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QUANTIFYING PHYSICAL HABITAT
IN
WADEABLE STREAMS

by

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ABSTRACT

We describe concepts, rationale, and analytical procedures for characterizing physical habitat in wadeable streams based on raw data generated from methods similar or equal to those of Kaufmann and Robison (1998) that are used by the U.S. Environmental Protection Agency (USEPA) in its Environmental Monitoring and Assessment Program (EMAP). We provide guidance for calculating measures or indices of stream size and gradient, sinuosity, substrate size and stability, habitat complexity and cover, woody debris size and abundance, residual pool dimensions and frequency, riparian vegetation cover and structure, anthropogenic disturbances, and channel-riparian interaction. The EMAP surveys locate sample reaches using a randomized, systematic design (Stevens and Olsen 1999). Within sample reaches, the EMAP field approach also employs a randomized, systematic design to systematically locate and space habitat observations on stream reaches, each of which have a length 40 times their lowflow wetted width. Two-person crews typically complete EMAP habitat measurements in 1.5 to 3.5 hours of field time. While this time commitment is greater than that required for more qualitative methods, these more quantitative methods are more repeatable (more precise). For EMAP field crews in which four people collect a variety of physical, chemical, and biological information, this level of effort is about 25% to 33% of that spent on biological measures.

We evaluated sampling precision of field habitat survey methods employed by EMAP in several hundred streams in Oregon and the Mid-Atlantic region, comparing variance among streams ("signal") with variance between repeat stream visits (measurement "noise"). Metrics with S/N <2.0 distort estimates of regional distributions based on survey results, and severely limit analyses of associations by regression and correlation; when metric S/N ratios are $10, these problems are relatively insignificant. Quantitative channel morphology and riparian canopy densiometer measurements had precise S/N ratios mostly between 6 and 20. Flow-sensitivity and ambiguity in features to be measured limited precision of some physical measurements, but still resulted in metrics of moderate to high precision (S/N 2-15). Semi-quantitative measurements (e.g. substrate size) and visual presence-absence determinations (e.g., canopy presence) also had moderate to high precision (S/N 2-16) The semi-quantitative metric group also included several integrated metrics, such as mean substrate diameter, that were very precise (S/N >20). Visual estimates of riparian canopy cover tended to have low to moderate precision S/N <4.0, as did visual estimates of fish cover. Commonly used flow-sensitive measures

(e.g. riffle/pool and width/depth ratios) and qualitative visual assessments (e.g., EPA's Rapid Bioassessment Protocol habitat scores) tended to be imprecise (S/N <2). While visual judgement methods are attractive because of their rapidity in the field and in data reduction, their lack of precision limits their use in many applications. The final measure of the utility of a habitat approach is whether it is useful for interpreting controls on biota or impacts of human activity. We recommend that researchers examine a full suite of habitat variables and consider the patterns of natural and anthropogenic controls and disturbances in their region, the type of biota, and their own particular research objectives, in addition to the precision of the habitat variables.

EXECUTIVE SUMMARY

We provide here a general description, rationale, and analytical guidance for entering, verifying, summarizing, interpreting, and evaluating the precision of field data generated by applying the physical habitat assessment methods similar or equal to those described by Kaufmann and Robison (1994,1998). Those methods are currently used as the standard method of stream habitat data collection by the U.S. Environmental Protection Agency (USEPA) in its Environmental Monitoring and Assessment Program (EMAP). In the broadest sense, stream habitat includes all the physical, chemical, and biological attributes that influence or provide sustenance to organisms within the stream (Karr et al., 1986). Physical habitat, for the purposes of EMAP field measurements, primarily concerns physical elements, but includes some biological elements, such as aquatic macrophyte, riparian vegetation, and large woody debris that are important in providing or controlling habitat structure. Using the EMAP field physical habitat raw measurements as a starting point, we provide guidance for calculating measures or indices of stream size and gradient, substrate size and stability, habitat complexity and cover, riparian vegetation cover and structure, anthropogenic disturbances, and channel-riparian interaction.

The EMAP surveys locate sample reaches using a randomized, systematic design (Stevens and Olsen 1999) that results in a set of sample sites that is regionally representative. Each sample reach is a length of stream channel 40 times as long as its wetted channel width at the time of sampling. The EMAP field approach also employs a randomized, systematic design to specify the location and spacing of habitat measurements and observations within sample reaches (Kaufmann and Robison 1994,1998). This reach-scale field sampling design at the makes calculating spatially representative stream reach habitat characterizations straightforward.

This report will help researchers calculate and evaluate the utility of metrics that summarize field data generated using EMAP methods and other similar quantitative habitat survey methods. The derived reach-level metrics can then be used in analyses to interpret regional patterns or temporal trends in habitat conditions, as well as associations with biological or other data. The field-based physical habitat measurements from EMAP habitat characterization are best used as a complement to other information (e.g., water chemistry, temperature, and remote imagery of basin land use and land cover). The combined data

analyses will more comprehensively describe additional habitat attributes and larger scales of physical habitat or human disturbance than are evaluated by the field assessment alone.

The physical habitat data collected by the EMAP and Regional EMAP (REMAP) field techniques described by Kaufmann and Robison (1994,1998) produce a large amount of data that, for most uses, must be condensed to stream reach-level summaries that describe particular aspects of physical habitat. In Appendix II, we describe a number of validation and verification activities that are necessary before calculating numerical summaries, metrics or descriptions of stream habitat from raw habitat survey data. These activities include checking and reconciling data file structure, missing values, values out of range, and illogical or unlikely combinations of variable values based on ecoregion, channel morphology, or other internal relationships among variables. The stream reach metric calculation approaches we recommend include simple statistical summaries, areal cover estimates from areal cover class data, proximity-weighted disturbance indices, and measures of woody debris abundance, residual pool dimensions and frequency, sinuosity, and bed substrate stability. We describe procedures for calculating these reach-level summary statistics, and have appended a CD (compact disk) containing documented SAS (Statistical Applications Software) computer code to make these calculations.

Effective environmental policy decisions require stream habitat information that is accurate, precise, and relevant. We evaluated sampling precision of field habitat survey methods employed by the USEPA's EMAP in several hundred streams in Oregon and the Mid-Atlantic region. We compared variance among streams ("signal") with variance between repeat stream visits (measurement "noise"). Quantitative channel morphology and riparian canopy densiometer measurements were precise (signal:noise (S/N) ratios mostly 6:1 to 20:1) when applied to features that are clearly defined and not excessively sensitive to differences in flow stage. Flow-sensitivity (e.g. width, depth) and ambiguity in features to be measured (e.g. incision height) limited precision, but still resulted in metrics generally within the moderate to high precision range (S/N 2.0 to 15). Semi-quantitative measurements (e.g. substrate size metrics) and presence-absence determinations (e.g. visual estimates of canopy presence) also had moderate to high precision (S/N 2.0 to 16) that was generally intermediate in precision between that of the two groups of quantitative metrics, those that are flow-sensitive and those that are flow-independent. The semi-quantitative metric group also included several integrated metrics, such as mean substrate diameter, that were very precise (S/N >20). Visual estimates of riparian canopy cover tended to have low to moderate precision S/N <4.0, as did visual estimates of the areal cover of fish concealment features. Commonly used flow-sensitive measures (e.g. riffle/pool and width/depth ratios) and qualitative visual assessments (e.g. EPA's Rapid Bioassessment Protocol habitat scores) tended to be imprecise (S/N <2).

Based on our results, we make the following generalizations concerning the precision of habitat measurement and assessment approaches:

- Measurements are more precise than visual estimates, but carefully-designed visual estimation procedures can be nearly as precise as measurements. To enhance precision, these visual observations are limited to measurable characteristics (e.g. cover or presence), rather than judgements of habitat quality, and they are made at multiple locations within a reach.

- Flow-sensitivity and complex definitions of habitat features can degrade precision of quantitative measurements (e.g. bankfull height and incision).

- Flow-sensitivity and subjectivity in habitat-unit classifications (e.g. %Pool) can seriously limit their usefulness in contrasting stream habitat among streams or in tracking changes in habitat through time.

- The precision of multiple visual cover-class determinations can be improved by re-interpreting this information as extent of presence-absence of some defined feature (e.g. summed vegetation cover in two layers reinterpreted as percent of observations in which cover is >0% in both layers), but perhaps at the expense of decreased sensitivity to stress.

- The precision of separate metrics can be improved by combining them into more integrated metrics. (e.g., the precision of %Substrate <16mm diameter is more precise than separate metrics of %Fine Gravel, %Sand, and %Fines; the precision of %Pools+Glides is more precise than %Pools), but perhaps at the expense of decreased sensitivity to stress..

- While visual judgement methods are attractive because of their rapidity in the field and in data reduction, their lack of precision limits their use in many applications.

- At least 20 within-season pairs of repeat visits to 8 to 20 field sites spread over several years are required for confident assessment of within-season precision in physical habitat metrics. These repeat samples are ideally drawn as a random or stratified random sub-sample from a regional probability sample of stream reaches.

- Metrics with S/N < 2.0 distort estimates of regional distributions based on survey results, and severely limit analyses of associations by regression and correlation.

- When metric S/N variance ratios are $10, field measurement variance and short-term temporal fluctuations cause relatively insignificant error and distortion in estimates of regional population distribution functions and offer relatively insignificant obstacles to analyses of association using regression and correlation.

In EMAP field surveys, two people typically complete the specified channel, riparian, and discharge measurements required in the quantitative approach within 1.5 to 3.5 hours of field time. In addition to Physical Habitat data, a 4-person EMAP field crew collects chemical water samples and data on fish assemblages, macroinvertebrates, periphyton, and frequently benthic metabolism. The time commitment for collecting physical habitat information is between 25% and 33% of the effort expended on biological measures, a balance we feel is appropriate. While the time commitment for collecting data using the EMAP habitat methods is greater than that required for more qualitative methods, the greater expenditure results in more repeatable (more precise) characterizations and assessments. The quantitative methods also provide greater flexibility in interpretation and re-interpretation than do the qualitative habitat scoring approaches, because interpretations of habitat quality are made during data analysis, rather than during field data collection.

The final measure of the utility of a habitat characterization approach is whether it contains useful information for interpreting controls on the biota or impacts of human activity. In regional surveys, or in temporal series, this measure of performance is demonstrated through analysis of associations among variables. As with precision, this aspect of habitat metric utility is also region-specific, and dependent on the type of biological assemblage of interest and the type of human disturbances present. We offer guidance to researchers in limiting the suite of habitat variables to be considered in analysis, based on our own research and that of others who have used EMAP habitat data in a variety of multivariate and other types of investigations associating habitat with fish, macroinvertebrates, periphyton, benthic metabolism, and landscape disturbances. The "short list" of 18 habitat variables includes representatives that we consider generally the most important from each of the 7 aspects of habitat presented in the introduction to this report. However, we recommend that researchers examine the full suite of variables available and take into consideration the patterns of natural and anthropogenic controls and disturbances in their region, the type of biota, and their own particular research objectives, in addition to the precision of the habitat variables.

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ACRONYMS, ABBREVIATIONS, AND MEASUREMENT UNITS

Acronyms and Abbreviations

ANOVA	Analysis of variance
CV	Coefficient of variation
DBH	Diameter at breast height
EMAP	Environmental Monitoring and Assessment Program
EMAP-SW	Environmental Monitoring and Assessment Program-Surface Waters Resource Group
EPA	(U.S.) Environmental Protection Agency
GPS	Global positioning system
LWD	Large woody debris
MAHA	Mid-Atlantic Highlands Assessment
MAIA	Mid-Atlantic Integrated Assessment
NAWQA	National Water-Quality Assessment Program
NHEERL	National Health and Environmental Effects Research Laboratory
ORD	Office of Research and Development
OSU	Oregon State University
PHab	physical habitat
QA	quality assurance
QC	quality control
RBP	(EPA) Rapid Bioassessment Protocol
REMAP	Regional Environmental Monitoring and Assessment Program
RMSE	Root mean square error
SD	Standard deviation
USEPA	U.S. Environmental Protection Agency
USGS	United States Geological Survey
WED	Western Ecology Division (Corvallis, OR)

ACRONYMS, ABBREVIATIONS, AND MEASUREMENT UNITS (CONTINUED)

Measurement Units

cm	centimeter
ft	feet
in	inches
hr	hours
kg	kilogram
m	meter
m^2	square meters
m^3	cubic meters
mm	millimeter
N	Newton
s	second

1 INTRODUCTION

1.1 PURPOSE OF THIS REPORT

We provide here a general description, rationale, and analytical guidance for verifying and summarizing field data generated by methods equal or similar to the quantitative and semi-quantitative habitat characterizations described by Kaufmann and Robison (1994, 1998). We also present results concerning the precision of these habitat methods, based upon field surveys in a variety of settings in the United States. The field approach described by Kaufmann and Robison (1994, 1998) has been used as the standard method of stream habitat data collection by the EPA's Environmental Monitoring and Assessment Program (EMAP), by various Regional Environmental Monitoring and Assessment Programs (REMAPs) in many states and EPA Regions, by several National Parks, and by private industries. Thousands of streams have been sampled using EMAP methods throughout the Mid-Atlantic region, the central U.S., Colorado, California, and the Pacific Northwest between 1993 and 1998. This guide will help researchers to calculate and evaluate the utility of metrics that summarize field data generated by these EMAP methods and similar approaches. The reach metrics derived from these field data can then be analyzed to interpret regional patterns or temporal trends in habitat conditions, and associations with biological or other data. Field-based physical habitat measurements from EMAP habitat characterizations are best used as a complement to other information (e.g., water chemistry, temperature, and remote imagery of basin land use and land cover). The combined data analyses will more comprehensively describe additional habitat attributes and larger scales of physical habitat or human disturbance than are evaluated by the field assessment alone. This entire report, including appendices, may also be available in the future on the EMAP website (*http://www.epa.gov/emap*).

1.2 PHYSICAL HABITAT COMPONENTS

In its broadest sense, habitat in streams includes all physical, chemical, and biological attributes that influence or provide sustenance to organisms within the stream (Karr et al., 1986). *Physical habitat* is an operational definition often used by stream ecologists to refer to the structural attributes of habitat, and typically excludes water chemistry and physical attributes such as water clarity, temperature, and light intensity. On the other hand, aquatic macrophyte, riparian vegetation, and large woody debris measurements are commonly included in physical habitat assessments (e.g., Platts et al., 1983; Hankin and Reeves, 1988; Kaufmann and Robison, 1994, 1998; Overton et al., 1997; Stanfield et al., 1997) because of their role in modifying habitat structure and light inputs, although they are actually biological measures. Summarizing the habitat results of a workshop conducted by EMAP on stream monitoring design, Kaufmann (1993) identified seven general physical habitat attributes important in influencing stream ecology:

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

Like biological characteristics, all these habitat attributes vary naturally – including the type and intensity of anthropogenic disturbance. Even in the absence of anthropogenic disturbances, expected values of the other habitat attributes vary according to their ecological setting. Within a given physiographic-climatic region, stream drainage area and overall stream gradient are likely to be strong natural determinants of many aspects of stream habitat, because of their influence on discharge, flood stage, and stream power (the product of discharge times gradient). In addition, all these attributes may be directly or indirectly altered by anthropogenic activities.

Stream Size is the primary determinant of the quantity of lotic habitat. The general size class of a stream, based on its drainage area, stream order or annual runoff, is relatively immutable. However, anthropogenic activities frequently alter channel dimensions, floods, and low flow discharges, therefore altering the quantity and quality of aquatic habitat. Kaufmann (1993) recommended that monitoring programs make field measurements of thalweg depth, depth cross-sections, wetted and bankfull width, and discharge as indicators of stream size. Field measurement of "baseflow" using a current meter at one channel cross-section is typical of most habitat monitoring procedures, and supplements an approximation of mean annual discharge calculated from watershed area and generalized runoff data (e.g., runoff maps by Bishop et al., 1998).

Channel Gradient is a very important determinant of the potential energy in a stream that can be converted into water velocity (Leopold et al., 1964). If discharge, channel cross-section area, channel shape, and hydraulic roughness are all held constant, then the velocity of water in a stream is determined by the water surface gradient (Chow, 1959). The water surface gradient of a reach is essential for calculating stream power, $\mathbf{QS}$, and bed shear stress, $\boldsymbol{\rho}\mathbf{gRS}$, where $\mathbf{Q}$=discharge, $\mathbf{S}$=water surface slope, $\mathbf{R}$=hydraulic radius (channel cross-section area ÷ wetted perimeter), $\boldsymbol{\rho}$=mass density of water, and $\mathbf{g}$=gravitational acceleration (Dingman, 1984). These hydraulic characteristics can, in turn, be used to estimate the bedload transport capacity and bed particle size that a stream can move under various flow conditions. By comparing observed and mobile particle sizes (Dingman, 1984), we can evaluate the stability of the stream bed and infer whether the sediment supply to the stream may be augmented from enhanced upslope erosion resulting from anthropogenic and other disturbances.

<u>Channel Substrate</u>: Bottom characteristics, including aquatic macrovegetation, are often cited as major controls on the species composition of macroinvertebrate, periphyton, and fish assemblages in streams (e.g., Hynes, 1972; Cummins, 1974; Platts et al., 1983). Along with bedform (e.g., riffles and pools), substrate size influences the hydraulic roughness and consequently the range of water velocities in a stream channel. It also influences the size range of interstices that provide living space and cover for macroinvertebrates, salamanders, sculpins, and darters. Substrate characteristics are often sensitive indicators of the effects of human activities on streams (MacDonald et al., 1991). Decreases in the mean substrate size and increases in the percentage of fine sediments, for example, may destabilize channels and indicate changes in the rates of upland erosion and sediment supply (Dietrich et al., 1989). Consequently, changes in substrate size distributions are often indicative of catchment and streamside disturbances that alter hillslope erosion or mobilize sediment. Accumulations of fine substrate particles also fill the interstices of coarser bed materials, reducing habitat space and its availability for benthic fish and macroinvertebrates (Platts et al., 1983; Hawkins et al., 1983; Rinne, 1988). In addition, circulation of well-oxygenated water is impeded when fine particles embed coarser, more permeable substrates. Most practitioners (e.g., Platts et al., 1983; Bauer and Burton, 1993) recommend a systematic “pebble count,” as described by Wolman (1954), to quantify the substrate size distribution, with visual assessments of substrate embeddedness as described by Platts et al. (1983). The EPA stream monitoring design workshop (Kaufmann, 1993) recommended also including estimates of aquatic macrophyte and filamentous algal cover because of their role as substrates and because their presence may be a useful indication of water velocities and trophic status.

<u>Habitat Complexity and Cover for Aquatic Fauna</u>: When other needs are met, complex habitat with abundant cover should generally support greater biodiversity than simple habitats that lack cover (Gorman and Karr, 1978; Benson and Magnuson, 1992). Habitat complexity is, however, difficult to quantify. The EPA’s stream monitoring workshop

participants agreed that the following components of complexity should be assessed (Kaufmann, 1993):

- Habitat Type and Distribution (e.g., Bisson et al., 1982; Frissell et al., 1986; Hankin and Reeves ,1988; Hawkins et al., 1993; Montgomery and Buffington, 1993, 1997, 1998).
- Large Woody Debris count and size (e.g., Harmon et al., 1986; Robison and Beschta, 1990).
- In-Channel Cover: Percentage of areal cover of various types of features that could provide fish concealment, including undercut banks, overhanging vegetation, large woody debris, boulders (e.g., Hankin and Reeves, 1988; Kaufmann and Whittier, 1997; Kaufmann et al., in review).
- Residual pools, channel complexity, hydraulic roughness (e.g.,. Lisle 1982, 1987; Kaufmann, 1987a, 1987b; Robison and Kaufmann, 1994).
- Width variance and bank sinuosity (Moore and Gregory, 1988).

Estimates of residual pool (Lisle 1982, 1987) frequency and size distribution, and reach-scale indices of slackwater volume, channel morphometric complexity, and hydraulic roughness can be quantitatively estimated from simple and rapid systematic profiles of width and depth along stream reaches (O'Neill and Abrahams, 1984; Kaufmann, 1987a, 1987b; Robison and Beschta, 1990; Stack, 1989; Kaufmann and Robison, 1994, 1998; Robison and Kaufmann, 1994, 1998). Indices of morphometric and hydraulic complexity may be correlated with nutrient retentivity and may also be indicators of high flow velocity cover in a stream reach (Kaufmann, 1987a, 1987b). Residual pool depths and volumes also give an indication of habitat space during extremely low flows (Lisle, 1986, 1987).

Riparian Vegetation: The importance of riparian vegetation to channel structure, cover, shading, nutrient inputs, large woody debris, wildlife corridors, and as a buffer against anthropogenic perturbations is well recognized (Naiman et al., 1988; Gregory et al., 1991). Riparian canopy cover over a stream is important not only for its role in moderating stream temperatures through shading, but also as an indicator of conditions that control bank stability and the potential for inputs of coarse and fine particulate organic material (MacDonald et al., 1991). Organic inputs from riparian vegetation become food for stream organisms and provide structure that creates and maintains complex channel habitat. The EPA stream monitoring workshop participants recommended evaluating channel shading (using canopy densiometer measurements) and riparian vegetation structure [by visual estimates of the areal cover and type of vegetation in three layers (canopy, mid-layer, and ground cover)], distinguishing evergreen from deciduous vegetation, and woody trees and shrubs from herbaceous vegetation.

Anthropogenic Alterations and Disturbances: Land use, buildings, and other evidence of human activities in the stream channel and its riparian zone may, in themselves, serve as habitat quality indicators; they may also serve as diagnostic indicators of anthropogenic stress. The EPA’s stream monitoring workshop recommended field assessment of the frequency and extent of both in-channel and near-channel human activities and disturbances. In-channel disturbances include channel revetment, pipes, straightening, bridges, culverts, and trash (e.g., car bodies, grocery carts, pavement blocks, etc.). Near-channel riparian disturbances include buildings, lawns, roads, pastures, orchards, and row crops.

Channel/Riparian Interaction: Anthropogenic activities including grazing, farming, flood control, channel revetment, and urbanization can result in the separation of streams from their floodplains and riparian zones. The secondary effects on channel structure, riparian vegetation, and ephemeral aquatic habitats can markedly affect biotic integrity of stream ecosystems. Expectations for the potential magnitude and extent of interaction of streams with the terrestrial environment differ for streams according to their channel type and degree of valley constraint (Rosgen, 1985, 1994; Gregory et al., 1991; Stanford and Ward, 1993). Possible metrics that might contribute to an index of channel/riparian interaction include channel sinuosity, channel incision, and channel morphometric complexity (based on the spatial pattern and variability in channel width and depth profile data).

1.3 SAMPLING CONSIDERATIONS

1.3.1 Sampling Season

The EMAP stream indicator development workshop participants concluded that, although physical habitat could be evaluated during any season, it would be most effective if habitat evaluations were concurrent with biological sampling (Hughes, 1993). Generally the most advantageous time for biological sampling in regional scale monitoring programs was identified as a low flow season after leaf out and not closely following major flood events. For most of the United States, this is the summer season, although some regional differences are likely and should be examined. For example, late summer (August) might be appropriate for snowmelt systems in the Rocky Mountains, while spring might be more appropriate in parts of the arid southwest.

1.3.2 Sample Reach Length

Local habitat shows repeating patterns of variation that are associated with riffle-pool structure and meander bend morphology. If field sampling reaches are not long enough to incorporate these patterns, the choice of the exact reach location will unduly influence habitat characteristics observed in the field. For example, comparing a pool reach in a disturbed basin with a riffle reach in a pristine basin will yield misleading results, no matter how well the basins are matched in size, topography, climate, and lithology. Recognizing the advantages of standardized reach lengths that are long enough to incorporate local habitat-scale variation, large-scale monitoring and assessment programs in the U.S. and Canada sample reach lengths that increase in proportion to stream size, typically measured as multiples of wetted or bankfull width. Based on fish assemblage and habitat sampling requirements, the U.S. EPA's EMAP program specifies sample reaches that are 40 times their low flow wetted width (Klemm and Lazorchak, 1994; Lazorchak et al., 1998), the U.S. Geological Survey's NAWQA program specifies reach lengths of 20 times wetted width (Fitzpatrick et al., 1998), Simonson et al. (1994) specifies 30 to 35 times wetted width for Upper Midwest streams, and Ontario Ministry of Environment specifies reaches 20 times bankfull width (Stanfield et al., 1997).

1.3.3 Intermittent and Ephemeral Streams

The EMAP stream indicator development workshop participants felt that most perennial stream habitat measures would be appropriate for intermittent and ephemeral streams (Kaufmann, 1993). It is important to make such measurements on dry and near-dry channels in order to characterize available aquatic habitat space and quantify changes over time that might result from such influences as climate change and irrigation withdrawal. Understandably, one would obtain values of zero for measures such as discharge, pool depths, and wetted width in a dry stream.

