3 PHYSICAL HABITAT CHARACTERIZATION

Physical habitat, typically refers to the structural attributes of the stream channel. For convenience of organization, we also discuss the measurement of physicochemical attributes of the stream water in this section. Habitat degradation from land-use change is the greatest threat to streams and their inhabitants (Allen and Flecker 1993, Sala et al. 2000, USEPA 2001). Although stream scientists generally agree that habitat degradation is a serious threat, no universally accepted index or procedure exists to rate physical habitat condition for streams. The complexity and natural variation of stream habitat, the need for rapid field protocols, and objectivity must be balanced before such a measure is accepted. While the development of such a universal tool is beyond the scope of this document, this work has modified existing procedures and developing new ones specifically for headwater streams. We believe that these procedures will contribute toward effectively quantifying condition, identifying causes of degradation, and restoring stream habitat.

Hierarchical classification across spatial and temporal scales is useful for delimiting sources of natural variability within and among complex systems and provides a framework for integrating information from different levels of resolution (O'Neill et al. 1986). Such a framework for streams ranges spatially from whole drainage networks down to microhabitats (Frissell et al. 1986). Implicit in this framework is an understanding that absolute linear dimensions for spatial scales across all streams (Brussock et al. 1985) or even longitudinally within a stream (Vannote et al. 1980, Montgomery 1999) are unattainable due to variation in geology, climate, and topography.

The stream reach is the most commonly used and practical spatial scale for study units. The spacing of distinctive features (e.g., pools, riffles) within streams is partly driven by channel width. The length of study reaches should be sufficient to incorporate multiple features of the same type to prevent evaluations based solely on potentially anomalous features. As discussed in Section 2.1, study reaches that are 30-m long are sufficient in most cases where streams are 1-to 2-m wide.

Transect sampling (i.e., line-intercept technique) is a commonly used method to quantify physical habitat at the reach scale (e.g., Platts et al. 1983, Fitzpatrick et al. 1998, Lazorchak et al. 1998). Transect sampling uses a series of lines (transects) that are positioned perpendicular to flow and cross the channel. Measurements are taken along these transects to characterize the stream reach, and thus, provide the investigator with mean estimations and a degree of variation along stream reaches. Transects can continue beyond the stream channel where measurements of the adjacent riparian zone, floodplain, and terraces are of interest. The number and positioning of transects should be sufficient to characterize the spatial scale of interest. Physical parameters that vary little along a stream reach will require fewer measurements (e.g., discharge) to arrive at representative values than those that can vary substantially (e.g., water depth). The positioning of transects can be done systematically (e.g., every meter), randomly or stratified random (e.g., stratified by habitat type). Systematic selection ensures that the measurements span the entire study reach and may be logistically easier; however, random selection may be preferred because all cross-sections have an equal chance of being measured (see Section 2, *Field sampling designs*).

As streams dry, surface water will gradually become constricted to the channel thalweg. Therefore, the thalweg will often be the last area to dry for a given channel cross-section. The thalweg is an important location for measuring many physical parameters because this can be a consistent and conservative target when comparing across sites with varying hydrologic permanence and ecological condition. Where transect sampling is used, the thalweg (rather than the banks) is the central axis along the stream where the transects should be perpendicularly spaced. Many of the measures described in the following sections are centered on the thalweg at sampling transects. Because of the narrow widths of headwater channels, these sampling points represent most of the channel width and the portion of the channel width that is inundated longest.

Characterization of physical habitat is widely used in stream assessments (see Somerville and Pruitt 2004); however, assessment protocols vary in purpose, breadth, and targeted stream type (Montgomery and McDonald 2002). Few protocols specifically target headwater streams, but several region-specific assessment protocols are potentially available. The associated objectives of these protocols vary somewhat. For instance, the Ohio Environmental Protection Agency's Primary Headwater Habitat Evaluation Form (Ohio EPA 2002) was developed to differentiated among 1) coldwater perennial streams, 2) warmwater perennial and intermittent streams, and 3) ephemeral streams. The North Carolina Division of Water Quality's Classification Method (NCDWQ 2005) and Fairfax County (VA) Stormwater Planning Division's Perennial Streams Field Identification Protocol (FCSPD 2003), were designed to classify streams based on hydrologic permanence (i.e., ephemeral, intermittent and perennial flow). Some agencies like the Louisville District of the U. S. Army Corps of Engineers (Sparks et al. 2003a, b) have adopted protocols developed for wadable streams (USEPA Rapid Habitat Assessment Form (RHAF); Barbour et al. 1999). The Louisville District uses RHAF, in conjunction with specific conductivity and macroinvertebrate bioassessment index scores (Pond and McMurray 2002), to assess the ecological integrity of headwater streams in the Eastern Coalbelt Region of Kentucky. Ideally, all three components are then used by district personnel when reviewing Clean Water Act Section 404 permit applications for dredging and filling headwater streams and determining appropriate mitigation or in lieu of fees for impacted streams.

Habitat assessment protocols vary in level of subjectivity; some use visually-based qualitative attributes across categories such as absent, weak, and strong, whereas others rely on quantitative measures. Qualitative protocols are advantageous under high workloads with limited resources and training because they often require less expertise and time to complete than quantitative assessments. However, the versatility, applicability, and rigor of qualitative assessments are more limited. For instance, the attribute scoring of individual measures or questions in qualitative assessments are weighted based on regionally derived investigations that may not be applicable outside the original region. The data for qualitative assessments are often categorical or discrete (i.e., integer values) over a limited range, whereas quantitative data can be distributed continuously or categorized for analyses. Lastly, data sets from sources that use the same quantitative measures are more feasible to combine for broader assessments than qualitatively collected parameters. Many habitat characteristics, however, are currently limited to only qualitative or semi-quantitative methods for assessments (e.g., habitat unit designations, substrate embeddedness, instream fish cover). Wang et al. (1996) noted that among 27 habitat characteristics evaluated for among-observer precision, those that were scored quantitatively (directly measured, rather than visually scored across categories) were more precise than qualitatively scored characteristics. In their review of physical stream protocols used by regulatory agencies, Somerville and Pruitt (2004) recommended the use of quantitative measures in physical habitat assessments, where practicable, to limit observer bias as much as possible.

The following subsections provide methods for measuring physical habitat parameters in headwater streams. We have attempted to explain the ecological relevance of each parameter and keep the methods as straightforward as possible. Headwater streams may be remote from roads or even hiking trails, so many of the methods described in the following sections use minimal equipment. Rather than providing a single method for measuring a parameter, we have attempted to include multiple methods from which the reader can choose based on her/his particular needs and situations.

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3.1 Designating hydrologic condition for stream reaches

General

This subsection provides guidance for rapidly designating hydrologic condition in headwater stream reaches. The categories of hydrologic condition (discussed in detail below) represent the degree of departure from a spatially-continuous flow (or conversely, a completely dry condition) at a given point in time and space. These designations describe the level of connectivity or fragmentation of the aquatic phase in headwater streams (Boulton 2003). The degree of hydrologic connectivity is fundamental in controlling the structure and function of headwater streams because it affects physicochemical properties, biotic dispersal, and refuge availability (e.g., Boulton and Lake 1990, Dietrich and Anderson 1998, Maltchik et al. 1994).

Hydrology of headwater stream reaches may follow a predictable sequence of hydrologic conditions related to seasonal (and/or greater time frames) fluctuations in precipitation and evapotranspiration. Shannon et al. (2002) described hydrologic conditions in arid ephemeral channels that occur at lower frequencies than would occur in more humid regions. At a given time, the hydrologic condition also varies spatially within and among headwater streams associated with differences in distance to the groundwater table, watershed vegetation, groundwater storage capacity, etc.

The hydrologic designations discussed here differ from those that represent general flow regimes over time (e.g., perennial, intermittent and ephemeral hydrology, Uys and O'Keeffe 1997). However, in the absence of continuous monitoring of hydrologic condition, designation of hydrologic conditions at least once during wet and dry seasons may provide a simple method for identifying flow regime types.

Procedure

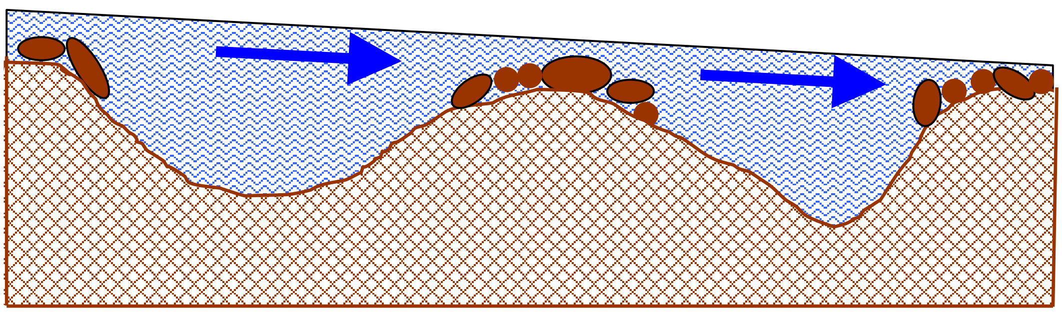
Hydrologic condition is determined by visually assessing surface water connectivity and water velocity within the thalweg of the study reach. Designation should be based upon the predominant hydrologic condition within the study reach. Mark the appropriate box on the field forms for the hydrologic condition identified (Figure 3-1).

STUDY REACH HYDROLOGIC CONDITION
☐ **Surface flow continuous (4)**
☐ **Flow only interstitial (3)**
☐ **Surface water present but no visible flow (2)**
☐ **Surface water in pools only (1)**
☐ **No surface water (0)**

Figure 3-1 Appropriate location for recording hydrologic condition on page 1 of field forms.

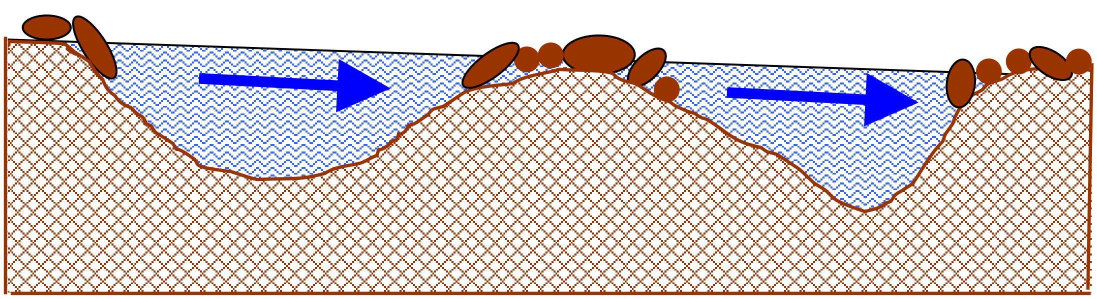
The text below describes five categories of hydrologic condition seen in headwater streams. Each category is represented by photos and a diagram showing a longitudinal section along the channel thalweg. Blue shading indicates surface water, arrows indicate presence and direction of visible flow, coarse stone substrate on the streambed is represented by solid brown, and the hatched brown areas indicated finer streambed substrate and underlying geology. The term "habitat units" refers to riffles and pools, the dominant habitat types in headwater streams. The five hydrologic categories and their numerical descriptors are as follows:

- **Visible surface flow continuous (4)**: Surface water is flowing and uninterrupted between habitat units and flowing. Most of the streambed stones within the thalweg are submerged.

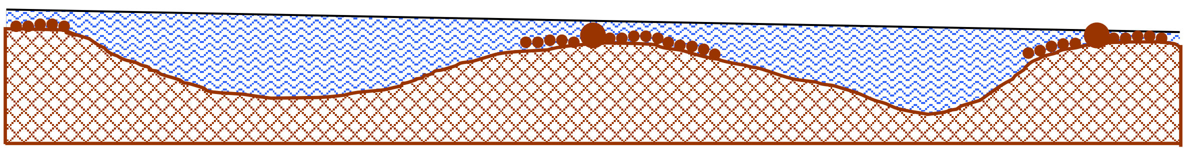


-

- **Visible flow interstitial (3)**: Surface water is interrupted between habitat units, such that the majority of streambed stones in shallow habitat units (i.e., riffles) are exposed. However, interstitial flow connecting habitat units is evident as trickles or rivulets flowing between stones or visible at the tail and heads of pools. Soluble tracers, such as fluorscein dye or NaCl solution may be added at the upstream end of a study reach and monitored downstream to determine if interstitial flow connects pools within a reach.

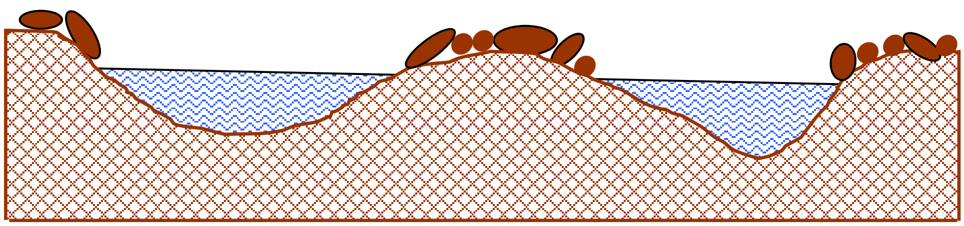


- **Surface water present but no visible flow (2)**: Surface water is uninterrupted between habitat units, however there is no evidence that the water is flowing throughout study reach. Water standing in pools may appear stagnant. This condition is likely to occur in low gradient headwater streams rather than in high gradient streams.

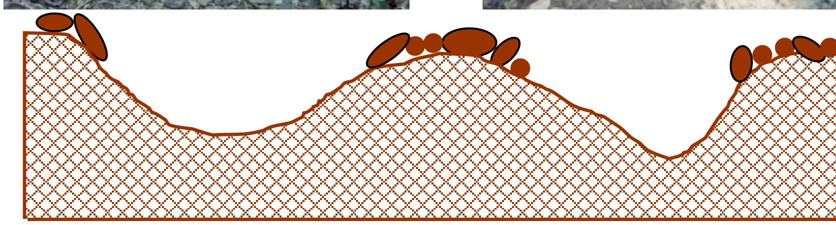


- **Surface water present in pools only (1)**: Surface water is found only in pools and there is no visible water or flow connecting pools. Stream bed sediments between pools may be moist.
-





No surface water (0): Surface water is absent from the channel thalweg.



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Equipment and supplies

Measuring tape (50 m)

Field forms

3.2 Continuous monitoring of hydrologic condition

General

This subsection describes a water sensor for continuously monitoring hydrologic condition (i.e., presence or absence of water) that is economical, light weight, and easy to install. The sensor described provides information regarding the timing, duration, and frequency of channel drying. Other methods such as float gages and pressure transducers with data loggers, which are widely used to continuously measure stream stage and subsequently, discharge (Rantz et al. 1982), also provide flow permanence data, but can be more costly and require more channel modification and maintenance.

Water sensors may be assembled by Intermountain Environmental, Inc (IEI)[11]. The components of the water sensor include an Onset Hobo® state data logger, Onset submersible case, and an encased cable (see Figure. 3-2, pen shown for scale). The state data logger was designed to continuously record binary changes (i.e., open vs. closed; on vs. off). The modification by IEI has allowed this data logger to record the timing and frequency of changes in hydrology (in terms of presence and absence of water). When present, water completes the circuit between the two exposed copper wires on the contact end of the cable and sends a "closed" signal to the sensor. When a stream dries and water no longer is present to complete the circuit, the data logger records an "open" signal. The datalogger does not record on time intervals, and only records the time when a change of state occurs. The data logger can

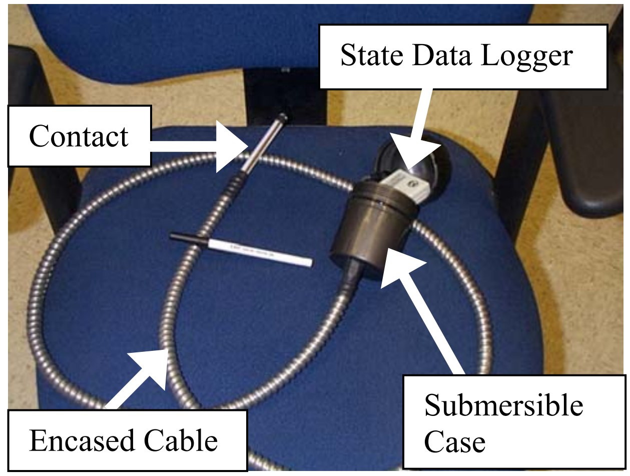

Figure 3-2 Primary components of a water sensor used to continuously monitor hydrologic condition.

record up to 2000 state changes (checking for changes of state every 0.5 seconds) and the battery will last approximately 1 year.

3.2.1 Launching and preparing for deployment

Procedure

Install the appropriate Onset software onto a personal computer. (Note that to launch data loggers via personal laptop computers Onset Boxcar Pro 4.3® or higher may be required.) Connect the PC interface cable to an open Com Port or serial port of the computer and the 3.5 mm jack of the data logger. Open the Onset Boxcar® program and either select Launch from the Logger menu or select the icon for launching on the tool bar. A launch dialog box should appear with setting options (Figure. 3-3). Note the condition of the battery; if it does not indicate that the battery is "good" then close the launch dialog box and change the battery (CR-2032 lithium). Under description, type locality information (e.g., Hoosier Natl. For.) and change text for "close" and "open" to "wet" and "dry", respectively. Do not select "wrap around" (this overwrites data already stored when >2000 state changes occur) or "stealth mode" (this turns off

[1] Intermountain Environmental, Inc.
601 W. 1700 S. Suite B., Logan, UT 84321
(800) 948-6236[1]

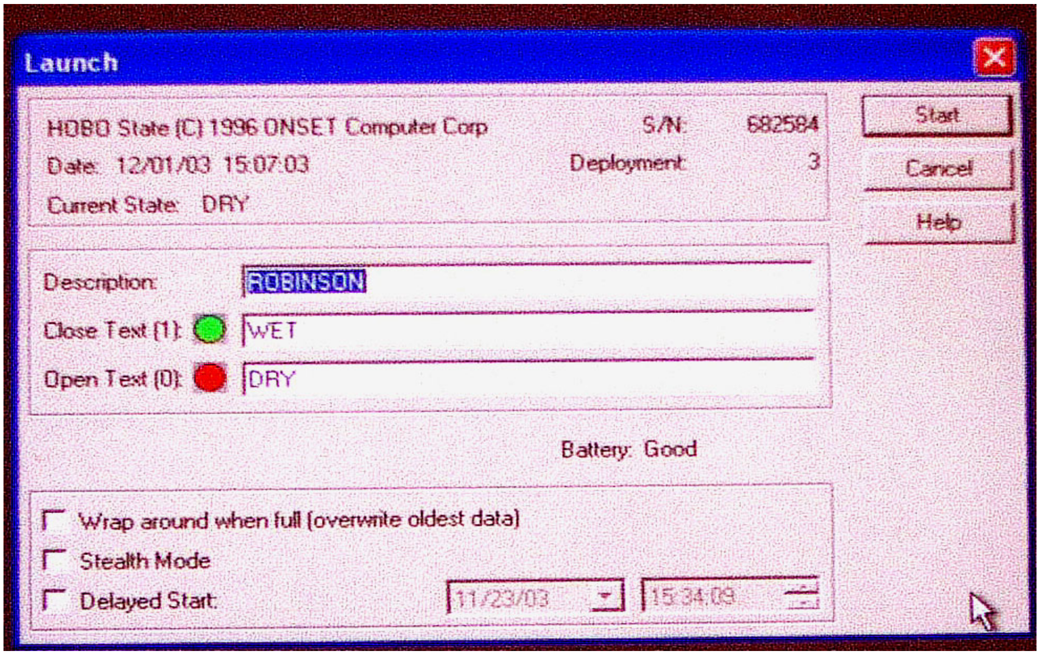

Figure 3-3 Launch dialog box for Onset Boxcar Pro.

indicator lights while data loggers are launched). Delayed setting may be selected, particularly when personal computers are not accessible near field sites and travel time to field sites may affect the battery life of data loggers. Select "start" and allow the launch progress bar to completely extend before disconnecting the data logger from the PC interface cable.
Note that the 6-digit serial number displayed by the BoxCar software matches the serial number printed on the data logger. Write this number on the outside of the submersible case using a permanent marker.

