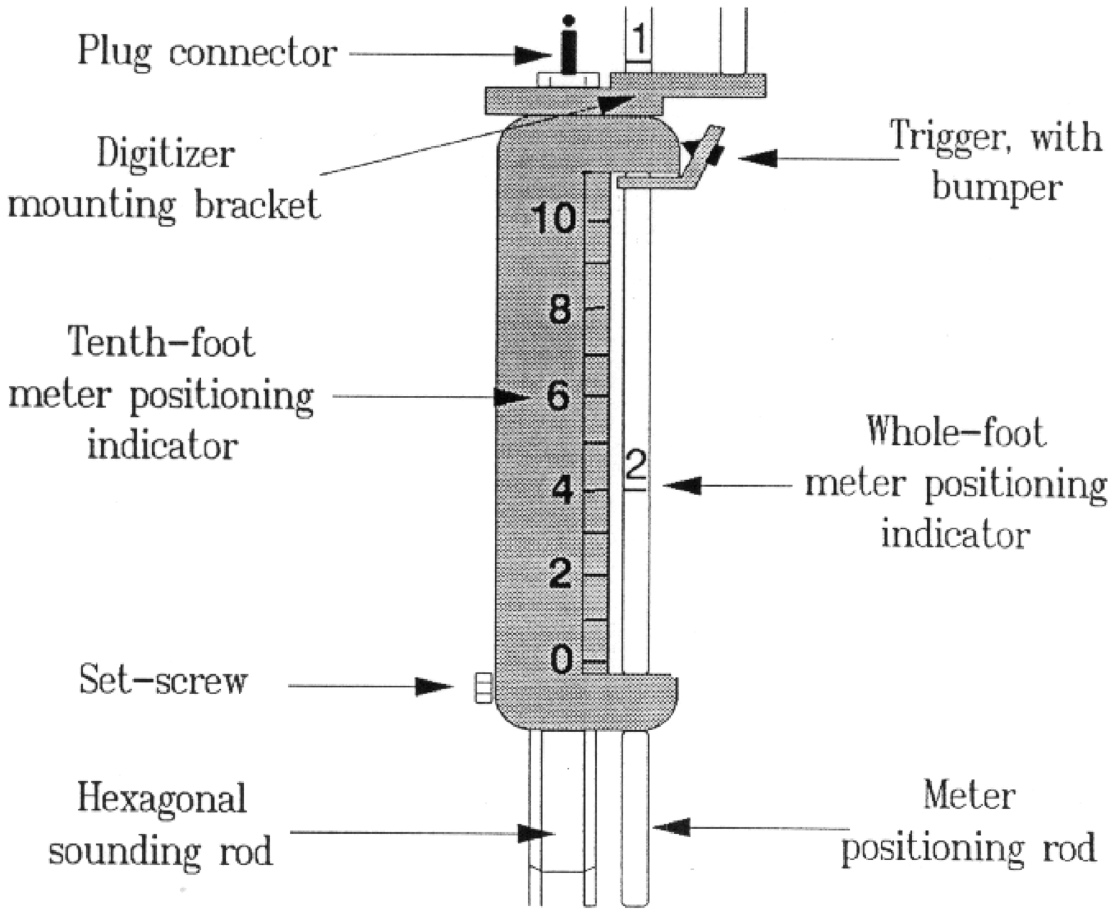



Figure 56. Close-up of the handle of a top-setting wading rod. The alignment of the "2" on the meter positioning rod and the "4" on the handle will position the current meter at 0.6 depth in 2.4 ft of water.

For depths greater than about 2.5 ft, velocities should be measured at 20% and 80% of the depth, and then averaged to obtain the mean column velocity. To obtain the 20% reading (from the surface), the meter positioning rod is set at a location equal to twice the depth. The 80% reading is taken with the meter positioning rod set at half the depth. For example, assume a depth of 3.4 ft. Half of 3.4 is 1.7, so the 80% reading is taken by aligning the "1" on the meter positioning rod with the "7" on the handle. The 20% reading is taken at double the depth (6.8) by aligning the "6" on the meter positioning rod with the "8" on the handle (Fig. 57).

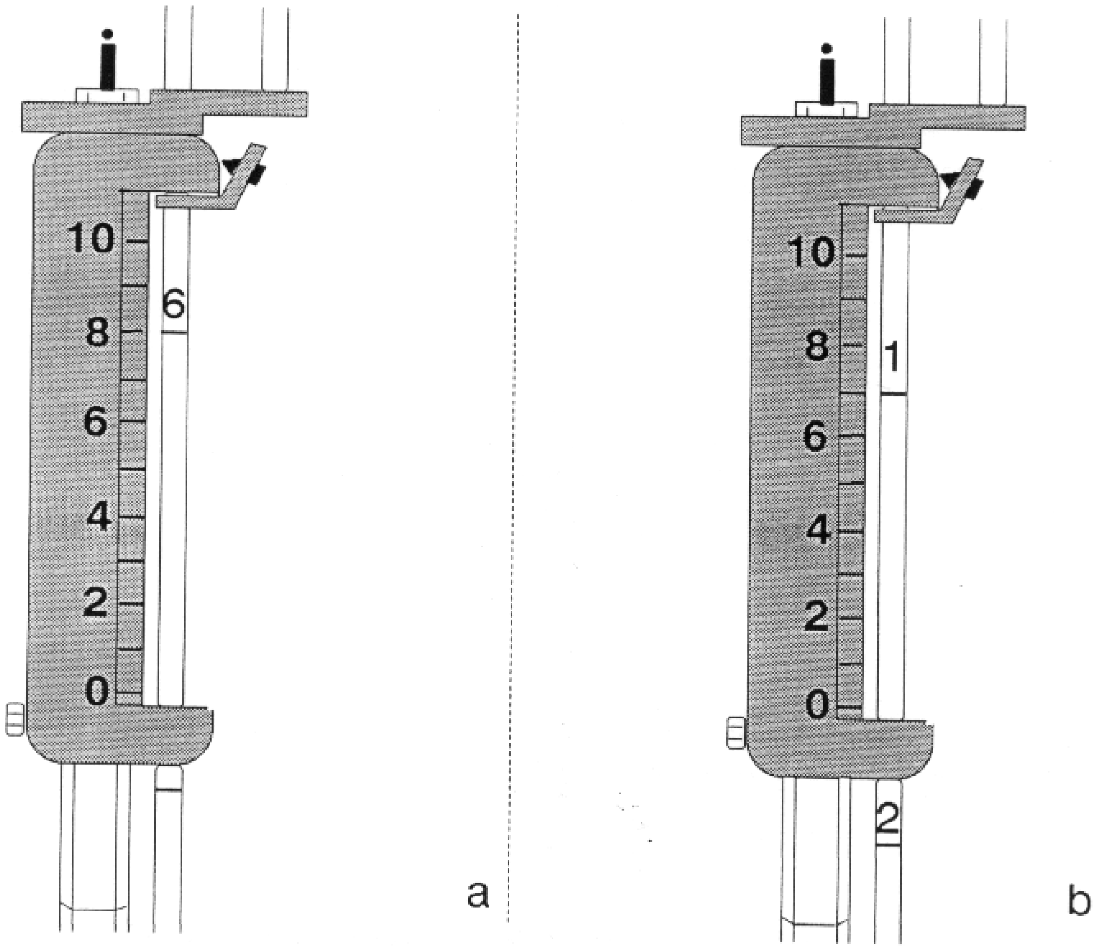



Figure 57. Alignment of whole- and tenth-foot positioning indicators to locate the current meter at 20% (a) and 80% (b) settings for determining the mean column velocity for a depth of 3.4 ft.

"Pack-rods" are manufactured as foot-long sectional rods that screw together to form a complete 3-5 ft wading rod (depending on the number of sections used). Two identifiable advantages of a pack-rod are that they are cheaper than a top-set rod (about half as much) and can be carried in a back-pack. With a sectional rod, however, the meter must be positioned manually and the electrical leads are external. Because of this, it takes about twice as long to take a measurement with a pack-rod than with a top-setting rod. Sectional rods also come unscrewed easily in fast water. Searching for rod and meter parts strewn along the streambed takes additional time that most field crews do not have. Because of these disadvantages, most investigators consider the additional cost of the top-set rod to be a good investment.

***Trouble-shooting Tips for Top-set Rods***

- The most common problems with top-set rods originate from loose parts. One such part is the base, which screws onto the bottom of the hexagonal sounding rod. During the normal wear and tear of many repeated measurements, the base can come loose invariably fall off where it is least recoverable. Some easy ways to avoid this problem include: (1) making sure the lock washer between the rod and base is in place, (2) checking the tightness of the base from time to time, and (3) carrying a spare base in a repair kit.
- Another part that often comes loose is the connection between the meter positioning rod and the sliding support that attaches the current meter. Many times if the whole-foot numbers on the meter positioning rod are turned away from the operator, the operator will twist the rod in order to see the numbers. Eventually, the rod comes unscrewed from the bolt holding it to the sliding meter support (usually in the middle of the river). Although there is little danger of losing the meter, the bolt, as well as the insulating washers (that prevent the signal from the meter from short-circuiting) can be lost. These problems can be avoided most simply by checking the tightness of the connection periodically.
- The connection between the telephone connector plug and the handle can be troublesome. The connector plug is screwed into a brass nut, which in turn, is screwed into the handle. The plug is attached by a microscopic terminal connector and screwed to a thin wire that isolates the electrical circuitry from the handle. This wire is necessary to isolate the positioning rod from the hex rod in order to prevent short-circuiting the signal from the meter. When the plug connector loosens, it tends to twist back and forth, until the thin wire breaks inside the handle. When this happens, you are faced with a rather major repair job, requiring very small tools, a steady hand, and <u>really</u> good eyesight. Try to avoid twisting the in handle-to-plug wire by keeping the plug screwed tightly into its brass fitting.

- Because of its exposed position, the wire lead connecting the current meter to the meter positioning rod is especially vulnerable to breaking. This is difficult to prevent, but can be repaired. It is advantageous to carry plenty of repair materials such as insulated wire, wire cutters and strippers, solderless terminals (eye-end and open-end), and electrical tape.

## Velocity Measurements

Velocities for PHABSIM are measured with one of four different types of current meters: ***vertical axis***, ***horizontal axis***, ***electromagnetic***, and ***acoustic doppler*** meters. Vertical- and horizontal-axis meters are mechanical devices that operate by relating the angular velocity of the meter to the velocity of the water. Electromagnetic meters and acoustic doppler meters are electronic devices, based on the principles of electromagnetic induction and doppler wavelength distortion, respectively.

***Vertical-axis Meters***

Vertical-axis meters include the Price-AA, Polymer AA (PAA), pygmy, and Gurley meters (Fig. 58). These meters are used nearly exclusively for stream gaging by the Water Resources Division of the U.S. Geological Survey. The vertical-axis meter has a rotor (known as a bucket wheel) with six cone-shaped cups mounted on a stainless-steel shaft. A pivot bearing supports the rotor shaft, the upper end of which extends into a cylindrical contact chamber on the top of the meter. The upper part of the rotor shaft is shaped like a cam and contacts a slender wire (known as a ***cat whisker***) each time the rotor completes a full revolution. In the Price-AA and PAA meters, there is a separate reduction gear, cat whisker, and binding post that provide a contact every five revolutions. Each time a contact is made, the electrical connection from the meter to the telephone plug connector on the wading rod or sounding reel is completed.

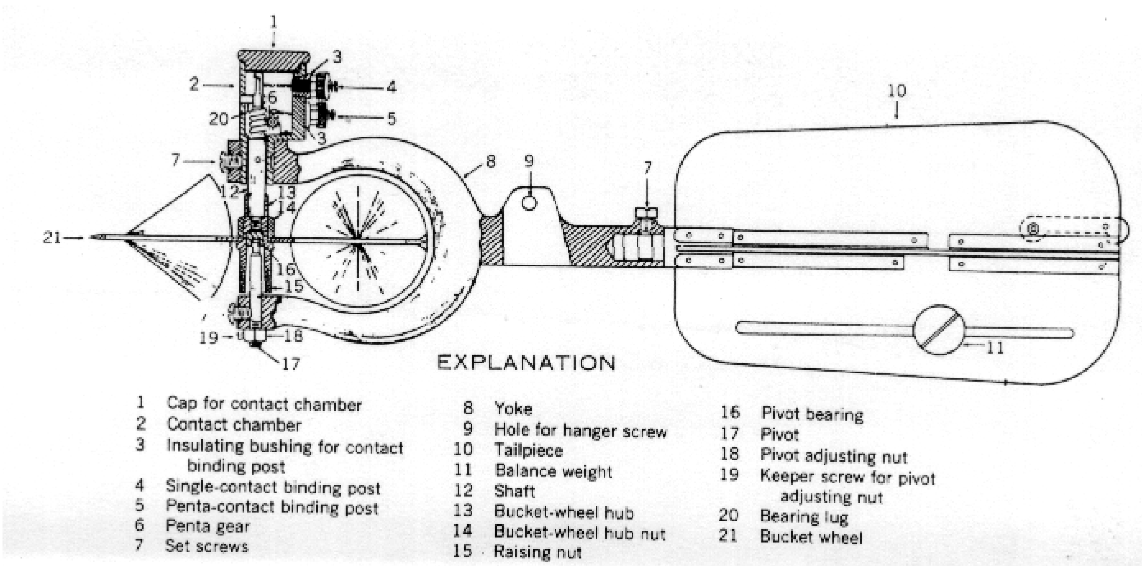



Figure 58. Assembly drawing of a Price AA current meter.

Some vertical-axis meters are equipped with an optical head (essentially a light source and a slotted disk, connected to a counter by optical fiber cable). Revolutions of the rotor shaft are counted by the flashes of light emanating from the contact chamber. [Note: Optical cables are not internalized into wading rods or sounding cables the way copper wires are].

Prior to about 1985, the operator of a current meter was equipped with a small headset and a stopwatch. With each revolution of the bucket wheel, the headset would click, or in slow water, make an annoying "fingernails-on-the-blackboard" noise as the rotor shaft scraped its way past the cat whisker. The operator would count the number of clicks or scratches for a time interval of at least 40 seconds. The number of revolutions and the time were recorded and converted to a velocity from a rating table for the instrument.

As an alternative to manually counting, timing, and converting velocities, the Hydrologic Instrumentation Facility (HIF) of U.S.G.S. has developed an electronic current meter digitizer. This small instrument can be mounted on a top-setting wading rod or used in conjunction with U.S.G.S. boat-mounted sounding equipment. To operate, the user turns the unit on, selects the mode appropriate for the type of meter being used, and pushes the start button. The digitizer counts electrical contacts and optical closures from the current meter, keeping a running display of revolutions and total elapsed time. At the end of the 40-second measurement period, the meter calculates and displays the velocity, and stores the number of revolutions, elapsed time, and velocity in recall. The start of the next velocity measurement erases the previous value, as well as values in recall. Though not flawless, the current meter digitizer has probably done more to improve the accuracy and efficiency of PHABSIM fieldwork than any other piece of equipment since the top-setting wading rod.

### *Trouble-shooting for Vertical-axis Meters*

- Vertical-axis meters are fairly rugged and reliable, and usually require only a minimum amount of maintenance. The most important aspects of upkeep involve preventing damage and loss of parts, maintaining proper adjustments and clearances, and keeping the instrument clean and well lubricated. Two components of vertical axis current meters are especially vulnerable to damage: the bucket wheel and the pivot and pivot bearing on which the bucket wheel turns (Parts 21 and 16, Fig. 58).
- Damage to bucket wheels occurs most often when the meter is in transit. When in use, care should be taken to avoid situation where the bucket wheel collides with the streambed or other hard objects. For example, position the current meter about halfway up the wading rod when you are moving around in the stream. If you fall, you will be less likely to slam the meter into the streambed as you try to catch your balance with the wading rod.
- Damage to the pivot and pivot bearing also occurs most often when the meter is in transit. When freely turning, there should be a small, but perceptible amount of play between the pivot and pivot bearing. Because of this play, however, there is a tendency for the bucket wheel to bounce up and down on the pivot whenever the meter is moved. The greater the amount of play between the contact chamber cap and

the pivot, the harder the pivot will collide with the pivot bearing. Eventually, these repeated collisions cause the formation of a burr on the point of the pivot, which will ultimately affect the rating of the meter.

- Damage to the pivot can be ameliorated, but not eliminated completely. On Price-AA, PAA, and Gurley current meters, there is a brass raising nut, located just above the bottom part of the yoke (part #15, Fig. 58). The purpose of the raising nut is to hold the rotor and bucket assembly apart so that the pivot and pivot bearing are not in contact. One of the easiest ways to prolong the life of a pivot is to screw down the raising nut each time before the instrument is moved a significant distance. [Note: Moving from vertical to vertical is not usually considered a significant distance, but moving from transect to transect is.]
- Pygmy meters are equipped with two types of pivots: one for traveling and one for working. The working pivot looks very much like the pivot from a Price-AA meter; it is sharply pointed, made from stainless steel, and has a pivot-adjusting nut and set-screw. The working pivot is removed during transit, so it is essentially immune to travel damage. The traveling pivot is made from soft brass and is comparatively blunt, so it should not cause much damage to the pivot bearing, no matter how hard it bounces up and down. It is very important to remember to exchange the working pivot for the traveling pivot whenever the meter is in transit. Equally important, the traveling pivot must be exchanged with the working pivot whenever stream gaging is being conducted.
- When in use, current meters should be partially disassembled, cleaned, and oiled daily; and after the completion of each transect if measurements are taken in water with large amounts of suspended sediment. Surfaces to be cleaned and oiled are the pivot and pivot bearing, pentagear teeth and cross-shaft bushings, and the thrust bearing that holds the rotor shaft in position inside the contact chamber.
- After cleaning or just before using the next time, the meter should be "spin-tested." Hold the instrument level and out of the wind, and give it a moderate spin. A Price-AA, PAA, or Gurley meter in good shape should spin for at least 2 minutes (new ones will go nearly 3 minutes). Pygmy meters should spin at least a minute, and preferably a minute and a half. If the meter spins for less than the requisite time, check for corroded surfaces, poorly lubricated bearings, organic "gunk" lodged in the pivot bearing, burred pivot, or a bent rotor shaft.