1.3.4 Habitat Characterization, Interpretation, and Replicability

There are two conceptually different approaches to assessing habitat characteristics or interpreting habitat quality. In one approach, exemplified by the EPA's Rapid Bioassessment Protocols (Plafkin et al., 1989; Barbour and Stribling, 1991; Barbour et al., 1997), habitat quality is interpreted directly in the field by biologists while sampling the stream reach. This approach takes about 15 to 20 minutes of field time and quickly yields a habitat quality assessment. However, the quality of that assessment depends upon the knowledge and experience of the field observer to make proper and consistent interpretations of both the natural expectations (potentials) and the biological consequences (quality) that can be attributed to the observed physical attributes.

The second conceptual approach confines observations to habitat characteristics themselves (whether they are quantitative or qualitative). The regional patterns and trends in these habitat characteristics themselves may well be of interest, as might be their association with stream biota or watershed land use. Furthermore, a habitat quality index may be derived by ascribing quality scoring to the habitat measurements as part of the data analysis process. Typically, this second type of habitat assessment approach employs more quantitative data collection, as exemplified by field methods for EMAP (Kaufmann and Robison 1994, 1998), a habitat characterization framework proposed by Simonson et al. (1994), the field methods of the U.S. Geological Survey's National Water Quality Assessment (NAWQA) program (Meador et al., 1993; Fitzpatrick et al., 1998) and others cited by Gurtz and Muir (1994). These field approaches typically define a reach length proportional to stream width and employ transect measurements that are systematically spaced (Kaufmann and Robison, 1994, 1998; Simonson et al., 1994; Fitzpatrick et al., 1998), or spaced by judgement to be representative (Meador et al., 1993). They usually include measurement of substrate, channel and bank dimensions, riparian canopy cover, discharge, gradient, sinuosity, in-channel cover features, and counts of large woody debris and riparian human disturbances. They may employ systematic visual estimates of substrate embeddedness, fish cover features, habitat types, and riparian vegetation structure. The field time requirement for these more quantitative habitat assessment methods is usually 1.5 to 3.5 hours with a crew of two people. Because of the greater amount of data collected, they also require more time for data summarization, analysis, and interpretation. On the other hand, the more quantitative methods and less ambiguous field measurements result in considerably greater precision when compared with qualitative approaches.

2 SYNOPSIS OF EMAP PHYSICAL HABITAT FIELD METHODS

2.1 DESIGN AND RATIONALE

This is not a field manual. We provide here only a synopsis of the EMAP field methods for physical habitat in wadeable streams, which are described in a detailed field training manual by Kaufmann and Robison (1994, 1998). Our purpose in the present document is to describe the data collection methods generally so that readers can fully understand the data reduction procedures and their rationale. Table 1 lists the components of the EMAP field methods for physical habitat. These methods are most efficiently applied during low flow conditions and after leafout of terrestrial vegetation, but may be applied during other seasons and at higher flows, except as limited by considerations of safety. It is designed for monitoring applications where robust, quantitative descriptions of reach-scale habitat are needed, but time is limited.

The midpoint locations of sample reaches in the EMAP surveys are specified using a randomized, systematic design (Stevens and Olsen, 1999). The EMAP field protocol defines the length of each sampling reach proportional to wetted stream width at the time of sampling, and then systematically places measurements to represent the entire reach statistically. Field crews measure upstream and downstream distances of 20 times the wetted channel width from the predetermined midpoints to center each 40 channel-width field sampling reach (Lazorchak et al., 1998). A minimum reach length is set at 150 m. Within each sample reach, the approach described by Kaufmann and Robison (1994, 1998) employs a systematic sampling design to locate the actual habitat measurements and observations. Once the downstream end of the reach is located, 11 transect positions are set at 1/10th of the sample reach length, or four times the mean wetted channel width apart. Thalweg depth measurements are spaced at very tight intervals 1/100th the sample reach length apart (1/150th in streams < 2.5 m wide); whereas channel wetted width, cross-section profiles, substrate, bank characteristics and riparian vegetation structure are measured at larger spacings (Figure 1). Woody debris is tallied along the full length of the stream reach, and discharge is measured at one location (Table 1). A set of completed EMAP field forms for habitat data collection is presented in Appendix A.

The randomized, systematic sampling design minimizes bias in the placement and positioning of measurements in EMAP field sampling and facilitates the calculation of

TABLE 1. COMPONENTS OF EMAP-SURFACE WATERS PHYSICAL HABITAT PROTOCOL

Adapted from Kaufmann and Robison (1994, 1998)

Component	Description
1. Longitudinal Profile:	Measure maximum (thalweg) depth, classify aquatic habitat, determine presence of soft/small sediment at 10-15 equally spaced intervals between each of 11 channel cross-sections (100-150 along entire reach). Measure wetted width at 11 channel cross-sections and midway between cross-sections (21 measurements).
2. Large Woody Debris:	Between each of the channel cross sections, tally large woody debris numbers within and above the bankfull channel according to size classes.
3. Channel and Riparian Cross-Sections:	at 11 cross-section stations placed at equal intervals along reach length: – Measure: channel cross section dimensions, bank height, undercut, angle (with rod and clinometer); gradient (clinometer), sinuosity (compass backsite), riparian canopy cover (densiometer). – Visually Estimate[a]: substrate size class and embeddedness; areal cover class and type (e.g., woody) of riparian vegetation in Canopy, Mid-Layer and Ground Cover; areal cover class of fish concealment features, aquatic macrophytes and filamentous algae. – Observe & Record[a]: human disturbances and their proximity to the channel.
4. Discharge:	In medium and large streams (defined later) measure water depth and velocity (at 0.6 depth with electromagnetic or impeller-type flow meter) at 15 to 20 equally spaced intervals across one carefully chosen channel cross-section. In very small streams, measure discharge with a portable weir or time the filling of a bucket.

[a] Substrate size class and embeddedness are estimated, and depth is measured for five particles taken at five equally-spaced points (2 marginal, 3 mid-channel) on each cross-section. The cross-section is defined by laying the surveyor's rod or tape to span the wetted channel. Woody debris is tallied over the distance between each cross-section and the next cross-section upstream. Riparian vegetation and human disturbances are observed 5m upstream and 5m downstream from the cross section station. They extend shoreward 10m from left and right banks. Fish cover types, aquatic macrophytes, and algae are observed within channel 5m upstream and 5m downstream from the cross section stations. These boundaries for visual observations are estimated by eye.

representative reach characteristics from raw data. Measures are taken over defined channel areas, and these sampling areas or points are located systematically at spacings that are proportional to low flow channel width (at the time of sampling). This systematic sampling design scales the sampling reach length and resolution in proportion to stream size. It also allows statistical and spatial series analyses of the data that are not possible with other designs. The authors of the EMAP methods strove to make the approach objective and repeatable by using easily learned, repeatable measures of physical habitat in

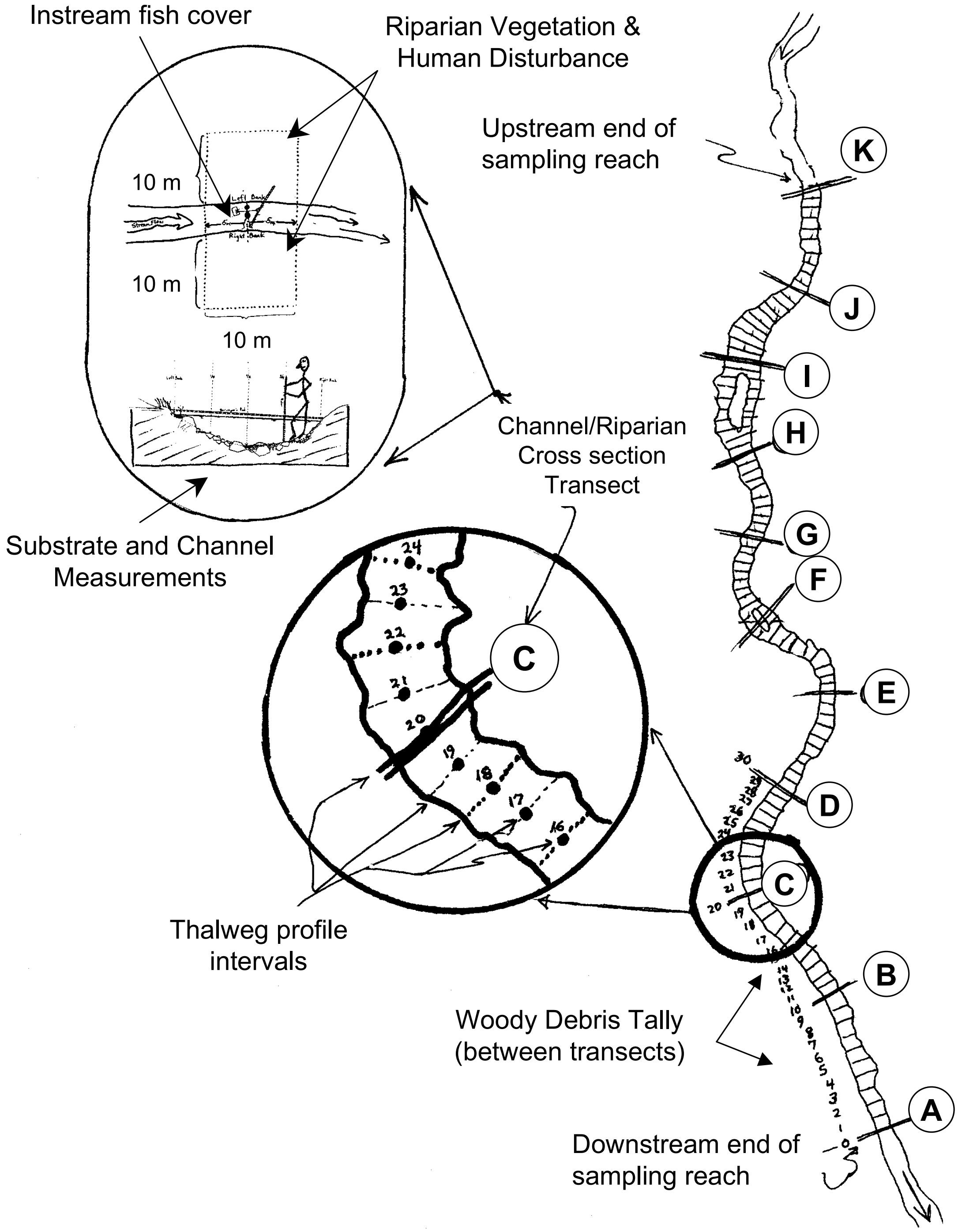

Figure 1. Sample reach layout (plan view). From Kaufmann and Robison, 1998.

place of estimation techniques wherever possible. Where estimation is employed, they direct the sampling crew to estimate attributes that are otherwise measurable, rather than to interpret the quality or importance of the attribute to biota or its importance as an indicator of disturbance directly. However, they included traditional visual classification of channel unit scale habitat types because they have been useful in past studies and enhance comparability with other work.

The field time commitment to gain repeatability and precision is greater than that required for more qualitative methods. In our field surveys, two people typically complete the specified channel, riparian, and discharge measurements in about 3 hours of field time. However, the time required can vary considerably with channel characteristics. On streams up to about 4 m wide with sparse woody debris, measurements can be completed in less than 2 hours. Crews may require up to 3.5 hours in large (> 10 m wide), complex streams with abundant woody debris and deep water. Modifications from earlier EMAP methods reduced the number of width measurements from 100 to 21 on sample reaches, reducing the time required to # 3.5 hours even on most large, complex wadeable streams.

2.2 HABITAT DATA COLLECTION

2.2.1 Longitudinal Profile

Data from the longitudinal profile allows calculation of indices of stream size, residual pool dimensions and spacing, pool sedimentation, channel complexity, and the relative proportions of habitat types such as riffles and pools. The longitudinal profile is a survey of thalweg (maximum) depth, wetted width, habitat class (*sensu* Bisson et al., 1982), and presence of loose substrate with diameter # 16 mm. Measurements are collected at 100 or 150 equally-spaced points along the centerline of the channel between the two ends of the stream reach. The "thalweg" is simply the deepest portion of the channel or cross-section. The longitudinal profile of EMAP habitat protocol proceeds upstream in the middle of the channel, rather than along the thalweg itself (though each thalweg depth measurement is taken at the deepest point at each cross-section or incremental distance upstream between cross-sections). The longitudinal profile measurements are spaced evenly a distance of ⅓ to ½ the channel width’s distance apart over the entire sample reach length. This close spacing insures that they do not "miss" deep areas and habitat units that are about as long as the channel is wide (Robison, 1998). A minimum sample reach length of 150 m is set in the EMAP stream sampling methods in order to adequately sample fish; the necessity for close depth sampling intervals results in a total of 150 thalweg sampling increments in streams with wetted widths < 2.5 m. With the exception of backwater pools, channel unit scale habitat classifications pertain to the main channel. In addition to the qualitative criteria listed in Table 2, these channel-unit scale habitat units should be at least as long as the channel is wide. Wetted width is measured perpendicular to the mid-channel line at 21 locations [at each of the 11 transects and midway between transects (Figure 1)].

2.2.2 Large Woody Debris Tally

The large woody debris (LWD) component of the EMAP Physical Habitat protocol allows quantitative estimates of the number, size, total volume and distribution of wood within the stream reach. The EMAP methods for LWD are a simplified adaptation of those described by Robison and Beschta (1990). LWD is defined here as woody material with small end diameter of at least 10 cm (4 inches), and length of at least 1.5 m (5 ft). For each LWD piece, field surveyors first visually estimate length and both end diameters in order to place it in one of twelve diameter and length categories. The diameter classes are 0.1 m to < 0.3 m, 0.3 m to < 0.6 m, 0.6 m to < 0.8 m, and > 0.8 m, based on the large end diameter. The length classes are 1.5m to < 5.0 m, 5 m to < 15 m, and $ 15 m, based on the portion of the LWD piece that is > 10 cm diameter. EMAP field crews separately tally all pieces of LWD that are at least partially in the channel up to bankfull height, then those that span above, but not into, the bankfull channel.

2.2.3 Slope and Sinuosity Measurements

The slope, or gradient, of the stream reach is useful in three different ways. First, the overall stream gradient is one of the major stream classification variables, giving an indication of potential water velocities and stream power, which are important controls on aquatic habitat and sediment transport within the reach. Second, the spatial variability of stream gradient is a measure of habitat complexity, as reflected in the diversity of water velocities and sediment sizes within the stream reach. Lastly, using methods described by Stack (1989) and Robison and Kaufmann (1994), the water surface slope will allow us to compute residual pool depths and volumes from the multiple depth and width measurements taken in the longitudinal profile. Compass bearings between cross section stations, along with the distances between stations, allow us to estimate the sinuosity of the channel (ratio of the length of the reach divided by the straight line distance between the two reach ends). Slope and bearing are measured by "backsiting" with a clinometer and compass downstream between cross-section transects B and A, C and B, D and C, etc., up to the 11th cross section K (Figure 1).

TABLE 2. HABITAT CLASSIFICATION AT CHANNEL UNIT SCALE[a]

Adapted from Kaufmann and Robison, (1998)

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

Code	Pool-Forming Element Category
N	Not Applicable, Habitat Unit is not a pool
W	Large Woody Debris.
R	Rootwad
B	Boulder or Bedrock
F	Unknown cause (unseen fluvial processes)
WR, RW, RBW	Combinations
OT	Other -- note in comments

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[a] Note that in order for a channel habitat unit to be distinguished, it must be at least as wide or long as the channel is wide.

2.2.4 Substrate and Channel Dimension Cross-sections

Measurements of substrate and channel dimensions at channel transects contribute directly to assessments of habitat volume, channel and bed stability, and habitat quality for benthic macroinvertebrates, periphyton, and fish. In the EMAP field methods (Kaufmann and Robison, 1994, 1998), substrate size and embeddedness are evaluated at each of the 11 detailed cross-sections using a combination of procedures adapted from those described by Wolman (1954), Bain et al. (1985), Platts et al. (1983), and Plafkin et al. (1989). The basis of the procedure is a systematic selection of 5 substrate particles from each of the 11 channel cross sections (Figure 2). In the process of measuring sediment sizes at each channel cross section, surveyors also measure the wetted width of the channel and the water depths at each sediment sample point. If the wetted channel is split by a mid-channel bar, the five substrate points are centered between the wetted width boundaries regardless of the bar in between. Consequently, sediment particles selected in some cross-sections may be "high and dry". For dry channels, field crews make cross-section measurements across the unvegetated portion of the channel. The crews visually estimate the size of particles according to the following classes:

RS	Bedrock (Smooth)	> 4000 mm
RR	Bedrock (Rough)	> 4000 mm
HP	Hardpan	> 4000 mm
BL	Boulders	> 250 to 4000 mm
CB	Cobbles	> 64 to 250 mm
GC	Gravel (Coarse).........	> 16 to 64 mm
GF	Gravel (Fine)	> 2 to 16 mm
SA	Sand	> 0.06 to 2 mm
FN	Silt, clay, muck	# 0.06 mm
WD	Wood	Regardless of Size
OT	Other	Regardless of Size

Field crews visually examine surface stains, markings, and algae to aid their estimation of the average percentage embeddedness of particles that are larger than sand within the 10-cm circle around the measuring rod. Embeddedness is the fraction of a particle's surface that is surrounded by (embedded in) fine sediments on the stream bottom. Sand and finer substrates are defined as 100% embedded.

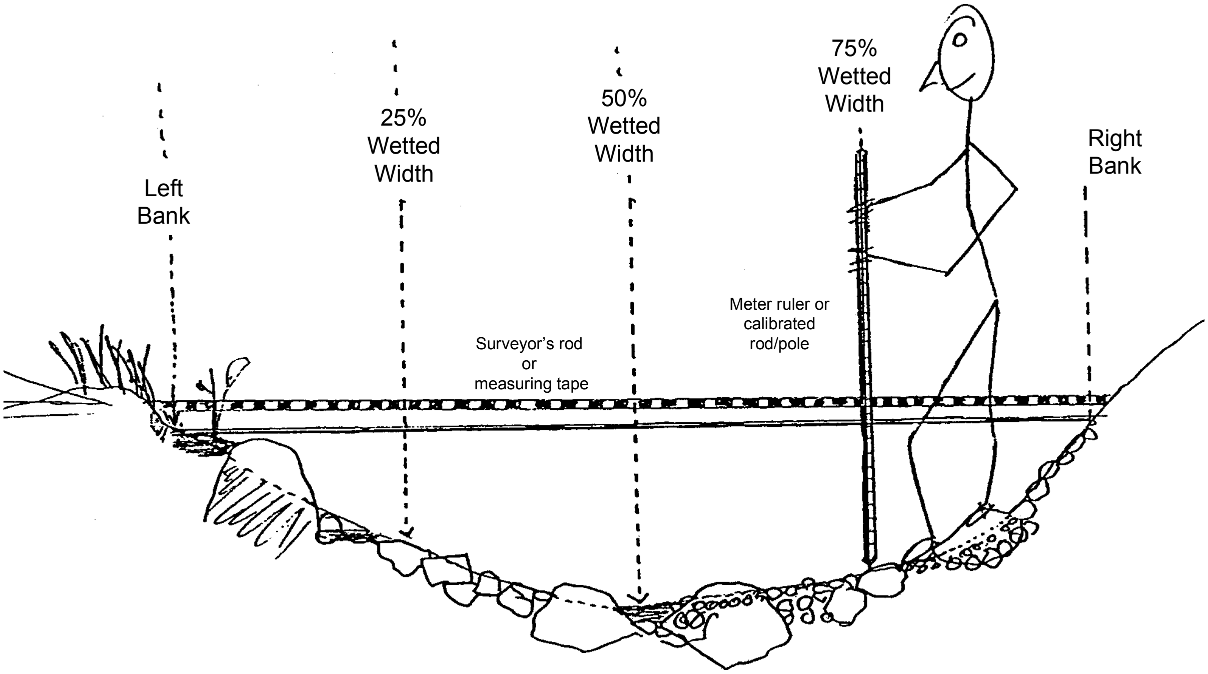


Figure 2. Substrate sampling cross-section. From Kaufmann and Robison (1998).

2.3.5 Bank Morphology

Bank morphology measurements contribute to assessments of channel stability during flood flows, long-term channel down-cutting, and fish concealment features such as undercut banks. Bank angle and undercut distances are measured on the left and right banks at each of the 11 cross sections. To measure bank angle, field surveyors lay a meter stick down against the bank with one end at the water's edge and measure the angle with a clinometer (e.g., vertical bank = 90 degrees), an adaptation of procedures described by Platts et al. (1983). If the bank is undercut, they measure the horizontal distance of the undercutting. They also measure and record the wetted width of the channel, the width of exposed mid-channel gravel or sand bars, the estimated incision height (depth, measured from the water surface to the first valley terrace above bankfull height), and the estimated height (depth) and width of the channel at bankfull stage.

2.3.6 Canopy Cover (Densiometer)

Canopy densiometer measurements are a relatively precise, objective means for quantifying riparian vegetation cover, though they tell little about the type or structure of this vegetation. Vegetative cover over the stream is measured at each of the 11 detailed cross section stations using a Convex Spherical Densiometer, model B (Lemmon, 1957), modified as described by Mulvey et al. (1992) to measure cover in 4 quadrats. For each of the 11 stations, densiometer measures are taken separately in four directions positioned at the center of the stream. These 44 observations are used to estimate canopy cover over the channel. Surveyors also measure canopy density facing the banks at the wetted channel margins at both sides of each of the 11 cross-sections. These 22 bank densiometer readings complement the visual estimates of vegetation structure and cover within the riparian zone itself, and are particularly important in wide streams, where riparian canopy may not be recorded when using the densiometer while positioned mid-stream.

2.3.7 Riparian Vegetation Structure

Visual estimation procedures are used to characterize the type and amount of various types of riparian vegetation. This semi-quantitative assessment is used to evaluate the condition and level of disturbance of the stream corridor. It also indicates the present and future potential for various types of organic inputs and shading.

Observations to assess riparian vegetation apply to the riparian area within 5 m upstream and downstream of each of the 11 cross-section stations (Figure 1). They include the visible area from the stream back a distance of 10 m (30 ft) shoreward from both the left and right banks, creating a 10 m × 10 m riparian plot on each side of the stream, centered on the transect (Figure 3). The riparian plot dimensions are estimated, not measured. On steeply sloping channel margins, the 10 m × 10 m plot boundaries are defined as if they were projected down from an aerial view. If the wetted channel is split by a mid-channel bar, the bank and riparian measurements are made on each side of the channel, not the bar.

In the EMAP field methods, the riparian vegetation is conceptually divided into three layers: a CANOPY LAYER (> 5 m high), an UNDERSTORY (0.5 to 5 m high), and a GROUND COVER layer (< 0.5 m high). Large and small diameter trees are distinguished in the canopy layer, as are herbaceous and woody vegetation in the understory. Note that several vegetation types (e.g., grasses or woody shrubs) can potentially occur in more than one layer. Similarly note that some attributes other than vegetation are possible entries for the "Ground Cover" layer (e.g., barren ground). The type of vegetation (<u>D</u>eciduous, <u>C</u>oniferous, broadleaf <u>E</u>vergreen, <u>M</u>ixed, or <u>N</u>one) in each of the two taller layers (Canopy and Understory) are recorded. A layer is considered "Mixed" if more than 10% of its areal coverage is made up of an alternate vegetation type. Areal cover is estimated separately in each of the three vegetation layers. Areal cover can be thought of as the amount of shadow cast by a particular layer alone when the sun is directly overhead. The maximum cover in each layer is 100%, so the sum of the areal covers for the combined three layers could add up to 300%. The four entry choices for areal cover within each of the three vegetation layers are "0" (absent: zero cover), "1" (sparse: < 10%), "2" (moderate: 10 to 40%), "3" (heavy: 40 to 75%), and "4" (very heavy: > 75%).