Note that the red LED (indicating “open” or “dry” state, see Figure 3-4) should be blinking if the data logger is properly launched. Place the data logger in its respective submersible case. Next connect the 2.5 mm cable to the 2.5 mm jack on side of data logger and place two desiccant packs inside the submersible case (Figure 3-4).

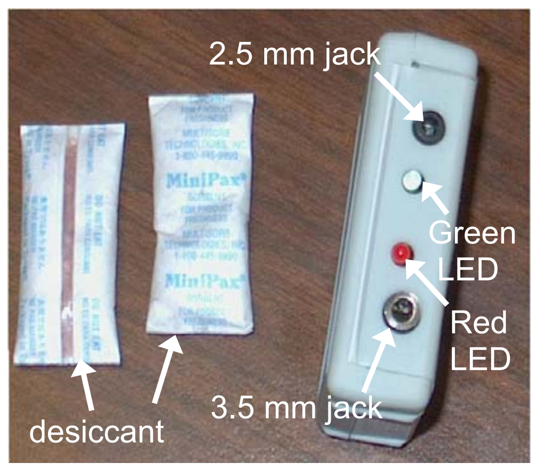

Figure 3-4 Desiccant packs and Onset Hobo® State data logger with jacks and LEDs shown.

Inspect the rubber O-ring and its seating on the submersible case (below the threads, Figure 3-5), making sure that the surfaces are clean and there are no cracks or damage to the O-ring. The O-ring should be replaced if there is cracking or damage. Lubricate the entire surface of the O-ring using the silicone compound by applying a thin, even coat.

Place the O-ring in its seating on the submersible case and screw on the submersible case cap. Ensure that the O-ring seats properly and does not extrude when screwing cap in place.

3.2.2 Deployment

Always make certain that the data logger stays dry. Record the location of the site using preferably GPS coordinates (e.g., latitude and longitude, UTMs) or precise directions. These directions should include road names, compass headings, turn directions and distances.

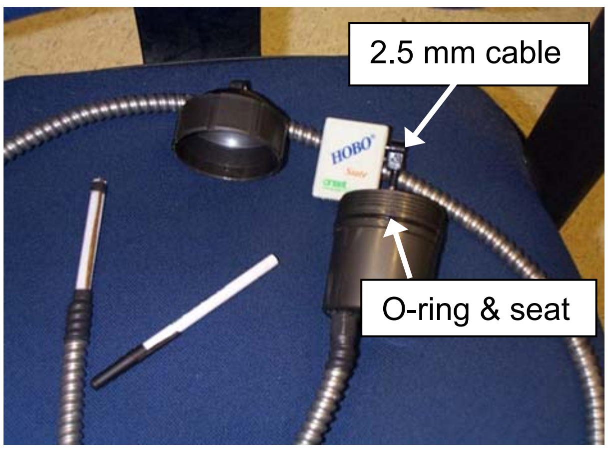

Figure 3-5 Water sensor with 2.5 mm cable, O-ring and seat shown.

Select a location within the channel thalweg that is the approximate average water depth of the thalweg for the entire 30 m reach. Where available, select a location that also has a steep bank; this will help to keep the data logger end of the water sensor dry during high flows. Use a small sledge hammer to drive a section of rebar or a stake into the stream bed. Make certain that the rebar is firmly embedded.

Select a water sensor with the appropriate encased cable length to extend from the streambed stake to a safe bank location. Assemble a stilling well by attaching PVC pipe to a PVC cap (Figure. 3-6). Three to four holes should be drilled into the bottom of the cap to allow the water level within the stilling well to fluctuate with the stream water level (Figure. 3-6). This stilling well will prevent false readings associated with debris accumulating on the contact wires. The bottom of the stilling well is positioned so it is flush with the stream bed. An O-ring (#10, ½" inner diameter) may be used to seal out rain from the stilling well opening around the flexible cable housing. Place the contact end of the sensor inside the stilling well so that the contact wires are a few millimeters above the PVC cap.

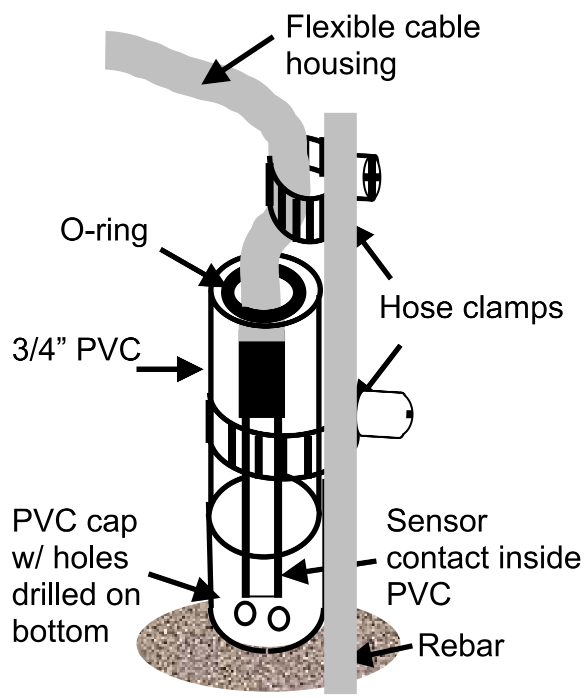

Figure 3-6 Schematic showing assembly of stilling well and contact end of water sensor.

Attach the contact end of the water sensor to the stake with 2 hose clamps or cable ties (above and around stilling well), making certain that they are tight (Figure 3-7). Extend the water sensor cable laterally to the bank, allowing the cable to conform to the contour of the channel and bank. Insert the second piece of rebar or stake by pounding it into the soil adjacent to the stream channel, making certain that it is firmly embedded.

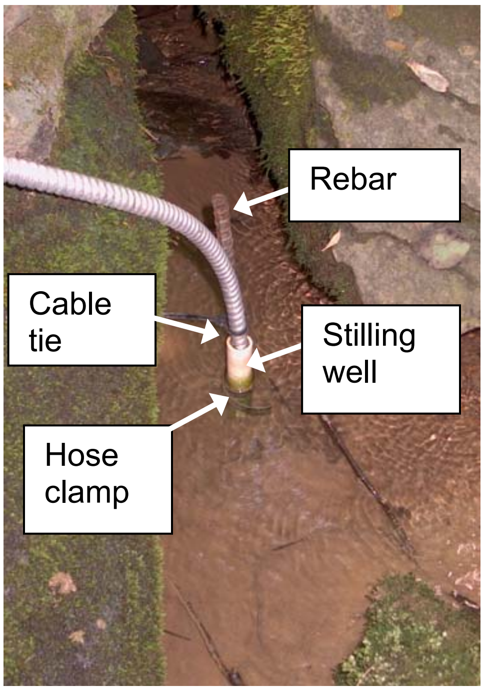

Figure 3-7 Water sensor securely attached to rebar above and below stilling well.

Attach the data logger end of the water sensor to the rebar with 2 cable ties. Gently place large cobble on top of cable to stabilize and camouflage the water sensor (Figure 3-8).

Unscrew the cap of the submersible case and note which light is blinking. Where the contact end is submersed in water the green LED ("closed" or "wet" state) should be blinking. If the contact end is not submersed in water the red LED ("open" or "dry" state)

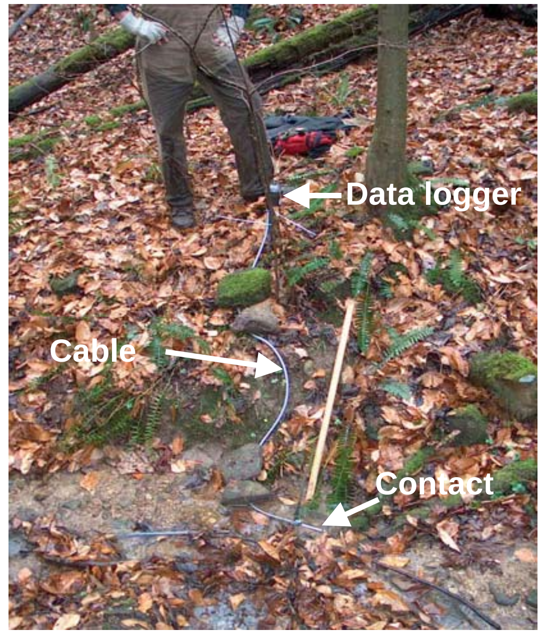

Figure 3-8 Water sensor positioned for continuous monitoring of hydrologic condition. Meter stick shown for scale.

should be blinking. If this is not occurring then check the connection of the 2.5 mm cable and jack. If this does not remedy the situation then replace the data logger or water sensor with another.

Record the data logger serial number, location, date, time, water depth (using a meter stick) and hydrologic condition for each sensor deployed. The predominant hydrologic condition of the study reach is categorized as: 1) visible surface flow continuous, 2) visible flow interstitial, 3) surface water present but no visible flow, 4) surface water in pools only and 5) no surface water.

3.2.3 Retrieval of the water sensor

Using the field sheets or notebook completed during deployment, return to the study reach within 1 year after the water sensor was installed. For each water sensor retrieved record the data logger serial number, location, date, time, water depth (using a meter stick) and hydrologic condition. Remove the rebar and water sensor from the water. Use clippers to cut the cable ties to disconnect rebar pieces from the data logger and contact ends.

3.2.4 Transferring data
Remove data logger from submersible case and connect PC interface cable to 3.5 mm jack on data logger. Open the Onset Boxcar® program and either select "readout" from the Logger menu or select the icon for readout on the tool bar. You will then be asked to save the logger datafile (*.dtf). The serial number of the data logger and year should be used to name the file. For example, if the data logger serial number is 682537 and data were collected from 15 April to 23 September 2004 then the file is named "682537_04.dtf". This will be a unique file name that can then be linked to field sheets or notebook for further site description. These files can then be saved within folders representing each stream.

From the File menu select "export" and the desired spreadsheet program (e.g., Microsoft Excel®, Lotus 1-2-3). You will then be asked to save the text file (*.txt). Use the same name given to the *.dtf file, but with the *.txt suffix.

Open the spreadsheet program and open a file containing water sensor data. The Text Import Wizard window should open. Select file type marked "delimited" and select "next". In the next window select "tab" as the delimiter and select "finish". This should then separate date + time, and hydrologic state into 2 separate columns. The number of data rows minus 1 should indicate the number of hydrologic state changes occurring over the period between launching and readout. Some of the state changes at the beginning and end of the data set may not represent the hydrologic changes at the study site. Using the date, time and hydrologic condition data from field sheets or notebook, the actual starting and ending time is entered into the columns. When entering the starting and ending date and time, enter each into the spreadsheet as single cells with a space between the date and time. For example, if the water sensor was actually deployed at 1:24 pm on 15 April, enter the date & time as follows: 4/15/03 1:24 PM. Then highlight the cell and change its cell format to the "custom" category and the "mm:ss.0" type. Be sure to also enter the hydrologic state ("wet" or "dry") for the starting and ending periods in the appropriate column. Below the cell that identifies the data logger serial number, enter the site name including stream name and site number.

To calculate the number of hours (duration) that had occurred between each state change use the following function in the column adjacent to the column containing hydrologic state labels. Type "= (A4-A5)*24. This example subtracts the date+time in cell A5 from a previous date+time in cell A4. Continue this down the column until the all durations are calculated. These can then be easily converted from hours to days by dividing the number of hours by 24. The total duration of dry or wetted condition can then be determined by summing every other cell within the column.

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Equipment and supplies

Water sensor
Field notebook or field forms
Pencil
Map of area
Metal stakes or rebar (2 per sensor)
Mallet or small sledge hammer
Watch
Hose clamps or cable ties (4 per sensor)
Personal computer (PC) with operating system that can support data logger software
Onset software Boxcar® 3.0+ or any version of Boxcar® Pro
PC interface cable (w/ 3.5 mm jack and serial port)
Submersible case kit (rubber O-ring, 2 dessicant packs, and tube of silicone compound)
Global Positioning System (GPS) unit
Meter stick

3.3 Identifying the channel head

General

This subsection provides instructions for identifying and recording the location of the channel head or channel origin of streams. Headwater streams link valley hillslopes to downstream water bodies through the downstream transfer of sediment and organic matter (Gomi et al. 2002, Hutchens and Wallace 2002). The channel head or origin is the upstream boundary between hillslopes and channels in the landscape, specifically between the valley head and channel. Characteristics of the surrounding valley (e.g., slope, geology and land use) determine the evolution of channels and therefore the location of channel heads (Dietrich and Dunne 1993, Montgomery 1999). The channel head rarely extends to the valley divide, so the valley network envelopes the channel network. Swales, hollows, and zero-order basins are other names used to describe hillslope landforms that drain into channel heads. These are located upslope from channel heads (Dietrich and Dunne 1993). The transition from hillslope to channel may be abrupt, in the form of headcut or step, or gradual (Figure 3-9). The channels emerging from zero-order basins have been called transitional channels and are often ephemeral or intermittent (Gomi et al. 2002).

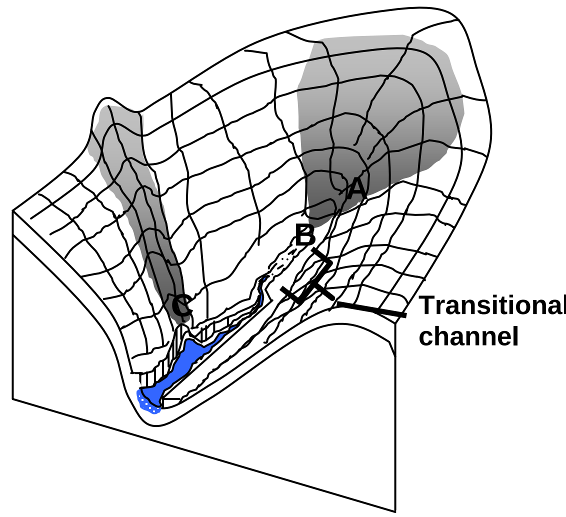

Figure 3-9 Drawing showing a valley hillslope (swale or hollow) relative to channel. Valley head (A), gradual (B) and abrupt (C) channel heads are identified. Gray areas indicate zero-order basins draining into channel heads. Redrawn from Dietrich and Dunne (1993).

The following procedure will provide field characteristics that can be used regardless of hydrologic status of a site. The observation of surface flow may not be the best indicator when defining whether a landform is or is not a channel. Surface runoff (Horton overland flow) and throughflow-return flow may be apparent on hillslopes, and are thus, not restricted by channel formation (Fetter 1988, Dietrich and Dunne 1993). Additionally, the distribution of surface flow in stream networks expands and contracts with water table fluctuations (Blythe and Rodda 1973, Stanley et al. 1997). Hydrologic permanence at the channel head may be dependent upon underlying geology and connectivity to groundwater. Springs or seeps originating from contact zones, faults, joints and fractures in the underlying geology can coincide with and/or control channel head location (Higgins and Coates 1990). The flow of these springs may be continuous or discontinuous over time.

The resolution of most topographic maps is too low to reveal the extent of headwater channels (e.g., Hansen 2001). Therefore, the terminations of blue lines (e.g. on USGS 1:24 000 quads) do not accurately represent channel heads (Mark 1983). Typically channel heads are located upslope from blue line terminations, extending into the contour line crenulations (see Figure 2-2).

The location of the channel head is recorded once for a given stream during the study because it is unlikely to change significantly over the timeframe of most monitoring studies (1-2 years). However, channel head location can shift depending upon characteristics of the surrounding hillslope (e.g., gradient, soil cohesiveness, land use) and stochastic events (e.g., mass failures). The channel head is a particularly sensitive feature in arid and semi-arid landscapes, where gully erosion caused by unstable channel heads is a serious socio-economic and environmental problem (Bull and Kirkby 2002). Infilling by debris flows and landslides can move the channel head downslope, whereas gullying or headcutting moves the channel head upslope (Benda and Dunne 1987, Miller et al. 2003). Therefore, over long time frames (10s to 100s of years), the position of the channel head may fluctuate in response to these processes.

Procedure

Hike the channel upstream of the "ephemeral" or upstream-most study reach (see Section 2.1 for description of study reach selection). You should focus on characteristics of the streambed and banks relative to the adjacent hillslope. The phrase "definable bed and banks" is often used to determine if a land form is a stream channel. Problematically, this phrase is not easily defined in objective terms although along larger streams and rivers it is visibly obvious. A channel is a landform that conveys water and sediment between banks. Banks are relatively narrow zones that have steeper gradients than adjacent hillslopes and the transverse slope of the channel bed (Dietrich and Dunne 1993).

Characteristics of abrupt channel heads

Abrupt channel heads appear as steep vertical steps from the valley head down to the channel (Figure 3-10). These abrupt steps are also known as "knickpoints" or "headcuts". No evidence of bank or channel forms is usually visible above abrupt channel heads.

Figure 3-10 An abrupt channel head in Wayne National Forest, OH.

Thus, the abrupt channel head represents a distinct start of continuous streambed and banks in the downstream direction. These abrupt changes often correspond to differences in surface sediment between the valley head and channel. Surface sediments above the valley head will be of colluvial origin (e.g., transported by gravity from adjacent hillslopes) and/or have soil nature (e.g., humus layer). In contrast surface sediment in the channel will be of a mixture of recently deposited colluvium and weathered material exposed from surface flow (e.g., bedrock and boulders). Vegetation type and density may also differ up- and downslope of the channel head. Terrestrial vegetation may be sparse or absent in the channel below the channel head compared to the upstream valley head. Be aware that steep vertical steps and headcuts are not restricted to channel heads and may occur within continuous channels. In this case, definable bed and banks are clearly evident upstream of the headcut (see Section 3.4). Record coordinates (latitude & longitude) and description of the hydrologic condition at the channel head in the Notes section for the datasheet of the nearest study reach.

