

**ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM-  
SURFACE WATERS:**

**FIELD OPERATIONS AND METHODS FOR MEASURING THE  
ECOLOGICAL CONDITION OF WADEABLE STREAMS**

Edited by

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## SECTION 7

### PHYSICAL HABITAT CHARACTERIZATION

by  
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In the broad sense, physical habitat in streams includes all those physical attributes that influence or provide sustenance to organisms within the stream. Stream physical habitat varies naturally, as do biological characteristics; thus, expectations differ even in the absence of anthropogenic disturbance. Within a given physiographic-climatic region, stream drainage area and overall stream gradient are likely to be strong natural determinants of many aspects of stream habitat, because of their influence on discharge, flood stage, and stream power (the product of discharge times gradient). Summarizing the habitat results of a workshop conducted by EMAP on stream monitoring design, Kaufmann (1993) identified seven general physical habitat attributes important in influencing stream ecology:

- ! Channel Dimensions
- ! Channel Gradient
- ! Channel Substrate Size and Type
- ! Habitat Complexity and Cover
- ! Riparian Vegetation Cover and Structure
- ! Anthropogenic Alterations
- ! Channel-Riparian Interaction

All of these attributes may be directly or indirectly altered by anthropogenic activities. Nevertheless, their expected values tend to vary systematically with stream size (drainage area) and overall gradient (as measured from topographic maps). The relationships of specific physical habitat measurements described in this section to these seven attributes

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are discussed by Kaufmann (1993). Aquatic macrophytes, riparian vegetation, and large woody debris are included in this and other physical habitat assessments because of their role in modifying habitat structure and light inputs, even though they are actually biological measures. The field physical habitat measurements from this field habitat characterization are used in the context of water chemistry, temperature, and other data sources (e.g., remote sensing of basin land use and land cover). The combined data analyses will more comprehensively describe additional habitat attributes and larger scales of physical habitat or human disturbance than are evaluated by the field assessment alone. A comprehensive data analysis guide (Kaufmann et al., in preparation) discusses the detailed procedures used to calculate metrics related to stream reach and riparian habitat quality from filed data collected using the EMAP field protocols. This guide also discusses the precision associated with these measurements and metrics.

These procedures are intended for evaluating physical habitat in wadeable streams. The EMAP field procedures are most efficiently applied during low flow conditions and during times when terrestrial vegetation is active, but may be applied during other seasons and higher flows except as limited by safety considerations. This collection of procedures is designed for monitoring applications where robust, quantitative descriptions of reach-scale habitat are desired, but time is limited. The qualitative nature of the habitat quality rank scores produced by many currently available rapid habitat assessment methods (e.g., those described in Section 14) have not been demonstrated, as yet, to meet the objectives of EMAP, where more quantitative assessment is needed for site classification, trend interpretation, and analysis of possible causes of biotic impairment.

The habitat characterization protocol developed for EMAP differs from other rapid habitat assessment approaches (e.g., Plafkin et al., 1989, Rankin, 1995) by employing a randomized, systematic spatial sampling design that minimizes bias in the placement and positioning of measurements. Measures are taken over defined channel areas and these sampling areas or points are placed systematically at spacings that are proportional to baseflow channel width. This systematic sampling design scales the sampling reach length and resolution in proportion to stream size. It also allows statistical and series analyses of the data that are not possible under other designs. We strive to make the protocol objective and repeatable by using easily learned, repeatable measures of physical habitat in place of estimation techniques wherever possible. Where estimation is employed, we direct the sampling team to estimate attributes that are otherwise measurable, rather than estimating the quality or importance of the attribute to the biota or its importance as an indicator of disturbance. We have included the more traditional visual classification of channel unit

scale habitat types because they have been useful in past studies and enhance comparability with other work.

The time commitment to gain repeatability and precision is greater than that required for more qualitative methods. In our field trials, two people typically complete the specified channel, riparian, and discharge measurements in about three hours of field time (see Section 2, Table 2-1). However, the time required can vary considerably with channel characteristics. On streams up to about 4 meters wide with sparse woody debris, measurements can be completed in less than two hours, whereas crews may require up to five hours in large (>10 m wide), complex streams with abundant woody debris and deep water, if 100 width measurements are required. However, reducing the number of width measurements from 100 to 21 locations on sample reaches limits time to # 4 hours even on large, complex wadeable streams.

The procedures are employed on a sampling reach length 40 times its low flow wetted width, as described in Section 4. Measurement points are systematically placed to statistically represent the entire reach. Stream depth and wetted width are measured at very tightly spaced intervals, whereas channel cross-section profiles, substrate, bank characteristics and riparian vegetation structure are measured at larger spacings. Woody debris is tallied along the full length of the sampling reach, and discharge is measured at one location (see Section 6). The tightly spaced depth and width measures allow calculation of indices of channel structural complexity, objective classification of channel units such as pools, and quantification of residual pool depth, pool volume, and total stream volume.

## 7.1 COMPONENTS OF THE HABITAT CHARACTERIZATION

There are four different components of the EMAP physical habitat characterization (Table 7-1), including stream discharge, which is described in Section 6. Measurements for the remaining three components are recorded on 11 copies of a two-sided field form, plus an a separate form for recording slope and bearing measurements. The **thalweg profile** is a longitudinal survey of depth, habitat class, and presence of soft/small sediment at 100 equally spaced intervals (150 in streams less than 2.5 m wide) along the centerline between the two ends of the sampling reach. "Thalweg" refers to the flow path of the deepest water in a stream channel. Wetted width is measured at 21 equally spaced intervals. Data for the second component, the **woody debris tally**, are recorded for each of 10 segments of stream located between the 11 transects. The third component, the **channel and riparian characterization**, includes measures and/or visual estimates of channel dimensions,

**TABLE 7-1. COMPONENTS OF PHYSICAL HABITAT CHARACTERIZATION**

<b>Component</b>	<b>Description</b>
<b>Thalweg Profile:</b> (Section 7.4.1)	<ul style="list-style-type: none"> <li>• Measure maximum depth, classify habitat and pool-forming features, and determine presence of soft sediment at 10-15 equally spaced intervals between each of 11 channel cross-section transects (100 or 150 individual measurements along entire reach).</li> <li>• Measure wetted width at 11 channel cross-section transects and midway between them (21 measurements).</li> </ul>
<b>Woody Debris Tally:</b> (Section 7.4.2)	<ul style="list-style-type: none"> <li>• Between each of the channel cross sections, tally large woody debris numbers within and above the bankfull channel according to length and diameter classes (10 separate tallies).</li> </ul>
<b>Channel and Riparian Characterization:</b> (Section 7.5)	<ul style="list-style-type: none"> <li>• At 11 cross-section transects placed at equal intervals along reach length: <ul style="list-style-type: none"> <li>- <u>Measure</u>: channel cross section dimensions, bank height, bank undercut distance, bank angle, slope and compass bearing (backsite), and riparian canopy density (densiometer).</li> <li>- <u>Visually Estimate</u><sup>a</sup>: substrate size class and embeddedness; areal cover class and type (e.g., woody trees) of riparian vegetation in Canopy, Mid-Layer and Ground Cover; areal cover class of fish concealment features, aquatic macrophytes and filamentous algae.</li> <li>- <u>Observe &amp; Record</u><sup>a</sup>: human disturbances and their proximity to the channel.</li> </ul> </li> </ul>
<b>Discharge:</b> (see Section 6)	<ul style="list-style-type: none"> <li>• In medium and large streams (defined in Section 6) measure water depth and velocity at 0.6 depth at 15 to 20 equally spaced intervals across one carefully chosen channel cross-section.</li> <li>• In very small streams, measure discharge by timing the filling of a bucket or timing the passage of a neutral buoyant object through a segment whose cross-sectional area has been estimated.</li> </ul>

<sup>a</sup> Substrate size class and embeddedness are estimated, and depth is measured for a total of 55 particles taken at 5 equally-spaced points along each of 11 cross-section transects. Cross-sections are defined by laying the surveyor's rod or tape to span the wetted channel. Woody debris is tallied over the distance between each cross-section and the next cross-section upstream. Riparian vegetation and human disturbances are observed 5m upstream and 5m downstream from the cross section transect. They extend shoreward 10m from left and right banks. Fish cover types, aquatic macrophytes, and algae are observed within the channel 5m upstream and 5m downstream from the cross section stations. These boundaries for visual observations are estimated by eye.

substrate, fish cover, bank characteristics, riparian vegetation structure, and evidence of human disturbance. These data are obtained at each of the 11 equally-spaced transects established within the sampling reach. In addition, measurements of the stream slope and compass bearing between stations are obtained, providing information necessary for calculating reach gradient, residual pool volume, and channel sinuosity.

## 7.2 HABITAT SAMPLING LOCATIONS WITHIN THE SAMPLING REACH

Measurements are made at two scales of resolution along the length of the reach; the results are later aggregated and expressed for the entire reach, a third level of resolution. Figure 7-1 illustrates the locations within the sampling reach where data for the different components of the physical habitat characterization are obtained. We assess habitat over stream reach lengths that are approximately 40 times their average wetted width at base-flow, but not less than 150 m long. This allows us to adjust the sample reach length to accommodate varying sizes of streams (see Section 2). Many of the channel and riparian features are characterized on 11 cross-sections and pairs of riparian plots spaced at 4 channel-width intervals. The thalweg profile measurements must be spaced evenly over the entire sampling reach. In addition, they must be sufficiently close together that they do not "miss" deep areas and habitat units that are in a size range of about  $\frac{1}{4}$  to  $\frac{1}{2}$  of the average channel width. Follow these specifications for choosing the interval between thalweg profile measurements:

!	<b>Channel Width &lt; 2.5 m</b>	—	<b>interval = 1.0 m</b>
!	<b>Channel Width 2.5-3.5 m</b>	—	<b>interval = 1.5 m</b>
!	<b>Channel Width &gt; 3.5 m</b>	—	<b>interval = 0.01 × (reach length)</b>

Following these guidelines, you will be making 150 evenly spaced thalweg profile measurements in the smallest category of streams, 15 between each detailed channel cross section. In all of the larger stream sizes, you will make 100 measurements, 10 between each cross section. For practical reasons, we specify width measurements only at the 11 cross-section transects and at the thalweg measurement points midway between each pair of transects (a total of 21 wetted widths). If more resolution is desired, width measurements may be made at all 100 or 150 thalweg profile locations.

## 7.3 LOGISTICS AND WORK FLOW

The four components (Table 7-1) of the habitat characterization are organized into three grouped activities:

1. Thalweg Profile and Large Woody Debris Tally (Section 7.4).  
Two people (the "geomorphs") proceed upstream from the downstream end of the sampling reach (see Figure 7-1) making observations and measurements at the chosen

Image Not  
Available

**Figure 7-1. Sampling reach layout for physical habitat measurements (plan view).**

increment spacing. One person is in the channel making width and depth measurements, and determining whether soft/small sediment is present under his/her staff. The other person records these measurements, classifies the channel habitat, and tallies large woody debris. Each time this team reaches a flag marking a new cross-section transect, they start filling out a new copy of the Thalweg Profile and Woody Debris Form. They interrupt the thalweg profile and woody debris tallying activities to complete data collection at each cross-section transect as it comes.