### *Horizontal-axis Meters*

Horizontal-axis current meters include the Ott, Neyrpic, Haskell, Hoff, Swoffer™, and the newly-developed Global Flow Probe™. Horizontal-axis meters appear to be much more popular in Europe than in the U.S. The Ott meter is made in Germany and the Neyrpic is made in France. In the United States, the Ott and Swoffer™ meters are probably used the most.

The rotor shaft of a horizontal-axis meter is turned by a propeller or screw, rather than by a bucket wheel. Although horizontal-axis meters look quite different from vertical-axis meters, they measure velocities in much the same way. A sender (often magnetic) inside the meter produces a signal which is transmitted to a counter/timer. Velocities are computed on the basis of a calibrated relationship between the angular velocity of the meter and the speed of the water.

Although not as durable and rugged as vertical-axis meters, horizontal meters have the advantages of generally being small in size and being less sensitive to velocity components not parallel to the meter axis. Because these meters are smaller and more streamlined than vertical-axis meters, they are somewhat less sensitive to filamentous algae or other types of vegetation.

The disadvantages of horizontal-axis meters, however, may seriously outweigh any advantages they have over vertical axis. Generally speaking, slow velocities are problematic with all types of current meters, but they are worse with propeller-driven meters. Because of the low inertia inherent in the propellers, horizontal-axis meters may be somewhat more sensitive to pulsating currents. Some users have found that it is more difficult to obtain consistent readings with a horizontal-axis meter than with vertical-axis meters. The most serious disadvantage of these meters is that they are incompatible with most commonly used suspension systems, such as U.S.G.S. top-setting wading rods or boat-mounted sounding cables. Although there is nothing inherently wrong with the meter, the wading rods that accompany the meters are flimsy compared to top-set rods.

### *Electromagnetic Meters*

Electromagnetic (EM) current meters operate according to the principles of Faraday's Law of electromagnetic induction. The principle of electromagnetic induction, as it applies to an EM current meter, is illustrated in Figure 59. As flowing water cuts the lines of the magnetic field generated by the internal electromagnet in the probe, an electromotive force (EMF) is induced in the water. This electromotive force is detected as a voltage gradient between the two electrodes mounted on the sides of the probe. The amount of EMF is proportional to the strength of the magnetic field and the velocity of the water. The meter itself is actually a very sensitive voltmeter, which translates the induced EMF signal into a velocity reading.

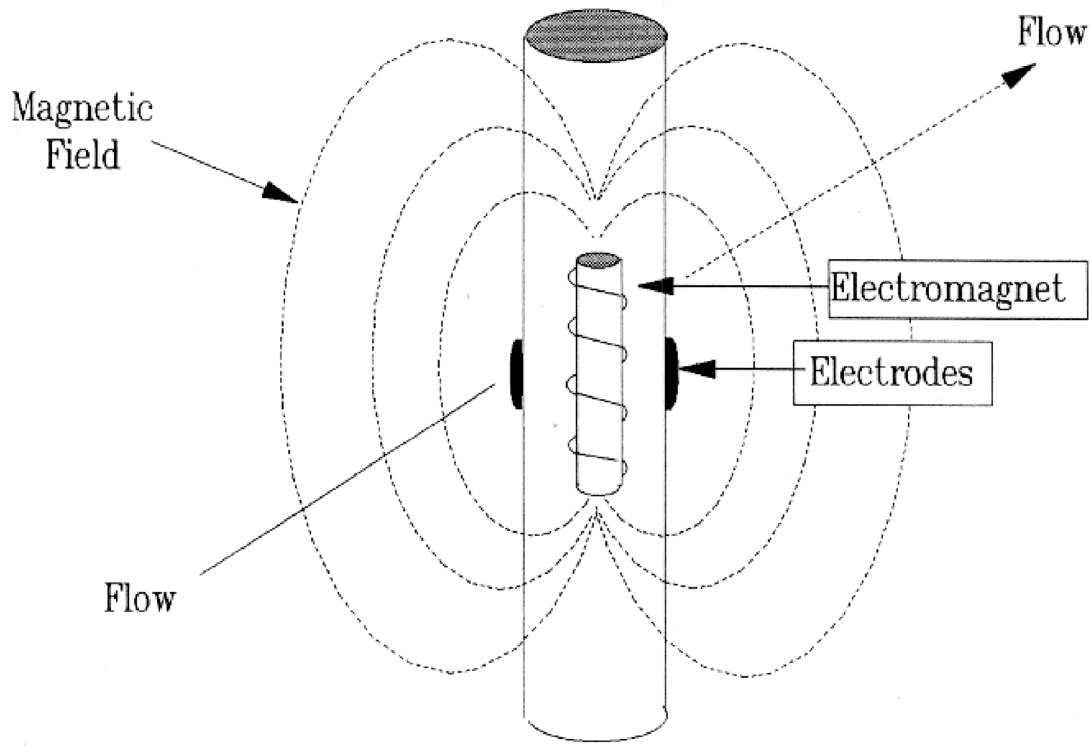



Figure 59. Operating principle of an electromagnetic current meter. Movement of a fluid through the magnetic field generated by the electromagnet induces an electomotive force, that is registered as a voltage gradient between the two.

The primary advantages of EM current meters are that they have no exposed moving parts, they have a rapid response time, and they are fully compatible with standard U.S.G.S. suspension equipment. With no exposed moving parts, the EM current meters are particularly well-adapted for streams containing vast amounts of filamentous algae, or for measuring small nooks and crannies between rocks or under banks. Conditions that would leave mechanical current meters hopelessly clogged are easily measured with an EM meter.

The rapid response time is purported by some users to be a major advantage of an EM meter over mechanical meters. Whereas it takes at least 10 seconds to obtain a velocity reading with a mechanical meter, readings can be taken in only one or two seconds with an EM meter. However, this may not be much of an advantage, because velocity measurements should be averaged over time, rather than being instantaneous Buchanan and Somers (1969). Although some of the newer EM meters have incorporated time-averaging electronics, the older models only provided instantly updated velocity measurements. Consequently, time averaging was poor and repeatability low with EM meters, especially in highly pulsating water.

Although many improvements have been made to EM meters over the

past five years or so, they still suffer from some major liabilities:
(1) EM current meters are heavy, owing to the large number of batteries required to power the electromagnet. They will feel even heavier at the end of the day.
(2) The "black box" part of the meter is not particularly water-proof (a poor feature for a current meter). If they are dunked, you will probably have to send it in to the factory to get it repaired. [Note-the new Marsh-McBirney meters are advertised as being water-proof. We have not tested them, however].
(3) EM current meters are the ultimate in black-boxes. Erroneous output from one of these meters looks just as valid as accurate information, and there are few outward clues that anything might be wrong with the meter. EM current meters cannot be spin-tested, therefore, EM current meters should be calibrated periodically against a vertical-axis meter in good working order.

***Acoustic Doppler Meters***

This is not a piece of equipment for a low-budget operation. At this writing, the going price for an Acoustic Doppler Current Profiler (ADCP) is about $55,000. Furthermore, the ADCP must be boat-mounted, so it is not appropriate equipment for streams with a mean depth of about 2 meters or less. The minimum operating depth of an ADCP is about 1.5 m.

An enormously oversimplified description of how Acoustic Doppler works is illustrated in Figure 60. What is shown as a transmitter is actually a gang of four separate transducers. Each transducer emits a sound wave of known frequency, which bounces off of materials suspended in the water column and is returned to the transducer (shown as separate receivers in Fig. 60). Echos returning to the transducer from downstream will be traveling against the current, and like the sound of departing vehicle, will have an apparent frequency lower than the transmitted sound wave. Conversely, echoes returning from upstream will be going with the current and will have an apparent frequency higher than the transmitted sound wave. The disparity in the frequencies is translated into a velocity. The faster the current, the greater the disparity in frequencies received by the two receivers.

The Doppler effect is probably more familiar to most people than are the principles of electromagnetic induction. However, acoustic Doppler meters are electronic devices and as such, fall into same "black-box" category as EM meters. The advantages and disadvantages of acoustic Doppler meters are virtually the same as those of EM meters.

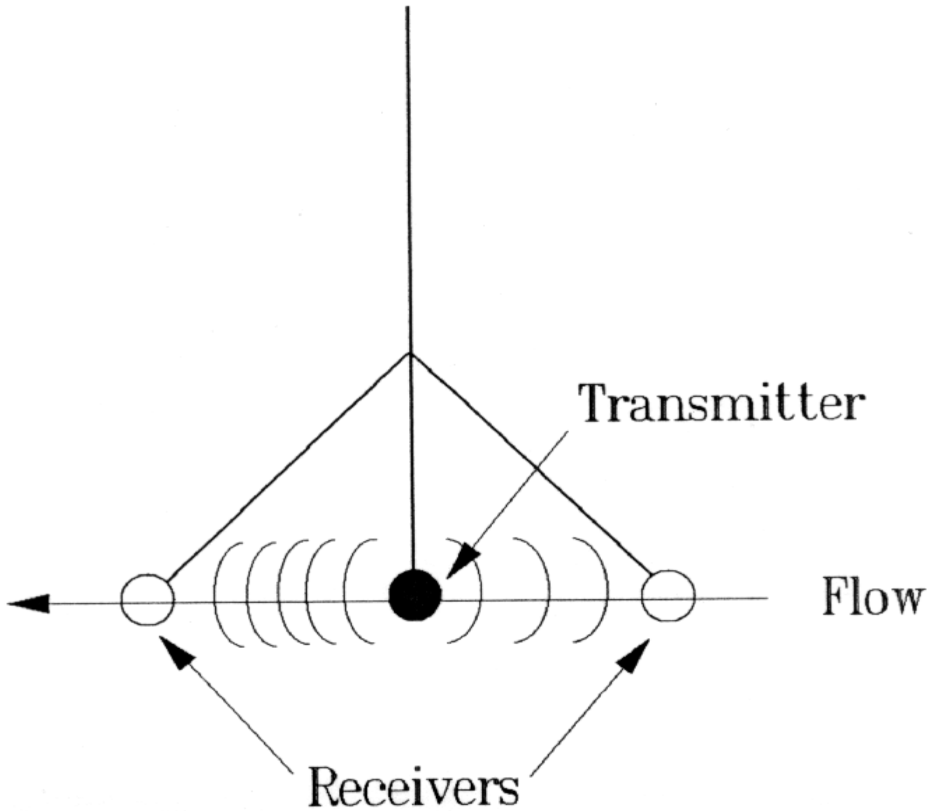



Figure 60. Operating principle of an acoustic Doppler current meter. Sound waves moving against the current are received as lower frequency than those moving with the current.

***Current Meter Considerations***

Velocity measurements collectively consume more field time than virtually any other aspect of PHABSIM data collection, and current meters often represent a sizable portion of the equipment budget. Therefore, it is appropriate to weigh the advantages and disadvantages of different types of meters when gearing up for PHABSIM field work. The following criteria are important considerations in the selection of current meters: (1) accuracy and precision, (2) cost, and (3) reliability.

***Accuracy and Precision***. None of the instruments described above are inherently more accurate than any of the others. Keeping the instrument in good working condition is probably the most important factor in maintaining high accuracy. It is easier to judge the working condition of vertical-axis meters than any other kind because they can be spin-tested and electrical contacts can be easily checked. If you choose another type of meter for most of your measurements, you should have at least one vertical-axis meter (kept in good condition) to calibrate other meters.

For meters in good working condition, the factor that most affects accuracy and precision is the ability to obtain a time-averaged measurement. Buchanan and Somers (1969) remark that the standard interval for velocity measurements for the calculation of discharge is between 40 and 70 seconds, although they acknowledge that 20-30 second intervals are sometimes acceptable. A primary advantage of mechanical current meters is that they are designed specifically to obtain a time-averaged velocity. Many electronic current meters were not designed for time-averaging, and are notoriously imprecise.

***Cost.*** When considering the cost of a current meter, you should also consider its adaptability and the conditions in which it will be used. The term "inexpensive current meter" is probably an oxymoron, but some are more moderately-priced than others. A modestly-priced meter, such as the Swoffer™, may be ideal for studies confined to wadeable streams. However, if you need the option to switch between wading and boat-mounted suspension systems, the more expensive, but more versatile Price-AA meter might be a better bargain. Electronic current meters are more expensive than mechanical meters, but may be worth the investment if you are working in streams with heavy vegetation. As a general rule, however, most electronic meters are not worth the extra cost. For the price of a single EM meter, without the wading rod, you can buy two full vertical-axis meter outfits, including top-set wading rod and digitizer. If you have enough operators, two Price-AA meters will always be faster than a single EM meter (unless you are willing to risk instantaneous measurements with the latter).

***Reliability***. Reliability of a current meter is related to its ruggedness, ease of troubleshooting and repair, and necessary maintenance. Considering all of these factors, we suggest that vertical-axis meters are generally the most reliable all-around. Although they are not indestructible, they are generally constructed for heavy-duty use. More importantly, they are easy to troubleshoot and fix in the field. Vertical-axis meters are unique in that their working condition can be ascertained any time, any place, with no special equipment or facilities. The only way to determine the working condition of other types of meters is by calibrating them against a good vertical-axis meter (or sending them in to the factory). With the exception of digitizers or other electronic instrumentation, it is possible to carry along enough spare parts to build a mechanical current meter from scratch. Even if the digitizer breaks, you can still use a vertical-axis meter. The same cannot be said for electronic meters because if they break, they have to be sent back to the factory for repair. Regardless of the type of meter you choose, however, we recommend maintaining at least a 33% - 50% back-up: that is, for every two or three meters you have running, you should have at least one in reserve.

### *Effects of Time-averaging Intervals on Velocity Measurements*

Because so many velocity measurements are made for PHABSIM, the difference between a 20-second and a 40-second averaging interval is a serious matter. By spending half as much time at each vertical, it is possible to cover twice as many verticals, resulting in much better spatial coverage of the stream. Several years ago, we conducted an experiment to determine whether it was possible to reduce the averaging interval to 20 seconds without seriously undermining the accuracy of the data.

At about 60 randomly selected locations in the Cache la Poudre River, we made three consecutive measurements of the velocity without moving the wading rod. The first measurement was made using a 40-second averaging interval, the second with a 20-second interval, and the third measurement with another 40-second interval. All three estimates were averaged to obtain a 100-second average velocity for each measurement vertical. The 100-second average was assumed to be the true velocity for the vertical. The error of an individual measurement was calculated as the difference between the "true" velocity and those measured over 40- and 20-second intervals, respectively.

The results of this experiment indicated that: (1) magnitudes of errors associated with 20- and 40-second averaging intervals were about the same for velocities greater than 1.5 fps, (2) 20-second intervals produced larger errors for velocities less than about 1.0 fps, and (3) errors at low velocities appeared to be biased using a 20-second interval (Fig. 61). On the basis of this experiment, an averaging interval of 20-seconds is probably acceptable when the mean column velocity exceeds 1.5 fps, but a 40-second interval should be used when the mean column velocity is less than 1.5 fps.

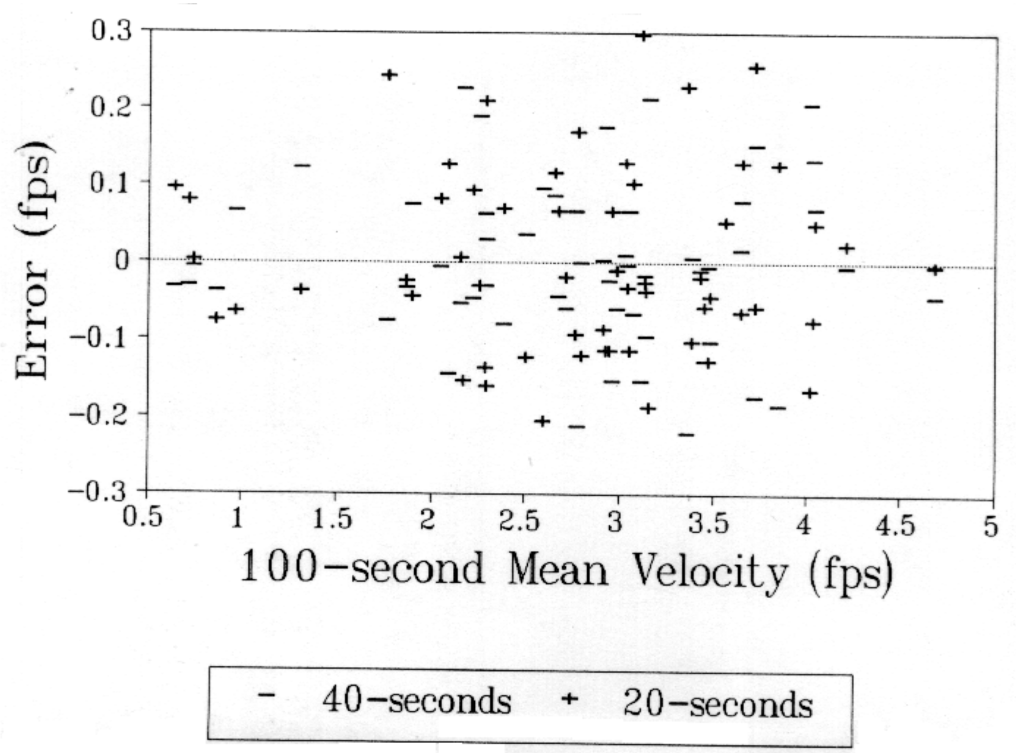



Figure 61. Comparison of velocity measurement errors for time-averaging intervals of 100 seconds, 40 seconds, and 20 seconds.