Characteristics of gradual channel heads
Gradual channel heads are less distinct than abrupt channel heads. These are characterized by a more gradual or discontinuous transition in bank and bed features, rather than the obvious boundary of a step or headcut. As you approach the channel head, the height and angle of the banks decline. The defined bed and banks are often discontinuous and may be interrupted by debris dams, tree roots, or bedrock outcropping. For the purposes of this study, we define the channel head as the point where the channel no longer has continuous defined bed and banks. Be aware that steep channels can have a step-pool or cascade structure and appear less continuous than riffle-pool reaches (Church 1992). Banks typically are less well defined at the "steps" compared with "pools" in these streams. However, the channels should be considered continuous if the steps are composed of visibly eroded material exposed from surface flow (e.g., bedrock and boulder) that may or may not be covered with moss and organic debris piles (Figure 3-11).

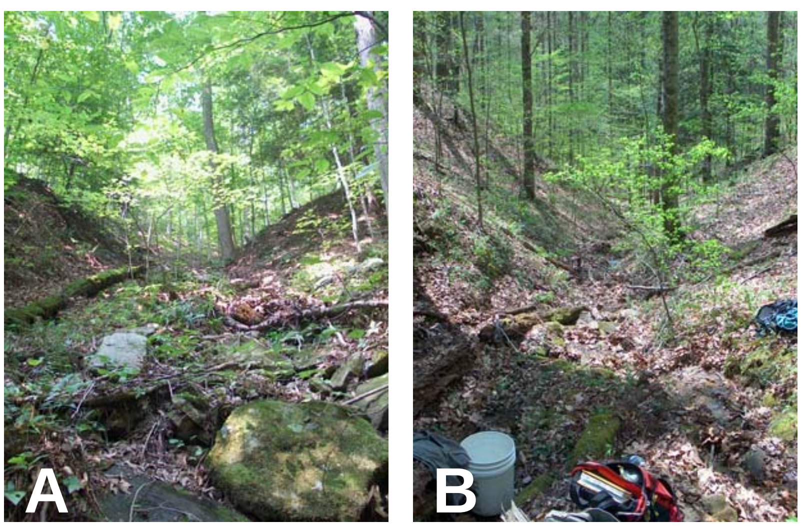

Figure 3-11 Views from gradual channel heads in east-central Kentucky. A) Looking upslope toward the valley head from the channel head position. B) Looking downslope at the cascade structure of the transitional channel.

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Equipment and supplies

GPS unit
Topographic map
Field forms

3.4 Identifying channel headcuts

General

This section provides instructions for the identification of channel headcuts in headwater streams. Headcuts are abrupt changes in streambed elevation (i.e., knickpoint) that migrate in an upstream direction (Leopold et al. 1964). This migration is a natural geomorphic process that is often accelerated due to human modification of the channel and/or surrounding watershed (Patrick et al. 1994, Montgomery 1999). The upstream migration of headcuts results in downcutting (i.e., degradation) of the streambed and incised channel morphology (Galay 1983, Simon 1989). Among the ecological effects downstream of headcuts may be loss of streamside vegetation, scoured streambeds, decreased sinuosity, and temporary increase in downstream sedimentation (Patrick et al. 1994). Headcuts can also influence the connectivity along headwater streams by steep changes in streambed elevation and hydrology. Abrupt changes in summer baseflow hydrology (and water temperature) occur at headcuts and are related to differences in distance from the groundwater table. As the summer groundwater table lowers (lower precipitation, higher evapotranspiration), it falls below the streambed upstream of the headcut before dropping below the stream bed downstream of the headcut. This causes flow to remain for longer periods downstream (often perennially) than upstream of headcuts. The presence of headcuts is determined once for a given reach during the study because their presence is unlikely to change significantly over short time periods (e.g., 1-2 y), however any upstream advance should be noted.

Procedure

Delineate the 30-m study reach so that the measuring tape is positioned along the thalweg. Survey the study reach for abrupt changes in streambed elevation. If a knickpoint is located, determine first whether the formation is simply a natural grade control point (e.g., large boulders, bedrock outcrops, or large woody debris). If it is not, then look for the following: 1) undercutting beneath the headcut face or headwall (Figure 3-12), 2) seepage or piping from the headwall, and 3) alluvial fan or deposits in the channel downstream of the headcut. Be aware that headcuts may stall their upstream migration at grade control features between large floods.

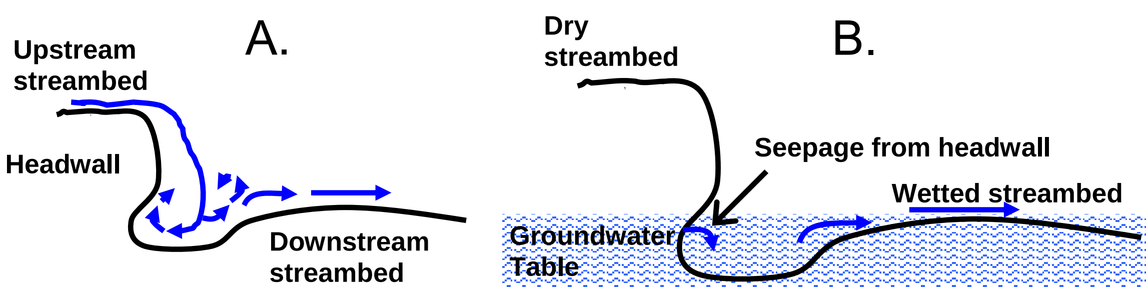

Figure 3-12 Longitudinal view of a headcut, (A.) Blue arrows illustrate flowpaths that lead to undercutting, failure of the headwall, and eventually upstream migration of the headcut; (B.) Abrupt change in summer baseflow hydrology at a headcut.

Indicate on the field form (Figure. 3-13) the presence or absence of a headcut within the study reach. Note location of headcut on study reach drawing and make notes characterizing the formation. Photographs of headwater streams with headcut formations are shown in Figures 3-14, 3-15 and 3-16.

PRESENCE OF HEADCUT IN REACH	ALGAL COVER INDEX	# CORES FOR SUBSTRATE MOISTURE (depositional)
Y N	1 $1^{1/2}$ 2 3 4 5	

Figure 3-13 Portion of page 1 of field forms showing the cell for recording presence of channel headcuts.

Figure 3-14 Subtle headcut in Falling Rock Creek in east-central KY (looking upstream).

Figure 3-15 Huge headcut (~2 m change in bed elevation) in an unnamed stream in Athens, GA (looking upstream).

Figure 3-16 Headcut in Taylor Branch in south-central IN (looking downstream), where streambed elevation at the arrow was ~ 1 m higher than streambed below headcut at the yellow circle.

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Equipment and supplies

Measuring tape

Field form

3.5 Measuring channel sinuosity

General

This section provides instructions for rapidly scoring channel sinuosity of headwater streams. This procedure is similar to that used by the Ohio Environmental Protection Agency (Ohio EPA 2002), where sinuosity is described as the number of well-defined bends or meanders over a distance of stream channel. This differs from the more quantitative measure, sinuosity index, which is the ratio of the channel thalweg distance to the downvalley distance (Gordon et al. 1992, Platts et al. 1983, Rosgen 1996). In association with other measures (e.g., channel slope, substrate particle size), sinuosity provides useful information regarding the degree of channel modification to headwater streams. Retention of nutrients and organic matter increases with increasing sinuosity, ensuring transformations that may be beneficial for downstream waters (e.g., Gücker and Boëchat 2004, Muotka and Laasonen 2002). Sinuosity is measured once for a given reach during the study because it is unlikely to change significantly over short time periods (e.g., 1–2 years).

Procedure

Delineate the 30-m study reach so the Measuring tape is positioned along the thalweg. Sinuosity is based on the number of well-defined bends over the 30-m study reach (approximately 20X the bankfull width of most headwater streams). Examples showing various degrees of sinuosity are shown in Figure 3-17. On the first page of the field form indicate the sinuosity in the appropriate cell (Figure 3-18).

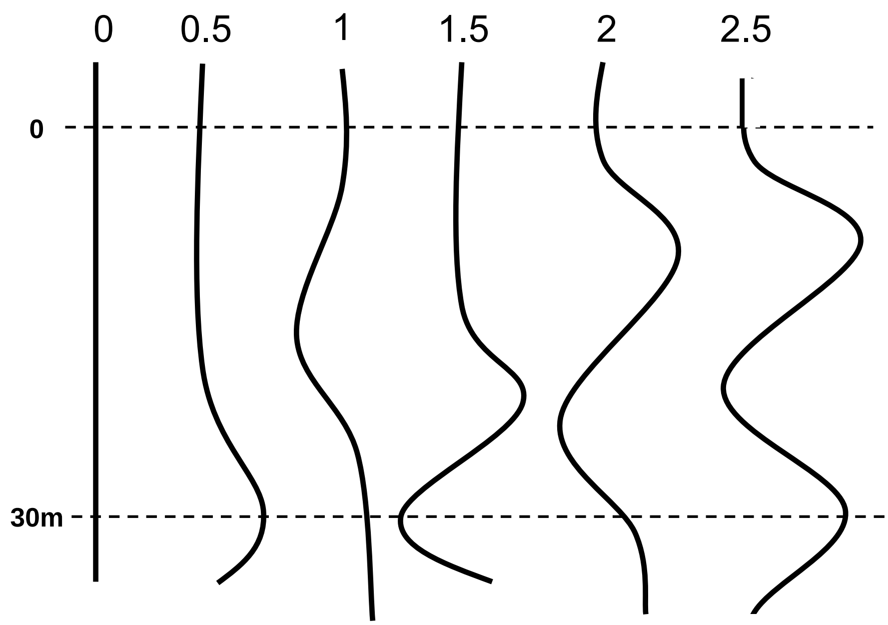

Figure 3-17 Examples of stream channels varying in sinuosity (number of bends) along 30-m study reaches.

MAX. POOL DEPTH (cm)	DEPTH TO BEDROCK / GROUNDWATER (m) (3 measures in depositional habitat)			SINUOSITY (number of bends)

Figure 3-18 Portion of page 1 of field forms showing the cell for recording channel sinuosity.

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Equipment and supplies
Measuring tape
Field forms

3.6 Designating habitat units

General

This subsection provides instructions for identifying habitat or channel units within headwater stream reaches. Habitat units (or "meso-habitats") are distinct channel units having characteristic physical properties. They are smaller than stream reaches and larger than microhabitats, according to the hierarchical levels used to describe the physical template of streams (Frissell et al. 1986). Within headwater streams with moderate to high gradient (slope ≥ 2 %), habitat units can range from <1 to 10 m in linear stream length (K. M. Fritz, personal observation). Habitat units in sandy, low-gradient or bedrock-dominated channels may be > 10 m long. These units are found longitudinally along the channel and may be spaced at fairly regular intervals along a stream reach (Leopold et al. 1964, Beschta and Platts 1986). Habitat units are delimited by elevational and lateral changes of the streambed (Hawkins et al. 1993). This is particularly evident in streams where the streambed particles are not primarily sand or silt (Leopold et al. 1964). Associated with these distinct channel units are characteristic water flow and depth regimes. Therefore, physical variation within a study reach can be accounted by the proportions of these habitat types. In many instances these characteristics lead to differences in the dominant streambed particle sizes among types of habitat units.

Assessment and restoration of streams are typically limited to the reach scale. However, for logistical reasons, biological communities are often sampled at spatial scales below the reach level (Cuffney et al. 1993, Lazorchak et al. 1998, Barbour et al. 1999), often stratified by habitat type. Inter-habitat variability in ecological measures can exceed variation seen among reaches or streams (e.g., Angradi 1996, Rabeni et al. 2002). Therefore, quantifying the extent of habitat types within stream reaches is fundamental to understanding the ecological status of water resources at larger spatial scales, not because of the inherent measurement of habitat units (Poole et al. 1997) but to put other measures in context for comparison.

The number of the physical parameters needed for designating habitat types increases as classification become more complex. The utility of a complex classification becomes limited because the variety of habitat types that can be identified within stream reaches can vary greatly among regions. To be useful, the categories of habitat type need to be applicable for all reaches examined in a study. In addition, as the specificity of habitat types increases there is typically a greater level of subjectivity involved in their designation (Roper and Scarnecchia 1995). The following procedure provides guidance to delimit the most basic categories of habitats within headwater streams (see Hawkins et al. 1993 and Lazorchak et al. 1998 for descriptions of finer levels of habitat types). These include erosional and depositional habitats (Moon 1939). Erosional habitats are identified as shallow areas with rapid flow and typically coarse streambed substrate. They include such habitats as riffles, fast runs, sheets, cascades and steps (in step-pool reaches). In contrast, depositional habitats are deeper areas with little or no visible flow and typically have fine streambed substrates but may also be bedrock. They include such habitats as pools and slow runs. Because water flow and depth are primary parameters used to designate habitat type and these can vary seasonally, this procedure should be carried out during each sampling period.

Procedure

Delineate the 30-m study reach so that the measuring tape is marking transects along the thalweg from downstream to upstream. At each meter mark along the thalweg of the study reach (0, 1, 2,…30m) assess water flow, water depth and substrate type to designate whether the habitat is erosional or depositional. The dotted line represents the study reach thalweg and the black arrow is pointing in the direction of flow in Figure 3-19.

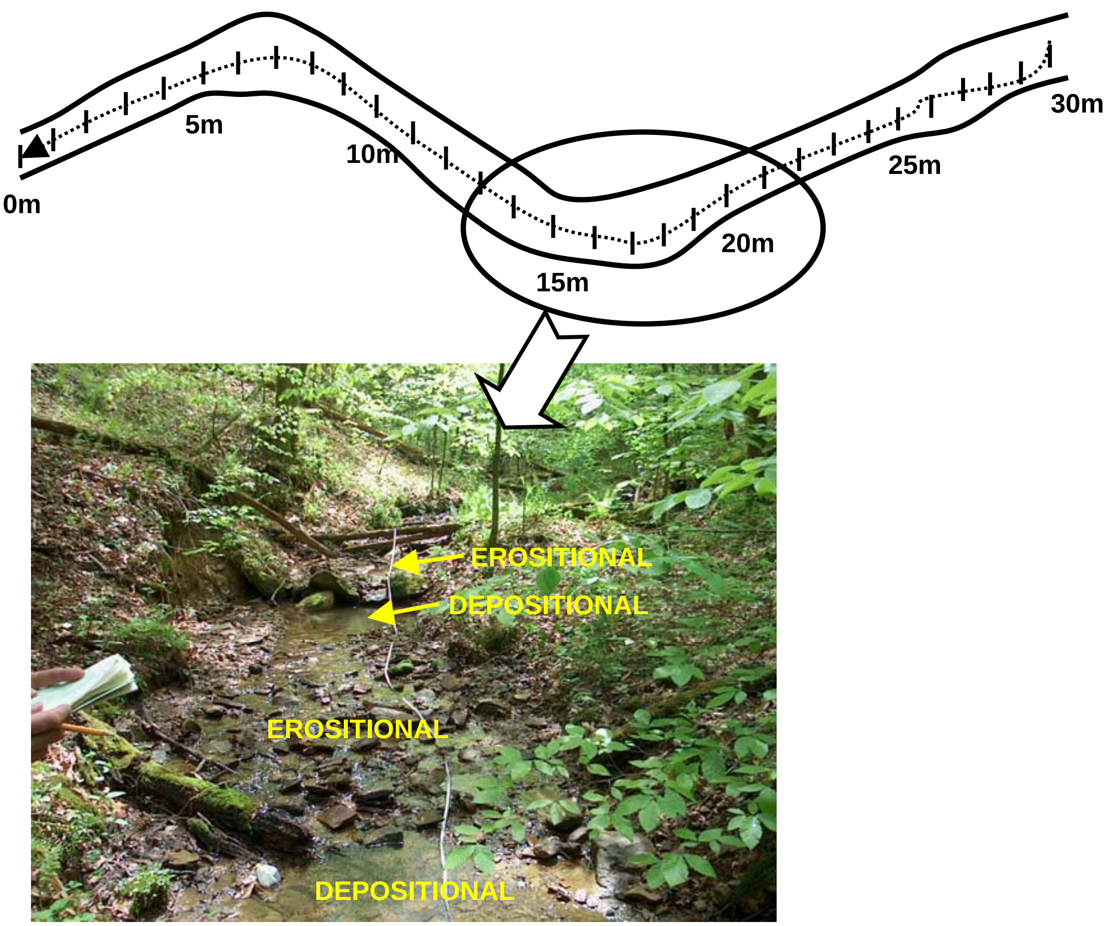

Figure 3-19 Plan view of study reach (top) and picture showing series of alternating erosional and depositional habitats along a headwater stream.

On the second page of the field form mark the habitat type for each transect (Figure 3-20). There is also a column on the field form for notes concerning the presence of large woody debris (LWD, diameter ≥ 10 cm), leaf packs, bryophytes, herbaceous vegetation, etc. within the thalweg at that meter mark (Figure 3-20).

The designation of habitat type relies more on the streambed characteristics where the stream is dry. Substrate size, streambed elevation and the distribution of organic matter are useful in determining habitat type at locations along dry channels.

*** MEASURES TAKEN IN THALWEG § Where FPA Width > 2.2X BF Width then indicate: >2.2BF Page 2 of 4**

Meter #	Modal Sediment Particle Size (mm) *	Water Depth (cm)*	Habitat Type (E/D)	Notes (e.g., LWD, Leafpack)	Velocity (m/s)*	Wetted Width (m)	BF Width (m)	BF Depth (m) *	FPA width (m) §
0			E	Leafpack					
1			E						
2			D	LWD					
3			D						

Figure 3-20 Appropriate location for recording habitat units and notes on Page 2 of the Field Forms.

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Equipment and supplies

Measuring tape
Field forms

3.7 Measuring channel slope

General

The following subsection provides methods for measuring channel slope or gradient in headwater streams. Channel slope is the drop in elevation per unit length of channel ("rise-over-run", Figure 3-21). Slope is an important variable because it determines the velocity, stream power, and tractive forces which shape channel morphology and control export of sediment and organic matter. Measurement of slope can range in spatial scale, generally losing resolution with increasing spatial extent. Slope can be determined either at the streambed or water surface. The following procedure describes the estimation of slope for the streambed along the study reach thalweg. Slope is measured once for a given reach during the study because it is unlikely to change significantly over short time periods (e.g., 1–2 years). This procedure will require 1–2 field crew members to perform depending on the method chosen.

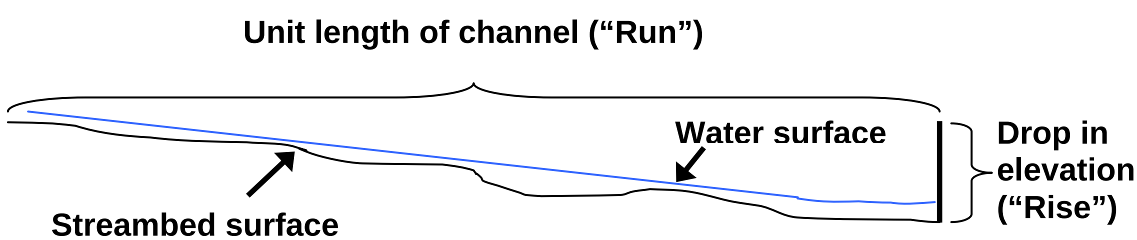

Figure 3-21 Longitudinal section of channel.

Procedure

Delineate the 30-m study reach so that a measuring tape is marking locations along the thalweg. Slope is measured at 10-m intervals (at 0-10, 10-20, and 20-30 m marks) along the study reach (Figure 3-22).

