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Field Data Collection Procedures for Use with the Physical Habitat Simulation System of the Instream Flow Group

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INTRODUCTION

Instream flow uses are the uses made of water in the stream channel and include fish and wildlife population maintenance, outdoor recreation activities, navigation, hydropower generation, waste load transport (water quality), conveyance to downstream points of diversion, and ecosystem maintenance. The latter includes fresh water recruitment to estuaries and to riparian vegetation and floodplain wetlands. The water requirements sufficient to maintain all of these uses at an acceptable level are the instream flow requirements.

The first and most important rule to observe when establishing an instream flow recommendation must be an appropriate physical description of the stream segment to which the recommendation applies i.e., from Point A on the river downstream to Point B.

A second rule is that instream flow recommendations are generally made in order to influence the allocation of water. The instream flow requirement may be based on the dominance of one particular use, or alternatively, on the resulting best mix of uses within the instream use sector. The apportionment of the available streamflow among the various instream and offstream uses must be determined by making trade-offs between the various uses. This can best be done through negotiation.

Traditionally, instream flow assessments have arrived at a single value recommendation for the fishery resource - "a minimum flow." Such an instream flow recommendation provides a limited opportunity for negotiation. This approach promotes the mistaken assumption that only streamflows below this "minimum" value will be detrimental to the fishery resource. Streamflow allocations made employing this concept do not consider the variable flow needs of the instream resource. The persistance of such fixed instream flow allocation is often detrimental to the attainment of both environmental and water management objectives. As a result of the inflexibility and weaknesses associated with traditional assessments it was apparent that a methodology was needed which could quantify the effects of incremental changes in streamflow on the fishery resource and was compatible with the decision-making process of the water managers.

The IFG Incremental Methodology attempts to quantify the amount of potential fish habitat available for each life history stage of a species as a function of stream flow. This method is intended to be used as a decision-making tool and is specifically tailored to demonstrate the impact of incremental changes in stream flow on fishery habitat.

The IFG Incremental Methodology is based upon various concepts of watershed dynamics and utilizes information and state-of-the-art methods from several disciplines. The reader is refered to Instream Flow Information Papers No. 12 and 5 for a detailed discussion of the techniques and theory. Only a brief description is presented here.

Within any watershed, four primary components can be identified which determine the character of instream habitat (Figure 1). Associated with each of these components are the respective subsets of parameters which interact to provide the myriad of physical-chemical conditions to which the stream biota responds. Analyzing habitat as a function of changes within these major components offers a logical division for approaching the task of managing the instream resources.

Determination of the relationships among components and between the physical and biological processes allows for the evaluation of consequential changes anywhere in the physical processes in terms of habitat. This approach starts with a hierarchical and modular setting. The modules and various analytical tools available constitute the "building blocks" of this methodology. A hierarchical approach is dictated by different levels of knowledge, operation levels of technology, and the precision required for a particular application (Figure 1). The Physical Habitat Simulation System (PHABSIM) was developed to calculate the physical habitat given the channel structure, flow and species criteria. PHABSIM relates only part of the components in Figure 1. PHABSIM is the principle tool for doing the various tasks outlined above available at this time. It is the purpose of this manual to discuss the collection of the data need to use PHABSIM. These field data collection procedures are critical to the application of PHABSIM. The foregoing introduction is provided primarily to inform the user of several fundamental concepts embodied in the IFG Incremental Methodology, and to assist with keeping the field work associated with the application of PHABSIM in perspective with the overall study effort. The user should see Instream Flow Information Paper No. 12 for additional assistance in the application of the incremental approach and in the use of PHABSIM.

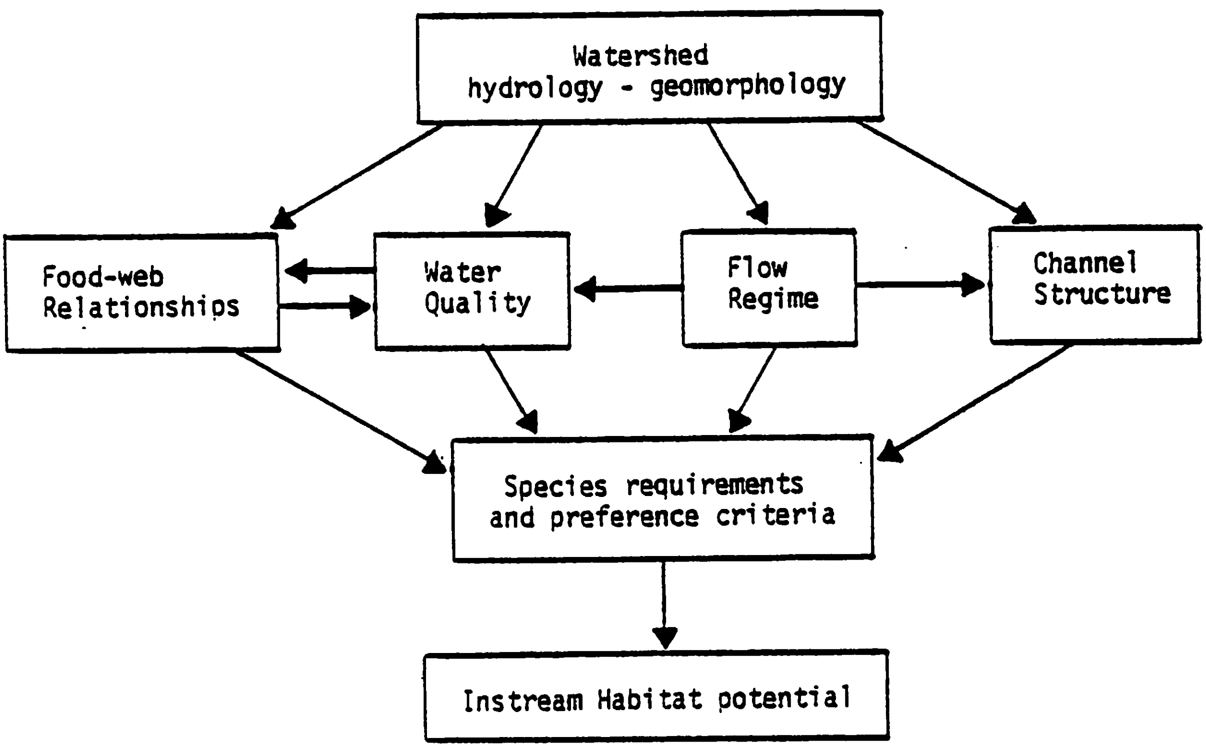

Figure 1. Schematic drawing showing interrelatedness of the primary components affecting fishery habitat potential.

This manual includes a review of the two hydraulic simulation models utilized in the Physical Habitat Simulation (PHABSIM) system, study site selection, a detailed discussion of transect location, and information on data requirements and collection. Additional information on surveying techniques, stream gaging procedures, techniques required for large rivers, a discussion of substrate and cover data measurement, and equipment requirements are contained in the appendices.

THE IFG HYDRAULIC SIMULATION MODELS

In the Physical Habitat Simulation (PHABSIM) system, microhabitat elements such as depth, velocity and boundary conditions (substrate and cover) are integrated with suitability indices (expressed as habitat suitability curves for target species) to determine Weighted Usable Area (WUA), an index of the suitability of a given stream reach at a particular flow for the target species.

The physical stream parameters (depth, velocity and boundary conditions) could be measured at several different flow levels, and a WUA calculated for each. This would be very time consuming; therefore it is important to be able to predict how these conditions vary over several flows of interest, given measurements for only a limited number of flows. Consequently, computer programs have been developed which calculate velocity and depth for flows other than those for which measurements were made.

Proper use of the computer programs involves some training in the field of hydraulic simulation modeling from both a conceptual and a field techniques standpoint. The accuracy of the computer predictions is directly related to the quality of the field data which is in turn dependent upon an understanding of the concepts applied during data collection.

Because this manual emphasizes field techniques, only general concepts and relevant terminology from hydraulic simulation theory will be presented to assist in continuity.

Terminology

Field data collection for PHABSIM is based upon measurements of certain parameters at multiple stream cross-sections according to techniques described later in this manual. Because definitions of certain parameters (flow, stream channel and cross-sectional features and conditions) vary among disciplines and practitioners, the following definitions are presented and used throughout the manual to prevent confusion.

Hydraulic Geometry. Hydraulic geometry refers to dimensions of certain stream features with respect to both the wetted and unwetted portions of the channel. Figure 2 illustrates the hydraulic geometry features used in PHABSIM measurements at individual and multiple cross-sections.

When considering multiple cross-sections the water surface slope is the slope of the water surface at a point and is usually approximated as the difference in water surface elevations at two points divided by the distance along the flow path between the points. The energy slope is the slope of the energy gradient at a point. The energy slope is also approximated as the difference in energy between two points divided by the distance along the flow path. The total energy at a point is the sum of the potential energy due to position (elevation) and kinetic-energy due to velocity.

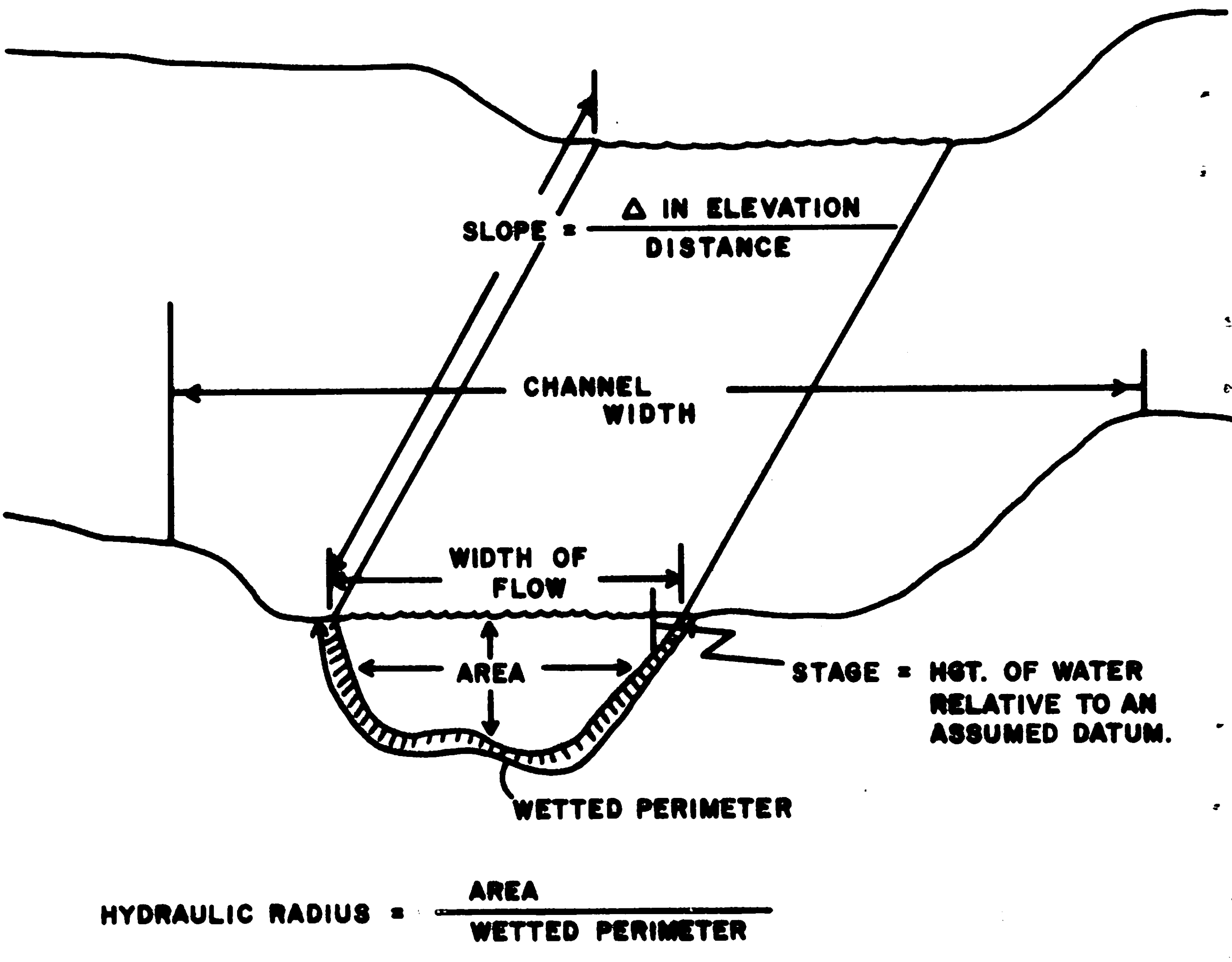

Figure 2. Terminology associated with hydraulic geometry.

Flow Conditions

The hydraulic engineer's terminology for different kinds of flow may be somewhat confusing to those not familiar with the discipline. The terms steady and unsteady flow refer to situations in which the discharge (volume of water flowing past a point in a given time) is respectively either constant or inconstant over time. Unsteady flow occurs below daily peaking hydroelectric dams or after rainstorms on a short time base, and over longer periods of time as streams rise and fall seasonally.

The definitions of the terms uniform and varied flow are potentially confusing, because the term flow, should not always be considered synonymous with discharge only. It is used here in a different sense in that velocities and depths are also components of flow.

Uniform flow occurs when the depths and velocities of flow are the same at all points within the channel reach of interest. Such conditions are very rare or non-existent in natural streams. Varied, or non-uniform flow describes a condition in which the depth and velocity of flow are not the same at all points in the reach. Note that these definitions refer to the structure of the flow in the channel and not to the changes in the discharge as did the terms steady and unsteady flow. If the changes in depth and velocity occur gradually, over long distances, the flow is gradually varied. If they occur over short distances, as in cascades and waterfalls or over wiers, the flow is rapidly varied.

Flow in natural channels is always varied, then, because depths and velocities change throughout the reach. Also, it may be steady or unsteady with respect to the measurement period. Of what concern is this to the field practitioner?

First, the hydraulic models used in the PHABSIM system are usable only if the discharge does not change significantly over a time period which varies with the model used. Second, the relationships used in the mathematical modeling are based on the physics of either uniform or gradually varied flow. Rapidly varied flow situations themselves are not the objects of reliable hydraulic modeling, although the gradually varied conditions in the same stream reach may be.

Hydraulic Controls

Often in aquiring field hydraulic measurement skills one encounters the term "flow control" or "hydraulic control". These terms define both a feature and a resultant condition. As a feature, a hydraulic control is an object which impedes or controls the depth of the flow of water, such as a dam, a wier, a riffle or a transverse bar. The effect of such an impediment is establishment of a predictable stage (see Figure 2) or water surface elevation upstream from the control feature to the next hydraulic control. The condition of preditable stage serves as the basis for our ability to determine certain hydraulic conditions (especially depth) at discharges other than those actually measured.

Hydraulic or flow controls themselves often create local expressions of rapidly varied flow. This condition usually occurs at or below the point of maximum control. If flow is gradually varied at most areas upstream from the control, some sort of hydraulic simulation modeling will probably be suitable. If there are numerous expressions of rapidly varied flow and numerous flow control conditions in the reach, hydraulic modeling may be less reliable.

THE PHABSIM HYDRAULIC SIMULATION COMPUTER MODELS

Depth, velocity and substrate or cover predictions are made using two very different computer models in the PHABSIM system. The object of each model is to predict: 1) velocities at the selected vertical locations or within the cells of the cross-sections and 2) water surface elevations at the cross-sections, from which depths at the verticals may be determined by subtraction of the bed elevations. Available substrate or cover is determined based on the width of flow over the defined substrate or cover types.

<u>WSP (IFG-2)</u>. The Water Surface Profile program calculates hydraulic parameters in gradually varied flow situations and requires that all hydraulic controls within the study reach be included in the measurements. This program determines energy losses between cross-sections for unmeasured flows and interprets these losses into predicted water surface elevations. From the predicted stages, velocities are determined by solution of the continuity equation:

$Q_i = A_i V_i$ where Q = the discharge in cell i

A_i = cross-sectional area at that discharge in cell i

and V_i = velocity in cell_i

The WSP program requires the following data for one discharge as minimum inputs:

1) Hydraulic geometry (cross-section profile across the width of channel) at each cross-section;

2) Water surface elevation at each cross-section;

3) An estimate of the bed roughness at distinct areas along the cross-sections;

4) Known or calculated discharge and;

5) Distance between cross-sections.

Major advantages of WSP are:

1) It may be used, cautiously, with only one set of field data;

2) It may be used to evaluate alternative channel designs and stream improvement structures or at sites where channel configurations change with flow regime, and;

3) It is reliable in the prediction of stage.

Major disadvantages are:

1) The range of extrapolation is limited; at best, predictions for flows 40% less than and 250% greater than the calibration flow are permitted;

2) It does not predict well if numerous occurances of rapidly varied flow or counter-currents exist;

3) Its use requires considerable experience in placement of cross sections because all hydraulic controls in the measured reach must be recognized and measured.

IFG-4 Simulation Program

Because WSP is most reliable for use in rather simple channels, or where few rapidly varied flow regions exist, a simulation technique suitable for use in complex aquatic environments was needed. Also, certain river management situations demanded accurate simulations over a very broad range of flows.

To meet these needs, the IFG-4 hydraulic simulation program was developed. This program represents a simulation system in which linear regression techniques are used to predict velocities and depths.

Empirical relationships for stage and velocity vs. discharge, based on data from a minimum of three measurement sets, are determined. These relationships are of the form:

$$S = aQ^{b} \text{ for stage at each cross-section}$$

$$V_i = a_i\, Q^{b_i} \text{ for velocity at vertical } i \text{ on the cross-section}$$

where:

S = stage
a = slope coefficient
b = intercept value
V = velocity
and Q = discharge

Stage-Discharge Relationships

The measurement of the discharge of a stream requires that both the hydraulic and geometric characteristics of the stream be analyzed. The resulting relationships apply to the measured discharge, but as the flow levels increase or decrease, hydraulic and geometric characteristics will vary. It is this requirement of knowing how the amount of water in the channel varies for unmeasured discharges that has led to the establishment of the stage-discharge relationships. Stages at unmeasured discharges can be obtained based on a measurement of stage (water surface elevation) and a plot of stage from the relationships between stage and discharge developed from data obtained from actual flow measurements. The stage-discharge relationship is influenced by the interactions among channel characteristics, including the cross-sectional area, slope, and roughness, and the volume of water that the channel can carry. A predictable stage-discharge relationship is dependent on steady flow conditions and a stable, permanent hydraulic control.

The stage-discharge relationship will usually not be simple in the following situation:

1) changing bed configuration in alluvial channels;

2) changing location and effect of hydraulic controls as flow changes; many features which provide control at low flows "wash out" at higer flows, changing the stage discharge relationship;

3) breaks in configuration across a cross-section resulting in different relationships during different regimes.

4) differences in vegetation during certain seasons.

The investigator should be aware of several points when attempting to make an accurate hydraulic simulation using stage-discharge models:

1) Predictions may have to be split into several ranges of flow based on the actual relationship of stage to discharge.

2) Hydraulic measurements should be made during the most stable portion of the rating curve.

3) A hydraulic engineer should be consulted if complex relationships exist.

Because cross-sections are treated independently in the IFG-4 program and no energy balancing occurs, there is no strict need for inclusion of hydraulic controls in the selected cross-sections. However, it is suggested that hydraulic controls be included in all measurements, regardless of which program is initially selected because:

1. If for unforseen reasons a third IFG-4 flow is not measured, it is better to use the data as a highly-calibrated and verified WSP than to attempt simulations using a two-point regression; and

2. Quite often, bedform changes will be detected when cross section plots for each flow are superimposed after the study is complete. If these changes are significant, it is inappropriate to use IFG-4 and an WSP simulation for each of the distinctive channel configurations is required.

Advantages of IFG-4 are:

1. Usability in reaches where rapidly-varied flow situations are relatively frequent (as in a cascade-pool situation);

2. Increased predictive range;

3. Reduced dependence upon inclusion of hydraulic controls and knowledge of open-channel hydraulics; and

4. Ability to simulate counter-currents.

Major disadvantages are:

1. Requirement for at least three field measurement trips,

2. Dependence upon extreme accuracy in measuring velocities at exactly the same locations on the cross section; and

3. Necessity for rigid bedforms at all cross sections under the measured range of flows.

STUDY SITE SELECTION

The Instream Flow Incremental Methodology has been developed to assess and predict the impact of altering existing streamflow conditions in reference to available aquatic habitat. The ability to predict the effect of alterations to the stream environment requires that the significant biological, chemical, and physical characteristics of the stream be stratified into logical segments. The variables which affect aquatic organism can be grouped into the categories of macro- and microhabitat. The stratification of a stream can be accomplished by defining how the macro-and microhabitat characteristics vary.

Macrohabitat features are relatively homogeneous and are a function of the rate of longitudinal change in both the biological and physical aspects of the stream. The major variables which describe the macrohabitat are changes in water temperature, water quality, channel structure, watershed, and flow regime. The resulting macrohabitat segments can be further defined by measuring the microhabitat variables of depth, velocity, substrate, and cover. The measurement of these representative microhabitat variables is the base for the Physical Habitat Simulation Model.

The following description will provide the basis by which the investigator can systematically select the macrohabitat study reaches to be analyzed. Accompanying the description of site selection is a checklist of the normal progression and decision-making steps in site selection. A brief description of the individual items can be found in the text and in a more detailed form in Bovee, 1980.

The objective of stream segmentation is to divide the stream into segments based on the differences of the defined macrohabitat features. Specifically, major changes in geology, stream gradient, land use practices, flow regime, and channel structure must be examined. Changes in water quality may also define segment boundaries. The determination of the significance of a change is based on the activity and the system to which it is applied. Frequently, one major macrohabitat change will affect another or several macrohabitat boundaries will roughly coincide with one another. Related to all of the variables is the distribution of aquatic species within the study area. Each of the defined factors may have an individual or a cumulative effect on the distribution of individual species in the stream.

In order to select sampling locations, it is necessary to identify those river segments which have significantly different macrohabitat characteristics. The sequence of steps followed in study site selection may vary with study requirements, knowledge of the stream, and availability of information.

Initial segmentation should be defined on topographic or other large scale maps of the drainage basin. Aerial photos often help the investigator to identify significant macrohabitat conditions. The first step is to determine where major changes in surficial geology and flow regime occur and label them on the map. Specifically, major sources of sediment, changes in geologic features, input of tributaries which amount to a 15% increase in streamflow, and the accretion or depletion of streamflow due to groundwater should be defined.

The second level of segmentation is made by analyzing the changes in basin relief over the length of the river (Figure 3) to be studied. A river naturally reduces in gradient as it flows downstream. However, sharp changes in gradient often indicate significant effects on the macrohabitat features. Steep, headwater areas are indicative of fast, cool water that is generally high in dissolved oxygen. In contrast, slow, low gradient water is usually warm and lower in dissolved oxygen. Significant changes in the stream gradient can limit species distribution and growth potential of aquatic species and should be defined with a segment boundary.

The third boundary segmentation step is to define areas where major changes in stream form and channel structure occur. This change is often closely associated with changes in the surficial geology of the river basin. Specifically, the relation of pools to riffles and runs, braiding, and significant aggradation or degradation should be evaluated. The differences between segments can be defined by changes in : sinuosity (P) defined as the length of the stream valley divided by the length of the stream; width/depth ratio of the stream channel; or changes in the average size of materials composing the bed of the stream. These changes are often the direct result of alteration of the watershed and/or different types of geologic conditions.

The next level of segment delineation should be to define those areas of the river where significant changes in water quality occurs. Specifically, point and non-point sources of pollution, thermal effluent, differences in riparian vegetation, permanent passage barriers, industrial and agricultural activity, and aquatic species distribution should be defined.

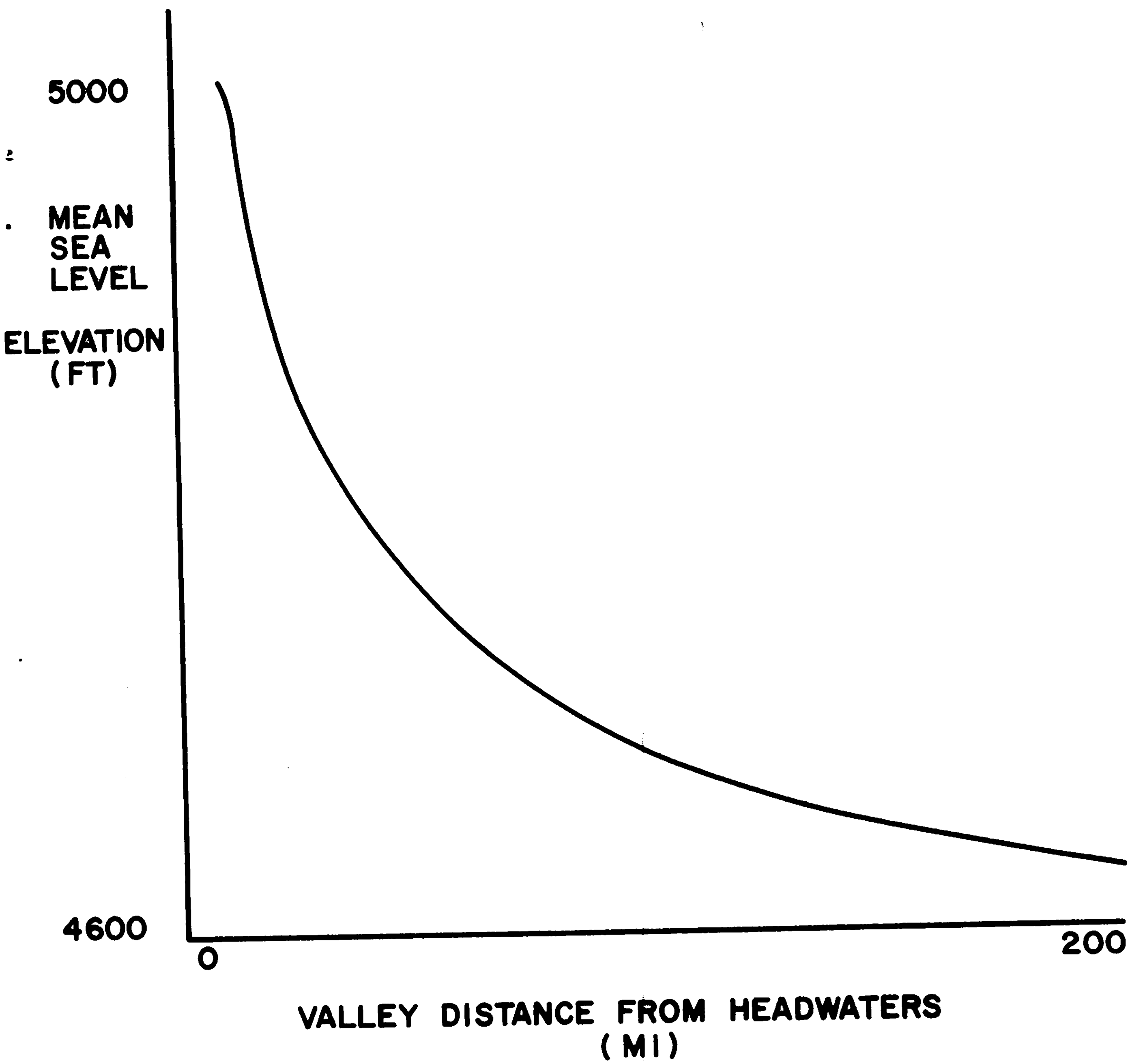

Figure 3. Basin relief diagram as used to determine initial segmentation.

After the major macrohabitat features have been defined, the boundaries should be consolidated to reduce the large number of boundaries and also eliminate any superfluous definitions. The consolidation of boundaries should be based on the significance of the boundary and the effect on adjacent segments. For example, the differences caused by two adjacent geologic formations may be insignificant, resulting in removal of several boundary segments. The effect of variable segments must be evaluted in relation to those boundaries which indicate definite changes in the stream environment. If the investigator is unable to determine the effect of a specific condition, help should be sought from competent professionals. Final segment boundaries should be selected based on discontinuities in the macrohabitat which are most relevant to the problems being analyzed. It is at this point that the investigator must also decide if the study is going to be based on a representative analysis of the river or if it will concentrate on specific river segments which contain conditions absolutely critical to the aquatic organisms being considered.