2.3.8 Fish Cover, Algae, and Aquatic Macrophytes

The EMAP habitat characterization includes semi-quantitative visual estimates of the areal cover of a number of channel features that are important (alone or in combination with other measures) for assessing habitat complexity, fish cover, macroinvertebrate habitat, and channel disturbance. These include filamentous algae, aquatic macrophytes, woody debris >0.3 m diameter, brush and small woody debris, overhanging vegetation < 1 m above the water surface, undercut banks, boulders, and artificial structures. Filamentous algae are long, streaming filaments of microscopic algal cells that often occur in slow moving, nutrient rich waters with little riparian shading. Aquatic macrophytes are floating, submerged, or emergent water loving plants, including mosses and wetland grasses that could provide cover for fish or macroinvertebrates. Woody debris comprise the larger pieces of wood that can influence cover and stream morphology. Brush/small woody debris pertains to the smaller wood that primarily affects cover but not morphology. Overhanging vegetation within one meter of the surface is the amount of brush, twigs, small debris, etc. that is not

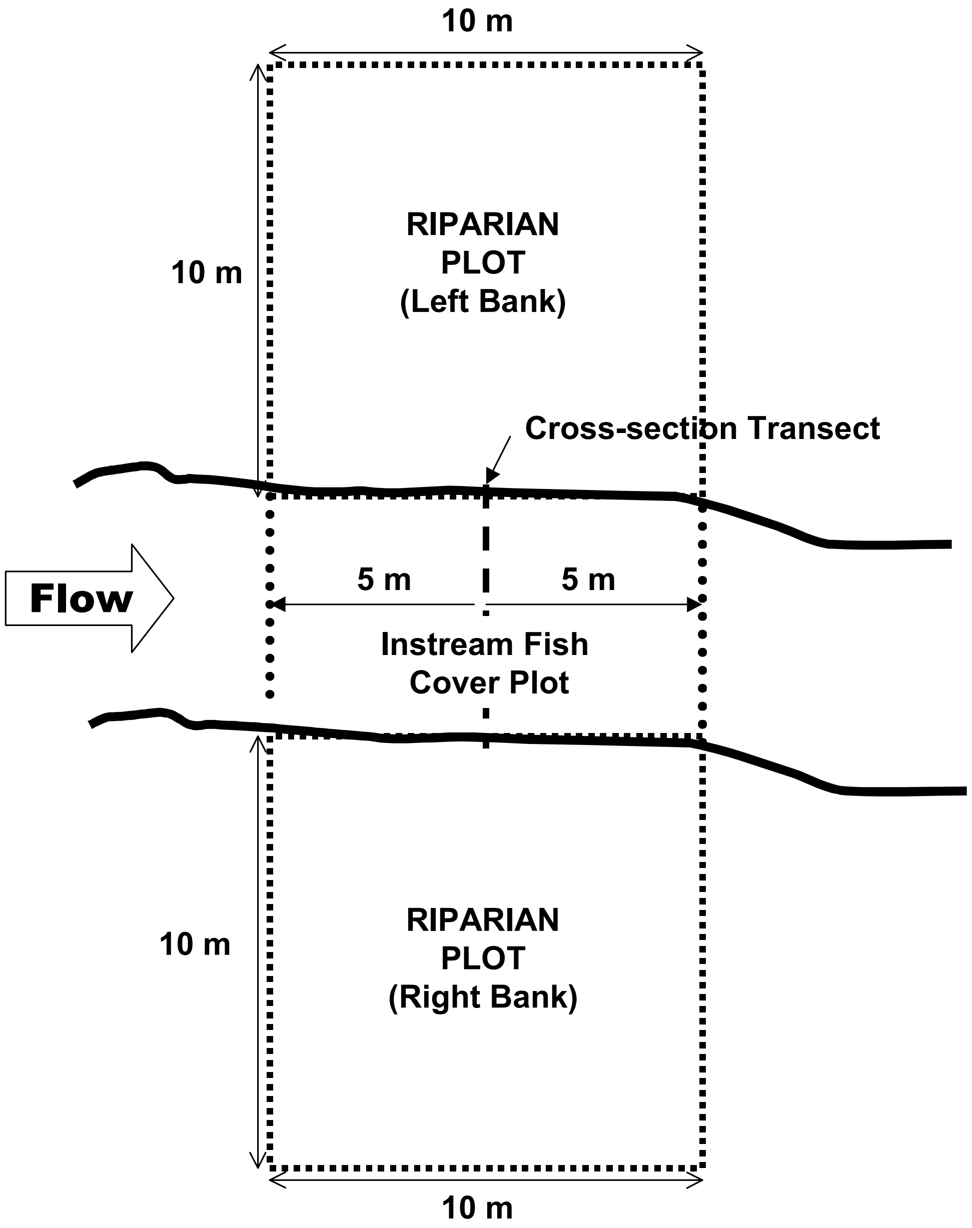


Figure 3. Boundaries for visual estimation of riparian vegetation, instream fish cover, and human influences (plan view). From Kaufmann and Robison (1998).

in the water but is close to the stream and provides cover. Boulders are typically basketball to car sized particles. In-channel artificial structures may include those designed for fish habitat enhancement and also those discarded (e.g., cars or tires) or purposefully placed for diversion, impoundment, channel stabilization, or other purposes. Observations to assess the areal cover of these in-channel features apply to the channel area within 5 m up- and downstream from each of the 11 cross-section stations (Figure 3). The four entry choices for areal cover of fish concealment and other features are "0" (absent: zero cover), "1" (sparse: < 10%), "2" (moderate: 10 to 40%), "3" (heavy: 40 to 75%), and "4" (very heavy: > 75%), the same as those used for riparian vegetation cover.

2.3.9 Human Influence

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

At each of the 11 detailed Channel and Riparian Cross-Sections, crews evaluate the presence/absence and the proximity of 11 categories of human influences:

- Walls/ dikes/ revetments
- Buildings
- Pavement
- Roads/railroads
- Pipes
- Landfills/trash
- Parks/lawns
- Row crops
- Pasture/range/hay fields
- Logging operations
- Mining activities.

Observations are confined to the stream and riparian area within 5 m upstream and 5 m downstream from each cross-section transect (Figure 3). The presence of each of these human activities and their proximity to the stream channel are evaluated and recorded separately for the left and right sides of the channel and banks. Proximity is distinguished according to whether the activity is within the channel or its margin, within the 10 m × 10 m riparian plot, or farther than 10 m from the bank.

3 CALCULATING REACH SUMMARY METRICS

3.1 INTRODUCTION

3.1.1 Conceptual Approaches

The physical habitat (PHab) measurements made using the EMAP and REMAP field techniques described by Kaufmann and Robison (1994, 1998) produce a large amount of data that, for most uses, must be condensed to stream reach summaries that describe particular aspects of physical habitat. For example, the 55 separate observations of substrate particle size class that are made at each stream reach are condensed into statistics that summarize the substrate characteristics of each reach, not individual particles or transects within a reach. For substrate, reach summaries include the geometric mean substrate particle diameter and the percentages of the reach substrate composed of sand, fines, or other size classes. EMAP's physical habitat sampling design within each reach is systematic; this feature makes calculating representative summaries of the habitat characteristics of stream reaches straightforward. These averages, percentiles and other data summaries are correctly interpreted as spatially representative estimates of the habitat characteristics measured. The metric calculation approaches we recommend include simple statistical summaries, areal cover estimates from cover class data, proximity-weighted estimates, and specific approaches for calculating woody debris abundance, residual pool characteristics, sinuosity, and bed stability of stream reaches. In this section, we discuss the conceptual basis and operational details for calculating summary metrics for all of the types of EMAP habitat data; the SAS computer code files are included as Appendix D on the compact disk. A set of raw data and an example calculation of all metrics for several sample reaches is included as Appendix E on the compact disk. This report and its appendices may be available in the future on the EMAP website (*http://www.epa.gov/emap)*.

3.1.2 Data Files, Verification, and Metric Calculation Codes

We use the following conventions to identify data files, variables, and computer code throughout this document:

- Data file names are written in lowercase, bold italics, (e.g., ***sub_bank, thalweg***).
- PHab measurement and metric variable names, as well as location and identification variable names and their values are written in uppercase letters, (e.g., WT_WID, TRANSDIR, STRM_ID, PCT_POOL, ORC38, ORST97-047).
- When referring to a piece of Statistical Applications Software (SAS) computer code we have included, we will specify "SAS code", and name the code in *UPPERCASE ITALICS*, or identify the code by description (e.g., ". . . SAS code *MH_RP* applied to the ***sub_bank*** data file.").

Before calculating physical habitat metrics, it is necessary to insure that the raw physical habitat data are accurate and that the raw data files match the intended structure that accommodates metric-calculating algorithms like the SAS code we include in this report. There are six general procedures for data verification and validation. They address (1) data file structure, (2) missing values, (3) allowable ranges, (4) unusual values, (5) plausible channel morphology, and (6) other evaluations of internal logic and consistency. These are described in detail in Appendix B, with computer code to aid this process (Appendix C on compact disk). After completing verification and validation of PHab data sets, there will be a comment file plus six "final" data files containing verified, validated raw physical habitat measurements (Table 3). The raw habitat variables contained in these files are listed and defined in Table 4; their file structure is indicated by "location" variables that include STRM_ID, YEAR, VISIT_NO, TRANSECT, TRANSDIR, STA_NUM, and INCREMNT. File structure and variable formats are illustrated in Appendix E. These final data files comprise the source data for computing all reach-level metrics.

We have included computer code that calculates stream reach level summary metrics as Appendix D, located on the compact disk. By "reach level", we mean that these are single value summaries of numerous attributes of each stream reach. These metric values are each calculated from numerous measurements or observations on each stream reach that are contained in one of the six detailed data files. There may be several pieces of code which calculate different metrics from the same data file, as summarized in Table 5. This code has been designed to run on the final PHab data files without prior alterations. Unless otherwise stated, missing and invalid values are excluded from these calculations. In order to use the code we have included, first run the verification/validation programs, starting with *AARDVARK.SAS* which, besides checking data structure and values, will

TABLE 3. PHYSICAL HABITAT MEASUREMENT DATA FILES AND THEIR CONTENTS

Data File[a]	Contents
thalweg	Thalweg Profile Data: Depth, Wetted-Width, Habitat Class, Pool-Forming Code; Presence of Mid-Channel Bars, Side-Channels, and soft/small sediment in thalweg. Slope and Bearing -- Primary and Supplemental Backsites: These data are initially in the file ***slopebrg***, then merged into ***thalweg*** during verification/ validation process
sub_bank	Channel Cross-Section data: Wetted and Bankfull Widths, Mid-channel Bar Width, Bankfull Depth, Incision Height, Bank Angle, and Undercut Distance. Depth, Embeddedness, and Substrate Size Class at cross-section verticals.
fishcov	Areal cover class of Filamentous algae, Aquatic Macrophytes, Large Woody Debris, Brush/small Woody Debris, Overhanging Vegetation, Undercut Banks, Rock Ledge and Boulder cover, Artificial Structures.
lgwoody	Number of wood pieces in each of 12 diameter-size classes both for wood at least partially within bankfull channel and wood above Bankfull channel.
canpycov	Canopy Density: Lemmon Model B Canopy Densiometer measurements.
riparian	Visual Riparian Estimates: Canopy: Vegetation Type, Large-diameter Tree Cover, Small-diameter Tree Cover. Understory: Vegetation Type, Woody Cover, Non-woody Vegetation Cover. Ground Cover: Woody, Herbaceous, Barren or duff. Human Influences -- Presence and proximity of: Walls/dikes/revetments Buildings Roads/railroads Pavement Influent or effluent pipes Landfill or trash Parks or lawns Row crop agriculture Pasture/range/hayfields Logging operations Mining activity
phabcom	Narrative field and data entry comments

[a] Data file names may vary somewhat from those we use in this report, but their basic content and structure will be as presented, and their file names should be similar to those presented in this table.

TABLE 4. VARIABLES IN THE PHYSICAL HABITAT MEASUREMENT DATA FILES

(These are prior to metric calculation)

Variable Name	Description
	thalweg variables:
STRM_ID	Individual site identification
YEAR	Year of sampling
VISIT_NO	Visit number-within year
DATE_COL	Date of site visit (MM/DD/YYYY)
TEAM_ID	Field sampling team identification
TRANSECT	Sampling transect number or letter (A-K)
TRANSP	Transect spacing (m)
STA_NUM	Thalweg depth sampling station number (0-9, or 0-14)
INCREMNT	Reach length / number of stations per reach
INDI	Number of stations per transect
BARWID	Mid-channel bar width (m)
BARYES	Mid-channel bar presence (X = Yes)
BEARING	Backsite bearing-transect to transect (degrees)
CHANUNIT	Habitat unit code
DEPTH	Thalweg water depth (cm)
POOLFORM	Pool forming agent code
REACHLEN	Length of sample reach (m)
SEDIMENT	Presence of fine sediments # 16mm (Y or N)
SIDECHAN	Presence of side channel (SC or Y for Yes)
SLOPE	Backsighted reach gradient (%)
BEAR2, BEAR3	Supplemental backsight bearing (0-359 degrees) -- named SUPBEAR in older data sets
SLOPE2, SLOPE3	Supplemental slope reading (%) --named SUPSLOPE in older data sets
PROPORTN, PROPORT2 PROPORT3,	Proportion of intra-transect segment represented by SLOPE, SLOPE2, SLOPE3; and BEARING, BEAR2, and BEAR3, respectively
WT_WID	Wetted width (m)
COMMENT	Comments
COM_FLDF	Comment flag
	lgwoody variables:
STRM_ID	Individual site identification
YEAR	Year of sampling
VISIT_NO	Visit number-within year
DATE_COL	Date of site visit (MM/DD/YYYY)
TEAM_ID	Field sampling team identification
TRANSECT	Sampling transect number or letter
PIECES	Number of woody debris pieces tallied within diameter-length class
PIEC_DIA	Diameter Class (S, M, L, X) -- S = 0.1to 0.3 m; M= 0.3 to 0.6 m; L = 06 to 0.8 m; X = > 0.8m
PIEC_LEN	Length Class (S, M, L) -- S=1.5-5 m; M=5-15 m; L= > 15 m
PIEC_TYP	Woody debris WET/DRY at Bankfull flow

(continued)

TABLE 4 (Continued)

Variable Name	Description
	sub_bank variables:
STRM_ID	individual site identification
YEAR	Year of sampling
VISIT_NO	Visit number-within year
DATE_COL	Date of site visit (MM/DD/YYYY)
TEAM_ID	Field sampling team identification
TRANSDIR	Direction or position of measurement at transect
TRANSECT	Sampling transect number or letter
ANGLE	Bank angle (degrees)
BANKHT	Bankfull height (m)
BANKWID	Bankfull width (m)
BARWID	Mid-channel bar width (m)
DEPTH	Water depth (cm)
DIST_LB	Distance from left bank at each TRANSDIR (m)
EMBED	Substrate embeddedness (%)
INCISED	Stream incision, height of first terrace above bankfull (m)
SIZE_CLS	Substrate size class
UNDERCUT	Lateral distance of bank undercut (m)
WT_WID	Wetted width (m)
******_F	Comment flag pertaining to variable ******
	fishcov variables:
STRM_ID	Individual site identification
YEAR	Year of sampling
VISIT_NO	Visit number-within year
DATE_COL	Date of site visit (MM/DD/YYYY)
TEAM_ID	Field sampling team identification
TRANSECT	Sampling transect number or letter
ALGAE	Fish cover -- areal plot coverage for filamentous algae
BOULDR	Fish cover -- areal plot coverage for boulders or rock ledges
BRUSH	Fish cover -- areal plot coverage for brush or small woody debris
MACPHY	Fish cover -- areal plot coverage for aquatic macrophytes
OVRHNG	Fish cover -- areal plot coverage for overhanging vegetation
STRUCT	Fish cover -- areal plot coverage for artificial structures
UNDCUT	Fish cover -- areal plot coverage for undercut banks
WOODY	Fish cover -- areal plot coverage for large woody debris
******_F	Comment flag pertaining to variable ******

(continued)

TABLE 4 (Continued)

Variable Name	Description
	canpycov variables:
STRM_ID	Individual site identification
YEAR	Year of sampling
VISIT_NO	Visit number-within year
DATE_COL	Date of site visit (MM/DD/YYYY)
TEAM_ID	Field sampling team identification
TRANSECT	Sampling transect number or letter
TRANSDIR	Direction and position of measurement at transect
DENSIOM	Canopy cover densiometer reading (0-17)
	riparian variables:
Vegetation:	
STRM_ID	Individual site identification
YEAR	Year of sampling
VISIT_NO	Visit number-within year
DATE_COL	Date of site visit (MM/DD/YYYY)
TEAM_ID	Field sampling team identification
TRANSECT	Sampling transect number or letter
TRANSDIR	Direction of observation at transect
BTRE	Riparian Canopy -- large tree cover (> 0.3 m diameter)
CANV	Riparian Canopy -- Dominant vegetation type
GCB	Riparian Ground cover - Barren or Duff
GCNW	Riparian Ground cover -- Non-woody vegetation
GCW	Riparian Ground cover -- Woody vegetation
NONW	Riparian Understory -- Non-woody vegetation cover
STRE	Riparian Canopy -- Small tree cover (# 0.3 m diameter)
UNDV	Riparian Understory -- Dominant vegetation type
WOOD	Riparian Understory -- Woody vegetation cover
Human Disturbance:	
BLDG	Human Influence-buildings
CROP	Human Influence-row crops
LDFL	Human Influence-landfill/trash
LOG	Human Influence-logging operations
MINACT	Human Influence-mining activity
PARK	Human Influence-park/lawn
PIPE	Human Influence-pipes(inlet/outlet)
PSTR	Human Influence-pasture/range/hay field
PVMT	Human Influence-pavement
ROAD	Human Influence-roads
WALL	Human Influence-wall/dike/riprap
******_F	Comment flag pertaining to variable ******

TABLE 5. COMPUTER PROGRAMS AND DATA FILES FOR CALCULATING REACH-LEVEL PHYSICAL HABITAT METRICS

Computer Code	Data file	Reach-Level Metrics Calculated
MH_DWC1.sas	***thalweg***	Mean and standard deviation (SD) of depth, wetted width, Width:Depth ratio, and Width-Depth product.
MH_HBCL.sas	***thalweg***	% of reach in each habitat class.
MH_RP.sas	***thalweg***	Reach aggregate and individual residual pool metrics.
MH_SLP.sas	***thalweg***	Mean and SD for reach slope.
MH_SIN.sas	***thalweg***	Reach sinuosity from backsighted bearings.
MH_SUBS.sas	***sub_bank***	Substrate size [% by class, mean and SD of size; median, lower and upper quartiles (Q_1 Q_3),and interquartile range of size class]. Log_{10}(geometric mean diameter).
MH_EMB.sas	***sub_bank***	Reach mean and standard deviation of embeddedness (channel center measurements only and channel center + stream margin measurements)
MH_LMET.sas (depends on previous metric calculations, so run last)	***mhsubs*** ***mh_slp*** ***mhwdcm*** ***mtha*** ***mhbkf*** ***mhresp***	Log_{10} of geometric mean substrate diameter in mm (LSUB_DMM), and model estimate of Log_{10} of maximum diameter of mobile substrate in mm (LTEST). “Relative bed stability” (LRBS_TST) = Log_{10}(observed mean substrate diameter / mobile substrate diameter).
MH_BKF.sas	***sub_bank***	Mean and SD of bankfull width, bankfull height, and incision height
MH_ANGCUT.sas	***sub_bank***	Mean, SD, Q_1 and Q_3, and interquartile range of bank angle and undercut distance
MH_FCV.sas	***fishcov***	Areal cover and proportional presence of fish concealment features
MH_WOOD.sas	***lgwoody***	Counts and volumes of large woody debris (LWD) size classes
MH_DEN.sas	***canpycov***	Mean and SD of canopy densiometer values (calculated separately for mid-channel and bank measurements)
MH_VGPC.sas	***riparian***	Riparian vegetation cover and presence metrics
MH_CMTYP.sas	***riparian***	Riparian vegetation type (proportion of reach with each type)
MH_HUM.sas	***riparian***	Proximity-weighted presence of human influences
MHLABELS.sas	***phabmet*** or final metric data files	Labels all final metric variables
PHABMET.sas	Final metric data files	Merges all final metric files to create ***phabmet***
PHABBEST.sas	***phabmet***	Extracts a reduced set of commonly-used variables from ***phabmet***

merge and assemble the appropriate sets of data for metric calculations. Edit the name of the required final PHab data file in the code where requested (file renaming may be necessary). The resulting data file should be saved and named appropriately for future merging with other EMAP metric data (e.g., fish or macroinvertebrate assemblage data files). The variable names and definitions of most of the reach physical habitat metrics calculated by these computer codes are listed in Table 6.

3.2 METRIC CALCULATION PROCEDURES AND RATIONALE

3.2.1 Channel Morphology Statistical Summaries

Wetted channel dimension measurements (e.g. width, depth, bank angle) can be directly reduced to whole-reach habitat characterizations by calculating their means and standard deviations, or by calculating percentages of observations within stated bounds. Because the data are systematically spaced, these averages and percentiles are estimates of the spatial distributions of the habitat characteristics measured. For example, the mean of the 100 thalweg depth measurements is an estimate of the mean thalweg depth in the stream reach.

When code *MH_HBCL* is applied to data file ***thalweg***, it uses frequencies of observations in each habitat class to calculate reach level percentages of each class (e.g., PCT_PP, the percentage of the reach length classified as plunge pool habitat). In addition, it combines classes into percentages of the following broader habitat classifications:

PCT_FAST = % (falls + cascades + rapids + riffles).
PCT_SLOW = % (all pool types + glides).
PCT_POOL = % all pool types (including impoundment, backwater, plunge, lateral scour, and trench).
PCT_DRS = % (dry channel + subsurface flow).

When code *MH_DW1C* is applied to data file ***thalweg***, it calculates simple reach level means and standard deviations for wetted width and thalweg depth. It also calculates mean width-depth products and width:depth ratios (Table 6), as well as the number of non-missing values of width, depth, width × depth, and width/depth.

3.2.2 Channel Cross-Section and Bank Morphology

When code *MH_BKF* is applied to data file ***sub_bank***, it calculates simple reach level means and standard deviations for bankfull width and height, incision height, and also

TABLE 6. PHYSICAL HABITAT METRIC VARIABLE NAMES AND LABELS

Variable	Description
	Identification Variables:
STRM_ID	Stream reach identification code
VISIT_NO	Site visit number
YEAR	Year of site visit
	Channel Morphology Metrics
REACHLEN	Length of sample reach (m)
XDEPTH	Mean thalweg depth (cm)
SDDEPTH	Standard deviation of thalweg depth (cm)
XWIDTH	Mean wetted width (m)
SDWIDTH	Standard deviation of wetted width (m)
XWXD	Mean wetted width x depth (m^2)
SDWXD	Standard deviation of wetted width × thalweg depth (m^2)
XWD_RAT	Mean wetted width / depth (m/m)
SDWD_RAT	Standard deviation of wetted width / thalweg depth (m/m)
PCT_FA	Percent falls
PCT_CA	Percent cascade
PCT_RA	Percent rapids
PCT_RI	Percent riffle
PCT_GL	Percent glide
PCT_PD	Percent impoundment pool
PCT_PP	Percent plunge pool
PCT_PL	Percent lateral scour pool
PCT_PT	Percent trench pool
PCT_PB	Percent backwater pool
PCT_P	Percent pool (unspecified type)
PCT_DR	Percent dry channel
PCT_SB	Percent subsurface flow
PCT_DRS	Percent dry or subsurface flow (PCT_DR + PCT_SB)
PCT_FAST	Percent falls + cascades + rapids + riffles
PCT_SLOW	Percent glides + all pool types
PCT_POOL	Percent all pool types
	Channel Cross-section and Bank Morphology Metrics:
XBKA	Mean bank angle (degrees)
XUN	Mean bank undercut distance (m)
MEDBKUN	Median bank undercut distance (m)
XBKF_W	Mean bank full width (m)
XBKF_H	Mean bank full height (m)
XINC_H	Mean incision height (m)

(continued)

TABLE 6 (Continued)

Variable	Description
	Channel Sinuosity and Slope Metrics:
SINU	Channel Sinuosity =Reach length / Straight line distance between reach ends)
XSLOPE	Water surface gradient over reach (%)
XBEARING	Mean direction of reach flow (degrees)
VSLOPE	Standard deviation of water surface gradient (%)
	Residual Pool Metrics:
AREASUM	Residual pool total vertical profile area (m^2/reach)
RP100	Mean residual depth [cm; equivalent to residual pool vertical profile area (m^2/100 m of reach)]
RPV100	Residual volume per 100 m of reach (m^3/ 100 m)
TOTPVOL	Residual volume for the entire reach (m^3 / reach)
RPGT50	Residual pools with residual depth > 50 cm (number/reach)
RPGT75	Residual pools with residual depth > 75 cm (number/reach)
RPGT100	Residual pools with residual depth > 100 cm (number/reach)
RPXLEN	Mean length of residual pools in reach (m/pool)
RPXAREA	Mean residual pool area (m^2/pool)
RPMDEP	Maximum residual depth of deepest residual pool in reach (cm)
RPMLEN	Length of longest residual pool in reach (m)
RPMAREA	Area (vertical profile) of largest residual pool in reach (m^2/pool)
PCTRSED	Presence of thalweg small sediments (% of reach length)
PCTPSED	Presence of thalweg small sediments (% of residual pool length)
	Substrate Size and Composition Metrics:
SUB_X	Substrate mean size class (see text)
SUB_V	Standard deviation of substrate size class (see text)
SUB_Q3	75th percentile of substrate size class
SUB_MED	Substrate median size class
SUB_Q1	25th percentile of substrate size class
SUB_IQR	Interquartile range of substrate size class
LSUB_DMM	Log_{10}[estimated geometric mean substrate diameter (mm)]
XEMBED	Substrate mean embeddedness -- channel + margin (%)
VEMBED	Standard deviation of embeddedness -- channel + margin (%)
XCEMBED	Substrate mean embeddedness -- mid channel (%)
VCEMBED	Standard deviation of embeddedness -- mid-channel (%)
PCT_RS	Substrate % smooth bedrock (>4000mm)
PCT_RR	Substrate % rough bedrock (>4000mm)
PCT_BDRK	Substrate % bedrock
PCT_BL	Substrate % boulder(250-4000mm)
PCT_CB	Substrate % cobble (64-250mm)
PCT_GC	Substrate % coarse gravel (16-64mm)
PCT_BIGR	Substrate % coarse gravel and larger (>16mm)