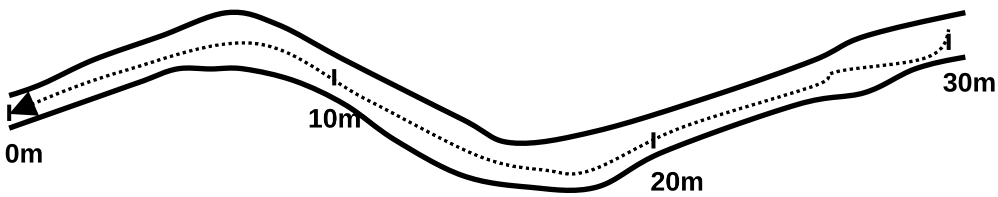

Figure 3-22 Plan view of study reach showing measurement locations (vertical black tick marks) for channel slope. Flow is from right to left and the dotted line represents the thalweg.

3.7.1 Measuring slope with a clinometer and stadia rod

The procedure requires one person holding the stadia rod and another person ("viewer") viewing the stadia rod through the clinometer. While standing on level ground, mark the stadia rod at the viewer's eye level with brightly colored flagging. This will be the target for the viewer when measuring slope. Make sure the viewer's posture is the same (stand-up straight and flat footed) when marking the stadia rod and when taking measurements. Alternatively, the clinometer may be positioned at a set height (top of meter stick or hiking pole), rather than held by an observer. The target height on stadia rod would then be flagged at the same set height.

The viewer stands at the 0-m mark in the thalweg, whereas the person holding the stadia rod stands at the 10-m mark in the thalweg (Figure 3-23). The stadia rod should be held perpendicular to the streambed at the 10-m mark. To standardize for differences in thalweg depth the viewer and the stadia rod should be positioned at the same water depth (e.g., level with surface of water; see Kaufmann and Robison 1998). However, this difference is often negligible when all three slope measurements along the reach are averaged.

The viewer looks through the clinometer with one eye and at the stadia rod with the other

Figure 3-23 Crew members measuring slope of intermittent stream.

eye. Allow the images to appear to be superimposed on each other and position the horizontal center line of the clinometer level with the marking on the stadia rod (Figure 3-24). Avoid covering side window of clinometer with your hand while viewing. This window allows light through, enabling you to read values. There are two scales along the measurement wheel: degrees and percentages. The percentage scale is on the right side of the measurement wheel of most clinometers. Tip your head up while viewing through the clinometer to see unit markings (e.g., %) and determine which side is the percentage scale. Slope measurements are recorded in percentages (to the nearest 0.5%) on the datasheet (Figure 3-25). Repeat the procedure for 10-20 and 20-30 m intervals along the reach thalweg.

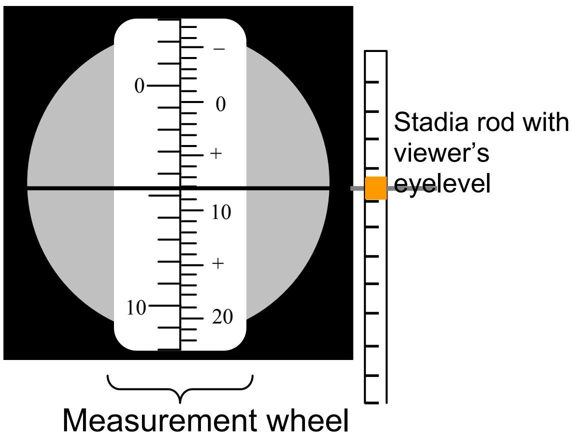

Figure 3-24 Superimposed views through clinometer and at stadia rod. Example shows percent scale on right side and degrees scale on left side of measurement wheel.

CHANNEL SLOPE (%) (for three 10 m sections of study reach)		
4.5	**10**	**8**

Figure 3-25 Portion of page 1 of field forms showing cells for percent slope values.

Conversion between percent and degrees can be done using:

$$\text{degree slope} = \tan^{-1}(\text{percent slope} / 100)$$
$$\text{percent slope} = (\tan(\text{degree slope})) \times 100$$

Modifications to the procedure can accommodate the use of alternatives to a clinometer for measuring slope (e.g., Abney level, theodolite, total station; see Gordon et al. 1992). This procedure can be modified to measure water slope by simply accounting for differences in water depth (or ensuring equal water depth) at the stadia rod and where the viewer is standing.

3.7.2 Hydrostatic (manometer) measurement of slope

Position stakes at the 0 and 10-m marks along the thalweg. Fill vinyl tube with water and ensure no air bubbles are trapped. Attach the ends of the vinyl tubing to the stakes and position the tubing along the thalweg of the streambed (Figure 3-26). Allow water level within the vinyl tubing to equilibrate. Using the meter stick, measure (in meters) the distance between the streambed and the water level (bottom of meniscus) within the vinyl tubing at both ends. Streambed slope (%) is $((h_2 - h_1) / L) \times 100$, where L = 10 m. Slope measurements are recorded in percentages on the datasheet (Figure 3-25). Repeat the procedure for 10-20 and 20-30-m intervals along the reach thalweg. An alternative to using rebar and clamps to hold the manometer in place is to have two people hold the ends of the manometer against meter sticks while taking measurements of h_1 and h_2.

An advantage of this procedure is that it can be done without a clear line of view along the reach and it is more accurate than the clinometer method. A disadvantage is that water must be available for the manometer. Water slope can be determined by measuring the distance between the water level within the tube and the water surface (rather than the streambed surface) at both ends.

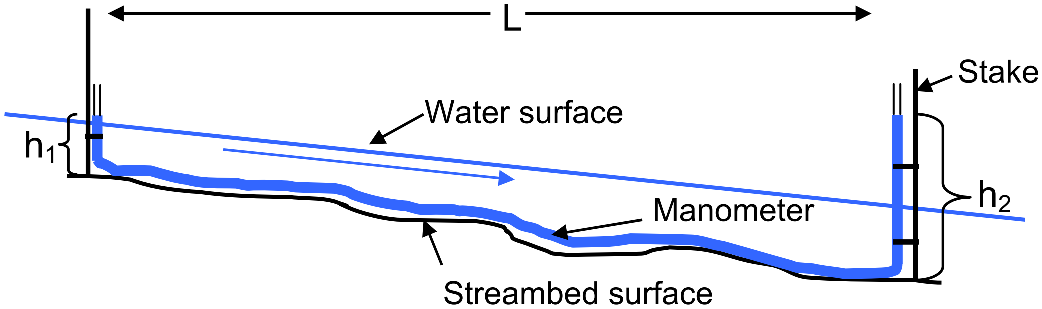

Figure 3-26 Longitudinal section of channel showing position of manometer and points of measurement to calculate slope (redrawn fro Gordan et al. 1992). Blue arrow shows direction of flow. L = horizontal length, h_1 = height at the upstream end and h_2 = height at downstream end.

References

Gordon, N.D., T.A. McMahon, and B.L. Finlayson. 1992. *Stream Hydrology: An Introduction for Ecologists*. John Wiley & Sons, Chichester, United Kingdom.

Kaufmann, P. R. and E. G. Robison. 1998. Physical habitat characterization. Pages 77-118 *in* J.M. Lazorchak, D.J. Klemm, and D.V. Peck (editors). *Environmental Monitoring and Assessment Program – Surface Waters: Field Operations and Methods for Measuring the Ecological Condition of Wadeable Streams*. EPA/620/R-94/004F. U.S. Environmental Protection Agency, Washington, D.C., USA.

Equipment and supplies
Measuring tape (50 m)
Field forms
A or B
A. Stadia rod and clinometer – See Procedure 3.7.1
B. Manometer (clear vinyl tubing, >10 m in length and ~10mm inner diameter), 2 survey stakes or pieces of rebar, hose clamps, and meter stick – See Procedure 3.7.2

3.8 Measuring water depth

General
This subsection provides instructions for measuring water depth (including maximum) for reaches of headwater streams. Along with wetted width (next section), water depth is a critical measure of the extent of wetted habitat available and a measure of water persistence or susceptibility to terrestrial predators. Water depth is therefore important in governing the distribution of biota in headwater streams (e.g., Harvey and Stewart 1991, Taylor 1997). Because water depth can vary considerably over time, this procedure should be carried out during each sampling visit.

Procedure
3.8.1 Longitudinal thalweg measurements
A total of 31 measurements of water depth are taken along each study reach (Figure 3-27). Water depth is measured at the center of the thalweg (illustrated as dotted line in Figure 3-27) at meter intervals (i.e., 0, 1, 2…30 m).

The meter stick is positioned with zero-end down, side(s) with units facing perpendicular to the direction of flow and the stick held perpendicular to the water level (Figure 3-27). Water depth measurements are recorded to the nearest 0.5 cm on the field form (Figure 3-28).

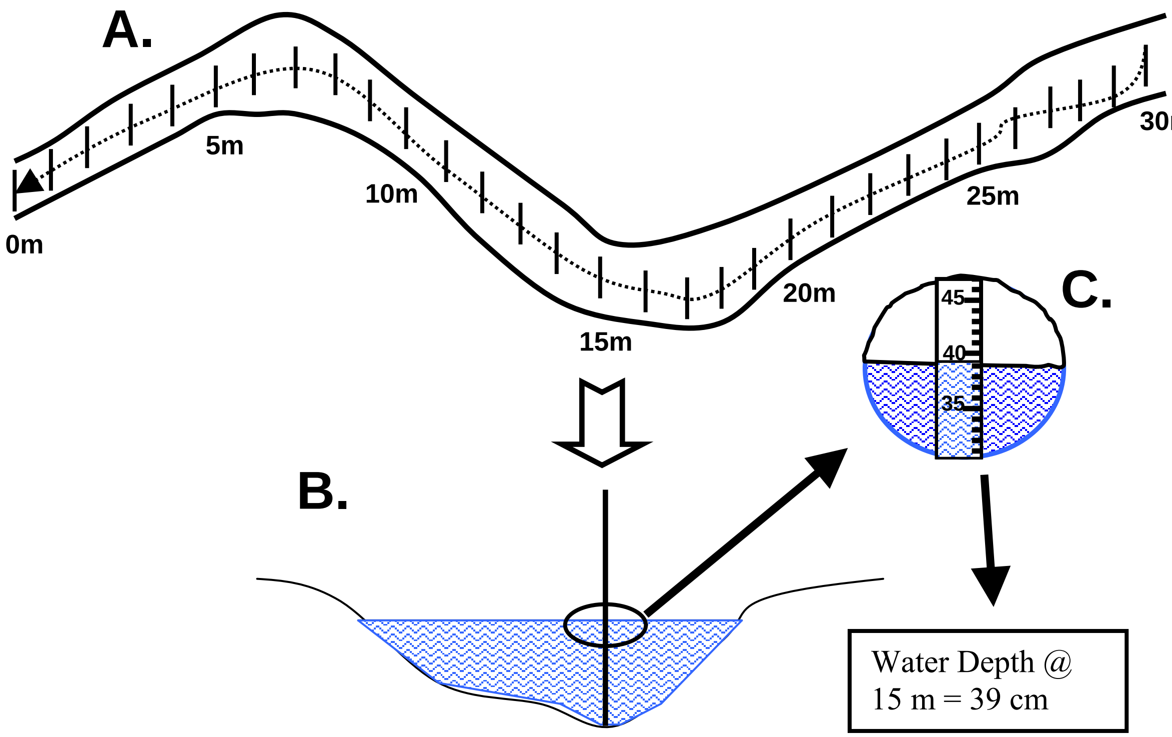

Figure 3-27 Overhead view of study reach showing locations for water depth measurement (vertical black tick marks) along the reach thalweg (dotted line). Water is flowing from right to left. (A.) overhead view of study reach (B.) channel cross-section, and (C.) lateral close-up of depth.

*** MEASURES TAKEN IN THALWEG § Where FPA Width > 2.2X BF Width then indicate: >2.2BF Page 2 of 4**

Meter #	Modal Sediment Particle Size (mm) *	Water Depth (cm)*	Habitat Type (E/D)	Notes (e.g., LWD, Leafpack)	Velocity (m/s)*	Wetted Width (m)	BF Width (m)	BF Depth (m) *	FPA width (m) §
0		22							
1		18							
2		5.5							
3		1							
4		2.5							
5		3							
6		50							
7		30							
8		35.5							
9		0							
10		0							
11		3							
12		34							
13		12							
14		8							
15		**39**							

Figure 3-28 Appropriate location for recording longitudinal water depth measurements on page 2 of the field forms.

The water level on the meter stick is usually not perpendicular to the unit markings where the water velocity is fast (Figure. 3-29). Measurements should be taken at the middle of the meter stick, rather than at the upstream or downstream-facing edges. Where there is no surface water present, zero water depth is recorded. Where there is surface water present, but it is less than 0.5 cm deep, "< 0.5 cm" should be recorded.

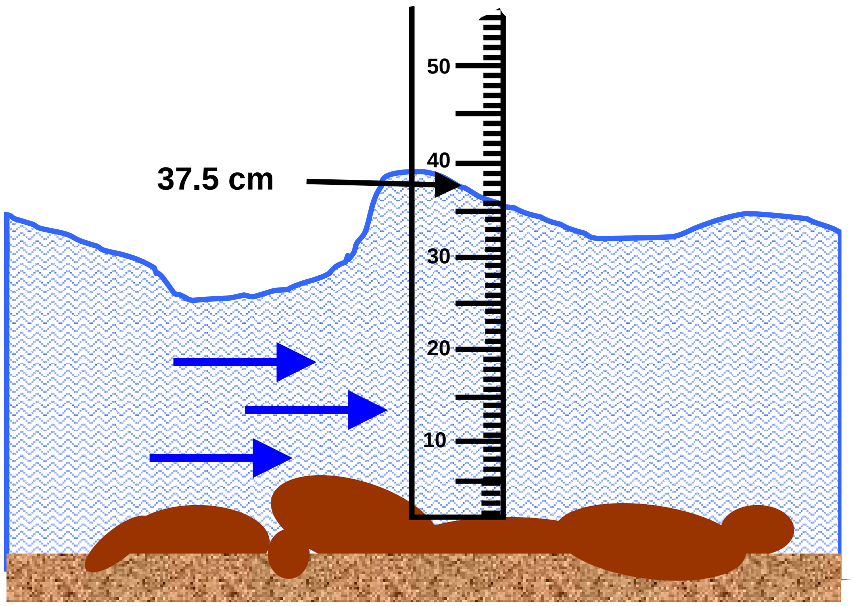

Figure 3-29 Schematic showing appropriate reading of water depth where water surface is turbulent.

3.8.2 Maximum water depth in study reach
A single measurement is recorded for the greatest water depth within the study reach. This measurement is not restricted to the 31 (1-m interval) thalweg measurements. Maximum water depth is recorded to the nearest 0.5 cm on the field form (Figure 3-30).

MAX. POOL DEPTH (cm)	DEPTH TO BEDROCK / GROUNDWATER (m) (3 measures in depositional habitat)			SINUOSITY (number of bends)
54				

Figure 3-30 Appropriate location for recording maximum pool depth measurement on page 1 of the field forms.

References

Harvey, B.C. and A.J. Stewart. 1991. Fish size and habitat depth relationships in headwater streams. *Oecologia* 87:336-342.

Taylor, C. M. 1997. Fish species richness and incidence patterns in isolated and connected stream pools: effects of pool volume and spatial position. *Oecologia* 110:560-566.

Equipment and supplies

Meter stick (with at least 0.5cm increments)
Measuring tape (50m)
Field forms

3.9 Measuring wetted width

General

This subsection provides instructions for measuring wetted width in headwater streams. Wetted width (or top width) is the stream width at the surface water level (Figure 3-31) and is perpendicular to the channel direction. This measure (and water depth) describes the extent of surface water habitat available within a study reach. Because wetted width can vary considerably over time, this procedure should be carried out during each sampling period.

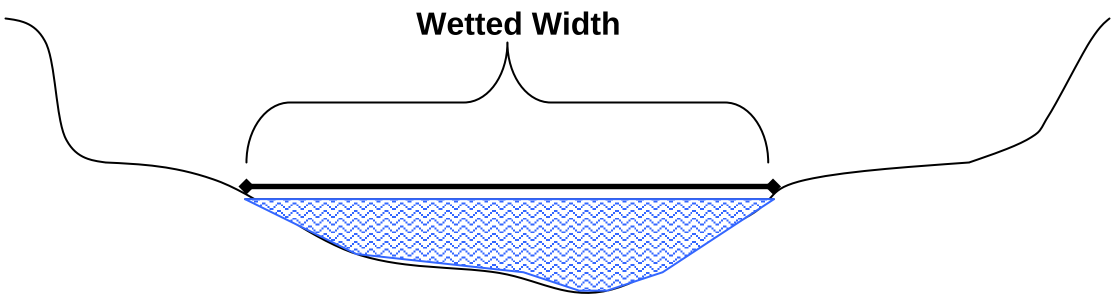

Figure 3-31 Channel cross-section illustrating wetted width.

Procedure

Delineate the 30-m study reach so that a measuring tape is marking locations along the thalweg. Wetted width is measured at 5-m intervals (at 0, 5, 10, 15, 20, 25 and 30-m marks) along the study reach (Figure 3-32).

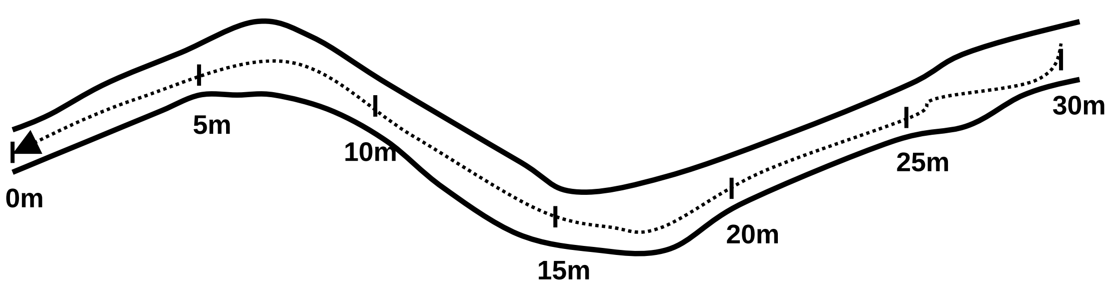

Figure 3-32 Overhead view of study reach showing measurement locations (vertical black tick marks for wetted width. Flow is from right to left and the dotted line represents the thalweg.

The meter stick can be used to measure wetted widths ≤ 1 m, whereas wider channels may require using a measuring tape (and a survey stake if done by one individual). At each location place the zero-end of the meter stick or tape at the water's edge on one side of the channel, position the measuring device perpendicular to channel direction, and determine the distance to the water's edge on the other side of the channel. Record the distance to the nearest 0.01m in the appropriate cell on the field form (Figure 3-33).

* MEASURES TAKEN IN THALWEG § Where FPA Width > 2.2X BF Width then indicate: >2.2BF Page 2 of 4									
Meter #	Modal Sediment Particle Size (mm) *	Water Depth (cm)*	Habitat Type (E/D)	Notes (e.g., LWD, Leafpack)	Velocity (m/s)*	Wetted Width (m)	BF Width (m)	BF Depth (m) *	FPA width (m) §
0						0.76			

Figure 3-33 Appropriate location for recording wetted width measurement on page 2 of the field forms.