These "critical" reaches may be areas required for successful passage or spawning or regions designated as special use areas. All unique reaches should be defined as Critical Reaches and included in the sampling program.

The remaining sampling areas must be selected based on being representative of the rest of the river. Each of the segments previously defined is subdivided into several Representative Reaches. The length of these sections can be based on the relationship of average width of the channel multiplied by 7, which results in an average length of repeating features or a standard unit of length. Each reach should include features that repeat throughout the section. These features may include pool-riffle sequences, meanders, or other channel features. Once the length of the representative reaches has been determined, the segments should be marked on the section map. Atypical or nonrepresentative sections should be immediately eliminated. Atypical reaches may include bridge crossings, culverts, unnatural constructions, and accretions or depletions from tributaries or diversions. The remaining segments should be sequentially numbered and through a random selection process, three to five candidate representative reaches should be selected.

The last step in the study site selection is to inspect each candidate site. This is best accomplished with a field reconnaissance trip, usually during low flow periods. Any previously undetected anomalies should disqualify the section as a representative reach but may be reclassified as a critical reach. The result is that one or more candidate reaches are chosen to represent conditions typical of the entire segment. These reaches, along with selected reaches from other segments become the object of the study of microhabitat conditions.

CHECKLIST FOR THE ESTABLISHMENT OF STUDY AREAS

1 ________ Topographic maps or suitable substitutes of the study area have been assembled so that entire area is shown on one map.

2 ________ Significant sediment sources, such as moraines, landslides, and areas of sediment generating land use have been identified and marked on map (if applicable).

3 ________ Geologic contacts between units of different sediment or water transmitting characteristics have been located and marked on map (if applicable).

4 ________ Tributaries accreting more than 15% of the total flow below the confluences have been identified and marked on map (if applicable).

5 ________ Diversions removing more than 15% of the total flow of the river above diversion have been identified and marked on map (if applicable).

6 ________ Ground water sources or diffuse small tributaries which in aggregate add 15% to the average base flow, or add 15% to the drainage area-precipitation product, have been isolated and marked on map (if applicable).

7 __________ Longitudinal profile of stream constructed.

8 __________ Segment boundaries based on relief have been determined.

9 __________ Locations where channel sinuosity changes appreciably have been identified and marked on map (if applicable).

10 __________ Locations where channel shape, bed particle size, or bank vegetation change appreciably have been identified and marked on map (if applicable).

11 __________ "Permanent" passage barriers have been identified and marked on map (if applicable).

12 __________ Point sources of pollution or thermal effluent have been located and marked on map (if applicable).

13 __________ Areas of land use affecting non-point accretions of waste load have been identified and marked on map (if applicable).

14 __________ Stream reaches containing populations of cold water species and warm water species, as well as transitional reaches have been identified and marked on map (if applicable).

15 __________ Segmentation based on temperature utilizes something besides species composition as determining factor. If this option is used describe factors used for segmentation (e.g. effect on water quality).

____

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16 __________ Segment boundaries isolating lengths of stream of less than 10% of the total stream length have been consolidated (remember "hard" segment boundaries take precedence over "soft" boundaries).

17 __________ If watershed or channel disequilibrium problems are anticipated, an expert in sediment transport and channel change has been consulted.

18 __________ If water quality is a problem, or may be a problem under proposed action, water quality monitoring or modeling stations have been identified and marked on map.

19 __________ Critical Reaches, if present, have been identified and marked on map (may include reaches less than 10% of total stream length in segment).

What is the nature of the critical reach? (Culvert, shallow bar inhibiting passage, spawning areas, etc.)

20 __________ Average width of stream within each segment has been determined.

21 __________ Length of candidate representative reaches has been calculated.

22 __________ Candidate representative reaches have been marked on map at appropriate spacing and numbered sequentially from the bottom of the segment to the top.

23 __________ Candidate reaches having bridge crossings or culvert crossings have been eliminated.

24 __________ Three to five representative reaches have been randomly selected.

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____

25 __________ Lengths of stream represented by representative reaches have been determined.

26 __________ Lengths of critical reaches have been determined.

27 __________ Total number of study sites selected (representative + critical reaches).

TRANSECT LOCATION

Transects must be located to characterize both the hydraulic and instream habitat conditions of the river segment being investigated. Each transect, even on a small stream, represents a time commitment of 1 to 2 man-hours of field work. Consequently, it is advisable to describe the study reach with as few transects as practical. However, the use of too few or improperly placed transects will usually result in a distorted assessment of the microhabitat conditions. From 5 to 7 transects will normally provide an adequate description of the microhabitat characteristics in a single pool-riffle sequence. Ten to twelve transects would be required for a two cycle pool-riffle or meander-crossing bar sequence.

Transect placement is dependent on the hydraulic simulation model used and the habitat characteristics of the study reach. The coupling of the WSP and IFG-4 hydraulic simulation models with the habitat requirements requires as a minimum two (2) transects. Recall that the WSP model is a model that relates one cross section to another. Consequently, each transect is dependent on the adjacent transects. The IFG-4 regression model treats transects independently and does not require complete hydraulic integrity. Only the WSP model requires that all hydraulic controls within the study site be measured; however, it is to the advantage of the investigator to detail each hydraulic feature. Therefore, with either hydraulic program, the downstream most transect should be placed at a hydraulic control and all controls within the study reach should be crossed by a transect (Figure 4).

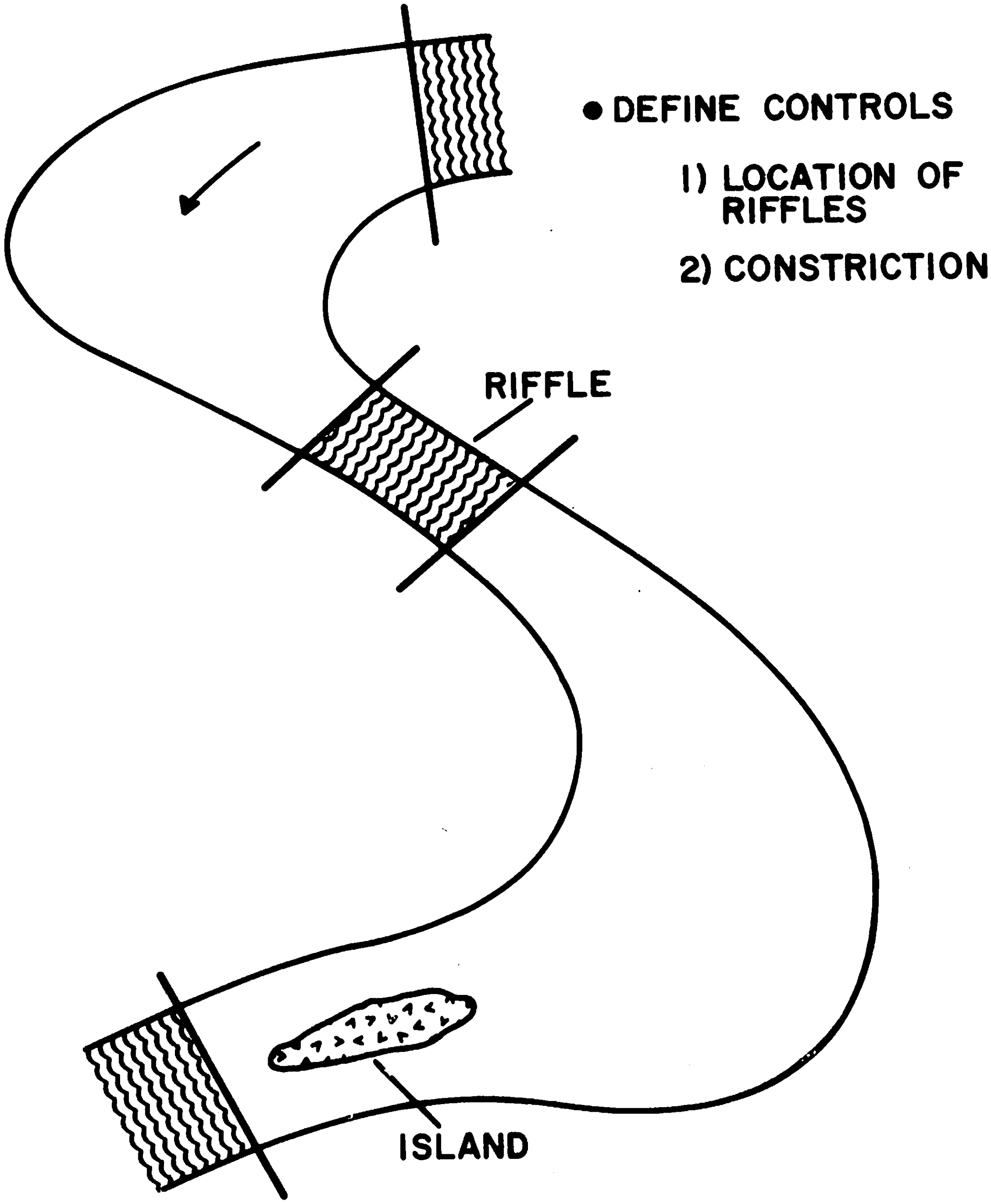


Figure 4. Initial transect placement defining the hydraulic controls.

After transects have been determined for all hydraulic controls in the study site, additional transects should be placed to define other significant channel shape and instream habitat conditions (Figure 5). Depending on the level of detail desired, additional transects may be added to define the transition zones from one type of habitat to another (Figure 6). The investigator will have to balance data needs with available time, manpower, and monetary resources. When placing habitat descriptive transects, remember that the computer extends the conditions on each transect both upstream and downstream, though. The user can specificy different weighting factors based on knowledge of the study site.

The placement of cross sections across islands requires that the water surface elevations must be equalized on both sides of the channel. This often requires that the transect be angled or dog-legged across the island (Figure 6). The ability to accurately and efficiently perform the hydraulic simulation is dependent on correct transect placement. A hydraulic engineer versed in the biological requirements should be consulted if complex stream channels or unique hydraulic situations arise.

The final suggestion concerning the placement of transects deals with location of transitional transects at the heads of pools. The head of a pool will often migrate upstream with an increase in discharge. The leading edge of this zone is especially prone to the development of local eddies and vortices. These currents may be quite violent at times of high flow and are impossible to adequately represent with the type of hydraulic models being applied. Therefore, it is recommended that transition transects be placed well toward the pool but still within the transition zone. At high flows this

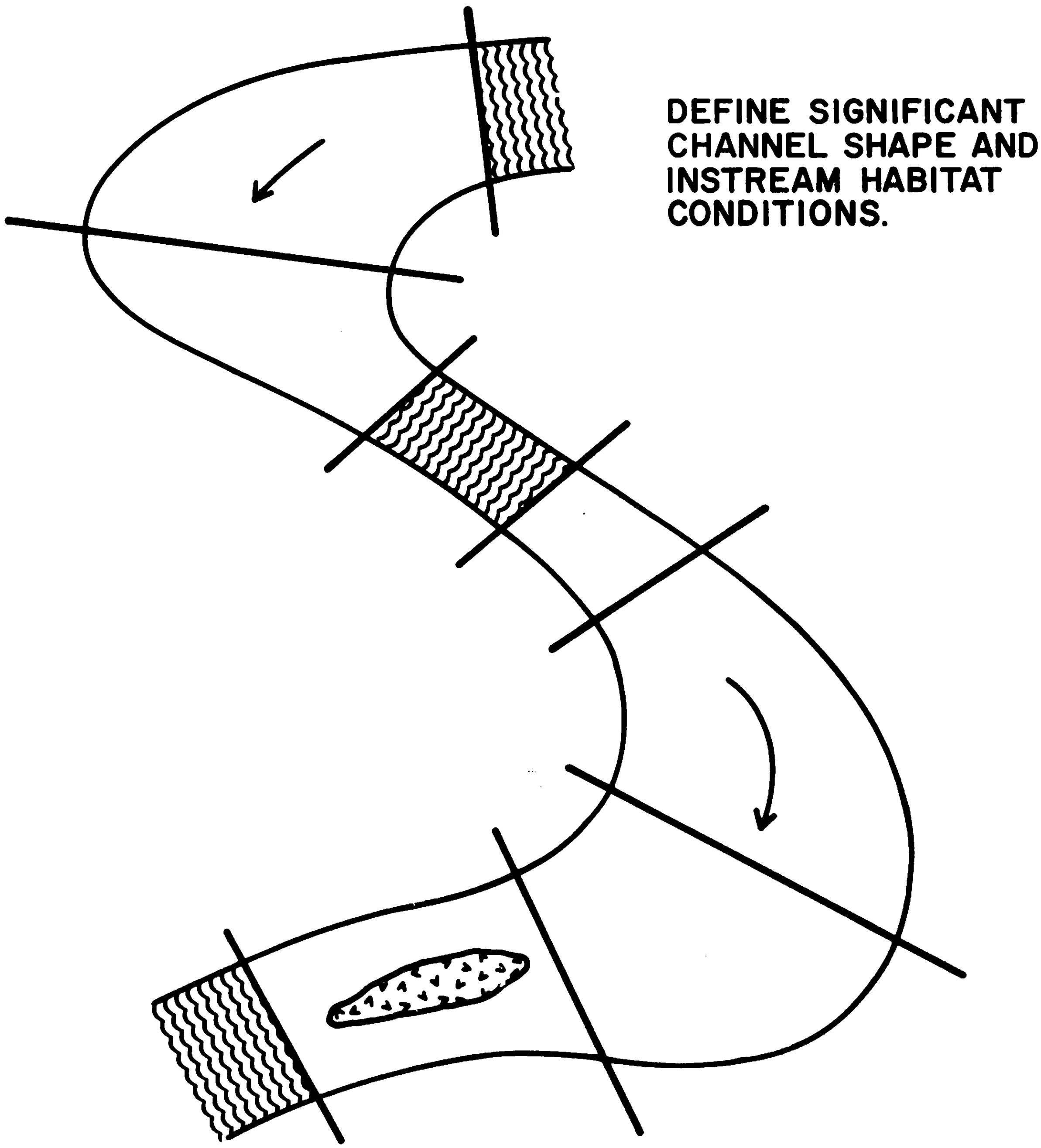


Figure 5. Addition of transects to describe the channel geometry and velocity characteristics of the stream.

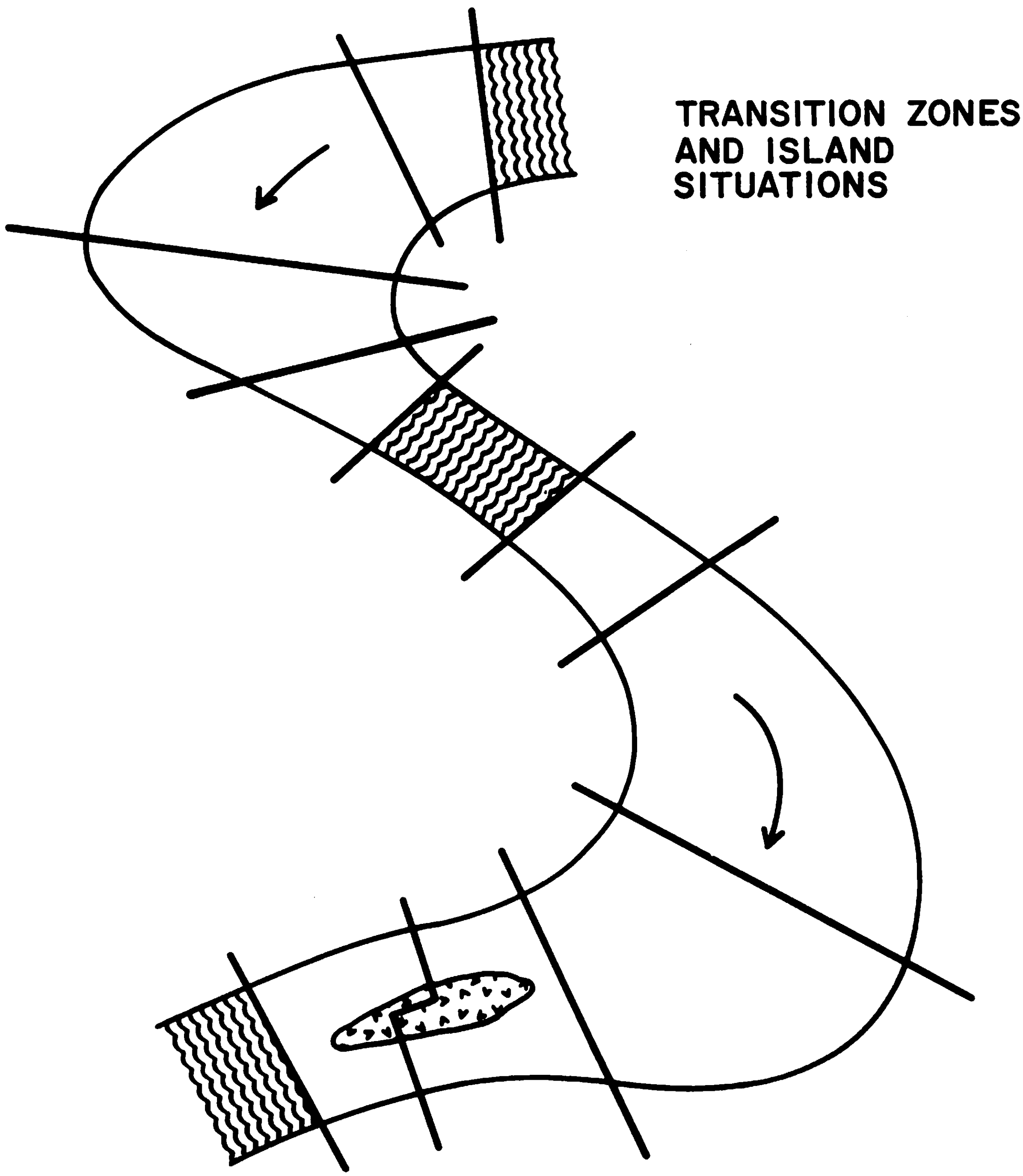


Figure 6. Final transect placement

transect will represent a rather distinct pool transition-type habitat which may be of considerable biological importance.

FIELD DATA AND INFORMATION REQUIREMENTS

Site specific data essential for successful use of either the WSP or IFG-4 hydraulic simulation model must be obtained at a minimum of four cross sections referenced to a common bench mark. These data requirements are:

1. Stream gaging notes containing depth and velocity measurements for each cross section, referenced to the left bank headstake (note whether looking upstream or downstream). One set of measurements for WSP, three sets for IFG-4.

2. A summary of water surface elevations for each flow for the individual cross sections, and a closed level loop through all headstakes and bench mark. (See Appendix A).

3. Stream bank distances between adjacent cross sections.

4. Substrate and/or cover composition at each vertical. (See Appendix D.)

5. A narrative description, sketch, or photographs of the study site depicting transect locations, bench mark, head and workpin positions, distance between transects, and any other pertinent information.

It is desireable to identify the location of the study reaches on topographic or highway maps. In addition, whenever the study is expected to provide the basis for a legal proceeding, or application for a water right under state law, it is advisable to include a legal description of the study site (temporary bench mark and head stakes at the downstream hydraulic control).

Field notes may be recorded in a variety of acceptable formats (Brinker and Barry, 1957, USBR, 1967, Grover and Harrington, 1966), but the Cooperative Instream Flow Service Group has found that for chain of custody purposes it is desirable to compile pertinent information and data onto a standardized field form. It is recommended that all field measurements and explanitory notes be directly entered into a waterproof field notebook. These data should then be compiled and transferred onto the appropriate field form and reduced by the field crew <u>prior to leaving</u> the study site. Both the field book and field forms constitute the raw field data.

SEQUENCE OF REQUIRED FIELD WORK

The following sequence of activities has been found to provide an efficient work plan, and to ensure that all relevant data are collected. While other sequences are possible, this one should be followed at least until proficiency is gained in carrying out both field and office phases of PHABSIM.

Step 1. Locate all transects within the study reach and establish a permanent benchmark. Establish headstake locations for each transect.

Step 2. Survey a level loop to determine relative headstake elevations (if distances or topography demand).

Step 3. Install a permanent staff gage that will remain in place over the course of the study. In addition, a temporary staff gage should be installed and read before and after each transect measurement.

Step 4. Complete a water surface elevation summary for both banks and each cross-section as quickly as possible.

Step 5. Survey the ground/streambed profile at each transect indicating the nature and extent of vegetation and substrate conditions.

Step 6. Measure velocity distribution and determine the discharge for each transect.

Step 7. Recheck and record the temporary staff gage upon completion of velocity measurements. Recheck and record the reading of the permanent staff gage after the last transect is measured.

Step 8. Measure distances between transects at water's edge along both banks.

Step 9. Prepare a reference map of the study area, noting angles of transects and unique situations.

Step 10. Review field notes for completeness.

Step 11. Inventory equipment.

Step 1: Locate Transects

Transect locations should be determined in accord with the previous discussion of that subject. Once located, the ends should be permanently marked by a headstake. A headstake may be a length of pipe, concrete reinforcing bar (rebar) or surveyor's hub driven well into the ground approximately flush with the surrounding surface. The headstake should be located to avoid disturbance by cattle, wildlife or humans and it must be long enough to penetrate through the frost zone so that frost heave will not change its elevation. The location of each headstake must be clearly documented, and flagged for future location.

The headstakes should not be used as tie-offs or anchors! If it is necessary to provide something with which to secure a tagline or teather a boat, drive a steel fence post into the streambank on line with the transect but at least two feet away from the head stake.

Step 2: Headstake Elevations

The purpose of determining headstake elevations is to provide a point of known elevation on each transect for use in determining the remaining ground elevations for the transect. Headstake elevations are determined by simple surveying techniques with respect to a defined benchmark elevation (Appendix A).

Headstake elevations should be measured to the nearest 0.01 foot or within acceptable closure error. The error of closure should be within the limits of third order accuracy. Third order accuracy is defined by Equation (1).

$$\text{Maximum Error of Closure} = 0.05\,(M)^{0.5} \qquad (1)$$

where: M = length of the level loop in miles

From an applications stand point this means that 0.02 ft is usually about the maximum error of closure allowed for the level loops where site specific application of the IFG hydraulic models is anticipated.

Step 3: Install Staff Gage (Permanent and Temporary)

A staff gage should be installed to facilitate monitoring changes in the streamflow water surface elevation. The permanent gage should be installed in a location where it will always be in the water and be solid and not allowed to shift during the study time period. In contrast, a temporary staff gage may be as simple as an engineer's ruler or a marked stick. The purpose of the gage is to provide an indication of whether the water level and consequently the discharge remained steady for the period of measure. The staff gage reading, date, and time of day are to be recorded when conducting the measurements and at subsequent field trips.

Step 4: Measure and Summarize Water Surface Elevations

Measurement of the water surface elevation requires a special procedure for the rodperson, and good coordination between rodperson and levelman. The rodperson should dip the rod to the water surface and lift it again as soon as the rod forms a meniscus with the water. The level operator should read the high rod reading repeated the most often. The rodperson can help by loudly indicating "touch" when the rod touches the water surface. Although somewhat difficult to learn, this technique often yields more effective and consistent water surface elevations than standing the rod at water's edge.

The water surface elevation should be measured on both sides of the river at each transect. If the elevations from both sides of a transect are not equal, an average should be calculated for the transect. One should expect water surface elevations to be unequal at the inside and outside edges of bends. Water surface elevations should be measured to the nearest 0.01 foot. Several readings may be taken of each point to ensure reproducability.

A water surface elevation summary sheet (or page) contains the water surface elevations on both banks at each transect within the study area and must always be completed prior to leaving the study site.

Step 5: Cross-sectional Profiles

A ground/streambed profile must be measured between the headstakes at each cross section. Such a profile is defined by a series of elevations and horizontal measurements, commonly referenced to the left bank headstake. (Note: Left bank here is defined as being on one's left side when looking upstream ~~downstream~~). Horizontal distances (X coordinates) are generally recorded to the nearest 1.0 foot, while elevations (Y coordinates) are measured to 0.10 foot. The shape of the cross-section is quite important in use and calibration of the PHABSIM computer models; the reader is advised to read Appendix F for computer interpretation of the input data.

Zero the tape over the headstake by tieing a piece of nylon cord to the end of the tape and tieing it off to a spike or tree on line with but behind the headstake.

While determining the cross sectional profile the rodperson needs only to make measurements where there is an obvious break in topography or where a change in substrate material is encountered. The investigator should note substrate measurement locations based on the establishment of the vertical segments. Usually 10 to 15 rod readings are adequate to describe the shape of a cross section. In deep rivers, if use of a level rod is impractical streambed elevations may be determined by sounding. Boat measurement techniques are discussed in Appendix C.

The substrate should be described at each measurement point along the cross section. Particular attention should be given to obtaining a groundpoint measurement whenever the substrate changes along the transect (Appendix B).

Step 6: Measure Velocity Distribution and Discharge

One transect is usually selected as being the best for a discharge measurement. However, both the WSP and IFG-4 hydraulic simulation models compute a discharge for each transect. Therefore, it is important to use good stream gaging techniques for each transect.

The location (X coordinate) at which a velocity measurement is made is called a "vertical". Verticals are to be referenced to the left bank headstake (left defined while looking ~~downstream~~ upstream) not the waters edge. Placement of verticals, like cross-section placement, is done to satisfy both hydraulic and descriptive data needs, and is only partially objective. Also, as in placing cross-sections, measurement of more verticals than are probably necessary seems an assurance to those who do not fully understand the reasons for vertical placement.

To prevent confusion, a vertical will be described here as an X-coordinate (distance from zero-point) at which a calibration velocity(ies) will be measured. Several ground-point elevations may be determined during the cross-section profiling process, but verticals will be placed only at the points which satisfy the following data needs:

1. Each vertical must describe the velocity and substrate conditions within the cell it bounds. (The first vertical bounds a cell between its position and the zero-point on the cross-section. The second vertical bounds a cell between its position and the position of the first vertical);

2. Each vertical must describe velocity conditions within cells through which no more than 10 percent of the total stream discharge passes.

In the simplest application, vertical placement directives are the same for both WSP and IFG-4 uses. In both cases, a vertical may be placed at the edges of breaks in hydraulic and/or habitat features such as substrate, velocity, depth or cover.

In the WSP program, the cell velocities (v_i) are determined from cell discharges using the equation $v_i = Q_i/A_i$ where Q_i is the cell discharge and A_i is the cross-sectional area of the cell. The cell discharges are obtained by distributing the total flow according to the relative ability of the cells to transport water.

Q is the total discharge at the reach and Q_i is the partial discharge for the cell in question. Cell velocity (v_i) is computed as

$$v_i = \frac{Q_i}{A_i}$$

In the IFG-4 program, the cell velocity transferred to the HABTAT program is computed as the average of adjacent velocities measured at the verticals:

$$v_i = \frac{V_1 + V_2}{2}$$

The depth of the cell is computed as the averaged depth of adjacent verticals, as above for velocity.

WRONG

~~The substrate or cover for a cell is defined by the right-most vertical of the cell in question. For example, looking downstream beginning at the left-bank of the channel, the substrate in the first cell is that defined by the second vertical; for the second cell, it is the substrate assigned by the third vertical, extending back to the second vertical, and so on.~~

If the velocity distribution is quite irregular, the velocities at adjacent verticals may be quite different, and their average quite different from the actual cell mean velocity. In such cases, a centroid velocity, measured in the center of the cell may be desirable for purposes of calibrating the WSP model. Typically, the "known" or "measured" velocities used as targets when calibrating WSP models are averages of the adjacent cell velocities. Measurement of a centroid velocity often provides a more meaningful value but must be done accurately in the center of the cell.

In summary, placement of verticals in the field should correspond to breaks in the depth, velocity, substrate and cover; the depth and velocity values utilized in HABTAT calculations are averages of adjacent verticals. Substrate values for individual verticals define conditions back to the previous verticals. Centroid velocities should be measured for calibration purposes when averaged adjacent vertical velocities are considered inaccurate.