2. Channel/Riparian Cross-Sections (Section 7.5). One person proceeds with the channel cross-section dimension, substrate, bank, and canopy cover measurements. The second person records those measurements on the Channel/Riparian Cross-section and Thalweg Profile Form while making visual estimates of riparian vegetation structure, instream fish cover, and human disturbance specified on that form. Slope and bearing are determined together by backsighting to the previous transect. Intermediate flagging (of a different color) may have to be used if the stream is extremely brushy, sinuous, or steep to the point that you cannot site for slope and bearing measures between two adjacent transects. (Note that the crews could tally woody debris while doing the backsite, rather than during the thalweg profile measurements.)
3. Discharge (Section 6). Discharge measurements are made after collecting the chemistry sample. They are done at a chosen optimal cross section (but not necessarily at a transect) near the X-site. However, do not use the electromagnetic current meter close to where electrofishing is taking place. Furthermore, if a lot of channel disruption is necessary and sediment must be stirred up, wait on this activity until all chemical and biological sampling has been completed.



## 7.4 THALWEG PROFILE AND LARGE WOODY DEBRIS MEASUREMENTS

### 7.4.1 Thalweg Profile

“Thalweg” refers to the flow path of the deepest water in a stream channel. The thalweg profile is a longitudinal survey of maximum depth and several other selected characteristics at 100 or 150 equally spaced points along the centerline of the stream between the two ends of the stream reach. Data from the thalweg profile allows calculation of indices of residual pool volume, stream size, channel complexity, and the relative proportions of habitat types such as riffles and pools. The EMAP-SW habitat assessment modifies traditional methods by proceeding upstream in the middle of the channel, rather than along the thalweg itself (though each thalweg depth measurement is taken at the deepest point at each incremental position). One field person walks upstream (wearing felt-soled waders) carrying a fiberglass telescoping (1.5 to 7.5 m) surveyor's rod and a 1-m metric ruler (or a calibrated rod or pole, such as a ski pole). A second person on the bank or in the stream carries a clipboard with 11 copies of the field data form.

The procedure for obtaining thalweg profile measurements is presented in Table 7-2. Record data on the Thalweg Profile and Woody Debris Data Form as shown in Figure 7-2. Use the surveyor's rod and a metric ruler or calibrated rod or pole to make the required depth and width measurements, and to measure off the distance between measurement points as you proceed upstream. Ideally, every tenth thalweg measurement will bring you within one increment spacing from the flag marking a new cross-section profile. The flag will have been set previously by carefully taping along the channel, making the same bends that you do while measuring the thalweg profile (refer to Figure 7-1). However, you may still need to make minor adjustments to align each 10th measurement to be one thalweg increment short of the cross section. In streams with average widths smaller than 2.5m, you will be making thalweg measurements at 1-meter increments. Because the minimum reach length is set at 150 meters, there will be 15 measurements between each cross section. Use the 5 extra lines on the thalweg profile portion of the data form (Figure 7-2) to record these measurements.

It is very important that thalweg depths are obtained from all measurement points. Missing depths at the ends of the sampling reach (e.g., due to the stream flowing into or out of a culvert or under a large pile of debris) can be tolerated, but those occurring in the middle of the sampling reach are more difficult to deal with. Flag these missing measurements using a “K” code and explain the reason for the missing measurements in the

**TABLE 7-2. THALWEG PROFILE PROCEDURE**

1. Determine the interval between measurement stations based on the wetted width used to determine the length of the sampling reach.
  - For widths < 2.5 m, establish stations every 1 m.
  - For widths between 2.5 and 3.5 m, establish stations every 1.5 m
  - For widths > 3.5 m, establish stations at increments equal to 0.01 times the sampling reach length.
2. Complete the header information on the thalweg profile and woody debris section of a Channel/Riparian Cross-section and Thalweg Profile Form, noting the transect pair (downstream to upstream). Record the interval distance determined in Step 1 in the "INCREMENT" field on the field data form.
  - NOTE: If a side channel is present, and contains between 16 and 49% of the total flow, establish secondary cross-section transects and thalweg measurement stations as necessary. Use separate field data forms to record data for the side channel, and designate each secondary transect as "X" followed by the primary transect letter (e.g., XA, XB, etc.). Collect all channel and riparian cross-section measurements from the side channel.
3. Begin at the downstream end (station "0") of the first transect 9Transect "A").
4. Measure the wetted width if you are at station "0", station "5" (if the stream width defining the reach length is \$ 2.5 m), or station "7" (if the stream width defining the reach length is < 2.5 m). Wetted width is measured across and over mid-channel bars and boulders. Record the width on the field data form to the nearest 0.1 m for widths up to about 3 meters, and to the nearest 5% for widths > 3 m. This is 0.2 m for widths of 4 to 6 m, 0.3 m for widths of 7 to 8 m, and 0.5 m for widths of 9 or 10 m, and so on. For dry and intermittent streams, where no water is in the channel, record zeros for wetted width.
  - NOTE: If a mid-channel bar is present at a station where wetted width is measured, measure the bar width and record it on the field data form.
5. At each thalweg profile station, use a meter ruler or a calibrated pole or rod to locate the deepest point (the "thalweg"), which may not always be located at mid-channel. Measure the thalweg depth to the nearest cm, and record it on the thalweg profile form. Read the depth on the side of the ruler, rod, or pole to avoid inaccuracies due to the wave formed by the rod in moving water.
  - NOTE: For dry and intermittent streams, where no water is in the channel, record zeros for depth.
  - NOTE: At stations where the thalweg is too deep to measure directly, stand in shallower water and extend the surveyor's rod or calibrated rod or pole at an angle to reach the thalweg. Determine the rod angle using the external scale of the clinometer. Leave the depth reading for the station blank, and record a "U" flag. Record the water level on the rod and the rod angle in the comments section of the field data form.

(continued)

**TABLE 7-2 (Continued)**

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6. At the point where the thalweg depth is determined, observe whether small, loose, soft sediments are present directly beneath your ruler, rod, or pole. Soft/small sediments are defined here as fine gravel, sand, silt, clay or muck readily apparent by "feeling" the bottom with the staff. Record presence or absence in the "SOFT/SMALL SEDIMENT" field on the field data form.
  7. Determine the channel unit code and pool forming element codes for the station. Record these on the field data form using the standard codes provided. For dry and intermittent streams, where no water is in the channel, record habitat type as dry channel (DR).
  8. If the station cross-section intersects a mid-channel bar, Indicate the presence of the bar in the "BAR WIDTH" field on the field data form.
  9. Record the presence or absence of a side channel at the station's cross-section in the "SIDE CHANNEL" field on the field data form.
  10. Proceed upstream to the next station, and repeat Steps 4 through 9.
  11. Repeat Steps 4 through 10 until you reach the next transect. Prepare a new Channel/Riparian Cross-section and Thalweg Profile Form, then repeat Steps 2 through 10 for each of the reach segments, until you reach the upstream end of the sampling reach (Transect "K").
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PHab: THALWEG PROFILE & WOODY DEBRIS FORM - STREAMS									
SITE NAME: <i>MILL CREEK</i>					DATE: <i>7/15/97</i> VISIT: <input checked="" type="checkbox"/> 1 <input type="checkbox"/> 2				
SITE ID: <i>MAIA97-999</i>					TEAM ID (X): <input checked="" type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5 <input type="checkbox"/> 6 <input type="checkbox"/> 7 <input type="checkbox"/> 8				
TRANSECT(X): <input type="checkbox"/> A-B <input checked="" type="checkbox"/> B-C <input type="checkbox"/> C-D <input type="checkbox"/> D-E <input type="checkbox"/> E-F <input type="checkbox"/> F-G <input type="checkbox"/> G-H <input type="checkbox"/> H-I <input type="checkbox"/> I-J <input type="checkbox"/> J-K									
THALWEG PROFILE							Increment (m) →		
STA-TION	THALWEG DEPTH (cm) (XXX)	WETTED WIDTH (m) (XX.X)	BAR WIDTH <sup>1</sup>		SOFT/SMALL SEDIMENT (X FOR YES)	CHANNEL UNIT CODE	POOL FORM CODE	SIDE CHANNEL (X FOR YES)	FLAG
			X	(XX.X)					
0	<i>14</i>	<i>3.6</i>	<i>X</i>	<i>0.8</i>		<i>RI</i>	<i>N</i>		
1	<i>13</i>		<i>X</i>			<i>RI</i>	<i>N</i>		
2	<i>27</i>		<i>X</i>			<i>RI</i>	<i>N</i>		
3	<i>46</i>		<i>X</i>			<i>PT</i>	<i>F</i>		
4	<i>40</i>		<i>X</i>			<i>PT</i>	<i>F</i>		
5	<i>35</i>	<i>4.4</i>	<i>X</i>	<i>1.0</i>		<i>PT</i>	<i>F</i>		
6	<i>34</i>				<i>X</i>	<i>PT</i>	<i>F</i>		
7	<i>47</i>				<i>X</i>	<i>PT</i>	<i>F</i>		
8	<i>53</i>				<i>X</i>	<i>PT</i>	<i>F</i>		
9	<i>57</i>				<i>X</i>	<i>PT</i>	<i>F</i>	<i>X</i>	<i>SIDE CHANNEL CONVERGENCE</i>
10									
11									
12									
13									
14									

LARGE WOODY DEBRIS (≥ 10 cm SMALL END DIAMETER; ≥ 1.5 m LENGTH) - TALLY EACH PIECE -						
DIAMETER LARGE END	PIECES ALL/PART IN BANKFULL CHANNEL			PIECES ABOVE BANKFULL CHANNEL		
	LENGTH 1.5 - 5 m	5 - 15 m	> 15 m	LENGTH 1.5 - 5 m	5 - 15 m	> 15 m
0.1 to <0.3 m	<i>    </i>	<i>    </i>				
	<i>6</i>	<i>4</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>
0.3 - 0.6 m	<i>  </i>		<i>1</i>			
	<i>2</i>	<i>0</i>	<i>1</i>	<i>0</i>	<i>0</i>	<i>0</i>
0.6 - 0.8 m				<i>1</i>		
	<i>0</i>	<i>0</i>	<i>0</i>	<i>1</i>	<i>0</i>	<i>0</i>
> 0.8 m						
	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>	<i>0</i>

CHANNEL UNIT CODES	
PP	Pool, Plunge
PT	Pool, Trench
PL	Pool, Lateral Scour
PB	Pool, Backwater
PD	Pool, Impoundment
GL	Glide
RI	Riffle
RA	Rapid
CA	Cascade
FA	Falls
DR	Dry Channel

POOL FORM CODES	
N	Not a pool
W	Large Woody Debris
R	Rootwad
B	Boulder or bedrock
F	Unknown, fluvial
O	Other (note in comments)

FLAG	COMMENTS
<i>F1</i>	<i>SUBSTRATE CLASS 'OT' = GRASS</i>

Flag Codes: K = no measurement made; U = suspect measurement; F1, F2, etc. = misc. flags assigned by each field crew. Explain all flags in comments. 1 = Measure Bar Width at Station 0 and Mid-Station (5 or 7), X small column if bar present at the rest of the stations.