If there is no surface water at a measurement location, indicate on the field form that the wetted width is 0 m. Where there are individual boulders or cobbles interrupting the surface water along the wetted width or there is visible interstitial flow (see Section 3.1), include the emergent particles in the measurement (Figure 3-34A). If there are isolated pools along the channel edge (no surface connection to main channel) or the channel is braided (where there are vegetated islands or patches of emergent substrate) do not include width of isolated side-pools and islands in the wetted width measurement (Figure.3-34B, C).

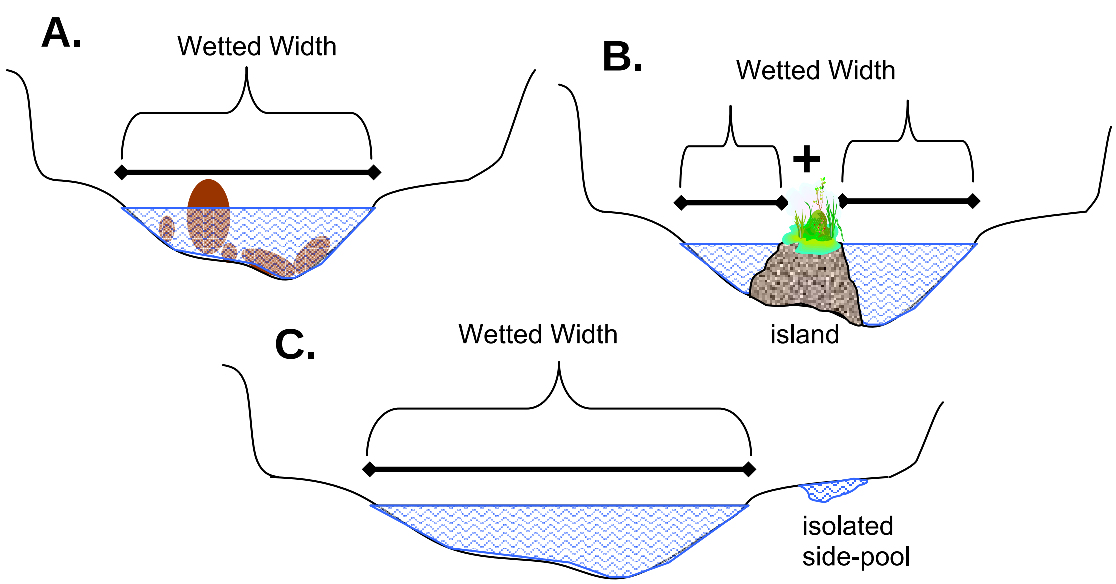

Figure 3-34 Channel cross-sections showing wetted width measurements where there is emergent cobble (A.), island (B.), and side-pool (C.).

Equipment and supplies
2 Measuring tapes (50m)
Meter stick
Survey stake (optional)
Field forms

3.10 Measuring basic channel geomorphology

General

This section provides instructions for rapidly measuring basic channel form of headwater streams. Specifically, this section provides directions for measuring three channel parameters: bankfull width, bankfull depth, and flood-prone area width. The stream channel is composed of the banks and the streambed. The banks often have steeper gradient (in cross-section) and are often composed of finer sediments than the streambed (Figure 3-35). Bankfull discharge occurs when there is sufficient flow to fill the entire channel. This level is called bankfull stage and typically occurs once every 1-2 years. Bankfull width is the horizontal distance between the banks (perpendicular to flow) at bankfull stage. Bankfull depth is the vertical distance between the streambed and the bankfull stage height at the thalweg. Flood-prone area width is the distance across the channel at a vertical level equaling 2X the bankfull depth. Entrenchment ratio is the ratio of the flood-prone area width to the bankfull width and is used to describe the degree of channel incision or "down-cutting" (Rosgen 1994, 1996). Channel dimensions vary with flow, the sediment being transported, and the material composition of the bed and banks. Channel geomorphology influences many structural and functional aspects in streams, including streambed substrates, organic matter retention, and biotic response to floods. The scouring forces of floods are dissipated on the banks to greater extent in wide, shallow channels, whereas these forces are focused on the streambed in constrained or incised

Figure 3-35 Headwater stream channel showing the location of the streambed and the banks (white arrows).

channels (Carling 1983). Geomorphology also governs the distribution of water as streams dry. Wetted widths will contract faster in wide, shallow channels than in incised channels. Wide, shallow channels may be more prone to surface water drying than incised channels because the summer groundwater table is more likely to be above the streambed (Stanley et al. 1997). However, where drying is severe, incised channels offer less interstitial refugia because the substrate layer above underlying bedrock may be thin. Habitat simplification reduces the biotic diversity directly, but also affects diversity indirectly through loss of refugia (Lake 2003).

Channel geomorphology is measured once for a given reach during the study because they are unlikely to change significantly over short time periods (e.g., 1-2 years). However, floods can significantly reshape channel geometry over short periods of time and should be taken into account when investigators need fine temporal resolution data. The following procedure will require 2-3 field crew members, depending upon the channel width.

3.10.1 Bankfull width (BF width)

Field determination of bankfull stage is particularly difficult for small channels where the floodplain may not be well-developed or may be absent. Useful indicators of bankfull stage include breaks in sediment particle size and bank vegetation. Swift and Ledford (1994) identifies the following characteristics for estimating bankfull stage in small southern Appalachian streams:

1. Topographic break from vertical bank to floodplain
2. Topographic break from steep to gentle slope
3. Top of point bar
4. Change in vegetation from temporary to permanent
5. Upper elevation of fine debris deposition
6. Rocks and/or roots exposed in banks
7. Change in size distribution of deposits
8. Change in texture of fines lodged between rocks

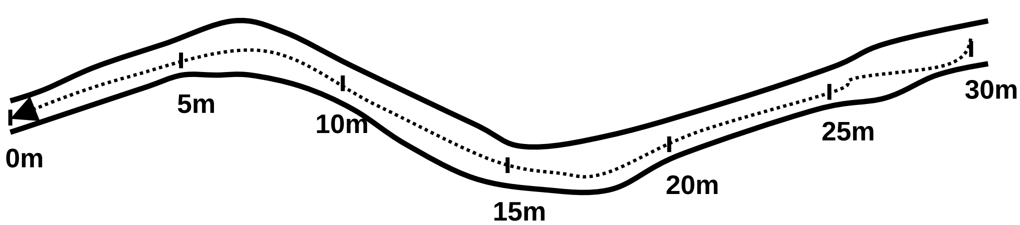

Figure 3-36 Plan view of study reach showing 5-m intervals. Direction of arrows shows direction of flow, and the dotted line represents the thalweg.

Procedure

Delineate the 30-m study reach so that a measuring tape is marking locations along the thalweg. Bankfull width and depth are measured at 5-m intervals (at 0, 5, 10, 15, 20, 25 and 30-m marks) along the study reach, whereas flood-prone area width is measured at 15-m intervals (at 0, 15, and 30-m marks; Figure 3-36). Measurements should be taken at the next meter mark (upstream or downstream) along the study reach where obstacles (e.g., large woody debris) or certain channel features (e.g., meanders, knickpoints) are present at original measurement locations

(0, 5, 10, 15, 20, 25, and 30 m). Note on the field form where measurements were taken.

It is useful to look upstream and downstream along both banks of measurement location to identify appropriate bankfull stage. When a consensus among crew members is made about the appropriate bankfull stage, the end of a measuring tape is staked at bankfull stage. The tape is pulled across the channel (perpendicular to direction of flow) to the other bank to determine bankfull width (Figure 3-37). A second crew member, standing downstream, provides instruction for adjusting the tape position so that it is horizontally level at the bankfull stage. This can be done more accurately if a laser level is used to adjust the tape position. Ensure that the tape is taut and record the distance (to the nearest 0.01 m) in the appropriate cell on the second page of the field form (Figure 3-38).

3.10.2 Bankfull depth (BF depth)

While the tape is still positioned for measuring bankfull width, a crew member uses the meter stick to measure bankfull depth (Figure 3-37). The meter stick (zero-end down) is positioned perpendicular to the tape measuring bankfull width at the center of the thalweg. Record the distance (to the nearest 0.01 m) between the

Figure 3-37 Photograph shows measurement of bankfull (BF) width and bankfull depth.

* MEASURES TAKEN IN THALWEG § Where FPA Width > 2.2X BF Width then indicate: >2.2BF Page 2 of 4									
Meter #	Modal Sediment Particle Size (mm) *	Water Depth (cm)*	Habita t Type (E/D)	Notes (e.g., LWD, Leafpack)	Velocity (m/s)*	Wetted Width (m)	BF Width (m)	BF Depth (m) *	FPA width (m) §
0							1.43	0.2	3.02

Figure 3-38 Appropriate location for recording bankfull (BF) width (red), bankfull depth (blue), and flood prone area (FPA) width (black) measurements on page 2 of the field forms.

streambed and the tape in the appropriate cell on the second page of the field form (Figure 3-38).

3.10.3 Flood-prone area (FPA) width and entrenchment ratio

At the 0, 15 and 30-m locations the crew members then locate 2X the bankfull depth and raise the tape to that level for measuring the width of the flood-prone area (FPA width, Figure 3-39). The crew member with the tape adjusts ends of the tape so that it is horizontally level and extended tautly across the channel to touch soil at both ends. Where the distance of the flood-prone area width is >2.2X the bankfull width, record ">2.2X BFW", otherwise record to the nearest 0.01 m

Figure 3-39 Photograph illustrating flood-prone area (FPA) width.

in the appropriate cell (Figure 3-38). The significance of the 2.2X bankfull width is based on Rosgen (1994, 1996) channel classification, where entrenchment ratios >2.2

(FPA ≥ 2.2X BFW) are classified as slightly entrenched (stream types C, D, or E). As was done when measuring the bankfull width, a crewmember provides instruction for adjusting the tape position so that it is horizontally level at the 2X bankfull depth. This can be done more accurately if a laser level is used to adjust the tape position.

References

Carling, P. A. 1983. Threshold of coarse sediment transport in broad and narrow natural streams. *Earth Surface Processes and Landforms* 8:1-18.

Lake, P. S. 2003. Ecological effects of perturbation by drought in flowing waters. *Freshwater Biology* 48:1161-1172.

Rosgen, D. 1994. A classification of natural rivers. *Catena* 22:169-199.

Rosgen, D. 1996. *Applied River Morphology, 2nd edition*. Wildland Hydrology, Pagosa Springs, CO.

Stanley, E. H., S. G. Fisher, and N. B. Grimm. 1997. Ecosystem expansion and contraction in streams *BioScience* 47:427-435.

Swift, L. W. Jr. and E. S. Ledford. 1994. Where is bankfull in small southern Appalachian stream channels? Pages 306-311 *in Riparian ecosystems in the humid U.S.: Functions, Values and Management*. National Association of Conservation Districts, Washington, D.C.

Equipment and supplies

2 Measuring tapes (50m)
Meter stick
Field forms
Survey stakes
Laser level (optional)

3.11 Measuring water velocity

General

The following subsection provides methods for measuring water velocity in headwater streams. Water velocity is the rate of water moving through a point and represents one aspect of stream flow. Hydraulics is among the more complex and dynamic characteristics of the stream environment (Statzner et al. 1988, Vogel 1994). For example, the relevancy of a velocity is dependent on organism size. Under the same velocity, smaller organisms may experience the near-bed velocity as laminar syrup, whereas larger organisms would experience a turbulent maelstrom. Although water velocity is just one aspect of stream hydraulics, it provides ecologically-relevant information. The following methods will offer coarse estimates that are useful in for making relative comparisons. For fine-scale and less-invasive measurements, alternative methods such as acoustic Doppler velocimeter (ADV, Bouckaert and Davis 1998, Finelli et al. 1999) and thermistor probes (LaBarbera and Vogel 1976, Dodds and Biggs 2002) are more suitable. As already discussed in Subsection 3.6, water velocity is useful for designating habitat units and can directly (e.g., food availability, dispersal) and indirectly (e.g., refuge from predators) affect the distribution of organisms (Hart and Finelli 1999). Mean water velocity for a stream reach may not necessarily decline as streams first begin to dry, but it will drop dramatically when streambed materials such as cobbles and boulders become emergent and flow becomes mostly interstitial. Because water velocity can vary considerably over time, measurements should be taken during each sampling visit. Below we detail four simple procedures for measuring water velocity along a stream reach; additional procedures are discussed by John (1978), Newbury (1984), and Ciborowski (1991).

Procedure
Delineate the 30-m study reach so that the measuring tape is marking locations along the thalweg. Point measurements of water velocity (Procedures 3.11.1, 3.11.2 and 3.11.3) at the streambed are taken at 5-m intervals (at 0, 5, 10, 15, 20, 25 and 30-m marks) along the study reach thalweg (Figure 3-40). Below are four procedures that can be used. In most cases (and when available) the velocity meter procedure is preferred;

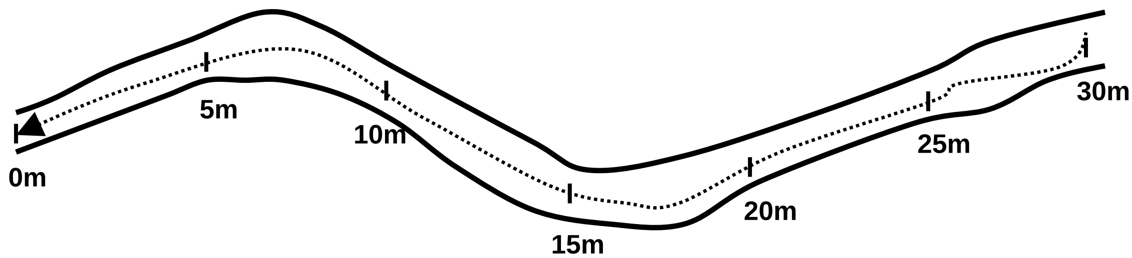

Figure 3-40 Plan view of study reach showing measurement locations (vertical black tick marks) for current velocity measurements. Flow is from right to left and the dotted line represents the thalweg.

however under some circumstances the other three procedures may be more suitable.

3.11.1 Velocity meter procedure
Before arriving at the field site read the instruction manual for the velocity meter (e.g., electromagnetic, propeller). Attach the wading rod to the velocity meter probe. Check to see that the meter is functioning properly and is calibrated. Set the selector switch to m/sec and the time constant switch to the lowest setting that gives stable readings. Stand downstream and to the side of each of the measurement locations when taking velocity readings. Hold the rod perpendicular to the water surface with the front of the velocity probe facing upstream, perpendicular to the channel cross-section (Figure 3-41). Set the bottom of probe ~ 0.5 cm off the streambed and take flow reading. Write the water velocity in the appropriate cell on the second page of the field forms (Figure 3-42). If no surface water is found at a measurement location, indicate on the field form that the water velocity is 0. If there is flowing surface water at a location but it is too shallow to measure with a velocity meter, then indicate that the water velocity is “>0”.

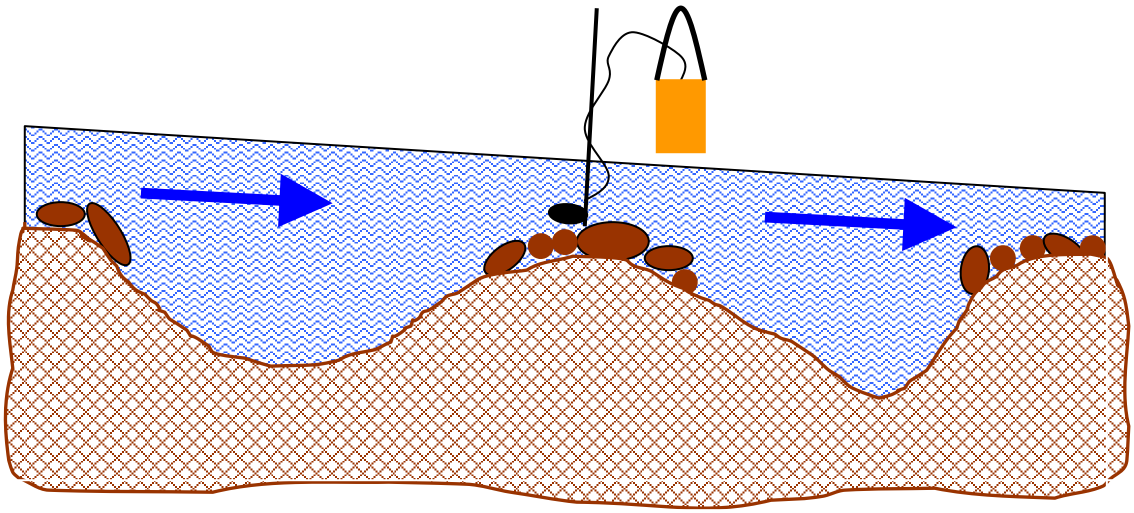

Figure 3-41 Longitudinal section across the channel thalweg showing orientation of the velocity probe for measurements.

* MEASURES TAKEN IN THALWEG			§ Where FPA Width > 2.2X BF Width then indicate: >2.2BF						Page 2 of 4
Meter #	Modal Sediment Particle Size (mm) *	Water Depth (cm)*	Habitat Type (E/D)	Notes (e.g., LWD, Leafpack)	Velocity (m/s)*	Wetted Width (m)	BF Width (m)	BF Depth (m) *	FPA width (m) §
0					0.02				

Figure 3-42 Appropriate location for recording water velocity on page 2 of the field forms.

3.11.2 Velocity-area procedure using a bag meter (Gessner meter)

A simple alternative to electromagnetic or propeller meters is the bag meter or Gessner meter (Gessner 1950). To assemble the bag meter: tape a plastic bag (e.g., small plastic grocery or bread bag) over the larger opening of a small plastic funnel with duct tape. Make sure that it is completely sealed and there are no holes in the plastic bag. Then tape a cylinder (e.g., plastic cup with bottom cut out, PVC pipe) that has a diameter slightly larger than the large opening of the funnel), to the outside of the large funnel opening and over the plastic bag (Figure 3-43). Calculate the area of the small funnel opening (i.e., $A = \pi r^2$).

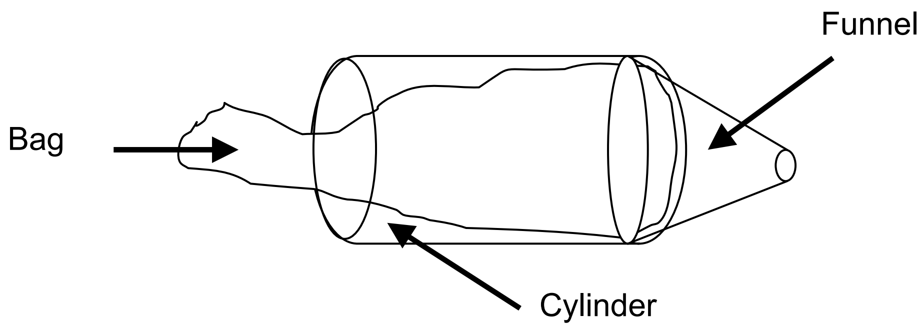

Figure 3-43 Bag meter used to measure water velocity.