(continued)

TABLE 6 (Continued)

Variable	Description
Substrate Size and Composition Metrics:	
PCT_GF	Substrate % fine gravel (2-16mm)
PCT_SFGF	Substrate % fine gravel and smaller (<=16mm)
PCT_SA	Substrate % sand (0.6-2mm)
PCT_FN	Substrate % fine (silt/clay; < 0.6 mm)
PCT_SAFN	Substrate % sand + fines (<2mm)
PCT_OM	Substrate % organic detritus
PCT_WD	Substrate % wood
PCT_ORG	Substrate % wood or detritus
PCT_RC	Substrate % concrete
PCT_HP	Substrate % hard pan
PCT_OT	Substrate % miscellaneous other types
Bed Substrate Stability Metrics:	
LTEST	Log$_{10}$ [Erodible substrate diam (mm)] -- Quick Estimate: LTEST=log$_{10}$[13.7×(0.5×XDEPTH×10)(XSLOPE/100)]
LDMB_BW4	Log$_{10}$ [Erodible substrate diam (mm)] -- Estimate 2: LDMB_BW4=Log$_{10}$[13.7$(\mathbf{R}_{bf} - \mathbf{R}_{w} - \mathbf{R}_{p})\times\mathbf{S}$) where: $\mathbf{R}_{bf}$ = 0.5[(XDEPTH x 10)+(XBKF_H × 1000)], $\mathbf{R}_{w}$ = (V1W_MSQ × 1000), $\mathbf{R}_{p}$ = (0.5 x RP100 × 10), $\mathbf{S}$ = (XSLOPE ÷ 100), and if $\mathbf{R}_{w} \geq (\mathbf{R}_{bf} - \mathbf{R}_{p})$ then $(\mathbf{R}_{bf} - \mathbf{R}_{w} - \mathbf{R}_{p}) = 0.1(\mathbf{R}_{bf} - \mathbf{R}_{p})$
LRBS_TST	Log$_{10}$ [Relative Bed Stability] = (observed mean substrate diameter) ÷ (erodible substrate diameter) -- Quick Estimate: LRBS_TST=LSUB_DMM - LTEST
LRBS_BW4	Log$_{10}$ [Relative Bed Stability] = (observed mean substrate diameter) ÷ (erodible substrate diameter) -- Estimate 2: LRBS_BW4 = LSUB_DMM - LDMB_BW4
Fish Cover Metrics:	
XFC_ALG	Filamentous algae areal cover
XFC_AQM	Aquatic macrophyte areal cover
XFC_LWD	Large woody debris areal cover
XFC_BRS	Brush and small woody debris areal cover
XFC_OHV	Overhanging vegetation areal cover
XFC_RCK	Boulder and rock ledge areal cover
XFC_UCB	Undercut bank areal cover

(continued)

TABLE 6 (Continued)

Variable	**Description**
	Fish Cover Metrics (continued):
XFC_HUM	Artificial structure areal cover
XFC_ALL	Sum of areal cover from all fish concealment types except algae and aquatic macrophytes.
XFC_BIG	Sum of cover from large wood, boulders, over-hanging banks and human structures
XFC_NAT	Sum of cover from large wood, brush, overhanging vegetation, boulders and undercut banks
PFC_*xxx*:	Proportion of reach with named cover types present, regardless of amount of cover. (*xxx represent the last 3 letters of the cover type variables above*)

Large Woody Debris (LWD) Metrics:

<u>LWD Size Definitions</u>:

LWD is tallied in a matrix with three length and four large end diameter classes:

	Length		
Diameter	S (1.5 m -5 m)	M (> 5 m - 15 m)	L (> 15 m)
S (0.1m-0.3m)	T	S	M
M (> 0.3m-0.6m)	S	M	L
L (>0.6m-0.8m)	S	L	L
X (> 0.8m)	M	L	X

The codes T, S, M, L, and X in this table are progressively larger piece sizes from very small to very large. A nominal mean volume is calculated for each piece of LWD according to its diameter-length class membership as described by Robison (1998):

$$\pi[1.33(\text{Class minimum Diameter} \div 2)^2]\times[1.33(\text{Class minimum Length})]$$

Total numbers and volumes of LWD in each diameter-length class are regrouped and assigned to one of five cumulative wood size classes:

Class 1 - T, S, M, L, X	Very small to Very Large
Class 2 - S, M, L, X	Small to Very Large
Class 3 - M, L, X	Medium to Very Large
Class 4 - L, X	Large to Very Large
Class 5 - X	Very Large

(continued)

TABLE 6 (Continued)

Variable	Description
	Large Woody Debris (LWD) Metrics:
LWD Metric Variables:	
C1W ... C5W	LWD in active channel (pieces/reach) -- size classes 1...5
V1W ... V5W	LWD volume in active channel (m^3/reach) -- size classes 1...5
C1WM100 ... C5WM100	LWD in active channel (pieces/100m) -- size classes 1...5
V1WM100 ... V5WM100	LWD volume in active channel (m^3/100m) size classes 1...5
C1W_MSQ ... C5W_MSQ	LWD in active channel (pieces/m^2) -- size classes 1...5
V1W_MSQ ... V5W_MSQ	LWD volume in active channel (m^3/m^2) -- size classes 1...5
C1T ... C5T	LWD in and above active channel (pieces/reach) -- size classes 1...5
V1T ... V5T	LWD volume in and above active channel (m^3/reach) -- size classes 1...5
C1TM100 ... C5TM100	LWD in and above active channel (pieces/100m) -- size classes 1...5
V1TM100 ... V5TM100	LWD volume in and above active channel (m^3/100m) -- size classes 1...5
	Riparian Cover (Densiometer) Metrics:
XCDENBK	Mean % canopy density at bank
XCDENMID	Mean % canopy density mid-stream
	Riparian Vegetation Cover and Structure Metrics:
XCL	Riparian canopy (> 5 m high) cover - trees > 0.3m DBH
XCS	Riparian canopy (> 5 m high) cover - trees # 0.3m DBH
XMW	Riparian mid-layer (0.5 to 5 m high) woody cover
XMH	Riparian mid-layer (0.5 to 5 m high) herbaceous cover
XGW	Riparian ground-layer (< 0.5 m high) woody cover
XGH	Riparian ground-layer (< 0.5 m high) herbaceous cover
XGB	Riparian ground-layer (< 0.5 m high) bare ground cover
XC	Riparian canopy cover (XCL+XCS)
XM	Riparian mid-layer cover (XMW + XMH)
XG	Riparian ground-layer vegetation cover (XGW + XGH)
XCM	Riparian canopy + mid-layer cover (XC + XM)
XCMW	Riparian canopy + mid-layer woody cover (XC + XMW)
XCMG	Riparian cover, sum of 3 layers (XC + XM + XG)
XCMGW	Riparian woody cover, sum of 3 layers (XC + XMW + XGW)
XPCAN	Riparian canopy presence (proportion of reach)
XPMID	Riparian mid-layer presence (proportion of reach)
XPGVEG	Riparian ground cover presence (proportion of reach)
XPCM	Riparian canopy and mid-layer presence (proportion of reach)
XPCMG	3-layer riparian vegetation presence (proportion of reach)

(continued)

TABLE 6 (Continued)

Variable	Description
Riparian Vegetation Cover and Structure Metrics (continued):	
PCAN_C	Coniferous riparian canopy presence (proportion of reach)
PCAN_D	Deciduous riparian canopy presence (proportion of reach)
PCAN_E	Broadleaf evergreen riparian canopy presence (proportion of reach)
PCAN_M	Mixed riparian canopy type presence (proportion of reach)
PMID_C	Coniferous riparian mid-layer presence (proportion of reach)
PMID_D	Deciduous riparian mid-layer presence (proportion of reach)
PMID_E	Broadleaf evergreen riparian mid-layer presence (proportion of reach)
PMID_M	Mixed riparian mid-layer type presence (proportion of reach)
Human Disturbance Metric Variables:	
W1H_BLDG	Riparian human disturbance -- Buildings (proximity-weighted index)
W1H_WALL	Riparian human disturbance -- Channel revetment (proximity-weighted index)
W1H_PVMT	Riparian human disturbance -- Pavement (proximity-weighted index)
W1H_ROAD	Riparian human disturbance -- Roads (proximity-weighted index)
W1H_PIPE	Riparian human disturbance -- Pipes, influent and effluent (proximity-weighted index)
W1H_LDFL	Riparian human disturbance -- Trash and Landfill (proximity-weighted index)
W1H_PARK	Riparian human disturbance -- Parks and Lawns (proximity-weighted index)
W1H_CROP	Riparian human disturbance -- Row Crop Agriculture (proximity-weighted index)
W1H_PSTR	Riparian human disturbance -- Pasture and Grass fields (proximity-weighted index)
W1H_LOG	Riparian human disturbance -- Logging (proximity-weighted index)
W1H_MINE	Riparian human disturbance -- Mining (proximity-weighted index)
W1_HALL	Riparian human disturbance index – All types (proximity-weighted sum)
W1_HNOAG	Riparian human disturbance index -- Non-agricultural types (proximity-weighted sum)
W1_HAG	Riparian human disturbance index -- Agricultural types (proximity-weighted sum)

lists the number of non-missing values used in these calculations as a quality assurance check (Table 6).

When code *MH_ANGCUT* is applied to data file ***sub_bank***, it calculates simple reach level means and standard deviations for bank angle and undercut distance. In addition, it calculates the median, upper and lower quartiles, and the inter-quartile range of these variables within each reach (Table 6). It also lists the number of non-missing values used in these calculations.

3.2.3 Sinuosity

Sinuosity (Schumm, 1963), or thalweg sinuosity (Leopold and Wolman 1957) is a mathematical expression of the degree of tortuosity or twisting of a stream channel as observed from above. Sinuosity is measured as the distance along the channel "as the fish swims" divided by the direct line-of-site distance "as the crow flies" up the valley between the two ends of the reach. Kaufmann and Robison (1998) prescribe compass bearing backsites between each of the 11 channel cross-section transects in the EMAP field methods, yielding 10 bearings and distances from which one can crudely map the course of the channel within the limits of the sample reach. It is extremely important to define the resolution and scale over which the measurements for sinuosity are made. For consistency in EMAP, we define the scale as a reach 40 times as long as its wetted width at low flow and the resolution of measurements as one measurement of length and bearing per 4 channel-widths' distance. To calculate sinuosity, the following calculations are made:

$$\text{Sinuosity} = (\text{Reach length}) \div (\text{“Crows” distance})$$
$$= [\Sigma(D_T)] \div [(\Sigma\text{“Northing”})^2 + (\Sigma\text{“Easting”})^2]^{½};$$

$$= \frac{\sum \mathbf{D_T}}{\sqrt{\left(\sum \mathbf{D_T} \cos\boldsymbol{\theta}\right)^2 + \left(\sum \mathbf{D_T} \sin\boldsymbol{\theta}\right)^2}} \quad \textbf{(1)}$$

where:

"Northing" and "Easting" are, respectively, the northern and eastern vector components of the distance from the downstream starting point.
$\mathbf{D_T}$ = Distance along channel between transects,
Σ = summation over transects,
$\boldsymbol{\theta}$ = compass bearing in radians= 2π(degrees of bearing/360 degrees).

When code *MH_SIN* is applied to the data file ***thalweg***, the first part of this code creates a data file containing backsight bearings, the distance between transects, and weights for each bearing backsite based on the proportion of between-transect distance over which the bearings were measured. Next, the code creates variables equaling the cumulative **x** ("Easting") and **y** ("Northing") coordinates for each transect, based on an arbitrary downstream starting point and the bearings and distances from each transect to its adjacent downstream transect. The straight line distance from the furthest upstream transect K back to transect A is then calculated as the denominator of Equation 1. As shown in the previous paragraph, sinuosity (Table 6) is calculated as the ratio of the total (tortuous) distance along the course of the channel divided by the straight line distance between the two ends of the reach. Code *MH_SIN* prepares a data file with cumulative

x and **y** coordinates of each transect, then optionally plots a simple planform map of the course of the reach. These plots may be used to compare stream reaches between visits or years, or to validate backsighted bearing data. Calculations of sinuosity and reach planform maps for streams with missing inter-transect bearings should be considered suspect if the field data has missing inter-transect bearings (i.e. if TRAN_N <10). The metric file created, ***mh_sin***, includes the crow's distance and along-stream distance between reach ends, reach sinuosity, distance between transects, and the number of transects.

3.2.4 Slope

Code *MH_SLP* calculates the channel centerline length-weighted mean slope for each sample reach. When the code is applied to data file ***thalweg***, it creates a new data set from the longitudinal profile data, from which mean and standard deviation of slope are calculated for each reach. The code bases these calculations on backsighted slope measurements between transects, weighting each slope measurement by the proportion of the inter-transect distance to which it applies. Field crews enter one or more slope backsites between transects, estimating these proportions. If supplemental measurements are entered without specifying inter-transect proportions, we assume the measurements were evenly-spaced between transects. For example, if two slopes are entered without proportions, we assume that these measurements were halfway between transects, and give weights of 50% to both the main and supplemental backsights. The code calculates length-weighted means for each inter-transect distance. Because the inter-transect distances within a reach are equal, the code calculates a length-weighted mean as the arithmetic average of all the inter-transect slope values (Table 6). Missing inter-transect slopes are not used in the calculation. The output data file becomes the permanent metric file ***mh_slp*****, where ** is set to the last two digits of the year of field measurements.

3.2.5 Residual Pool Analysis

Mean residual depth, reach-aggregates of residual pool area, and other residual pool statistics are flow-independent measures of channel morphology that have distinct advantages over highly flow-dependent descriptions, such as visual pool classifications. Refining a concept first introduced in general terms by Bathurst (1981) in a discussion of factors controlling hydraulic resistance due to gravel bars, Lisle (1982, 1986, 1987) defined a "residual pool" as an area in a stream that would contain water even at zero discharge due to the damming effect of its downstream riffle crest. Kaufmann (1987a,b) concurrently applied this idea at long reach scales (30 to 40 times their baseflow wetted width). He defined individual pool and aggregate stream reach residual pool longitudinal profile areas on the basis of tightly-spaced, systematic thalweg bed elevation measurements. Residual pool depths are calculated from these longitudinal bed elevation profiles by projecting a level horizontal line upstream from the downstream control point (i.e., riffle crest) of each residual pool until it meets an elevation greater than or equal to the elevation of the control point (Figure 4A). Subsequent residual pool characteristics are then based upon the elevation difference between the residual surface and the stream bed. Stack (1989), Stack and Beschta (1989), and Robison and Kaufmann (1994) subsequently developed rapid field techniques for approximating residual pool characteristics from much less time-consuming thalweg depth profile and reach water surface slope data. Robison and Kaufmann (1994) and Robison (1998) describe the rapid approach in detail, reporting close agreement in reach aggregate residual pool statistics compared with values determined using the more rigorous (but more time-consuming) thalweg bed elevation technique that requires surveyed bed elevation data.

In the rapid residual pool approximation, the residual surface is graphically represented on a longitudinal depth profile by a line extending upstream from the downstream riffle crest to a thalweg depth shallow enough for the bed to intercept this line. Because this residual surface is, by definition, perpendicular to the gravity vector, the slope of the water surface must be accounted for and the depth measurements corrected accordingly. This correction appears as a downward "tilt" of the residual surface in the upstream direction when it is plotted on a longitudinal profile of water depth (Figure 4B). The relation between the angle of correction ("tilt") and the reach mean slope was determined empirically by Stack (1989), to best match residual pool areas based on surveys of bed elevation:

$$\textbf{Correction angle of residual surface} = 0.12 + 0.25(\textbf{slope}) \qquad \textbf{(2)}$$

Once a residual pool longitudinal profile of a reach is calculated, individual pool dimensions and reach aggregate volumes or summary statistics can be calculated from these profiles. Kaufmann (1987a) found reach aggregate residual pool vertical profile areas to be closely related to the amount of large woody debris and transient hydraulic storage volume in stream reaches in the Oregon Coast Range; the mean values for individual pool volume and maximum residual depth varied with pool type and pool-forming agents (e.g., debris jam, rootwad, single log, boulder). We describe below an approach for calculating reach aggregate, and individual measures of the dimensions of residual pools from longitudinal thalweg profiles measured using the EMAP survey methods of Kaufmann and Robison (1994,1998).

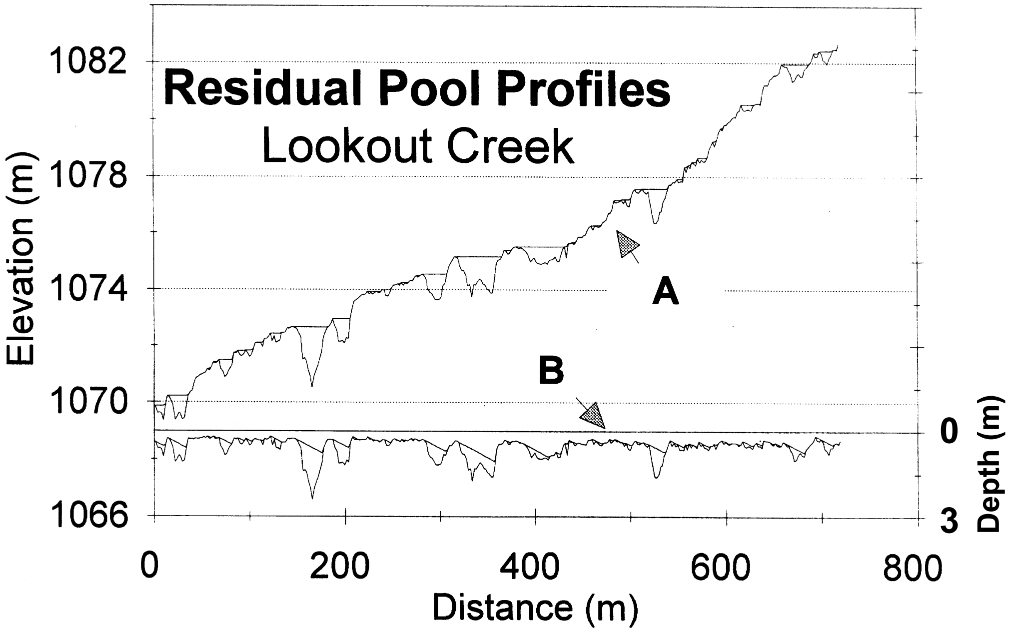


Figure 4. Residual pool profile. A) based on channel thalweg elevation data; B) based on thalweg depth and reach slope data. Adapted from Robison and Kaufmann, 1994.

Lisle and Hilton (1992) proposed an index of sediment supply for gravel-bed streams, based on the volume of fine sediment in pools. Using field measurements of residual pool depths and fine sediment layer depths at many points within pools (determined by pounding a metal bar down through fine sediment to a hard gravel-cobble pool bottom), this approach evaluates the proportion of the pool volume filled with fine sediments. The fraction of pool volume filled with fines (**V***) was calculated as the fines volume divided by the sum of fines volume plus residual pool volume:

$$\mathbf{V}^* = \frac{\mathbf{V}_f}{(\mathbf{V}_f + \mathbf{V}_r)} = \frac{\mathbf{V}_f}{\mathbf{V}_{sp}} \qquad \textbf{(3)}$$

where $\mathbf{V}_f$, $\mathbf{V}_r$, and $\mathbf{V}_{sp}$ are, respectively, the volume of fines in the pool, the residual pool volume, and the scoured pool volume (i.e., $\mathbf{V}_f + \mathbf{V}_r$).

Lisle and Hilton (1992) found this index of pool sedimentation to be positively related to sediment production rates, and to the area and intensity of logging and road building in Northern California stream drainage basins. For routine monitoring in surveys such as EMAP, Kaufmann and Robison (1998) found it impractical to obtain all the residual depth and fines depth information necessary to formally calculate $\mathbf{V}^*$. However, by collecting information on the presence of “soft, small“ substrate (# 16mm diameter) at 100 to 150 points along the thalweg, a related surrogate of $\mathbf{V}^*$ can be calculated from EMAP survey data as the percentage of the total length of residual pools in each stream reach that have loose, relatively mobile fine sediments deposited along the thalweg (PCTPSED). We expect that this index would be less sensitive to pool filling from upslope sediment production than $\mathbf{V}^*$. However, we hypothesize that, as pool volume is filled by fine sediments, the pool bottom surface area covered by fines will increase, and this trend should be detected in EMAP surveys as an increase in the presence of fine sediments within the residual pool portion of the thalweg bottom profile (as well as a decrease in the depth and volume of the residual pools themselves).

The SAS code *MH_RP* prepares longitudinal thalweg profile data from the file ***thalweg*** and then calculates individual and aggregate residual pool statistics. Using the code, the downstream riffle crest (control point) of each residual pool in the longitudinal thalweg depth profile is detected iteratively, by scanning the sequence of thalweg depths for a value that exceeds the previous (downstream) depth by an amount determined using Stack’s correction angle equation, as follows:

$$\mathbf{depth}_{(i)} > \mathbf{depth}_{(i-1)} + \{[0.12 + 0.25(\mathbf{slope})] \times \mathbf{interval}\} \tag{4}$$

where:

$\mathbf{depth}_{(i)}$ is the measured thalweg depth at the *ith* point in the upstream direction along the sampled reach. $\mathbf{Depth}_{(1)}$, used for the first measured depth(i = 1), is taken to be the thalweg depth mean minus the thalweg depth standard deviation, to allow detection of the first pool in those cases where a sampled reach begins in a pool;

'i' is the thalweg depth measurement index, starting at 1 and continuing to the upstream end of the reach, generally either 100 or 150;

slope is the mean water surface slope of the reach, and

interval is the distance between consecutive measurement points.

Once this riffle crest is detected, the residual pool continues upstream until it's calculated residual surface intersects the thalweg bed surface. This point is detected by scanning the sequence of thalweg depths until the following relation is true:

$$\mathbf{depth}_{(e)} \# \mathbf{depth}_{(b)} + \{[0.12 + 0.25(\mathbf{slope})] \times [\mathbf{interval} \times (\boldsymbol{e} - \boldsymbol{b})]\}; \qquad \mathbf{(5)}$$

where:

depth$_{(b)}$ is the water depth at the estimated downstream riffle crest defining this particular residual pool;

depth$_{(e)}$ is the measured thalweg depth at the estimated upstream end of the residual pool. It represents the point at which the residual surface intersects the streambed. This point may or may not be the downstream control point of the next upstream residual pool;

slope is the mean water surface slope of the reach;

interval is the distance between consecutive measurement points;

b is the value of the index *i* at which the downstream starting point of the pool was detected using Equation 4;

e is the value of the index *i* at which this relation holds, marking the detected upstream end of the residual pool.

The last term in Equation 5, [**interval** × (***e*** **-** ***b***)], is the length of the detected residual pool. The residual depth is defined as the difference between the measured thalweg depth and the calculated residual surface depth, as shown in Equation 6:

$$\mathbf{resd}_{(i)} = \mathbf{depth}_{(i)} - \{\mathbf{depth}_{(b)} + [0.12 + 0.25(\mathbf{slope})][\mathbf{interval} \times (\boldsymbol{e} - \boldsymbol{b})]\} \qquad \mathbf{(6)}$$

where:

resd$_{(i)}$ is the residual depth at the *ith* measurement point along the sample reach.

The “sagittal” area (i.e., the longitudinal profile area) of the residual pool is the summation over the pool of the product of the thalweg depth at a point and the interval between it and the measurement preceding it. This is given in Equation 7:

$$\text{area} = \sum_{i=b}^{i=e-1} \left[(\text{resd})_{(i)} \ (\text{interval}) \right] \qquad \mathbf{(7)}$$

Wetted widths are obtained at each transect and halfway between transects. We calculate residual widths corresponding to each measured thalweg depth by linear interpolation between measured width values. Assuming a triangular channel cross section, the residual width is calculated from wetted width, thalweg depth, and residual depth using the geometric relationship in Equation 8, as described by Robison and Kaufmann (1994) and Robison (1998). Again, assuming a triangular channel cross-section, the volume of the residual pool can then be calculated from both residual depths and widths using Equation 9:

$$\mathrm{resw}_{(i)} = \left[\left(\mathrm{wt\_wid}_{(i)} \right) \left(\frac{\mathrm{resd}_{(i)}}{\mathrm{depth}_{(i)}} \right) \right] \qquad \textbf{(8)}$$

$$\mathrm{volume} = \sum_{i=b}^{i=e-1} \left[\left(0.5 \times \mathrm{resd}_{(i)} \right) \left(\mathrm{resw}_{(i)} \right) \left(\mathrm{interval} \right) \right] \qquad \textbf{(9)}$$

where:

resw$_{(i)}$ is the residual width at measurement point *i*;
wt_wid$_{(i)}$ is the measured wetted width at measurement point *i*.

The SAS code *MH_RP* creates a temporary data set containing a downstream starting control point depth equal to the mean thalweg depth in the reach minus its standard deviation. This surrogate control point depth is prepended to the sequence of measured depths and used as an initial depth for detecting residual pools. This allows the detection and inclusion of a portion of a residual pool which may be located at the downstream starting point of thalweg measurements. The temporary data set also contains the mean slope of the reach, the reach length, the distance (increment) between inter-transect measurement locations (STA_NUMs), and a value equal to the number of measurements between transects minus one, as well as variables used for identification and other accounting processes.