***Don't Leave Home Without Them (Spare Parts, That Is)***

It is possible to carry along enough spare parts to completely rebuild a wading rod, cable suspension system, or current meter. However, some parts tend to break more often than others. The following is a list of spare parts that you should carry with you every time you go out to the field.

- For top-set wading rods:
  - base (1)
  - spool of 14-16 gauge insulated wire and solderless terminals (for rebuilding the connection between current meter and meter positioning rod)
  - bolt connecting the sliding support and meter positioning rod (2)
  - insulated bushings between sliding support and meter positioning rod (4)
  - plug connector, male (1)
  - microscopic eye terminals and set-screws for plug connector (6 of each)
- For U.S.G.S. sounding reels:
  - cable-to-hanger bar connector (usually pressed-sleeve type)
  - clevis pins and cotter keys (4)
  - hanger bar (1)
  - hanger bar pins (2)

screw holding handle to reel (2)
wing nuts for attaching reel to boom (4)

- For vertical axis current meters:
  pivots with adjusting nut and set-screw (2)
  bucket wheel (1)
  pivot set-screw (2)
  set-screws to attach meter to rod (6)
  catwhisker terminals and wires, single count (2)
  cap for contact chamber (1)
- For horizontal axis current meters:
  propellers (2)
  propeller retaining nut (2).
- For current meter digitizers:
  female telephone connectors with microscopic eye terminals and set screws (2 sets),
  spare batteries (each unit takes 5 AA batteries)
  rod-to-digitizer pigtails (2)
- Tools you should carry along:
  flat-head screwdrivers (1/8 in., 1/4 in., 1/2 in)
  Phillips-head screwdrivers (1/8 in., 1/4 in)
  adjustable-end wrenches (6 in., 10 in., 12 in)
  diagonal wire cutters (a.k.a. side cutters, dikes)
  pliers (regular and needle-nose)
  vice grips
  wire stripper/crimper
  open-end wrench set (including an extra 7/16 in. wrench)
  electrical tape
  light machine oil

Additional tools may be needed to repair other field equipment, but this will generally suffice for most hydrographic equipment.

## DISCHARGE CALCULATIONS

For most of the transects in a study site, the primary purpose of width, depth, and velocity measurements is for calibration of the velocity-prediction models within PHABSIM. However, it will be necessary to compute the discharge at one or more transects for one of the following reasons: (1) to calibrate the relationship between discharge and water surface elevations for the transect, (2) to calibrate a stage-discharge relationship for a semi-permanent gage at the site, (3) to evaluate inter-transect data errors, or (4) to define the calibration discharge for the velocity measurements at a transect.

The mean-section method and the mid-section method are two options, similar to the distinctions between HABTAE and HABTAV, for calculating discharge from current meter measurements. Both of these methods are based on the formula:

$$Q = \sum (a_i v_i)$$

where Q = the discharge,
$a_i$ = the cross-sectional area of an individual partial section (equivalent to a cell in PHABSIM terminology), and
$v_i$ = the average velocity normal to the partial area.

The differences in calculation procedures originate in how the partial sections and average hydraulic parameters are treated.

The ***mean-section method***, illustrated in Figure 62, treats the partial section as the area between two measurement verticals (similar to the cell treatment in HABTAE). The width of the partial section is calculated as the distance between the verticals on either side. The average depth of the partial section is calculated as the arithmetic average of the depths of the verticals at the edges. The partial area, $a_i$, is calculated as:

$$a_i = w_i \frac{(d_i + d_{i+1})}{2}$$

where $a_i$ = the cross-sectional area of an individual partial section
$w_i$ = the width of the partial section between vertical i and i+1,
$d_i$ = the depth at vertical i,
$d_{i+1}$ = the depth at vertical i+1,
$v_i$ = the velocity at vertical i, and
$v_{i+1}$ = the velocity at vertical i+1
and the average velocity, normal to the partial area, is calculated as:

$$\bar{v} = \frac{(v_i + v_{i+1})}{2}$$

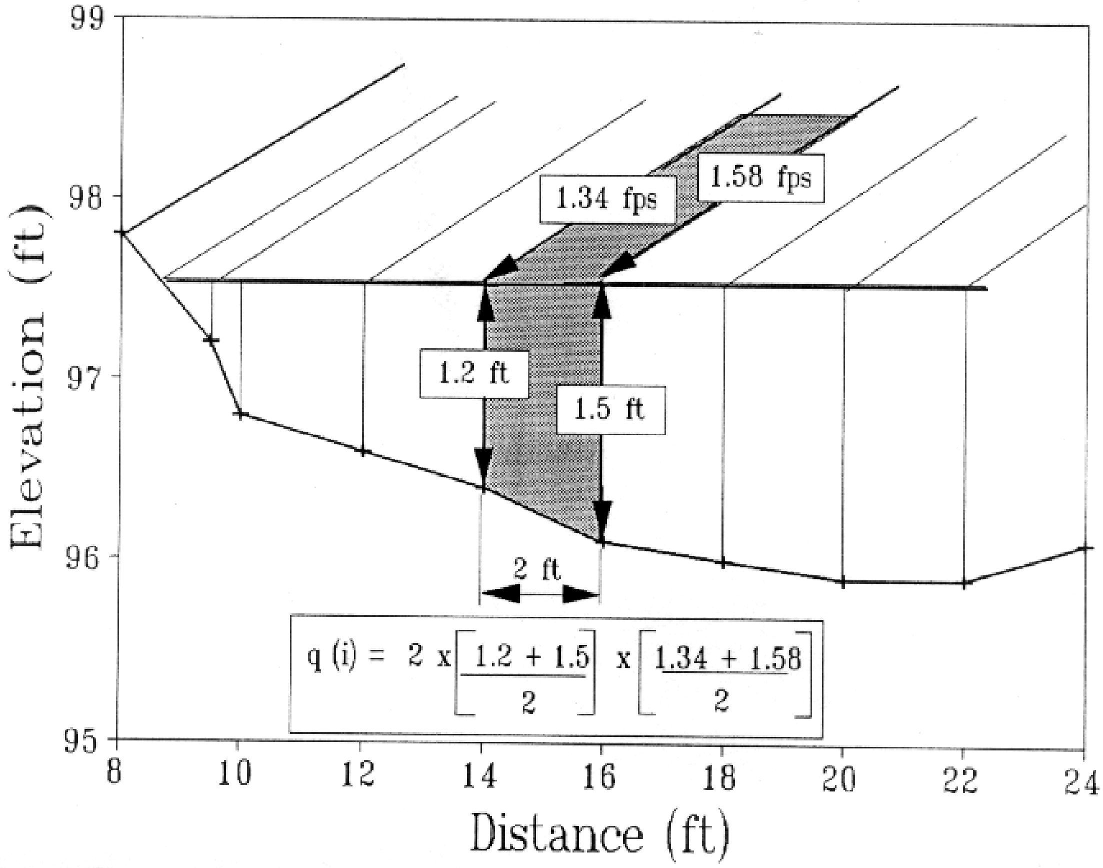



Figure 62. Definition of partial section and calculation of partial discharge using the mean-section method.

The ***mid-section method***, illustrated in Figure 63 treats the vertical as the mid-point of a partial section which extends laterally half the distance from the preceding vertical to half the distance to the next (as in HABTAV). In this formulation, the width of the partial section must be calculated, but the depth and velocity at the vertical are assumed to represent averages for the partial section. The partial discharge for the section at location *i* is calculated as:

$$q_i = v_i d_i \frac{(b_{i+1} - b_{i-1})}{2}$$

where $q_i$ = the partial discharge,

$v_i$ = the mean column velocity measured at vertical i,

$d_i$ = the water column depth measured at vertical i,

$b_{(i-1)}$ = the distance from vertical i to the previous vertical, and

$b_{(i+1)}$ = the distance from vertical i forward to the next vertical.

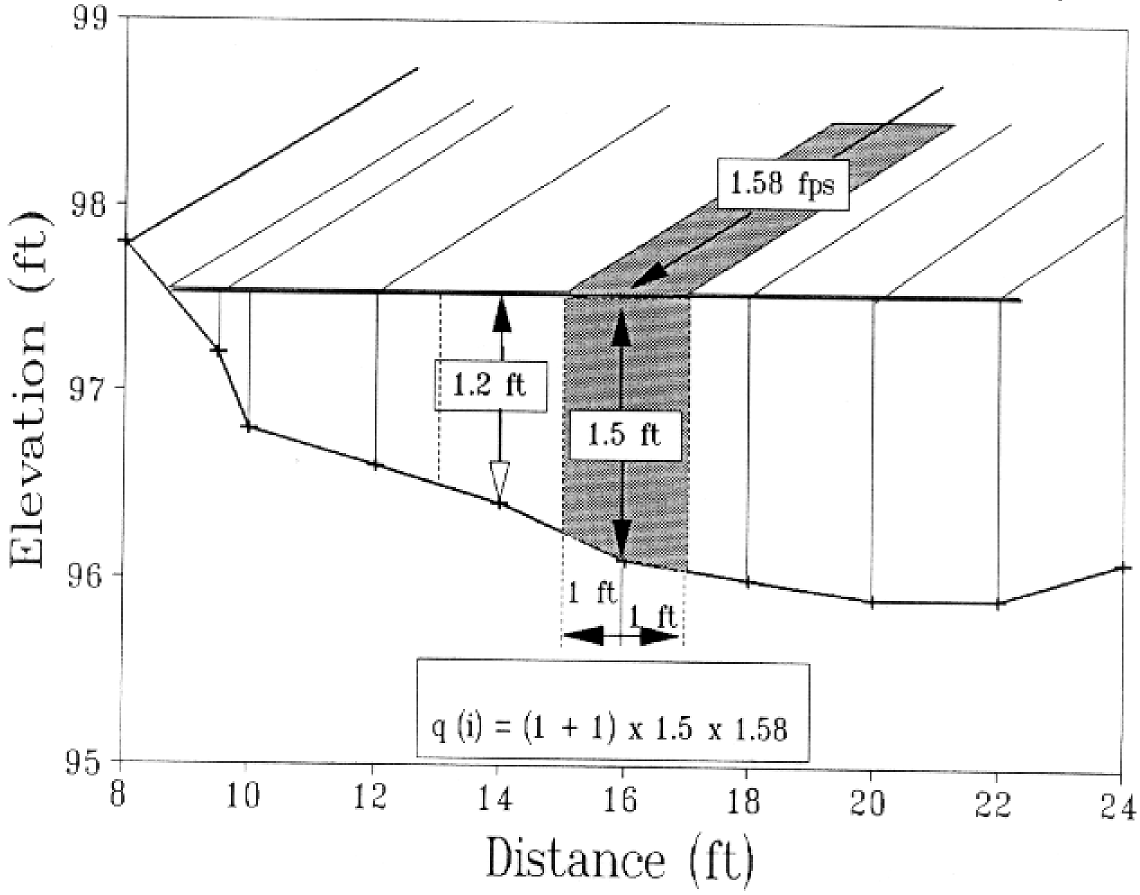



Figure 63. Definition of partial section and calculation of partial discharge using the mid-section method.

The summation of the discharges for all of the partial sections is the total discharge for the stream. Either the mean-section or mid-section method can be used to calculate the discharge. However, Young (1950) concluded that the mid-section method was simpler to compute and slightly more accurate than the mean-section method. The measurement notes for stream gaging data should continue on page facing the stream profile notes, aligned such that the first calculated width (using the mid-section method) is recorded for the first vertical occurring beyond the edge of water (Fig. 64). [Note: A thin sliver of water at either bank is not counted using the mid-section method. Despite this omission, the mid-section method is considered more accurate than the mean-section method.]

Rock Creek, Seg 1, Shallow Pool # 2, XSEC 3
7/15/92 1020 h BS to BM1 = 4.33
BM1 = 100, 00, HI = 104.33

| STA | FS | Elev. | Cov | Sub | Emb. |
|---|---|---|---|---|---|
| 0 | 3.9 | 100.4 | NC | Silt | 1.0 |
| 2 | 4.1 | 100.2 | NC | Silt | 1.0 |
| 4 | 4..4 | 99.9 | NC | Silt | 1.0 |
| 6 | 4.5 | 99.8 | NC | Silt | 1.0 |
| 7.9 | 4.6 | 99.7 | NC | Silt | 1.0 |
| 8 | 6.5 | 97.8 | UCB | MG | .5 |
| 9.5 (w e) | 7.1 | 97.2 | UCB | MG | .25 |
| 10 | 7.5 | 96.8 | LOGS | Sand | 1.0 |
| 12 | 7.7 | 96.6 | LOGS | Sand | 1.0 |
| 14 | 7.9 | 96.4 | LOGS | Sand | 1.0 |
| 16 | 8.2 | 96.1 | BLDR | MG | .25 |
| 18 | 8.3 | 96.0 | NC | MG | .25 |
| 20 | 8.4 | 95.9 | NC | SC | 0 |
| 22 | 8.4 | 95.9 | COBL | SC | 0 |
| 24 | 8.2 | 96.1 | BLDR | SC | 0 |
| 26 | 8.0 | 96.3 | NC | | |
| 30 | 7.9 | | | | |
| 32 | | | | | |

Rock Cr. Seg 1., SP #2, XSEC 3 (cont.)
GH start = 1.42 Time start 0920
GH end = 1.44 Time end 1000
BS to BM1 = 3.89 HI = 103.89

| FS(L) | FS(M) | FS(R) | AVG | WSL |
|---|---|---|---|---|
| 6.32 | 6.34 | 6.35 | 6.34 | 97.55 |

| Width | Depth | Vel .6 | Vel .2 | Vel .8 | Avg | qi |
|---|---|---|---|---|---|---|
| 1.25 | 0.8 | 0.45 | | | | 0.45 |
| 2 | 1.0 | 0.97 | | | | 1.94 |
| 2 | 1.2 | 1.34 | | | | 3.22 |
| 2 | 1.5 | 1.58 | | | | 4.74 |
| 2 | 1.6 | 1.89 | | | | 6.05 |
| 2 | 1.7 | 2.04 | | | | 6.94 |
| 2 | 1.7 | 2.15 | | | | 7.31 |
| 2 | 1.5 | 2.39 | | | | 7.17 |
| 2 | 1.3 | 2.23 | | | | 5.80 |
| 2 | 1.2 | 2.42 | | | | 5.81 |

Figure 64. Addition of hydrographic data to sample cross-sectional data from Figure 41. Note: (1) discharge is calculated by the on mid-section method, (2) gage heights and times were recorded for the start and end of the measurements, (3) water surface elevations were measured, and (4) profile and hydrographic data are recorded on facing pages, so all of the data for a transect are visible without flipping pages back and forth.

## Water Surface Elevations and Stage Measurements

***Stage*** and ***water surface elevation*** are often used interchangeably to define the water level in the river. Although related, the two expressions of water level can be a source of confusion, no doubt aided by a lax usage of terms. **Water surface elevations** are related to the same reference datum that was established when the site was set up. The stage refers to a reading on a staff gage, and is not directly related to the elevations of benchmarks. Water surface elevations are consistent with the ground elevations determined during the profile measurements. The stage is not. Relations between discharge and water surface elevations are used to calibrate hydraulic simulation models, enabling the prediction of water surface elevations at unmeasured stream flows. Relationships between discharge and stage are used to calibrate stream gages, enabling instantaneous determinations of discharge from a gage reading.

### ***Measuring Water Surface Elevations***

For most applications of PHABSIM, we recommend the measurement of water surface elevations at a minimum of three widely separated stream flows (i.e., an order of magnitude difference between the low flow and the high flow measurements). In hydraulically complex situations, such as divided channels, it may be advisable to measure six or seven water surface elevations. Regardless of the number of times the water surface elevation is measured, one of them (often a mid-range flow) must correspond to the discharge at which the calibration velocities were measured. In Figure 64, the water surface elevation data are recorded as three foresights (left, middle, and right) across the channel. These are averaged to determine the mean water surface elevation for cross-section 3. **[Note: The HI is different on page 2 of the notes, compared to page 1. This is because the cross-section profile and hydrographic data were collected on different days. This is just one reason why it is important to write down details such as the date, time, and HI on every page of your notes.]**

Theoretically, there is nothing especially complicated or difficult about measuring the water surface elevation. The level is set up and a backsight is taken to a known elevation to determine the instrument height. The rod operator then lowers the level rod until it just touches the water surface (Fig. 65). When the rod first forms a meniscus on the water surface, the rod operator verbally signals the level operator (usually by saying "touch"), who reads several foresights for the location. It is best to take three or four separate readings at each location (left, middle, right) and record the mode.

Some rod operators prefer to lower the rod slowly until it just touches the water, then lift it quickly as the "touch" command is communicated to the level operator. The level operator records the largest reading as the foresight for each touch. We have found that holding the rod as still as possible, in contact with the water surface, and indicating to the level operator when the reading should be made works best (i.e., "good, good, good, oops, no good, no good, good, good"). Either way will work, but the latter is easier on the level operator.

From a practical standpoint, operating the rod for water surface elevations is one of the more difficult skills to be learned for PHABSIM data collection. The rod operator must be consistent in the way that he or she indicates the contact between rod and water surface. Additionally, the rod must be kept plumb during the measurement. Because the rod operator must concentrate on the meniscus at the water surface, tricks for plumbing the rod, such as rocking it or using a rod level, will not work very well. There are, however, several things you

can do to make this measurement easier and more accurate:
(1) Hold the rod at about arm's length, especially in fast water. The water surface will be affected by your presence in the stream. If you hold the rod close to your body, you may not get an accurate reading.
(2) Try to take the measurements in relatively shallow water. If you are in 3-4 ft of water, you will be holding the rod at the bottom 1-2 ft. This gives you terrible leverage and makes the rod very hard to control.
(3) Extend the rod to no more than three sections if possible. The more rod you have in the air, the harder it is to keep it plumb. One of the nice features of using a total station is that the prism is mounted on a 3-ft range pole, and is extremely easy to control.
(4) Avoid measuring water surface elevations when the wind is blowing (especially if you have very much rod in the air). The bottom of the rod might be steady, but the part the level operator is looking at may be moving furiously.
(5) If using a fiberglass level rod, hold the joint between the first and second sections lightly between thumb and index finger of your upper support hand. Rock the rod gently until you feel the top of the rod "flop" past plumb, and then "flop" back. When the rod is plumb, it will feel like it is balanced between the two points.