Stand downstream and to the side of each of the measurement locations when measuring velocity. Before taking a measurement, empty and deflate the bag as much as possible. While holding the bag meter by the cylinder in one hand, use your other to cover the small funnel opening. Submerge and hold the bag meter near (will depend on diameter of large funnel opening) and parallel to the stream bed, so that the small opening is facing into the current. Simultaneously note the second hand position on your wristwatch (alternatively signal "start" to another crew member with a stopwatch) and uncover the small funnel opening. Let the bag fill with water for 10 seconds (or shorter time in very fast current) and recover the funnel opening. Carefully pour the water from the bag into the calibrated container. Determine the volume to the nearest 0.005 liter. In the cells for water velocity on the field form (Figure 3-42) write the volume and fill time (e.g., 0.25 L / 10 sec). Indicate on page 3 of the field form that the bag meter was used to measure discharge and the area of the small funnel opening.

After returning from the field, the water velocities can be calculated by first converting the volumes from liters to m^3 (i.e., divide by 1000). The volume is divided by the filling time (e.g., 10 sec) and then the resulting value is divided by the area of the small funnel opening (in meters). Repeat this for all measurement locations. If there is no surface water at a measurement location, indicate on the field form that the water velocity is 0. If there is flowing surface water at a location but it is too shallow for this method indicate that the water velocity is >0.

3.11.3 Neutrally-buoyant object procedure

This procedure can be used when a velocity meter is not available or if flow is too shallow for accurate meter readings. Indicate on page 3 of the field form that this procedure was used. Designate the upstream and downstream boundaries of 2-m segments that are centered on each of the measurement locations (1 m upstream and downstream of the 0, 5, 10,…30-m locations, Figure 3-44). While standing downstream of the release point and outside the thalweg, hold the neutrally-buoyant object (see Equipment and supplies for examples; consistently use the same object across all measurements) in the thalweg (at 0.4X the water depth). In unison, gently release the neutrally-buoyant object and start the stop watch. Note the time required for the object to travel the 2-m segment. If the object becomes stuck or drags along the bottom repeat the release and/or slide the segment position upstream or downstream to avoid areas where the object sticks or drags. In fast segments 2 people may be required to accurately measure segment travel time. One person at the upstream boundary simultaneously releases the object and signals "start". This indicates to the second person who is standing at the downstream boundary to start the stopwatch. The second person then stops the watch when the object crosses the downstream boundary. Divide the segment length by the travel time and write this in the appropriate cell on the field form. If there is no surface water at a measurement location, indicate on the field form that the water velocity is 0. If there is flowing surface water at a location but it is too shallow for this method indicate that the water velocity is >0.

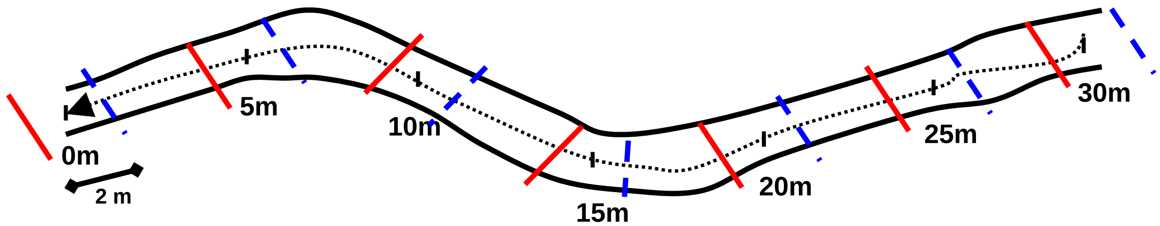

Figure 3-44 Overview of study reach showing measurement locations (black tick marks crossing the thalweg, shown as dotted line), upstream (dashed blue lines) and downstream segment boundaries (solid red lines) for the neutrally-buoyant procedure to measure water velocity.

3.11.4 Fluorescent dye procedure

This procedure can be used when a velocity meter is not available or if flow is too shallow for accurate meter readings. Indicate on page 3 of the field form that this procedure was used. This procedure provides only a general measure of water velocity for the entire reach, in contrast to the methods described above which provide estimates for average and variation of water velocity. Pour ~ 1 ml fluoroscene dye (or rhodamine WT) into a 1 L plastic bottle and add 500 ml of stream water. Cap and shake bottle until dye is thoroughly dissolved. In fast-flowing reaches 2 people may be required for this method, one person with the dye at the 30-m location (upstream boundary of study reach) and the other person with a stopwatch at the 0-m location (downstream boundary of study reach). Before starting, make sure that other field personnel are outside of the study reach. The person at the upstream boundary will simultaneously release the dye (gently pouring bottle contents from ~ 5 cm above the water level) into the thalweg at the 30-m location and signal "Start". This indicates to the person at the downstream boundary to start the stopwatch. The downstream person records the time when the "leading" and "trailing" edges of the dye plume cross the downstream boundary (Figure 3-45). The trailing edge is identified as the last visible portion of the plume in the thalweg. Ignore any dye that may have gotten caught in backwater pockets. On the field form write the distance of the dye release (should be 30 m if entire study reach is flowing) and travel times for leading and trailing edges in seconds.

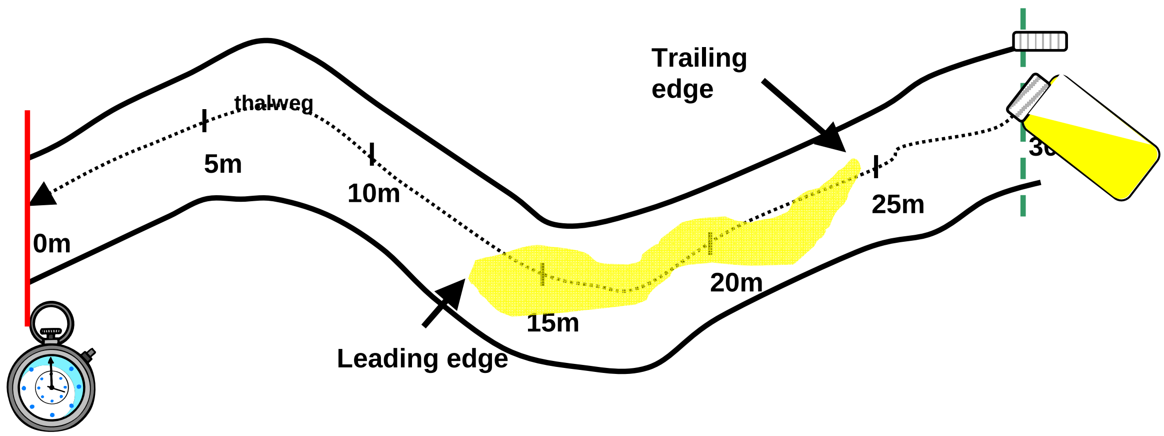

Figure 3-45 Overhead view of study reach showing leading and trailing edges of fluoroscene plume.

References

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Equipment and supplies
Measuring tape (50 m)
Field forms
A, B, C or D

A. Velocity meter (electromagnetic, propeller, or cup) and spare batteries – see Procedure 3.11.1
B. Stopwatch and bag meter – see Procedure 3.11.2
C. Stopwatch and neutrally buoyant object (e.g., piece of orange peel, film canister partially filled with stream water, small stick) – see Procedure 3.11.3
D. Stopwatch, 1L plastic bottle, fluoroscene dye (1 ml per 500 ml streamwater) – see Procedure 3.11.4

3.12 Measuring discharge
General
This subsection provides methods for measuring discharge (Q) or flow rate of water in headwater streams. Discharge (in conjunction with stream size or drainage area) is a quantitative measure for describing the hydrologic condition. This measure of flow is useful in following and describing temporal patterns in water chemistry. When conditions are allowable, discharge should be measured during each sampling visit. The methods described in this subsection are modified from those described by John (1978), Platts et al. (1983), Kilpatrick and Cobb (1985), Gordon et al. (1992), Gore (1996), and Kaufmann (1998). For long-term studies continuous discharge monitoring may be considered. The simplest method is a staff gauge, where discharge can be determined by monitoring the stage (or water depth) at a permanent location. Stage-discharge relationships (rating curves) are plotted by measurements of stage against discharge over a range of flows (Gordon et al. 1992). Peak flow between field visits can be determined from crest gauges (Gordon et al. 1992, Harrelson et al. 1994). A simple crest gauge consists of stilling well, a meter stick, and ground cork. The stilling well can be a length of plastic pipe (3 to 4 cm diameter) with caps on both ends. Holes are drilled in the bottom cap so the water level within the stilling well represents the stage. The top cap of the well should be loose fitting or vented. Finely ground cork and the meter stick are placed in the well. After a peak flow the cork will adhere to the meter stick at the crest or peak stage. The gauge is then easily reset by washing the cork off the meter stick and back into the well. The design and equipment for gauging stations can vary from a simple staff gauges to more permanent flumes and weirs. Gauging station design and data storage are discussed in John (1978), Herschy (1995), Clemmons et al. (2001), and Bureau of Reclamation (2001).

Procedure
Delineate the 30-m study reach so that a measuring tape is positioned along the thalweg.

3.12.1 Velocity-area procedure using a velocity meter
Before arriving at the field site read the instruction manual for the velocity meter. Attach the wading rod to the velocity meter probe. Check to see that the meter is functioning properly and is calibrated. Set the selector switch to m/sec and the time constant switch to the lowest setting that gives stable readings (unit setting may be switched to ft/s under extremely low flow conditions). The location for discharge

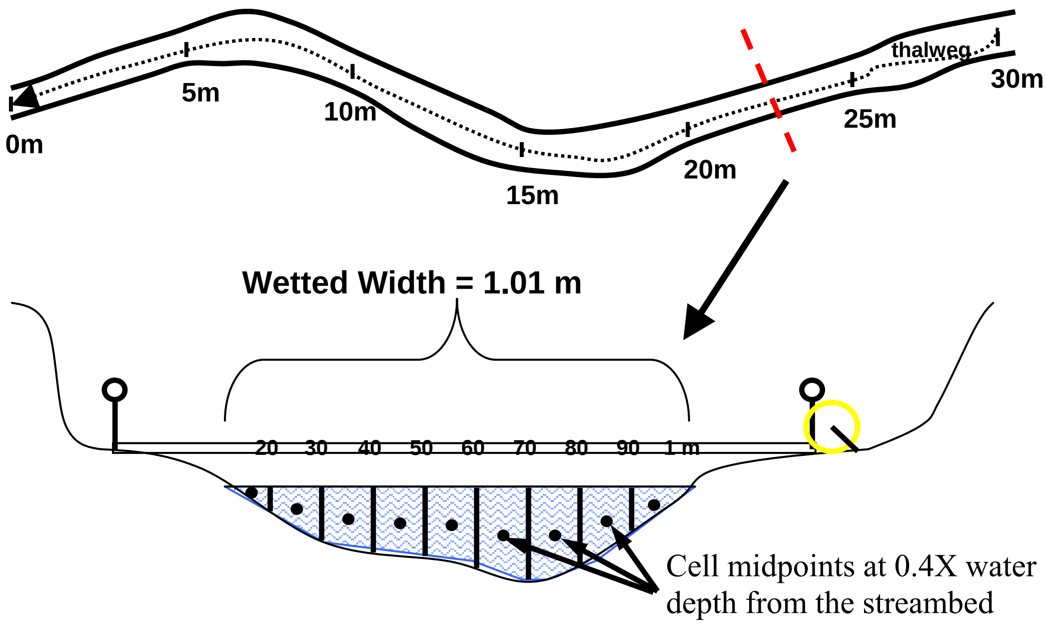

Figure 3-46 Plan view of study reach (top) showing discharge measurement cross-section (red dashed line). Cross-section for discharge measurement (bottom) showing measurement cells.

measurement is not restricted to the 30-m study reach; however, the discharge at the measurement location should be representative of the discharge seen in the study reach. Locate a channel cross-section that has the following characteristics (or can be modified to have these characteristics*): 1) channel immediately upstream and downstream is straight (~ 3 m in both directions of discharge transect), 2) free of obstructions (e.g., woody debris, macrophytes, emergent stones, braided channel), 3) "U" shaped so that ≥ 90% of the cross-section has water depths sufficiently deep for accurately measuring water velocity with the velocity meter, and 4) water velocity across the channel is relatively uniform and ≥ 90% of the cross-section has water velocities >0.01 ms^{-1}. Runs and glides are typically good habitat units for measuring discharge.

At the measurement cross-section, stretch the second measuring tape taut across the channel so that it is perpendicular to flow and ≥ 5 cm above the stream surface (Figure 3-46). Determine the wetted width of the channel to the nearest 0.01 m. Divide the wetted width into 6 to 12 equally sized intervals or cells. Cells should be ≥ 5 cm wide.

Write the wetted and cell widths in the appropriate blanks on the field form (Figure 3-47). Water depth and water velocity are measured midway across each cell or cell midpoint (Figure 3-46).

* The channel can be modified (e.g., remove rocks, obstructions) prior to taking any discharge measurements. Once measurements have begun however, do not modify the channel.

Start measurements from one bank and move across. Stand downstream and to the side of each depth and velocity measurement. Use the meter stick to measure water depth (to the nearest 0.5 cm). Water velocity is then measured at ~ 0.4X water depth from the streambed for each cell. If this depth is too shallow to submerge the velocity meter probe or propeller, measure velocity closer to the streambed. Write the water depth and its associated water velocity measurement in the cells on the field form (Figure 3-47). Discharge is calculated by multiplying the cell width * water depth * water velocity of each cell then summing across all cells.

STREAM DISCHARGE										**Page 3 of 4**
Wetted Width (m) :__1.01_	CELL WIDTH (m) :_0.1___									
Depth(cm)	4	7	11	16.5	25	28	27	10.5	5.5	
Velocity(m/s)	0	0.05	0.09	0.12	0.22	0.25	0.18	0.08	0	
Q (m^3s^{-1}) = _0.02908_	Discharge procedure: Velocity-area Velocity procedure/meter model: Marsh-McBirney Flowmate									

Figure 3-47 Appropriate location for recording discharge and procedures used on page 3 of field forms. Example values shown in red.

3.12.2 Velocity-area procedure using a bag meter

To assemble the bag meter: tape a plastic bag (e.g., small plastic grocery or bread bag) over the larger opening of a small plastic funnel with duct tape. Make sure that it is completely sealed and there are no holes in the plastic bag. Then tape a cylinder (e.g., plastic cup with bottom cut out, PVC pipe that has a diameter slightly larger than the large opening of the funnel), to the outside of the large funnel opening and over the plastic bag (Figure 3-48). Calculate the area of the small funnel opening (i.e., $A = \pi r^2$).

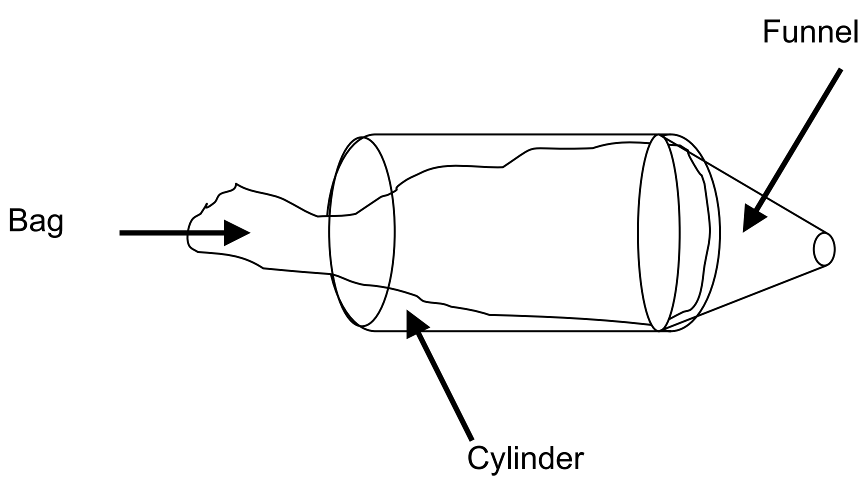

Figure 3-48 Bag meter used to measure discharge.

Select and delimit a measurement cross-section as described in **3.12.1**. Follow the same procedures except use the bag meter to measure water velocity at 0.4X the water depth from the stream bed. Before taking a measurement completely empty the bag of water and deflate the bag of air as much as possible. While holding the bag meter by the cylinder in one hand use your other to cover the small funnel opening. Submerge and hold the bag meter at the appropriate measuring depth, so that the small opening is facing into the current and the bag meter is perpendicular to the measurement cross-section. Simultaneously note the second hand position on your wristwatch (alternatively shout "start" to another crew member with a stopwatch) and uncover the small funnel opening. Let the bag fill with water for 10 seconds (or shorter time in very fast current) and recover the funnel opening. Carefully pour the water from the bag into the calibrated container. Determine the volume to the nearest 0.005 liter. In the cells for water velocity on the field form write the volume and fill time (e.g., 0.25 L / 10 sec). Indicate on the field form that the bag meter was used to measure discharge and the area of the small funnel opening.

After returning from the field, the cell water velocities can be calculated by first converting the volumes from liters to m^3 (i.e., divide by 1000). The volume is divided by the filling time (e.g., 10 s) and then the resulting value is divided by the area of the small funnel opening (in meters). Repeat this for all cells of the measurement cross-section and determine discharge as instructed in **3.12.1**.

3.12.3 Timed filling procedure

This method can be used where the channel is small and there are one or more natural spillways or plunges along the reach where the entire stream flow can be captured (the channel can be modified to ensure that all the flow is funneled). Simultaneously start the stopwatch and position the wide-mouth container (i.e., bucket or basin) under the spillway to collect the entire flow. Collect water for 10–30 seconds, depending upon the level of discharge. Transfer the water from the wide-mouth container to a calibrated one and determine the volume (to the nearest 0.005 liter). Alternatively, one may simply record the time required to fill a bucket or basin to a known volume (e.g., 2 L). Repeat this procedure 3 times at given spillway. Indicate that the timed filling procedure was used to measure discharge and write the volume and respective filling time for each trial on the field form.

3.12.4 Dilution gauging procedures

These methods use dilution over time of biologically inert substances introduced into a stream reach. Commonly used substances (tracers) included salt solutions (NaCl, KBr) and dyes (e.g. fluorescene, rhodamine WT). Tracers should be readily detectable at low concentrations (low or no background concentrations), and soluble in water at stream conditions (Gordon et al. 1992). Depending upon the tracer used, general (electrical conductivity meter, fluorometer) or tracer-specific probes can be used for *in situ* measurements. Alternatively, samples can be collected in bottles and returned to the laboratory for analysis. An estimate of discharge is needed to determine the initial tracer concentration so that the measured concentration is easily detectable (5 to 10 times background). The two general methods for dilution gauging are the slug injection and constant injection. The slug injection method involves releasing a known volume and concentration of a tracer as a single pulse. Background measurement for the tracer should be measured before beginning the injection. The point of injection should be a zone with turbulent mixing. Tracer concentration is measured at regular intervals at a downstream station from the start of the injection until concentrations reach background levels. The measurement interval will depend upon the level of discharge and the size of the study reach. Discharge (Q) is determined from using the area under the concentration curve (Figure 3-49). The following equation from Gordon et al. (1992) is used:

$$Q = 1000 \frac{Vc_t}{\int_{t_1}^{t_f} (c - c_0)dt}$$

Where V is the slug volume (in liters), c_t is the initial tracer concentration, c_0 is the background concentration in the stream water, c is the concentration at time t.