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PHab: CHANNEL/RIPARIAN CROSS-SECTION &amp; THALWEG PROFILE FORM - STREAMS - 2

Figure 7-2. Thalweg Profile and Woody Debris Form.

comments section of the field data form. At points where a direct depth measurement cannot be obtained, make your best estimate of the depth, record it on the field form, and flag the value using a "U" code (for suspect measurement), explaining that it is an estimated value in the comments section of the field data form. Where the thalweg points are too deep for wading, measure the depth by extending the surveyor's rod at an angle to reach the thalweg point. Record the water level on the rod, and the rod angle, as determined using the external scale on the clinometer (vertical = 90/).

At every thalweg measurement increment, determine by sight or feel whether soft/small sediment is present on the channel bottom. These particles are defined as substrate equal to or smaller than fine gravel (# 16 mm diameter). These soft/small sediments are **NOT** the same as "Fines" described when determining the substrate particle sizes at the cross-section transects (Section 7.5.2). For the thalweg profile, determine if soft/small sediment deposits are readily obvious by feeling the bottom with your boot, the surveyor's rod, or the calibrated rod or pole.

Wetted width is measured at each transect (station 0), and midway between transects (station 5 for larger streams having 100 measurement points, or station 7 for smaller streams having 150 measurement points). The wetted width boundary is the point at which substrate particles are no longer surrounded by free water.

While recording the width and depth measurements and the presence of soft/small sediments, the second person chooses and records the habitat class and the pool forming element codes (Table 7-3) applicable to each of the 100 (or 150) measurement points along the length of the reach. These channel unit habitat classifications and pool-forming elements are modified from those of Bisson et al. (1982) and Frissell et al. (1986). The resulting database of traditional visual habitat classifications will provide a bridge of common understanding with other studies. With the exception of backwater pools, channel unit scale habitat classifications are to be made at the thalweg of the cross section. The habitat unit itself must meet a minimum size criteria in addition to the qualitative criteria listed in Table 7-3. Before being considered large enough to be identified as a channel-unit scale habitat feature, the unit should be at least as long as the channel is wide. For instance, if there is a small deep (pool-like) area at the thalweg within a large riffle area, don't record it as a pool unless it occupies an area about as wide or long as the channel is wide.

Mid-channel bars, islands, and side channels pose some problems for the sampler conducting a thalweg profile and necessitate some guidance. Bars are defined here as

**TABLE 7-3. CHANNEL UNIT AND POOL FORMING ELEMENT CATEGORIES**

<b>Channel Unit Habitat Classes<sup>a</sup></b>	
<b>Class (Code)</b>	<b>Description</b>
Pools:	Still water, low velocity, smooth, glassy surface, usually deep compared to other parts of the channel:
Plunge Pool (PP)	Pool at base of plunging cascade or falls.
Trench Pool (PT)	Pool-like trench in the center of the stream
Lateral Scour Pool (PL)	Pool scoured along a bank.
Backwater Pool (PB)	Pool separated from main flow off the side of the channel.
Impoundment Pool (PD)	Pool formed by impoundment above dam or constriction.
Pool (P)	Pool (unspecified type).
Glide (GL)	Water moving slowly, with <u>a smooth, unbroken surface</u> . Low turbulence.
Riffle (RI)	Water moving, with <u>small ripples, waves and eddies</u> -- waves not breaking, <u>surface tension not broken</u> . Sound: "babbling", "gurgling".
Rapid (RA)	Water movement rapid and turbulent, surface with <u>intermittent white-water</u> with breaking waves. Sound: continuous rushing, but not as loud as cascade.
Cascade (CA)	Water movement rapid and very turbulent over steep channel bottom. Most of the water surface is broken in <u>short, irregular plunges, mostly whitewater</u> . Sound: roaring.
Falls (FA)	<u>Free falling water</u> over a vertical or near vertical drop into plunge, water turbulent and white over high falls. Sound: from splash to roar.
Dry Channel (DR)	No water in the channel

**(continued)**

<sup>a</sup> Note that in order for a channel habitat unit (other than a backwater pool) to be distinguished, it must be at least as wide or long as the channel is wide.

**TABLE 7-3 (Continued)**

<b>Categories of Pool-forming Elements<sup>b</sup></b>	
<b>Code</b>	<b>Category</b>
N	Not Applicable, Habitat Unit is not a pool
W	Large Woody Debris.
R	Rootwad
B	Boulder or Bedrock
F	Unknown cause (unseen fluvial processes)
WR, RW, RBW	Combinations
OT	Other (describe in the comments section of field form)

<sup>b</sup> Remember that most pools are formed at high flows, so you may need to look at features, such as large woody debris, that are dry at baseflow, but still within the bankfull channel.

mid-channel features below the bankfull flow mark that are dry during baseflow conditions (see Section 7.5.3 for the definition of bankfull channel). Islands are mid-channel features that are dry even when the stream is experiencing a bankfull flow. Both bars and islands cause the stream to split into side channels. When a mid-channel bar is encountered along the thalweg profile, it is noted on the field form and the active channel is considered to include the bar. Therefore, the wetted width is measured as the distance between wetted left and right banks. It is measured across and over mid-channel bars and boulders. If mid-channel bars are present, record the bar width in the space provided.

If a mid-channel feature is as high as the surrounding flood plain, it is considered an island. Treat side channels resulting from islands different from mid-channel bars. Handle the ensuing side channel based on visual estimates of the percent of total flow within the side channel as follows:

Less than 15%	Indicate the presence of a side channel on the field data form.
16 to 49%	Indicate the presence of a side channel on the field data form. Establish a secondary transect across the side channel and designate it as "X" plus the primary transect letter; e.g., XA). Complete the detailed channel and riparian cross-section measurements for the side channel, using a separate copy of the field data form.

When a side channel occurs due to an island, reflect its presence with continuous entries in the "Side Channel" field on the thalweg profile form (Figure 7-2). In addition, note the points of divergence and confluence of the side channel in the comments section of the thalweg profile form. Begin entries at the point where the side channel converges with the main channel; note the side channel presence continuously until the upstream point where it diverges. When doing width measures with a side channel separated by an island, include only the width of the main channel in the measures at the time and then measure the side channel width separately.

For dry and intermittent streams, where no water is in the channel at a thalweg station, record zeros for depth and wetted width. Record the habitat type as dry channel (DR).



## 7.4.2 Large Woody Debris Tally

Methods for large woody debris (LWD) measurement are a simplified adaptation of those described by Robison and Beschta (1990). This component of the EMAP physical habitat characterization allows quantitative estimates of the number, size, total volume and distribution of wood within the stream reach. LWD is defined here as woody material with a small end diameter of at least 10 cm (4 in.) and a length of at least 1.5 m (5 ft.).

The procedure for tallying LWD is presented in Table 7-4. The tally includes all pieces of LWD that are at least partially in the baseflow channel, the "active channel" (flood channel up to bankfull stage), or spanning above the active channel. The active (or "bank-full") channel is defined as the channel that is filled by moderate sized flood events that typically recur every one to two years. LWD in the active channel is tallied over the entire length of the reach, including the area between the channel cross-section transects. As in the thalweg profile, LWD measurements in the channel segment between each cross section transect and the next one upstream are recorded on the first 10 thalweg profile and woody debris forms (Figure 7-2). The location of the large end of each piece of LWD determines the segment to which it is assigned.

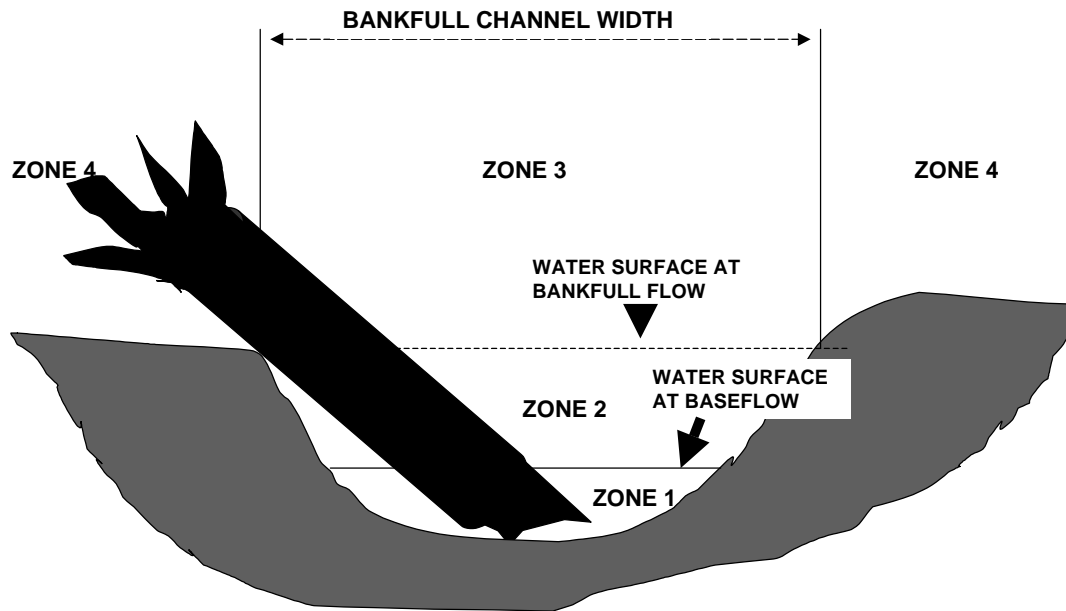
First, tally all the pieces of LWD that are at least partially in the bankfull channel (Figure 7-3, Zones 1 or 2). Then tally all the pieces of LWD that are not actually within the bankfull channel, but are at least partially spanning (bridging) the bankfull channel (Figure 7-3, Zone 3). For both the Zone 1-2 wood and the Zone 3 LWD, the field form (Figure 7-2) provides 12 entry boxes for tallying debris pieces visually estimated within three length and four diameter class combinations. Each LWD piece is tallied in only one box. Pieces of LWD that are not at least partially within Zones 1, 2, or 3 are not tallied.

For each LWD piece, first visually estimate its length and its large and small end diameters in order to place it in one of the diameter and length categories. The diameter class on the field form (Figure 7-2) refers to the large end diameter. Sometimes LWD is not cylindrical, so it has no clear "diameter". In these cases visually estimate what the diameter would be for a piece of wood with a circular cross section that would have the same volume. When evaluating length, include only the part of the LWD piece that has a diameter greater than 10 cm (4 in). Count each of the LWD pieces as one tally entry and include the whole piece when assessing dimensions, even if part of it is in Zone 4 (outside of the bankfull channel). For both the Zone 1-2 wood and the Zone 3 LWD, the field form (Figure 7-2) provides 12 entry boxes for tallying debris pieces visually estimated within three length and

**TABLE 7-4. PROCEDURE FOR TALLYING LARGE WOODY DEBRIS**

Note: Tally pieces of large woody debris (LWD) within each segment of stream at the same time the thalweg profile is being determined. Include all pieces whose large end is located within the segment in the tally.