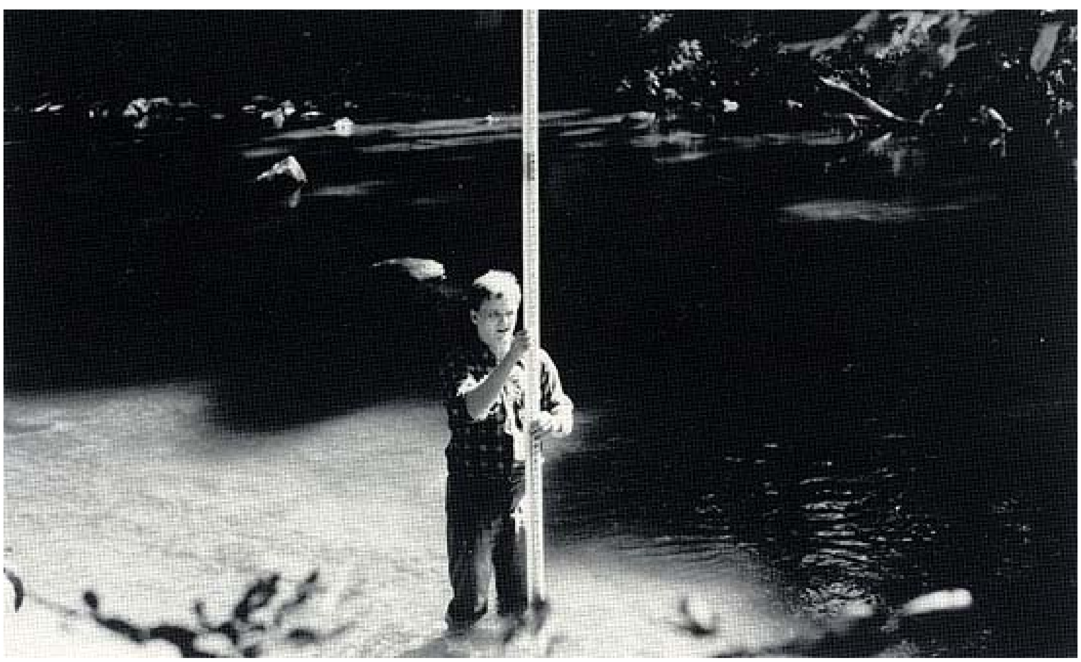


Figure 65. Water surface elevations being measured at a transect. The rod is held plumb and just in contact with the water. When a meniscus forms, the rod operator notifies the level operator to take the reading.

***Stage Measurements***

***Stage*** refers to a reading on a stream gage, and several types of gages are commonly used in an application of the IFIM. The amount of information that can be extracted from a stage measurement depends largely on the type of gage it came from. **Temporary** gages are used during PHABSIM data collection to document changes in discharge. Usually, it is not possible to determine the discharge from a temporary gage reading, because the relation between stage and discharge is rarely determined for a temporary gage (the gages are not calibrated). **Permanent** or **semi-permanent** stream gages are used to obtain quick and accurate estimates of discharge for one of more PHABSIM sites. A well-established relationship between stage and discharge is determined to calibrate these types of gages.

***Temporary Gages***

Recording the stage at the beginning and the end of hydrographic data collection (e.g., Fig. 64) is the only reliable way to determine whether transect-to-transect differences in discharge were caused by stream gaging error or unsteady flow. These stage measurements could be made from a permanent or semi-permanent gage, but these gages are not often located conveniently for continuous monitoring. The sole purpose of a temporary gages is to monitor changes in discharge while hydrographic measurements are being made. Temporary gages are generally rudimentary (e.g., a ruler tied to a piece of rebar), they are not calibrated, but they are convenient. The most complicated aspect of constructing a temporary staff gage is to mount the ruler so that the big numbers are at the top. For rulers marked in inches on one side and centimeters on the other side, all members of the field crew should agree which side to read. These gages should be placed in a convenient location out of high-traffic areas, and should be read at the beginning and end of each set of transect measurements. As the crew moves to new transects, it is permissible to move the gage and re-install it at a new location with the same gage reading it had at the previous location (provided it is done quickly enough to minimize the chance that the discharge will change in the interim).

***Semi-permanent Gages***

Semi-permanent stream gages are often necessary in an IFIM study, especially for hydrograph synthesis on ungaged streams. In other cases, however, the installation of a semi-permanent gage may be more a matter of convenience than anything else. The purpose of a semi-permanent stream gage is to permit an instantaneous and accurate determination of the discharge. However, semi-permanent gages are not normally equipped with any type of continuous recording devices, which are a hallmark of permanent gages.

Although a semi-permanent gage is not as secure, well-rated or instrumented as a permanent U.S.G.S. gaging station, it should incorporate some of the same features as a permanent gage. The gage should be accessible, easy to read, well-calibrated, and difficult to vandalize.

One of the first decisions to be made about a semi-permanent stream gage is where to put it. Some investigators try to make their gages fool-proof by hiding them in some obscure, nearly inaccessible area along the stream. This approach may work, but it is easy to forget exactly where the gages are and it may take hours to find them. [Note-A Precision GPS with real-time differential correction in navigation mode will help solve this problem.] An alternative approach is to locate gages where access is easy, but where they are out of the way of major traffic patterns. For example, bridge crossings or other places where the stream comes close to a road are natural places to establish a semi-permanent gage.

In order to make the gage easy to read, it will be necessary to control surges that cause the water level to oscillate up and down along the face of the staff gage. At permanent gaging stations, surging is controlled through the use of a **stilling well**, essentially a casing (galvanized culverts and concrete sewer pipes are commonly used), sunk in a hole next to the river. Surging at a staff gage can be controlled by locating the gage in a quiet backwater, or by enclosing it in a length of 6-8 in. slotted or perforated clear plastic pipe.

The unfortunate truth about semi-permanent gages is that they are extremely vulnerable to theft and vandalism. Vandalism can be inhibited by immobilizing the gage to the extent possible (i.e., bolting the gage to a bridge piling or embedding it in concrete). However, it is probably not feasible to eliminate the possibility of vandalism entirely. Therefore, you should take steps that will enable you to re-establish the gage if it is disturbed or destroyed.

You can make your gage recoverable simply by establishing a known elevation for the original gage when it is installed. This is done by referencing the top of the gage to a permanent benchmark, using the differential leveling techniques described earlier. If the elevation at the top of the gage is recoverable, all of the gage readings from the new gage can be matched up exactly with those from the old gage.

### *Rating the Gage*

A gage is rated by measuring the discharge and the staff gage reading at several widely-separated discharges. These paired data are then used to develop an empirical relation, called a ***rating curve***, between the gage readings and the discharge. A rating curve should be constructed from no fewer than six stage-discharge pairs, spanning at least an order of magnitude of discharges.

The ideal location for making discharge measurements is in a uniform, rectangular channel with no boulders, tree snags, or other obstructions that will affect flow patterns. Please note that the semi-permanent gage, and its attendant discharge-measurement transect, do not need to be located at a PHABSIM site. Furthermore, the place where discharge is measured does not have to be at precisely the same location as the temporary gage. The two locations should be close enough to one another, however, that you can read the gage within a few minutes of making the discharge measurement.

The reason for developing a rating curve is so that an investigator can immediately determine the discharge from any reading on the gage. There is a natural tendency for rating curves to be curvilinear when plotted on arithmetic graph paper. As long as you are interpolating between the points, and not striving for super accuracy, there is nothing wrong with simply reading the discharge directly off an arithmetically plotted rating curve. However, you will probably find it more convenient to linearize the rating curve because:

(1) linearization facilitates extrapolation to discharges that are higher or lower than the measured extremes;

(2) the discharge can be determined from a regression equation, rather than estimated graphically; and

(3) the accuracy of the rating curve can be evaluated more readily.

The most straightforward method to linearize a rating curve is logarithmic transformation of the stage-discharge pairs. A simple linear regression is performed between the logarithms of the stage and the logarithms of the discharge. Either base 10 or natural logarithms can be used, but be sure to specify what kind you are using in the regression equation. To find the discharge for any particular gage reading, simply find the logarithm of the stage, solve the regression equation for the logarithm of the discharge, and take its anti-log.

***Parts is Parts***

After several years of PHABSIM work, you will inevitably end up with an assortment of broken tapes and unreadable sections of level rod. Rather than discarding this equipment, recycle it by constructing staff gages. Sections of broken measuring tape, for example, can be epoxied onto a 6-ft steel fence post and coated with shellac (big numbers at the top, of course), to make an inexpensive, virtually indestructible staff gage. One advantage of measuring tapes is that you can make extremely tall staff gages.

Old sections of level rods also make good staff gages. To convert a section of a level rod into a staff gage:

(1) Cut off the bottom part of the section just above the spring-loaded button that locks the section in place when extended.

(2) Measure the inside diameter of the section (if round) and obtain a 6-8 ft piece of galvanized pipe that will fit snugly inside it. For oblong-shaped rod sections, obtain two 6-8 ft pieces of 1-in (outside

diameter) galvanized pipe.

(3) Drive the pipe(s) into the streambed at the desired location of the gage, and slip the rod section over the top of the pipes until it contacts the streambed.

(4) Fill the pipe(s) and rod section with dry-mixed concrete, and add a little water. Shake or vibrate gently to settle the concrete. When the concrete sets up, you will have a staff gage that is nearly bullet-proof.

## SUMMARY

- Hydrographic data are used to develop relationships between stage and discharge or between water surface elevation and discharge, and to calibrate velocity predicting programs within PHABSIM.
- Widths are most commonly measured using tapes, taglines, or marked cables. Measuring tapes are preferred for streams less than about 200 ft across because of their high accuracy and convenient handling capabilities. Taglines and marked cables are generally stronger and more versatile than tapes, but are more difficult to read. Taglines are generally preferred for streams ranging in width from 200-300 ft. For streams over 300 ft wide, marked cables (preferably Kevlar®) are recommended.
- Depth is measured by sounding. In shallow water, the instrument of choice is the top-set wading rod. The most useful lengths of top-set rods are 4 ft and 6 ft. Where the depth exceeds about 5 ft, or where the product of depth times velocity exceeds 10, the preferred sounding equipment is the boat-mounted system developed by the U.S. Geological Survey at the Hydrologic Instrumentation Facility.
- Velocity is most commonly measured with one of four types of current meters: vertical axis, horizontal axis, electromagnetic, or acoustic Doppler meters. For routine PHABSIM work, vertical-axis meters (especially with current meter digitizers) provide the optimum balance of accuracy, reliability, and cost, in comparison with other types of meters. Electromagnetic and acoustic Doppler meters are especially advantageous when there is an abundance of aquatic vegetation that will clog a mechanical meter, or when measurements very near the streambed are needed. Some electronic current meters have very poor time-averaging capabilities, however, and are decidedly less precise than mechanical meters.
- The U.S. Geological Survey recommends a time-averaging interval of 40-70 seconds for velocity measurements associated with discharge calculations. For PHABSIM, however, an averaging interval of 20 seconds is acceptable if the velocity is greater than 1.5 fps. A 40-second interval is still recommended for velocities less than 1.5 fps.
- Discharge is calculated according to the general formula:

$$Q = \sum (a_i v_i)$$

where Q = the discharge in cfs,

$a_i$ = the cross-sectional area of a partial section (equivalent to a stream cell), and

$v_i$ = the average velocity normal to the partial section.

Discharge can be calculated using either the mean-section or mid-section approach, but the mid-section method is preferred due to its simplicity and slightly higher accuracy.

- Water surface elevations should be measured at a minimum of three discharges, the lowest and highest of which are separated by an order of magnitude. One set of water surface elevations must be measured at the same discharge at which calibration velocities are measured (usually a mid-range discharge). Water surface elevations are measured to the nearest 0.01 ft, using differential leveling techniques.
- Stage refers to a discharge reading on a stream gage, and is often confused with water surface elevations, which are referenced to the same datum as the vertical elevation control for a study site. Temporary gages are rudimentary, portable, unrated, and used exclusively to monitor changes in discharge while hydrographic measurements are being made. Semi-permanent gages are installed to enable an investigator to determine the discharge accurately and instantaneously, simply by reading the gage. Semi-permanent gages must be constructed to withstand theft and vandalism, and must be rated.
- Field notes for hydrographic data should be recorded on facing pages to data on the channel profile, and aligned with the horizontal stationing used for the profile survey. Necessary information to be recorded with hydrographic data include:
  (1) continuation information (site #, transect #, date),
  (2) time and gage height at the beginning of transect measurements,
  (3) time and gage height at the end of transect measurements,
  (4) water surface elevations at velocity calibration discharge,
  (5) water surface elevations and discharges at other (high or low) flows,
  (6) width of partial sections, and
  (7) depth and mean column velocity at each vertical deep enough to measure.

Additional hydrographic information that may be recorded includes:
(1) nose velocities at specified distances above streambed,
(2) partial and total calculated discharges, and
(3) an evaluation of the quality of the cross-section for discharge measurement.

# SCHEDULES AND BUDGETS

Data for PHABSIM analysis is one of the most expensive items in the budget for an IFIM study. A tension exists between collecting sufficient data to accurately describe a study area, finishing the study in a timely manner, and keeping the costs down. It is impossible to simultaneously optimize all three of these factors, although it is possible to strike a reasonable balance among detail, time, and cost. To some extent, this balancing act should be reflected in the scope of work or in the study plan. However, given a relatively fixed budget and schedule of deliverables, it is incumbent upon every field crew to work as efficiently as possible.

A PHABSIM analysis can be conducted with remarkably little data, provided that no one is expecting remarkably high accuracy. Figure 66 illustrates a hierarchy of the types of data that could be collected in a PHABSIM analysis, and the approximate trade-off between increased accuracy and increased cost.

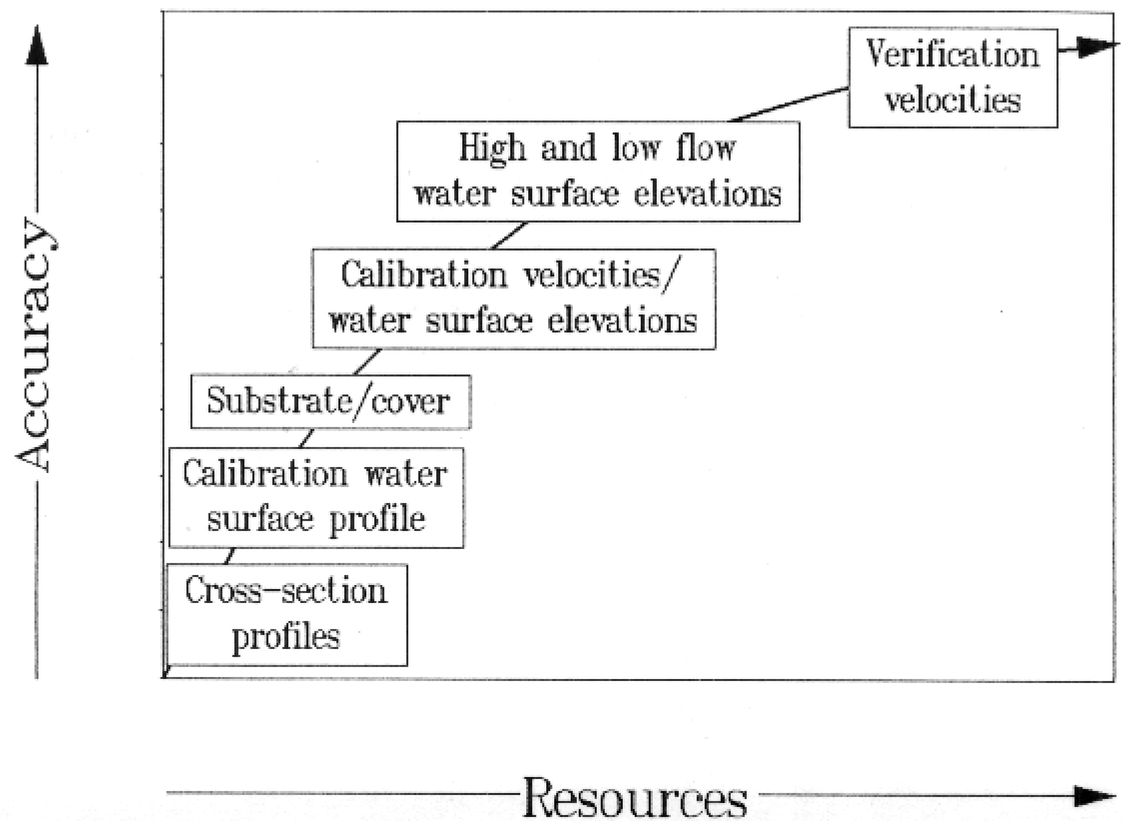



Figure 66. Trade-offs between level of detail and level of effort in data collection for PHABSIM.

If there is such a thing as a standard PHABSIM data set, it would consist of:

(1) a planimetric map of the study site, including distances between transects and lengths of cells,

(2) level loop notes detailing the elevations of all benchmarks in the site,
(3) channel geometry data (x and y coordinate pairs) for each transect,
(4) substrate and cover descriptors or codes for each transect,
(5) one set of calibration velocities, a good estimate of the discharge, and an accompanying water surface elevation for each transect[1], and
(6) at least two additional pairs of water surface elevation and discharge measurements for each transect. The low flow and high flow should be separated by at least one order of magnitude.

## SCHEDULING FIELD WORK

It should be apparent by now that it will not be possible to obtain all the data required at a site in a single trip, unless you have total control over the discharge from day to day. Even with such control, it is unlikely that you can collect all the data in a single day. To help you tailor your work schedule to the environment in which you are working, the following guidelines may be helpful in setting up a schedule.