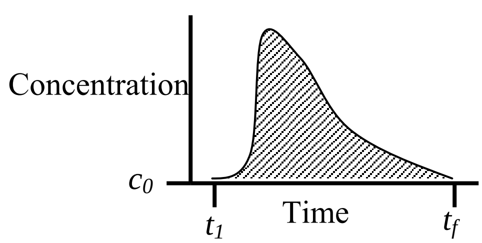

Figure 3-49 Example of a concentration curve from a slug injection. Discharge (m^3s^{-1}) is the hatched area under the curve.

The constant injection method also uses a known concentration of the tracer, but the rate of injection is constant over the duration of the measurement rather than as a slug. Tracer concentration will increase and then stabilize at the downstream station (Figure 3-50). Constant injection can be done using a peristaltic pump or a Mariotte bottle (see Webster and Ehman 1996). Discharge using this method is calculated using the equation from Gordon et al. (1992):

$$Q = 1000 \frac{(c_t - c_1)}{(c_1 - c_0)} Q_t$$

Where c_1 is the stabilized concentration, Q_t is the tracer injection rate ($l\ s^{-1}$), and the other variables are the same as shown in the previous equation.

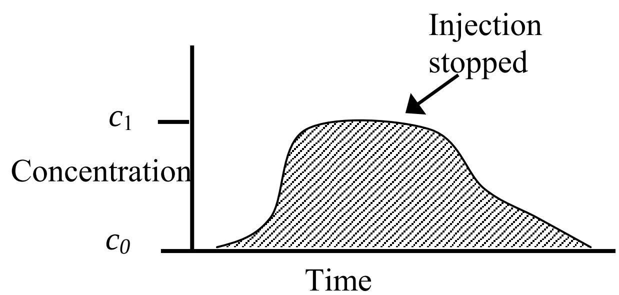

Figure 3-50 Example of a concentration curve from a continuous injection. Discharge (m^3s^{-1}) is the hatched area under the curve.

Although these methods may be more accurate and feasible during low flows than previously described methods, insufficient mixing and anastomosing flow through reaches may also limit discharge measurement using dilution gauging methods. Some disadvantages of dilution methods compared to other methods include need for prior knowledge of approximate discharge level, additional equipment bulk, and drift response by biota (Wood and Dykes 2002).

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Equipment and supplies
Measuring tape (50 m)
Field forms
A, B, C, or D

A. Second measuring tape, survey stakes, meter stick, velocity meter (electromagnetic, propeller, or cup) and spare batteries – see **Procedure 3.12.1**
B. Second measuring tape, meter stick, wristwatch with second hand, bagmeter (small funnel taped to plastic bag enclosed in plastic pipe), and calibrated container (e.g., volumetric cylinder) – see **Procedure 3.12.2**
C. Stopwatch, wide-mouth container (e.g., bucket, wash basin), and calibrated container (e.g., volumetric cylinder) – see **Procedure 3.12.3**
D. Stopwatch, tracer substance (stock solution), calibrated pipette and tips, volumetric cylinder, mixing container, tracer probe or fluorometer, peristaltic pump or Mariotte bottle – see **Procedure 3.12.4**

3.13 Measuring depth to bedrock and groundwater table

General

This section provides instructions for measuring depth to underlying bedrock and groundwater table in headwater streams. The hyporheic zone is the interface between the surface stream and the underlying groundwater (Boulton et al. 1998, Jones and Mulholland 2000). The importance of the hyporheic zone to the structure and function of streams depends upon the permeability and discharge through the hyporheic zone to the overlying surface water (Brunke and Gonser 1997). Because the subsurface environment (e.g., temperature, flow) is relatively more stable than the overlying streambed surface, the hyporheic zone may serve as a refuge for stream organisms from disturbances such as floods and drying (e.g., Clinton et al. 1996, Dole-Olivier et al. 1997). This rapid method provides an estimate of the extent and hydrologic status of the hyporheic zone, and therefore the potential for it to serve as refuge.

Depth to groundwater table can vary with intra- and interannual differences in catchment precipitation and evapotranspiration, and it is important to measure whenever surface water is absent. Depth to bedrock is unlikely to change significantly over short time periods (e.g., 1-2 years), and therefore only needs to be measured once during the study period. Because these measurements use the same procedure (e.g., sounding rod, Valett 1993), we recommend taking both measurements during drier periods (when more than one sampling visit is planned).

The development of ground-penetrating radar (GPR) offers an alternative, non-invasive method to describe subsurface features of streambeds, including the depth to bedrock and groundwater (Naegeli et al. 1996, Huggenberger et al. 1998). However, the utility of GPR can be limited where interfaces are not clearly defined (e.g., saturated fine sediments) or below dense layers, such as clays (Poole et al. 1997). The cost and bulk of equipment are other considerations that may limit the application of GPR in large scale assessments of headwater streams.

Procedure
Delineate the 30-m study reach so that a measuring tape is marking locations along the thalweg. Locate 3 depositional habitat units near the 0, 15, and 30-m marks of the study reach. Depth measures are taken in the thalweg at these 3 locations.

3.13.1 Depth to bedrock
Hammer the sounding rod or "T"-bar vertically into the stream bed at intervals of 5-10 cm with the hand sledge (Figure 3-51). Wiggle the upper end of the sounding rod in circular motion by hand (Figure 3-52). This will prevent the rod from becoming stuck within the stream bed. Continue tapping the rod until it strikes bedrock (or large boulder). This will be evident from the "pinging" sound the rod makes when hammered (and resistance to further downward movement). Some stream beds have cobble deposition that may impede the rod's downward progress. You can penetrate through cobble layers by rotating the rod tip in a circular motion while continuing to hammer (Figure 3-52). This process will often allow the rod to pass through interstitial spaces between the cobbles. If not, simply shift the rod location slightly and repeat the process. When you have struck bedrock, use your forefinger and thumb (or cable tie) to mark the point on the rod where it is even with the stream bed surface. Pull the rod out of the stream bed and measure the distance with the meter stick (to the nearest 1 cm) between the lower end of the rod and your finger. Write this measurement in the appropriate cell on the field form (Figure 3-53). If the depth to bedrock appears to exceed the length of the sounding rod (> 85 cm for 91 cm sounding rod) then indicate

“>85 cm” on the field form. Where the stream bed surface is bedrock then indicate “0 cm” on the field form.

Figure 3-51 Using sounding rod and hand sledge hammer to estimate depth to bedrock and the groundwater table.

3.13.2 Depth to groundwater table
Where the stream contains surface water the depth to the groundwater table will equal the water depth at the measurement location. Indicate this on the form by writing "+" and the water depth. Where the stream bed is dry begin by following the same procedure used to measure depth to bedrock. After the groundwater table is reached, water seeping into the hole will create resistance on the rod. Moving the top of the rod in a circular motion or gently lifting the rod a few centimeters will help you determine if you have entered the groundwater table. If the rod has entered the water table, you may either hear a “slurping” sound or feel suction resistance when the rod is lifted. Before fully removing the sounding rod from the streambed, mark the point (with a finger or cable tie) on the sounding rod where it is even with the stream bed surface.

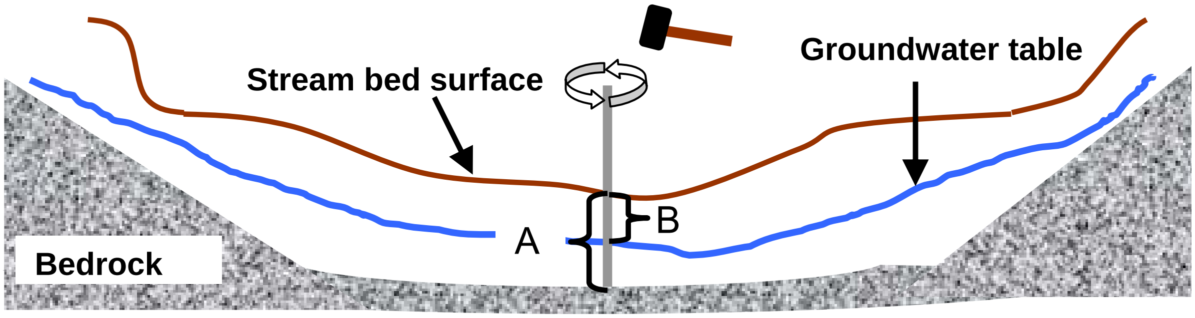

Figure 3-52 Cross-section of a dry channel illustrating depth to underlying bedrock (A) and depth to the groundwater table (B).

Immediately after removing the sounding rod from the stream bed identify the highest point along the rod where there is water (wet enough to drip). Measure the distance between stream bed level and the highest wetted point on the rod with the meter stick (to the nearest 1 cm). Write this measurement in the appropriate cell on the field form (Figure 3-53). Indicate that this represents a measurement below the stream bed surface by writing a "-" before the distance. If the depth to the groundwater table appears to exceed the length of sounding rod (>85 cm for 91 cm sounding rod) then indicate ">-85 cm" on the field form.

MAX. POOL DEPTH (cm)	DEPTH TO BEDROCK / GROUNDWATER (cm) (3 measures in depositional habitat)			SINUOSITY (number of bends)
	54 / -24	34 / +8	0 / -14	

Figure 3-53 Appropriate location for recording depth to bedrock (example values in blue) and depth to groundwater (example values in red) on page 1 of field forms.

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Equipment and supplies
Measuring tape (50 m)
Sounding rod (steel rod, ≥ 3 ft or 91 cm) or "T"-bar
Hand sledge hammer
Meter stick
Field forms

3.14 Gravimetrically measuring streambed sediment moisture

General
This subsection provides instructions for measuring the relative moisture of streambed sediments in dry headwater channels. In other words, this procedure quantifies the degree of "dryness" or desiccation of the benthic habitat in streams when visible surface water is absent. This is especially relevant to organisms that inhabit intermittent or ephemeral streams and possess life histories or physiological traits (i.e., diapause, quiescence, and aestivation) for surviving the dry periods (Davis 1972, McKee and Mackie 1983, Danks 1987, Williams 1998, Dunphy et al. 2001). Mortality during such periods can depend on the desiccation level of the surrounding sediments, and therefore can influence the spatial distribution of organisms (Suemoto et al. 2005). Soil moisture is measured during the summer sampling period (when sediment moisture is expected to be lowest) within study reaches that have no visible surface water.

Procedure
Delineate the 30-m study reach so that a measuring tape is positioned along the thalweg. Mark three 15-cm pieces of 3/4" PVC with a line 10 cm from one end using a permanent marker (volume ~ 28.5 cm^3).

3.14.1 Sediment collection
Three individual sediment cores are taken along study reaches lacking visible surface water. Cores are extracted from the streambed in depositional habitat units with fine sediments (e.g., sand, silt, fine gravel). In addition to being more feasible to collect, moisture content is expected to be relatively high in thick patches of fine sediment (i.e., capillary fringe) because of greater capillary tension compared to levels associated with coarser particles (Dunne and Leopold 1978). Where possible, cores from each study reach

should be taken from separate depositional units within the thalweg.

Find a suitable location and brush aside detritus (i.e., leaf litter) from the streambed surface. Position the core vertically so that the 10-cm mark is away from the streambed (Figure 3-54). Tap the core vertically into the streambed with the hand sledge until the

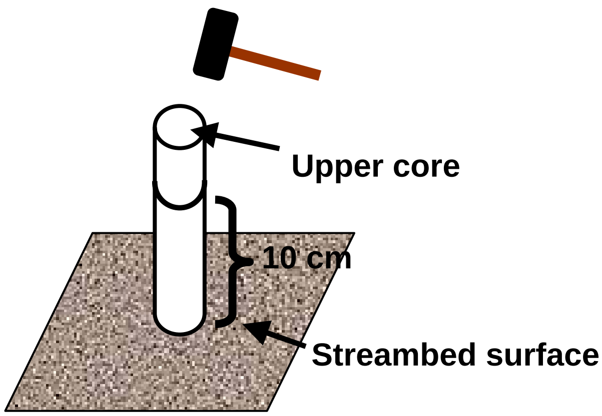

Figure 3-54 Sampling sediment moisture.

10-cm mark is flush with the streambed (Figure. 3-55). Place a rubber stopper into the upper core opening. Carefully pull the core out of the streambed and place a second rubber stopper into the lower core opening.

Place core in a resealable plastic bag. Label the bag and/or core using a permanent marker with relevant information (e.g., locality, date, collector's initials). Remove excess air within the bag when sealing. Log the number of sediment core samples taken at each site on the field forms (Figure 3-56). Store samples in a cooler with ice or in a refrigerator until the samples can be measured in the laboratory. Measure moisture of the sample within 4 days of collection. A soil borer or auger can be used collect samples rather than PVC cores. Care must be taken to keep sediment samples airtight (e.g., Shelby tube) to maintain soil moisture levels.

Figure 3-55 Tapping core vertically into streambed.

PRESENCE OF HEADCUT IN REACH		ALGAL COVER INDEX						# CORES FOR SUBSTRATE MOISTURE (depositional)
Y	N	1	$1^{1/2}$	2	3	4	5	3

Figure 3-56 Appropriate location for recording the number of sediment moisture cores collected on page 1 of field forms.

3.14.2 Laboratory measurement

In the laboratory, use a weighing spatula or thin metal rod to transfer sediment from cores into separate evaporating dishes or crucibles. Be sure that the dishes are uniquely identified (e.g., dish #s), so that results can be associated with specific samples. Measure the wet weight of the sediment samples with an analytical balance to the nearest 0.01g. Record dish identification, sample abbreviation, and wet weight on the data sheets (Figure 3-57).

HISS Sediment Moisture Data Sheet		DATE: 9/23/03		Page 1 of 1
Dish #	**Study Site Abbrev.**	**Sediment Core**	**Wet Weight (g)**	**Dry Weight (g)**
123	Four-FC-3	A	39.36	
144	Four FC-3	B	38.47	
135	Four FC-3	C	38.95	
142	Four-FC-4	A	29.29	

Figure 3-57 Example of the sediment moisture data sheet.

Place samples into the drying oven for 24 h with temperature set at 90º C. Remove samples from the oven using tongs and allow them to cool to room temperature. If a desiccator is available, the samples can be directly placed into the desiccator to cool. Measure the dry weight of the sediment samples with the balance to the nearest 0.01g and record on the data sheet. Percent moisture is calculated using the following equation:

$$\text{Percent Moisture} = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Wet Weight}} \text{ x } 100$$

Cores can be collected from locations where/when surface water is present to provide a relative comparison of sediment moisture. Alternatively, water can be added to previously dried samples until visibly saturated. The cores are then weighed to determine percent moisture at saturation. The amount of organic matter within the sediments can be determined by ashing the core contents in a muffle furnace at 550° C for two hours and then reweighing to determine ash-free dry mass (AFDM).

Alternative means for measuring soil moisture include the use of soil moisture probes (e.g., tensiometers, capacitance sensors; see Miller et al. 1997); but these are not commonly used in the relatively coarse sediments of intermittent streambeds. A procedure described by Greacen et al. (1989) indirectly measures sediment moisture by way of water absorption onto filter paper and then gravimetric determination of water content. Techniques that have been used to extract water from soil cores include centrifugation, squeezing, and vacuum extraction (e.g., Adams et al. 1980).

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Equipment and supplies
Measuring tape (50 m)
Cores (15 cm long, ¾ inch inner diameter PVC pipe)
Hand sledge hammer
Rubber stoppers (2 per core, No.1 or 2)
Resealable plastic bags (1 per core)
Cooler
Ice or ice packs
Permanent marker
Field forms
Weighing spatula or metal rod (laboratory)
Evaporating dishes or crucibles (laboratory)
Drying oven (laboratory)
Analytical balance (laboratory)
Desiccator (laboratory)
Lab notebook or bench sheets (laboratory)

3.15 Characterizing the size distribution of streambed sediments

General

This subsection provides a simple method for characterizing the size structure of streambed sediments within headwater stream reaches. Sediment characteristics influence many other physical properties, including habitat stability, interstitial habitat volume, nearbed velocities, organic matter retention, and re-aeration. Consequently, streambed sediments directly and indirectly influence community structure and stream processes. The characteristics of the streambed are expected to influence stream processes to a greater degree in headwater streams than in larger rivers because headwaters have a higher ratio of streambed surface area to instantaneous flow volume (m^2/m^3) than larger streams and rivers. Geology, climate, topography, and drainage area are factors that naturally govern the natural composition of stream sediments. Land-use changes can cause deleterious alteration to streambed properties (e.g., siltation) and subsequent shifts in biological integrity.

Particle size is the most common measure used to characterize streambed sediments, mainly because of the ease to which it can be objectively quantified compared to other characteristics (e.g., sphericity, specific density). A frequently used method to characterize sediments on streambed surfaces is the Wolman pebble count procedure (Wolman 1954, Leopold 1970, Kondolf & Li 1992), where the sizes of individual stones are randomly selected and measured along a reach. Vertical characterization can be done by coring (Cummins 1962, Everest et al. 1980, Wesche et al. 1989) and ground-penetrating radar (Naegeli et al. 1996, Huggenberger et al. 1998). Other aspects of the streambed sediments that have been measured include texture (Downes et al. 1998, Bergey 1999), porosity (Maridet et al. 1992), bed roughness (Statzner 1981, Ziser 1985), topographic complexity or fractal geometry (Schmid 2000, Robson et al. 2002, Stewart and Garcia 2002) and stability (Biggs et al. 1997, Duncan et al. 1999). The composition of streambed sediments influences aspects related to the rate of stream drying (i.e., permeability), wetted surface area as stream levels decline (boulder-dominated reaches will have more emergent sediments at low flows than gravel reaches), and the availability of interstitial refugia when streams are dry.

The protocol below is based on methods described in Walters et al. (2003) for particle size characterization by patches rather than individual grains or stones. Streambed sediment characterization is measured once for a given reach during the study because reach-level particle size measures are unlikely to change significantly over the timeframe of most ecological studies (1-2 years).

Procedure

Streambed surface sediments are measured at 31 locations, longitudinally at every meter mark along the thalweg of each 30-m study reach (Figure 3-58). Each particle size measurement is based upon 0.25 m^2 patches of particles, rather than a single particle measurement. The patches are centered around each meter mark (0, 1, 2,…30 m) along the study reach thalweg. The modal particle size class or the size class with the greatest patch coverage is estimated for each patch location. Once the patch is located, visually assess the size classes within each patch, determine which size class has the greatest coverage, and select a representative particle of that size class. The dimension used to determine particle size is the intermediate axis (i.e., β-axis) or the median value among the length, width, and height of the particle. Exact measurement of the intermediate axis is not needed because size classes are used. Particle size classes are based upon the Wentworth size classification or phi (Φ) scale (Cummins 1962, Table 3-1). The value for sediment particle size to be entered in the field form (Figure 3-59) is the upper bound value of the size class (bold-faced values in Table 3-1). The particle size classes are also listed on the bottom of page 3 of the field forms.