1. Scan the stream segment between the two cross-section transects where thalweg profile measurements are being made.
2. Tally all LWD pieces within the segment that are at least partially within the bankfull channel. Determine if a piece is LWD (**small end diameter \$10 cm [4 in.]; length \$1.5 m [5 ft.]**)
3. For each piece of LWD, determine the class **based on the diameter of the large end** (0.1 m to < 0.3 m, 0.3 m to <0.6 m, 0.6 m to <0.8 m, or >0.8 m, and the class based on the length of the piece (1.5m to <5.0m, 5m to <15m, or >15m).
  - If the piece is not cylindrical, visually estimate what the diameter would be for a piece of wood with circular cross section that would have the same volume.
  - When estimating length, include only the part of the LWD piece that has a diameter greater than 10 cm (4 in)
4. Place a tally mark in the appropriate diameter × length class tally box in the “PIECES ALL/PART IN BANKFULL CHANNEL” section of the Thalweg Profile and Woody Debris Form.
5. Tally all LWD pieces within the segment that are not actually within the bankfull channel, but are at least partially spanning (bridging) the bankfull channel. For each piece, determine the class based on the diameter of the **large end** (0.1 m to < 0.3 m, 0.3 m to <0.6 m, 0.6 m to <0.8 m, or >0.8 m), and the class based on the length of the piece (1.5 m to <5.0 m, 5 m to <15 m, or >15 m).
6. Place a tally mark for each piece in the appropriate diameter × length class tally box in the “PIECES BRIDGE ABOVE BANKFULL CHANNEL” section of the Thalweg Profile and Woody Debris Form.
7. After all pieces within the segment have been tallied, write the total number of pieces for each diameter × length class in the small box at the lower right-hand corner of each tally box.
8. Repeat Steps 1 through 7 for the next stream segment, using a new Thalweg Profile and Woody Debris Form.



**Figure 7-3. Large woody debris influence zones (modified from Robison and Beschta, 1990)**

four diameter class combinations. Each LWD piece is tallied in only one box. There are 12 size classes for wood at least partially in Zones 1 and 2, and 12 for wood partially within Zone 3. Wood that is not at least partially within those zones is not tallied.

## **7.5 CHANNEL AND RIPARIAN MEASUREMENTS AT CROSS-SECTION TRANSECTS**

### **7.5.1 Slope and Bearing**

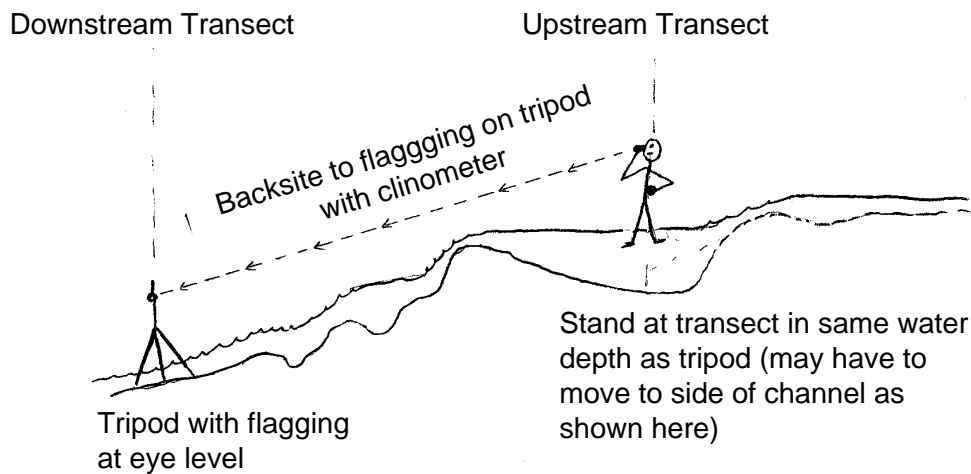
The slope, or gradient, of the stream reach is useful in three different ways. First, the overall stream gradient is one of the major stream classification variables, giving an indication of potential water velocities and stream power, which are in turn important con-

trols on aquatic habitat and sediment transport within the reach. Second, the spatial variability of stream gradient is a measure of habitat complexity, as reflected in the diversity of water velocities and sediment sizes within the stream reach. Lastly, using methods described by Stack (1989) and Robison and Kaufmann (1994), the water surface slope will allow us to compute residual pool depths and volumes from the multiple depth and width measurements taken in the thalweg profile (Section 7.4.1). Compass bearings between cross section stations, along with the distance between stations, will allow us to estimate the sinuosity of the channel (ratio of the length of the reach divided by the straight line distance between the two reach ends).

Measure slope and bearing by "backsiting" downstream between transects (e.g., transect "B" to "A", "C" to "B", etc.) as shown in Figure 7-4. To measure the slope and bearing between adjacent stations, use a clinometer, bearing compass, tripod, tripod extension, and flagging, following the procedure presented in Table 7-5. Record slope and bearing data on the Slope and Bearing Form as shown in Figure 7-5.

Slope can also be measured by two people, each having a pole that is marked at the same height. Alternatively, the second person can be "flagged" at the eye level of the person doing the backsiting. Be sure that you mark your eye level on the other person or on a separate pole beforehand while standing on level ground. Site to **your eye level** when backsiting on your co-worker. If two marked poles are used, site from the mark on one pole to the mark on the other. Also, be sure that the second person is standing (or holding the marked pole) at the water's edge or in the same depth of water as you are. The intent is to get a measure of the **water surface slope**, which may not necessarily be the same as the bottom slope. The clinometer reads both percent slope and degrees of the slope angle; be careful to read and record percent slope. Percent slope is the scale on the right-hand side as you look through most clinometers. If using an Abney Level, insure that you are reading the scale marked "PERCENT." With the clinometer or the Abney level, verify this by comparing the two scales. Percent slope is always a higher number than degrees of slope angle (e.g., 100% slope=45/ angle). For slopes > 2%, read the clinometer to the nearest 0.5%. For slopes < 2%, read to the nearest 0.25%. If the clinometer reading is 0%, but water is moving, record the slope as 0.1%. If the clinometer reading is 0% and water is not moving, record the slope as 0%.

## Slope (gradient) Measurement



## Bearing Measurement Between Transects

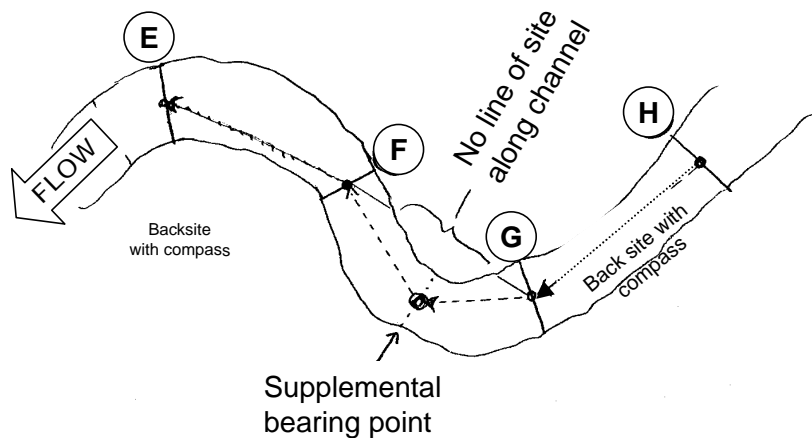


Figure 7-4. Channel slope and bearing measurements.

**TABLE 7-5. PROCEDURE FOR OBTAINING SLOPE AND BEARING DATA**

1. Stand in the center of the channel at the downstream cross-section transect. Determine if you can see the center of the channel at the next cross-section transect upstream. If not, you will have to take supplementary slope and bearing measurements.
2. Set up the tripod in shallow water or at the water's edge at the downstream cross-section transect (or at a supplemental point). Standing tall in a position with your feet as near as possible to the water surface elevation, set the tripod extension and mark it with a piece of flagging at your eye level. Remember the depth of water in which you are standing when you adjust the flagging to eye level.
  - On gradually sloped streams, it is advisable to use two people, each holding a pole marked with flagging at the same height on both poles.
3. Walk upstream to the next cross-section transect. Find a place to stand at the upstream transect (or at a supplemental point) that is at the same depth as where you stood at the downstream transect when you set up the eye-level flagging.
  - If you have determined in Step 1 that supplemental measurements are required for this segment, walk upstream to the furthest point where you can still see the center of the channel at the downstream cross-section transect from the center of the channel. Mark this location with a different color flagging than that used to mark the cross-section transects.
4. With the clinometer, site back downstream on your flagging at the downstream transect (or at the supplementary point). Read and record the **percent** slope in the "MAIN" section on the Slope and Bearing Form. Record the "PROPORTION" as 100%.
  - If two people are involved, place the base of each pole at the water level (or at the same depth at each transect). Then site with the clinometer (or Abney level) from the flagged height on upstream pole to the flagged height on the downstream pole.
  - If you are backsiting from a supplemental point, record the slope (%) and proportion (%) of the stream segment that is included in the measurement in the appropriate "SUPPLEMENTAL" section of the Slope and Bearing Form.
5. Stand in the middle of the channel at upstream transect (or at a supplemental point), and site back with your compass to the middle of the channel at the downstream transect (or at a supplemental point). Record the bearing (degrees) in the "MAIN" section of the Slope and Bearing Form.
  - If you are backsiting from a supplemental point, record the bearing in the appropriate "SUPPLEMENTAL" section of the Slope and Bearing Form.
6. Retrieve the tripod from the downstream cross section station (or from the supplemental point) and set it up at the next upstream transect (or at a supplemental point) as described in Step 2.
7. When you get to each new cross-section transect (or to a supplementary point), backsit on the previous transect (or the supplementary point), repeat Steps 2 through 6 above.

Reviewed by (initial): DP

PHab: SLOPE AND BEARING FORM - STREAMS										
NOTE: ON BACK SIDE OF THIS FORM IS THE TORRENT EVIDENCE ASSESSMENT FORM!										
SITE NAME: <u>MILL CREEK</u>		DATE: <u>7/15/97</u>		VISIT: <input checked="" type="checkbox"/> 1 <input type="checkbox"/> 2						
SITE ID: <u>MAIA97-999</u>		TEAM ID (X): <input checked="" type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5 <input type="checkbox"/> 6 <input type="checkbox"/> 7 <input type="checkbox"/> 8								
TRANSECT	MAIN			FIRST SUPPLEMENTAL			SECOND SUPPLEMENTAL			FLAG
	SLOPE	BEARING 0-360	PROPOR- TION	SLOPE	BEARING 0-360	PROPOR- TION	SLOPE	BEARING 0-360	PROPOR- TION	
A-B	3.5%	203°	50	4.5%	226°	50				
B-C	2.0%	218°	40	2.0%	203°	30	2.0%	230°	30	
C-D	1.0%	184°	100							
D-E	3.0%	179°	100							
E-F	1.0%	193°	100							
F-G	2.0%	211°	100							
G-H	4.5%	177°	25	3.0%	163°	75				
H-I	3.0%	176°	100							
I-J	2.0%	189°	10	2.0%	203°	90				
J-K	3.0%	209°	100							
FLAG	COMMENTS									

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PHab: SLOPE &amp; BEARING FORM - STREAMS - 1

Figure 7-5. Slope and Bearing Form.

For bearing measurements, it does not matter whether or not you adjust your compass bearings for magnetic declination, but **it is important that you are consistent in the use of magnetic or true bearings** throughout all the measurements you make on a given reach. Note in the comments section of the Slope and Bearing Form which type of bearings you are taking. Also, guard against recording "reciprocal" bearings (erroneous bearings 180 degrees from what they should be). The best way to do this is to know where the primary (cardinal) directions are in the field: (north [0 degrees], east [90 degrees], south [180 degrees], and west [270 degrees]), and insure that your bearings "make sense."