In alluvial channels, it is a good idea to collect your data either on the rising limb of the hydrograph or the falling limb. Generally, the falling limb lasts longer so you will not be as pressed for time. You should avoid straddling the peak of the hydrograph with your measurements because the hydraulic control may be altered during flood flows. In northern climates, ice-breakup may have the same affect. If the hydraulic control is altered, the relationship between water surface elevation and discharge will also change, and calibration will be difficult (one of those "pay me now or pay me later" situations). In bedrock-controlled or ***colluvial*** (streambed made up of large rock that has fallen from the valley walls or terraces) streams, you do not need to worry about the controls changing during high runoff or ice break-up unless the event causes mass-wasting into the stream.

Transferability testing of habitat suitability criteria depends on the seasons for which criteria are available. For most criteria sets, data are collected through the summer and the spawning season. To the extent possible, test criteria at an intermediate flow level. At very high or very low discharges, the microhabitats available to the fish are the most restricted so you may not get a fair test of the criteria.

Mesohabitat typing and inventories, cell and transect placement, cross-section profiles, and cover/substrate descriptions should be conducted at relatively low discharges. The structural characteristics of the stream are much less evident at high flows, and your chances of missing something important will increase dramatically.

Horizontal surveys and level loops are easier to complete when trees and brush have lost their foliage. Bushwhacking reaches a maximum when surveys are completed during summer. (If you are going to survey in the fall, however, avoid red, orange, or yellow flagging tape or you will lose most of your transects and cell boundaries). We have found that there is slightly less bushwhacking with a total station than with a level. However, the difference between fall surveying and summer surveying is like night and day. Calibration velocities should be measured at a relatively high discharge, so that a large proportion of in-channel cells have water flowing in them. This does not mean that you have to try to measure velocities during floods. However, the discharge should be high enough so that most of the cells within the active channel have measurable velocities. This will increase the quality of your calibration, and will decrease the amount of time you or someone else has to calibrate manually (another "pay me now or pay me later" situation).

At least two water surface elevation/discharge pairs should be taken, in addition to the data collected in association with the calibration velocities. One water surface elevation pair should be measured at low flow and the other at high flow. One of the most consistent mistakes made in PHABSIM data collection is not getting enough separation between these two flows. The hydraulic calibrations and simulations are much easier and much better if the low flow and the high flow water surface elevations are separated by at least an order of magnitude in discharge. Although the models can still be calibrated with less separation in calibration discharges, the reliance on "smoke and mirrors" techniques becomes more necessary (Pay Me Now Or Pay Me Later).

In divided-channel sites, the discharge in each of the side channels at several (3-4) widely separated discharges should be measured. By knowing the relation between total discharge and the flow in the side channels, each side channel can be calibrated and simulated independently. This simplifies the calibration, increases your flexibility in the field (e.g., you can use different numbers of transects in different side channels, depending on microhabitat complexity), and improves accuracy. If the side channels will be affected by variable backwaters, try to measure a few water surface elevations at very low flows, when the side channel is not flowing, and several more at higher flows, when it is flowing. If the island separating two or more side channels will be inundated at high flows, try to get at least one water surface elevation when it is inundated.

Although PHABSIM field work is usually conducted during summer, the guidelines presented above suggest a slightly different approach to scheduling, particularly in alluvial streams. Mesohabitat typing and inventory activities can be conducted in early spring, before runoff or in early- to mid-summer as soon as the water clears up enough to distinguish mesohabitat types. Spring spawning activities may start in March or April, so transferability testing of appropriate habitat suitability criteria should also be initiated at this time. It is probably safe to lay out PHABSIM sites prior to the runoff period, but unless you plan to complete all measurements on the rising hydrograph, measurements of channel profile and hydrographic data should be deferred until runoff begins to subside. The recessional limb of the hydrograph is a good time to measure high and mid-flow water surface elevations, as well as calibration velocities. August and September are usually ideal times for conducting surveys of the cross-section profiles, collecting substrate and cover data, and obtaining low-flow water surface elevations. Many fall-spawners will be active during October and November; a good time to test their habitat suitability criteria. Normally, there is not too much reason to be out in the stream during winter, unless you are testing habitat suitability criteria. If you do not quite finish with velocity measurements and water surface elevations, they may be completed on the rising portion of the snowmelt hydrograph, provided that the stream does not experience substantial ice scour over winter.

In colluvial or bedrock channels, try to set up your sites and conduct the cross-sectional profile surveys and substrate/cover descriptions during the low flow period of late winter or early spring. From the onset of the snowmelt runoff until it peaks, concentrate on getting several widely separated water surface elevations at all of your sites. Calibration velocities and any remaining water surface profiles can then be taken at your leisure on the falling limb of the hydrograph. Be sure to recheck your control(s), however, and be ready to collect a new set of water surface elevations if the control(s) were appreciably affected during high flows.

## ESTIMATING TIME REQUIREMENTS FOR DATA COLLECTION

One of the most important aspects of running an efficient field operation is to match crew size and equipment to the scale of the job. Jakle (1988) coined the term "Safari Factor" to those aspects of field work that reduce efficiency and add to the time it takes to complete a task. One of the premier inefficiencies in PHABSIM field work is caused by deviations from the optimum number of workers. From many years of trial and error, we estimate the ideal crew size for most PHABSIM work to be three people in wadeable streams and four when measurements are made from boats. Surveying activities can often be done with one less person, but if the site is heavily vegetated, the extra person can help maintain lines of sight. During profile and velocity measurements, one person serves as a level operator/data recorder and the other two people operate level rods or current meters.

Ideally, when boats are used in PHABSIM studies, the best crew size per boat is two people: one to run the sounding equipment and one to run the boat and record data. However, conducting this work from a boat slows the process down tremendously, because it can take as long to string the static line across the channel as it does to measure the cross-section. Consequently, two boats work best if you are working on a large river. One boat crew can keep busy stringing cables for the other crew, if you have only one complete U.S.G.S. boat-rig. Alternatively, if both boats are properly equipped, two transects can be measured simultaneously. The time-on-transect may not change too much if boats are involved, but without careful planning, the Safari Factor can increase by a factor of four or more. For every boat in the water, you must deal with three vehicles: the towing vehicle, the boat trailer, and the boat itself. Add to this the problems of trying to find a decent put-in for the boats and sufficient room to park or turn around two trucks and two boat trailers. The final insult, according to Jakle (1988) is accomplished by having key people or equipment in different vehicles. [Note: Key equipment can sometimes be something as minor as a pencil!]

Although we may have to accept the Safari Factor as a necessary evil, Jakle (1988) lists the following precautions to keep it to a minimum:

(1) divide large groups into small, more efficient crews;
(2) have separate "show and tell" trips for stakeholders and supervisors (e.g., do not mix field work with informational trips); and
(3) assemble and maintain self-contained work units.

***Consolidate Your Data!***

What makes the Safari Factor so dangerous is that individual elements usually waste only a little time and motion. Cumulatively, however, these elements can gang up on the unsuspecting study team. Death by a thousand cuts. One of the most insidious time-wasters is created when data for several sites are contained in a single field book! This activity is usually done in the name of expediency to the field crew. However, it will cause nothing but grief as you try to sort out your data and enter it into a computer input file. It may not be possible to get all of the data for a site into one field book, especially if the site is a representative reach. If this is the case, dedicate two or more field books to data for that site.

A single field book might seem too large to dedicate to the data for a single mesohabitat type. Therefore, it is tempting to crowd the data from several sites into one book. Avoid this temptation, unless you are certain that you can do it without confusing data from one site with data for another site. This means you must anticipate how much room the data for a site will take up, and dedicate that portion of the field book to the site. This sneaky little Safari Factor element has "pay me now or pay me later" written all over it.

# ESTIMATING COST REQUIREMENTS FOR DATA COLLECTION

Costs generally accrue through three avenues: salaries, travel expenses, and equipment. The first economizing measure is to minimize the Safari Factor. Never send four people when you need three. Never send three people when you need four. Try to maximize the ratio between work time and travel time. Consider staying in a motel close to the site if you are spending as much time on the road as you are in the water. [Note: We have often found housing owned by a state agencies, such as Departments of Natural Resources or Universities, that were made available to us for nearly nothing. Our most expensive state-provided housing was in West Virginia, where we were charged a rate of $10 per night. During our Huron River study, we rented a house large enough for our entire research crew (6 to 10 people) for $100 a month from the University of Michigan. Camping out may be a viable option, but consider the time you will lose each day in meal preparation, clean-up, and drying out tents. Also, remember that a lot of your equipment and probably some of your crew will not tolerate getting wet at night].

The common factor in estimating time and costs for data collection is the estimated time per transect; this is the total work-time required to collect the all of the data for a transect, including set-up and preparation of the site, but not including travel or other down-time. The amount of work-time per transect depends on the size of the river, the size of the site, how easy it is to move around in the stream, whether a boat must be used, and the density of streamside vegetation.

To estimate the amount of crew-time (3 if by foot, 4 if by boat) per transect, start with requirements for baseline stream: 50 ft wide, fully wadeable, no streamside vegetation. The total amount of time it should take a crew of three people to complete all data collection activities associated with such a baseline transect is about an hour. This includes: (1) setting up the site, (2) conducting horizontal and vertical control surveys, and (3) measuring the cross-sectional profile, cover and substrate distributions, calibration velocities, and water surface elevations. The time-on-transect for other situations can be estimated using the following formula:

Time/transect = 1 hr x SWF x MHI x UVF

where SWF = the Stream Width Factor,
MHI = a Moving Hazards Index, and
UVF = the Unobstructed View Factor.

Stream width influences time-on-transect in two ways. First, as the stream becomes wider, sites generally become longer. This means that it will take longer to lay out the site and perform the horizontal and vertical surveys. Second, the wider the stream, the longer it will take to cross. Moving back and forth across the stream eats up tremendous, frequently invisible, amounts of time. To calculate the Stream Width Factor, multiply the time-per-transect estimate for the baseline transect by 1.2 for every doubling in width above 50 ft. There is no reduction in the SWF for streams less than 50 ft wide. Other factors constant, it will take about an hour and a quarter to complete work in a stream that is 100 ft wide, nearly 2.5 hours for a stream 200 ft wide, and about 5 hours for one 400 ft wide.

The Moving Hazards Index is a descriptor of how difficult it is to move around in the stream. There are two MHI's: one for wading and one for boating. For wadeable streams, the MHI is a function of depth and velocity, and the size, irregularity, and slipperiness of the substrate. The base MHI is 1.0 if the average depth for the site, multiplied by its average velocity, results in a number less than 4.0. For every doubling of the depth-velocity product, add 0.5. To the base MHI is added a factor that describes footing and traction while wading, the wadeability factor. A sand/gravel substrate with no diatoms or other forms of slime has a wadeability factor of 0.0. Large, slippery boulders have a maximum wadeability factor of 1.0. Based on the Moving Hazards Index, it could take up to three hours per transect to finish PHABSIM measurements in a 50-ft wide stream that was deep, fast, and slippery.

As a general rule, the base MHI for boats is 2.0, because it either takes twice as long to complete measurements on a transect, or it takes twice as many boats. About the only factor that adds to the base MHI for boats is related to how many obstacles must be traversed by portaging. A Portage Factor of between 0.0 and 2.0 is added to the base MHI for the number of places in the site that are too shallow (or too turbulent) for your boat equipment and must be portaged around.

The Unobstructed View Index (also known as the Bushwacker Factor) determines how difficult site lay-out and the horizontal and vertical surveys will be. The UVI is normally a function of vegetation density along the stream. However, the sinuosity of the stream can also play a role in determining the unobstructed line of sight. If the unobstructed line of sight exceeds 300 ft, assign a UVI of 1.0. For every halving of the unobstructed line of sight, add 0.5 to the UVI score (e.g., if the average line of sight is between 37 and 75 ft, the UVI would be about 1.5 - 2.0).

The time-on-transect formula is an approximation, but it should give you a rough idea of how long it will take to do the actual work. Simply estimate the time per transect, and multiply by the number of transects. To determine the full amount of time to complete all of the data collection, I recommend multiplying the time estimate for actual work by a factor of two. This should allow for travel time, rain-outs or other weather delays, and breakdowns (equipment and otherwise).

***Equipment Costs***

Having good equipment is one of the best assurances for success using PHABSIM, and skimping on equipment one of the worst examples of false economy. We cannot stress enough the importance of keeping spare parts and redundant systems on hand. These costs are minimal, compared to the problems you may encounter if a piece of equipment breaks in the field (i.e., in the middle of Desolation Canyon, three days to the nearest bridge crossing) and you have no back-up equipment or spare parts.

The following tables list what we consider to be essential equipment for different stream settings and tasks. Tables 3-6 contain information on the number of each equipment item necessary for a standard crew of three (for wadeable streams) or four (for unwadeable streams). Equipment costs, derived from several sources, are also listed with the date of the source noted next to the cost. Some equipment is available to government agencies at a considerable discount from the Hydrologic Instrumentation Facility (U.S.G.S.). Personal equipment, such as waders or raingear, or equipment necessary for transferability testing is not listed. For suggested equipment for gathering habitat use data, see Bovee (1986).

Table 3. Standard equipment, with associated cost estimates, necessary for PHABSIM data collection procedures.

| **Standard equipment** | **Unit cost (date)** |
|---|---|
| Price-AA current meters (3)[a] | $720 (1992)[a]<br>$1,600 (1991) |
| Pygmy current meter (1)[a] | $430 (1992)[a]<br>$1,100 (1991) |
| Top-setting wading rods, 4-ft (2), 6-ft (1)[a] | $275 (1992)[a] |
| Current meter digitizer (2)[a] | $420 (1992)[a]<br>$1,200 (1991) |
| Auto-level (2) | $800 - $1,100 (1994) |
| Tripod (1) | $120 - 150 (1991) |
| Level rod, 25-ft fiberglass (3) | $170 - $200 (1991) |
| Measuring tapes, steel ny-clad, 200 ft (3) | $70 - $80 |

[a] This equipment, at the listed prices, is available to government agencies from the Hydrologic Instrumentation Facility (U.S.G.S.).

Table 4. Alternative measuring equipment, with associated cost estimates, necessary for PHABSIM data collection procedures.

| Alternative measuring equipment | Unit cost (date) |
|---|---|
| Swoffer™ current meter, w/ 3½ ft wading rod and digital readout indicator (3) | $1,650 - $2,000 (1991) |
| Electromagnetic current meter, w/o wading rod (3) | $3,000 - $3,500 (1993) |
| Total station/electronic transit, w/ prism (1) | $3,000 - $16,000 (1986) |
| Electronic distance meters (1) | $3,000 - $7,000 (1986) |
| Chains/taglines, 300 ft (3) | $100 (1991) |

Table 5. Accessories, with associated cost estimates, necessary for PHABSIM data collection procedures.

| Accessories | Unit cost (date) |
|---|---|
| Chaining pins, w/ holder (11 count) | $25 (1991) |
| Plastic surveyor's markers (3/4 in. plug, 200 count) | $45 (1991) |
| Tape clamp, cam type (2) | $30 (1991) |
| Vinyl flagging tape, day-glo pink (carton of 12) | $12 (1991) |
| Machete, 24 in., with sheath (2) | $40 - $50 |
| Bank blade, 16 in. w/ 40 in. handle and sheath | $50 - $60 |
| Hand stamp steel dies (for marking transects and benchmarks), 1/8 in. characters (2) | $10 - $35 |
| Hand sledge, 2-4 lb (2) | $10 - $20 |

Table 6. Boat-mounted hydrographic equipment (excluding boat, motor, trailer, and other boating accessories), with associated cost estimates, necessary for PHABSIM data collection procedures.

| **Boat-mounted hydrographic equipment** | **Unit cost (1992)** |
|---|---|
| HIF boat equipment unit (2)[a] | $920[a] |
| A-55 sounding reel (2)[a] | $1,000[a] |
| Cable replacement kit (1)[a] | $110[a] |
| Kevlar® cable, 400-600 ft (2)[a] | $120 - $180[a] |
| HIF cable reel, vertical axis (2)[a] | $130[a] |
| Hanger (3)[a] | $5 - $10[a] |
| Sounding weight, 30 lb (2)[a] | $210[a] |
| Hand winch (come along) (3) | $40 - $50 |
| Wire rope grips (3) | $20 |

[a] This equipment, at the listed prices, is available to government agencies from the Hydrologic Instrumentation Facility (U.S.G.S.).

# PREPARING DATA FOR ENTRY INTO PHABSIM

**Please see the PHABSIM for Windows Documentation at http://www.mesc.usgs.gov/products/pubs/15000/15000.shtml for a complete description of data entry procedures for PHABSIM for Windows. The following text is retained for compatibility with PHABSIM Ver. 2.0.**

Unfortunate but true, no computer scanner has yet been built that can read your field book and automatically create the input files needed for PHABSIM. In fact, a few steps are usually required between field book and input file because: (1) some of the data required in PHABSIM input files must be calculated from your field data before it can be entered, and (2) some judgment may be required regarding which specific data to input.

## DATA ENTRY SOFTWARE OPTIONS

Although PHABSIM data entry has come a long way since the days of key-punched computer cards, data entry is not always straightforward and logical. The original data entry software for PHABSIM was designed to write each group of data independently and then merge them together with an editor to create the input file. One program (CORDIN) wrote the untitled coordinate lines for all of the transects in the site. Then another program was used to write all of the numerical channel index codes for a single transect, which were inserted with an editor between the coordinates for transect 1 and transect 2. Another program wrote out the hydrographic data, which were inserted by editor, and so on.

In about 1985, a small BASIC program named IFG4IN was written to build an IFG4 data input file (Milhous et al. 1989). IFG4IN allows you to enter data more interactively, starting with a file of coordinate data, and adding in other data, or more transects. Most people find IFG4IN to be easier to work with than the CORDIN approach. In the future, we anticipate writing programs in spreadsheet format that should make the job of data entry even easier. However, many of the same data manipulations and decisions will be necessary, regardless of the file building procedure you use.