Up to 99 measurements may be recorded at a single transect and used with either hydraulic model. The number of verticals used will usually be relatively independent of stream size. For the determination of the velocity distribution, 10-20 verticals are typically used, whereas the transect used for the discharge measurement should employ 20-30 verticals. In all cases, the velocity to be measured is the mean column velocity at the vertical. Velocity measurement techniques and rules governing measurement of mean column velocity may be found in Appendix B.

Because measurement of the velocity distribution is usually the most time consuming portion of the data collection procedure, it is recommended that current meters be provided for more than one member of the field crew. The cost of additional equipment is minimal compared to the savings in time and manpower afforded by extra current meters.

When multiple sets of field measurements are to be used (IFG-4 hydraulic model) it is imperative that all the velocity measurements for subsequent data sets are made at the same verticals (X-coordinates) as they were for the initial data sets. If the stream width has increased since the initial measurement additional velocity measurements are made along both shorelines to extend the original spacing. If streamflow has decreased to the point where some of the verticals used during a previous measurement are dry, simply enter "no flow" in the field book. Do not ignore the situation and fail to comment on the flow condition!

Step 7: Recheck Staff Gage

Recheck the staff gage after you have finished the velocity measurement. The purpose of checking the staff gage is to determine if your measurements were taken during steady flow (constant discharge).

If the stage has changed during the course of the measurement, record this difference. In the past, if the two calculated discharge measurements were not within 20% of one another, it was suggested that the measurements be redone. However, by knowing the stage change between cross sections, a correction factor can be calculated based on a reference discharge and cross section area. The utility of this correction factor is effectively limited to differences of less than 50% of each other.

Step 8: Distance Between Transects

Each transect must be assigned an index value which clearly identifies its location with respect to all other transects in the study reach. The surveyor's jargon for such an index value is "stationing". It usually represents the thalweg distance from a particular transect to the most downstream transect in the study reach.

Surveyors commonly record horizontal distances as stationing in 100 foot units plus the remaining fractional part. For example, stationing for a distance of 327 feet would be written as 3+27. Station indexing should start at the most downstream transect (0+00) and increase in the upstream direction. For most instream flow studies the horizontal measurements used to determine stationing need only be measured to the nearest 0.5 foot, with station indexing computed to one foot. Stationing provides a continuous longitudinal reference datum through the study reach. As such, it may be used to define distances between transects; used in conjunction with top widths to estimate surface area, or used with streambed and water surface elevations to estimate gradients.

To determine transect stationing, measurements are made between adjacent transects at the water's edge <u>on both sides of the stream</u>. This is particularly important around bends or where transects cut across the stream channel at an acute angle.

Step 9: Sketch and Photograph the Study Reach

In all cases a sketch should be made and photographs taken of the study site. It is a rare instream flow study that is completed with only one trip to the field sites and relocating transects is difficult if not impossible without documentation. Also it is an exceptional investigator who can convincingly present an argument or author an effective report without employing sketches and/or photographs of the study reach.

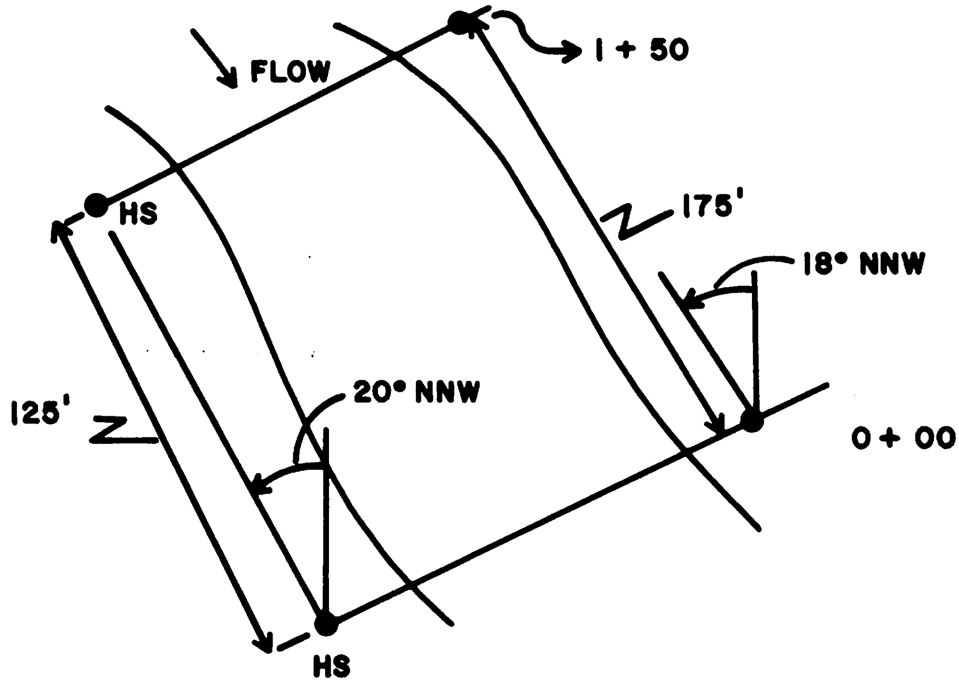
In many cases a sketch drawn to scale is indispensable, particulary when communicating with the engineers. Scale drawings can be easily constructed if headstake locations are clearly referenced to one another. This can be accomplished to either of two ways (Figure 7):

1. The distance and magnetic bearing between headstakes of adjacent transects is recorded along with the distance and magnetic bearing between the left and right bank headstakes at each transect, or;

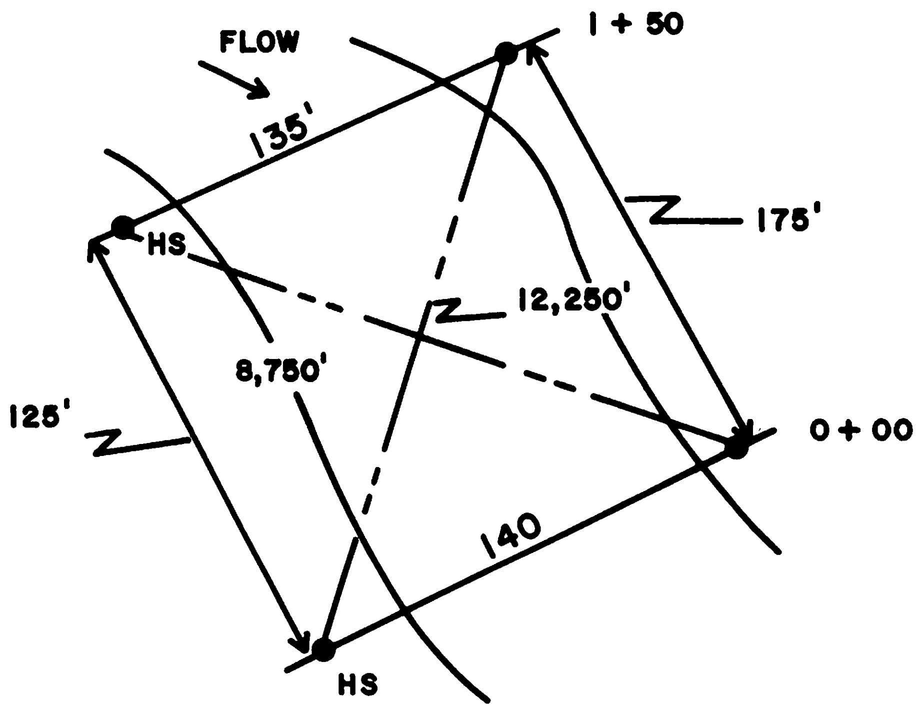
2. The diagonal (over water) distances between headstakes of adjacent transects is recorded in addition to the streambank distances between them.

Step 10: Review Field Notes

Before leaving the study site a quick check should be made of the field books to ensure that nothing has been overlooked. The following information and field measurements should be recorded reflecting the order in which the data were collected.



(A) DISTANCE AND MAGNETIC BEARINGS



(B) DIAGONAL DISTANCES

Figure 7. Sketch of a study reach.

1. sketch and brief narrative description of the study site; including magnetic bearings of each transect

2. level notes (with personnel identified)

3. water surface elevations at each transect

4. cross section profiles; includes substrate and streambank vegetation

5. staff gage reading before and after velocity measurements

6. velocity measurements at each transect

7. discharge measurement calculated for each cross section

8. photos, if not taken during an earlier visit

Step 11: Inventory Equipment

While the field notes are being reviewed for completeness, other members of the field crew should assemble all the equipment to ensure that nothing has been left on the streambank. It is also a good practice to write down any maintenance or repair that might be needed while the problem is still fresh in the user's mind.

FIELD DATA FORMS

Two types of data forms are usually used in a PHABSIM measurement process. The first is an engineer's surveying notebook, preferably for transit notes, which has 4" x 6" pages and ruled columns and rows. The pages are securely bound and made of 50% rag paper which does not deform or spread pencil image when wet. All field measurements necessary for PHABSIM may be recorded in such notebooks. The format for entering surveying data in such notebooks is presented in Appendix A.

The second form is an intermediate office form, useful in compiling field notes for easy review prior to entry into computer data forms. An example of one such form is presented here. While the following form is useful in discharge computations and the coding of WSP data, a form which compiles point velocity depth and elevation values at multiple flows might be more useful in compiling and reviewing IFG-4 data.

INSTRUCTIONS AND EXPLANATORY NOTES
FOR
FIELD DATA FORMS

This form provides a standard format for the compilation of field measurements and related data collected for use with the PHABSIM system for instream flow studies. These forms are to be completed by field personnel as part of their work assignment prior to leaving the job site.

These forms and accompanying field notes constitute the critical evidence in a legal proceedings. They should, therefore, be legible and retained in a secure and permanent file.

Page 1 - General

The *study site* may be identified by any popular name which has meaning to the field crew.

Location provides information which references the study reach to an appropriate legal description, river mile, highway mile post, latitude-longitude, township and range, etc. The description should allow one unfamiliar with the study to locate the field site on a map or aerial photograph.

Crew members identify individuals and their field duties.

Weather conditions are important to note for they often have both a direct and indirect influence on the field work. Air temperature, precipitation, and wind conditions should be noted as well as snow or ice conditions along the stream.

Page 1 - Transect Data

Indicate the *transect number* with respect to the total number of transects at the study site (i.e., 5 of 7). The *magnetic bearing* of the transect is an essential piece of information if one intends to prepare a scale drawing of the study reach. (A scale drawing is needed if centroid reach lengths are to be used with the WSP model.) The bearing should be recorded to the nearest 30 minutes with a reliable compass.

Both diagonal overwater measurements between the water's edge marks on adjacent transects may be substituted for magnetic bearings, if desired.

The *date(s)* during which the field work was conducted should be recorded and a conscious effort made to *photograph* the study site and each transect. If this cannot be done, indicate "no photographs" by checking the appropriate box on the form.

Identify the *left and right* streambanks while looking ~~downstream~~ upstream. Data reduction and coding will be easiest if one looks ~~downstream~~ upstream and references all field measurements pertaining to the channel geometry and horizonal spacing of the velocity measurements to the head stake on the left bank. (Horizontal distances will increase from the left bank to the right bank with this orientation.) Occasionally, field conditions may dictate that the right streambank be used as the reference bank. This is acceptable, but the right bank head stake must be clearly identified as the reference point in all field notes which pertain to that transect.

Several measurements should be recorded at each transect early in the field exercise to serve as a "double check" on measurements that will later be recorded as part of the cross section and velocity measurement work. Among the most valuable measurements to obtain twice are: the overall distance between the left bank and right bank head stakes (LBHS to RBHS) and, if applicable, the horizontal distances between the head stakes and workpins (LBHS to LBWP and RBWP to RBHS). It is also quite useful to have the left and right water's edge (LEW and REW) referenced to the respective head stake or workpin and the top width of the stream recorded. It is possible that the transects can be located and cross-sectional geometry measured prior to streamflow measurements. If the streamflow has changed since the transects were first located, then the edge of water and top width measurements contained in the streamflow data will not correlate with the initial cross section measurements. In such cases, the field crew is responsible for providing a brief clarifying statement regarding the reason for the apparently contradictory measurements.

The ***elevation*** of the ***head stakes, workpins,*** and the left bank and the right bank ***water surface elevations*** are required to the nearest 0.01 foot at each transect. These elevations are best determined by differential leveling techniques.

It is important to measure the *horizontal distance between the transects* near the water's edge along both stream banks to the nearest 1 foot. Transects must be placed perpendicular to the flow. At times, they may not be parallel to each other and the horizontal distance between adjacent transects measured along one stream bank may be significantly different than the distance measured along the opposite stream bank.

Page 2 - Cross Section Profile Data

Indicate which point along the transect is being used as the *base (zero) point* for the horizontal measurements and reference elevation. Normally this is the left bank head stake (LBHS).

Record the elevation of the base point with respect to the project datum (Temporary Bench Mark) as determined by differential leveling. Indicate the *backsight* rod reading and the computed *instrument height.* If soundings are to be made, the water surface elevation must be determined and clearly recorded. Rod readings or soundings are made at major breaks in stream bank/streambed topography or changes in substrate/streambank vegetation.

Record the horizontal *distance from the head stake* to the point at which rod readings or soundings are being made. Normally, this will be measured from the left bank (LB) but may, at times, need to be referenced from the right bank (RB). Indicate which head stake is being used as the base (zero) point for the horizontal measurement by circling the appropriate abbreviation (LB or RB).

Rod readings are recorded to the nearest 0.1 foot whenever possible. Many field situations will not accomodate measurement to this degree of precision, particularly when the substrate consists of irregular shaped or soft materials, or when one is sounding for the channel bottom. In such cases, simply record the measurement as best you can.

Ground/stream bed elevation is determined by subtracting the rod reading from the instrument height or the sounding from the water surface elevation.

Substrate is the plant or mineral base upon which aquatic insects live or fish spawn. It should at least be identified by the "eyeball technique" (i.e., sand, cobble, boulder, etc.). A cross section profile measurement (rod reading) is to be made wherever the substrate type changes (i.e., silt-sand to sand; or submerged vegetation and brush to cobble streambank).

Page 62 also provides a gridded work space for use in plotting the ground/streambed profile (cross section) at the transect. Visual inspection of the plot is normally all that is required to detect errors or omissions in the raw data entries (distance from head stake, rod reading, or sounding). The plot will also aid in determining the number and placement of verticals needed for velocity measurements and substrate descriptions; particularly in turbid streams. The points selected for determination of the ground/streambed profile and changes in substrate composition need not necessarily coincide with those selected later for measurement of velocity distribution.

Page 3 - Velocity Data

Indicate whether the streamflow being measured is the low, medium, or high calibration flow.

The water surface elevation must be recorded at the time velocity measurements are made. It is recommended that the water surface elevations be measured at both water's edges at each transect; once before and once after velocity measurements are taken.

Distance from head stake is the horizontal measurement from the head stake to each vertical along the transect at which the flow depth and velocity measurements are made. It should be measured to the nearest foot for most situations. On very small streams or large rivers, discretion and common sense should prevail. Error in horizontal measurement less than 1% is desired but up to 5% is acceptable. *It is extremely important that during return visits to the study site, velocities are measured over the same points on the streambed (i.e., at these same distances from the head stake).*

Streamflow will be computed from the velocity and depth information recorded at the verticals. Thus, in addition to describing the horizontal velocity distribution one should attempt to subdivide the channel such that 5% to 10% of the total flow passes between adjacent verticals. This is especially important for the transect(s) selected as being "the best" for obtaining the discharge measurement.

Circle either LB or RB to indicate which head stake is being used as the reference point; then continue to use it for all return visits.

Angle coefficient is usually 1.0 since transects are to be placed at right angle to flow. However, flow direction may shift with a change in discharge. A transect placed at right angles to high flow may be skewed with respect to a lower flow. In such cases an effort must be made to determine the angle at which the flow intersects an imaginary line perpendicular to the transect. Record the cosine of that angle as a correction factor. As a general rule of thumb, the correction factor for angles of intersect up to 15 degrees is insignificant and nothing need be recorded.

Flow depth is the vertical distance from the water surface to the channel bottom at the place where the velocity is measured. Flow depth is to be recorded to the nearest 0.1 foot, if possible. If the channel bottom is soft, care must be taken to avoid submerging the foot of the wading rod or the sounding weight and obtaining an erroneous depth measurement.

Streambed elevation is computed at each vertical by subtracting the measured flow depth from the average of the RB and LB water surface elevations for that transect at that particular flow.

Observation depth indicate at what depth the point velocity was measured (i.e., 0.6 or 0.2 and 0.8 the depth measured from the water surface).

Revolutions - The velocity at the point of the current meter is determined by counting the number of signals ("clicks") per unit of time. Each meter is calibrated by the supplier and an equation for the relationship between velocity and revolutions per unit time is derived. To facilitate field use, the equation is solved for a number of revolutions ("stop counts") and various time steps. A rating table which shows the velocity for a given number of revolutions per time interval is provided with each meter. The real trick in using the rating table is to memorize the "stop counts." One should count clicks for at least 40 seconds, remembering to stop counting at one of the "stop counts" indicated in the rating table. Failure to do so will negate the ability to obtain the velocity directly from the rating table.

Time - A stopwatch is an essential piece of equipment for velocity measurement. Forty seconds is often the smallest time interval listed in rating tables. This time interval is required in order to get a time-averaged velocity. After 40 seconds has elapsed, it is only necessary to concentrate on stopping at a "stop count." The rating table is usually constructed in one-second steps from 40 seconds to 70 seconds. If a direct readout meter is used, it is still important to observe the velocity readout scale for at least 40 seconds.

Point velocity is the velocity obtained from the rating table using revolution and time information or the velocity reading from the visual display on a direct readout meter.

The *mean vertical velocity* is the average of the 0.2 and 0.8 point velocity readings for the vertical. If the velocity was measured only at 0.6 the depth, the point velocity and mean vertical velocity are the same.

Cell depth is the same as the flow depth for the verticals.

Cell width is the horizontal distance between midpoints of adjacent verticals. Cell widths may or may not be equal. Verticals are to be placed such that they best describe velocity distribution and changes in the cross-sectional channel geometry.

Cell area is computed by multiplying the cell depth with the cell width and the angle coefficient.

Flow is computed by multiplying cell area with the mean vertical velocity.

Summation of all values in the flow column will indicate ***total flow*** at the transect. Theoretically, the same total flow would be computed for all transects at the study site. However, this rarely happens in the field, particularly when transects are located for purposes other than making discharge measurements (i.e., describing fishery habitat). Disparities in the range 20-25% are not to be alarming. However, the transect which you believe has provided the most reliable discharge measurement should be identified.

Field Data Digest Form

This form should be completed by the individual in charge of the field study as part of his/her summary of the overall data collection effort. The format has been selected to provide a brief summary of those field measurements which are of principal importance, and to alert one to missing data or major errors. It must be emphasized that insufficient data appears on the field data digest form to support application of the PHABSIM computer programs. Therefore, it must be accompanied by a completed set of field forms (transect data, cross section profile data, and velocity data) for each transect in the study reach as well as all supporting field notes (i.e., level notes, chaining notes, etc.).

FIELD FORM

______ Study Site ______ Location ______ Stream

Crew Members ______

Weather Conditions ______

______

TRANSECT DATA

Transect # ______ of ______ ______ Magnetic Bearing ______ Date

Photographs [YES] [NO]

Horizontal Distances:

LBHP to RBHP ______

LBHP to LBWP ______

LBWP to LEW ______

Top Width ______

REW to RBWP ______

RBWP to RBHP ______

______ Total

Elevations: Left Bank Right Bank

Head Pin ______ ______

Work Pin ______ ______

Water's Edge ______ ______

Longitudinal Distances:

Distance From Adjacent Downstream Transect ______ Left Stream Bank ______ Right Stream Bank

CROSS SECTION PROFILE DATA

Transect # ________ of ________ Stream ________________________________

________ Base Point ________ Elevation ________ Back Site ________ Instrument Height

Distance from Head Pin (ft) LB RB	Rod Reading or Sounding (ft)	*Ground Stream Channel Elevation (ft)*	Substrate

Distance from Head Pin (ft) LB RB	Rod Reading or Sounding (ft)	*Ground Stream Channel Elevation (ft)*	Substrate

VELOCITY DATA

Transect# ________ of ____________ Stream ______________________________

Flow Regime Being Measured [LOW] [MED] [HI] Date ______________

Elevation of Water's Edge: Left Bank Right Bank

Before Velocity Measurement ______________ ______________

After Velocity Measurement ______________ ______________

Distance from Head Pin (ft) LB RB	Angle Coef.	Flow Depth (ft)	*Streambed Elevation*	Observation Depth %	Revolutions #	Time (sec)	*Velocity fps*		*Cell Width (ft)*	*Cell Area (ft)*	*Flow (ft/sec)*
							Point	*Mean Vertical*			

Discharge for this Transect ______________

Type of flow meter ______________ I.D. Number ______________

Computations by ________ Checked by ________

LITERATURE CITED

Bouchard, H., and F. H. Moffitt. 1965. Surveying. International Textbook Company, Scranto, PA. 754 pp.

Bovee, K. D. 1980. Draft, A Users' Guide to the IFG Incremental Method. Cooperative Instream Flow Service Group, Fort Collins, CO.

Bovee, K. D., and R. T. Milhous. 1978. Hydraulic Simulation in Instream Flow Studies: Theory and Techniques. Instream Flow Information Paper Number 5. FWS/OBS-78/33. U.S. Fish and Wildlife Service, Washington, DC. 130 pp.

Brinker, R. C., and B. A. Barry. 1957. Noteforms for Surveying Measurements. International Textbook Company, Scranton, PA. 55 pp.

Brinker, R. C., and W. C. Taylor. 1963. Elementary Surveying. International Textbook Company., Scranton, PA. 621 pp.

Bureau of Reclamation. 1967. Water Measurement Manual. Department of the Interior. A Water Resources Technical Publication. Second Edition, 329 pp.

Chow, V. T. 1959. Open Channel Hydraulics. John Wiley and Sons, Inc., New York, New York.

Grover, N. C., and A. W. Harrington. 1966. Stream flow measurements, records and their uses. Dover Pulications Inc., New York, New York. 363 pp.

APPENDIX A

SURVEYING TECHNIQUES

This appendix discusses the basic equipment and surveying techniques commonly used to obtain measurements for use with the hydraulic models in PHABSIM. The techniques described are somewhat abbreviated, and confined to those techniques most often used for instream flow work. For a more complete description of surveying techniques, the reader is referred to an Instream Flow Group's field methods workshop or to one of the references cited.

Two basic types of surveying measurements are routinely used in association with collecting calibration data for the IFG hydraulic models. The first is the measurement of horizontal distances between two points. This may be accomplished by taping (chaining), stadia survey or electronic distance measuring devices (EDM). The second basic type of surveying measurement is the determination of the difference in elevation between various points in the study site. This is accomplished through the application of differential leveling techniques.

For additional details concerning surveying techniques the reader is referred to Bouchard and Moffitt, 1965 and Brinker and Taylor, 1963 which were heavily utilized in the preparation of this appendix.

Appendix A - Surveying Techniques

MEASURING HORIZONTAL DISTANCES

Horizontal distances are measured several times during the field work. Distances are measured between headstakes, between transects, and to each vertical on the transect. The most commonly used equipment for measuring distance are steel, cloth, and fiberglass tapes; steel taglines; level rod and level (stadia); and electronic distance meters (EDM).

Taping

Taping is the most commonly used technique for measuring horizontal distance. Several types of tapes are available, but the fiberglass surveyor's tape and the U.S.G.S. tagline are the most popular. The surveyor's tape is graduated in one-tenth foot increments. (Do not use a tape marked in feet and inches. These units are not compatible with units used elsewhere in the field work and will require a great deal of time for conversion.) Taglines are small diameter (1/8" to 5/32") steel cables commonly used in conjunction with stream gaging work. The tagline is marked with a series of beads such that it can be used to measure distances.

A standard tagline is marked with a triple bead at zero and each 100 feet. Between zero and 50 feet a single bead appears every two feet and a double bead every ten. From 50 to 150, the single bead marks every 5 feet; beyond 150 feet, a single bead is used every ten feet. There are no double bead marks used beyond 50 feet. Taglines may be specially made to any specification.

The distance to be measured is the horizontal distance between objects, whether headstakes, transects or positions on a transect. The greatest source of error is introduced by stringing the tape up, over, and around obstructions along the bank. One may avoid this problem by setting up the initial visit to the study area at a fairly low flow, so that the tape can be stretched along the waters edge in the streambed rather than through the brush along the bank.

Some error may be introduced by sag when a tape is stretched across a transect. In many cases, the error is small enough that it can be neglected. However, for long transects, the magnitude of the sag error may be large enough to warrant correction.

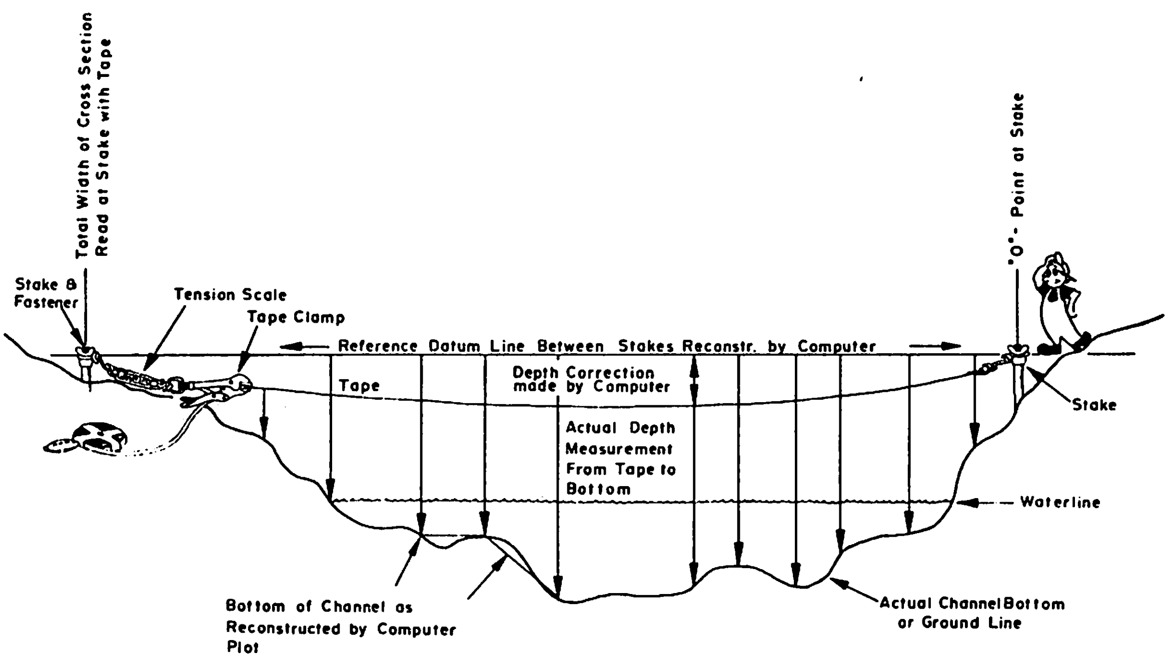


Figure A-1. Sag-tape measurement showing use of tape clamp and tension scale.

The correction factor, C, is always negative and is added algebraically to L to determine the corrected total distance across the channel. Errors due to sag are systematic in that they always cause the recorded distance to be greater than the true distance.

A correction for sag is necessary only if the magnitude of the error is significant with respect to the level of precision with which the distance measurements are made. Without benefit of special equipment, however, the upper limit for taping across channels and not correcting for tape sag is about 300 feet.

Use of Stadia

Horizontal, straight line distances can also be measured indirectly with many surveying levels which contain two small horizontal cross hairs above and below the main horizontal cross hair. The distance between the telescope and rod is found by subtracting the rod reading for the lower stadia cross hair from that of the upper stadia hair and multiplying by a stadia constant (usually 100). Figure A-2 shows a view through the telescope on a stadia rod 93 feet away.