As stated earlier, it may be necessary to set up intermediate ("supplementary") slope and bearing points between a pair of cross-section transects if you do not have direct line-of-site along (and within) the channel between stations (see Figure 7-4). This can happen if brush is too heavy, or if there are sharp slope breaks or tight meander bends. Mark these intermediate station locations with a different color of plastic flagging than used for the cross-section transects to avoid confusion. Record these supplemental slope and bearing measurements, along with the proportion of the stream segment between transects included in each supplemental measurement, in the appropriate sections of the Slope and Bearing Form (Figure 7-5). Note that the main slope and bearing observations are always downstream of supplemental observations. Similarly, first supplemental observations are always downstream of second supplemental observations.

### 7.5.2 Substrate Size and Channel Dimensions

Substrate size is one of the most important determinants of habitat character for fish and macroinvertebrates in streams. Along with bedform (e.g., riffles and pools), substrate influences the hydraulic roughness and consequently the range of water velocities in the channel. It also influences the size range of interstices that provide living space and cover for macroinvertebrates, salamanders, and sculpins. Substrate characteristics are often sensitive indicators of the effects of human activities on streams. Decreases in the mean substrate size and increases in the percentage of fine sediments, for example, may destabilize channels and indicate changes in the rates of upland erosion and sediment supply (Dietrich et al, 1989; Wilcock, 1998).

In the EMAP protocol, substrate size and embeddedness are evaluated at each of the 11 cross-section transects (refer to Figure 7-1) using a combination of methods adapted from those described by Wolman (1954), Bain et al. (1985), Platts et al. (1983), and Plafkin et al. (1989). The basis of the protocol is a systematic selection of 5 substrate particles

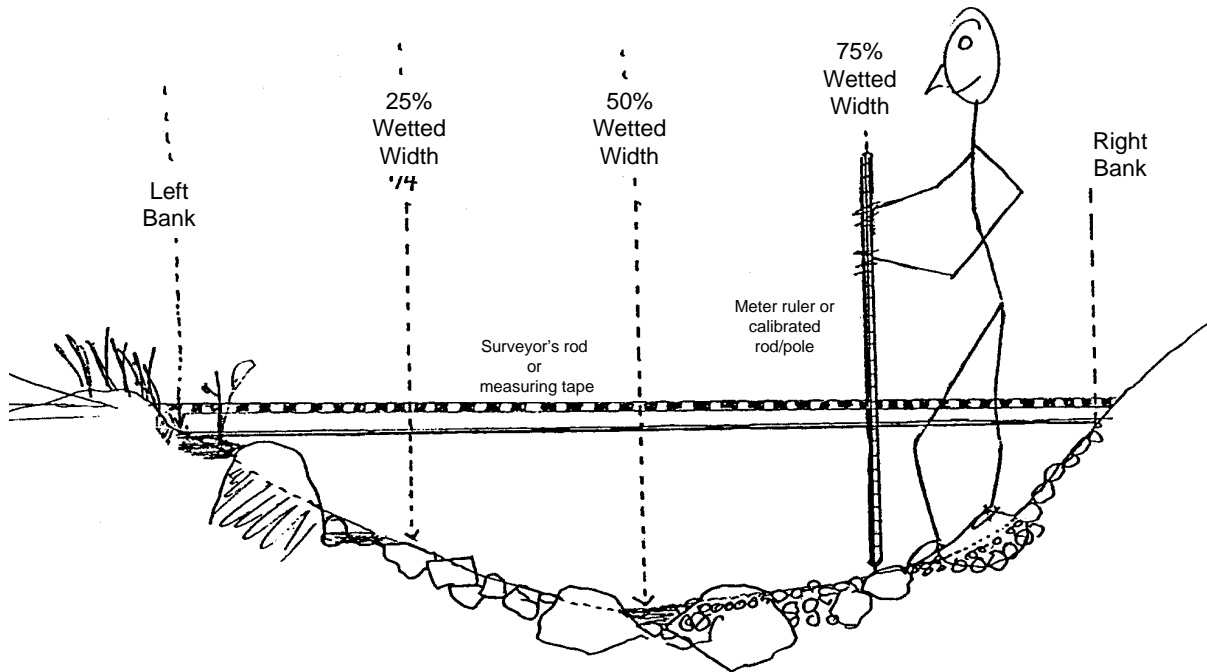


from each of 11 cross-section transects (Figure 7-6). In the process of measuring substrate particle sizes at each channel cross section, you also measure the wetted width of the channel and the water depth at each substrate sample point. If the wetted channel is split by a mid-channel bar (see Section 7.4.1), the five substrate points are centered between the wetted width boundaries regardless of the mid-channel bar in between. Consequently, substrate particles selected in some cross-sections may be "high and dry". For dry channels, make cross-section measurements across the unvegetated portion of the channel.

The distance you record to the right bank is the same as the wetted channel width. (NOTE: this is the same value that is also recorded under "BANK MEASUREMENTS" on the cross-section and thalweg profile data form [Section 7.5.3]). The substrate sampling points along the cross-section are located at 0, 25, 50, 75, and 100 percent of the measured wetted width, with the first and last points located at the water's edge just within the left and right banks.

The procedure for obtaining substrate measurements is described in Table 7-6. Record these measurements on the Channel/Riparian Cross-section and Thalweg Profile Form as shown in Figure 7-7. To minimize bias in selecting a substrate particle for size classification, it is important to concentrate on correct placement of the measuring stick along the cross-section, and to select the particle right at the bottom of the stick (not, for example, a more noticeable large particle that is just to the side of the stick). Classify the particle into one of the size classes listed on the field data form (Figure 7-7) based on the middle dimension of its length, width, and depth. This "median" dimension determines the sieve size through which the particle can pass. Always distinguish "hardpan" from "fines", coding hardpan as "HP". Similarly, always distinguish concrete or asphalt from bedrock; denote these artificial substrates as "other" ("OT") and describe them in the comments section of the field data form. Code and describe other artificial substrates (including metal, tires, car bodies, etc.) in the same manner. When you record the size class as "OT" (other), assign an "F"-series flag on the field data form (Figure 7-7) and describe the substrate type in the comments section of the field form, as shown in Figure 7-2.

Examine particles larger than sand for surface stains, markings, and algal coatings to estimate embeddedness of all particles in the 10 cm diameter circle around the substrate sampling point. Embeddedness is the fraction of a particle's surface that is surrounded by (embedded in) sand or finer sediments on the stream bottom. By definition, the embeddedness of sand, silt, clay, and muck is 100 percent, and the embeddedness of hardpan and bedrock is 0 percent.



**Figure 7-6. Substrate sampling cross-section.**

### 7.5.3 Bank Characteristics

The procedure for obtaining bank and channel dimension measurements is presented in Table 7-7. Data are recorded in the “Bank Measurements” section of the Channel/Riparian Cross-section and Thalweg Profile Form as shown in Figure 7-7. Bank angle and bank undercut distance are determined on the left and right banks at each cross section transect. Other features include the wetted width of the channel (as determined in Section 7.5.2), the width of exposed mid-channel bars of gravel or sand, estimated incision height, and the estimated height and width of the channel at bankfull stage as described in Section 7.4.2 and Figure 7-3. The “bankfull” or “active” channel is defined as the channel that is filled by moderate-sized flood events that typically occur every one or two years. Such flows do not generally overtop the channel banks to inundate the valley floodplain, and are believed to control channel dimensions in most streams.

**TABLE 7-6. SUBSTRATE MEASUREMENT PROCEDURE**

1. Fill in the header information on page 1 of a Channel/Riparian Cross-section and Thalweg Profile Form. Indicate the cross-section transect. At the transect, extend the surveyor's rod across the channel perpendicular to the flow, with the "zero" end at the left bank (facing downstream). If the channel is too wide for the rod, stretch the metric tape in the same manner.
2. Divide the wetted width of the channel by 4 to obtain the locations of the substrate measurement points along the cross-section. In the "DISTLB" fields of the form, record the distances corresponding to 0% (LFT), 25% (LCTR), 50% (CTR), 75% (RCTR), and 100% (RGT) of the measured wetted width.
3. Place your sharp-ended meter stick or calibrated pole at the "LFT" location (0 m). Measure the depth and record it on the field data form.
  - Entries for the water's edge at the left and right banks may be 0 (zero) if the banks are gradual.
  - If the bank is nearly vertical, let the base of the measuring stick fall to the bottom, rather than holding it suspended at the water surface.
4. Pick up the substrate particle that is at the base of the meter stick (unless it is bedrock or boulder), and visually estimate its particle size, according to the following table. Classify the particle according to its "median" diameter (the middle dimension of its length, width, and depth). Record the size class code on the field data form.

Code	Size Class	Size Range (mm)	Description
RS	Bedrock (Smooth)	>4000	Smooth surface rock bigger than a car
RR	Bedrock (Rough)	>4000	Rough surface rock bigger than a car
HP	Hardpan		Firm, consolidated fine substrate
BL	Boulders	>250 to 4000	Basketball to car size
CB	Cobbles	>64 to 250	Tennis ball to basketball size
GC	Gravel (Coarse)	>16 to 64	Marble to tennis ball size
GF	Gravel (Fine)	> 2 to 16	Ladybug to marble size
SA	Sand	>0.06 to 2	Smaller than ladybug size, but visible as particles - gritty between fingers
FN	Fines	<0.06	Silt Clay Muck (not gritty between fingers)
WD	Wood	Regardless of Size	Wood & other organic particles
OT	Other	Regardless of Size	Concrete, metal, tires, car bodies etc. (describe in comments)

5. For particles larger than sand, examine the surface for stains, markings, and algae. Estimate the average percentage embeddedness of particles in the 10 cm circle around the measuring rod. Record this value on the field data form. By definition, sand and fines are embedded 100 percent; bedrock and hardpan are embedded 0 percent.
6. Move successively to the next location along the cross section. Repeat steps 4 through 6 at each location.
7. Repeat Steps 1 through 6 at each new cross section transect.