## USING IFG4IN

To run IFG4IN, the executable program (IFG4IN.EXE) and the batch file (RIFG4IN.BAT) that runs the program must be installed on your microcomputer. If you obtain PHABSIM from us, or from our agents, you will also obtain a user interface called RPM. RPM is a menu-driven system designed to help you through the myriad programs of PHABSIM with reduced confusion over program syntax and operating commands. RPM will present several levels of menus, for various types of data entry and programs. IFG4IN will be found under the Main Menu topic of "HYDRAULICS" and a secondary menu topic of "File Building." RPM will then direct you to a listing of software designed for constructing an IFG4 input file, including IFG4IN and CORDIN.

IFG4IN is organized hierarchically and it is possible to step forward and backward through the system as needed. When you select IFG4IN, RPM will display a dialog box, showing the name of the program, program syntax (what files are called or and in what order they are produced), and the default names of input and output files. You may change the input and output file names whenever and however you want. Pushing the F10 key runs the program. The first screen that appears will show the following options within IFG4IN:

**IFG4 DATA ENTRY AND EDITING**

**0. EXIT this program**
**1. GET an existing IFG4 data set from disk**
**2. ENTER a new data set for IFG4**
**3. SELECT new transect data**
**4. EDIT IFG4 data set**
**5. SCRUTINIZE and IFG4 data set**
**6. LIST IFG4 data set**

You must first ENTER or GET a data set. You can only GET files that have an ".IN4" extension (data sets entered for the first time are automatically saved with this extension). The data entry prompts within IFG4IN are not tremendously informative, but generally, there will be a heading at the top of the page, informing you of the type of data needed at that particular location. If you are entering coordinate data, for example, the heading at the top of the page will indicate that you are to enter either x's (distances) or y's (elevations). A series of numbers from 1 to 99 follows. The first number corresponds to the first x coordinate for a transect. Enter the distance and push the ENTER key. The distance will be stored and the cursor will move to the location for the second x or y coordinate. Continue entering distances until all are entered, then push the TAB key. This switches you to another screen where the elevations for all of the verticals are entered. When finished with both the x's and y's, push ESC to leave the editing area. Note-only the x and y data and NS data toggle back and forth like this. For all other data, you only have to deal with a single screen.

The template for data entry for PHABSIM is the input file format of the hydraulic simulation program, IFG4. When you first ENTER data, IFG4IN takes you methodically through the file format illustrated in Figure 67. However, if you do not have an answer or want to skip a particular entry, simply press the ESC button. IFG4IN will ask you if you want to continue with file building, and if you answer "yes," the program will move forward to the next type or group of data. When you "EDIT" an existing file, you can direct IFG4IN to the exact location in the file where you wish to add or modify data.

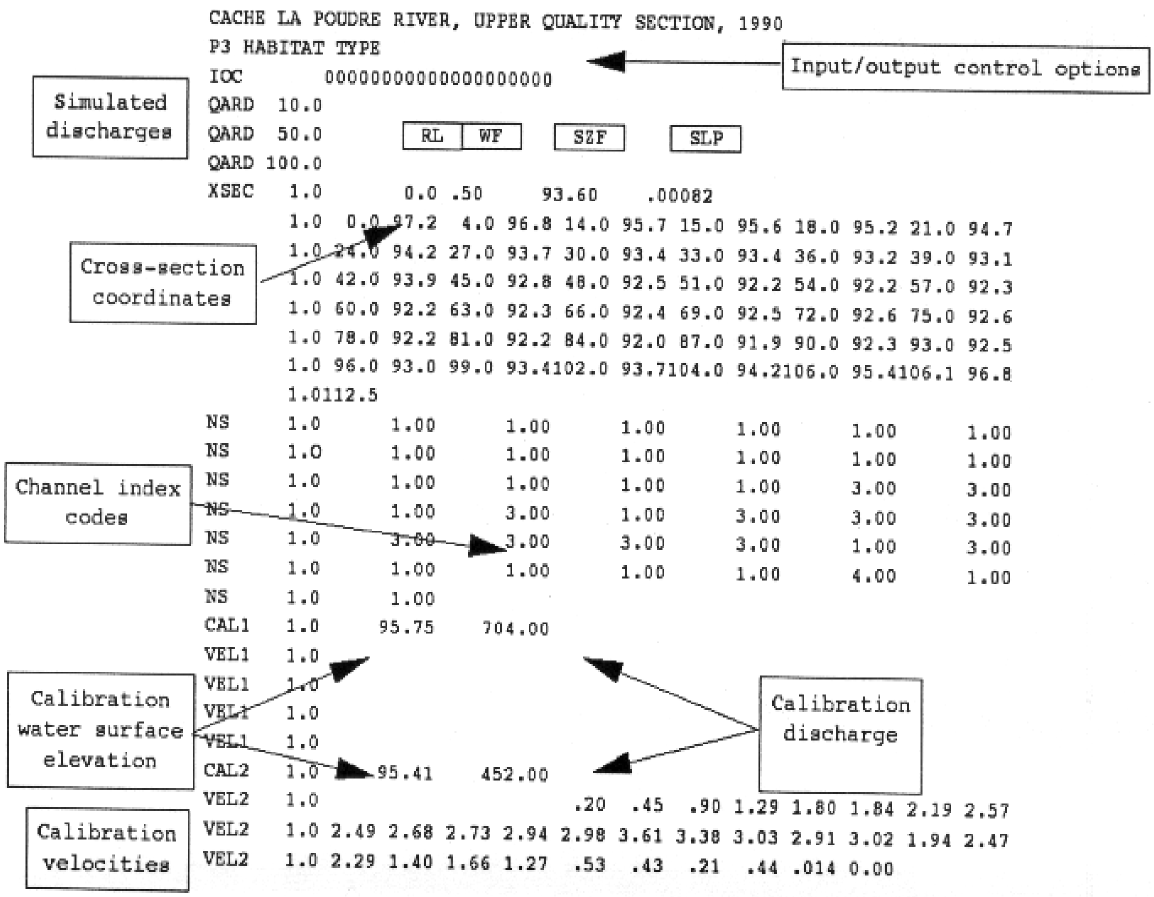



Figure 67. Portion of an IFG4 input file, showing the variables and data which must be provided from field notes.

## IFG4IN INPUT FILE ORGANIZATION

The first several lines of data in Figure 67 do not come directly from the data in the field notes. The first two lines describe which river and site the input file represents. The IOC line contains a series of "on-off" switches that control various options for input, output, and computational procedures in IFG4. Although highly pertinent to calibrating IFG4, the IOC line has little bearing on data entry from field notes. The lines entitled QARD contain the discharges to be simulated.

The entry of data from field notes starts with the line entitled XSEC. Note that the first entry on the XSEC line and all subsequent lines is **1.0**. This identifies the number of the transect where the data was recorded (in this case, transect #1). Data for the next transect would be initiated by another XSEC line, with a **2.0** in the space for the transect identifier. The XSEC line also contains information that relates that transect to other transects in the site (e.g., distance to the next transect, relative length of cells, information about the control (or lack thereof) and the hydraulic slope across the transect). In Figure 67, the locations for these variables are indicated by the boxed text located just above the XSEC line.

Below the XSEC line is a group of untitled lines of data. These lines contain the x and y cross-section coordinates that describe the surveyed channel profile. Note that each row contains six coordinates from left to right, and the sequence of data on the line is distance followed by elevation.

The numbers on the NS line in Figure 67, are numerical channel index codes. In this case, the numbers refer to cover types, but could just as easily refer to substrates. The spaces between the channel index codes are reserved for Manning's n values that are inserted during the calibration process. There are six pairs of spaces for Manning's n and channel index codes in each row, corresponding in position to the six pairs of channel coordinates in the preceding block of data.

The lines delineated by the headings CAL and VEL contain the hydrographic data for the transect: CAL lines contain pairs of water surface elevation/discharge data and VEL lines contain calibration velocities. From left to right, the entries on the CAL line are: "CAL," the cross-section identifier (1.0), the water surface elevation (95.75), and the calibration discharge (704). IFG4 input files are designed to contain all of the input data for a transect. As a consequence, CAL and VEL lines must be provided for all of the calibration discharges, even though nothing was measured at some of them. For example, a water surface elevation and discharge were recorded for the highest calibration flow of 704 cfs, but no calibration velocities were measured. Nonetheless, four blank VEL1 lines, corresponding to a calibration flow of 704 cfs are included in the input file. Calibration velocities were measured at the second water surface elevation (CAL2; 452 cfs).

IFG4 keeps track of what data go with what coordinates by their positions in the input file. The positions of coordinate data and the NS lines, for example, correspond perfectly. Unfortunately, such consistency was not retained in the VEL lines. The positions of the velocities on the VEL lines correspond in sequence to the coordinates describing the cross-section profile. However, each VEL line has positions for 12 velocities, so there is no one-to-one correspondence between data on the VEL line and the coordinate data. For example, the entry of .20 on the first VEL2 line is in the fifth "slot" allotted for velocity data. This velocity corresponds to the fifth vertical across the transect, at a distance of 18.0 ft.

An unhandy feature of IFG4IN is that it will allow you to edit information for transects that have already been entered into a ".IN4" file, but will not allow you to add more transects. For example, if you have XSEC lines for transects 1-4, you can add other types of data to those transects. You cannot, however, add data for transect 5. One trick in creating a master file that contains all of the transects for a site, is to create the XSEC lines (see below) for all the transects first. Then, the other types of data can be added via the editing mode of IFG4IN, rather than building numerous bits and pieces of a file and pasting it together electronically.

## DATA PREPARATION

### ***XSEC Data***

The first "real" data for a transect is entered on the XSEC line, which unfortunately, is some of the most confusing data in virtually all of PHABSIM. The boxed legends above the numbers on the XSEC line in Figure 67 indicate the type of data incorporated on the XSEC line. RL stands for **R**each **L**ength, WF for **W**eighting **F**actor, SZF for **S**tage of **Z**ero **F**low, and SLP for **S**lope.

Reach lengths and weighting factors can be very confusing, particularly to PHABSIM newcomers. Part of the confusion is related to the treatment of these variables in the programs. Furthermore, reach lengths and weighting factors represent different things, depending on whether the data describe a representative reach or a collection of mesohabitat types.

#### **Reach Lengths and Weighting Factors for Representative Reaches**

The representative reach concept pre-dates mesohabitat typing. Consequently, the reach length/weighting factor convention was developed to define the length of stream cells in a representative reach. Under this convention, the ***reach length*** is defined as the distance between adjacent transects. The ***weighting factor*** is defined the proportional distance between transects to the cell boundary. For example, the distance between transect 1 and transect 2 in Figure 68 is 150 ft, and the cell boundary is 40 ft upstream from transect 1. Therefore, the weighting factor for transect 1 found by dividing 40 by 150 (0.27). The part of the cell downstream from transect 2 is calculated as:

$$WF_{2DS} = (1 - WF_{1US})$$

where $WF_{2DS}$ = the weighting factor for the portion of the cell downstream from transect 2, and

$WF_{1US}$ = the upstream weighting factor applied to transect 1.

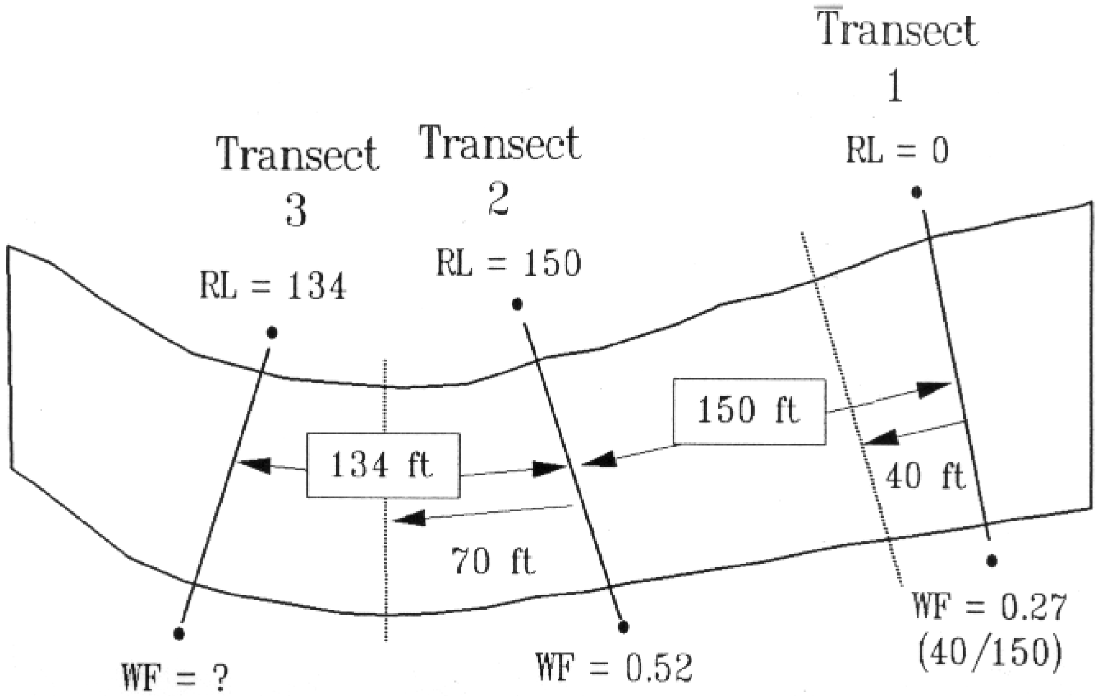



Figure 68. Determination of reach lengths and weighting factors to describe relative cell lengths in a representative reach.

What makes all this confusing is that the distance between transects 1 and 2 is recorded in the RL position for **transect 2**, not for transect 1 (hence the 0.0 under RL for XSEC 1.0). However, the weighting factor for transect 1 is recorded in the WF position on transect 1, not transect 2. The reason for this odd treatment of the reach length stems from the fact that the original model, around which most of PHABSIM was built, was the WSP hydraulic simulation program developed by the U.S. Bureau of Reclamation in the late 1960's.

Transects were identified in WSP by a process known as ***stationing***, which is the accumulation of distances upstream from the first transect. The stationing indexes are used in WSP to calculate distances between transects. The stationing index for the first transect is always 0 (recorded as 0+00). In Figure 68, transect 2 is 150 ft upstream from transect 1, so its stationing index would be 1+50 (entered as 150 in IFG4). Transect 3 is 134 ft upstream from transect 2, but the cumulative distance from Transect 1 is 284 ft The stationing index for Transect 3 is 2+84 (150+134). Because stationing is a cumulative distance and the first transect is 0+00, the reach length between two transects must be determined from the next transect upstream. To preserve compatibility with WSP, the stationing convention was retained in development of the remainder of PHABSIM's programs. In retrospect, it would have been less confusing to re-write WSP.

**Reach Lengths and Weighting Factors for Mesohabitat Types**

Recall the principal differences between the representative reach approach and habitat mapping as discussed in the chapter on representing the segment. In a representative reach, distances between transects and weighting factors collectively describe how much of the reach is occupied by each longitudinal stream cell. The proportions of cells in a representative reach are assumed to be the same as those in the segment.

The habitat mapping approach treats each PHABSIM site in each mesohabitat type as a self-contained unit. Cells and transects may represent equal or unequal portions of the site, depending on how the site was set up. The segment, however, is represented by all of its component mesohabitat types. By extension, the segment is ultimately described by all of the longitudinal cells that collectively make up all the mesohabitat types.

In data entry, our ultimate goal is to create a single IFG4 input file that contains all the transects for all the mesohabitat types. The reason for combining all of the transects into a single data file is that when the microhabitat simulation is completed, we will have a single WUA-discharge relationship for the entire segment. If the transects were not all contained in a single input file, we would obtain a WUA-discharge relationship for each mesohabitat type. These individual WUA-discharge relationships would then need to be combined into some sort of weighted average. Although combining the transects at the beginning is not simple, it is easier than trying to combine the results at the end.

The IFG4 input file that is constructed from mesohabitat typing depicts the segment as an idealized 1,000-ft segment of stream. The approach for proportioning the cell lengths for each transect in the idealized 1,000-ft segment is as follows:

(1) The proportion of a particular mesohabitat type in the actual segment is determined from the mesohabitat inventory.

(2) The proportion of a site in a mesohabitat that is represented by an individual cell is determined. If transects were placed systematically or randomly in the site, each transect represents 1/nth of the site (where n is the number of transects). If discrete cell boundaries were identified in the site, the proportion of the site represented by a transect is equal to the length of the cell divided by the length of the site.

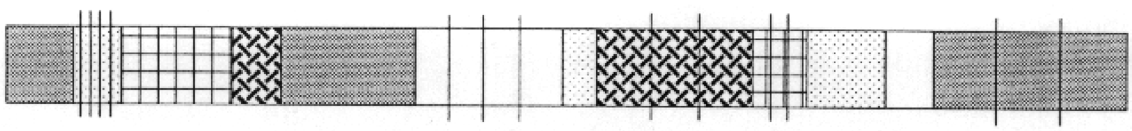
(3) The proportion of the idealized segment represented by a transect is found by:

$$P_{transect/segment} = (P_{transect/meso\text{-}type})(P_{meso\text{-}type/segment})$$

where $P_{transect/segment}$ = the proportion of the idealized segment represented by an individual transect,
$P_{transect/meso\text{-}type}$ = the proportion of a site in a mesohabitat type represented by an individual transect, and
$P_{meso\text{-}type/segment}$ = the proportion of the actual segment represented by the mesohabitat type.

(4) The reach length assigned to a transect is calculated by multiplying $P_{transect/segment}$ by 1,000 ft. The weighting factor for most transects is set at 1.0 (but see example below).