The metric calculation code (*MH_RP*) then performs the following operations on the temporary data set to calculate aggregate residual pool metrics and statistics:

1) The relevant data (depth, sediment presence/absence, wetted width, TRANSECT, STA_NUM, and a flag denoting if the data are in the main or a side channel) are transposed so that values for an entire reach are in a single record.

2) The beginning and end of each 'segment' is determined, where a segment is a section of the data sequence bounded by either the beginning of data collection, the end of data collection, or by a gap in the data lasting longer than 10 intervals (or stations, if you prefer). A reach consists of a segment for the main channel, and one or more for the side channels (if present and sampled).

3) Determine the 'head' of each defined segment. These are points which put a segment in its context - they may be a point in the main channel (where a side channel empties into it) or the surrogate starting control point (if the segment is either the main channel or a side channel which empties into the main channel below the study reach).

4) The pool calculations are done for each segment to find incremental lengths, sedimented lengths, depths, widths, areas and volumes of the residual pools.

5) Side channel pools occurring at channel confluences are joined to the main channel pool at the confluence if present.

These first five steps are done for each reach in the study. At the completion of all reaches, and prior to the next step, it is possible to plot out the depths, residual pool surfaces, and sediment locations for each reach.

6) The incremental values are then transposed to place values for each measurement point on separate records. They are then summed over the length of the individual pools to obtain residual dimensions and derivative statistics, such as means and quartiles. These values are saved in a file ***mhrpind*****, where ** is set to the last two digits of the year that the study took place.

7) Reach summary metrics are calculated from the data for individual pool data within each reach (Table 6). These are stored in the file ***mhresp*****, where ** is set to the last two digits of the year that the study took place.

3.2.6 Substrate Size and Composition

Systematic channel pebble counts can be directly reduced to whole-reach substrate characterizations by calculating percentages of observations within stated size classes. Because the data are systematically spaced, these averages and percentiles are interpreted as unbiased representations of the substrate characteristics measured. For example, the percent sand substrate obtained from the 55 particles in the EMAP pebble count (Kaufmann and Robison, 1998) is an estimate of the percent of the surface area of the stream reach that has surficial substrate composed of sand.

In an approach adapted from that of Bain et al. (1985), we calculate a mean substrate diameter after assigning numeric values to the substrate size classes that are proportional to the logarithm of the midpoint diameter of each size class. We calculate substrate mean diameter class (SUB_X) and its standard deviation (SUB_V) as the arithmetic mean of the numerically-transformed size classes (shown in the following paragraph). The logarithmic nature of the substrate size classes specified in the EMAP methods makes these mean size class values proportional to the geometric mean substrate diameter. Based on assigning geometric midpoint diameters to each particle diameter class, we derived the following relationship to transform mean diameter class values into estimates of the $\log_{10}$ of mean substrate diameter in millimeters (LSUB_DMM):

If **SUB_X** # 2.5 then **LSUB_DMM** = -4.61 + (2.16 × **SUB_X**) **(10a)**

If **SUB_X** > 2.5 then **LSUB_DMM** = -1.78 + (0.960 × **SUB_X**) **(10b)**

When code *MH_SUBS* is applied to data file ***sub_bank***, it uses the frequency of particles in each substrate size class to calculate reach level percentages in each size class (from Table 6) and in the following combined size classes:

PCT_SAFN = % substrate in size classes smaller than sand (# 2mm)
PCT_SFGF = % substrate in size classes # fine gravel (# 16 mm)
PCT_BIGR = % substrate in size classes larger than fine gravel (> 16mm)
PCT_BDRK = % substrate as smooth or rough bedrock.
PCT_ORG = % substrate composed of wood or organic detritus

This code assigns numeric values to the various substrate size classes. Substrate classes RR, RS, HP, and RC (concrete) are assigned a value of 6 (see Section 2.2.4 for code definitions). Class BL is assigned a value of 5, CB a value of 4, GC a value of 3.5, GF a value of 2.5, SA a value of 2, and FN a value of 1. The program then calculates simple reach level means, standard deviations, and percentiles for substrate size classes and lists the number of non-missing values used in the calculations. Using Equations 10a and 10b, it calculates the $\log_{10}$ of geometric mean substrate diameter (mm) from mean substrate size class values (Table 6).

When computer code *MH_EMB* is applied to data file ***sub_bank***, it calculates a reach mean and standard deviation of substrate embeddedness for the channel alone and for the channel plus channel margin together (Table 6), as well as listing the number of non-missing values used in the calculations. Note that observations of sand and fine substrates are assigned embeddedness values of 100%, and bedrock (smooth or rough), hardpan, and concrete are assigned embeddedness values of 0%.

3.2.7 Bed Substrate Stability

Many human activities directly or indirectly alter the size and composition of stream substrates. Consequently, excessive erosion, transport and deposition of sediment in streams and rivers is a major problem in surface waters throughout the United States. In fact, the 1996 National Water Quality Inventory [Section 305(b) Report to Congress] ranked sediments as a leading cause of water quality impairment in assessed surface waters. Accumulations of fine substrate particles fill the interstices of coarser bed materials, reducing habitat space and its availability for benthic fish and macroinvertebrates (Platts et al., 1983; Hawkins et al., 1983; Rinne, 1988). However, substrate sizes vary naturally in streams of different sizes and slopes. In order to evaluate impairment from sedimentation, it is essential to have some measure of how much the substrate size (e.g., % fines) in a stream deviates from that expected in the absence of human activities. The bed substrate stability index we derive herein is a measure of stream bed textural "fining" that occurs as a response to increases in the rate of upland erosion, and the increased mobility or instability of the bed substrate that accompanies such inputs of fine textured substrates.

Among streams flowing at the same slope, larger streams naturally tend to have coarser substrates than lower gradient streams, because their generally deeper flows exert more shear stress on their beds and tend to quickly transport fine substrates downstream (Leopold et al., 1964; Morisawa, 1968). The size composition of a streambed depends on the balance between the rates of supply of various sediment sizes to the stream and the rate at which the flow takes them downstream, i.e., the stream's sediment transport capacity (Mackin, 1948, Schumm, 1971). The sediment supply rate and the type and size of particles delivered to a stream by upslope erosion and mass transport is controlled and influenced by basin characteristics, including lithology, topography, climate, vegetative cover, runoff characteristics, and land disturbances. On the other hand, the potential erosive, or transport, capability of a stream is largely dependent on its slope, watershed area and runoff regime, characteristics which determine the velocity and depth of water flow. This potential transport capability can be lessened by channel features that impart hydraulic roughness and dissipate energy.

Good quality in-channel habitat is generally neither excessively stable (substrate coarse relative to transport capability), or unstable (substrate fine relative to transport capability). Some movement of the streambed is beneficial and essential to maintaining habitat quality, because it allows flows to scour and rework substrates to maintain complex pool habitat and to clean gravels that are important for fish spawning and production of aquatic invertebrates. Although natural rates of sediment input vary among and within regions, human activities can alter these inputs. Excessive watershed erosion from these activities can transport large amounts of fine sediments into streams, leading to frequent bed mobility and poor instream habitat. Conversely, some human alterations like dredging, channelization or upstream impoundments, may lead to a lack of fine sediments in some parts of the channel, but an excess in other places. Clearing vegetation from banks and riparian areas may increase siltation and reduce large woody debris in streams. Logging or farming up to the stream banks, building roads across or along streams, dredging and straightening the stream channel, and building dams or other diversion structures in the stream channel may destabilize stream banks and change bottom substrate size and composition.

Wilcock (1998) argues that, for gravel-bed rivers, a threshold of sand proportion greater than 20% to 40% initiates bed instability, as the bed transitions from a “framework-supported” bed of gravel and cobble to a “matrix-supported” bed in which these larger particles are supported by mobile sand and finer materials. However, these substrate stability guidelines are limited to streams that naturally have gravel or coarser substrates. By comparing the size range of streambed sediments with a stream’s erosive capability (i.e., bed shear stress) during typical flood conditions (e.g., Dingman, 1984: Dietrich et al., 1989: Buffington and Montgomery, 1992: Buffington, 1995: Montgomery et al., 1999), we can assess bed stability over a wider range of stream slopes, drainage areas, and substrates. If most of the streambed sediments are finer than the size the stream is capable of moving, those sediments move frequently, and are therefore relatively unstable. Following is a derivation of the relative bed stability index (Dingman, 1984), adapted to the type of data collected in a regional survey such as EMAP.

Sediment transport theory (e.g., Simons and Senturk, 1977) allows an estimate of the average streambed shear stress or erosive tractive force (τ_{bf}) on the bed during bankfull flow. Stream channels can be very complex, exhibiting a wide range in local bed shear stress due to small-scale spatial variation in slope, depth, and roughness within a channel reach. The following estimate of τ_{bf} is an expression of the average shear stress over the bed of the entire reach over which the measurements of channel morphology are averaged:

$$\tau_{bf} = \rho_{H_2O} g R_{bf} S \tag{11}$$

where:

τ_{bf} = Bankfull channel bed shear stress (Force per unit area = kg-m-s^{-2} = N-m^{-2})
ρ_{H2O} = mass density of water [kg-m^{-3}]
g = gravitational acceleration [m-s^{-2}]
R_{bf} = Bankfull channel hydraulic radius = Cross-sectional area ÷ wetted perimeter [m]
S = Channel water surface slope (Dimensionless: m/m)

Assumptions: *This estimate of* τ_{bf} *pertains to flow conditions that are uniform (spatially), and steady (relatively unchanging in time as water flows through the reach). These conditions are approximated by making measurements over long reaches within which discharge can be assumed to change only very slowly. Paola and Mohrig (1996) argue that quasi-steady flow can be assumed if discharge fluctuations occur on time scales >>* u/gS*, while quasi-uniform flow can be assumed if reach lengths are >>* R/S*; where* **u** *is mean velocity,* **g** *is gravitational acceleration,* **R** *is hydraulic radius (approximately flow depth), and* **S** *is slope. Buffington (1998) used Paola and Mohrig's criteria to evaluate the suitability of applying Equation 11 in a study partitioning shear stress in complex pool-riffle channel reaches. We followed the same logic in examining the characteristics of 150 EMAP sample reaches in the Mid-Atlantic region survey to determine how well they fit these criteria for approximating steady, uniform flow. Assuming bankfull mean velocities of ~1m*$^{-2}$*, the median value of* u/gS *was 0.2 minutes with a maximum of 3 minutes in these sample reaches. The quasi-steady flow assumption appears reasonable: even during storm events, discharges could easily be assumed to remain approximately constant for much longer periods of time. The quasi-uniform flow assumption is somewhat strained, but still reasonable, as more than half the 150 reaches in the same survey had reach lengths 6 times* R/S*. Less than 25% had reach lengths shorter than 2.5 times* R/S*, and these were reaches with slopes < 0.5%. Therefore, the calculation of reach-average shear stress as* $\tau_{bf} = \rho_{H2O} g R_{bf} S$ *is probably a reasonable approximation overall, but it is better for moderate to high gradient than for low gradient streams (slope < 1%).*

Bed particle movement by erosion is dependent upon particle size, water depth and velocity, the difference between the mass densities of fluid and particles, and the shape and arrangement of particles. The shear stress necessary to move a particle, the critical shear stress (τ_c), can be defined as a function of particle diameter as follows:

$$\boldsymbol{T}_{\mathbf{c}} = \theta\left(\rho_{\mathbf{sed}} - \rho_{\mathbf{H_2O}}\right)\mathbf{gD} \qquad \textbf{(12)}$$

where:

$\boldsymbol{\theta}$ = "Shields parameter", expressing the erodibility of particles as related to their shape, arrangement, and the presence and size of other particles. It is experimentally determined by relating shear stress to particle diameter. Yalin and Karahan (1979) report a value of 0.044 for relating D_{50} of non-cohesive, spherical particles > 0.1 mm diameter to shear stress in "fully rough" turbulent flows (i.e., Reynolds number \$ 70 and values of $\mathbf{R_{bf}S}$ \$ 10^{-4} m). The great majority of natural streams are "fully rough" (e.g., > 99% of 150 stream reaches sampled by EMAP in the Mid-Atlantic region passed these criteria).

$\rho_{\mathbf{sed}} - \rho_{\mathbf{H_2O}}$ = The difference between the mass densities of sediment particles and water [kg-m^{-3}]

D = the substrate particle diameter [in m, if τ_c is in N-m^{-2}].

By setting critical shear stress equal to bankfull shear stress,

$$\mathbf{T_c = T_{bf}} \qquad \textbf{(13a)}$$

$$\theta\left(\rho_{\mathbf{sed}} - \rho_{\mathbf{H_2O}}\right)\mathbf{gD} = \rho_{\mathbf{H_2O}}\mathbf{gR_{bf}S} \qquad \textbf{(13b)}$$

we calculate the *critical* (or maximum) diameter of particles that can be transported at bankfull flow ($\mathbf{D}_{cbf}$). Because it is calculated from a representation of the *average* or median bankfull shear stress within a long reach of channel, $\mathbf{D}_{cbf}$ is an estimate of the average or median substrate critical diameter within the reach:

$$\mathbf{D}_{cbf} = \frac{\left(\rho_{H_2O}\mathbf{g}\mathbf{R}_{bf}\mathbf{S}\right)}{\left[\theta\left(\rho_{sed} - \rho_{H_2O}\right)\mathbf{g}\right]} \qquad \textbf{(14a)}$$

Substituting $\mathbf{g}$=9.81 m-s^2, $\boldsymbol{\theta}$ = 0.044, ρ_{sed} = 2,650 kg-m^{-3} (average density for silicate mineral substrate particles), and ρ_{H_2O} = 998 kg-m^{-3} for freshwater at 20 °C, Equation 14a simplifies to the following expression, where $\mathbf{D}_{cbf}$ and $\mathbf{R}_{bf}$ are in the same units (e.g, if $\mathbf{R}_{bf}$ is in mm, then the estimate of $\mathbf{D}_{cbf}$ is mm):

$$\mathbf{D}_{cbf} = 13.7\mathbf{R}_{bf}\mathbf{S} \qquad \textbf{(14b)}$$

A first-cut of these estimates makes the simplifying assumption of a wide (Width/Depth > 20), longitudinally uniform channel of triangular cross-section, lacking large woody debris and pool-riffle structure. Under these wide channel assumptions, hydraulic radius can be approximated by mean channel depth, because wetted perimeter is then approximately equal to wetted width. Then assuming approximately triangular flow cross-sections (see Robison and Beschta, 1989), mean depth of a channel cross-section can be calculated as one-half maximum (thalweg) depth. $\mathbf{R}_{bf}$, the mean bankfull hydraulic radius (m), is calculated from EMAP data by adding mean bankfull height (XBKF_H) plus mean thalweg depth [(0.5 × XDEPTH)/10], and then dividing the sum by two (dividing XDEPTH by 10 converts thalweg depth to m). This first estimate ($\boldsymbol{\rho}\mathbf{g}\mathbf{R}_{bf}\mathbf{S}$) gives the potential bed shear stress, or *total bankfull shear stress* based on a hydraulically simple, low-roughness channel of a size and slope that would be determined mostly by topographic and climatic considerations (i.e., slope and discharge). The *effective* shear stress experienced by particles on the bed of actual stream channels is typically reduced from this potential value by sources of roughness that differ among streams, including bank irregularities, bars, and wood (Einstein and Banks, 1950, Nelson and Smith, 1989, Buffington, 1998).

In an approach analogous to those of other researchers (e.g., Buffington and Montgomery, 1992; Buffington, 1995), we incorporate terms to accommodate the reduction in shear stress and consequent bed textural “fining” that results from the presence of large woody debris and channel cross section irregularities. In our approach, we adjust $\mathbf{D}_{cbf}$ by reducing $\mathbf{R}_{bf}$ in Equation 14b by the approximate roughness height of large woody debris and pool-riffle scale channel irregularities. We calculate the effective hydraulic radius, $\mathbf{R}^{*}_{bf}$, by subtracting from $\mathbf{R}_{bf}$ the large woody debris “mean depth” ($\mathbf{R}_w$ = m^3 wood volume per m^2

channel surface area = m wood “depth” = V1W_MSQ), and the cross-section mean residual depth (**R_p** = one-half the thalweg mean residual depth = [0.5 × RP100]/10), multiplying RP100 by 0.5 to approximate mean depth in a triangular cross-section, and dividing by 10 to convert cm to m. Note that in the calculation **R^*_{bf}** = (**R_{bf}** - **R_w** - **R_p**), we make the simplifying assumptions that woody debris volume per channel bottom area is uniform over the wetted and bankfull channel, and that residual depth is a reasonable surrogate for the large scale roughness due to bars and irregularities in channel cross-section. There is good justification for using residual depth as a surrogate for large scale roughness, as residual depth has been shown to be related to transient hydraulic storage volume and, if discharge is taken into account, also to the Darcy-Weisbach friction factor (Kaufmann, 1987a; 1987b). However, the assumption of uniform large woody debris spacing likely underestimates the reduction in shear stress due to LWD. It might be possible to apply an adjustment to the equations to augment **R_w** to account for LWD “clumpiness,” or to alter the approach for encorporating the roughness due to pools, bars, bends, and other channel irregularities. The current calculations make the working assumption that the mean roughness “heights” of LWD and pool-riffle structure translate directly to reductions in effective hydraulic radius. Other approaches to more realistically incorporate the influence of roughness elements typically require more intensive data collection to describe their size, shape, spacing and orientation in relation to stream flow (e.g., Shields and Gippel, 1995; Buffington, 1998). The EMAP field data lack the detailed information that would allow direct adjustments to account for these complexities.

Finally, we calculate **RBS**, a measure of Relative Bed Stability (Dingman, 1984) as the ratio (**D_{50}/D^*_{cbf}**) of the observed substrate median diameter (approximated by the geometric mean diameter) divided by the average critical diameter at bankfull flow (the reach average for the largest particle that is mobile during bankfull flow):

$$\mathbf{RBS} = \frac{\mathbf{D_{50}}}{\mathbf{D^*_{cbf}}} = \frac{\mathbf{D_{50}}}{\left(\mathbf{13.7\,R^*_{bf}S}\right)} \qquad \mathbf{(15)}$$

Similar comparisons of observed substrate size with that predicted from shear stress have been used to evaluate the effects on substrate from changes in sediment supply (e.g., Montgomery et al., 1999) or large scale roughness elements such as LWD (Buffington, 1995; 1998). The RBS ratio is also conceptually similar to the “Riffle Stability Index” of Kappesser (1993), and is also similar to the ratio discussed by Dietrich et al. (1989) of median diameters of the substrate armor layer divided by that of the substrate beneath that layer, which is taken to be the bedload.

In calculating RBS using EMAP physical habitat data, we approximate the $\mathbf{D}_{50}$ by the bed surface substrate geometric mean diameter, SUB_DMM, and the reach average critical diameter ($\mathbf{D}^*_{cbf}$) by DMB_BW4, both expressed in mm (see Table 6). Note that $\mathbf{R}^*_{bf}$ must also be expressed in mm to match DMB_BW4. For convenience and to normalize their variances, we find it useful to express RBS values as logarithms. An RBS value of 1 corresponds to an LRBS (i.e., Log_{10} of RBS) value of 0. A value of LRBS equal to 0 results when a stream has $\mathbf{D}_{50} = \mathbf{D}^*_{cbf}$, indicating that the average bed shear stress during bankfull flows is sufficient to move the median (or in this case, the geometric mean) particle size. There is some uncertainty, when $\mathbf{D}_{50} = \mathbf{D}^*_{cbf}$, whether, in a particular stream, particles smaller than $\mathbf{D}_{50}$ will be selectively mobilized at lower flows, with different sizes of particles moving at progressively higher flows; or if the entire bed will become mobile in threshold fashion (see discussion by Montgomery et al., 1999). Parker et al. (1982) postulated that, in relatively coarse stream beds with a wide range of particle sizes, small grains “hidden” by larger armor-layer particles become mobile only when the larger particles move. At that threshold, the whole bed becomes mobile. A further complexity advanced by Wilcock (1997) is that partial mobility may occur in some channels, where only some substrate particles of a given size are mobile at a particular flow. Montgomery et al. (1999) observe that, at present, there is no scientific consensus regarding the particular conditions under which threshold (equal) mobility, selective transport, or partial mobility of stream bed substrates will occur. These authors suggest, however, that selective transport may occur in highly sediment-laden rivers, but when sediment supply rates decline, this process over time results in the winnowing away of fines and the development of an armor layer. They further suggest that “. . . as selective transport represents high or continuous sediment loading (Sutherland, 1987), . . . threshold mobility (Parker et al., 1982) characterizes channels with relatively low or intermittent sediment supply . . . ”.

On the basis of the previous discussion, we may assume that if $\mathbf{D}^*_{cbf}$ is accurately estimated, and that the RBS ratio $\mathbf{D}_{50}/\mathbf{D}^*_{cbf}$ is # 1, then at least half the bed substrate particles become mobile during bankfull flows that typically occur every year or two. A high positive value of RBS (e.g., 1000, an LRBS value of 3.0) indicates an extremely stable, immovable stream substrate like that in an armored canal, a “tailwater” reach below a dam, or other situations where the sediment supply is low, relative to the hydraulic competence of the stream to transport bedload sediments downstream (Dietrich et al., 1989). In contrast, very small values (e.g., 0.003, an LRBS value of -2.5) indicate a channel composed of substrates that are frequently moved by even relatively small floods. Note that LRBS values are logarithms of ratios, so a value of -2.5 denotes a stream in which bankfull flows have sufficient mean tractive force to move particles with diameter 300 times larger than the geometric mean particle size in the stream.

The RBS ratio $\mathbf{D}_{50}/\mathbf{D}^*_{cbf}$ is not only a measure of the mobility of stream bed substrates, but also gives an indication of the supply of sediment to the stream channel. An increase in the percentage of fine substrate particles (“textural fining”) in a stream bed often occurs when sediment supply is augmented due to land use activities that increase hillslope erosion (Lisle, 1982; Dietrich et al., 1989; Lisle and Hilton, 1992), suggesting an augmented sediment supply in relation to the stream’s downstream bedload transport capability (Dietrich et al., 1989). Buffington (1998) hypothesized that for a given bed shear stress, stream bed substrate size ($\mathbf{D}_{50}$) should be inversely related to sediment supply, because sediment supplies that overwhelm the local sediment transport capacity would reduce the bed-surface $\mathbf{D}_{50}$ through deposition of fine-grained particles that are typically in transport. The RBS ratio $\mathbf{D}_{50}/\mathbf{D}^*_{cbf}$ is therefore an indicator of sediment supply, but the relationship between RBS and sediment supply should be quantitatively proportional only if the channel is at equilibrium, i.e., if the rate of sediment transport through the channel is equal to the rate of sediment supply (Buffington, 1998). Even in streams draining “pristine” watersheds that are at equilibrium between sediment supply and transport, one might expect different characteristic values of RBS that are dependent upon the “natural” rates of erosion (Buffington 1998). In the absence of human activities, these natural erosion rates would depend upon climate, basin geology, geomorphology, channel position within the watershed, and related features such as glaciers and natural landslide frequency. However, even if a stream channel is not yet in equilibrium with a recently augmented sediment supply or a pulse of sediment influx (e.g., a landslide), a decrease in its RBS ratio will indicate the increased sediment supply, but the ratio cannot then be used to estimate the magnitude of the sediment supply.

We hypothesize that, given a natural disturbance regime, sediment supply in watersheds not altered by human disturbances may be roughly in long-term equilibrium with transport. RBS values for streams draining watersheds relatively undisturbed by humans should tend toward a characteristic value typical to the region. Dietrich et al. (1989) argue that, in most relatively undisturbed watersheds and streams, low hillslope erosion rates will allow some surface coarsening or armoring of streambeds. In these situations LRBS should be near or slightly above 0, and this is what we generally observe in the EMAP stream populations sampled in the mid-Atlantic region and in Western Oregon (P.R. Kaufmann, unpublished data). The least-disturbed of EMAP streams sampled in the Midwest Cornbelt/Great Plains generally tend to have LRBS values between -0.5 and +0.5. In all of these regions, progressive intensity of human land uses is generally associated with progressive sediment “fining”, indicated by declining values of LRBS (P.R. Kaufmann, unpublished data). Highly disturbed basins typically had LRBS < -1.0 in the mid-Atlantic region, and < -2.0 in Western Oregon and the Midwest Cornbelt/Great Plains, except where streams were extensively channelized, revetted, or dredged. In such cases, we often observed extremely high LRBS values (e.g., > 2.0).