Reviewed by (initial): *SA*

PHab: CHANNEL/RIPARIAN CROSS-SECTION & THALWEG PROFILE FORM - STREAMS

SITE NAME: *MILL Creek* SITE ID: *MAIA 97-999* DATE: *7/15/97* VISIT: ☒ 1 ☐ 2

TEAM ID(X): ☒ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8

TRANSECT(X): ☐ A ☒ B ☐ C ☐ D ☐ E ☐ F ☐ G ☐ H ☐ I ☐ J ☐ K

I. SUBSTRATE CROSS-SECTIONAL INFORMATION		III. FISH COVER/ OTHER		COVER IN-CHANNEL					V. VISUAL RIPARIAN ESTIMATES		FLAG	
Loc.	Dist LB XX.XX m	DEPTH XXX cm	SIZE CLASS CODE	EMBED. 0-100%	FLAG	0 = ABSENT 1 = SPARSE 2 = MODERATE 3 = HEAVY 4 = VERY HEAVY (X ONE)	0 = ABSENT 1 = SPARSE 2 = MODERATE 3 = HEAVY 4 = VERY HEAVY (X ONE)	0 = ABSENT 1 = SPARSE 2 = MODERATE 3 = HEAVY 4 = VERY HEAVY (X ONE)	0 = ABSENT 1 = SPARSE 2 = MODERATE 3 = HEAVY 4 = VERY HEAVY (X ONE)	0 = ABSENT 1 = SPARSE 2 = MODERATE 3 = HEAVY 4 = VERY HEAVY (X ONE)	0 = ABSENT 1 = SPARSE 2 = MODERATE 3 = HEAVY 4 = VERY HEAVY (X ONE)	0 = ABSENT 1 = SPARSE 2 = MODERATE 3 = HEAVY 4 = VERY HEAVY (X ONE)
LFT	0.00	0	SA	100								
LCTR	1.38	10	SA	100								
CTR	2.75	17	OT	0	F1							
RCR	4.13	14	FN	100								
RGT	5.50	0	GF	60								

RS = BEDROCK (SMOOTH) • (LARGER THAN A CAR)  
 RR = BEDROCK (ROUGH) • (LARGER THAN A CAR)  
 BL = BOULDER (250 TO 4000 MM) • (BASKETBALL TO CAR)  
 CB = COBBLE (64 TO 250 MM) • (TENNIS BALL TO BASKETBALL)  
 GC = COARSE GRAVEL (16 TO 64 MM) • (MARBLE TO TENNIS BALL)  
 GF = FINE GRAVEL (2 TO 16 MM) • (LADYBUG TO MARBLE)  
 SA = SAND (0.06 TO 2 MM) • (GRITTY - UP TO LADYBUG SIZE)  
 FN = SILT/CLAY/MUCK • (NOT GRITTY)  
 HP = HARDPAN • (FIRM, CONSOLIDATED FINE SUBSTRATE)  
 WD = WOOD • (ANY SIZE)  
 OT = OTHER • (COMMENT)

II. BANK MEASUREMENTS		IV. CANOPY COVER MEASUREMENTS	
LOCATION	BANK ANGLE 0-360°	UNDERCUT DIST. (m) X.XX	FLAG
LEFT	40°	0.00	
RIGHT	75°	0.00	
WETTED WIDTH		5.5 m	
BANK WIDTH		3.5 m	
BANKFULL WIDTH		5.7 m	
BANKFULL HEIGHT		0.3 m	
INCISED HEIGHT		0.9 m	

HUMAN INFLUENCE		FLAG	
0 = NOT PRESENT C = WITHIN 10 m P = > 10 m	0 = NOT PRESENT C = WITHIN 10 m P = > 10 m	0 = NOT PRESENT C = WITHIN 10 m P = > 10 m	0 = NOT PRESENT C = WITHIN 10 m P = > 10 m
WALL/DIKE/RETENTION/ROAD/DAM			
BUILDINGS			
PAVEMENT			
ROAD/RAILROAD			
PIPES (INLET/OUTLET)			
LANDFILL/TRASH			
PARK/LAWN			
ROW CROPS			
PASTURE/RANGE/HAY FIELD			
LOGGING OPERATIONS			
MINING ACTIVITY			

Flag Codes: K = no measurement made;  
 U = suspect measurement; F1, F2, etc. =  
 misc. flags assigned by each field crew.  
 Explain all flags in comments section  
 on the reverse side of this form.

PHab: CHANNEL/RIPARIAN CROSS-SECTION & THALWEG PROFILE FORM - STREAMS - 1

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Figure 7-7. Channel/Riparian Cross-section and Thalweg Profile Form.

**TABLE 7-7. PROCEDURE FOR MEASURING BANK CHARACTERISTICS**

1. To measure bank angle, lay the surveyor's rod or your meter ruler down against the left bank (determined as you face downstream), with one end at the water's edge. Lay the clinometer on the rod, read the bank angle in degrees from the external scale on the clinometer. Record the angle in the field for the left bank in the "BANK MEASUREMENT" section of the Channel/Riparian Cross-section and Thalweg Profile Form.
  - A vertical bank is 90 degrees; undercut banks have angles >90 degrees approaching 180 degrees, and more gradually sloped banks have angles <90 degrees. To measure bank angles >90 degrees, turn the clinometer (which only reads 0 to 90 degrees) over and subtract the angle reading from 180 degrees.
2. If the bank is undercut, measure the horizontal distance of the undercutting to the nearest 0.01 m. Record the distance on the field data form. The undercut distance is the distance from the water's edge out to the point where a vertical plumb line from the bank would hit the water's surface.
  - Measure submerged undercuts by thrusting the rod into the undercut and reading the length of the rod that is hidden by the undercutting.
3. Repeat Steps 1 and 2 on the right bank.
4. Hold the surveyor's rod vertical, with its base planted at the water's edge. Using the surveyor's rod as a guide while examining both banks, estimate (by eye) the channel incision as the height up from the water surface to elevation of the first terrace of the valley floodplain (Note this is at or above the bankfull channel height). Record this value in the "INCISED HEIGHT" field of the bank measurement section on the field data form.
5. Still holding the surveyor's rod as a guide, examine both banks to estimate and record the height of bankfull flow above the present water level. Look for evidence on one or both banks such as:
  - An obvious slope break that differentiates the channel from a relatively flat floodplain terrace higher than the channel.
  - A transition from exposed stream sediments to terrestrial vegetation.
  - Moss growth on rocks along the banks.
  - Presence of drift material caught on overhanging vegetation.
  - transition from flood- and scour-tolerant vegetation to that which is relatively intolerant of these conditions.
6. Record the wetted width value determined when locating substrate sampling points in the "WETTED WIDTH" field in the bank measurement section of the field data form. Also determine the bankfull channel width and the width of exposed mid-channel bars (if present). Record these values in the "BANK MEASUREMENT" section of the field data form.
7. Repeat Steps 1 through 6 at each cross-section transect. Record data for each transect on a separate field data form.

If the channel is not greatly incised, bankfull channel height and incision height will be the same. However, if the channel is incised greatly, the bankfull level will be below the level of the first terrace of the valley floodplain, making bankfull channel height smaller than incision height (Figure 7-8). You may need to look for evidence of recent flows (within about one year) to distinguish bankfull and incision heights. In cases where the channel is cutting a valley sideslope and has oversteepened and destabilized that slope, the bare "cutbank" is not necessarily an indication of recent incision. Examine both banks to more accurately determine channel downcutting.

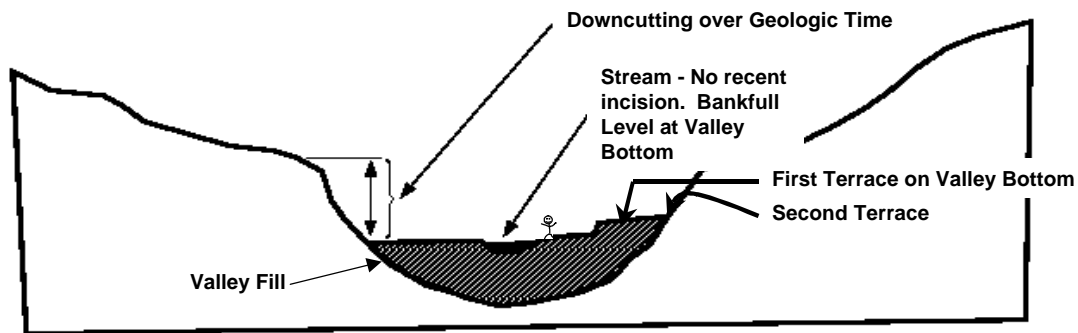
Spotting the level of bankfull flow during baseflow conditions requires judgement and practice; even then it remains somewhat subjective. In many cases there is an obvious slope break that differentiates the channel from a relatively flat floodplain terrace higher than the channel. Because scouring and inundation from bankfull flows are often frequent enough to inhibit the growth of terrestrial vegetation, the bankfull channel may be evident by a transition from exposed stream sediments to terrestrial vegetation. Similarly, it may be identified by noting moss growth on rocks along the banks. Bankfull flow level may also be seen by the presence of drift material caught on overhanging vegetation. However, in years with large floods, this material may be much higher than other bankfull indicators. In these cases, record the lower value, flag it, and also record the height of drift material in the comments section of the field data form.

#### **7.5.4 Canopy Cover Measurements**

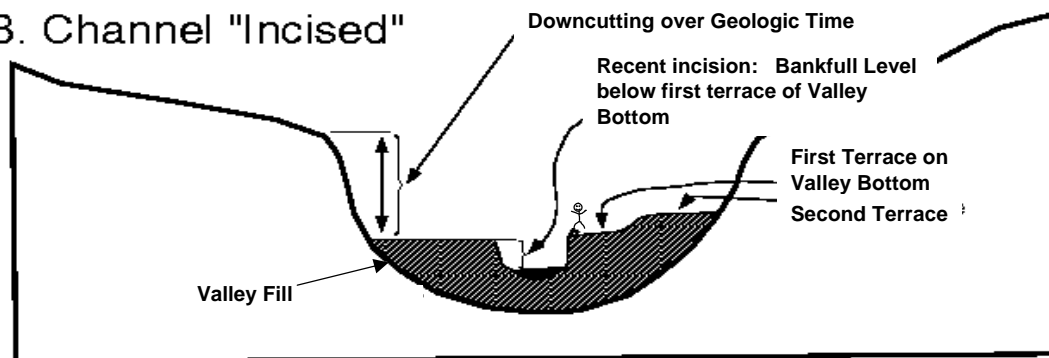
Riparian canopy cover over a stream is important not only in its role in moderating stream temperatures through shading, but also as an indicator of conditions that control bank stability and the potential for inputs of coarse and fine particulate organic material. Organic inputs from riparian vegetation become food for stream organisms and structure to create and maintain complex channel habitat.

Canopy cover over the stream is determined at each of the 11 cross-section transects. A Convex Spherical Densiometer (model B) is used (Lemmon, 1957). The densiometer must be taped exactly as shown in Figure 7-9 to limit the number of square grid intersections to 17. Densiometer readings can range from 0 (no canopy cover) to 17 (maximum canopy cover). Six measurements are obtained at each cross-section transect (four measurements in four directions at mid-channel and one at each bank). The mid-channel measurements are used to estimate canopy cover over the channel. The two bank measurements complement your visual estimates of vegetation structure and cover within the

### A. Channel not "Incised"



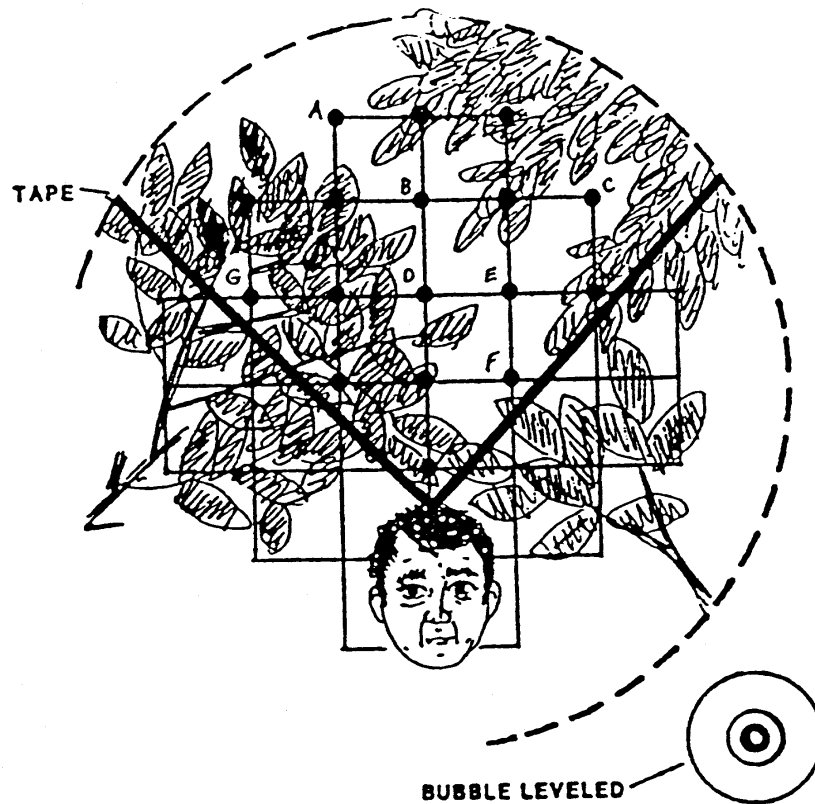
### B. Channel "Incised"



**Figure 7-8. Schematic showing bankfull channel and incision for channels. (A) not recently incised, and (B) recently incised into valley bottom.** Note level of bankfull stage relative to elevation of first terrace on valley bottom (Stick figure included for scale).

riparian zone itself (Section 7.5.5), and are particularly important in wide streams, where riparian canopy may not be detected by the densiometer when standing midstream.