The apportioning of reach lengths and weighting factors for an idealized 1,000-ft segment is demonstrated in Figure 69. This figure shows the inventory of a segment, described earlier in Figure 24, with the addition of various numbers of transects in each mesohabitat type. In this example, the transects were all installed systematically, so each transect represents 1/nth of the site in which it occurs.



| Habitat type | Proportion of type in segment | Proportion of site per transect | Proportion of segment per transect |
|---|---|---|---|
| A | 0.344 | 0.50 | 0.172 |
| B | 0.152 | 0.25 | 0.038 |
| C | 0.137 | 0.50 | 0.069 |
| D | 0.190 | 0.50 | 0.095 |
| E | 0.177 | 0.33 | 0.058 |

Figure 69. Determination of proportions of cell lengths in a segment depicted by various numbers of transects in five mesohabitat types. Proportional cell lengths are used to assign reach lengths and weighting factors on the XSEC line of an IFG4 input file used with the mesohabitat typing method.

During the inventory, $P_{meso\text{-}type/segment}$ for mesohabitat type A was 0.344. Two equally-spaced transects were used in the site used to describe mesohabitat type A, so $P_{transect/meso\text{-}type}$ for each transect is 0.50. Each of the transects in mesohabitat type A, therefore represents 0.172 of the segment. The reach length assigned to each of these segments would be 172-ft, and the weighting factors for both transects are 1.0.

This procedure is continued, mesohabitat-by-mesohabitat. The next site in the sequence (from right to left) is Mesohabitat C, which represents 0.137 of the segment. Mesohabitat C has two equally-spaced transects, so each transect represents 0.0685 of the segment, and each is assigned a reach length of 68.5 ft. It is noteworthy that we could assemble the mesohabitat data in any order we wish, because each site is calibrated independently.

Remember that the reach length for a transect is recorded on the XSEC line for the next transect in the input file, regardless of its actual sequence in the stream. In our example, the first transect in the input file is from mesohabitat type A, which has a recorded reach length of 0.0. The reach length for the first transect in mesohabitat type A (172.0) is recorded on the XSEC line for the second transect. However, the reach length for the second transect in mesohabitat type A is recorded on the XSEC line for transect 3, which, in this example, is the first transect in mesohabitat type C.

Where the process gets especially interesting is when we reach the last transect in mesohabitat type B. Because there are no transects after this one in the input file, there is no reach length recorded for it. If this oversight goes uncorrected, the transect will not be used in the calculation of microhabitat.

There are two ways to avoid losing the information from the last transect. The simplest approach is to make an exact duplicate of all the input lines for the last transect, change the station ID to indicate one more transect, insert the reach length for the previous transect, and append the "dummy transect" to the end of the input file. The only valuable piece of information carried with this transect is the reach length for the last actual transect in the input file. PHABSIM will go through the motions of calculating WUA's for the dummy transect, but because there is no transect upstream, the dummy transect has no reach length and all its WUA values will be zero.

The second approach to prevent loss of the last transect is a bit more efficient, but makes building the input file more difficult. A reach length, corresponding to the total reach length of the last two transects, is assigned to the XSEC line of the last transect. Then, an appropriate weighting factor is assigned to the next-to-the-last transect in the series. For example, the combined reach length of the last two transects in mesohabitat type B is 76 ft. By assigning a weighting factor of 0.5 to the previous transect, both would represent cells that were 38 ft long. [Note: The good news is that if you can figure out how to manipulate reach lengths and weighting factors, everything else related to data entry will be simple by comparison.]

**Stage of Zero Flow**

Simply stated, the ***stage of zero flow*** is either the lowest point on the hydraulic control or the lowest point on the transect (termed the ***thalweg***). What we are looking for is the water surface elevation when the discharge is zero (Fig. 70). Pools are created by the backwater effects of a hydraulic control. Therefore, the stage of zero flow in a pool will be the same as the lowest point on the hydraulic control. In riffles and other "channel-controlled" mesohabitats, there is no backwater effect and the stage of zero flow is the lowest point on the transect.

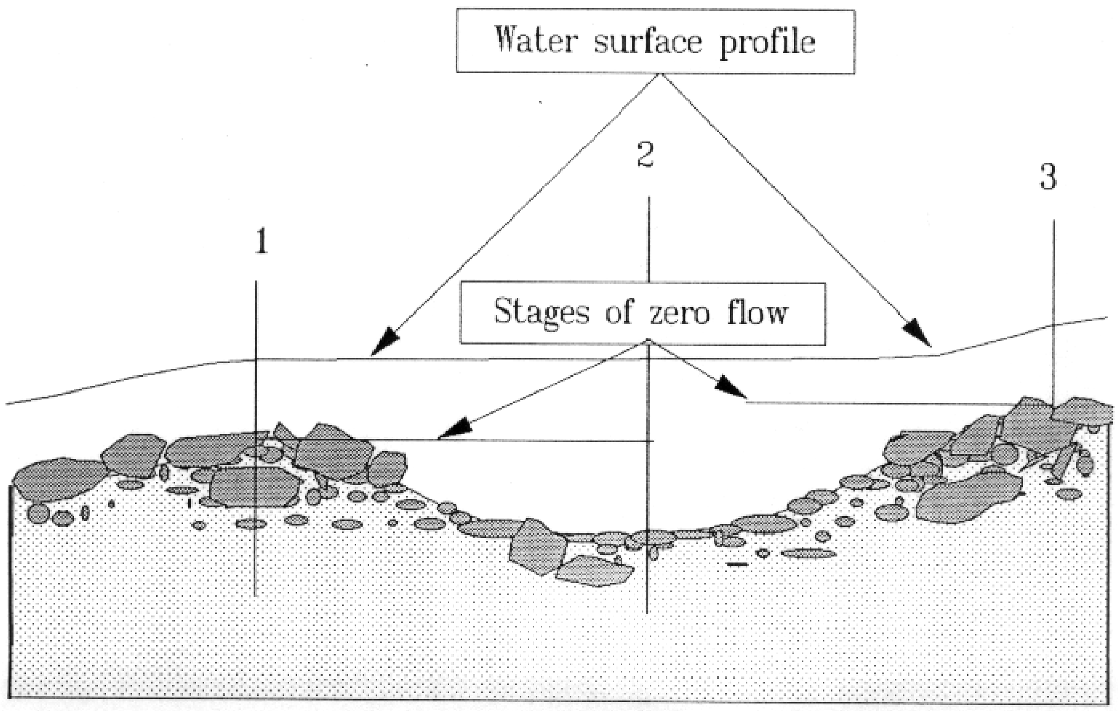



Figure 70. Side view of a stream showing longitudinal profile of the thalweg (a line connecting the deepest part of each transect). In riffles there is no backwater effect at low discharge, so the thalweg elevation of the riffle is the stage of zero flow. In pools, the thalweg elevation at the downstream hydraulic control is the stage of zero flow.

Effectively, the stage of zero flow establishes the y-intercept for the relationship between water surface elevation and discharge. At zero flow, riffles will go dry but pools will still have depth, sometimes appreciable. If the stage of zero flow for a pool is entered as the low point on the transect, the model will simulate pools with no water in them at zero discharge.

**Hydraulic Slope**

The discussion of reach lengths and weighting factors associated with mesohabitat typing may have left the reader with the perception that the actual distances between transects are meaningless in PHABSIM. In truth, the actual distances are extremely important in calculating the slopes used during model calibration and the simulation of velocities.

In most hydraulic simulation models, the slope used in the model is supposed to represent the energy gradient: calculated as the difference in total energy at two transects, divided by the distance between them. In PHABSIM data collection, we make the simplifying assumption that the hydraulic slope and the energy gradient are parallel. The hydraulic gradient is calculated as the difference in water surface elevations at two different transects, divided by the distance between them. Normally, we will be working in areas where the hydraulic and energy gradients actually are parallel, or very nearly so.

The slope recorded on the XSEC line for a transect is supposed to reflect the slope at the transect. For the first transect in a series, we recommend calculating the slope between the first and second transects. For transects in the middle of a site, use the water surface elevations and distances for the transects on each side of the one you are working on. For example, use the water surface elevations from transects 2 and 4 to calculate the hydraulic gradient across transect 3. Use the water surface elevations for the penultimate and last transects in the site to calculate the slope at the last transect.

PHABSIM is not very sensitive to the slope you insert on the XSEC line. In fact, IFG4 defaults to a slope of 0.0025 if you do not supply one. The reason that we suggest that you calculate slopes for individual transects is that during velocity calibration, IFG4 uses the slope on the XSEC line (either the one you give it or the default value) to calculate roughness coefficients for Manning's n equation. If the real slope is much different from the default slope, IFG4 will produce roughness coefficients that will seem truly bizarre to a hydraulic engineer. Although bizarre slopes do not necessarily produce bizarre velocity predictions, they can cast doubt on the credibility of your simulations.

***Channel Coordinates***

There are only a few rules affecting the entry of coordinate data:

(1) the smallest negative number that can be entered is -99.9,
(2) the largest positive number that can be entered is 999.9,
(3) stations across the transect must progressively increase, and
(4) vertical lines are not allowed.

For use in IFG4IN, elevations must be calculated independently before they are entered. Commercial spreadsheet programs are available that can be used very effectively for translating foresights and HI's into elevations. Spreadsheets are much easier to proofread for errors, and provide a means of storing data and intermediate calculations permanently, if so desired. An ancillary advantage of using spreadsheets is that they provide superior graphics capabilities for generating plots of cross-sectional and longitudinal profiles.

If the left-side floodplain is more than 99 ft wide, and you have recorded negative distances from the headpin, it will be necessary to re-number the stations along the transect at this time (see discussion of re-stationing in the chapter on cross-section profiles). To re-station, the zero-point for the transect must be moved to its left-most coordinate. All other stations along the transect must then be corrected to reflect the difference in distance (again this is a good use for a spreadsheet). For example, suppose the end of the transect is -200 ft from the left-bank headpin. A zero distance is assigned to the left end of the transect, and 200 ft added to all of the stations recorded in the field book.

IFG4 and its companion programs all have an option called a "cross-section multiplier," for entering horizontal distances across transects that are greater than 999.9 ft wide. The restriction of widths to 999.9 ft stems from a lack of space: only five spaces are allotted to each character for stations and elevations, one of which is used by a decimal implied in the penultimate space in each field (Milhous et al. 1989). If the transect is more than 1,000 ft wide, you should divide recorded distances by ten, and enter the rescaled stations into the input file. Remember to switch on the option to multiply it back out again, however (see IOC options in Milhous et al. 1989).

### ***NS Data***

Each NS line has spaces for a manually-entered values of Manning's n and numerical channel index codes. The "N" in NS refers to Manning's n, and the "S" refers to substrate (a throw-back to an earlier time when substrate was the only channel index used in PHABSIM). Each "NS" pair corresponds to the x and y coordinate in the same position on the coordinate line. During the initial phases of data entry, only the channel index codes are entered. [Note: Substrate or cover descriptors must be put into a numerical codes before they can be entered. However, PHABSIM will run without channel index codes (leave the NS lines blank) if neither cover nor substrate are important to the target species, or if these data are not available].

You have two options for data entry when separate data have been collected for substrate and for structural cover objects. The first choice is to construct a single set of NS data, using a composite numerical code. The second option is to construct separate data files, with cover codes on one set of NS lines and substrate codes on another. The advantage of combining cover and substrate into a single channel index code is that it makes data entry for the transects easier. Unfortunately, it also makes data entry for habitat suitability criteria more difficult because you must determine a suitability value for every coded combination of cover and substrate. Unless the habitat suitability criteria were specifically designed to consider cover/substrate combinations, you will find yourself estimating suitabilities for combinations for which you have no data, and probably little experience. Therefore, it is usually preferable to develop separate files for NS lines with cover and NS lines with substrate. The file containing cover information is used to calculate WUA for life stages that are most affected by cover, and vice versa.

### *CAL Data*

The CAL line contains paired water surface elevation and discharge data for a single calibration discharge. Preparing water surface elevation and discharge measurements to enter on the CAL lines can more complicated than it seems. Discharge data can be especially troublesome for two reasons in particular: (1) not all transects in a PHABSIM site are equally suitable for discharge measurements, and (2) unsteady flow conditions can make it difficult to determine the actual discharge at the time the water surface elevation was measured.

Under steady flow conditions, the following measurements should be used for water surface elevation and discharge, respectively: the water surface elevation measured from a transect, and the **best estimate** of the discharge at the transect at the time the water surface elevation was measured. The same conditions that foster good microhabitat conditions for fish often create terrible conditions for stream gaging. Therefore, the best estimate of discharge may come from another transect. If there is one transect in the site that appears to be well-suited for discharge measurements, then the discharge measured at this transect should be used as the best estimate of discharge for all the transects in the site. Discharges from all of the transects can also be averaged if none of the transects is noticeably better than the others for accurate discharge measurements. If all of the transects in the site are poor places for discharge measurements, the best estimate of the discharge may have to come from outside the site.

The best way to deal with unsteady flow is to install a semi-permanent staff gage at a convenient location where good discharge measurements can be. With a rated staff gage close to a site, a good estimate of the discharge can be obtained quickly, whenever the water surface elevation for a transect is measured within the site. In the absence of a rated staff gage, the alternative is to measure the discharge at the transect when the water surface elevation was measured. These discharge measurements can represent an unnecessary expenditure of time, and because not all transects are created equal when it comes to stream gaging, this alternative leaves much to be desired.

***Velocity Data***

Velocity data can be entered into PHABSIM in two places. The most common and obvious is the insertion of mean column velocities on the VEL lines. The other place where velocities might be inserted is in the habitat simulation programs, where an equation relating mean column and nose velocities is entered.

The only real trick to entering data on VEL lines is to match the velocities to their corresponding coordinates. What makes velocity data deceptive is that each VEL line has twelve spaces for velocities and each coordinate line contains only six coordinates. Therefore, velocities and coordinates must be aligned by counting over to the first coordinate where a velocity was measured. Blank spaces are left on the VEL line for all coordinates that were above water (or velocities not measured). The first recorded velocity on the VEL line corresponds to the first vertical where a velocity was measured. When entering velocity data, be aware of verticals in the middle of the data set where velocities were not measured. For example, some verticals in the middle of a transect might cross over a large boulder, so no velocities would be recorded at these locations. It is important not to record a velocity at verticals that were above the water surface, because doing so confuses IFG4 quite badly.

The normal procedure for velocity calibration and simulation in IFG4 is illustrated in Figure 71. At each vertical, IFG4 calculates the depth from the elevations of the bed and water surface. The slope is read from the XSEC line, and the mean column velocity for the vertical is read from the VEL line. These data are then used in a modification of Manning's equation to calibrate a roughness coefficient for the vertical:

$$n_i = \frac{1.49}{v_i} d_i^{2/3} S^{1/2}$$

where $n_i$ = the roughness coefficient,
$v_i$ = the mean column velocity,
$d_i$ = the depth, and
S = the hydraulic slope.

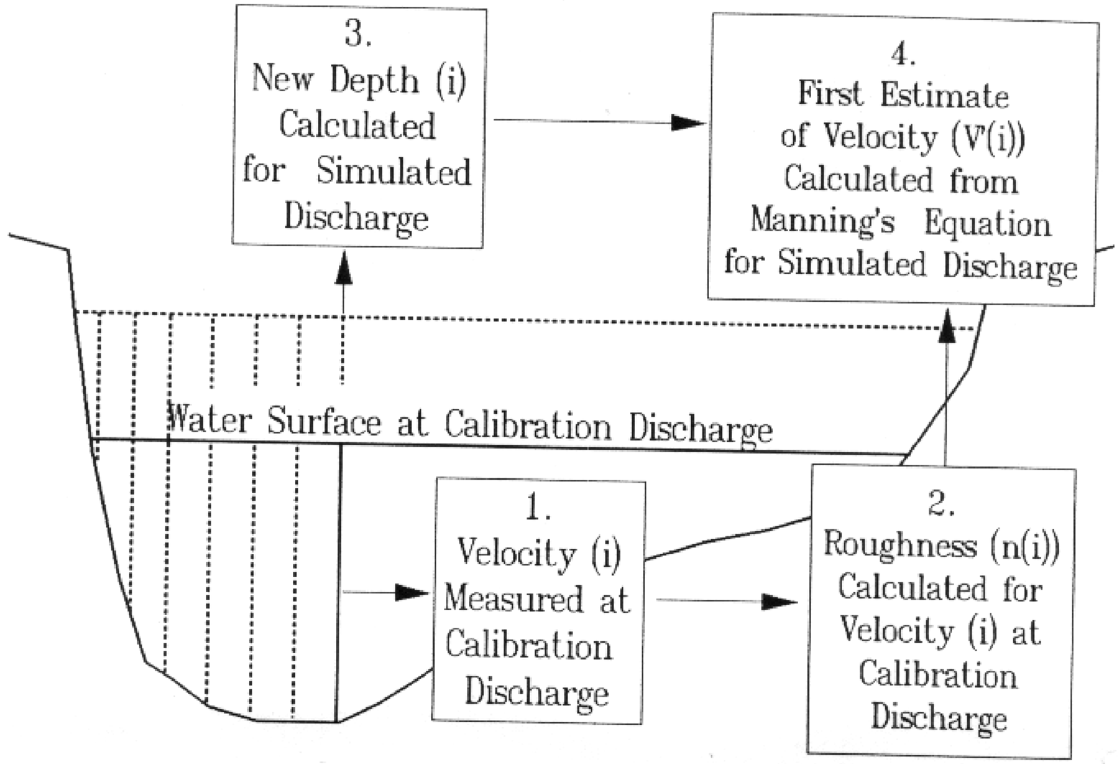



Figure 71. Steps in calibration and simulation of velocities, using Manning's equation in IFG4.

The process is reversed during simulation. A new water surface elevation is predicted at a simulated discharge, resulting in a new depth at each vertical. The depth is substituted back into Manning's n equation to derive the first estimate of the mean column velocity:

$$v_i = \frac{1.49}{n_i} d_i^{2/3} S^{1/2}$$

where all terms are as defined above.