The accuracy of stadia measurements is largely dependent on the skill of the individual, the type of instrument and rod used, and on atmospheric conditions. For sights up to 400 feet, it is usually possible to determine the intercepted distance on a level rod to 0.01 foot. This translates into a horizontal measurement of 400 ft within ± 1.0 foot.

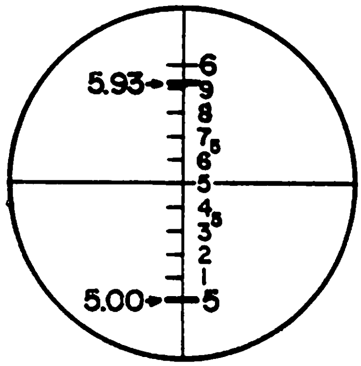


Figure A-2. View of stadia hairs through a level, on a stadia rod 93 feet away.

<u>Electronic Distance Meters (EDM's)</u>

An electronic distance meter works on the principle of determining the time required for an induced electromagnetic wave to reach a reflector and return to the sender. Automatic equipment converts this time to a distance. Two different types of EDM's are available. The first type is activated by a infrared frequency signal or laser beam. The signal is reflected from a bank of retroprisms, and the distance calculated by the time required for the signal to return to the source. Since this type of EDM is "light-frequency" activated, a clear line of sight to the target is required. Foliage, mist, and smoke can interfere with the signal. Additionally, the target and signal source must be essentially on-line, resulting in a narrow band within which the target must remain in order to obtain a reading.

The second type of EDM broadcasts a microwave to a receiver, which relays the signal back to the source. This type of EDM is unaffected by reduced visibility, but may be jammed by transmission lines or other high energy electomagnetic fields. (They are not affected by normal radio transmission). The feature which makes these meters particularly attractive for hydrographic work is that they can maintain signal contact when the source and receiver units are offset by as much as 45^{o}. Thus, it is much easier to prevent loss of signal when moving a boat across the channel. An advantage of this type of measurement meter is that if contact is broken, they do not need to be recalibrated in order to continue measurements.

The price of electronic distance meters is quite high, ranging from about $3000 to $20,000 in 1980. However, they are practically indispensible for working on extremely large rivers and may be rented or leased. Even a fairly "inexpensive" EDM has an accuracy of about 0.04 feet at 1600 feet. The price is usually reflected in the width and range of the beam, not the accuracy.

Use of the Level

A level is an instrument combining a telescopic sight having both vertical and horizontal cross hairs, with a level vial which indicates when the instrument is in a level position. The types of levels most commonly used for instream flow work are the engineer's (dumpy) level and the self-leveling level. A transit may be substituted for a level, but it is somewhat more difficult to use and somewhat less precise. For nearly all instream flow studies, a self-leveling instrument is recommended (Figure A-3).

AUTOMATIC LEVELS

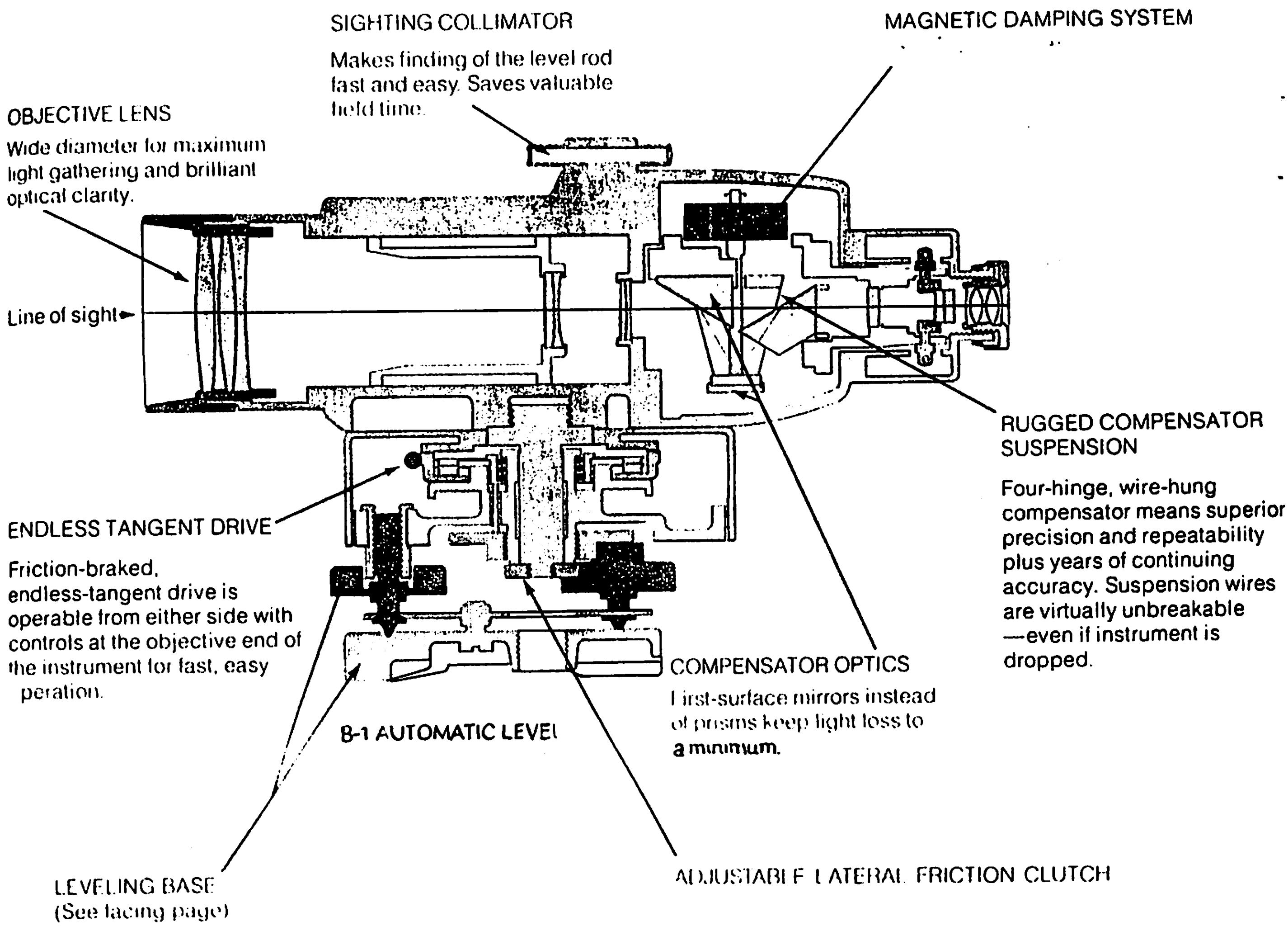


Figure A-3. Self-leveling level.

Setting Up the Level

The safest way of transporting a level is to carry it in the case provided. In the field, it is common practice to carry the tripod and level from place to place as a single unit. When mounting the level on the tripod, it is important that the level is screwed snugly to the tripod. If the level is mounted too loosely, the instrument is unstable and will be difficult or impossible to level. If the mount is too tight, the instrument may freeze to the tripod. One should be particularly alert to avoid this problem developing whenever taking an instrument out of a warm vehicle for use in cold climates.

When setting up the tripod, determine the direction of sighting for most of the sights, and set one leg of the tripod in that direction. This will leave a space for the levelman to stand while sighting, without straddling one of the legs. On side hill setups, placing one leg on the uphill side and two on the downhill slope usually gives a stable setup. Once the tripod is adequately positioned, the legs may be firmly pressed into the ground by stepping on the tripod leg spurs near the bottoms of the legs. The leg bolts (wing nuts) should be loosened and the tripod legs adjusted in such a way that the platform is approximately level to start with. This will facilitate leveling the instrument. Before leveling the instrument, be sure to retighten the tripod leg wing nuts but do not over-tighten.

Leveling the Instrument

One of the most obvious differences between an engineer's level and a self-leveling level is the procedure used in leveling the instrument.

Engineer's levels typically have four leveling screws and a spirit level (a sealed vial partially filled with alcohol). A self-leveling level has three leveling screws and a bull's-eye (circular) spirit level.

In leveling the Engineers level, the telescope is turned until it lines up over two opposite screws. The bubble is approximately centered in the level vial by turning both leveling screws under the telescope in opposite directions, at the same speed. Failure to move both screws at the same speed will often leave the level head wobbly. A simple rule is that the bubble moves in the same direction as the left thumb. The leveling procedure is then repeated with the telescope rotated 90^{o} so it is lined up over the other two leveling screws. It is impractical to attempt to exactly center the bubble in the spirit level on the first try. It will be thrown off during the cross-leveling. Readjusting each pair of screws about three times is usually enough to complete the leveling process. The telescope should be rotated a full 360^{o} checking the spirit level each 90^{o} before being used.

A self-leveling level has a three-screw head and a bull's-eye spirit level. These levels contain a system of internal prisms which allow a level line of sight even if the instrument itself is not exactly level. For a three-screw head, the telescope is aligned over one screw. The telescope is made level by turning the three screws in various combinations, until the bubble appears in the center of the bull's-eye. The telescope need not be rotated in the process.

Focusing

The process of focusing is the most important function to be performed with a telescopic sight. The telescope consists of an objective lens (mounted on a sliding tube inside the tube), a reticle (cross hairs), and an eyepiece. The purpose of the objective lens is to focus the object image on the reticle. The focusing pinion for the objective lens is a large knob on the top or side, near the center of the tube.

Since the reticle remains fixed in the telescope tube, the distance between it and the eyepiece must be adjusted to suit the eye of the observer. This is done by focusing the eyepiece on the cross hairs with the eyepiece focusing ring. After the eyepiece has been adjusted, objects are brought into focus with the objective focusing pinion. If the cross hairs appear to travel over the object sighted when the eye is shifted slightly in any direction, parallax exists. Further adjustment of either the objective lens system or the eyepiece is required to eliminate parallax.

Holding the Rod

The manner in which the rodperson performs his duties can make or break the survey. This individual must understand what is being measured, how the measurement will eventually be used in the analysis, and the importance of its precision every time the rod is positioned for a measurement. In addition the rodperson sets the pace of the field work and often influences (or directs) movement of the level.

Basically the rodperson must keep the rod plumb over the point being measured. The rod should be accompanied by a rod level to make this task easier. A rod level is a small bull's eye spirit level, mounted on an L-shaped bracket which can be attached to the rod. When the bull's eye bubble is centered, the rod is plumb in both directions. This is especially important when determining headstake and water surface elevations.

In the absence of a rod level, the levelman makes certain the rod is plumb in a lateral direction by its coincidence with the vertical cross hair. The rodperson then rocks the rod forward and backward, through the plumb line. The levelman watches through the telescope, noting the minimum rod reading. The minimum rod reading will occur when the rod is standing plumb.

Reading the Rod

A twenty-five foot telescopeing fiberglass level rod is recommended for most instream flow work. The fiberglass rod is very durable, stands up well under repeated use in water and its 25 foot length eliminates many problems that would be encountered when cross sectioning with a 12 to 14 foot rod. However, fiberglass rods do not float and can easily be lost if dropped into a deep pool.

Graduations on the level rod are accurately-painted alternate black and white spaces 0.01 ft (1 cm if metric) in width. The 0.1 and 0.05 ft graduations are emphasized by spurs extending from the black markings. Tenths are designated by black numerals straddling the proper graduation, whereas whole feet or meters are marked by red numerals. On some rods, small red numerals are placed alongside the black numerals to facilitate reading the proper "whole foot" on short sights where only a small portion of the rod is visible through the telescope.

A typical view of a level rod through a level would appear as in Figure A-4. The horizontal cross hair has intersected the rod at 5.495 feet. Such a reading would normally be recorded as 5.50.

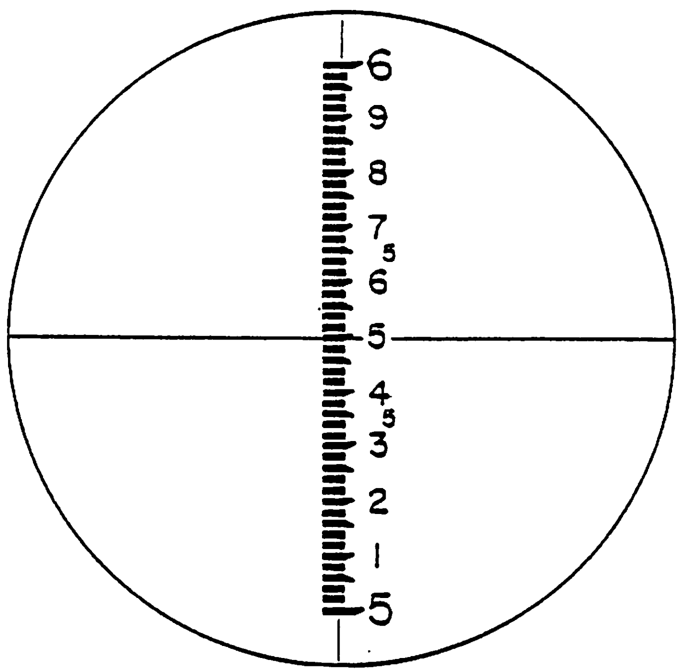


Figure A-4. View through a level on a rod reading of 5.495 feet.

Many levels have short horizontal cross hairs above and below the center cross hair. These are called <u>stadia hairs</u> and are used in the measurement of distances. A discussion on the use of stadia will be given later in this appendix. Be especially careful not to read an elevation of a stadia hair instead of the central cross hair.

Peg Test

Surveying instruments are quite durable but they only perform properly if well treated. A sudden blow can completely destroy the precision of a good level without leaving a mark on it. Therefore every instrument should be checked out before taking it into the field by performing a "peg test."

Establish two points, A and B, near ground level, 200-300 feet apart. The test may be run between these points or stakes in the following manner.

1. Set up exactly halfway between A and B. Take a rod reading, a, on Stake A and a rod reading, b, on Stake B. The computed elevation difference, a-b, is the true difference, regardless of instrument error. Set up close enough to A so that a rod reading can be obtained either by reading through the telescope in reverse or by measuring up to the horizontal axis of the telescope by steel tape. Take a rod reading c on Stake A and a reading d on Stake B. If the instrument is in adjustment, (c-d) will equal (a-b). If the instrument is out of adjustment, compute what the correct rod reading e on B should be (e=b+c-a) and submit the instrument for adjustment.

Leveling

Two different types of leveling procedures are commonly followed when doing the field work: 1) headstake elevations are determined by running a closed level loop and 2) the cross sectional stream channel geometry is determined by running a ground profile. Both procedures are based on a concept called "differential leveling" - determining the elevation of an unknown point by direct measurment of the difference in elevation between that point and a point of known elevation.

A few definitions are necessary before attempting to conduct a survey:

1. <u>Backsight</u>

A backsight (BS) is a rod reading taken on a point of known elevation. It is the actual vertical distance from the point of known elevation to a horizontal line projected by the instrument. There is only one backsight for each setup of the instrument. Please note that the term "backsight" has nothing to do with the direction in which the instrument is pointed. The algebraic sign of the backsight is positive (+).

2. <u>Height of Instrument</u>

The height of instrument (HI) is the elevation of the line of sight projected by the instrument. It is found by adding the backsight rod reading to the known elevation of the point on which the backsight was taken. Figure A-5 shows a backsight on a benchmark to determine the height of instrument.

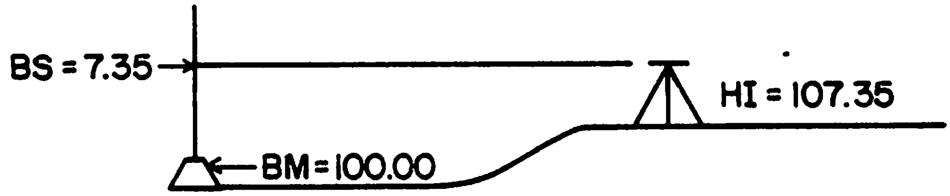


Figure A-5. Determination of the height of instrument by taking a backsight on a bench mark.

3. Foresight

A foresight (FS) is a rod reading taken on any point, in order to determine its elevation. The FS is subtracted from the HI to find the elevation of the point in question. Figure A-6 shows a foresight on a headstake to determine its elevation. The algebraic sign of the foresight is negative (-).

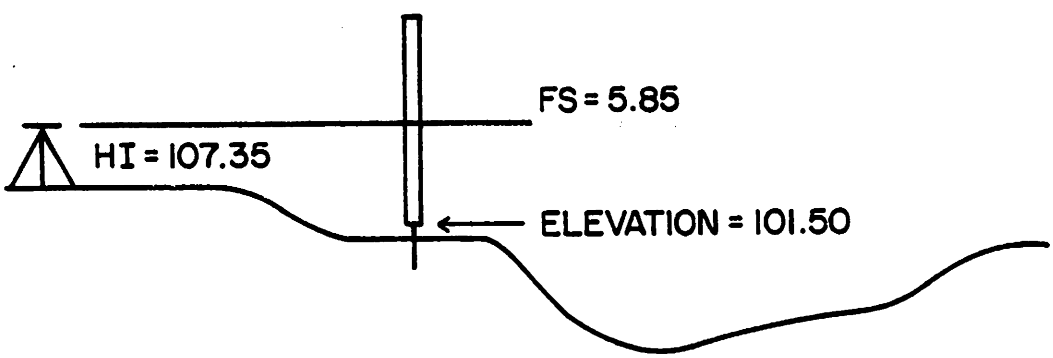


Figure A-6. Determination of an unknown headpin elevation by taking a foresight from a known height of instrument.

4. Turning Point

A turning point is a solid mark upon which a foresight and a backsight reading is made in order to continue a line of levels. Turning points are selected on their ability to retain the same elevation while the instrument is being moved. Normally large rocks are used as turning points. However it is a good practice for the rodperson to carry a couple of large bridge spikes which can be pounded into the ground and used as turning points in the event a suitable rock is not available. Figure A-7 shows the principal involved in using a turning point.

5. Bench Mark

Any solid object which can be readily identified and that will retain its elevation over an extended period of time. Rock outcrops, bridge abutments, large spikes driven into solid logs, power poles or trees are normally used. If a rock outcrop or bridge abutment is to be used the exact location of the bench mark must be indicated by a PK tack, masonry nail or other indelible mark. The elevation of the bench mark may be assumed or tied into a project datum or mean sea level.

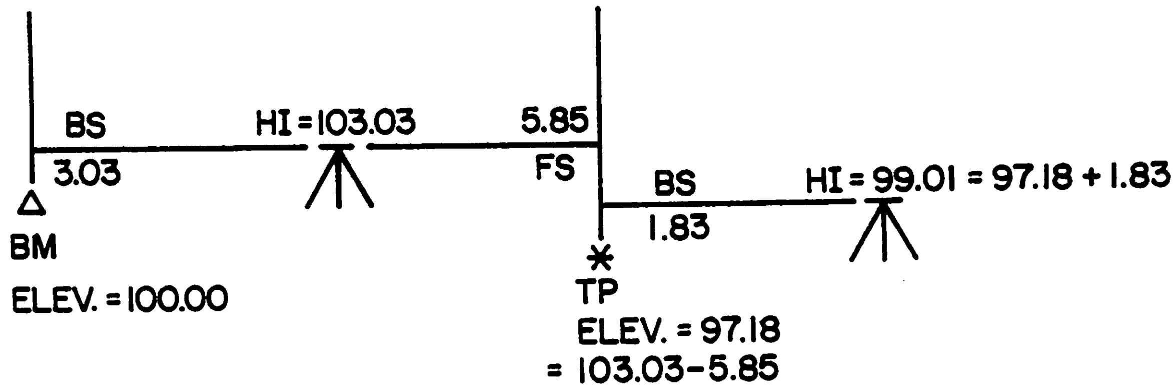


Figure A-7. Principle involved in using a turning point to establish a new height of instrument.

Determination of Headstake Elevations

Differential leveling techniques are used to determine headstake elevations relative to a previously established benchmark. As a minimum the elevation of at least one headstake on every transect must be included in the level loop. However, it is strongly recommended that all headstakes and work pins be included to serve as a check on the cross sectioning.

The most important aspect of determining headstake elevations is running a closed level loop. Elevations are determined for each headstake; moving the level as required to make sights. After the last headstake has been measured, the instrument is moved again and releveled. A backsight is made on the last headstake surveyed. Then all remaining headstakes are resurveyed on a return survey back to the benchmark. While it may be possible to sight all of the headstakes from a single instrument position, the instrument must be moved at least once before attempting to close the level loop. This is necessary in order to detect errors that might be associated with the initial instrument setup.

Figures A-8 and A-9 show a typical headstake level loop performed on a hypothetical stream reach. Backsights are indicated by plus signs (++++) while foresights are indicated by minus signs (----). The rod reading for each sight is written directly above the line of sight. Elevations of headstakes, turning points, and instrument heights are given for each location.

Figure A-8 shows the forward (usually upstream) survey of headstake elevations through the study reach. Field notes for the forward and return survey are shown in Figure A-10. From left to right, the column headings are station (STA), backsight (BS), instrument height (HI), foresight (FS), and elevation (Elev.). Elevations should be calculated for each headstake or turning point as the survey proceeds.

Having completed the level loop, the error of closure is determined. Using the equation for allowable error previously introduced:

$$\text{Allowable error} = 0.05 * (660/5{,}280)^{0.5} = 0.018$$

The error of closure at the benchmark for the sample level loop was 100.00 - 99.99 = 0.01 ft. Therefore, closure was obtained within allowable limits for third order precision.

Cross Sectioning

Differential leveling techniques are used in conjunction with some means of measuring horizontal distances to determine the ground/streambed profile between the left and right bank headstakes at each transect. Most often a cloth or fiberglass tape is zeroed over the left bank headstake stretched

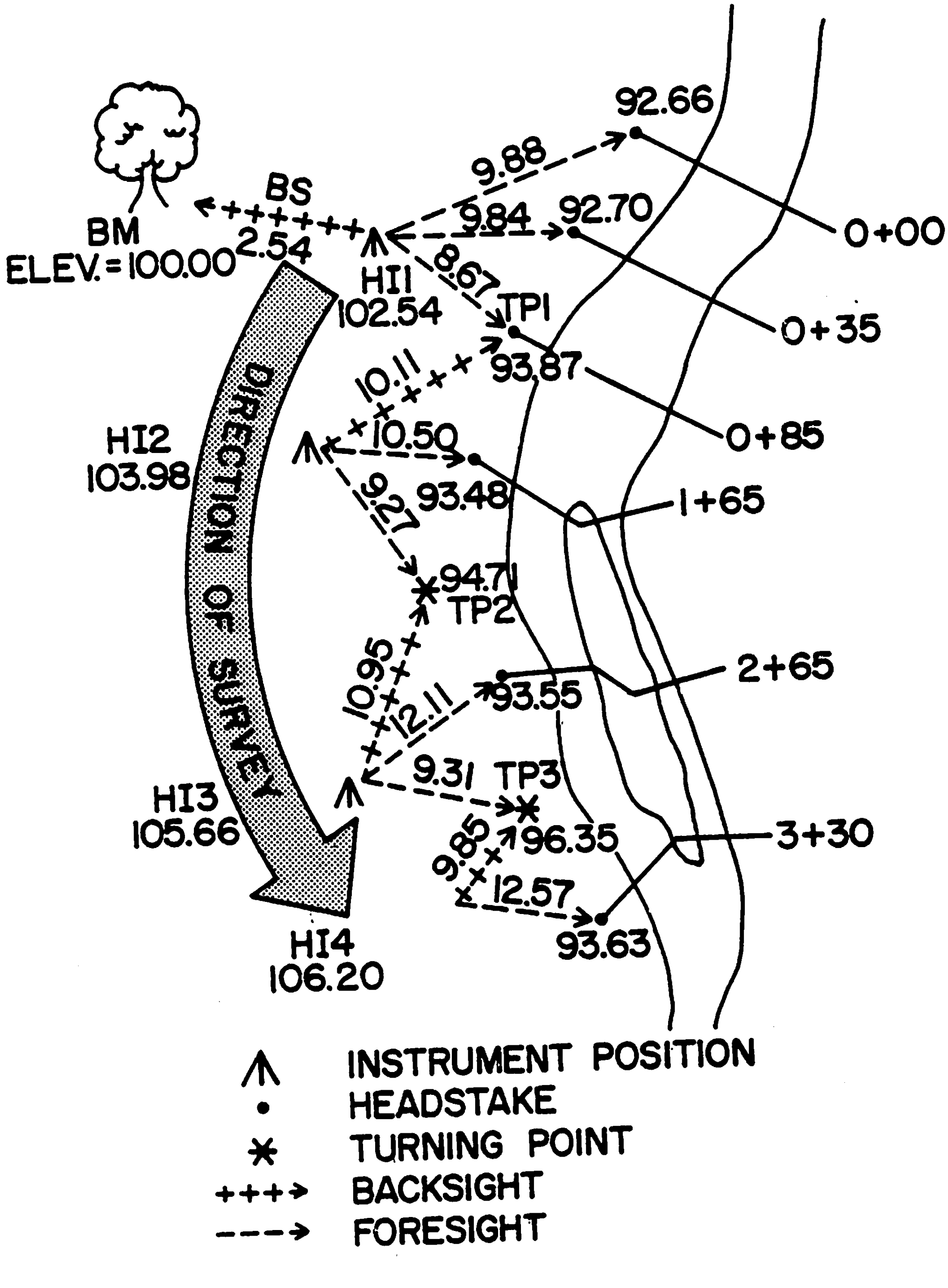


Figure A-8. Forward (upstream) survey of headstake elevations through the study area.

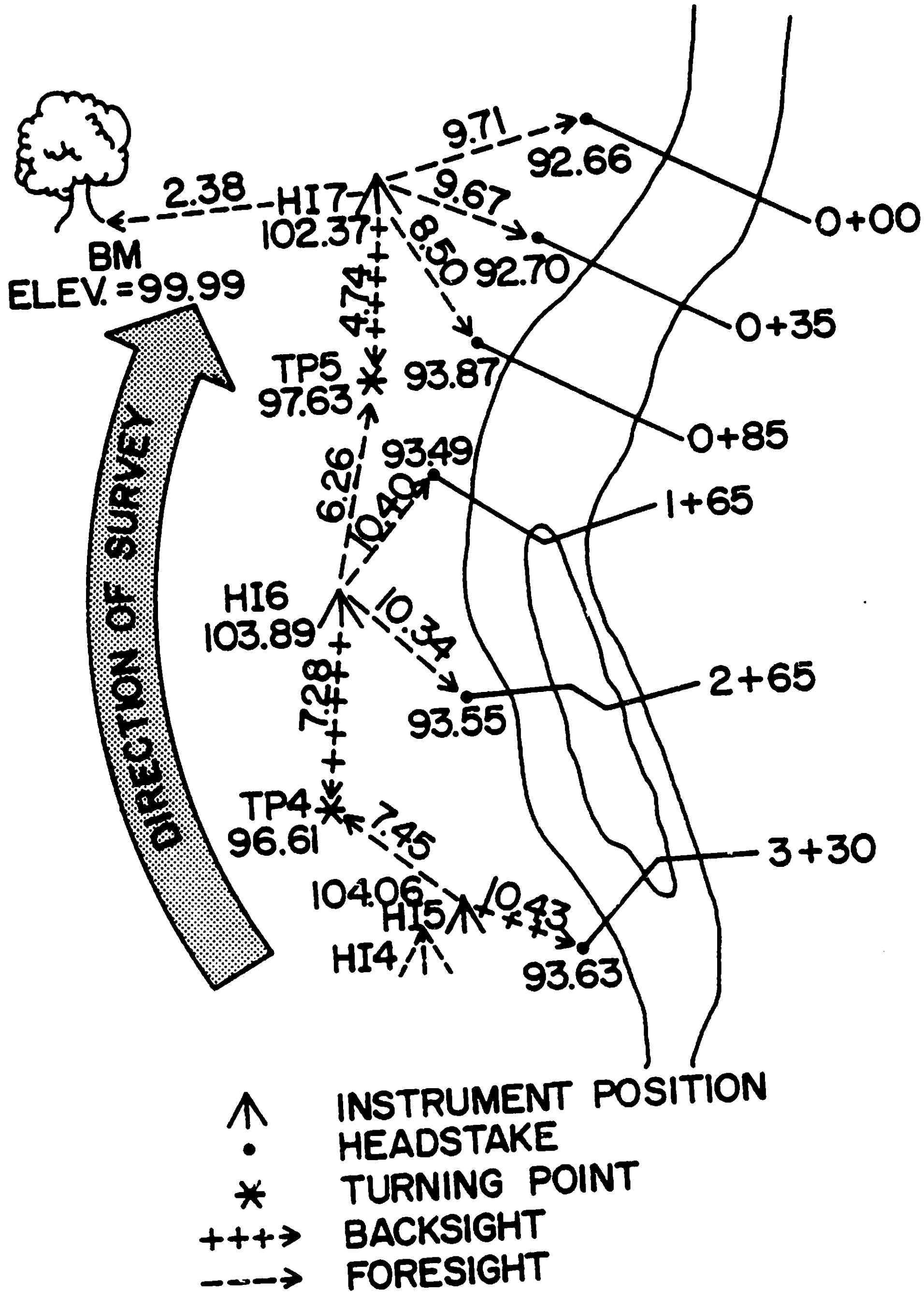


Figure A-9. Return check survey (downstream) of headstake elevations and benchmark through the study area.