Based on these considerations, we have set condition thresholds after workshop discussions with regional stream ecologists. They are expressed as LRBS, the Log_{10} of RBS, and are set in the spirit of hypotheses to be refined as we learn more about the reference levels for RBS in undisturbed streams in various regions, associations between RBS and disturbance, and the relationships between RBS and biota:

	Mid-Atlantic Highlands	Cornbelt/Great Plains
"Good Condition"	>0.2 to 1.0	>-0.5 to +0.5
"Impaired"	>-1.0 to + 0.2 and >1.0 to 2.0	>-2.5 to -0.5 and >0.5 to 2.5
"Highly Impaired"	<-1.0 and >2.0	<-2.5 and >2.5

Instructions for calculating these bed substrate stability metrics from EMAP physical habitat data are contained in Table 6 and in Appendix D (on the compact disk). These instructions include algorithms for calculating LDMB_BW4=$\text{Log}_{10}(\mathbf{D}^*_{\text{cbf}})$, the estimated critical median diameter (in mm) for bed substrate under bankfull conditions, with adjustments for Large Woody Debris and channel complexity. We also give instructions for calculating the estimated relative bed stability under bankfull conditions (LRBS_BW4 = $\text{Log}_{10}[\mathbf{D}_{50}/\mathbf{D}^*_{\text{cbf}}]$). The calculations must be made from a dataset that merges channel, substrate, residual pool, woody debris, and fish cover variables, as these are not contained in the single PHab data files. In the EMAP data management system, data sets named ***phabmet*** or ***phabbest*** contain the required suite of variables for these calculations. The estimates LTEST and LRBS_TST are also calculated using SAS code in Appendix D (compact disk) and are contained in the EMAP data files. They are empirical approximations of the more refined estimates LDMB_BW4 and LRBS_BW4, but do not explicitly involve bankfull depth, residual pool depth, and large woody debris volume in calculations. They are rough empirical approximations using one-half the mean thalweg depth as a surrogate for effective bankfull hydraulic radius: $\mathbf{R}^*_{\text{bf}} \sim (0.5 \times [\text{XDEPTH}/\ 10])$, a relationship that may sometimes be inaccurate, but can be derived as a quick "ballpark" estimate requiring very little field data.

3.2.8 Fish Cover

Field data estimating the presence and cover of fish concealment features according to field procedures described by Kaufmann and Robison (1994, 1998) consists of visual estimates of the cover class category of eight specific types of features in 11 observation plots distributed along each stream sample reach. To calculate reach-level metrics of fish cover, apply code *MH_FCV* to the data file ***fishcov***. The metric summaries calculated by this code are whole-reach averages, based on cover or presence estimates at 11 stations. For each fish concealment type, field crews estimated areal cover in four classes: absent (0), sparse (0 to 10%), moderate (10 to 40%), heavy (40 to 75%) and very heavy (> 75%). Based on cover estimation techniques described by Daubenmire (1968), reach fish cover metrics are calculated by assigning cover class midpoint values (i.e., 0%, 5%, 25%, 57.5%, and 87.5%) to each plot's observations and then averaging those cover values across all 11 stations. These calculations yield metrics of single types of fish concealment features listed in Table 6 (e.g., XFC_BRS -- the proportional areal cover of brush and small woody debris). In addition, the code calculates cover estimates of the following combined cover types, whose summed cover may exceed 100% (i.e., proportional areal cover > 1.0) :

XFC_ALL = sum of proportional areal cover from all types of fish "cover" excluding algae and aquatic macrophytes.
XFC_NAT = sum of proportional areal cover from natural concealment features (rocks and boulders, overhanging vegetation, brush, LWD, and undercut banks)
XFC_BIG = sum of proportional areal cover from large features (Rocks and boulders, LWD, undercut banks, and artificial structures).

Further summarization of fish cover information is accomplished by calculating reach fish cover presence metrics as the fraction of the 11 in-channel plots that had cover values > 0 for each category of fish concealment feature (e.g., PFC_BRS) or for defined combinations of features (e.g., PFC_BIG in Table 6).

3.2.9 Large Woody Debris

Large woody debris (LWD) pieces observed between each transect and the next upstream transect in each stream reach are tallied on the EMAP habitat field forms according to 12 diameter and length size classes, with indication whether the piece is in or outside the bankfull channel. To calculate LWD metrics, code *MH_WOOD* is applied to data file ***lgwoody.*** A nominal size-class volume is assigned to each piece, based on empirical pilot studies in which the dimensions of every piece of woody were measured (Robison, 1998). Reach summary metrics are then calculated as the total number and estimated volume of wood in various size classes.

Tallies and wood volume metrics are calculated for the original 12 length-diameter classes; separately for wood in the active channel, wood spanning but not in the active channel, and the combined total wood in the reach:

	Length		
Diameter	S (1.5 m to 5 m)	M (> 5 m to 15 m)	L (> 15 m)
S (0.1 m to 0.3 m)	T	S	M
M (> 0.3 m to 0.6 m)	S	M	L
L (> 0.6 m to 0.8 m)	S	L	L
X (> 0.8 m)	M	L	X

The codes T, S, M, L, and X in this table are progressively larger piece sizes from very small to very large. A nominal mean volume is calculated for each piece of LWD according to its diameter-length class membership as described and tested by Robison (1998):

$$\textbf{Volume} = \pi\left[1.33\left(\frac{\text{Class Minimum Diameter}}{2}\right)^{2}\right]\left[1.33(\text{Class Minimum Length})\right] \qquad \textbf{(16)}$$

Total numbers and volumes of LWD in each diameter-length class are regrouped and assigned to one of five cumulative wood size classes:

Class 1 - T, S, M, L, X	(Very small to Very Large)
Class 2 - S, M, L, X	(Small to Very Large)
Class 3 - M, L, X	(Medium to Very Large)
Class 4 - L, X	(Large to Very Large)
Class 5 - X	(Very Large)

As done for the separate diameter-length classes, *MH_WOOD* calculates separate summaries for the two locational classes plus a combined total, expressing them on per reach, per 100 m, and per m^2 basis. Unless noted in the data set, missing values in the wood tallies are assumed to be zero.

3.2.10 Riparian Canopy Cover (Densiometer)

The multiple canopy densiometer measurements collected in the EMAP field methods (Kaufmann and Robison, 1994, 1998) can be directly reduced to whole-reach canopy density characterizations by calculating their means and standard deviations. Because the data are systematically spaced, these averages and percentiles are spatially representative estimates of canopy density on and along the stream. When code *MH_DEN* is applied to data file ***canpycov***, it calculates separate reach level summary statistics for mid-channel and bankside canopy cover. Mean densiometer readings, their standard deviation, and the number of non-missing observations used in these calculations are generated separately for the 44 instream measurements (4 observations × 11 stations), and the 22 bank measurements (2 observations × 11 stations). These metrics are converted to percent canopy density by dividing the mean and standard deviation of densiometer reading values by 17, the highest possible canopy densiometer value, and multiplying the result by 100.

3.2.11 Riparian Vegetation Structure

Riparian vegetation cover field data collected by EMAP methods consist of visual cover class estimates for a number of specific features or types of vegetation in multiple observation plots distributed along each stream sample reach. The desired metric summaries are whole-reach averages, rather than multiple separate cover or presence estimates for each transect or riparian plot.

Riparian vegetation type and areal cover are visually estimated in three layers at each of the 22 riparian vegetation plots located at the left and right sides of 11 transects. The vegetation layers are: canopy (> 5 m high), mid-layer (0.5 to 5 m high) and ground cover (< 0.5 m high). Coniferous, deciduous, and broadleaf evergreen vegetation types are distinguished in the canopy and mid-layer. Canopy layer tree cover is divided into large diameter (> 0.3 m) and small diameter (< 0.3 m) trees; woody and herbaceous vegetation cover are distinguished in the mid-layer; and woody, herbaceous, and barren ground are distinguished in the ground cover layer. For each of the vegetation layer categories, areal cover is estimated in four classes: absent (0), sparse (0 to10%), moderate (10 to 40%), heavy (40% to 75%) and very heavy (> 75%).

When code *MH_VGPC* is applied to the data file ***riparian*****,** it produces two permanent metric data files, ***mh_canr*** and ***mh_canp*****.** Reach riparian cover metrics ***(mh_canr)*** are calculated by assigning the cover class mid-point value, as described for fish cover, to each riparian plot's observations and then averaging those cover values across all 22 stations. These calculations yield the single vegetation type metrics listed in Table 6 (e.g., XCL, the areal cover proportion of large diameter trees). Further summarization of riparian vegetation information is accomplished by summing the areal cover or tallying the presence of defined combinations of riparian vegetation layers or vegetation types. The riparian vegetation metrics that sum more than one layer may have areal cover proportions greater than 1.0 (i.e., cover > 100%):

XC = total canopy level cover (XCL + XCS)
XM = total mid layer veg. cover (XMW + XMH)
XG = total ground cover (XGW + XGH)
XCM = total canopy and mid veg. layer cover (XC + XM)
XCMG = total veg cover from canopy, mid and ground layers (XC + XM + XG)
XCMW = total canopy plus mid layer woody cover (XC + XMW)
XCMGW = total woody veg. cover in all three cover layers (XC + XMW + XGW).

In the second metric data file ***(mh_canp)*** calculated from ***riparian***, the code *MH_VGPC* assigns an indicator of presence to each type of vegetative cover. Reach riparian cover presence metrics are calculated as the fraction of the 22 riparian plots with non-zero cover values for any given vegetation-layer category (e.g., XPCL, the proportion of the reach that is bordered by large diameter trees). As for riparian cover metrics, combinations of cover presence are calculated (Table 6).

Finally, estimated percentages of the reach riparian area with canopy and midlayer comprised of deciduous, coniferous, broadleaf evergreen, or mixed vegetation types (Table 6) are calculated by applying code *MH_CMTYP* to the data file ***riparian***.

3.2.12 Riparian Human Disturbances

In the EMAP field methods, crews record the presence and proximity of 11 predefined types of human land use or disturbance based on 22 separate visual observations at both the left and right sides of the channel at 11 transect locations. Observations are specified in three proximity categories: “B” within the channel or on the stream bank, “C” within the 10 m × 10 m riparian sample plots, and “P” behind or adjacent to the plots. For each of the 11 disturbance categories, we calculate the proportion of riparian stations where the disturbance was in each proximity category (e.g., for roads, these are calculated within the *MH_HUM* computer code as the variables BXPROAD, CXPROAD, and PXPROAD). These metrics are calculated by applying code *MH_HUM* to data file ***riparian***. In addition, we calculate proximity-weighted disturbance indices by tallying the number of riparian stations at which a particular type of disturbance was observed, weighting each observation according to its proximity to the stream, and then averaging over the 22 riparian stations on the reach (e.g., W1H_ROAD in Table 6). Weightings were 1.5 for disturbance observations within the channel or on the stream bank (“B”), 1.0 for observations within the 10 m × 10 m riparian sample plots (“C”), and 0.667 for those behind or adjacent to the plots (“P”). Aggregated metrics were calculated by combining simple metrics of the various types of human disturbance observations (e.g., W1_HALL in Table 6).

3.2.13 Metric Variable Labeling and File Merging

The code *PHABMET* merges all the separate types of physical habitat metric files into the new file ***phabmet***. If one desires a reduced set of variables, code *PHABBEST* may be applied to ***phabmet*** to create ***phabbest***, a file containing only the most commonly used habitat variables. Although the separate metric calculation codes label all the variables they create, we also provide the code *MHLABELS* to attach labels to every variable in the merged metric data file ***phabmet*** or the separate metric files. To use the labeling code, enter the permanent data file name of each metric file (or ***phabmet*** at the appropriate place in *MHLABELS*.

4 PRECISION OF HABITAT CHARACTERIZATION

4.1 THEORETICAL CONSIDERATIONS

Effective environmental policy decisions require stream habitat information that is accurate, precise, and ecologically relevant (i.e., it contains useful information for interpreting controls on the biota or impacts of human activity). We evaluated sampling precision of field habitat survey methods employed by the USEPA's EMAP in probability samples of several hundred streams in Oregon (Herlihy et al., 1997) and the Mid-Atlantic region (Paulsen et al., 1991) between 1993 and 1996. We compared the within-year variance among streams ("signal") with the variance between repeat stream visits within the same year (measurement "noise"), combining our estimates of within-year variance over four years of study. We employed this statistical model in our evaluation of the precision of habitat metrics:

$$\mathbf{Y}_{ijk} = \mu + \mathbf{T}_i + \mathbf{S}_{j(i)} + \mathbf{E}_{ijk} \qquad \mathbf{(17)}$$

where *i* indexes years (*i* = 1993 to 1996), *j* indexes stream reaches (*j* = 1, . . . , n_i), *k* indexes visits to a particular stream reach (*k* = 1, . . . , $r_{j(i)}$), $\mathbf{Y}_{ijk}$ is the measured metric value for visit *k* to stream *j* during year *i*, μ is the grand mean among stream reaches, $\mathbf{T}_i$ is the mean difference of metric values during year *i* from the grand mean, $\mathbf{S}_{j(i)}$ is the mean difference of stream *j* from the mean within year *i*, and $\mathbf{E}_{ijk}$ is the residual variation that we have termed "noise." We assume that $\mathbf{T}_i \sim (0, \sigma^2_{yr})$, $\mathbf{S}_{j(i)} \sim (0, \sigma^2_{st(yr)})$ and $\mathbf{E}_{ijk} \sim (0, \sigma^2_{rep})$. The analysis of variance is as follows:

Source	*df*	*Mean Square*	*E(Mean Square)*
Years	*y-1*	MS_{Year}	$\sigma^2_{rep} + c_1\sigma^2_{st(yr)} + c_2\sigma^2_{yr}$
Streams(Years)	$\sum_i (n_i - 1)$	$MS_{Stream(Year)}$	$\sigma^2_{rep} + c_1\sigma^2_{st(yr)}$
Residual	$\sum_i \sum_j (r_{ij} - 1)$	$MS_{Residual}$	σ^2_{rep}

The term $\sigma^2_{st(yr)}$ is the within-year variation among streams in a region that is not attributable to measurement uncertainty or interannual variability, and these differences among streams are frequently the "signal" of interest in a regional survey. Residual variation, or "noise" variance (σ^2_{rep}) in our model was estimated by pooling the variances of repeat visits to a random subset of the probability sample of streams visited during the summer sampling periods (in Oregon, the subset was a stratified random sample). We have attempted to accurately represent the variances that would be encountered in a large-scale survey, not a highly controlled research project in which all measurements can be made by the same researchers at precisely the time that the data are needed. Therefore, in addition to measurement variation, we recognize that the noise variance includes the combined effects of within-season habitat variation, differences in estimates obtained by separate field crews, and uncertainty in the precise relocation of the unmarked sample reaches (relocated on subsequent visits using global positioning system (GPS) receivers, map, compass, landmarks, and field notes). Because our purpose here is to examine the precision with which habitat attributes can be measured during a period in which habitat quality is believed not to have changed, we do not include variation between years, which may more likely include actual changes in these attributes. Rather, we block our ANOVA by year, examining the within-year variation in repeat measurements. We define the precision of physical habitat metrics using three measures: σ_{rep}, CV, and the signal:noise variance ratio, S/N, calculated as $\sigma^2_{st(yr)}/\sigma^2_{rep}$.

The first expression of metric precision, σ_{rep}, is the root mean square error (RMSE) from our variance model, and is equivalent to the pooled standard deviation of repeat measurements (SD_{rep}) of a habitat metric. The lower the value of σ_{rep} for a given habitat metric, the more precise the measurement. The units of this expression of precision are the actual units of the habitat measurement. Consequently, σ_{rep} is particularly useful in cases where an investigator is familiar with the habitat attribute, its expected response to disturbances, and the relationship between biota and changes in the numeric value of the habitat metric. Precision comparisons based on σ_{rep} are more difficult to interpret for "indexes" that have less tangible meanings (e.g., W1_HALL, a proximity-weighted index of riparian human disturbances). It is also difficult to compare values of σ_{rep} among metrics that are expressed in different units or have different potential ranges.

The second measure of precision is the coefficient of variation (CV = 100 σ_{rep}/Mean). Many researchers use the CV as their primary expression of precision. Here, as is typical in regional applications, the CV is calculated as the pooled SD of replicates (in this case repeat visits) divided by the grand mean across sites. This CV can be misleading because of its dependence on the regional mean, which may differ substantially among field applications. For example, it would be reasonable to conclude that measurement precision is equal in two regional surveys in which canopy cover was measured with σ_{rep}=0.1, even if regional mean riparian canopy covers were 0.1 and 0.9. However, the respective CVs for the two surveys would be [100 × (0.1/0.1)] = 100% and [100 × (0.1/0.9)] = 11%, indicating vastly different “precision.” The measure σ_{rep} avoids this problem by expressing the precision as equal in the two cases, and we feel it is more appropriate for evaluating and comparing the precision of techniques applied across many streams.

In the third expression of precision, the S/N ratio ($\sigma^2_{st(yr)}/\sigma^2_{rep}$), we compare the variance of the habitat metric observed across a regional sampling of streams (“signal”) with the “noise” variance resulting from field measurement within the sampling season. This variance ratio is related to “intraclass correlation” or “heritability” (Snedecor and Cochran, 1980). Heritability is a similar ratio defined as $\sigma^2_{st(yr)}/(\sigma^2_{st(yr)} + \sigma^2_{rep})$. The higher the value of S/N, the more precise the metric is relative to the context of its regional variation. One advantage of this measure of precision is that it facilitates comparisons among different metrics. When the regional stream sample set and the subset of repeat streams are both random samples, S/N is related to the F-ratio commonly used in analysis of variance for evaluating the ability of a metric to discern differences among streams over the “noise” of measurement variation. This F statistic is calculated as $\{MS_{Stream(year)}\}/(MS_{Residual})$, and is an estimate of $(\sigma^2_{rep} + c_1\sigma^2_{st(yr)})/\sigma^2_{rep}$, where c_1 is a constant varying between 1 and *r*, the number of times the repeat-sample streams are visited. If all the sample streams were visited the same number of times, c_1 would be equal to *r* (see Neter and Wasserman, 1974). Our signal:noise ratio is related to the F statistic as follows:

$$\mathbf{S/N} = \text{Signal:Noise ratio} = \frac{\sigma^2_{\mathbf{st(yr)}}}{\sigma^2_{\mathbf{rep}}} = \frac{(F - 1)}{c_1} \qquad \mathbf{(18)}$$

The higher the S/N ratio is for a habitat metric surveyed within a region, the more that metric is able to discern differences among streams. If anthropogenic changes in habitat are similar in type and magnitude to the differences observed among streams across the region, then S/N is also a useful predictor of the metric’s potential for discerning trends or changes in habitat in single or multiple sites.

4.2 HABITAT METRIC PRECISION RESULTS

Three measures of precision, σ_{rep}, CV, and the S/N ratio ($\sigma^2_{st(yr)}/\sigma^2_{rep}$), are presented in a series of tables for a large selection of EMAP physical habitat metrics. They are grouped in tables according to the type of metric as follows: Channel Morphology measurements, Channel Habitat Classifications, Substrate, Fish Cover, Riparian

Vegetation, and Riparian Human Activities and Disturbances. In cases where metric values are tangibly understandable or have well-constrained ranges (e.g., substrate size percentages and cover proportions), we compare precision within a group of similar metrics primarily on the basis of σ_{rep} in the following discussions, with consideration of S/N to compare their precision with other types of metrics and to assess the likely utility of metrics in a regional survey. Where the range of a variable is not rigidly constrained (e.g. width, slope, depth), we rely mainly on values of S/N to express and compare precision. However, σ_{rep} gives a tangible measure of the precision of these metrics expressed in their units of measurement (for example, it is inherently useful to know that mean Residual Depth was measured with a precision of $\pm$ 1.6 cm in the Mid-Atlantic region survey, regardless of the magnitude of regional variation in that metric). We avoid focusing our assessment of metric precision on CVs, but present these commonly used numbers and show how they can frequently be misleading.

4.2.1 Channel Morphology and Habitat Classifications

Quantitative measurements of relatively flow-independent channel morphology (e.g., XSLOPE, SDDEPTH) and Residual Pool metrics (e.g., RP100, RPGT75, RPXAREA) were quite precise, with S/N ratios ranging from 6 to 33 (Table 7). Even though mean depth, mean width, and mean width-depth product (XDEPTH, XWIDTH, XWXD) vary somewhat with flow stage, they were also reasonably precise, with S/N values ranging from 6.9 to 15. Presumably because of their greater dependence upon flow stage, mean width-depth ratio (XWD_RAT), standard deviation of width-depth ratio (SDWD_RAT), mean bank angle (XBKA), and mean undercut distance (XUN) were imprecise (S/N values mostly < 2.9).

Channel percentages in various habitat classifications (e.g., % Pool Habitat) are similarly dependent on flow stage, but are also considerably dependent on personal judgement; as expected, these were relatively imprecise, with S/N ratios mostly < 2 (Table 8). Exceptions that were alternately quite precise (S/N = 7.5 to 21) or very imprecise (S/N < 2) in one or the other regional survey included %Falls, %Cascades, and the aggregated metrics %Fast Water and %Slow Water Habitats. Compared with other channel habitat features, these classifications are less variable within the summer baseflow sampling period and more reliably recognized in the field. Stream habitat unit classifications lack repeatability both because of their subjectivity and their flow-dependency (Platts et al., 1983). One commonly reported channel description, %Pool, had σ_{rep} = 11 to 16%, CV = 48 to 88%, and measured values varied almost as much between visits as among streams (S/N = 1.2 and 2.1 in the two surveys). These findings, in general agreement with Ralph et al. (1994), Roper and Scarnecchia (1995), Wood-Smith and Buffington (1996), and Poole et al. (1997), are of concern, because many stream monitoring efforts collect this type of data

TABLE 7. PRECISION OF PHYSICAL HABITAT METRICS FOR QUANTITATIVE STREAM CHANNEL MORPHOLOGY IN THE MID-ATLANTIC REGION AND OREGON
(for the Mid-Atlantic Region, n=169 with 50 replicates; for Oregon, n=44 with 22 replicates)

Variable Name -- Description **CHANNEL MORPHOLOGY METRICS**[a]	**RMSE=σ_{rep} (in units of metric)**		**CV=σ_{rep}/0 (%)**		**S/N =$\sigma^2_{st(yr)}/\sigma^2_{rep}$**	
	Mid-Atlantic	**Oregon**	**Mid-Atlantic**	**Oregon**	**Mid-Atlantic**	**Oregon**
XDEPTH – Thalweg mean depth (cm)	6.4	6.2	22	17	7.3	6.9
SDDEPTH – Thalweg Std. Deviation of depth (cm)	1.7	3.4	13	23	16	6.0
XWIDTH -- Mean Wetted Width (m)	0.93	0.89	18	17	15	14
SDWIDTH -- Std. Deviation of Wetted Width (m)	0.58	0.60	38	35	6.4	5.1
XWXD – Mean Width-Depth Product (m^2)	0.79	0.80	39	33	8.2	8.1
SDWXD – Standard Deviation of Width-Depth Product (m^2)	0.32	0.75	32	61	15	2.9
WD_RAT – Mean ratio of Wetted Width to Thalweg Depth	6.8	2.6	32	16	0.9	6.5
SDWD_RAT – Standard Deiation of Width-Depth Ratio	6.5	3.4	52	36	0.8	2.9
AREASUM – Residual Pool Vertical Profile Area (m^2/reach)	4.6	7.6	19	25	29	17
RP100 -- Mean Residual Depth (m^2/100 m = cm)	1.6	2.2	17	19	16	9.0
RPGT75 -- Number of Residual Pools with Depth > 73 cm (number/reach)	0.60	0.98	47	52	9.5	8.2
RPXAREA – Mean Residual Pool Vertical Profile Area (m^2/pool)	0.69	1.0	30	41	33	6.8
RPMDEP – Maximum Residual Depth of Deepest Pool in Reach (cm)	14	34	19	37	7.6	1.5
XINC_H – Mean Incision Height (m)	0.38	0.76	26	53	7.6	0.8
XUN – Mean Bank Lateral Undercut Distance (m)	—	0.025	—	70	—	2.1
XBF_H -- Mean Bankfull Height (m)	0.33	0.13	71	22	0.2	3.5
XBF_W – Mean Bankfull Width (m)	1.7	1.1	24	12	5.2	24
XBKA -- Mean bank angle (degrees)	8.1	8.4	18	22	2.4	2.0
XSLOPE -- Mean Channel Gradient (%)	0.80	0.87	42	25	18	24
VSLOPE -- Std. Deviation of Channel Gradient (%)	0.40	0.66	43	46	14	4.7
SINU -- Channel Sinuosity	0.10	0.25	8.3	20	4.1	1.1

[a] Variable names in **bold** are aggregate metric variables.