The procedure for obtaining canopy cover data is presented in Table 7-8. Densiometer measurements are taken at 0.3 m (1 ft) above the water surface, rather than at waist level, to (1) avoid errors because people differ in height; (2) avoid errors from standing in water of varying depths; and (3) include low overhanging vegetation more consistently in the estimates of cover. Hold the densiometer level (using the bubble level) 0.3 m above the



**Figure 7-9. Schematic of modified convex spherical canopy densiometer (From Mulvey et al., 1992).** In this example, 10 of the 17 intersections show canopy cover, giving a densiometer reading of 10. Note proper positioning with the bubble leveled and face reflected at the apex of the "V."

water surface with your face reflected just below the apex of the taped "V", as shown in Figure 7-9. Concentrate on the 17 points of grid intersection on the densiometer that lie within the taped "V". If the reflection of a tree or high branch or leaf overlies any of the intersection points, that particular intersection is counted as having cover. For each of the



**TABLE 7-8. PROCEDURE FOR CANOPY COVER MEASUREMENTS**

1. At each cross-section transect, stand in the stream at mid-channel and face upstream.
2. Hold the densiometer 0.3 m (1 ft) above the surface of the stream. Hold the densiometer level using the bubble level. Move the densiometer in front of you so your face is just below the apex of the taped "V".
3. Count the number of grid intersection points within the "V" that are covered by either a tree, a leaf, or a high branch. Record the value (0 to 17) in the "CENUP" field of the canopy cover measurement section of the Channel/Riparian Cross-section and Thalweg Profile Form.
4. Face toward the left bank (left as you face downstream). Repeat Steps 2 and 3, recording the value in the "CENL" field of the field data form.
5. Repeat Steps 2 and 3 facing downstream, and again while facing the right bank (right as you look downstream). Record the values in the "CENDWN" and "CENR" fields of the field data form.
6. Repeat Steps 2 and 3 again, this time facing the bank while standing first at the left bank, then the right bank. Record the values in the "LFT" and "RGT" fields of the field data form.
7. Repeat Steps 1 through 6 at each cross-section transect. Record data for each transect on a separate field data form.

six measurement points, record the number of intersection points (maximum=17) that have vegetation covering them in the "Canopy Cover Measurement" section of the Channel/Riparian Cross-section and Thalweg Profile Form as shown in (Figure 7-7).

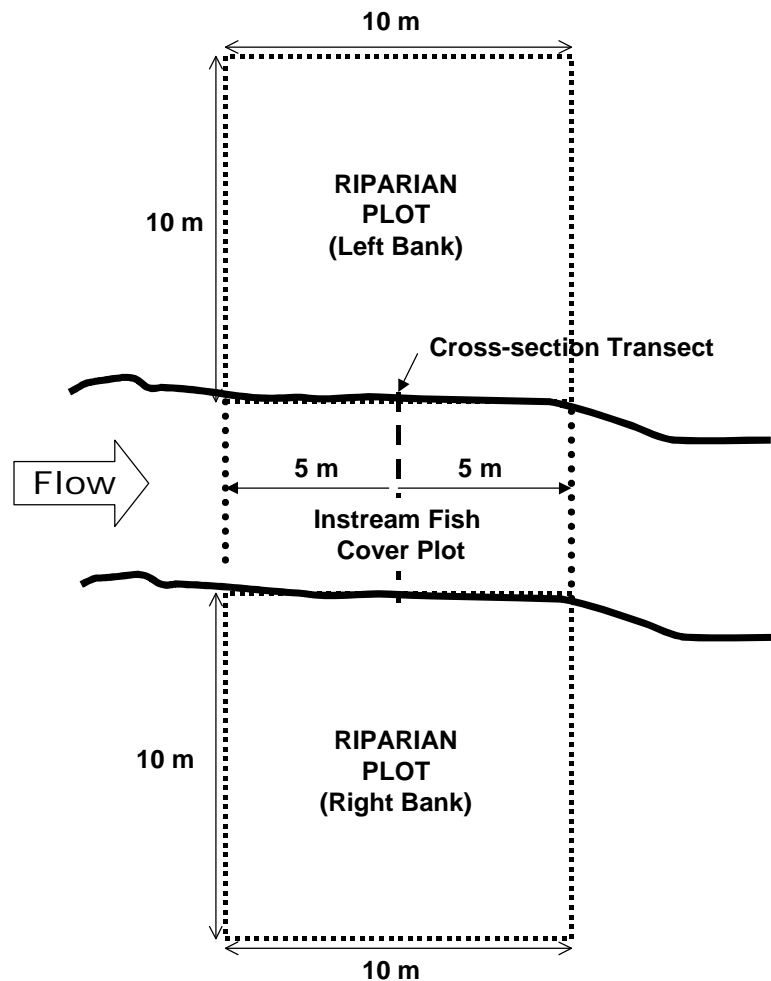
### 7.5.5 Riparian Vegetation Structure

The previous section (7.5.4) described methods for quantifying the cover of canopy over the stream channel. The following visual estimation procedures supplement those measurements with a semi-quantitative evaluation of the type and amount of various types of riparian vegetation. These data are used to evaluate the health and level of disturbance of the stream corridor. They also provide an indication of the present and future potential for various types of organic inputs and shading.

Observations to assess riparian vegetation apply to the riparian area upstream 5 meters and downstream 5 meters from each of the 11 cross-section transects (refer to Figure 7-1). They include the visible area from the stream back a distance of 10m (~30 ft) shoreward from both the left and right banks, creating a 10 m × 10 m riparian plot on each side of the stream (Figure 7-10). The riparian plot dimensions are estimated, not measured. On steeply sloping channel margins, the 10 m × 10 m plot boundaries are defined as if they were projected down from an aerial view. If the wetted channel is split by a mid-channel bar, the bank and riparian measurements are made at each side of the channel, not the bar.

Table 7-9 presents the procedure for characterizing riparian vegetation structure and composition. Figure 7-7 illustrates how measurement data are recorded in the "VISUAL RIPARIAN ESTIMATES" section of the Channel/Riparian Cross-section and Thalweg Profile Form. Conceptually divide the riparian vegetation into three layers: a CANOPY LAYER (> 5 m high), an UNDERSTORY (0.5 to 5 m high), and a GROUND COVER layer (< 0.5 m high). Note that several vegetation types (e.g., grasses or woody shrubs) can potentially occur in more than one layer. Similarly note that some things other than vegetation are possible entries for the "Ground Cover" layer (e.g., barren ground).

Before estimating the areal coverage of the vegetation layers, record the type of vegetation (Deciduous, Coniferous, broadleaf Evergreen, Mixed, or None) in each of the two taller layers (Canopy and Understory). Consider the layer "Mixed" if more than 10% of the areal coverage is made up of the alternate vegetation type.



**Figure 7-10. Boundaries for visual estimation of riparian vegetation, fish cover, and human influences.**

Estimate the areal cover separately in each of the three vegetation layers. Note that the areal cover can be thought of as the amount of shadow cast by a particular layer alone when the sun is directly overhead. The maximum cover in each layer is 100%, so the sum of the areal covers for the combined three layers could add up to 300%. The four areal cover classes are “absent”, “sparse” (<10%), “moderate” (10 to 40%), “heavy” (40 to 75%),

**TABLE 7-9. PROCEDURE FOR CHARACTERIZING RIPARIAN VEGETATION STRUCTURE**

1. Standing in mid-channel at a cross-section transect, estimate a 5 m distance upstream and downstream (10 m total length).
2. Facing the left bank (left as you face downstream), estimate a distance of 10 m back into the riparian vegetation.
  - On steeply-sloping channel margins, estimate the distance into the riparian zone as if it were projected down from an aerial view.
3. Within this 10 m × 10 m area, conceptually divide the riparian vegetation into three layers: a CANOPY LAYER (>5m high), an UNDERSTORY (0.5 to 5 m high), and a GROUND COVER layer (<0.5 m high).
4. Within this 10 m × 10 m area, determine the dominant vegetation type for the CANOPY LAYER (vegetation > 5 m high) as either Deciduous, Coniferous, broadleaf Evergreen, Mixed, or None. Consider the layer "Mixed" if more than 10% of the areal coverage is made up of the alternate vegetation type. Indicate the appropriate vegetation type in the "VISUAL RIPARIAN ESTIMATES" section of the Channel/Riparian Cross-section and Thalweg Profile Form.
5. Determine separately the areal cover class of large trees (> 0.3 m [1 ft] diameter at breast height [DBH]) and small trees (< 0.3 m DBH) within the canopy layer. Estimate areal cover as the amount of shadow that would be cast by a particular layer alone if the sun were directly overhead. Record the appropriate cover class on the field data form ("0"=absent: zero cover, "1"=sparse: <10%, "2"=moderate: 10-40%, "3"=heavy: 40-75%, or "4"=very heavy: >75%).
6. Look at the UNDERSTORY layer (vegetation between 0.5 and 5 m high). Determine the dominant vegetation type for the understory layer as described in Step 4 for the canopy layer.
7. Determine the areal cover class for woody shrubs and saplings separately from non-woody vegetation within the understory, as described in Step 5 for the canopy layer.
8. Look at the GROUND COVER layer (vegetation < 0.5 m high). Determine the areal cover class for woody shrubs and seedlings, non-woody vegetation, and the amount of bare ground present as described in Step 5 for large canopy trees.
9. Repeat Steps 1 through 8 for the right bank.
10. Repeat Steps 1 through 9 for all cross-section transects, using a separate field data form for each transect.

and "very heavy" (>75%). These cover classes and their corresponding codes are shown on the field data form (Figure 7-6). When rating vegetation cover types, mixtures of two or more subdominant classes might all be given sparse ("1") moderate ("2") or heavy ("3") ratings. One very heavy cover class with no clear subdominant class might be rated "4" with all the remaining classes rated as either moderate ("2"), sparse ("1") or absent ("0"). Two heavy classes with 40-75% cover can both be rated "3".