STA	BS	HI	FS	Elevation
BM				100.00
	2.54	102.54		
0+00 (HP1)			9.88	92.66
0.35 (HP2)			9.84	92.70
0.85 (TPI)			8.67	93.87
	10.11	103.98		
1+65 (HP4)			10.50	93.48
TP2			9.27	94.71
	10.95	105.66		
2+65 (HP5)			12.11	93.55
TP3			9.31	96.35
	9.85	106.20		
3+30 (HP6)			12.57	93.63
	10.43	104.06		
TP4			7.45	96.61
	7.28	103.89		
2+65			10.34	93.55
1+65			10.40	93.49
TP5			6.26	97.63
	4.74	102.37		
0+85			8.50	93.87
0+35			9.67	92.70
0+00			9.71	92.66
BM			2.38	99.99

Figure A-10. Example field notes for the entire survey to determine headstake elevations at a study site.

across the stream and tied off behind the right bank headstake (use tape clamps; do not tie or wrap the tape around logs or trees). The instrument is then set up at a convenient vantage point, and a backsight (BS) is made on a headstake to determine the Height of Instrument (HI). Following this, the rod man merely walks along the tape stopping at major breaks in topography, substrate, or vegetative cover and plumbs the rod. The horizontal distance from the left bank headstake is read directly from the tape by the rodman and the instrument man reads the rod through the level.

Figure A-11 shows a typical instrument setup for obtaining the water surface elevation and cross sectional profile of transect 0+00 of figures A-8 and A-9. Note that the precision of ground elevations across the transect is to the nearest 0.1 ft, but the water surface elevation is measured to 0.01 foot. A typical set of field notes for the profile is shown in Figure A-12. Note that the field notes for each profile contains a description of the substrate as provided by the rodman as he traverses the cross section.

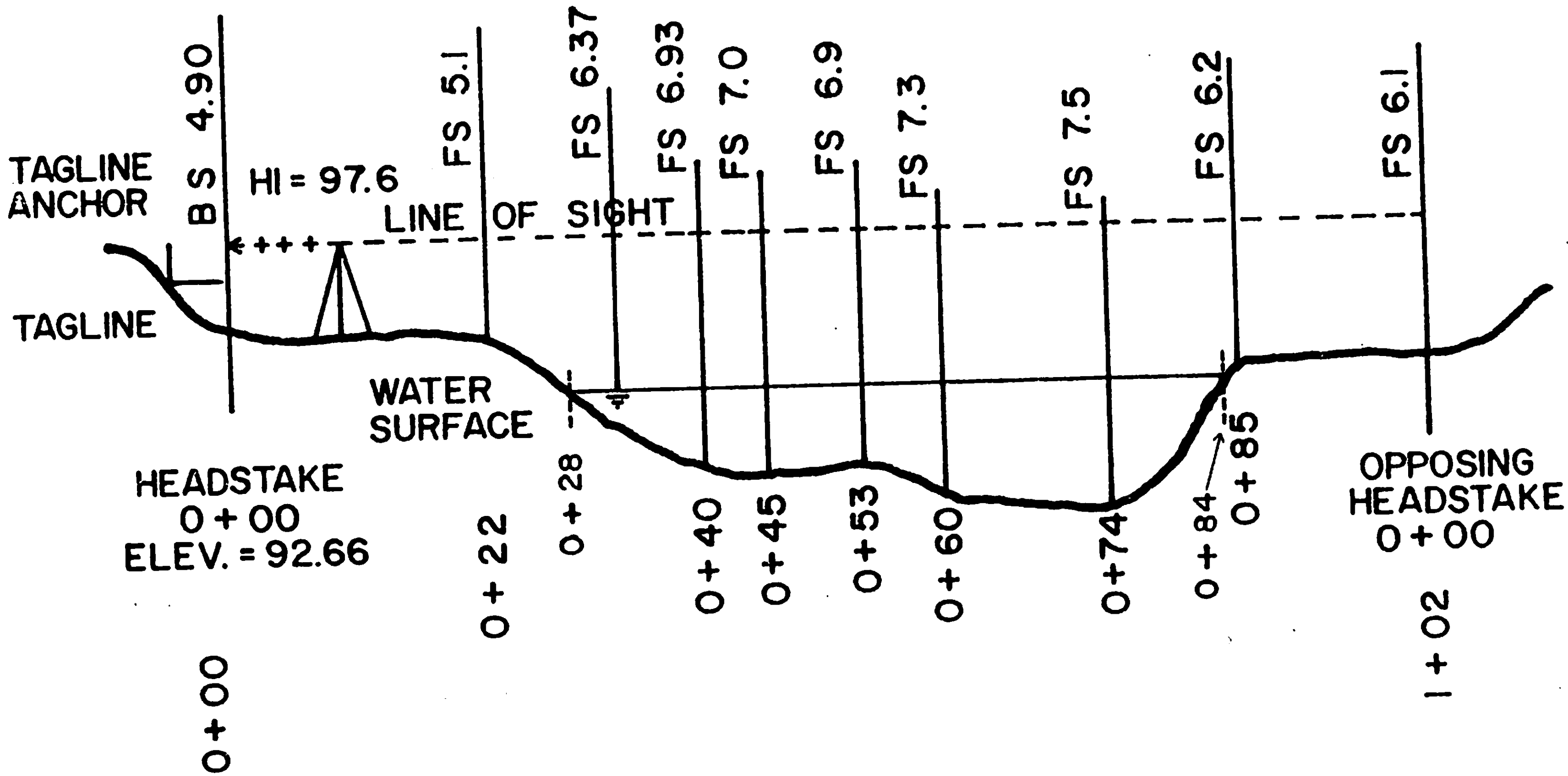


Figure A-11. Diagram of survey of cross-section 0+00 dimensions including ground and water surface elevations and horizontal distances.

Cross Section Profile
Station 0+00, Deer Creek Site A-1

STA	BS	HI	FS	Elevation	Substrate
0+00	4.90			92.66	Left Bank Headstake silt
		97.56			
0+22			5.1	92.5	50/50 sand, gravel
WS 0+28			6.37	91.19	water surface
0+40			6.9	90.7	25/25/50 gravel, small cobble, medium cobble
0+45			7.0	90.6	25/75 large cobble, small boulder
0+53			6.9	90.7	medium boulder
0+60			7.3	90.3	medium boulder
0+74			7.5	90.1	medium boulder
0+84			6.39		
0.85			6.2	91.4	50/50 sand, gravel
1+02			6.1	91.5	right bank headstake, silt

Figure A-12. Field notes for profile leveling, for cross section 0+00.

DRAFT

APPENDIX B

VELOCITY MEASUREMENTS

Velocity measurements are made to determine the velocity distribution across a transect, and are also used in the calculation of the discharge. Depth measurements are also used in the calculation of the discharge; and on rivers where surveying the cross section is impractical, depth measurements can be substituted for rod readings to obtain the cross sectional profile.

EQUIPMENT

Current Meters

The most commonly used instrument for measuring velocity is a vertical axis current meter. This meter consists of a wheel which rotates in flowing water and a device for determining the number of revolutions. Figure B-1 shows a line drawing of a Price AA current meter, which is fairly typical of all "vane-type" meters. As the bucket wheel (21) rotates, an electrical contact is closed on either a single-contact cam, or a penta gear (6). If a headset is connected to the penta-contact post (5), a signal is produced once every five revolutions. The penta-contact is very useful in fast water.

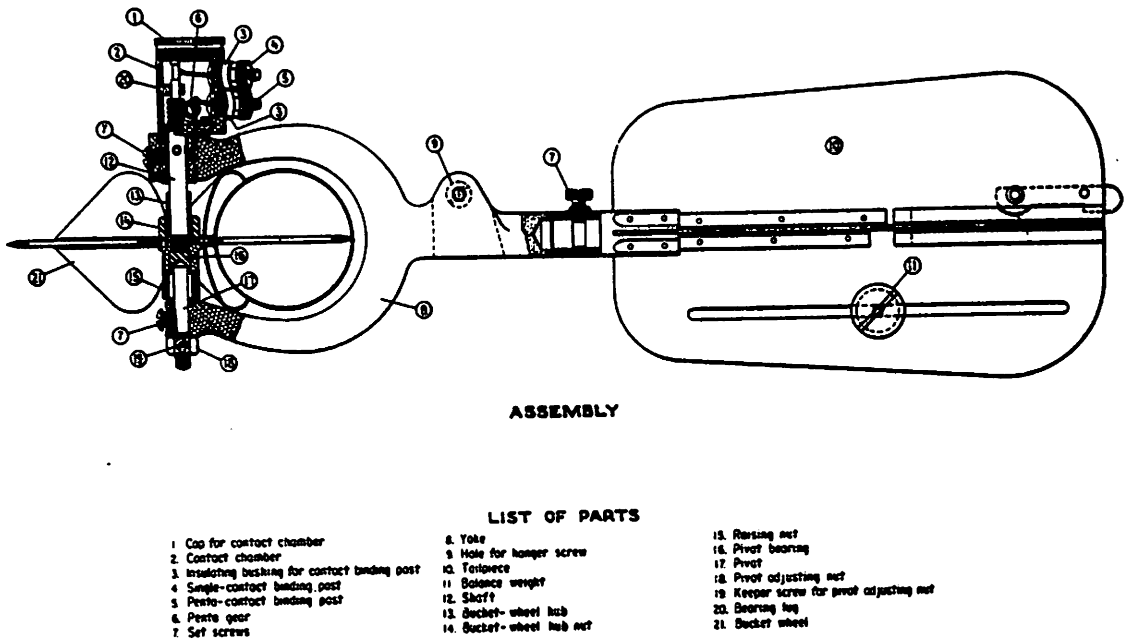


Figure B-1. Line drawing of a Price AA current meter.

The velocity at the point of the current meter is measured by counting the number of signals (revolutions in a specified time interval). Thus, a standard piece of equipment accompanying the use of a current meter is a stopwatch. Each meter is calibrated by the supplier and an equation for the relationship between velocity and revolutions per unit time derived. For most Price meters, the meter is supplied with a rating table, such as the one shown in Figure B-2, which shows the velocity for a given number of revolutions in a given time interval. From Figure B-2, 40 revolutions in 40 seconds equals a velocity of 2.17 feet per second. Notice that 40 seconds is the smallest time interval listed on the rating table. This time interval is required to obtain a time-averaged velocity at the point. The user would be well advised to

V = 2.14 N + 0.03   N < 1.00
V = 2.19 N - 0.01   N > 1.00

DEPARTMENT OF INTERIOR - BUREAU OF RECLAMATION

RATING TABLE FOR TYPE ________ METER NO ________

SUSPENSION ________ RATED ________

EQUATIONS: ________ NO ________

Limits of Actual Rating ______ to ______ ft. per sec.
at Bureau of Standards, Washington, D.C.

Condition of Meter

Time, Seconds	VELOCITY IN FEET PER SECOND — Revolutions 3	5	7	10	15	20	25	30	40	Time, Seconds
40	0.190	0.297	0.404	0.565	0.832	1.10	1.37	1.63	2.17	40
41	0.186	0.291	0.395	0.552	0.813	1.07	1.34	1.60	2.12	41
42	0.181	1.264	0.387	0.539	0.793	1.05	1.30	1.56	2.07	42
43	0.179	0.278	0.378	0.528	0.776	1.03	1.27	1.52	2.02	43
44	0.175	0.273	0.370	0.515	0.759	1.00	1.25	1.49	1.98	44
45	0.173	0.267	0.363	0.505	0.742	0.980	1.22	1.46	1.93	45
46	0.169	0.263	0.355	0.494	0.727	0.960	1.18	1.43	1.89	46
47	0.166	0.256	0.348	0.485	0.712	0.941	1.17	1.40	1.85	47
48	0.162	0.252	0.342	0.475	0.697	0.922	1.14	1.37	1.81	48
49	0.160	0.248	0.336	0.466	0.684	0.903	1.12	1.34	1.78	49
50	0.158	0.244	0.329	0.458	0.672	0.886	1.10	1.31	1.74	50
51	0.156	0.239	0.323	0.449	0.659	0.868	1.08	1.29	1.71	51
52	0.154	0.235	0.318	0.440	0.646	0.853	1.06	1.26	1.68	52
53	0.151	0.231	0.312	0.434	0.635	0.836	1.04	1.24	1.65	53
54	0.149	0.229	0.308	0.425	0.624	0.821	1.02	1.22	1.62	54
55	0.147	0.224	0.301	0.419	0.614	0.808	1.00	1.20	1.59	55
56	0.145	0.220	0.297	0.413	0.603	0.793	0.984	1.18	1.56	56
57	0.143	0.218	0.293	0.404	0.592	0.781	0.969	1.16	1.53	57
58	0.141	0.214	0.288	0.398	0.584	0.768	0.952	1.14	1.51	58
59	0.139	0.211	0.284	0.391	0.573	0.755	0.937	1.12	1.48	59
60	0.137	0.207	0.280	0.387	0.565	0.742	0.922	1.10	1.46	60
61	0.134	0.205	0.276	0.380	0.556	0.731	0.907	1.08	1.43	61
62	0.132	0.203	0.271	0.374	0.547	0.721	0.892	1.07	1.41	62
63	0.132	0.199	0.267	0.370	0.539	0.708	0.879	1.05	1.39	63
64	0.130	0.196	0.263	0.363	0.530	0.697	0.866	1.03	1.37	64
65	0.128	0.194	0.261	0.359	0.524	0.689	0.853	1.02	1.35	65
66	0.126	0.192	0.256	0.355	0.515	0.678	0.841	1.00	1.33	66
67	0.126	0.190	0.252	0.348	0.509	0.669	0.828	0.988	1.31	67
68	0.124	0.188	0.250	0.344	0.502	0.659	0.817	0.972	1.29	68
69	0.122	0.184	0.246	0.340	0.494	0.650	0.804	0.960	1.27	69
70	0.122	0.181	0.234	0.336	0.487	0.642	0.793	0.948	1.25	70
	3	5	7	10	15	20	25	30	40	

Time, Seconds	VELOCITY IN FEET PER SECOND — Revolutions 50	60	80	100	150	200	250	300	350	Time, Seconds
40	2.73	3.27	4.37	5.47	8.20	10.94	13.68	16.42	19.15	40
41	2.66	3.19	4.26	5.33	8.00	10.67	13.34	16.01	18.69	41
42	2.60	3.12	4.16	5.20	7.81	10.42	13.02	15.63	18.24	42
43	2.54	3.05	4.06	5.08	7.63	10.18	12.72	15.27	17.82	43
44	2.48	2.98	3.97	4.97	7.46	9.94	12.43	14.92	17.41	44
45	2.42	2.91	3.88	4.86	7.29	9.72	12.15	14.58	17.02	45
46	2.37	2.85	3.80	4.75	7.13	9.51	11.89	14.27	16.65	46
47	2.32	2.79	3.72	4.65	6.98	9.31	11.64	13.96	16.30	47
48	2.27	2.73	3.64	4.55	6.83	9.11	11.40	13.68	15.96	48
49	2.22	2.67	3.57	4.46	6.69	8.93	11.16	13.40	15.63	49
50	2.17	2.62	3.49	4.37	6.56	8.75	10.94	13.12	15.32	50
51	2.13	2.57	3.43	4.28	6.43	8.58	10.73	12.87	15.02	51
52	2.09	2.52	3.36	4.20	6.31	8.41	10.52	12.63	14.73	52
53	2.05	2.47	3.30	4.12	6.19	8.25	10.32	12.39	14.45	53
54	2.01	2.42	3.23	4.05	6.07	8.10	10.13	12.16	14.18	54
55	1.98	2.38	3.18	3.97	5.96	7.95	9.94	11.94	12.93	55
56	1.94	2.34	3.12	3.90	5.86	7.81	9.77	11.72	13.68	56
57	1.91	2.30	3.06	3.83	5.75	7.67	9.60	11.52	13.44	57
58	1.87	2.26	3.01	3.77	5.65	7.54	9.43	11.32	13.20	58
59	1.84	2.22	2.96	3.70	5.56	7.41	9.27	11.13	12.98	59
60	1.81	2.17	2.91	3.64	5.47	7.29	9.12	10.94	12.76	60
61	1.78	2.13	2.86	3.58	5.38	7.17	8.96	10.76	12.56	61
62	1.76	2.10	2.82	3.52	5.29	7.05	8.82	10.59	12.35	62
63	1.73	2.07	2.77	3.47	5.20	6.93	8.68	10.42	12.16	63
64	1.70	2.04	2.73	3.41	5.12	6.83	8.54	10.26	11.97	64
65	1.68	2.01	2.69	3.36	5.04	6.73	8.41	10.10	11.78	65
66	1.65	1.98	2.64	3.31	4.97	6.63	8.29	9.94	11.60	66
67	1.63	1.95	2.60	3.26	4.89	6.53	8.16	9.80	11.43	67
68	1.60	1.92	2.57	3.21	4.82	6.43	8.04	9.65	11.26	68
69	1.58	1.89	2.53	3.16	4.75	6.34	7.92	9.51	11.10	69
70	1.56	1.86	2.49	3.12	4.68	6.25	7.81	9.38	10.94	70
	50	60	80	100	150	200	250	300	350	

Figure B-2. Rating table for a Price AA current meter.

memorize the "stop counts" in the columns of Figure B-2. Stopping the count at some intermediate number of revolutions (27, for example) negates the use of the table and requires the use of the equation to calculate the velocity.

In order to ensure consistant accuracy with a current meter, good preventive maintenance is a must. For all vane-type meters such as the Price AA, the pygmy, or the Gurley, a most important maintenance item is the protection of the pivot (Figure B-1, 17) and the pivot bearing (Figure B-1, 16). The pivot assembly provides a low-friction surface on which the bucket wheel is supported. If the pivot becomes blunted, or the pivot bearing damaged, the resistance increases and the meter will give low velocity readings. The greatest potential for damage occurs when a meter is transported with the pivot bearing and pivot in contact. On the Price AA meters, a raising nut (15) is provided. When screwed down, the raising nut lifts the pivot bearing off the pivot and prevents contact. <u>Whenever a Price AA meter is transported, if only across the river, the raising nut should be screwed down</u>. Pygmy meters and some Gurley meters are provided with a blunt brass travelling pivot. This pivot may be replaced for the operational pivot by loosening the set screw at the front of the yoke (7) and slipping one pivot out and the other in. <u>Do not attempt to measure velocities with the travelling pivot in</u>! Likewise, do not transport one of these meters with the operational pivot in.

Prior to and immediately following each use, the components of the meter should be cleaned and lubricated. A light, water-resistant oil should be used for a lubricant. Key oil for clarinets has been found to be a good, inexpensive lubricant. Oil should be applied to the pivot and pivot bearing, the penta gear and penta gear bushings (6), and the bearing lug (20). If measurements are made in silty or turbid water, the meter should be oiled frequently (several times daily) during its use.

The condition of the bearings should be checked prior to each use by a "spin test." With the shaft in a vertical position and cups protected from wind currents, the cups are given a quick spin. If the meter is in good condition, the cups should not stop spinning for at least three minutes. If the duration of spin is more than 1 minute, the meter may be used for all but very low velocities (less than 1 foot per second). A spin of less than 1 minute indicates that the instrument should be reconditioned. For pygmy meters, a spin of 30 seconds or less indicates the reconditioning is warranted.

For fairly deep or fast water, the Price AA type meter is usually the most practical instrument. For depths of less than about 0.5 feet (15 cm) the pygmy meter is more appropriate. Pygmy meters are essentially limited to velocities less than 3 feet per second (90 cm/sec).

SERVICE NOTES AA TYPE METER

To Take Current Meter Apart

Remove cap from commutator box. Loosen both set screws in frame half a turn. Withdraw pivot and lock nut and commutator box. Care must be taken in the removal of commutator box so that the gear is not injured. Unscrew shaft. Do this by lifting bucket wheel until hole in shaft projects above frame, insert adjusting pin in hole and turn counter clockwise. Bucket wheel can now be withdrawn from frame. Hub and bearing can be separated from the bucket wheel by unscrewing hex nut, but this is necessary only when replacing a hub and bearing. Loosen tailpiece set screw and withdraw tailpiece from frame. Lift up curved end of vane catch to release the stop pin, then swing the catch 180°. Separate vanes by pulling each in direction shown by engraved arrow.

To Replace and Adjust Pivot

Be certain that the cap is screwed tightly in commutator box. The pivot is inserted through the hole in the lower limb of the yoke, and after adjusting the pivot so as to give the proper vertical play to the shaft assembly, the set screw is tightened. The proper amount of play is obtained in the following manner: first the set screw in the pivot adjusting nut is released, with the contact chamber cap tightly in place, the meter is turned over so that the top of the shaft rests against the cap. The pivot is then inserted into the pivot bearing until there is no vertical play. The screw for holding pivot is then tightened and the pivot adjusting nut is advanced until it rests against the yoke. The set screw is then released slightly and the pivot adjusting nut is further advanced a quarter of a turn. With the pivot adjusting nut in this position, the keeper set screw is firmly tightened, thus locking the nut. Upon completion of this adjustment the set screw in the yoke is retightened. This adjustment provides an end play of about 0.008 inch. The meter is rated with this amount of play and it is essential that this adjustment be made when installing a new pivot or when the point becomes worn.

To Adjust Contact Wire

The contact wire should be bent to make a LIGHT contact with the cam or eccentric of the shaft. Too heavy pressure will cause drag and wear on the shaft and contact wire. Assemble the meter with headphone and battery. Listen to the clicks as the bucket wheel revolves at a moderate rate. The clicks should be sharp with no dragging sound. Adjust contact wire to give proper signal. With proper adjustment of the pivot and contact, the bucket wheel should spin freely.

To Lubricate Meter

When rating or using meter, frequent oiling is necessary. Any of the popular brands of household or light machine oils may be used, provided they are cleaned off at the end of each day's run.

Lubricate shaft. Remove cap from commutator box. Oil top of shaft, steady bearing, worm and gear and small worm gear bearing. If extra batteries are used on earphone, it may be necessary to keep commutator box filled with oil in order to reduce sparking, to prevent pitting of the eccentric and fins on worm gear and to prevent burning of the contact wires.

Lubricate pivot. Loosen lower set screw and withdraw pivot from frame. Wipe off grease or gummy oil from pivot; clean bearing with sharpened stick. Hold meter with commutator box down. Oil bearing and replace pivot, tightening set screw using screw driver.

To Clean Current Meter

Meters should always be cleaned at the end of each day's use. The ease and speed with which a Gurley Meter can be taken apart and cared for leaves little excuse for the neglect to which meters are too often subjected.

It is sometimes necessary to clean the meter during a days use. Dousing in a pail of clean water should be done when measuring sewage flow, streams heavily silted or those containing trade wastes. In winter it may be necessary to keep hot water (or coffee) available to thaw out the meter if it is held in the air for any length of time after a measurement.

When storing the meter, even over night, it should be taken apart and carefully dried and cleaned. In order to get the best possible results, a highly polished tungsten carbide hub bearing is used with a tool steel pivot. By regular drying and oiling, these parts can be kept free from rust. The bearing should be cleaned with a round toothpick. Upon receipt of a new Meter, or the return of one from a rating laboratory, the bearing parts should be examined, and if necessary, oiled. When storing the Meter for longer than a few days, the bearings should be covered with a light grease. Light oils may evaporate leaving a residue which sometimes accelerates rusting, if left to stand in that condition. Grease should be removed from the bearing before using.

SERVICE NOTES PYGMY CURRENT METER

The Pygmy Current Meter is shipped with a special shipping pivot in place of the regular pivot. This must be removed and replaced with the regular pivot before use. See below for method of adjustment. Since the Pygmy Meter is not provided with a Raising Nut as in the larger Price Meter, the shipping pivot should be used to protect the pivot and bearing when transported or stored.

To Take Current Meter Apart

Refer to cross section.

Loosen set screw in frame half a turn. Withdraw pivot and lock nut. Unscrew shaft. Do this by lowering bucket until shaft is withdrawn from the commutator box. Use small wrench or pliers on flats of shaft and turn counter-clockwise. Bucket can now be withdrawn from frame. Hub and Bearing can be separated from the bucket wheel by unscrewing hex nut, but this is necessary only when replacing a hub and bearing or bucket wheel.

To Replace and Adjust Pivot

Be certain that the cap is screwed in commutator box. The shipping pivot is removed by loosening set screw. The pivot is inserted through the hole in the lower limb of the yoke, and after adjusting the pivot so as to given the proper vertical play to the shaft assembly, the set screw is tightened. The proper amount of play is obtained in the following manner: first the set screw in the pivot adjusting nut is released. The meter is inverted so the shaft rests against the upper bearing. The pivot is then inserted into the pivot bearing until there is no vertical play. The screw for holding the pivot is then tightened and the pivot adjusting nut is further advanced a quarter of a turn. (Be sure the pivot does not turn with the nut.) With the pivot adjusting nut in this position, the keeper screw is firmly tightened, thus locking the nut. Upon completion of this adjustment the set screw in the yoke is retightened. This adjustment provides an end play of about 0.008 inch. The meter is rated with this amount of play and it is essential that this adjustment be made when installing a new pivot or when the point becomes worn.

Direct Readout Meters

Over the past three years, a new type of current meter has been developed which allows direct determination of water velocities. This portable meter eliminates the need for rating tables and also provides a savings in time in reducing discharge measurement notes. In addition, this type of meter also allows reverse or negative flow situations to be analyzed.

The components of the direct read meter system consist of a sensing unit, indicator unit, and connecting cable. Each of these components are connected through an electrical circuit.

Sensing Unit. The sensing unit can consist of a modified Price AA type of meter or an electromagnetic flow probe. When the electromagnetic probe is immersed in flowing water, a voltage is created around the probe. This voltage is sensed by electrodes imbedded in the probe and transmitted through the cable and to the indicator unit. This voltage potential is proportional to the rate of flowing water.

Indicator Unit. The indicator unit processes the electromagnetic signal and displays the results on an indicator scale or LED readout. Most indicator units have several calibrated scales, their use depending on the sensitivity required.

Service Notes - Direct Read Meters

The direct read meters are an integrated assemblage of sensors and indicators tied together by an electrical circuit. The ability of the meters to provide consistently accurate measurements is dependent on the care and maintenance the unit is given. Internal adjustments of the meter or indicator should only be attempted by factory personnel. Field maintenance of the meter is limited to changing the batteries or cleaning the sensing probe. Care should be taken to ensure that the cable connections are solid and that no wire deterioration occurs.

The unit is calibrated at the factory and in that respect, the investigator should periodically check the direct read meter against a standard current meter.