TABLE 8. PRECISION OF PHYSICAL HABITAT METRICS FOR STREAM CHANNEL HABITAT CLASSIFICATION IN THE MID-ATLANTIC REGION AND OREGON

(for the Mid-Atlantic Region, n=169 with 50 replicates; for Oregon, n=44 with 22 replicates)

Variable Name -- Description CHANNEL HABITAT CLASSIFICATION METRICS[a]	$RMSE=\sigma_{rep}$ (in units of metric)		$CV=\sigma_{rep}/0$ (%)		$S/N = \sigma^2_{st(yr)}/\sigma^2_{rep}$	
	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon
PCT_FA – % Falls	0.4	1.0	204	382	19	~0
PCT_CA – % Cascades	1.7	3.7	105	47	10	21
PCT_RA -- % Rapids	12	3.0	229	80	~0	1.6
PCT_RI – % Riffles	18	14	39	59	0.7	1.6
PCT_GL – % Glides	14	15	42	79	1.9	2.1
PCT_PP – % Plunge Pools	3.3	5.0	215	219	1.1	0.1
PCT_PD – % Impoundment Pools	5.2	12	199	140	3.0	1.4
PCT_PT – % Trench Pools	9.0	12	250	100	0.1	2.5
PCT_PL – % Lateral Scour Pools	8.4	9.5	196	211	~0	0.2
PCT_PB – % Backwater Pools	1.1	1.2	310	411	0.4	~0
PCT_POOL % Pools / Reach Length	11	16	88	48	1.2	2.1
PCT_SLOW % Pools+Glides / Reach Length	16	12	35	23	1.7	7.5
PCT_FAST % Fast Water Habitat / Reach Length	16	12	31	25	1.6	7.6
PCT_DRS % Dry or Submerged Flow / Reach Length	9.9	1.2	397	586	0.7	0.9

[a] Variable names in **bold** are aggregate metric variables.

and intend to use it for trend assessment. Although flow-dependent data are necessary and useful as covariates to aid understanding biological data, their flow-dependency severely limits their use in assessing channel habitat changes in response to human activities. To increase the precision of stream habitat classifications, Wood-Smith and Buffington (1996) recommend determining or envisioning habitat types at a characteristic stage (e.g., bankfull); Roper and Scarnecchia (1995) recommended simplifying or aggregating complex habitat classifications and replacing them when possible with objective measurements. To the same end, Ralph et al. (1994) recommended using direct, objective measurements over visual and subjective judgements.

To illustrate the effects that aggregating classifications, measuring rather than estimating, and decreasing flow stage dependency have on metric precision, it is instructive to compare metrics that quantify pool habitat in stream reaches (Table 9). Individual metrics quantifying the percentage of specific pool types visually classified by field crews were the least precise of these metrics. Though σ_{rep} values increased when habitat classes were combined into PCT_POOL (5 pool classes) and PCT_SLOW (5 pool classes + glides), this effect does not indicate a loss of precision, as it results simply because these summed metric values (and their variances) are greater than their subcomponent values. Note, for example, that CV's of these combined classes are substantially lower than those for glide or pool habitat metrics taken individually. The increase in precision of aggregating these pool classifications is indicated by the slight to moderate increases in the S/N ratios of the PCT_POOL and PCT_SLOW over the general S/N values of separate pool classes. Even if field crews made perfect, consistent classifications of pool habitat along the thalweg, the characteristics upon which these classifications depend are themselves dependent upon the flow stage. An area that is clearly a pool during low flows may become a glide, riffle, or even a rapid at higher flows. The lower S/N ratios of PCT_POOL and PCT_SLOW in the Mid-Atlantic region (April-June), compared with the Oregon survey (July-Sept) may have resulted because that survey was conducted during more rapidly changing springtime flow conditions.

Mean thalweg depth (XDEPTH) is dependent upon stream basin size, flow stage and the bed profile of the stream reach. While it appears quite precise, XDEPTH likely derives much of its regional variability, and thus its high S/N ratio, from the broad size range of streams in the surveys. Mean residual depth (RP100) and its surrogate SDDEPTH, are flow-independent indices of bottom complexity, pool vertical profile area, and pool volume (Kaufmann, 1987a; Robison and Kaufmann, 1994). Though it is not meaningful to compare directly the σ_{rep} values of RP100 and SDDEPTH with those for PCT_POOL and PCT_SLOW, their S/N ratios were 3 to 8 times higher, indicating a much higher level of precision for the quantitative, flow-independent metrics. Like XDEPTH, part of the regional variance of stream residual pool area depends upon the stream basin size, which, for a given runoff, influences the mean annual and flood stage discharges. Consequently S/N ratios for RP100 and SDDEPTH are enhanced somewhat by regional differences in stream size.

A flow-dependent analogue of PCT_POOL, percent residual depth (P_RESD), is derived by dividing mean thalweg residual depth by mean thalweg total depth. In absolute terms (σ_{rep}), P_RESD was somewhat more precise than PCT_POOL (Table 9). Relative to among-stream variation (i.e., considering S/N), P_RESD had about the same very low precision as PCT_POOL in the Mid-Atlantic survey (S/N=1.1), but was moderately precise in

TABLE 9. COMPARISON OF PRECISION IN METRICS DESCRIBING STREAM REACH POOL HABITAT IN SURVEYS OF THE MID-ATLANTIC REGION AND OREGON
(for the Mid-Atlantic Region, n=169 with 50 replicates; for Oregon, n = 44 with 22 replicates)

Variable Name -- Description POOL HABITAT METRICS[a]	RMSE=σ_{rep} (in units of metric)		CV=$\sigma_{rep}/0$ (%)		S/N = $\sigma^2_{st(yr)}/\sigma^2_{rep}$	
	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon
PCT_P* – % of individual pool types -- 5 metrics	1.1 to 12		100 to 411		0 to 2.5	
PCT_POOL – % Pools / Reach Length	11	16	88	48	1.2	2.1
PCT_SLOW – (% Pools+Glides) / Reach Length	16	12	35	23	1.7	7.5
XDEPTH – Mean Thalweg Depth (cm)	6.4	6.2	22	17	7.3	6.9
SDDEPTH – Standard Deviation of Thalweg depth (cm)	1.7	3.4	13	23	16	6.0
RP100 -- Mean Residual Depth (m^2/100 m = cm)	1.6	2.2	17	19	16	9.0
P_RESD – % Residual Depth = 100 × (RP100/XDEPTH)	9.8	5.4	29	18	1.1	4.9

[a] Variable names in **bold** are aggregate metric variables.

the Oregon survey (S/N=4.9), where flows were relatively stable within each year's field season.

4.2.2 Substrate

Substrate metrics were reasonably precise, with 10 of 14 substrate percent composition metrics having σ_{rep} # 7% in one or both surveys (Table 10). However, the following information suggests that the precision of substrate metrics could be improved by increasing the number of "pebbles" in the systematic pebble count from 55 up to 100 particles, for example, even if size classifications were still determined by eye. Assuming binomial sampling probabilities (Snedecor and Cochran, 1980), where the standard deviation = $\{[p(1\text{-}p)]/n\}^{1/2}$, pebble counts of 55 particles taken from substrates with compositions in the range of 0 to 50% of a designated size class should have σ_{rep} between 4 and 7%, assuming no error in size classifications. The observed σ_{rep} values are typically in this range, suggesting that the precision of these field methods is limited more by the number of substrate particles in the sample than by uncertainties in the size classifications, which are judged visually. Percent Sand + Fines, for example, had σ_{rep} = 7.7% in the Mid-Atlantic region survey. With a regional sample mean PCT_SAFN = 32%, we would predict

TABLE 10. PRECISION OF PHYSICAL HABITAT METRICS FOR STREAM REACH SUBSTRATE IN THE MID-ATLANTIC REGION AND OREGON

(for the Mid-Atlantic Region, n=169 with 50 replicates; for Oregon, n=44 with 22 replicates)

Variable Name -- Description SUBSTRATE METRICS[a]	RMSE=σ_{rep} (in units of metric)		CV=σ_{rep}/0 (%)		S/N = $\sigma^2_{st(yr)}/\sigma^2_{rep}$	
	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon
PCT_RR -- % Substrate - Rough Bedrock	9.2	2.6	255	100	~0	3.1
PCT_RS – % Substrate - Smooth Bedrock	5.6	4.6	210	176	0.7	0.7
PCT_BL – % Substrate - Boulders	5.1	6.2	58	42	3.9	6.0
PCT_CB – % Substrate - Cobbles	4.9	6.2	26	42	8.0	2.9
PCT_GC – % Substrate - Large Gravel	7.4	7.6	45	45	1.4	1.4
PCT_GF – % Substrate - Fine Gravel	5.3	8.7	47	87	2.2	~0
PCT_SA – % Substrate - Sand	9.8	7.9	68	118	1.4	0.1
PCT_FN -- % Substrate - Fines (Silt,Clay, and Muck)	11	7.4	60	32	2.8	15
PCT_HP -- % Substrate - Hardpan	0.2	3.0	310	142	11	12
PCT_SAFN -- % Substrate - Sand + Fines	7.7	11	24	36	10	7.1
PCT_SFGF -- % Substrate # 16mm diameter	7.5	12	17	30	11	5.0
PCT_BIGR -- % Substrate > 16 mm diameter	6.2	8.1	12	16	19	16
PCT_BDRK -- % Substrate - Bedrock	9.1	4.0	144	76	0.7	3.9
PCT_WD -- % Substrate - Organic Debris	3.6	3.8	146	102	0.2	0.4
PCT_OT -- % Substrate - Miscellaneous	3.6	4.7	480	217	~0	0.6
XEMBED -- % Substrate Embedded - mid-channel + margin	15	9.5	27	18	1.9	7.7
XCEMBED – % Substrate Embedded - mid-channel only	17	13	36	27	1.5	4.1
SUB_X – Mean Substrate Size Class (0 to 6)	0.20	0.24	6.4	7.8	22	23
SUB_V – Std. Deviation of Substrate Size Class (0 to 6)	0.20	0.18	18	17	2.4	3.9
LSUB_DMM – Log$_{10}$[Estimated Geometric Mean Substrate Diameter (mm)]	0.26	0.32	n.a.	n.a	20	24
LTEST – Log$_{10}$[Mobile Substrate Diameter (mm)]	0.27	0.27	n.a.	n.a	2.6	7.4
LRBS_TST – Log$_{10}$(Relative Bed Stability)	0.35	0.44	n.a.	n.a	9.0	6.8

[a] Variable names in **bold** are aggregate metric variables.

that σ_{rep} would be approximately 6.3% in repeated samples of 55 particles, if there were no error in the classification of particle size for each particle. The observed σ_{rep} value of 7.7% for PCT_SAFN means that if the observed mean value for a stream reach was 25% Sand + Fines, the true reach mean ± 1SD is estimated to be 25% ± 7.7%. The Log_{10} of the geometric mean substrate diameter (LSUB_DMM) had $\sigma_{rep} = 0.26$ in the same survey, giving a ± 1 SD range of 5.5 to 18mm for a mean diameter of 10 mm. The S/N ratios of substrate metrics were mostly high, with half of the 22 metrics having S/N > 5 and 7 metrics with S/N $\geq$ 10. Aggregated or averaged metrics (e.g., PCT_SAFN, PCT_BIGR, LSUB_DMM, and LRBS_TST) tended to have much higher S/N ratios than percentages of single classes of substrate (e.g., PCT_RR, PCT_SA).

4.2.3 Fish Cover and Large Woody Debris

All metrics for single fish cover types (e.g., XFC_UCB, XFC_RCK) are expressed as areal cover proportions that range from 0 to 1. Because fish concealment features can be layered upon each other, the sums of several types of cover types (e.g., XFC_NAT) can theoretically have a total equal to the number of cover types in the sum. Even though all of the fish cover metrics are visual estimations, the “plots” over which they are determined are well-defined, and their classifications are tightly constrained. As a result, almost all were estimated with relatively low standard errors ($\sigma_{rep} < 0.1$) by field crews (Table 11). In fact, half of the fish cover metrics were quite precise, with $\sigma_{rep} < 0.05$ in one or both surveys. Because the variances the sums of variables are additive, summed cover metrics such as XFC_NAT, with $\sigma_{rep} = 0.18$, had relatively higher σ_{rep} than typical for their subcomponents (which are single fish cover types). Signal:noise ratios of the metrics for single and aggregate fish cover categories ranged from low to moderate (0 to 6.2), the majority having S/N values between 2 and 4.

Fish cover presence metrics (e.g., PFC_LWD) differ from fish cover metrics (e.g., XFC_LWD) by being estimates of the percent of the reach length with any of the cover type present, in contrast to being an estimate of the average areal cover of that type in the reach. Like single cover-type metrics, metrics expressing the portion of the stream reach in which one or more cover types were present have ranges constrained from 0 to 1. Because many fish cover elements were typically present (though not necessarily abundant) at all transects in most streams of the MAHA and Oregon surveys, regional variation in the values of cover-presence metrics was not generally as great as that for metrics expressing the amount of cover of fish concealment features. Consequently, S/N ratios for aggregated cover-presence metrics were relatively low in the MAHA survey (S/N < 2) and barely moderate in the Oregon survey (S/N 2.8 to 2.9), driven down not as much by imprecise measurement, as by low variance among streams.

TABLE 11. PRECISION OF PHYSICAL HABITAT METRICS FOR INSTREAM FISH COVER AND LARGE WOODY DEBRIS (WITHIN BANKFULL CHANNEL) IN THE MID-ATLANTIC REGION AND OREGON (for the Mid-Atlantic Region, n=169 with 50 replicates; for Oregon, n=44 with 22 replicates)

Variable Name -- Description FISH COVER AND LARGE WOODY DEBRIS (LWD) TALLY METRICS[a]	RMSE=σ_{rep} (in units of metric)		CV=σ_{rep}/0 (%)		S/N = $\sigma^2_{st(yr)}/\sigma^2_{rep}$	
	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon
Fish Cover, Algae and Macrophyte Metrics:						
XFC_ALG -- Filamentous Algae - Areal Cover Proportion	0.067	0.089	224	197	0.8	0.9
XFC_AQM – Aquatic Macrophytes - Areal Cover Proportion	0.031	0.068	102	117	4.7	2.8
XFC_LWD -- Large Woody Debris - Areal Cover Proportion	0.040	0.036	142	53	0.2	3.9
XFC_BRS -- Brush - Areal Cover Proportion	0.037	0.065	59	63	1.2	1.0
XFC_OHV -- Overhanging Vegetation - Areal Cover Proportion	0.11	0.069	87	36	0.6	5.1
XFC_UCB -- Undercut Bank - Areal Cover Proportion	0.040	0.040	64	56	2.1	6.2
XFC_RCK -- Boulder, Rock Ledge - Areal Cover Proportion	0.095	0.14	55	64	3.5	2.1
XFC_HUM -- Artificial Structures - Areal Cover Proportion	0.13	0.006	679	203	~0	3.6
XFC_NAT -- Sum of Natural Fish Cover Types - Areal Cover Proportion	0.18	0.18	39	28	1.7	2.8
XFC_ALL -- Sum of All Fish Cover Types - Areal Cover Proportion	0.22	0.18	46	28	0.8	2.8
XFC_BIG -- Sum of LWD, Undercut Bank, and Rock Cover - Areal Cover Proportion	0.18	0.14	64	40	0.7	2.9
PFC_ANY – Portion of Reach with Any Type of Cover	0.15	0.07	16	7.1	~0	~0
PFC_NAT – Portion of Reach with Natural Cover	0.12	0.07	13	7.1	1	~0
PFC_BIG – Portion of Reach with LWD, Undercut Bank, or Rock Cover	0.22	0.12	26	14	0.4	2.9

[A] Variable names in **bold** are aggregate metric variables.

(continued)

TABLE 11 (continued)

Variable Name -- Description FISH COVER AND LARGE WOODY DEBRIS (LWD) TALLY METRICS[a]	**RMSE=σ_{rep} (in units of metric)**		**CV=σ_{rep}/0 (%)**		**S/N = $\sigma^2_{st(yr)}/\sigma^2_{rep}$**	
	Mid-Atlantic	**Oregon**	**Mid-Atlantic**	**Oregon**	**Mid-Atlantic**	**Oregon**
Selected Large Woody Debris Tally Metrics:						
Log_{10}(**C1WM100**) -- LWD, all sizes (Pieces/100 m)	0.50	0.40	n.a.	n.a.	3.9	7.0
Log_{10}(**C4WM100**) -- LWD, Large +Extra Large sizes (Pieces/100 m)	0.93	0.63	n.a.	n.a.	~0	2.4
Log_{10}(**V1WM100**) -- LWD Volume, all sizes (m^3/100 m)	0.53	0.34	n.a.	n.a.	2.5	12
Log_{10}(**V4WM100**) -- LWD Volume, Large + Extra Large sizes (m^3/100 m)	1.17	0.82	n.a.	n.a.	~0	2.5

[a] Variable names in **bold** are aggregate metric variables.

In an absolute sense, LWD tallies produced reach estimates that were quite imprecise, but when viewed relative to the magnitude of metric values or the range of variation within the region, the precision of LWD tally metrics was moderate to high, depending on the size class of LWD. The range of LWD abundance in streams within both regions was quite extreme, with distributions and repeat variances that were decidedly skewed. Repeat visit variance was proportional to the number or volume of woody debris in the tally. For this reason, we conducted the ANOVA on log-transformed data. Values of σ_{rep} in a selection of LWD count and volume tally metrics ranged from 0.50 to 1.15 in the Mid-Atlantic survey and 0.34 to 0.82 in Oregon (Table 11). Because these are log-transformed values, they may be interpreted as proportional σ_{rep} values of 3 to 15 times the measured value for Mid-Atlantic streams and 2 to 6 times the measured value for Oregon Streams. The total amount of LWD and the variation among streams in the Oregon survey was substantially higher than in the Mid-Atlantic survey, leading to higher S/N values. In Oregon, the median count for all sizes of LWD in the 35 sample stream reaches was 12 pieces (median volume =5.4 m^3) per 100 m, compared with 5 pieces (volume =1.8 m^3) per 100 m in the Mid-Atlantic reaches. The greater abundance of LWD in Oregon streams is accentuated when one considers only the “Large” and “Extra Large” length and diameter classes (see Table 6 for size class definitions). In Oregon, the medians for the sample reaches were 0.5 pieces per 100 m and 1.5 m^3 per 100 m, compared with medians of zero in the Mid-Atlantic survey. As a result primarily of the greater quantity and variation in Oregon streams, metric precision in terms of S/N ratios was high for LWD (all sizes combined) in Oregon streams (7.0 to 12), compared with only moderate precision in the

Mid-Atlantic survey (S/N = 2.5 to 3.9). For large and extra-large diameter and length classes, S/N precision was barely moderate in Oregon (S/N = 2.4 to 2.5), but very low in the Mid-Atlantic (S/N ~0), because wood of that size is relatively rare in that region.

4.2.4 Riparian Vegetation

Riparian canopy cover measured with a canopy densiometer was determined with virtually the same precision by field crews in the Mid-Atlantic region and Oregon surveys (σ_{rep} = 5.7 and 5.8 % for XCDENMID). Corresponding values of S/N were 19 and 15 for XCDENMID in the two surveys (Table 12). The 2 sets of crews had similar backgrounds of education and experience, used the same field manual, and were trained identically. However, the Oregon survey and its repeat site visits were done in midsummer (July 1 to Sept. 15), whereas the Mid-Atlantic region streams were sampled between April and June (after snowmelt but before full leafout), to optimize detecting acidic deposition effects on chemistry and biota. In the Mid-Atlantic region, crews were instructed to “imagine” tree cover under leafout conditions based on the extent of bare branches and newly budding leaves they frequently encountered in the riparian canopy. Surprisingly, actual changes in canopy cover and ambiguity in reading densiometer values during the spring sampling period did not appear to erode the precision of measurements in that region. Canopy density measurements taken at the stream banks (XCDENBK) were less precise than mid-channel measurements in the Mid-Atlantic region; the reverse was true in Oregon. Lower precision in Mid-Atlantic region streams may have resulted because that survey was conducted during more rapidly changing springtime flow conditions in which stream width was declining, changing the distance between the wetted bank and the edge of riparian vegetation. However, the smaller number of bank densiometer measurements (22), compared with mid-channel measurements (44) is theoretically sufficient to account for the lower precision in XCDENBK. Based on bionomial sampling theory, this difference in the number of individual densiometer observations is sufficient to result in a σ_{rep} value 1.41 times higher using 22, rather than 44 measurements (and assuming equal mean canopy densities for the bank and mid-channel).

Besides the canopy densiometer metrics, the other riparian vegetation metrics showed considerable range in precision (Tables 12 and 13). With the exception of XC in both regions, and XCL in Oregon, and the ground cover metrics XGH and XGB in the Mid-Atlantic region, virtually all single vegetation type cover magnitude (not presence) metrics were relatively imprecise, with σ_{rep} mostly between 10% and 20% and S/N < 2.5. Cover magnitude estimates summing two or more layers of vegetation were similarly imprecise or moderately precise. In contrast, virtually all single and combined cover *presence* metrics (i.e., those with names beginning with XP... or P...) were moderately precise, with σ_{rep} # 8%

TABLE 12. PRECISION OF PHYSICAL HABITAT METRICS FOR CANOPY DENSITY, COVER, AND PRESENCE IN MULTIPLE LAYERS OF RIPARIAN VEGETATION ALONG STREAMS OF THE MID-ATLANTIC REGION AND OREGON
(for the Mid-Atlantic Region, n=169 with 50 replicates; for Oregon, n=44 with 22 replicates)

Variable Name -- Description RIPARIAN VEGETATION METRICS -- MULTIPLE LAYER[a]	RMSE=σ_{rep} (units of metric)		CV=σ_{rep}/0 (%)		S/N = $\sigma^2_{st(yr)}/\sigma^2_{rep}$	
	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon
Canopy Densiometer Metrics:						
XCDENMID -- Canopy Cover Midstream - Densiometer (%)	5.7	5.8	7.5	8.1	19	15
VCDENMID -- Std. Deviation of Canopy Cover Midstream - Densiometer (%)	3.7	3.9	19	21	9.3	4.3
XCDENBK -- Canopy Cover at Bank - Densiometer (%)	8.0	3.9	10	4.4	7.3	17
VCDENBK -- Std. Deviation of Canopy Cover at Bank - Densiometer (%)	5.6	5.7	31	42	5.3	2.2
Visual Cover Estimation Metrics:						
XCM -- Sum of Canopy + Mid-Layer Cover (Proportion of Riparian)	0.33	0.27	40	34	0.6	0.8
XPCM -- Both Canopy and Mid-Layer Present (Proportion of Riparian)	0.09	0.08	11	9.8	7.1	7.9
XCMW -- Sum of Woody Canopy + Mid-Layer (Proportion of Riparian)	0.22	0.22	28	33	2.3	1.4
XCMG -- Sum of Canopy + Mid-Layer + Ground Cover (Proportion of Riparian)	0.41	0.40	29	28	0.3	0.1
XPCMG -- 3-Layers of Vegetation Present (Proportion of Riparian)	0.10	0.08	13	9.8	5.8	8.0
XCMGW -- Sum of Woody Vegetation Cover in 3 Layers (Proportion of Riparian)	0.25	0.36	28	40	2.3	0.7

[a] Variable names in **bold** are aggregate metric variables.

and S/N $ 5. The cover presence metrics XPCAN and (in the Oregon surveys) PMID_C had high precision (σ_{rep} #5 and S/N $ 10), rivaling that of canopy densiometer metrics.

It is instructive to examine the precision that can be gained by applying quantitative methods or by changing the interpretation of visual cover observations from estimates of cover magnitude to estimates of cover presence. Table 14 compares the precision of densiometer measurements (XCDENMID, XCDENBK) with that of purely visual estimates of canopy cover (XC, XPCAN) that have similar or identical conceptual meaning. It is clear

TABLE 13. PRECISION OF PHYSICAL HABITAT METRICS FOR COVER AND PRESENCE WITHIN SINGLE LAYERS OF RIPARIAN VEGETATION IN STREAMS OF THE MID-ATLANTIC REGION AND OREGON (for the Mid-Atlantic Region, n=169 with 50 replicates; for Oregon, n=44 with /22 replicates)

Variable Name -- Description RIPARIAN VEGETATION METRICS -- SINGLE LAYER[a]	**RMSE=σ_{rep} (units of metric)**		**CV=σ_{rep}/0 (%)**		**S/N = $\sigma^2_{st(yr)}/\sigma^2_{rep}$**	
	Mid-Atlantic	**Oregon**	**Mid-Atlantic**	**Oregon**	**Mid-Atlantic**	**Oregon**
XCL – Large Diameter Tree Canopy Cover (Proportion of Riparian)	0.097	0.057	51	38	0.9	4.6
XCS – Small Diameter Tree Canopy Cover (Proportion of Riparian)	0.11	0.12	41	55	1.5	1.4
XC -- Tree Canopy Cover (Proportion of Riparian)	0.14	0.12	32	33	2.3	2.4
XPCAN – Tree Canopy Presence (Proportion of Riparian)	0.07	0.08	8.4	8.7	10	10
XMW – Mid-Layer Woody Vegetation Cover (Proportion of Riparian)	0.12	0.12	37	41	1.6	0.9
XMH – Mid-Layer Herbaceous Vegetation Cover (Proportion of Riparian)	0.19	0.13	272	100	~0	0.9
XM – Mid-Layer Vegetation Cover (Proportion of Riparian)	0.22	0.19	57	44	0.1	0.6
XPMID – Mid-Layer Vegetation Presence (Proportion of Riparian)	0.09	0.03	10	3.5	3.6	2.1
XGW – Ground Layer Woody Vegetation Cover (Proportion of Riparian)	0.07	0.17	55	77	1.4	0.1
XGH – Ground Layer Herbaceous Vegetation Cover (Proportion of Riparian)	0.11	0.16	27	40	3.6	1.1
XGB – Ground Layer Barren or Duff Cover (Proportion of Riparian)	0.085	0.07	29	47	6.5	2.0
XG – Ground Layer Vegetation Cover (Proportion of Riparian)	0.14	0.22	26	36	1.9	~0
PCAN_C – Conifer Riparian Canopy (Proportion of Riparian)	0.03	0.11	169	58	4.3	8.5
PCAN_D – Broadleaf Deciduous Riparian Canopy (Proportion of Riparian)	0.14	0.13	22	31	4.9	7.4
PCAN_M – Mixed Conifer-Broadleaf Canopy (Proportion of Riparian)	0.10	0.16	49	65	7.2	2.9
PMID_C – Conifer Riparian Mid-Layer (Proportion of Riparian)	0.04	0.02	136	55	6.5	37

[a] Variable names in **bold** are aggregate metric variables.