### **7.5.6 Instream Fish Cover, Algae, and Aquatic Macrophytes**

This portion of the EMAP physical habitat protocol is a visual estimation procedure that semi-quantitatively evaluates the type and amount of important types of cover for fish and macroinvertebrates. Alone and in combination with other metrics, this information is used to assess habitat complexity, fish cover, and channel disturbance.

The procedure to estimate the types and amounts of instream fish cover is outlined in Table 7-10. Data are recorded in the "Fish Cover/Other" section of the Channel /Riparian Cross-section and Thalweg Profile Form as shown in Figure 7-7. Estimate the areal cover of all of the fish cover and other listed features that are in the water and on the banks 5 meters upstream and downstream of the cross-section (see Figure 7-10). The areal cover classes of fish concealment and other features are the same as those described for riparian vegetation (Section 7.5.5).

The entry "Filamentous algae" refers to long streaming algae that often occur in slow moving waters. "Aquatic macrophytes" are water-loving plants, including mosses, in the stream that could provide cover for fish or macroinvertebrates. If the stream channel contains live wetland grasses, include these as macrophytes. "Woody debris" are the larger pieces of wood that can influence cover and stream morphology (i.e., those pieces that would be included in the large woody debris tally [Section 7.4]). "Brush/woody debris" refers to smaller wood pieces that primarily affect cover but not morphology. "Overhanging vegetation" includes tree branches, brush, twigs, or other small debris that is not in the water but is close to the stream (within 1 m of the surface) and provides potential cover. "Boulders" are typically basketball- to car-sized particles. "Artificial structures" include those designed for fish habitat enhancement, as well as in-channel structures discarded (e.g., cars or tires) or purposefully placed for diversion, impoundment, channel stabilization, or other purposes.

**TABLE 7-10. PROCEDURE FOR ESTIMATING INSTREAM FISH COVER**

1. Standing mid-channel at a cross-section transect, estimate a 5m distance upstream and downstream (10 m total length).
2. Examine the water and the banks within the 10-m segment of stream for the following features and types of fish cover: filamentous algae, aquatic macrophytes, large woody debris, brush and small woody debris, overhanging vegetation, undercut banks, boulders, and artificial structures.
3. For each cover type, estimate the areal cover. Record the appropriate cover class in the "FISH COVER/OTHER" section of the Channel/Riparian Cross-section and Thalweg Profile Form ("0"=absent: zero cover, "1"=sparse: <10%, "2"=moderate: 10-40%, "3"=heavy: 40-75%, or "4"=very heavy: >75%).
4. Repeat Steps 1 through 3 at each cross-section transect, recording data from each transect on a separate field data form.

### **7.5.7 Human Influence**

The field evaluation of the presence and proximity of various important types of human land use activities in the stream riparian area is used in combination with mapped watershed land use information to assess the potential degree of disturbance of the sample stream reaches.

For the left and right banks at each of the 11 detailed Channel and Riparian Cross-Sections, evaluate the presence/absence and the proximity of 11 categories of human influences with the procedure outlined in Table 7-11. Relate your observations and proximity evaluations to the stream and riparian area within 5 m upstream and 5 m downstream from the station (Figure 7-10). Four proximity classes are used: In the stream or on the bank within 5 m upstream or downstream of the cross-section transect, present within the 10 m × 10 m riparian plot but not in the stream or on the bank, present outside of the riparian plot, and absent. Record data on the Channel/Riparian Cross-section and Thalweg Profile Form as shown in Figure 7-6. If a disturbance is within more than one proximity class, record the one that is closest to the stream (e.g., “C” takes precedence over “P”).

A particular influence may be observed outside of more than one riparian observation plot (e.g., at both transects “D” and “E”). Record it as present at every transect where you can see it without having to site through another transect or its 10 m × 10 m riparian plot.

## **7.6 EQUIPMENT AND SUPPLIES**

Figure 7-11 lists the equipment and supplies required to conduct all the activities described for characterizing physical habitat. This checklist is similar to the checklist presented in Appendix A, which is used at the base location (Section 3) to ensure that all of the required equipment is brought to the stream. Use this checklist to ensure that equipment and supplies are organized and available at the stream site in order to conduct the activities efficiently.

**TABLE 7-11. PROCEDURE FOR ESTIMATING HUMAN INFLUENCE**

1. Standing mid-channel at a cross-section transect, look toward the left bank (left when facing downstream), and estimate a 5m distance upstream and downstream (10 m total length). Also, estimate a distance of 10 m back into the riparian zone to define a riparian plot area.
2. Examine the channel, bank and riparian plot area adjacent to the defined stream segment for the following human influences: (1) walls, dikes, revetments, riprap, and dams; (2) buildings; (3) pavement (e.g., parking lot, foundation); (4) roads or railroads, (5) inlet or outlet pipes; (6) landfills or trash (e.g., cans, bottles, trash heaps); (7) parks or maintained lawns; (8) row crops; (9) pastures, rangeland, or hay fields; (10) logging; and (11) mining (including gravel mining).
3. For each type of influence, determine if it is present and what its proximity is to the stream and riparian plot area. Consider human disturbance items as present if you can see them from the cross-section transect. Do not include them if you have to site through another transect or its 10 m x10 m riparian plot.
4. For each type of influence, record the appropriate proximity class in the "HUMAN INFLUENCE" part of the "VISUAL RIPARIAN ESTIMATES" section of the Channel/Riparian Cross-section and Thalweg Profile Form. Proximity classes are:
  - B ("Bank") Present within the defined 10 m stream segment and located in the stream or on the stream bank.
  - C ("Close") Present within the 10 x 10 m riparian plot area, but away from the bank.
  - P ("Present") Present, but outside the riparian plot area.
  - O ("Absent") Not present within or adjacent to the 10 m stream segment or the riparian plot area at the transect
5. Repeat Steps 1 through 4 for the right bank.
6. Repeat Steps 1 through 5 for each cross-section transect, recording data for each transect on a separate field form.



**EQUIPMENT AND SUPPLIES FOR PHYSICAL HABITAT**

<b>QTY.</b>	<b>Item</b>	
1	Surveyor's telescoping leveling rod (round profile, metric scale, 7.5m extended)	
1	50-m fiberglass measuring tape & reel	
1	Hip chain (metric) for measuring reach lengths ( <u>Optional</u> )	
1	Clinometer (or Abney level) with percent and degree scales.	
1	Lightweight telescoping camera tripod (necessary only if slope measurements are being determined by one person)	
2	½-inch diameter PVC pipe, 2-3 m long, each marked at the same height (for use in slope determinations involving two persons)	
1	Meter stick. Alternatively, a short (1-2 m) rod or pole (e.g., a ski pole) with cm markings for thalweg measurements, or the PVC pipe described for slope determinations can be used	
1 roll ea.	Colored surveyor's plastic flagging (2 colors)	
1	Convex spherical canopy densiometer (Lemmon Model B), modified with taped "V"	
1	Bearing compass (Backpacking type)	
1 or 2	Fisherman's vest with lots of pockets and snap fittings. Used at least by person conducting the in-channel measurements to hold the various measurement equipment (densiometer, clinometer, compass, etc.). Useful for both team members involved with physical habitat characterization.	
2 pair	Chest waders with felt-soled boots for safety and speed if waders are the neoprene "stocking" type. Hip waders can be used in shallower streams.	
	Covered clipboards (lightweight, with strap or lanyard to hang around neck)	
	Soft (#2) lead pencils (mechanical are acceptable)	
11 plus extras	Channel/Riparian Cross-section & Thalweg Profile Forms	
1 plus extras	Slope and Bearing Forms	
1 copy	Field operations and methods manual	
1 set	Laminated sheets of procedure tables and/or quick reference guides for physical habitat characterization	

**Figure 7-11. Checklist of equipment and supplies for physical habitat.**

## 7.6 LITERATURE CITED

- Bain, M.B., J.T. Finn, and H.E. Boone. 1985. Quantifying stream substrate for habitat analysis studies. *North American Journal of Fisheries Management* 5:499-500.
- Bisson, P.A., J.L. Neilsen, R.A. Palmason, and L.E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilizations by salmonids during low stream flow. pp. 62-73 IN: N.B. Armantrout (ed.). *Acquisition and Utilization of Aquatic Habitat Inventory Information*. Symposium Proceedings, October 18-30, 1981, Portland, Oregon. The Hague Publishing, Billings, Montana.
- Dietrich, W.E., J.W. Kirchner, H. Ikeda, and F. Iseya. 1989. Sediment supply and the development of the coarse surface layer in gravel bed rivers. *Nature* 340:215-217.
- Frissell, C.A., W.J. Liss, C.E. Warren, and M.D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environmental Management* 10(2):199-214.
- Kaufmann, P.R. (ed.). 1993. Physical Habitat. pp. 59-69 IN: R.M. Hughes (ed.). *Stream Indicator and Design Workshop*. EPA/600/R-93/138. U.S. Environmental Protection Agency, Corvallis, Oregon.
- Kaufmann, P.R., P. Levine, E.G. Robison, C. Seeliger, and D.V. Peck. In preparation. *Quantifying Physical Habitat in Wadeable Streams*. Environmental Monitoring and Assessment Program, U.S. Environmental Protection Agency, Corvallis, Oregon.
- Lemmon, P.E. 1957. A new instrument for measuring forest overstory density. *Journal of Forestry* 55(9):667-669.
- Linsley, R.K., M.A. Kohler, and J.L.H. Paulhus. 1982. *Hydrology for Engineers*. McGraw-Hill Book Co. New York, NY. 508 p.
- Mulvey, M., L. Caton, and R. Hafele. 1992. *Oregon Nonpoint Source Monitoring Protocols Stream Bioassessment Field Manual for Macroinvertebrates and Habitat Assessment*. Oregon Department of Environmental Quality, Laboratory Biomonitoring Section. 1712 S.W. 11th Ave. Portland, Oregon, 97201. 40 p.

- Plafkin, J.L., M.T. Barbour, K.D. Porter, S.K. Gross, R.M. Hughes. 1989. *Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish*. EPA/440/4-89/001. U.S. Environmental Protection Agency, Assessment and Watershed Protection Division, Washington, D.C.
- Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. *Methods for Evaluating Stream, Riparian, and Biotic Conditions*. USDA Forest Service General Technical Report INT-183. 71 p.
- Robison, E.G. and R.L. Beschta. 1990. Characteristics of coarse woody debris for several coastal streams of southeast Alaska, USA. *Canadian Journal of Fisheries and Aquatic Sciences* 47(9):1684-1693.
- Robison, E.G. and P.R. Kaufmann. 1994. Evaluating two objective techniques to define pools in small streams. pp. 659-668, IN: R.A. Marston and V.A. Hasfurther (eds.). *Effects of Human Induced Changes on Hydrologic Systems*. Summer Symposium proceedings, American Water Resources Association,. June 26-29, 1994, Jackson Hole, Wyoming. 1182 p.
- Stack, B.R. 1989. *Factors Influencing Pool Morphology in Oregon Coastal Streams*. M.S. Thesis, Oregon State University. 109 p.
- Wilcock, P.R. 1988. Two-fraction model of initial sediment motion in gravel-bed rivers. *Science* 280:410-412.
- Wolman, M.G. 1954. A method of sampling coarse river-bed material. *Transactions of the American Geophysical Union* 35(6):951-956.