Suspension Systems

Current meters are suspended by a sounding system which allows concurrent measurement of depth and velocity. For shallow, wadable rivers, the most convenient system is a top-setting wading rod. The top-set rod has a main column, 1/2 inch, hexagonal stock which is graduated in 0.1 foot increments for measuring the depth. Interval markings follow the convention of a single mark every 0.1 foot, a double mark for each 0.5 foot increment, and a triple mark at each whole foot increment. Metric rods are usually singly marked at each centimeter and double marked at decimeters.

For unwadable situations, the use of a boat-mounted cable suspension system is suggested. Such systems consist of a sounding reel (a hand winch with a depth gage precise to 0.1 foot), a length of small diameter cable, a hanger bar (to which the current meter is attached), and a sounding weight. Additionally, a boom assembly is required to extend the suspension system beyond the bow of the boat. Appendix C discusses boat-mounted systems in detail.

For most suspension systems, the 0.2, 0.6, and 0.8 depths must be calculated from the total depth as determined by sounding. However, the top-set wading rod has a feature which allows the current meter to automatically be set at the 0.6 level. The head of a top-set rod is shown in Figure B-3. The depth of the vertical is read on the hexagonal sounding rod. Then the meter is placed in the 0.6 depth position appropriate for the measured depth by the meter positioning rod. If the depth is 1.4 feet, the "1" mark on the meter

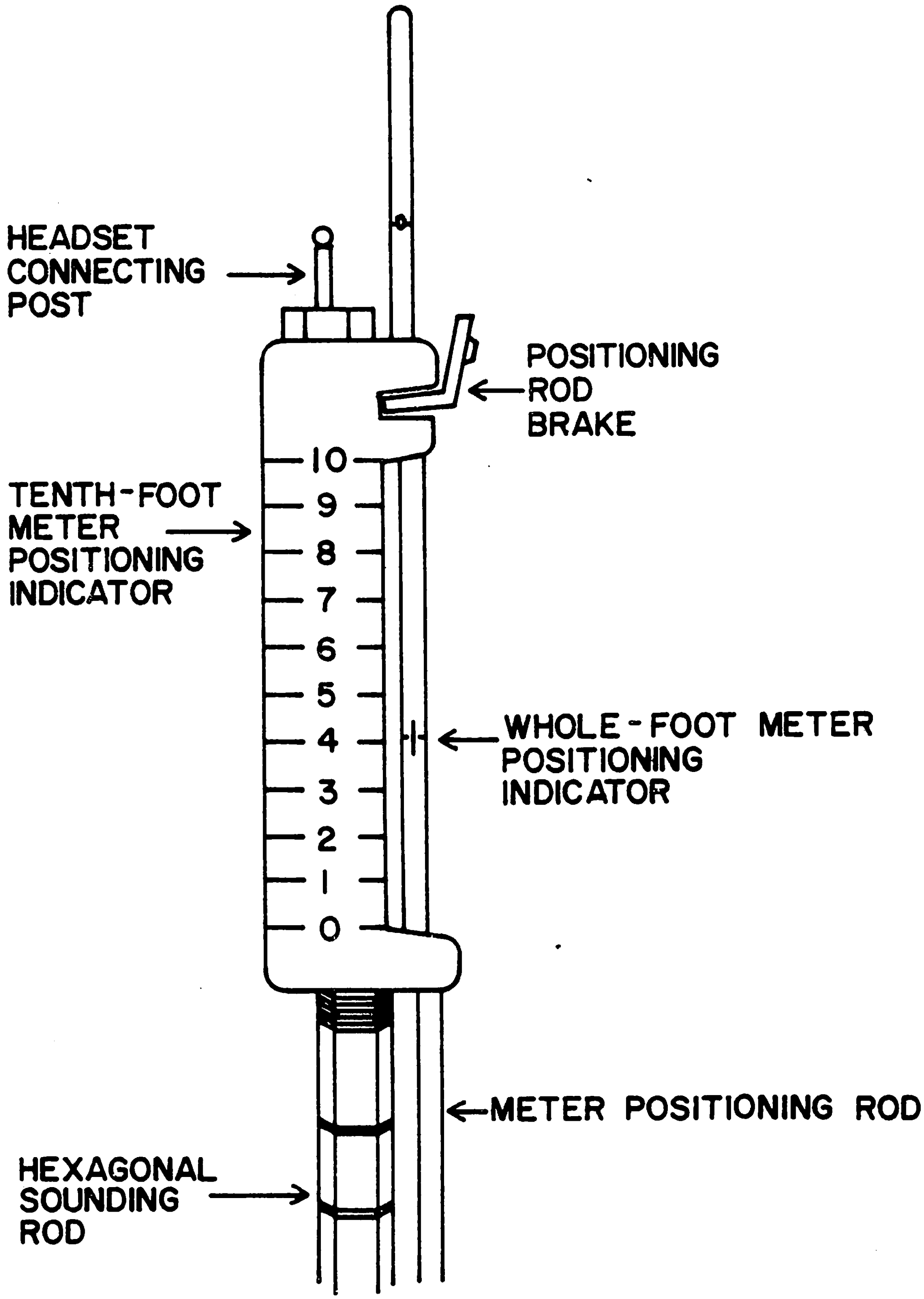


Figure B-3. Automatic six-tenths depth suspension of current meter on a top setting wading rod.

positioning rod is set even with the "4" mark on the grip of the wading rod (see Figure B-3). To move the meter positioning rod, the brake must be released by pushing the brake in toward the grip with the thumb. When releasing the brake, hold on to the positioning rod so that the meter does not slam into the ground. When the positioning rod is in this position, the meter will be suspended exactly 0.84 feet below the surface, which is 0.6 times 1.4, the depth of the vertical.

To Assemble Wading Rods

The collapsible wading rod is assembled by screwing the shaft sections together to obtain the length of wading rod required.

The double end hanger slides over the wading rods, which are flush jointed, and may be clamped in any position by the knurled-head clamp screws. The meter frame and the tailpiece are held in position by set screws. The bottom rod section screws into the wading base the height of the latter being such that this rod section at its top measures 2 feet from the bottom of the wading base.

The Pygmy Wading Rod assembly is little different than the regular rod. There are these differences:

1. The Pygmy Meter does not use a tailpiece.

2. The Wading Rod Base has a shorter vertical dimension than the regular, to allow the meter to be set lower.

3. The bottom section, English or Metric, is longer to compensate for the shorter base and maintain the correct measurement from the bottom of the base.

To Assemble Suspension Cables

Assemble Meter, with tailpiece, to weight hanger, using screw. The hanger bar has several holes through which the meter can be attached. The size of the sounding weight determines which hole to use. The object is to keep the meter 1.0 ft above the sounding weight. Assemble lead weight to bottom of hanger, using weight pin.

The Gurley connector is used to assemble the cables, to the weight hanger and to each other. This is a link consisting of two parallel flat plates with pintle pins at each end, held in place by cotter keys. The cables end in metal eyelets which can be readily connected to the pintle pins. The steel cable, being of smaller diameter than the rubber covered cable is generally connected directly to the weight hanger, since the current exercises less down stream drag on it and less weight is required to keep the meter in the plane of measurement. The standard length of steel cable is 15 feet, but special lengths may be had, or extra 15 foot lengths may be fastened together by connectors to give the desired depth of submergence. The rubber covered cable may be submerged, but is generally kept above the water surface, where its larger diameter makes it easier to handle. Connector attaches the rubber cable to the telephone set cable.

The rubber covered cable contains copper conductors with two leads at the lower end. One lead is grounded to the link connector with the binding post and the other connected to the upper lead on the steel wire cable. The steel wire cable contains an insulated copper core wire which extends at each end in a short lead. The bottom lead is connected to the binding post on the commutator box. Connect to the upper binding post if counting single revolutions, to the lower binding post for every fifth revolution. The circuit is completed through the Meter parts, weight hanger connector, etc. Power is supplied by a dry cell, which should be live enough to give an audible click in the earphone. With long suspension cables, additional dry cells, connected in series, may be required. In such cases binding posts should be provided as the contact wires will not last so long under the higher voltage. Filling the contact chamber with oil, reduces the sparking and makes the contact wires last longer. A 15 pound weight is regularly supplied with this outfit. Conditions may require the use of heavier weights; 30, 50, and 75 lb weights are available.

VELOCITY MEASUREMENTS

In making a velocity distribution or discharge measurement, each cross section is divided into 10-30 partial sections depending on the level of detail desired. For discharge measurements, 20-30 partial sections are used. A partial section is a rectangle whose depth is equal to the sounded depth at a "vertical" and whose width is equal to the sum of half the distances to the adjacent verticals. At each vertical the following observations are made: (1) the distance to a reference point (zero point) on the bank, (2) the depth, and (3) the average velocity of the water column in the vertical.

The velocity in any vertical water column varies from zero at the bottom to a velocity at the surface about 1.15 times the average velocity in the column. Figure B-4 shows a typical vertical velocity distribution. The average velocity in the vertical may be approximated by one of the three following equations:

$$V_{AVG} = V_{.6d} \tag{B-1}$$

$$V_{AVG} = (V_{.2d} + V_{.8d})/2 \tag{B-2}$$

$$V_{AVG} = (V_{.2d} + V_{.8d} + 2V_{.6d})/4 \tag{B-3}$$

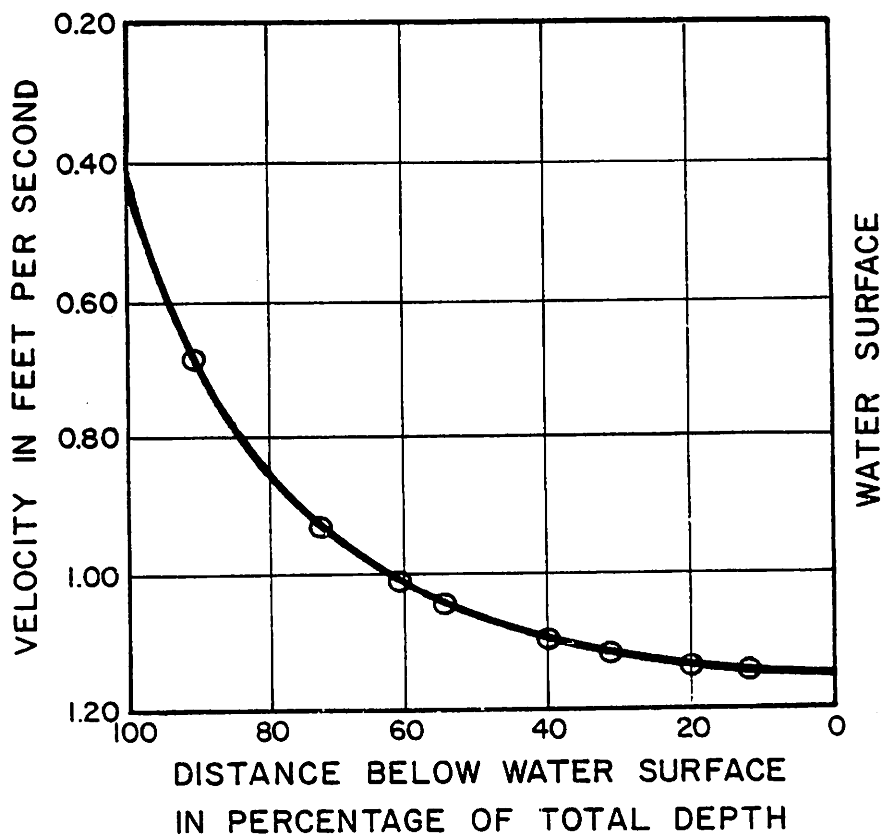


Figure B-4. Vertical velocity distribution typical of open channel flow.

Where V_x is measured at a fraction, x, of the depth from the surface. For example, $V_{.6d}$ is the velocity measured at a depth of 0.6 times the total depth of the vertical. If the depth is 1.0 foot, the velocity is measured 0.6 foot below the surface. The use of equation B-1 is termed the one-point method; equation B-2, the two-point; and equation B-3, the three-point method. Equation B-1 should be applied only where the depth of the vertical is less than 2.5 feet (about 75 cm). The two-point method is usually applied only when the depth is greater than 2.5 feet. The three-point method is used when the velocities in the vertical are abnormally distributed, or when the 0.8 measurement is affected by bed turbulence or an obstruction.

DISCHARGE CALCULATIONS

As previously defined, a vertical is measured at the center of each partial section. A partial section represents an approximate rectangle, the width of which is the sum of half the distances to the adjacent verticles. The mean depth for the partial section is very close to the depth measured at the vertical. These concepts are shown in Figure B-5. The cross-sectional area for each partial section, i, is equal to the width of the partial section, w_i, times the depth, d_i.

By the equation of continuity, the discharge through the partial section (called a partial discharge) is given as:

$$q_i = a_i \times v_i = w_i \times d_i \times v_i$$

where v_i is the mean column velocity as measured at the vertical, and the other terms are previously defined.

The total discharge for the cross section is the sum of all the partial discharges.

$$Q = \Sigma\ q_i = \Sigma\ (V_i \times w_i \times d_i)$$

When measuring discharges, the U.S. Geological Survey recommends that no more than 10%, and preferably no more than 5%, of the total discharge flow thorugh any partial section. For further details concerning discharge measurements, the reader is referred to the IFG Field forms contained in Appendix E, Buchanan and Somers (1968) and Simmons and Peterka (1967).

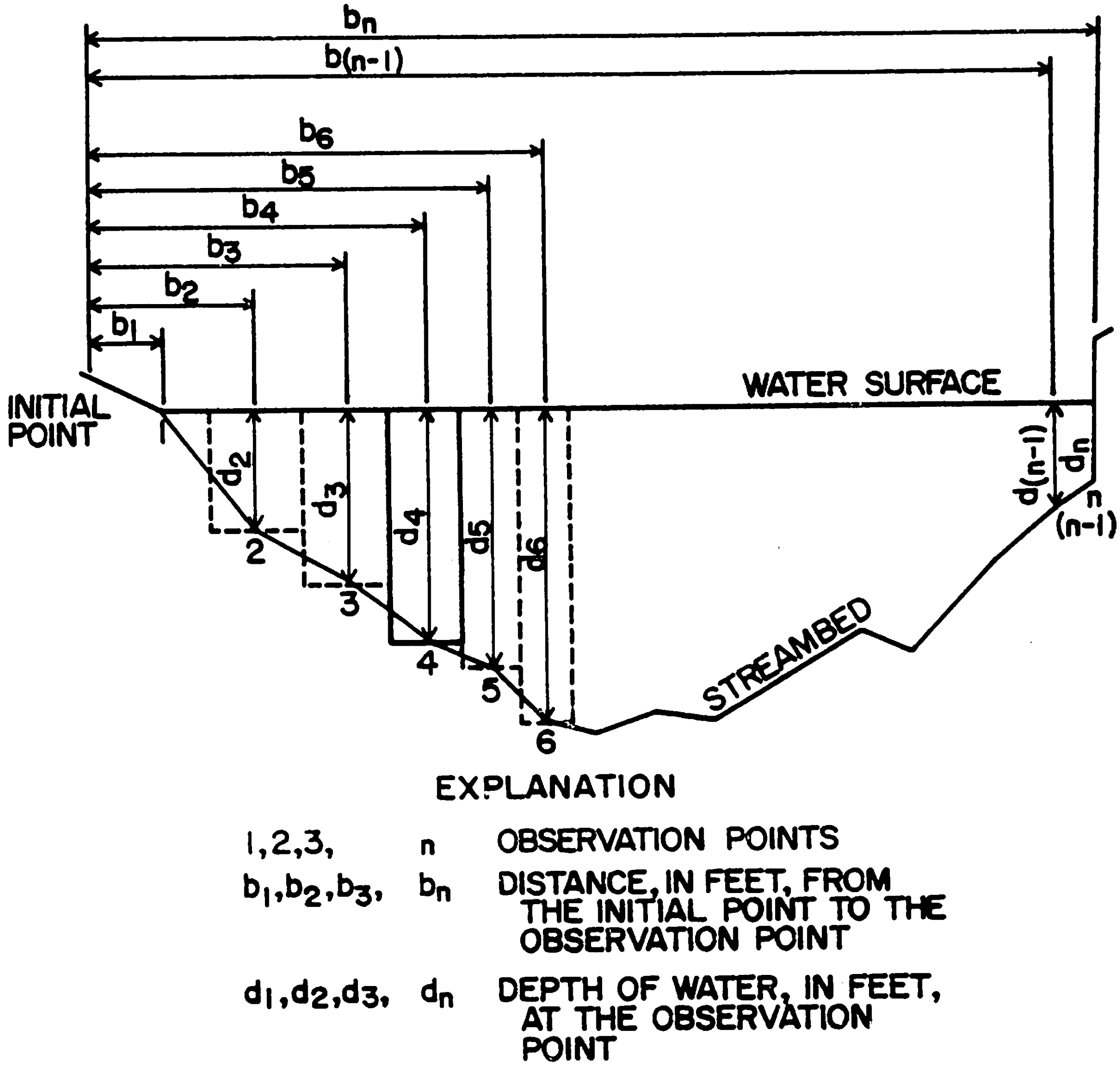


Figure B-5. Partial section concept used in measuring and calculating discharge.

APPENDIX C

FIELD TECHNIQUES FOR LARGE RIVERS

In theory, there is little difference between hydraulic simulations in small or large rivers. Hydraulic simulation models and data specifications are the same regardless of the size of the stream. Obviously, problems associated with large river data collection techniques are problems of scale. Often, problems of scale can be solved using equipment especially designed for the scale of the problem.

The principal difficulty encountered with large river data collection is in obtaining cross-sectional measurements. Specifically, cross section measurements may be broken down into three problem areas:

1) Maintaining a line of measurements on the transect (maintaining position).

2) Measuring distances from a reference point on the bank.

3) Measuring elevations, velocities, and substrate sizes at points on the transect.

MAINTAINING POSITION

Even if one could walk on water, he would have trouble maintaining position in a river. However, since most of us require the use of boats, the problems of maintaining a stable position relative to the bank can sometimes acquire massive proportions. The selection of a boat and power unit should be given careful consideration. Some researches prefer to use a deep-keeled boat for its ease of handling in moving water. However, deep-keeled boats tend to be somewhat unstable if the crew has to move about in the boat. A flat-bottomed boat is a more stable platform for the crew, but may be difficult to hold on line in moving water. Perhaps a suitable compromise would be to use a boat of tri-hull design.

Three techniques may be used for maintaining position on-line:

1) Fixed line, fixed point system.

2) Fixed line, floating point system.

3) Floating line, floating point system.

With a fixed line, the transect is marked so that the boat can be placed on a semi-permanent line relative to the bank, and boat position is maintained by the boat crew. With a floating line, the transect is unmarked and the position of the boat is controlled by an observer on the bank. A fixed point system means that the boat is physically anchored on-line. Under a floating point system, the position of the boat would be controlled by a motor.

Fixed Line, Fixed Point System

For detailed hydraulic simulation models the fixed line, fixed point system is the most desirable. Any time a fixed position must be maintained for a relatively large time period, this system will give the most reproducible results.

The transect is marked by a 1/8 inch cable which is stretched across the stream, passed over the headstakes, and firmly anchored on either side of the stream. The cable is then tightened by a hand- or battery-operated winch or a come-along. The boat is attached directly to the cable using a bracket mount listed in the equipment section (Figure C-1). For the greatest directional stability, the boat should be clipped to the cable at the gunwales, forward of amid-ships. Anchoring to the bow allows the boat to fishtail badly, making stationary measurements difficult.

The channel width which can be traversed successfully using this method depends on the scale of gear used. Given the size of boats normally available for this type of work (14 to 16 feet on the average--with 25 to 40 h.p. motors), the largest crossing practical would be on the order of 500 to 750 feet. Longer crossings would require a larger spool for carrying cable, and would require a larger, more powerful, craft to string the cable across the channel. Figure C-2 demonstrates the sequence involved in stretching a cable across a large channel.

With the boat anchored to the cable, the boat crew may pull the boat to measurement locations on the transect. If the cable is graduated in feet or meters, the distance from the reference point on the bank can be read directly from the cable by the boat crew.

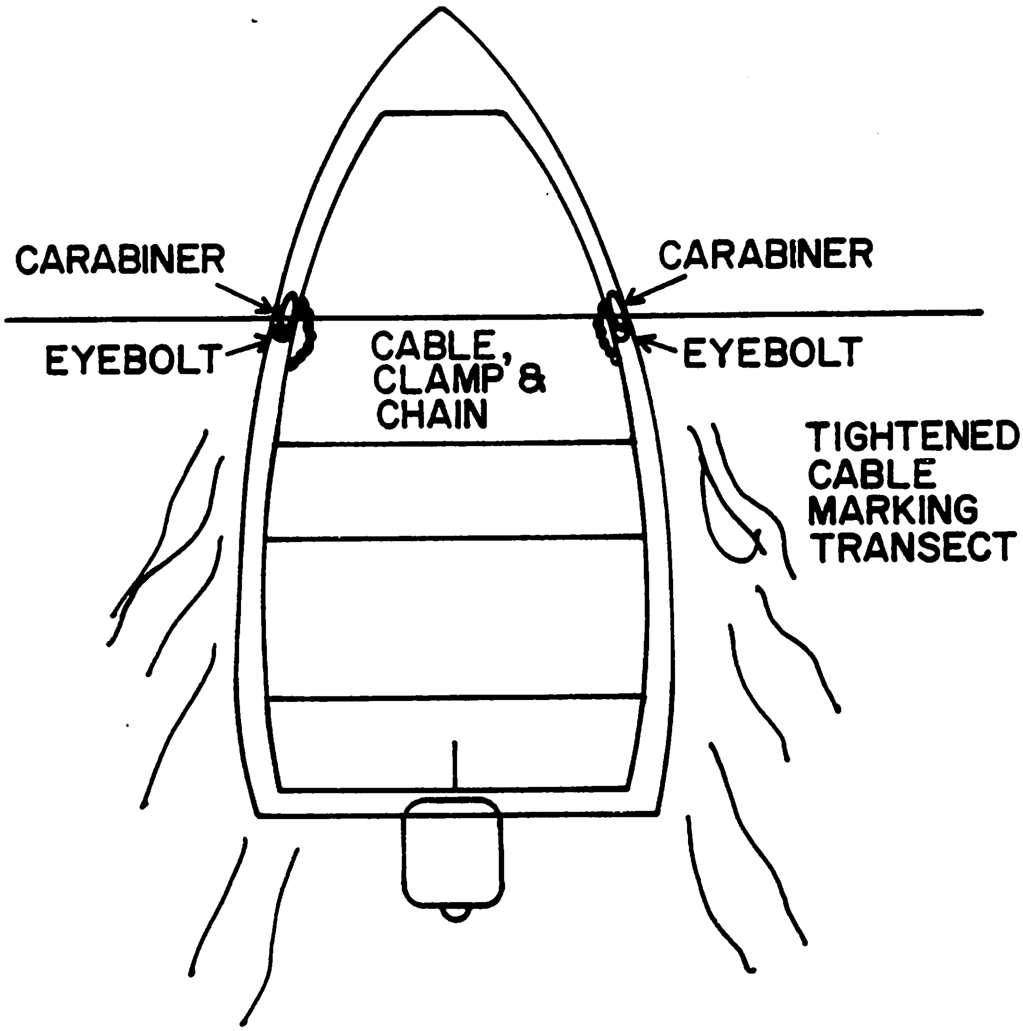


Figure C-1. Fixed line, fixed point method of maintaining longitudinal and lateral position in an unwadeable stream.

Fixed Line, Floating Point System

The fixed line, floating point system utilizes a series of buoys to mark the line of sight of an observer on the bank. Markers can be placed at specified distances from a reference point on the bank through the use of stadia or an EDM setup at the headstake (Appendix A). The line of sight is set by an observer sighting through a level to the opposing bank headstake. The observer in the boat is responsible for setting out the markers according

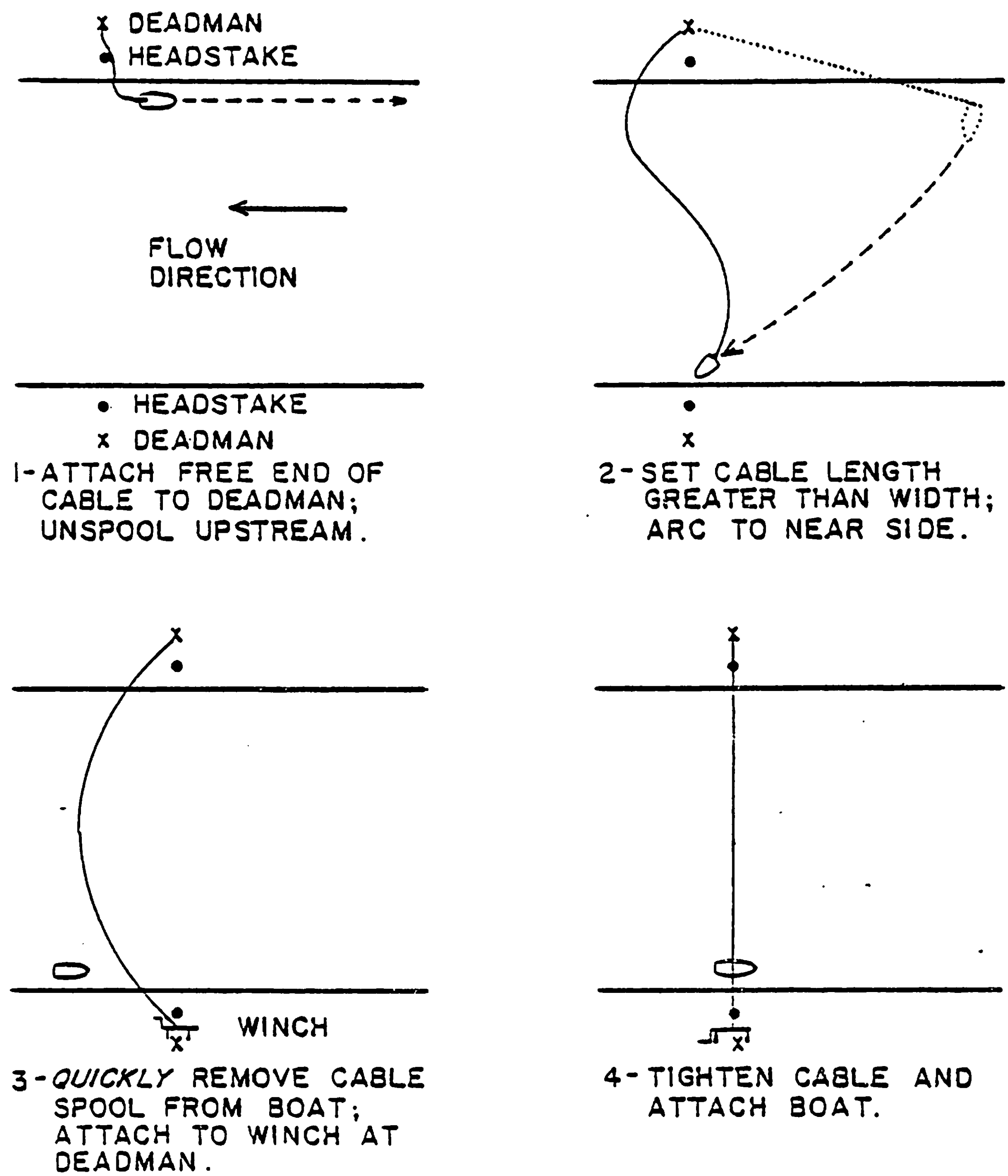


Figure C-2. Sequence involved in stretching cable or tagline across a large channel.

to directions supplied from the bank, and for holding the boat in place long enough for the distance measurement to be made. Distance measurements may be deferred until sounding measurements are made, if desired.

Because of the effect of different depths across the section, the initial placement of markers will result in the floats being on a crooked line across the river. Therefore, initial marker drops should be considerably upstream from the desired line of sight. They can then be towed downstream until the floats are on-line (Figure C-3). Option a) of Step 3 in Figure C-3 would be appropriate for either a water surface profile (WSP) model, or the initial data set for a rating curve model. Here, the target (either stadia rod or prism) mounted on the boat is held at the marker buoy by the helmsman, while the distance is read by the observer on shore. If the rating curve approach is used, second and third data sets must be taken at very nearly the same places as the initial data set. This may be accomplished as in option b of Step 3, where the helmsman holds the line longitudinally, but is directed laterally to the right place by the observer on shore. A third option would be to reposition the buoys so that they mark the correct positions on the transect.