It is possible to enter more than one set of velocities into an IFG4 input file. However, IFG4 should not be used for velocity simulations with more than one velocity set at a time. If there is more than one velocity set in the input file, IFG4 will not use Manning's equation. Instead, the program will attempt to relate mean column velocities with discharges in a linear regression. We have learned that the regression approach becomes mathematically unstable when high discharges are simulated (e.g., IFG4 has predicted velocities approaching the speed of light in extreme instances).

If there are two or more sets of calibration velocities, it is recommended that the IFG4 input file be used simply as a repository for the data. Different velocity sets would then be used in conjunction with Manning's equation (i.e., one velocity set at a time) to simulate specific portions of the total range of flows. Calibration velocities measured at low flows should be used to simulate a range low flows; high flow calibrations are more suitable for high flow simulations.

Nose velocities pose an interesting problem in PHABSIM. Nose velocity criteria for fish and aquatic macroinvertebrates tend to be more broadly transferable than criteria based on mean column velocities. For example, trout in the Big Thompson River in Colorado might prefer exactly the same nose velocities as trout in the Yellowstone River in Montana. Because the Yellowstone River is so much larger, however, the mean column velocities utilized by trout in the two rivers could be appreciably different. From a biological perspective, nose velocities are appealing because they may provide a more accurate description of the microhabitat for the target species. The counterpoint to using nose velocities routinely in PHABSIM is that predictions of nose velocities at unmeasured discharges are notoriously inaccurate. The paradox of nose velocities is that they are relevant in explaining fish (and invertebrate) behavior, but they are nearly impossible to simulate accurately.

The standard approach to handling nose velocities in PHABSIM is to simulate them using one of the habitat simulation programs (e.g., HABTAE). Several options are available for simulating the velocity at various locations in the water column, but the favored alternative is to develop an empirical regression equation in the form:

$$\frac{V_n}{V} = a\left(\frac{D_n}{D}\right)^b$$

where $V_n$ = the nose velocity,
V = the mean column velocity,
$D_n$ = the distance above the streambed at which the nose velocity is measured,
D = the depth at the location, and
a and b are regression parameters.

Under normal practices, the investigator would measure nose velocities at 50-100 locations in the stream, and derive the regression coefficients, a and b by least squares.

Experiences with empirical regression equations (and the other nose velocity equations in PHABSIM) have indicated a tremendous amount of scatter between predicted and measured nose velocities. The suspected source of error lies in the irregular distribution of particle sizes on the beds of natural streams. Virtually all nose velocity equations were developed in flumes at hydraulic engineering laboratories, where the bed material is all the same size and the slope is the same from one end of the flume to the other. Consequently, the nose velocity equations in PHABSIM work just fine if they are applied in a stream that matches the conditions of a flume. However, the greater the variation in the particle size distribution of the streambed, the worse these equations perform.

Better results (i.e., less scatter) can be achieved by stratifying the regression data according to like-sized groups of substrate materials. However, PHABSIM is not organized to deal with this type of stratification, so performing a completed simulation becomes a convoluted exercise of tricking the programs into doing what you want them to.

There is an alternative to calibrating an empirical nose velocity equation or using one of the standard relationships in PHABSIM: entering nose velocities on the VEL lines, in place of mean column velocities. Be forewarned that this option may not be very practical. For one thing, it will require the measurement of nose velocities at all of the verticals, possibly in addition to measurements of mean column velocities. This may also be a controversial alternative, because it requires that the "mass-balancing" feature of IFG4 be turned off. Without getting into a lengthy discussion of mass-balancing, suffice it to say that the mass-balancing process is an important quality assurance component of hydraulic simulations in PHABSIM. What makes this approach controversial is that any semblance of hydraulic theory has been discarded and replaced by an essentially untested empiricism.

If nose velocities are substituted for mean column velocities on the VEL line, it is advisable to test the accuracy of the predicted nose velocities. Model performance can be tested by collecting a limited amount of verification data at another discharge, and displaying standard measures of prediction errors, such as error dispersion. Unfortunately, if the errors are large and abundant, there is relatively little you can do to improve the predictions, owing to the highly empirical nature of the simulation. In other words, a tremendous amount of time and money might be invested in the collection of nose velocity calibration and verification data, but there is no guarantee that model accuracy will be improved at all. For these reasons, we usually advise people to avoid using nose velocity data unless it is absolutely necessary.

## SUMMARY

- The most user-friendly program for data entry is IFG4IN, which allows the user to create new files from scratch or to edit existing files. In the future, data entry programs are likely to be developed in spreadsheet mode, which should make data entry even easier.
- In the "new file" mode, IFG4IN starts at the title lines and works

methodically through each type or group of data required by IFG4. The user can specify the portion of a file to edit, but additional transects cannot be added to an existing file. Therefore, a master file containing all of the XSEC lines should be built first, and other data for individual transects added later.

- The template for data entry to PHABSIM is the input file format of the hydraulic simulation program, IFG4. General information about the input file is contained on the title lines, the input/output control (IOC) line, and the QARD (simulated flows) lines. Data for each transect is contained as a group of lines including: XSEC, channel coordinates, NS, CAL, and VEL.
- The first real data for a transect is found on the XSEC line, which contains information on the distances between transects, lengths of cells, the stage of zero flow, and the hydraulic slope.
- In representative reaches, cell lengths are specified by entering the product of the distance between transects and an upstream weighting factor. When mesohabitat typing is done, reach lengths are adjusted according to the proportion of the site represented by a transect and the proportion of the segment represented by the site. All of the sites are combined into a single data file that depicts an idealized 1,000-ft stream segment.
- The stage of zero flow is the thalweg elevation for transects not affected by a backwater. In pools, the stage of zero flow is the thalweg elevation of the downstream hydraulic control.
- The hydraulic slope is assumed to be parallel to the energy gradient and is calculated as the difference in water surface elevations between two transects, divided by the distance between them.
- The coordinate lines on the data sheet contain pairs of data consisting of distances and elevations. Six pairs of coordinates are contained on each line. If the left-most transect distance is less than 99.9, the transect must be re-stationed, setting 0.0 as the left-most coordinate point. If coordinates are entered with the program CORDIN, the instrument height or other datum can be entered and elevations will be computed from foresights. IFG4IN requires actual elevations to be entered. If the cross-section data contains a combination of surveyed and sounded ground elevations, it is advisable to first calculate elevations in a spreadsheet and then enter them as elevations into IFG4.
- During the data entry phase, the only information entered on the NS lines are numerical channel index codes. If substrate and cover information were recorded as alpha-numeric codes in the field, they must be translated into a numerical code prior to entry to PHABSIM. Channel index codes may be created to represent a combination of substrate and cover, which facilitates data entry for IFG4 but makes development of habitat suitability criteria more difficult. Unless the habitat suitability criteria contain specific inferences to

combined substrate and cover characteristics, it is better to develop separate IFG4 input files: one with substrate codes and one with cover codes.

- CAL lines contain pairs of measured water surface elevations and discharges for each transect. There is one CAL line for each data pair. The discharge recorded on the CAL line should represent the best estimate of the discharge at the time the water surface elevation was measured. If the flow is steady, the best estimate of the discharge may be derived from another transect or from an average of several transects. If the flow is unsteady, the best estimate of the discharge should be obtained from a calibrated, semi-permanent staff gage.
- VEL lines usually contain the mean column velocities for each of the coordinates contained on the coordinate lines. Velocities must be matched with coordinates by leaving blanks corresponding to verticals that were above water during the calibration measurements. Nose velocities can also be entered on the VEL lines, but the mass-balancing feature of IFG4 must be disabled. If this option is used, an independent set of nose velocities should be measured at a different stream flow to test the accuracy of the simulations. Otherwise, a limited number of nose velocities are measured in conjunction with mean column velocities, and used to calibrate an empirical relationship between the two. These relations are often highly inaccurate where there is a highly variable particle size distribution on the streambed. Because of the inaccuracies involved in nose velocity predictions, they should not be used unless absolutely necessary. Verification data should always be collected for nose velocities.

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# Glossary

**Aggradation:** A state of channel disequilibrim, whereby the supply of sediment exceeds the transport capacity of the stream, resulting in deposition and storage of sediment in the active channel.

**Alluvial channel:** A channel that is eroded into sedimentary materials that were previously deposited by the stream under contemporary conditions of flow regime and sediment input.

**Armoring:** The process of continually winnowing away smaller substrate materials and leaving a veneer of larger ones.

**Backsight:** A measurement taken to a point of known elevation to determine the height of instrument (HI) relative to the known elevation.

**Base flow:** Streamflow contributed solely from shallow groundwater in the absence of significant precipitation or runoff events.

**Base level:** The lowest elevation to which a stream can erode its bed (e.g., mean sea level is the ultimate base level).

**Baseline:** A reference condition, against which alternatives are compared (e.g., a hydrologic baseline refers to the current flow regime with all existing water uses in place).

**Benchmark:** A surveyor’s monument of known position and elevation, used as a reference point in horizontal surveys and differential leveling.

**Colluvial stream:** A streams whose channel shape and streambed are dominated by materials which have washed into the stream by forces other than the stream’s current flow regime (e.g., mass wasting, glacial outflows, catastrophic floods).

**Cover:** Structural features (e.g., boulders, log jams) or hydraulic characteristics (e.g., turbulence, depth) that provide shelter from currents, energeticially efficient feeding stations, and/or visual isolation from competitors or predators.

**Cross-sectional area:** The area of a surface defined by the space between the water surface and the streambed along a transect across the stream, approximated by :

$$A = \Sigma W_i d_i$$

Where $W_i$ and $d_i$ are widths and depths of small rectangular sections along the transect.

**Datum:** A point, line, or surface used as a reference in surveying, mapping, or geology. In IFIM, a datum usually refers to a known or assumed elevation.

**Degradation:** Erosion and downcutting of an alluvial channel caused when the sediment transport capacity of the stream exceeds the sediment yield from the watershed.

**Destination stream:** A stream to which a set of habitat suitability criteria is to be applied, for the purpose of calculating a microhabitat vs. flow relationship in PHABSIM.

**Differential leveling:** A surveying technique by which the elevations of topographic features are determined, by measuring the distance between the unknown point and a horizontal line of known elevation (HI or height of instrument).

**Dynamic equilibrium:** A quasi steady state condition attained in an alluvial channel, whereby sediment supplies are just balanced by sediment transport capacity, resulting in no net change in average streambed elevation over time.

**Embeddedness:** An ordinal scale depicting the relative percentage of fine materials (e.g., clay, silt, sand) incorporated in a matrix of coarser substrate particles.

**Exceedance probability:** The probability that an event in a time series will be equalled or exceeded in magnitude by other events in the same series.

**Explicit zonation:** A variation of stratified random sampling, whereby a stream segment is subdivided according to geomorphic features to ensure representation of different channel characteristics.

**Flow regime:** The distribution of annual surface runoff from a watershed over time (hours, days, or months). See also, hydrologic regime.

**Foresight:** The vertical distance from a known horizontal elevation (HI or height of instrument) to a position of unknown elevation.

**Habitat suitability criteria:** Graphical or statistical models that depict the relative utility of increments or classes of microhabitat variables (e.g., depth, velocity, cover type) to a life stage of a target species.

**Headpin:** A semi-permanent monument (e.g., a stake or piece of rebar) used to mark the left (zero) side of a transect, looking upstream.

**Hip-chain:** A hands-free distance measuring device. A thread is tied to a starting point and as the user walks, the thread is drawn from a spool attached to a counter similar to an odometer. The thread is biodegradable, so when measurements are completed, the thread is discarded and counter reset.

**Hydraulic control:** A horizontal or vertical constriction in the channel, such as the crest of a riffle, that creates a backwater effect in an upstream direction.

**Hydraulic radius:** A variable used in hydraulic simulation models, calculated as the ratio between cross-sectional area and wetted perimeter.

**Hydrologic regime:** The distribution of water in a catchment, among precipitation, evaporation, soil moisture, groundwater storage, surface storage, and runoff, over time.

**Level loop:** A reverse survey used to determine the amount of error in elevations as calculated by differential leveling.

**Line of sight index:** An ordinal scale indicating the relative difficulty of surveying a site.

**Macrohabitat:** The set of abiotic conditions that control the longitudinal distribution of organisms along one of several environmental gradients: hydrology, geomorphology, temperature, water quality, or energy source.

**Manning's n:** An empirical calibration parameter used in the Manning equation to represent roughness, or resistance to flow, as a function of the size and irregularity of streambed materials relative to depth of streamflow (e.g., large particles in shallow water are "rougher" than small particles in deep water).

**Mean column velocity:** The average of the scalar values of the velocity measured at intervals from the streambed to the water surface. Approximated by a single velocity measurement at 0.6 of the depth (from the surface) in shallow water, and by the average of the velocities measured at 0.2 and 0.8 of the depth in deep water.

**Mesohabitat:** A discrete area of stream exhibiting relatively similar characteristics of depth, velocity, slope, substrate, and cover, and variances thereof (e.g., pools with maximum depth < 5 ft, high gradient riffles, side channel backwaters).

**Mesohabitat typing:** Also known as **habitat mapping**. A method of representing the types and proportions of mesohabitats in a stream segment, following a stratified sampling protocol involving definition, large scale inventory , and mathematical proportioning of mesohabitat types in the segment.

**Microhabitat:** A subset of mesohabitat defining the spatial attributes (e.g., depth, mean column velocity, cover type, and substrate) of physical locations occupied or utilized by a life stage of a target species sometime during its life cycle.

**Moving hazards index:** A scale from 1-10 indicating the relative difficulty of moving around in  site.

**Nose velocity:** Current speed (usually) measured near the surface of the substrate, presumably at the approximate nose level of benthic-oriented fish or macroinvertebrates.

**Partial section:** A subdivision of a stream cross-section, delineated by its measurement verticals, used in the calculation of stream discharge.

**Rating curve:** An empirical relationship between river stage or water surface elevation and discharge at a specific location on a stream.

**Recurrence interval:** The average time interval between events equalling or exceeding a given magnitude in a time series.  (See also, exceedance probability)

**Representative reach:** A length of stream used to represent the microhabitat characteristics of a segment,  approximately 10-15 channel widths in length, assumed to contain all of the mesohabitat types of the segment, in the same proportions as the segment.

**Riffle**: A depositional mesohabitat type characterized as being relatively shallow and swift, and having coarse substrate materials.  Stage-discharge relationship is not influenced by backwater effects under moderate to low flow conditions.

**Sinuosity:** A measure of channel pattern pertaining to the relative amount of meandering exhibited by a stream.

Calculated as the ratio between river length and valley length.

**Slope distance:** The distance corresponding to the hypotenuse of a right triangle, formed between a horizontal line of sight from the instrument and a vertical line to the target.

**Sounding:** A procedure for determining the elevation at a point on the streambed by subtracting the depth at a location by a known elevation of the water surface.

**Source stream:** A stream from which the data for a set of habitat suitability criteria were obtained.

**Stage of zero flow:** The water surface elevation at a cross-section, when the discharge is zero. For cross-sections not influenced by backwater effects, the SZF is the same as the lowest elevation on the transect.

**Stage:** A somewhat ambiguous term refering to: (1) The distance of the water surface in a river above an arbitrary datum, not necessarily tied to the same reference elevations as the ground and water surface elevations at a site (e.g., flood stage is 14.9 ft). (2) The distance of the water surface above a known datum, if tied to the same reference elevations as the ground and water surface elevations at a site.

**Stationing:** A method of identifying transects or points along a traverse by calculating the cumulative distance from a starting point. Station indexes are presented in a format of hundreds of length units, and single length units (e.g., 1+50 = 150 feet).

**Stilling well:** A casing set into the river bank to attenuate surging of the water surface during the measurement of river stage.

**Stream cell:** The basic microhabitat accounting unit in PHABSIM, defined as a rectangle (or trapezoid), the width of which is the distance between verticals on a transect, the length of which is the longitudinal distance represented by the transect, as defined by the field investigator.

**Stream segment:** A relatively long section of river having a relatively homogeneous hydrologic regime and similar channel pattern and structure throughout. Used as the fundamental habitat accounting unit in the IFIM.

**Tailpin:** A semi-permanent monument (e.g., a stake or piece of rebar) used to mark the right side of a transect, looking upstream.

**Thalweg:** A longitudinal profile of the lowest elevations of a sequential series of cross sections.

**Transect:** A sampling line established across a river channel, perpendicular to the direction of flow.

**Transferability:** 1. Applicability of a model (e.g., habitat suitability criteria) to a setting or conditions that differ from the setting or conditions under which the model was developed. 2. Applicability of data obtained from a remote source (e.g., a meteorological station) for use at a location having different environmental attributes.

**Triangulation:** Location of an unknown point by forming a triangle having the unknown point and two known points as vertices.

**Type I error:** Error of rejecting a true null hypothesis. In criteria transferability tests, the error of accepting non-transferable criteria.

**Type II error:** Error of accepting a false null hypothesis. In criteria transferability tests, the error of rejecting perfectly good criteria.

**Variable backwater:** Variable pooling effect caused when a dominant low flow hydraulic control is inundated by the backwater effect of another hydraulic control at high flow. The result is a radically non-linear stage-discharge relationship, often accompanied by a distinct flattening of the water surface gradient at high flows.

**Vertical:** A sampling location on a transect. (1) in PHABSIM, a vertical marks the lateral boundaries of a stream cell.

**Weighted usable area:** An index of microhabitat availability, calculated by multiplying the surface area of a stream cell by its composite habitat suitability index.

**Wetted perimeter:** The length of a line in contact with the streambed, from the wetted surface on one side of the channel to the wetted surface on the other side, normal to the direction of flow.

**Zero azimuth:** A fixed reference direction (usually true North) assigned 0 deg, from which the horizontal angular distance to another position is measured, usually in a clockwise direction.

# INDEX