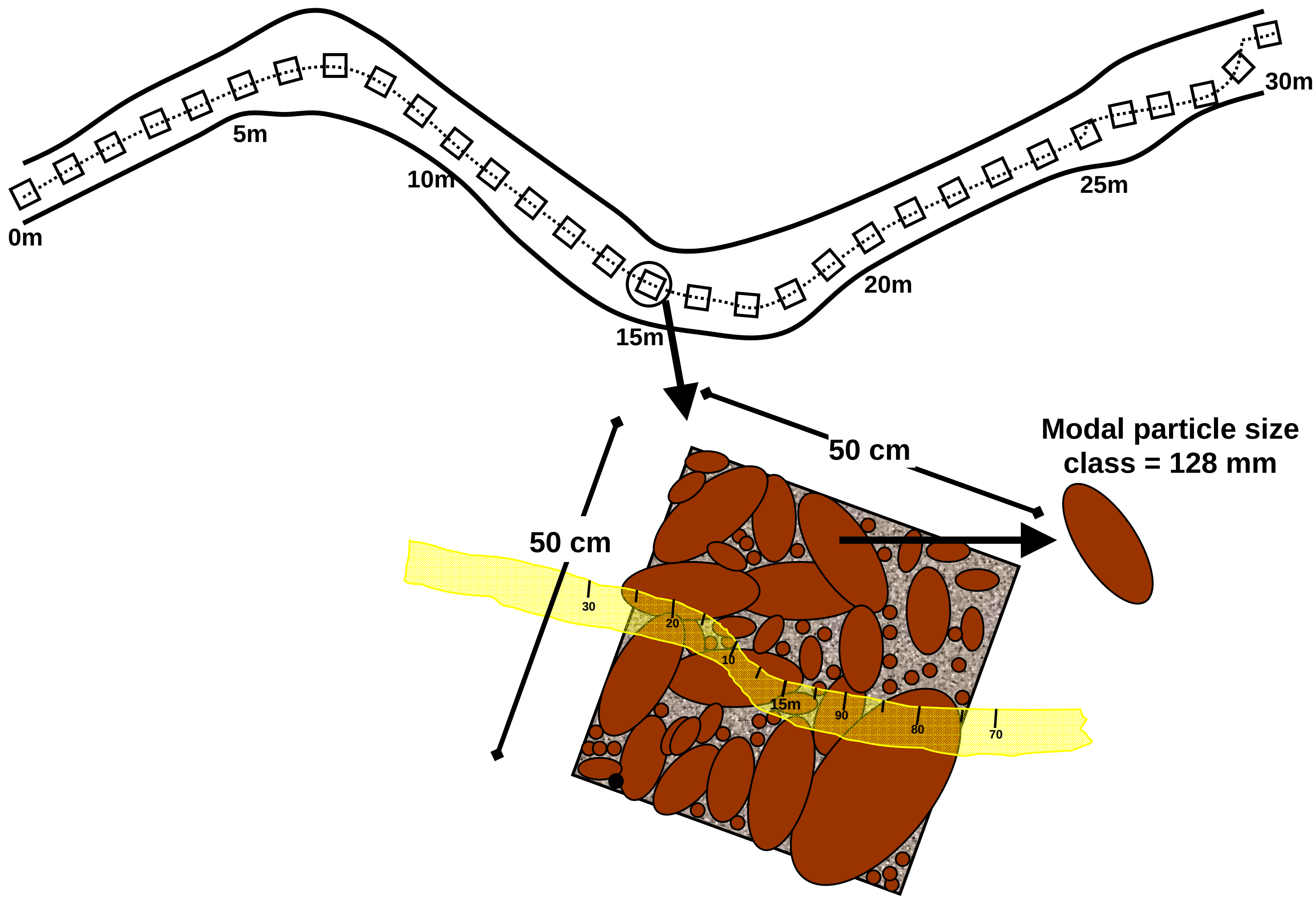

Figure 3-58 Schematic of study reach illustrating thalweg (dotted line) and patch locations for determining modal sediment particle size class. Inset provides a close-up of a patch (overlaid) with measuring tape used in designating patch locations longitudinally along the study reach).

Table 3-1 Modified Wentworth scale for sediment particle size classes. Bold-faced numbers indicate values to be entered on field forms

Class	Size range (mm)	Phi (Φ)
Sand, silt, and clay	**≤ 2**	≥ 0
Fine gravel	>2 to **4**	-1 to -2
Medium gravel	>4 to **8**	-2 to -3
Coarse gravel	>8 to **16**	-3 to -4
Small pebble	>16 to **32**	-4 to -5
Large pebble	>32 to **64**	-5 to -6
Small cobble	>64 to **128**	-6 to -7
Large cobble	>128 to **256**	-7 to -8
Boulder	>256 to **512**	-8 to -9
Bedrock and hardpan	**>512**	≤ -9

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Equipment and supplies

Meter stick or ruler
Measuring tape (50m)
Field forms

* MEASURES TAKEN IN THALWEG § Where FPA Width > 2.2X BF Width then indicate: >2.2BF Page 2 of 4

Meter #	Modal Sediment Particle Size (mm) *	Water Depth (cm)*	Habitat Type (E/D)	Notes (e.g., LWD, Leafpack)	Velocity (m/s)*	Wetted Width (m)	BF Width (m)	BF Depth (m) *	FPA width (m) §
0	< 2								
1	< 2								
2	4								
3	16								
4	> 512								
5	> 512								
6	16								
7	64								
8	64								
9	< 2								
10	< 2								
11	32								
12	8								
13	> 512								
14	256								
15	128								

Figure 3-59 Appropriate location for recording modal particle size data on page 2 of field forms (example from Figure 3-58 highlighted).

3.16 In situ water chemistry measurements

General

This subsection provides procedures for measuring *in situ* water chemistry of headwater streams. The basic water chemistry measurements discussed in this section are: 1) temperature, 2) conductivity, 3) pH, and 4) dissolved oxygen. Instructions for collecting water samples and measuring additional chemical parameters (i.e., nutrients, cations, anions) can be found in Wetzel and Likens (1991), Herlihy (1998), and APHA (2005). Because characteristics of water change with residence time, these measurements may be useful in distinguishing between groundwater and throughflow (i.e., water in unsaturated soil zones during and immediately after precipitation). Physicochemical amplitudes (seasonal and diel) are typically greater in temporary waterbodies than in perennial counterparts (Zale et al. 1989, Boulton et al. 2000). As flow begins to decline, deeper groundwater inputs may represent the dominant source of surface flows, resulting in relatively subtle physicochemical shifts (Dahm et al. 2003). More dramatic changes in water physiochemistry can occur as waterbodies dry, and such changes can have equally dramatic effects on the inhabiting biota (Moore and Burn 1968, Magoulick and

Kobza 2003). Maximum diel variation and absolute extremes are commonly measured when surface water becomes limited to disconnected pools (Stehr and Branson 1938, Boulton and Lake 1990) and depending upon the pool depth, vertical stratification can occur (e.g., Neel 1951, Wood et al. 1992). Conductivity and water temperature typically increases as streams dry (e.g., Baron et al. 1998), whereas dissolved oxygen tends to decrease (e.g., Slack and Feltz 1968, Chapman and Kramer 1991). Declines in water volume from evaporation and evapotranspiration lead to greater water surface area to volume ratios that subsequently cause water temperatures to rise from rapid solar heating. Warmer water and contraction of surface water intensifies community respiration that can lead to declines in dissolved oxygen. Evaporation, increased soil residence time, and organic matter breakdown elevates stream water concentrations of dissolved ions and alters pH (Williams and Melack 1997, Hamilton et al. 2005). The buffering capacity (or acid-neutralizing capacity, ANC) of stream water will determine the direction of pH change during drying. In some streams, high leachate concentrations from organic matter may decrease pH (Slack and Feltz 1968). Increases in pH during dry seasons can occur where ANC is strongly influenced by acid rain or snowmelt during wet seasons (Wigington et al. 1996) or where stream water is naturally low in base cations (e.g., Ca^{++}, K^{+}, Mg^{++}) and drying concentrates strong acid anions (e.g., SO_4^{--}, Cl^{-}, NO_3^{-}, Bayley et al. 1992). Although water quality can decline with drying, these changes may be mitigated where there is intact forest to buffer the stream environment (e.g., Feminella 1996). Conversely, reduced flows and drying exacerbates water quality problems in areas with nutrient input and removal of riparian canopy (Casey and Ladle 1976, Chessman and Robinson 1987), particularly if remaining flow is effluent-dominated (e.g., Lewis and Burraychak 1979, Jennings and Gasith 1993, Suren et al. 2003, Brooks et al. 2006). Because *in situ* water chemistry can vary considerably over time, measurements should be taken during each sampling visit. Note that the following procedure is for taking point measurements rather than measuring diel variation or extremes.

Procedure

Before arriving at the field sites read the instruction manual for portable meters and check batteries. Check to see that the meters are functioning properly and are calibrated. Use standards to calibrate meters at least daily. Record pre- and post-calibration values on the instrument log sheet (Figure 3-60). Calibrate the dissolved oxygen meter for the appropriate elevation for each study site (elevation can be read from the 7.5 min. topographic maps, or GPS units). Suggested data quality objectives (DQO) for *in situ* water chemistry are shown in Table 3.16.1.

Date	Instrument	Inspected by	Pass inspection (Y or N)	Degree deviated from calibration standard (+ or - include units)	Recalibrated (Y or N)
9/22/03	Hydrolab Quanta (#2)	KMF	Y	pH @ 3: +0.1 @ 7: +0.2	Y
9/22/03	Hydrolab Quanta (#2)	KMF	Y	Cond @ 45: +7 µS @ 147: -12 µS	Y

Figure 3-60 An example of an instrument inspection and calibration log sheet.

Delineate the 30-m study reach so that the measuring tape is positioned along the thalweg. *In situ* water chemistry measurements should be taken before all other measurements. Note the location and time of measurements on the field form (Figure 3-61). If the pH, conductivity, and dissolved oxygen meters also measure temperature, consistently use one of these to measure temperature. When available, submerge probes in the area of flowing water (note that some probes cannot be completely submerged) and monitor the readout until values stabilize. Where hydrologic condition is “surface water in pools only” (see Section 3.1 for designation of hydrologic condition), *in situ* water chemistry should be measured in all pools where biological samples are taken. Write values for measurements in the appropriate cells on the field form (Figure 3.16.2). Record time of day when measurements were taken in "comments" section. If additional space is needed use space on page 3 of the field form. Turn off meters and then repeat measurements to meet DQO in Table 3.16.1. If repeat measurements do not meet DQO standards then flag those values on the field forms to indicate that they are suspect.

Table 3-2 Data Quality Objectives (DQO) for in situ water chemistry measurements

Measurement	Data Quality Required
Temperature	two measurements taken with less than 5% deviation.
pH	two measurements with less than 10% deviation
Dissolved Oxygen (DO)	two measurements with less than 10% deviation
Conductivity	two measurements with less than 10% deviation

IN SITU WATER QUALITY MEASUREMENTS					
Location of Measurements	Cond (μS/cm)	Temp (°C)	DO (mg/l)	pH	Comments
10 m	**24**	**10**	**1.23**	**6.3**	**@ 9:30 am**

Figure 3-61 Appropriate locations for recording in situ water quality measurements on page 1 of field forms, example values shown in red.

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Equipment and supplies
Measuring tape (50 m)
pH meter

Conductivity meter
Dissolved oxygen meter
Thermometer
Associated calibration standards for meters
Field form
Spare batteries

3.17 Measuring riparian canopy cover

General

This subsection provides instructions for measuring riparian canopy cover for headwater streams. Canopy cover is a useful measure of riparian condition that can strongly influence the structure (e.g, organic substrate, algal biomass) and function (e.g., primary production) of streams (Gregory et al. 1991, Naiman and Decamps 1997). This procedure is a modification of the original method described by Lemmon (1957) for use with a convex spherical densiometer. Measurements of irradiance with pyrheliometers or photosynthetically active radiation with quanta sensors provide quantitative measures of incoming solar energy (Moulton et al 2002, also see reviews by Hauer and Hill 1996, Jennings et al. 1999). A disadvantage of these measures is their sensitivity to cloud cover and angle of the sun. Another method for estimating canopy cover is the use of fisheye or hemispheric photography (Davies-Colley and Payne 1998, Ringold et al. 2003, Kelly and Krueger 2005). Especially with the advent of digital photography and analytical software this method offers short processing times, consistency, and precision. One limitation of photographic methods is ensuring proper lighting conditions. Direct overhead sunlight, reflection on vegetation, and dark clouds can lead to data misinterpretation (Kelly and Krueger 2005). Measurements of canopy cover are taken during each season (spring and summer) because this will likely change through time.

Procedure

Delineate the 30-m study reach so that the measuring tape is positioned along the thalweg. Canopy cover is measured while facing upstream, downstream, left bank, and right bank at the 15-m mark of the study reach.

Canopy measurements are taken by holding the densitometer about 0.3 m above the stream surface at the thalweg. Level the densitometer using the bubble level and position it so that your reflection is just below the mirror grid (Figure 3-62). Calculate the percent cover by first identifying the grid intersections (of 37 total intersections) that are covered by vegetation (e.g., leaves, branches, trunks) or stream banks. Percent cover values for intersections are equivalent to the number of squares meeting at an intersection (Figure 3-62), ranging from 1% to 4%. For example, an intersection where 4 squares meet and is covered by vegetation is equivalent to 4% cover (Note that based on this value system, the total percentage is 98% and therefore approximates 100%.). Sum percent cover and record in the appropriate cell on the field form (Figure 3-63).

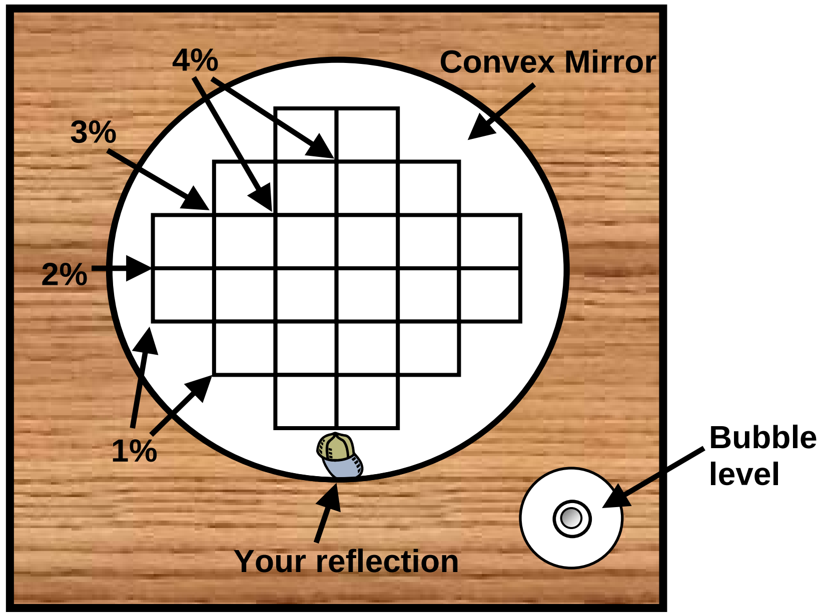

Figure 3-62 Plan view of a convex spherical densitometer, showing percent cover values associated with intersections. Values are equivalent to the number of squares meeting at each intersection.

Where canopy over the stream channel is heavy, it is more efficient to measure the percentage of open by identifying and summing grid intersections values that are not covered by vegetation, etc. Percent canopy cover is then simply calculated by subtracting total percent open canopy from 100%.

DISTANCE TO NEAREST SURFACE WATER (m)	CHANNEL SLOPE (%) (for three 10 m sections of study reach)			% CANOPY COVER (facing upstream, downstream, right & left banks			
0 <100 100-500 >500							

Figure 3-63 Appropriate location for recording percent canopy cover on page 1 of field forms.

The methods used by USEPA's EMAP and USGS's National Water-Quality Monitoring Program (NAWQA) differ slightly from the method discussed above. Rather than using all 37 intersections on the convex mirror for measurements, only 17 intersections are evaluated (Figure. 3-64, Fitzpatrick et al. 1998, Kaufmann and Robison 1998). A "V" is taped on the mirror surface to delimit the 17 intersections. This modification is intended to minimize repeated observations of cover structures during multiple readings from the same position (e.g., facing upstream, downstream, left and right bank) and reduces measurement time (Strichler 1959). Each intersection is weighted equally, rather than by the number of squares meeting at the intersections. The number of covered intersections is recorded for measurements facing upstream, downstream, left and right banks (standing at mid-channel) for the 11 transects (per study reach) in the EMAP protocol (Kaufmann and Robison 1998), whereas two measurements, facing the each bank at the water's edge, are taken at the 11 transects (per study reach) in the National Water Quality Assessment (NAQWA) protocol (Fitzpatrick et al. 1998). The NAQWA protocol measures canopy closure, rather than canopy cover (also called canopy density). Canopy closure includes the overhead area bracketed by vegetation, whereas canopy density includes only area of sky completely blocked by vegetation. Canopy closure is intended to be less influenced by season (i.e., leaf abscission) than canopy density (Strichler 1959). For both protocols, percent cover or closure is calculated as the ratio of covered to total intersections.

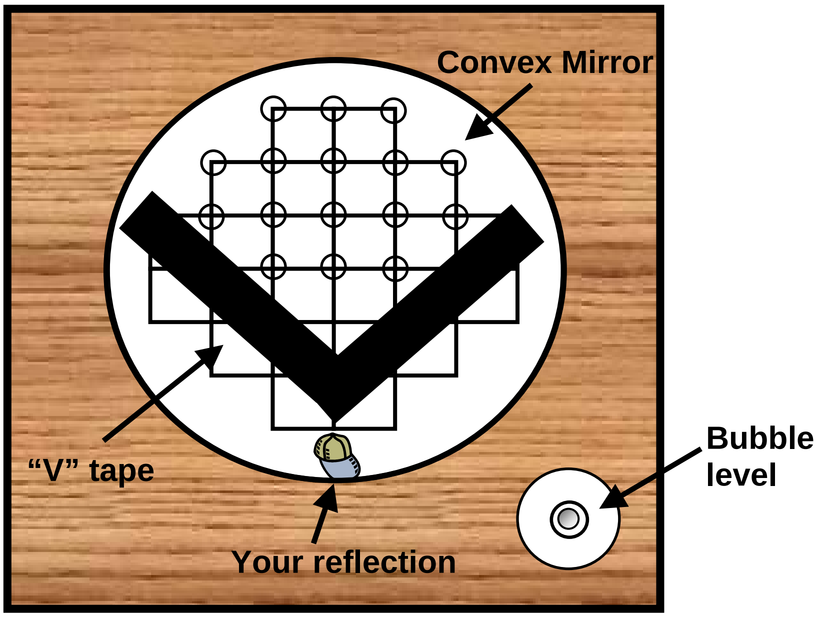

Figure 3-64 Plan view of a convex spherical densitometer, modified for measuring over 17 intersections (open circles) that are delimited by a "V" taped to the convex mirror.

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Equipment and supplies

Measuring tape (50 m)
Convex spherical densiometer
Field forms