An alternative fixed line, floating point system might consist of a light tag line stretched across the channel in place of the cable used under the fixed point system. In this case, it may be possible to traverse a considerably wider river because of the smaller weight of the tag line. The boat would not be attached to the tag line, but free to be positioned at the appropriate place on the transect by the helmsman.

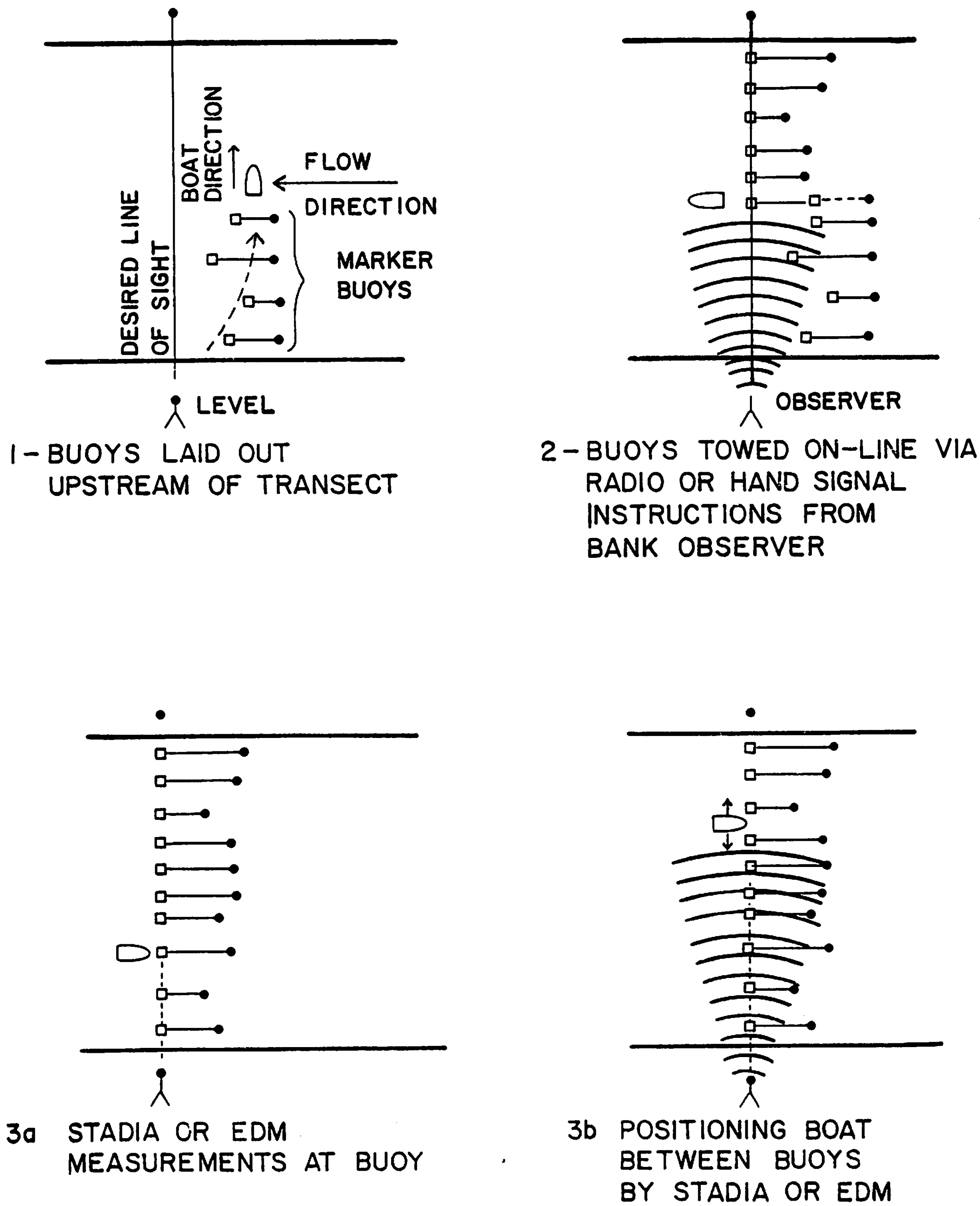


Figure C-3. Use of marker buoys for horizontal location in fixed line, floating point measurement technique.

Floating Line, Floating Point System

Under this system, the location of the transect is "blind" to the helmsman. The boat is positioned both longitudinally and laterally at each measurement location by the bank observer either by radio contact or hand signals. All measurements, depth, velocity, substrate, and distance from the reference point, should be made concurrently at each position. This system is somewhat faster than either of the fixed line systems. However, the reproducibility of data collection points depends largely on the skill of the helmsman, and the coordination between the helmsman and the shore observer. Since the helmsman has no immediate reference point on the transect, great care must be taken to insure that the boat is not drifting while measurements are being made. This is the primary responsibility of the observer.

MEASURING DISTANCES

The preceding discussions should given the reader a fair idea of the options available for measuring distances across large rivers. Rivers up to about 600 feet in width can be measured using an incremented cable to which the boat is anchored. Substituting a light polypropylene tag line for the cable and maintaining boat position by motor, it might be feasible to measure as far as 800 to 1,000 feet. The traversable distance depends on the adequacy of the deadmen, the strength and weight of the line, and the pull capacity of the winch.

When attaching a cable to a dead man, it is important not to kink the cable. A cable with a tensile strength of 2 tons will break under 200 pounds of pull if it is kinked. The free end of the cable should be equipped with either a hook or a clevis for attachment to the deadman. The deadman might be a tree, where the cable is attached by means of a chain around the trunk, with the cable clevis attached to the chain. In this case, an old tire or other protection feature should be placed between the chain and the tree to prevent stripping off the bark. Specific streamside environments may require different types of cable anchoring devices. In most situations, 5 to 6 foot steel fenceposts can be driven into the river banks to provide a solid attachment. For permanent anchors, the fenceposts may be set in concrete. The cable can be attached and stretched with the use of a come-along and cable pullers.

In situations where the streamside environment is a vertical rock face, an expanding star-bolt may be driven into a hole drilled in the rock and utilized as an attachment point. The success of this procedure depends on the rock type and expansion of the wedge into the rock. Typically, the device works well in sandstone but poorly in crystalline rock. An eyebolt can be used as the attachment point if the star bolt is threaded. Such bolts are available through hardware stores and masonry equipment suppliers.

Use of either stadia or an EDM requires that a target be mounted in the boat. With stadia, either a rodman or a bracket is needed in the boat to hold the rod. Under reasonable conditions, errors in stadia distances should not exceed 1 foot in a 600 foot sight; nor 10 feet in a 1,000 foot sight. If an EDM is used, a retroprism target should be securely mounted in the boat. A cheap EDM target can be constructed from a piece of plywood covered with bicycle reflectors. An EDM is accurate to about 0.04 foot for distances from 1,600 feet to 3 miles, depending on the instrument.

SOUNDING

Sounding is a method of determining depths or bed elevations, and for measuring velocities. In some cases, an estimate of the substrate may also be determined by sounding.

If only a stream bed profile is desired, an electronic depth sounder may be used. These units are quite useful even if a more precise set of measurements are desired, as the boat crew can traverse the channel several times and determine major features beneath the surface. The precision of depth sounders is around 0.5 to 1.0 foot, and many exhibit feedback (read secondary echoes reflecting off the bottom of the boat) in water less than about 6 feet deep. These problems can be mitigated somewhat by using narrow-beam instruments.

In most cases, velocity measurements are required along with depth measurements. Electronic depth sounders cannot be used to measure velocity, so an additional piece of equipment is needed. The most practical suspension system when both depths and velocities are required, is the sounding reel cable suspension described in Appendix B.

The most pertinent features of a cable sounding system are: (1) the sounding reel, (2) the boat boom, (3) cable, (4) hanger bar, (5) current meter, and (6) sounding weight.

Sounding Reels

Sounding reels are compact, level wind, hand-operated winches equipped with a length (50 to 100 feet) of 1/10 inch cable. They are also equipped with a gage which measures the amount of cable unwound from a zero point.

This gage can be "zeroed" at the point that the sounding weight just touches the surface. When the weight is lowered to the bottom, the gage measures the distance to the nearest 0.1 foot.

Boat Boom

Boat booms must usually be fabricated to the specifications of the boat. However, they have several common design features. First, the cable boom must extend beyond the bow. If a heavy (75 to 100 pound) sounding weight is to be used, the boom should go straight off the bow. Skewing the boom to one side will cause the boat to list badly.

The boom must be firmly anchored to solid structural supports of the boat. Many booms are constructed with an A-Frame design, with a mounting plate for the sounding reel and a cable pulley at the end. Crew members making the soundings will appreciate boom construction with sufficient length that the sounding reel can be operated from one of the seats in the boat.

Suspension System

In addition to the boom and sounding reel, the suspension system consists of the cable, hanger bar, and sounding weight. The general assembly of a Price AA current meter on a cable suspension system is given in Figure C-4.

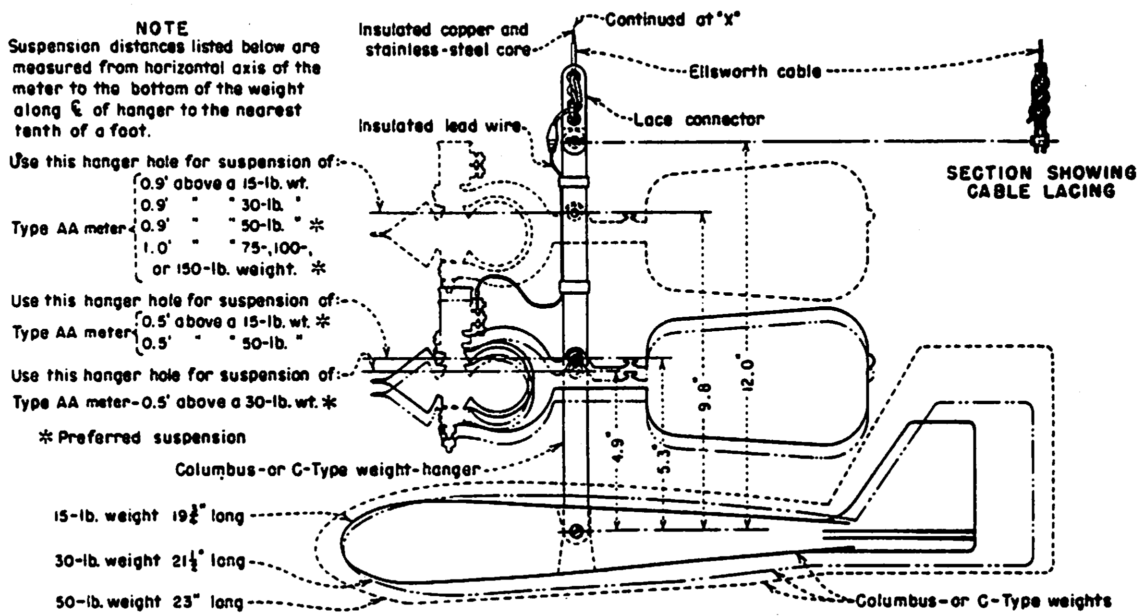


Figure C-4. General assembly of a Price AA current meter and sounding weight on a cable suspension system.

Sounding weights come in various sizes ranging from 15 to 150 pounds. Generally, the heavier weights are for use in faster water. High water velocities can cause the sounding line to deviate from a true vertical position, as shown in Figure C-5. An approximation of the true depth below the boom may be determined by using a heavier weight and/or making an angle correction. In Figure C-5, assuming the depth at points A and B are equal, the measured line AC is too long. If the angle of deflection is known, the line BC can be calculated by:

$$BC = AC \cos \alpha$$

where α is the angle of deflection. This can be measured by attaching a protractor to the beam and noting the angle of intersection of the cable.

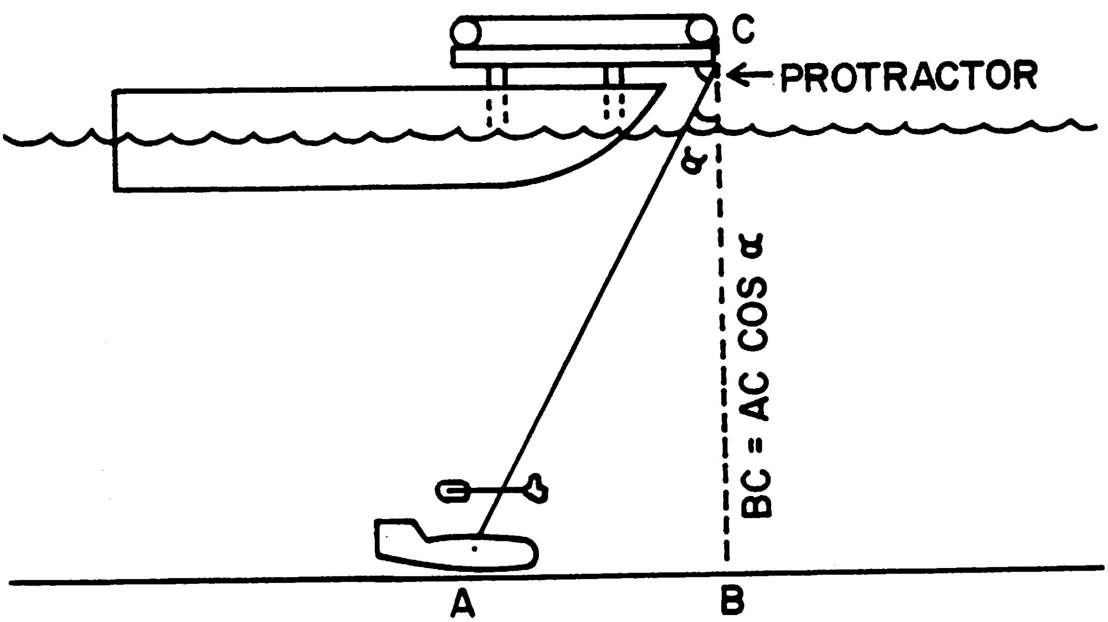
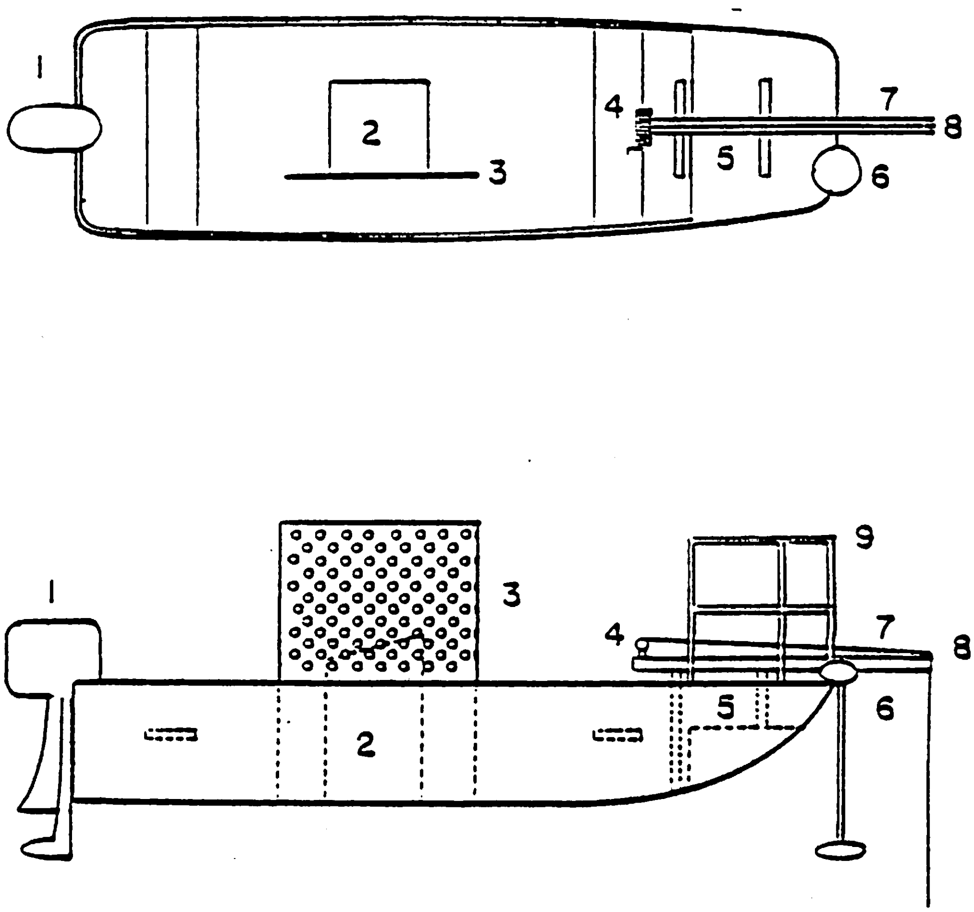


Figure C-5. Angle correction for sounding in high velocity water.

Figure C-6 shows the layout for a typical large river boat, rigged for use with a cable sounding system and EDM distance measurement. The boat is equipped with two outboard motors. The primary motor should be powerful enough for the basic transportation duties of the boat, or towing taglines across the stream. For floating point systems, a small trolling motor (5 to 7 h.p.) is suggested for holding position. The trolling motor has a larger arc and is thus more responsive for lateral movements. However, it is not powerful enough to produce the acceleration to affect current meter measurements.



1- PRIMARY MOTOR, 25 - 120 h.p., as required.
2- CONTROL CONSOLE
3- EDM TARGET; PLYWOOD AND BICYCLE REFLECTORS
4- SOUNDING REEL AND CABLE
5- A-FRAME STRUTS ON SOUNDING BOOM
6- TROLLING MOTOR, 5 - 7 h.p.
7- SOUNDING BOOM
8- PULLEY, SEALED BEARING OR BRASS BUSHING
9- SAFETY RAILING

Figure C-6. Layout for a typical large river boat, rigged for cable sounding and EDM distance measurement.

APPENDIX D

SUBSTRATE AND COVER ANALYSIS

The determination of the amount of Weighted Usable Area is the goal of the Physical Habitat Simulation. The calculation of the WUA is dependent on the accurate simulation and evaluation of the hydraulic/habitat environments based on known habitat suitability for a species. These preference criteria were developed from observation of the species in a variety of habitats and by assuming that the preference for a specific combination of conditions is related to the species frequency of occurrence in the observed habitat. The suitability of the existing habitat is calculated based on the variable hydraulic parameters of depth and velocity, and the fixed boundary condition of substrate/cover. The suitability of existing habitat is defined by preference factors calculated from actual observations and simulated conditions.

The combined affect of the individual preference factors results in a Joint Preference Factor (J.P.F.). The aggregation of the individual factors can be accomplished by one of three methods: multiplication of the individual preference factors, implying a synergistic effect; determination of the geometric mean of the preference factors, implying compensation between factors; and the lowest or limiting factor approach. Each of these aggregating techniques assumes independence between the preference factors. Traditionally, the synergistic approach has been the method suggested for calculation of the Weighted Usable Area.

Future determination of the J.P.F.'s will be developed around the possible interaction between variables. The result will be a probability function for each variable. This function will link the factors based on the dependency link between them.

The combined preference factor calculated by this method will give an accurate calculation of the existing habitat preferences. This type of analysis requires extensive amounts of data and the development of studies specifically designed to collect this type of information. The investigator should be aware of the requirements of each type of preference factor and determine the constraints required prior to data collection.

SUBSTRATE AND/OR COVER ANALYSIS

The inclusion of substrate/cover as a variable utilized in the determination of the Joint Preference Factor, assumes a fixed right hand boundary condition. This assumption defines the affect of substrate/cover on the J.P.F. as unchanging as the flow varies. However, as the depth and velocity components vary, the J.P.F. will change.

Cover can be incorporated into the analysis by either direct substitution for the substrate parameter or inclusion of the substrate variable as a portion of the cover analysis. The following discussion will center on a description of substrate alone and as included as an element of the cover analysis.

Substrate

Substrate can be categorized based on a modified Wentworth particle size scale (Table D1). Substrate sizes and types can be coded to typify the existing substrate. An example is Table D2. The coded values are used to define the J.P.F.

Table D2. Substrate Codes

1	Plant Detritus
2	Mud
3	Silt (< .062 mm)
4	Sand (.062 - 2 mm)
5	Gravel (2 - 64 mm)
6	Rubble (64 - 250 mm)
7	Boulder (250 mm - 4000 mm)
8	Bedrock (solid rock)

A mixture of two adjacent substrate types can also be described with this numeric code. For example, a code value of 5.5 indicates a substrate mixture of 50% gravel and 50% rubble. A value of 4.2 indicates a 80%/20% combination of sand and gravel. In contrast, a 4.8 value indicates a 20%/80% mixture of sand and gravel. Intermediate code values refer to percentage mixtures and not size gradation.

Substrate information should be collected for each coordinate and velocity vertical of the cross section. Any combination of substrate values should be noted. These coded values can then be coupled with either hydraulic simulation program. With the IFG-2, Water Surface Profile, computer program, the substrate values are entered on the basis of the location of the Mannings N verticals. This method requires that the measurements may be mixed. The

Table D1. Modified Wentworth particle size scale.

	RANGE mm	Approx. MEDIAN mm
Mamouth Boulder	4000	--
Very Large Boulder	3500 - 4000	3750
	3000 - 3500	3250
	2500 - 3000	2750
	2000 - 2500	2250
Large Boulder	1650 - 2000	1825
	1330 - 1650	1490
	1000 - 1330	1165
Medium Boulder	830 - 1000	915
	665 - 830	750
	500 - 665	580
Small Boulder	415 - 500	450
	335 - 415	375
	250 - 335	290
Large Cobble	190 - 250	220
	130 - 190	160
Small Cobble	100 - 130	115
	64 - 100	85
Very Course Gravel	50 - 64	57
	32 - 50	40
Course Gravel	16 - 32	24
Medium Gravel	8 - 16	12
Fine Gravel	4 - 8	6
Pea Gravel	2 - 4	3
Very Course Sand	1 - 2	1.5
Sand	.062 - 1	.5
Silt-Clay	.062	--

IFG-4 computer program requires a substrate index for each designated coordinate point.

Cover

Analysis of the effect of cover on the aquatic species was not possible with the early version of PHABSIM. However, now that the boundary conditions of the individual cells can be represented by an integer value, cover can be substituted or integrated with the substrate analysis. This can be accomplished through the following steps:

Step 1: Develop a numerical coding system by which different types and amounts of cover can be described. The code can be either integer or real number.

Step 2: Develop a "cover curve" for the life stage or species indicating the relative preference of the aquatic species for the different types of cover coded in Step 1.

Step 3: Enter the appropriate cover code for each cell based on the cover designation collected during the hydraulic measurements.

No specific guidelines have been established for cover data collection. Therefore, the intensity and thoroughness of data collection is dependent on the requirements of the investigator. At the present time, the HABTAT program allows up to 99 coordinate points to be used to define the types and

13	0 - 25% of the cell has object cover combined with overhanging vegetation
14	25 - 50% of the cell has object cover combined with overhanging vegetation
15	50 - 75% of the cell has object cover combined with overhanging vegetation
16	75 - 100% of the cell has object cover combined with overhanging vegetation
17	0 - 25% of the cell has object cover combined with undercut bank
18	25 - 50% of the cell has object cover combined with undercut bank
19	50 - 75% of the cell has object cover combined with undercut bank
20	75 - 100% of the cell has object cover combined with undercut bank
21	0 - 25% of the cell has a combination of undercut bank and overhanging vegetation
22	25 - 50% of the cell has a combination of undercut bank and overhanging vegetation
23	50 - 75% of the cell has a combination of undercut bank and overhanging vegetation
24	75 - 100% of the cell has a combination of undercut bank and overhanging vegetation
25	0 - 25% of the cell has a combination of object cover, undercut bank, and overhanging vegetation
26	25 - 50% of the cell has a combination of object cover, undercut bank, and overhanging vegetation
27	50 - 75% of the cell has a combination of object cover, undercut bank, and overhanging vegetation
28	75 - 100% of the cell has a combination of object cover, undercut bank, and overhanging vegetation

The above code could be made more detailed by several means. One obvious way would be to subdivide affected areas by tenths rather than fourths. Also, superimposed cover, such as object cover under overhanging vegetation, could be distinguised from the same amount of the same two cover types spatially separated but still in the same cell. The amount of detail that can be incorporated into this type of cover code is not a constraint. Instead, it is up to the investigator to place limits on the amount of detail by deciding to what extent various types of cover differ in their effects on the species of interest.

combinations of cover for a habitat suitabilty curve. The information used to define the curves can be obtained from: specific studies designed to obtain cover relationships; personal experience and knowledge; and literature accounts. To ease cover data collection, the investigator should define the habitat suitability curve, prior to collection of the cover data. An example of the technique required for a cover analysis is described below.

Step 1. Design a code for cover type. Two considerations should be incorporated: a descriptor for cover type and a measure of relative abundance of that cover type in the cell. For example, the type of cover could be simply described as objects that a fish could hide behind or as overhead cover. Alternatively, the cover code can be very specific, identifying objects by size or by specific substrate type, such as distinguishing rocks, logs, or root wads.

An integer code can easily be devised to indicate the percentage of a cell affected by any of several different types (or combination of types) of cover. As an example, consider the following cover code:

Cover Code	Cover Description
0	No physical cover
1	0 - 25% of the cell affected by object cover
2	25 - 50% of the cell affected by object cover
3	50 - 75% of the cell affected by object cover
4	75 - 100% of the cell affected by object cover
5	0 - 25% of the cell has overhanging vegetation
6	25 - 50% of the cell has overhanging vegetation
7	50 - 75% of the cell has overhanging vegetation
8	75 - 100% of the cell has overhanging vegetation
9	0 - 25% of the cell has undercut bank
10	25 - 50% of the cell has undercut bank
11	50 - 75% of the cell has undercut bank
12	75 - 100% of the cell has undercut bank

Step 2. In order to incorporate cover availability into HABTAT, it is necessary to estimate the preference of a species by life stage for various cover types. Presently, the lack of data forces the user to construct cover preference curves based predominantly on experience and judgment. The logic and assumptions used to build these curves should be documented as thoroughly as possible. It is usually easiest to identify the cover type or combination which is most preferred by the species and then rate all others relative to the preferred type. A table of preference by species vs. cover code can then be constructed. Not all intermediate values need be recorded; these will be interpolated by the computer. The points used in the table are entered as substrate data. Figure D-1 illustrates hypothetical cover preference curves for adult brown corresponding to the previously developed cover code. The investigator should develop these curves prior to field data collection.

Step 3. The cell-by-cell determination of the reach cover types requires accurate cover mapping (Figure D-2). The ability to compare individual cells requires that each cell be defined on an equal size basis with similar lengths and widths. This cell definition will require that additional transects and cell divisions, beyond those needed for hydraulic simulation, be estimated. The development of the additional cell boundaries and data collection, increases the field time and field measurements. Examples of the types of problems inherent in a cover analysis can be described. A common type of cover is undercut banks. Undercuts can be continuous or discontinuous and the actual value as cover may be over or underestimated depending on the placement of the transects. Instream objects also present a problem since it is not the area occupied by the object but the low velocity area behind the object which

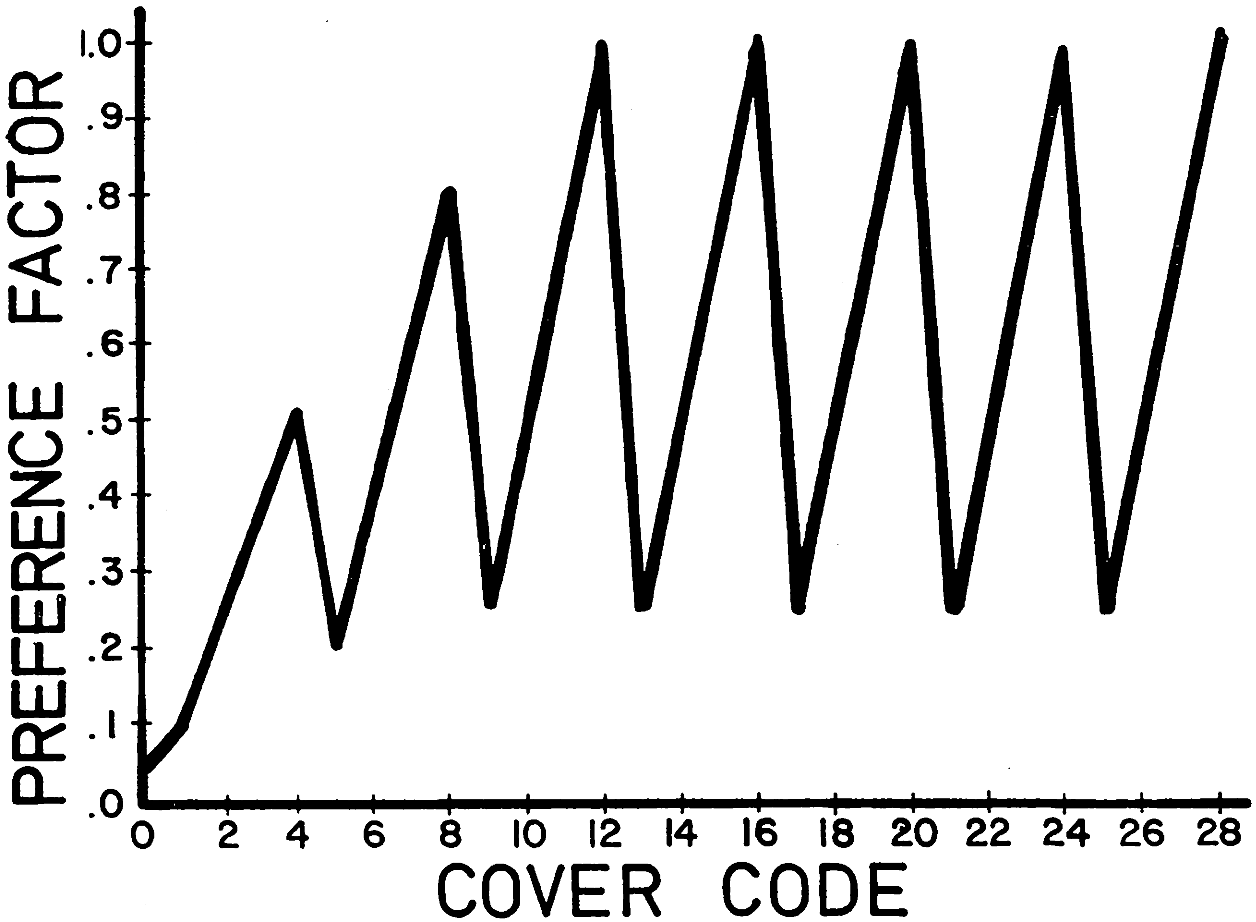


Figure D-1. Example of a coded cover curve developed for adult brown trout.

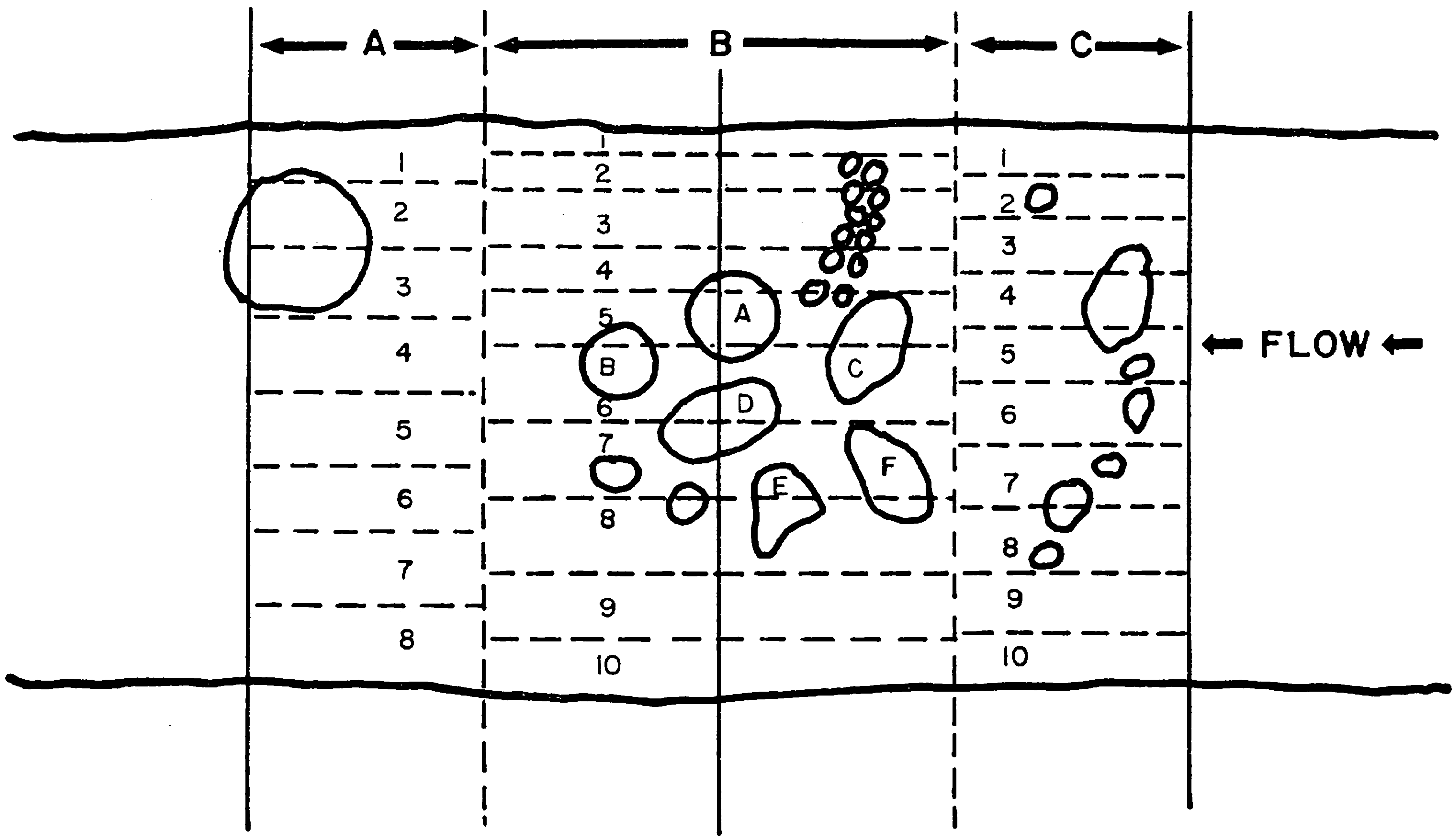


Figure D-2. Quantification of instream object cover in a typical study reach.

is utilized by a fish. Therefore, the investigator should quantify the cover between objects and not their actual number. Individual rocks or clusters must be evaluated as to actual instream cover value.

The investigator should be aware of these potential problems and develop data reduction techniques for their analysis.

APPENDIX E

EQUIPMENT COSTS AND SUPPLIERS

The following is a list of equipment that would be needed for an instream flow study and a list of potential suppliers. This list is not all inclusive but should be used to compare with local equipment outlets. The listing of specific brand names does not constitute an endorsement. If equipment cannot be purchased, the investigator could lease or rent the proper equipment.

Table E1. Field Equipment

Item Description		Approximate Unit Cost
Surveying Equipment		
Automatic levels--preferred for ease of leveling, superior optics, and internal level compensation. For large river work the magnification should be at least 30x. For rivers under 300 ft in width, 20-25x will suffice.		
Brand Names and Numbers		
Lietz B-1	without tripod	$ 1,595
Nikon AE (32x)	"	1,295
Geotec AL2 (32x)	"	795
Lietz B-2 (25x)	"	995
Lietz C-3 (25x)	"	695
Geotec AL3 (25x)	"	495
Model S-201 (30x) Cat No. 43724	"	505
Model S-302 (20x) Cat No. 43722	"	382
Builders Levels--more difficult to level than automatics, but comparable in optical properties; may be more durable and stand up better under abuse.		
Dumpy Level		
Berger 450 (33x)	without tripod	425
(20 to 44x zoom)		460
Berger 110B (20x)	with tripod	170
Lietz Engineers Level (33x)	without tripod	395

Item Description	Approximate Unit Cost
Tripod	120
Level Rod	
Philadelphia type	
(10 ft) graduated in 0.1 and 0.01	$ 45
(13 ft) " "	72
Fiberglass telescoping (preferred--saves steps and turns)	
(20 ft)	100
(25 ft)	120
(30 ft)	140
Rod Bubble	5
Survey stakes	
½" x 30" concrete reinforcement bar (rebar)	15¢/lb
plastic (16")	1.45@
Distance Metering Equipment	
Steel tape (stainless or chrome plated) with reel	
(200 ft)	210
(300 ft)	300
Fiberglass tape*	
(200 ft)	25
(300 ft)	40
Tape clamps	14
1/8" cable tagline - 300 ft	#####
Incremental tagline--constructed from ¼" rope and marked (painted) at regular intervals.	
Nylon	10¢/ft
Polyester	3¢/ft
Electronic distance meters--applicable to rivers larger than about 600 ft in width.	
Geonometer (range to 2 miles, price inclues a theodolite so level is not needed)--Laser activated.	7,500
Beetle 500--infrared light source. Range = 1600 ft. Accuracy = ± .03 ft.	3,000

*May break if tape is allowed to drag in current and is then tightened.

Item Description	Approximate Unit Cost
Retroprisms and traverse equipment.**	450
Battery pack and charger	$ 150
Adaptor for mounting on level	170
Hewlett Packard	
3805 mounts on Tribrach--glass extra 1 mile range with triple prism. Infrared.	5,000 to 5,650
Total Station 3810 1 mile range, slope-distance vertical 20", sensitive to cold, not super accurate, not read electronic. Infrared.	9,250 to 10,500
ETS 3820 3 mile range, horizontal and vertical angles all electronic.	18,000 to 20,000
Range Finders	
Lietz - lens displacing type. Range 29 to 1000 ft. Accuracy: 1 percent up to 300 ft; 2 percent 300 to 500 ft; 5 percent 500 to 1000 ft	300
Stream Gaging Equipment	
Current Meters	
Pygmy--used for shallow areas with velocities less than about 3 ft/second	230
Price AA--used for water greater than 0.4 feet in depth, with velocities measurable up to about 10' per second	240
Marsh-McBirney--direct readout on scale	1,500
Teledyne Gurley--direct readout	1,500

**For our accuracy requirements, plus the fact that the target will be mounted on a boat, the traverse equipment can be replaced by a large target made of plywood covered with highway reflectors.

Item Description	Approximate Unit Cost
Field Support Equipment	
Large, unwadeable rivers	
Boat, 16' flat bottom or tri-hull	1,000 to 2,000
18 h. p. outboard motor	1,000
Small, (less than 400 ft wide) unwadeable rivers	
Boat, 14' flat bottom or tri-hull	500 to 1,500
7½ h. p. outboard motor	500
Small, partially unwadeable rivers	
Boat, 14' flat bottom or tri-hull	500 to 1,500
or	
Raft, 5-man inflatable	150 to 300
Anchor rope, ½"	
Nylon	25¢/ft
Polyester	10¢/ft
Bank anchors, ½" x 48" rebar (2 for each transect)	15¢/lb
Quick release carabiners (2) for attaching boat to anchor rope	7
Hand-held 2-way radios (walkie-talkie)	
Standard	500 to 700
Business frequency, not CB	850 to 1,100
Compass, magnetic, for stream mapping, site identification and transect relocation	
Brunton type	85
Silva ranger	20
Sounding Systems	
Topsetting wading rod--may be used in streams up to 4 ft in depth	150
Suspended Systems	
Hand-held, with hanger bar; 15 pound sounding weight; 35 ft plastic coated cable, attached to 15 ft bare calbe; with current meter	400
Boat-mounted, Type A crane (3 wheel); with B56 sounding reel, including 75' of cable	1,400
B56, reel with cable, only	900

Item Description	Approximate Unit Cost
Immovable, hand built crane, materials	
3 - 4" pulleys with sealed bearings	25
¼" x 2" angle iron (24' @ 3.2 lbs/ft)	
Used	15
New	19
¼" x 2" strap iron (6')	5
Labor (cutting and drilling)	50
	114
Sonar	
Raytheon Model 719-B depth sounder with narrow beam transducer; 2 - 6 ft dead space (i.e., useful only in water more than 6 ft deep)	2,500
Headset and Battery	10 to 25
Boat Equipment	
Retractable Boom	90
Hose	170
Cross Piece	220
Weight, sounding (15 lb)	100
(30 lb)	100
(50 lb)	125
Hanger bar and pin	10

The equipment listed in the preceding table is available from a variety of sources. The following list of suppliers should serve as a reference for specific equipment. This list is by no means a complete list but should provide the investigator with a place to begin. Local outlet and suppliers should be utilized when available.

Surveying Equipment

Forestry Suppliers, Inc.
205 West Ranking Street
Box 8397
Jackson, MS 39204
1-607-354-3565

Ben Meadows Co.
3589 Broad Street
Atlanta, GA 30366
1-404-455-0907

Field Support

Hardware and Sportware Goods Stores
Radio and Electronics Shops
Farm Supply

Boat Equipment/Stream Gaging

U.S. Geologic Survey
Hydrologic Instrumentation Service
Gulf Coast Hydroscience Center
Building 2101
NSTL Station, MS 39529

Scientific Instruments
518 Cherry Street, West
Milwaukee, WS 53212
1-414-263-1600

Marsh-McBirney, Inc.
8596 Grovemont Circle
Gaithersburg, MD 20760
1-202-869-4700

Teledyne Gurley
514 Fulton Street
Troy, NY 12181
1-710-443-8156

APPENDIX F

THE CROSS SECTION SHAPE AS USED IN THE PHABSIM SYSTEM OF COMPUTER PROGRAMS

The purpose of this Appendix is to describe the transfer of information on the cross section shape between the various elements of the Physical Habitat Simulation System (PHABSIM). PHABSIM is a system of computer programs with the user being able to select a path through the total system. There are two types of information being manipulative by the user - cross section related information and flow related information. The general nature of the information flow is shown in Figure F-1 and F-2. Figure F-2 illustrates the case where all data is one one file and used directly by the HABTAT program. The second case is where the cross section and some flow related data are used by the hydraulic simulation programs and new flow related data generated. In this case, the information on the cross section shape is transferred on TAPE3. At the option of the user, the substrate index can be modified, and the cross section information transferred on to the HABTAT program on TP3. If the substrate is not modified, TAPE3 is used directly by the HABTAT program.

The cross section shape is defined by a series of coordinate points as shown in Figure F-3. The points are connected by straight lines to form the shape. The shape used by each major program use is disclosed below. It is assumed the reader is familiar with the users manual for each program.

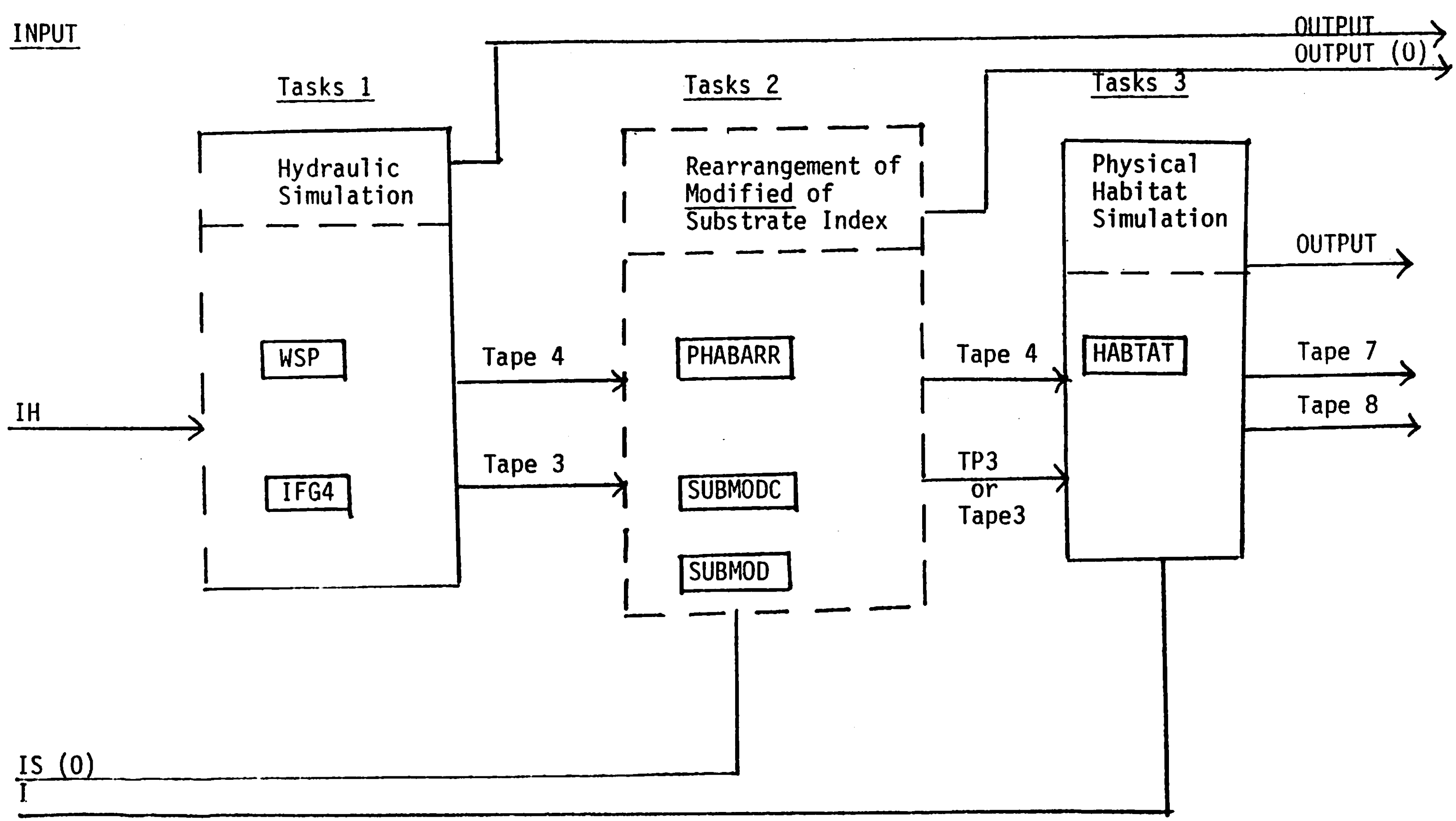


Figure F-1. Major Elements of PHABSIM

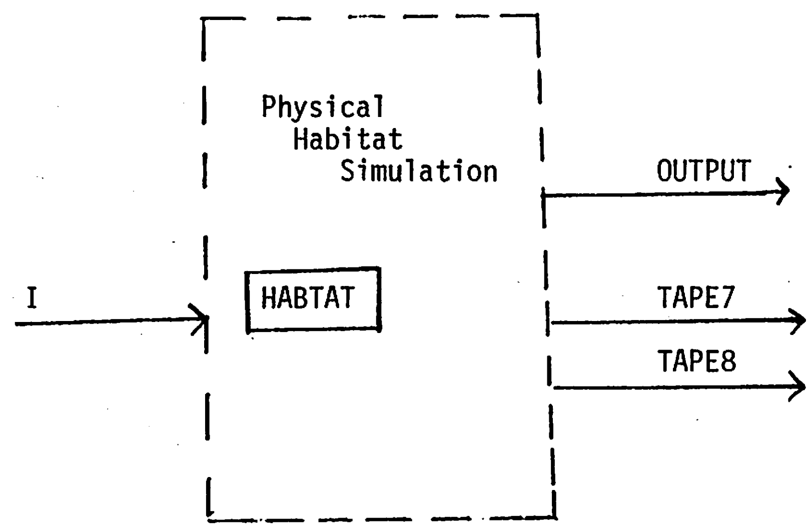


Figure F-2. Direct Entry of Data HABTAT.

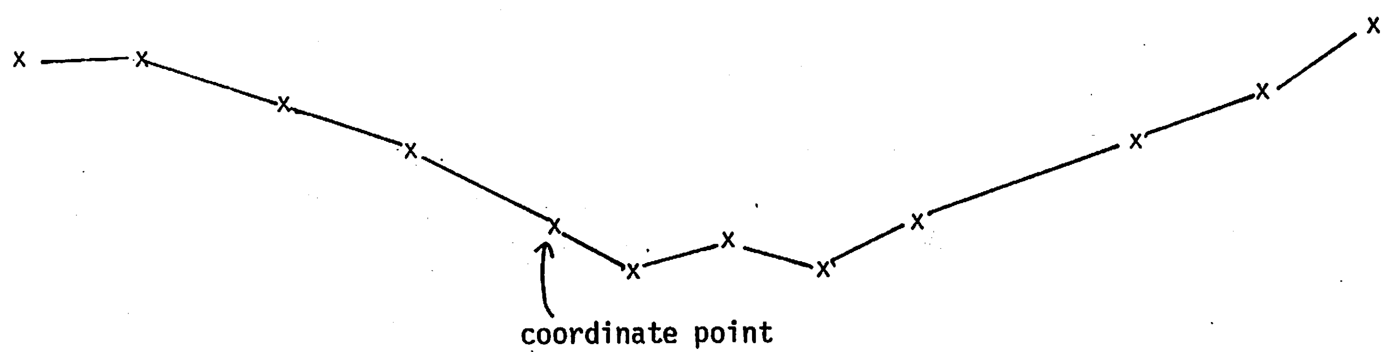


Figure F-3. The Cross Section

Direct Entry to HABTAT

The cross section shape is defined by the data on the COORD cards. The data is used directly and without modification.

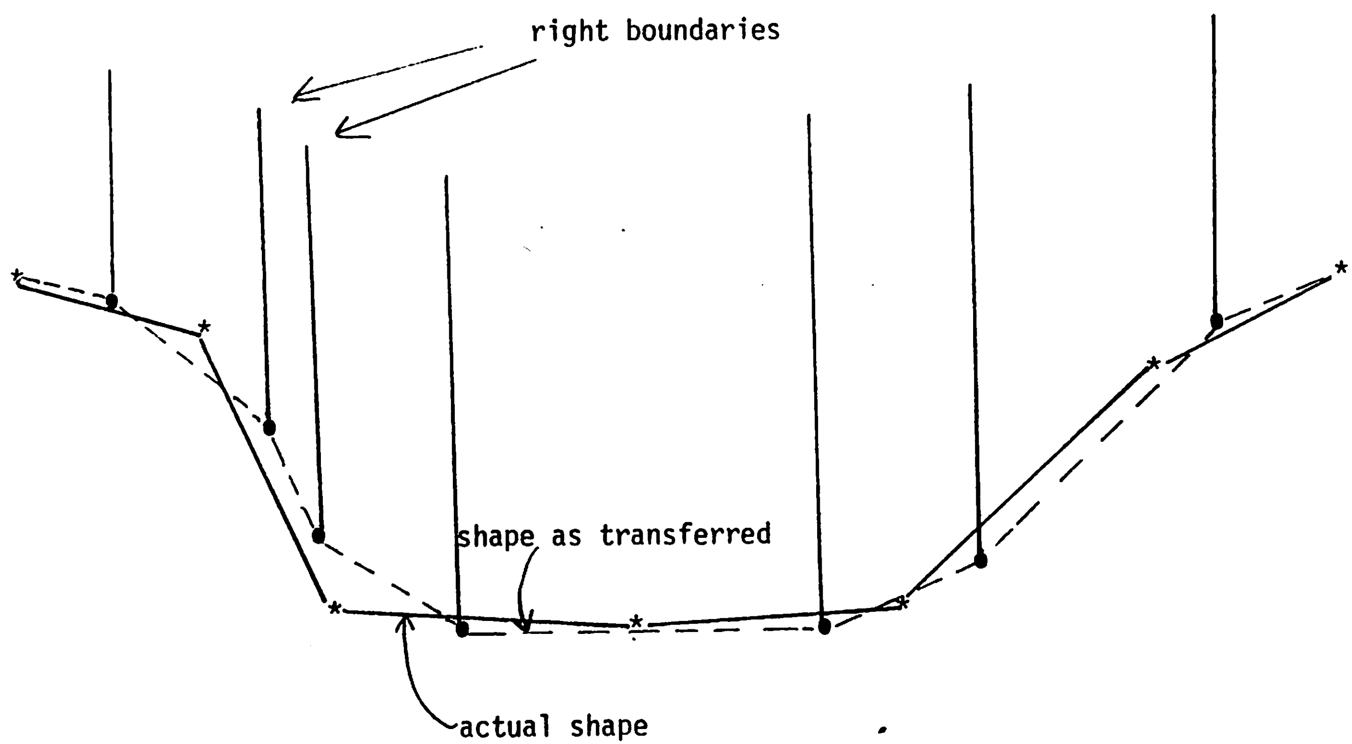
Hydraulic Simulation using IFG4, then HABTAT

The cross section shape is defined by the coordinate data on the coordinate data card. The hydraulic simulation is made using these data as the boundaries of the cells. The cross section coordinates are then written on TAPE3 for use by HABTAT, SUBMOD, or SUBMODC. Neither SUBMOD nor SUBMODC modify the coordinate data. TAPE3 or TP3 are used by HABTAT as the sources of the cross section data.

Hydraulic Simulation using WSP, then HABTAT

The data used by the WSP program to define the cross section shape is defined by data on the coordinate cards. The boundaries of the cells are defined by the right boundaries on the roughness card.

The WSP program generates a coordinate for each right boundary and adds this point to the set of coordinate numbers used by the WSP program. The coordinates are generated by linear interpolation between adjacent points. The coordinate data written on TAPE3 is only the coordinates for the boundaries of the cells. This is shown in Figure F-4. If the right boundary is the same as the coordinate point on the coordinate card, the point will be on TAPE3; if not, the point will not be transferred.

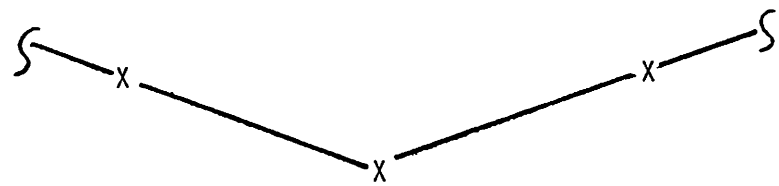


* coordinate points

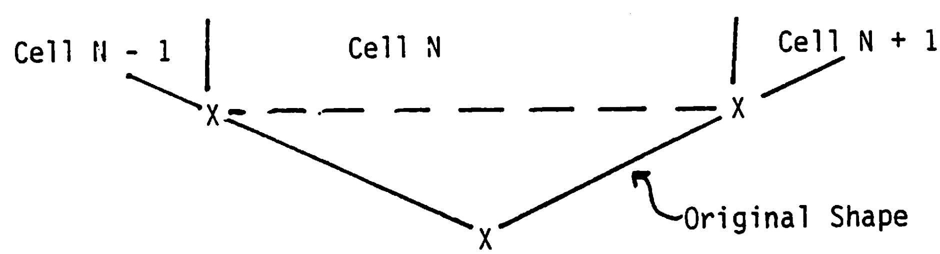
● coordinate points as defined by right boundaries

Figure F-4. The Cross Section as Defined by WSP.

The determination of right boundaries is especially important in defining the low point in the section. For instance, assume we have three coordinate points as shown below.



If the right boundaries correspond to the points, the cross section shape is the same. If the right boundaries are as shown below:



In this case, the shape used by HABTAT is significantly different from the shape used by WSP.

The best way to define the right boundaries is to use each coordinate point and to subdivide the cells formed by the coordinate points by additional right boundaries.