(continued)

TABLE 13 (Continued)

Variable Name -- Description RIPARIAN VEGETATION METRICS -- SINGLE LAYER[a]	$RMSE=\sigma_{rep}$ (units of metric)		$CV=\sigma_{rep}/0$ (%)		$S/N = \sigma^2_{st(yr)}/\sigma^2_{rep}$	
	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon
PMID_D – Broadleaf Deciduous Riparian Mid-Layer (Proportion of Riparian)	0.15	0.33	23	58	3.8	0.7
PMID_M – Mixed Conifer-Broadleaf Canopy (Proportion of Riparian)	0.13	0.32	61	87	4.4	0.6

[a] Variable names in **bold** are aggregate metric variables.

that the least precise of the four canopy cover metrics is XC, which depends upon visual judgement to estimate both the canopy cover in a set of riparian plots and the dimensions of those 22 plots. Precision is substantially increased by reinterpreting the same visual data to calculate percentage cover presence along the stream reach (XPCAN), rather than cover magnitude (σ_{rep} decreases from 12-14% to 7-8% and S/N increases from 2.3-2.4 up to 10). Not surprisingly, field crews using purely visual judgement were able to estimate canopy *presence* more reliably than canopy *cover*. Analogous patterns can be seen by comparing the precision of XM with XPMID, XCM with XPCM, and XCMG with XPCMG (Table 12). Depending on the region, however, these gains in precision were often accompanied by a reduction in the range of variability among sites. Choosing metrics of vegetation presence over vegetation cover may also result in a loss of ecological information and decreased sensitivity to stress in some regions. As mentioned in a previous paragraph, XCDENBK and XCDENMID are expressions of mean canopy cover based on, respectively, 22 bank and 44 mid-channel canopy densiometer observations along the sample reach. Both the quantitative densiometer approaches, XCDENBK and particularly XCDENMID, are more precise than the purely visual estimation procedures (Table 14), but have the disadvantage of lacking ecological specificity. Unlike XC, for example, the densiometer measurements make no distinction between shrub and tree cover. For these reasons it is advantageous to retain both semi-quantitative visual riparian estimates and quantitative canopy densiometer measurements in characterizing riparian vegetation cover and structure.

4.2.5 Riparian Human Activities and Disturbances

Riparian human disturbance metrics ranged from low to high precision, but most were in the low to moderate range; slightly more than a third had S/N ratios >4, but half had S/N <2 in one or the other regional survey (Table 15). The precision of individual metrics varied greatly between the two surveys. In the Mid-Atlantic region, the most precise

TABLE 14. COMPARISON OF PRECISION OF FOUR STREAMSIDE RIPARIAN CANOPY COVER METRICS IN THE MID-ATLANTIC REGION AND OREGON

(for the Mid-Atlantic Region, n=169 with 50 replicates; for Oregon, n=44 with 22 replicates)

	RMSE=σ_{rep} (% Cover)		**CV=σ_{rep}/0 (%)**		**S/N = $\sigma^2_{st(yr)}/\sigma^2_{rep}$**	
Variable Name -- Description RIPARIAN CANOPY COVER METRICS	**Mid-Atlantic**	**Oregon**	**Mid-Atlantic**	**Oregon**	**Mid-Atlantic**	**Oregon**
Visual % Tree Canopy Cover (**XC** × 100)[a]	14	12	32	33	2.3	2.4
Visual % Tree Canopy Presence (**XPCAN** × 100)[a]	7.1	8.0	8.4	8.7	10	10
XCDENBK – Canopy %Cover at Bank - Densiometer	8.0	3.9	10	4.4	7.3	17
XCDENMID -- Canopy %Cover Midstream - Densiometer	5.7	5.8	7.5	8.1	19	15

[a] Values expressed as % for comparison purposes.

individual disturbance metrics (σ_{rep} # 0.05 or S/N >7.0) were those assessing revetments, influent/effluent pipes, pastures, row crops, and logging activities. Precision was generally lower in the Oregon survey, and those metrics assessing lawns/parks, buildings, pastures, influent/effluent pipes, and pavement were most precise (σ_{rep} # 0.06 or S/N > 4.9). Seemingly a rather straightforward observation, the road disturbance metric W1H_ROAD was the only metric determined with low precision in both surveys (σ_{rep} $ 0.15 and S/N # 1.4). The poor performance of this metric may have resulted from inconsistent inclusion of paths, railroads, and pavement in the tally, and the inconsistent tallying of roads that are not directly observed, but are heard (traffic) or known to be beyond the riparian plot. Aggregating (summing) human disturbance metrics into variables such as W1_HALL resulted in generally higher σ_{rep} values than the subcomponents, which is not surprising, because the repeat visit variances (σ^2_{rep}) of the summed subcomponents are additive. For the same reason, the aggregated human disturbance metrics generally had S/N ratios approximately midway within the range exhibited by their subcomponents. The summed agricultural disturbance metric W1_HAG was determined with greater precision in both surveys (S/N 6.9 and 8.8) than the non-agricultural disturbance sum (S/N 3.4 and 0.9).

4.2.6 EPA's Rapid Bioassessment Protocol (RBP) Habitat Quality Scores

In tandem with the more intensive EMAP habitat characterization procedures that are the primary focus of this report, the EPA and OSU field crews in the Mid-Atlantic and Oregon surveys employed EPA's Rapid Bioassessment Protocol (RBP) habitat quality assessment field procedures as described by Barbour and Stribling (1991) and Klemm and

TABLE 15. PRECISION OF PHYSICAL HABITAT METRICS FOR STREAMSIDE RIPARIAN HUMAN ACTIVITIES AND DISTURBANCES IN THE MID-ATLANTIC REGION AND OREGON

(for the Mid-Atlantic Region, n=169 with 50 replicates; for Oregon, n=44 with 22 replicates)

Variable Name -- Description RIPARIAN HUMAN DISTURBANCE METRICS[a]	RMSE=σ_{rep} (in units of metric)		CV=σ_{rep}/0 (%)		S/N = $\sigma^2_{st(yr)}/\sigma^2_{rep}$	
	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon	Mid-Atlantic	Oregon
W1H_BLDG -- Riparian Human Disturbance - Buildings (Proximity-weighted index)	0.13	0.09	82	74	1.3	5.3
W1H_CROP -- Riparian Human Disturbance - Row Crop Agriculture (Proximity-weighted index)	0.05	0.09	118	168	7.1	2.7
W1H_LDFL -- Riparian Human Disturbance - Trash and Landfill (Proximity-weighted index)	0.13	0.32	178	245	1.9	~0
W1H_LOG -- Riparian Human Disturbance - Logging (Proximity-weighted index)	0.05	0.36	98	167	16	0.3
W1H_MINE -- Riparian Human Disturbance - Mining (Proximity-weighted index)	0.07	—	364	—	1.2	—
W1H_PARK -- Riparian Human Disturbance - Parks and Lawns (Proximity-weighted index)	0.13	0.03	100	70	1.8	18
W1H_PIPE -- Riparian Human Disturbance - Pipes, Influent or Effluent (Proximity-weighted index)	0.03	0.04	162	170	3.4	0.1
W1H_PSTR -- Riparian Human Disturbance - Pasture, Grass or Hay Field (Proximity-weighted index)	0.15	0.14	50	70	7.9	4.9
W1H_PVMT -- Riparian Human Disturbance - Pavement) (Proximity-weighted index)	0.16	0.06	125	73	0.6	11
W1H_ROAD -- Riparian Human Disturbance - Roads (Proximity-weighted index)	0.15	0.16	56	63	1.4	1.2
W1H_WALL -- Riparian Human Disturbance - Channel Revetment (Proximity-weighted index)	0.02	0.17	20	331	185	~0
W1_HALL -- Riparian Human Disturbance Index (Proximity-weighted)	0.51	0.78	41	66	3.3	0.9
W1_HAG -- Riparian Human Disturbance Index - Agricultural Types (Proximity-weighted)	0.17	0.12	49	47	6.9	8.8
W1_HNOAG -- Riparian Human Disturbance Index - Non-agricultural Types (Proximity-weighted)	0.45	0.76	50	81	3.4	0.9

[a] Variable names in **bold** are aggregate metric variables.

Lazorchak (1994). RBP precision was assessed using the same ANOVA procedures to compare among-stream variance to within-year repeat sampling variance (see Section 4.1). For RBP habitat procedures, precision estimates in the Mid-Atlantic region were based on sampling 459 streams with 36 within-season repeat visits over two field seasons (1993 and 1994). In the Oregon survey, RBP precision was assessed from a sample of 34 streams, with 16 within-season repeat visits over the period from 1993-1996.

The RBP habitat quality assessment consists of 12 subcomponent habitat assessment metrics that are summed to yield the RBP Habitat Quality Score (Barbour and Stribling 1991). Separately for twelve aspects of channel and riparian habitat (Table 16), field surveyors use their observations and judgement to rate habitat condition from poor (score=0) to excellent (score=20). These subcomponent scores sum to a potential range from 0 to 240 for the RBP habitat quality total score. Subcomponent metric σ_{rep} values ranged from 2.0 to 4.3 points and CV's ranged from 12% to 32%, somewhat higher (less precise) than those reported by Barbour and Stribling (1994), who measured CVs of 5% to 20% for the RBP sub-metrics in replication by 17 investigators rating habitat quality during one day on a single, good quality mountain stream in New Mexico. The range of S/N ratios for the RBP sub-metrics in our two surveys ranged from 0 to 7.4. The "Riffle Frequency" metric in the Oregon survey had the highest S/N ratio (7.4); all others had S/N < 4.2. The "Channel Alteration", "Sediment Deposition", "Grazing and other Disruptive Pressure", and "Riparian Zone Width" metrics had moderate precision, with S/N between 2 and 4.2 in at least one of the surveys. Field determinations of the remaining seven RBP habitat subcomponent metrics were rather imprecise relative to among-stream variation, with S/N between 0 and 1.8 in both surveys.

The RBP Habitat Quality Assessment total score had σ_{rep} values of 23 and 20 points, respectively, for the Mid-Atlantic and Oregon surveys. Our CVs of 14% and 12% were relatively low and similar to those reported for RBP habitat assessment in other studies (e.g., Barbour and Stribling, 1994; Hannaford et al., 1997). On the basis of these σ_{rep} and CV values, the repeat visit variance of the RBP habitat score is relatively small compared with its potential range of variation and its mean value. If the total RBP score faithfully represents habitat quality over its potential range of 0 to 240 points, these σ_{rep} values would indicate a good potential for discerning among-stream variation and changes in habitat quality over time. However, at least in the two regions considered, and in agreement with findings by Hannaford and Resh (1995) in several California streams, we did not observe great variation in the total score among streams relative to variation between visits to the same site. The RBP total score usually revealed sites with very severe habitat degradation and those with very high quality, in agreement with Hannaford et al. (1997), who observed

TABLE 16. PRECISION OF RAPID BIOASSESSMENT PROTOCOL (RBP) HABITAT QUALITY METRICS (BARBOUR AND STRIBLING, 1991) WITHIN SAMPLE SEASON IN THE MID-ATLANTIC REGION AND OREGON (for the Mid-Atlantic Region, n=459 streams with 36 repeats over 2 years;
for Oregon, n=34 streams with 16 repeats over 3 years)

RAPID BIOASSESSMENT PROTOCOL HABITAT METRICS[a]	**RMSE=σ_{rep} (in units of metric)**		**CV=σ_{rep}/0 (%)**		**S/N = $\sigma^2_{st(yr)}/\sigma^2_{rep}$**	
	Mid-Atlantic	**Oregon**	**Mid-Atlantic**	**Oregon**	**Mid-Atlantic**	**Oregon**
Instream Cover for Fish -- Score (0-20)	3.7	3.4	28	24	0.7	1.0
Epifaunal Substrate -- Score (0-20)	4.3	3.6	30	27	~0	0.6
Embeddedness (or Pool Substrate[b]) – Score (0-20)	3.6	2.8	28	20	0.6	1.1
Velocity/Depth Regime (or Pool Variability[b]) – Score (0-20)	3.2	3.8	25	32	0.9	1.4
Channel Alteration -- Score (0-20)	2.0	2.9	12	19	2.0	1.1
Sediment Deposition -- Score (0-20)	2.5	2.9	19	23	2.5	1.9
Riffle Frequency (or Channel Sinuosity[b]) – Score (0-20)	2.8	2.0	18	15	1.1	7.4
Channel Flow Status -- Score (0-20)	3.2	4.1	22	31	0.8	0.1
Bank Condition -- Score (0-20)	2.5	2.3	18	17	1.8	1.3
Bank Vegetative Protection -- Score (0-20)	3.7	3.8	25	25	0.4	0.2
Grazing or Other Disruptive Pressure -- Score (0-20)	2.3	2.9	15	17	3.3	1.0
Riparian Vegetation Zone Width -- Score (0-20)	2.9	3.0	24	27	4.2	3.1
RBP Habitat Quality Total Score -- (0 to 240)	**23**	**20**	**14**	**12**	**1.6**	**3.3**

[a] Variable names in **bold** are aggregate metric variables.

[b] Mid-Atlantic Region survey data did not include repeat visits to measure these low gradient stream habitat assessment features; Oregon survey included repeat visits to both low gradient and high gradient streams.

greater consistency among observers in RBP habitat scores for obviously pristine or obviously degraded streams than for moderately impaired streams.

The great majority of our Mid-Atlantic region sites had mid-value total scores within a range that did not greatly exceed the range observed between measurements made on different visits to single streams. Barbour and Stribling (1994) observed a 19 point range in total RBP habitat scores for determinations of habitat quality at a single good quality site in New Mexico. However, in a comparison of 10 sites, they reported that, in general, within-site variability was smaller than variability among sites. In our surveys, S/N ratios for the total score were quite low, indicating either a true lack of variation in habitat quality among streams, or lack of RBP habitat metric responsiveness to actual habitat quality variation. This was particularly true in the Mid-Atlantic region, where measurement variance was almost as great as the variance among streams in the region (S/N = 1.6). In Oregon, the S/N ratio was somewhat higher (3.3), perhaps consistent with the smaller number of field crews involved and the more localized regional extent compared with the Mid-Atlantic region survey (more similar to conditions evaluated by Barbour and Stribling [1994]). In the smaller region, crews could be trained under conditions more closely resembling the range of conditions they later sampled, a factor reported by Hannaford et al. (1997) to be important in RBP habitat training. However, the S/N value of the RBP total score in Oregon was also heavily influenced by the one high S/N value of one of its subcomponent metrics, “Riffle Frequency” (“Channel Sinuosity” in low gradient streams), which had S/N=7.4. In addition, combining the lowland Willamette Valley with the upland Cascade Mountain ecoregion in the Oregon survey enhanced regional variability of the RBP score in the Oregon survey. The “Riffle Frequency”, “Sediment Deposition, and several other RBP metrics tend to score high gradient, coarse-bedded, forested mountain streams higher than low gradient streams. When the ANOVA for Oregon streams is calculated separately to factor out ecoregional differences, sample sizes are rather small to make firm conclusions, but S/N values of 0.6 and 1.4 (for the Cascade Mts. and Willamette Valley) suggest the same result as found for the Mid-Atlantic region: either the streams lack habitat quality variation within the two Oregon ecoregions or the RBP habitat score is unable to discern actual habitat quality differences above the “noise” of measurement uncertainty.

After applying four separate qualitative habitat quality assessment approaches in a survey of northern prairie streams in the U.S., Stauffer and Goldstein (1997) recommended that the variability of index scores could be improved by basing them on counts (or measurements) rather than judgements in the field. Hannaford and Resh (1995) attributed inconsistent RBP habitat assessments to a combination of “viewer” error and differences in the precise location where multiple habitat observations were made in their study. They reasoned that increased training or substitution of measurements for judgement might reduce “viewer” error. To reduce variability due to small-scale differences in site location, they recommended spreading a series of observations over a longer stream segment than required by Plafkin et al. (1989) or Barbour and Stribling (1991).

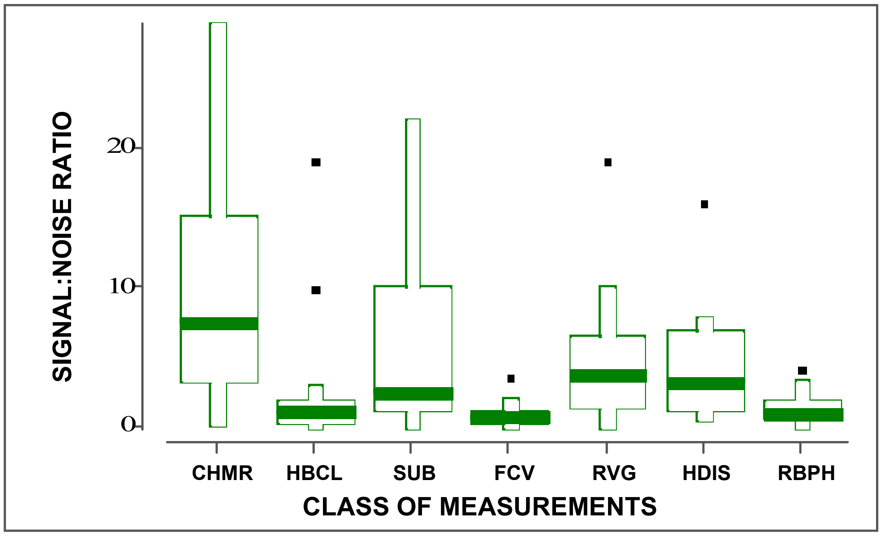
4.3 SUMMARY OF HABITAT METRIC PRECISION

Our results from testing physical habitat field sampling procedures and analytical approaches exhibit consistent patterns of metric precision in each of the two regional surveys. The most precise general classes of metrics were those describing channel morphology and substrate. Most of the metrics with S/N > 6 were in these two categories (Figure 5). Riparian vegetation and human disturbance metrics had intermediate precision; although these two categories had many imprecise metrics (S/N < 2) most of their metrics had S/N values > 2 and many > 6. Fish cover metrics had intermediate S/N ratios (most between 2.8 and 6.0) in the Oregon survey, but lower values (most from 0.8 to 2.1) in the Mid-Atlantic region survey. Since the absolute precision of these Mid-Atlantic metrics was actually better than that in the Oregon survey (lower σ_{rep} values in Table 11), the results indicate low precision only with respect to a low variability of fish cover among streams in the Mid-Atlantic region. Two classes of metrics were generally imprecise: those involving visual channel habitat unit classification and RBP habitat quality assessments. Most metrics in these classes had S/N < 2.0.

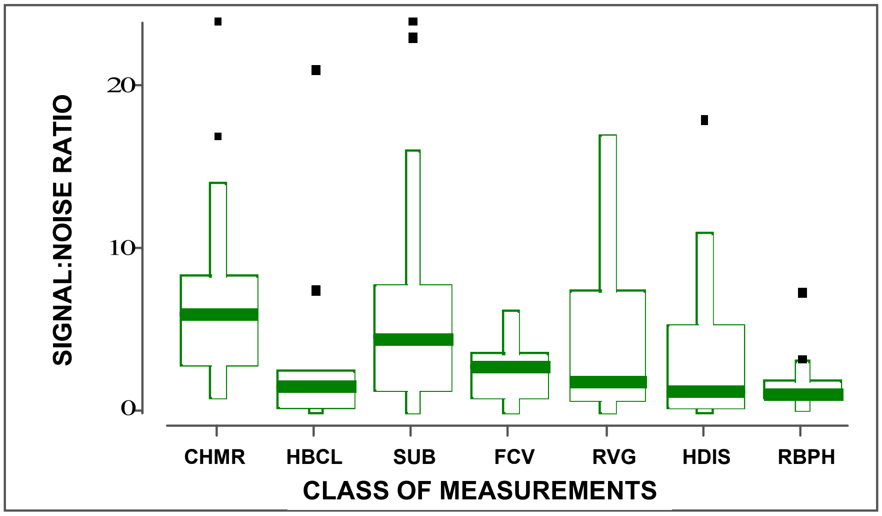
Most of the metric classes discussed in the previous paragraph contain a mix of metrics determined using various approaches that involve greater or lesser degrees of quantification, judgement, and sensitivity to variation in stream flow stage. We regrouped the various metrics according to their measurement approach to more clearly compare the precision of various approaches (Figure 6). The categories include:

QMS: Quantitative measurement of stable and easily defined features (e.g., slope, residual depth, canopy density),
F_QM: Quantitative measurement of flow-dependent or difficult-to-define features (e.g. thalweg depth, incision height),
SQM: Semi-quantitative measurements or determinations of presence-absence (e.g. substrate size, canopy presence, LWD tally metrics),
VSC: Visual estimates of areal cover (e.g., visual estimates of areal cover of riparian vegetation and fish concealment features),
F_HB: Visual determinations of flow-sensitive channel unit class (e.g. %Riffle, %Pool), and
JUD: Visual assessments requiring field judgements of habitat quality (e.g. RBP Habitat Quality Score).

In both the Mid-Atlantic and Oregon surveys, measurement group QMS was clearly the most precise group of metrics; most of these metrics had S/N between 6 and 18 (Figure 6). Flow-sensitivity and ambiguity in measured features certainly degraded the precision of group F_QM relative to the first group, but group F_QM metrics were still generally within the moderate precision range (S/N 2.0 to 6.0). Semi-quantitative measurements and presence-absence determinations (group SQM) were intermediate in precision between the

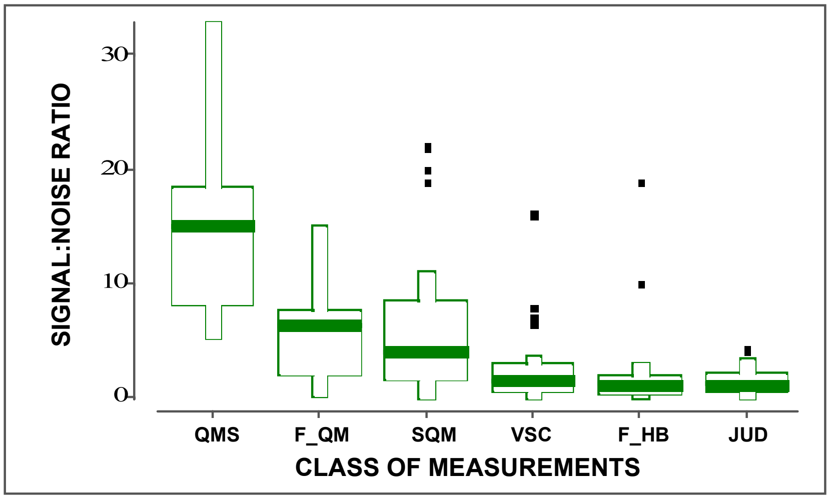


A) Mid-Atlantic Region

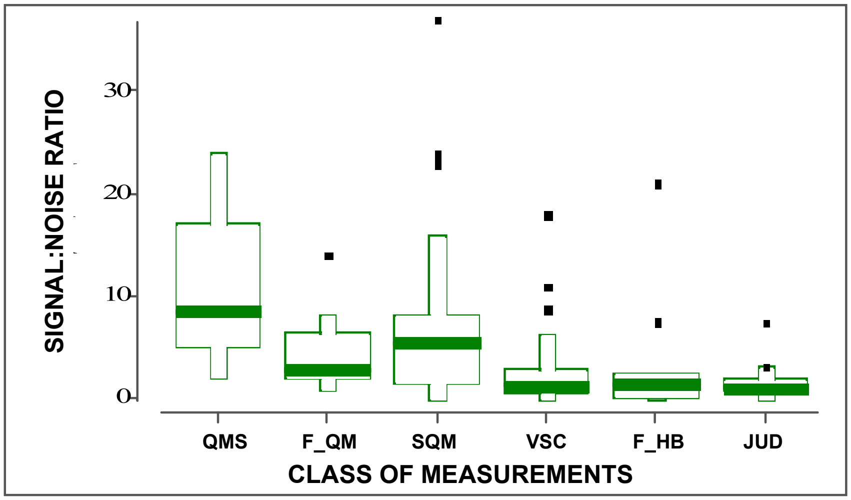


B) Oregon

Figure 5. Frequency distribution of signal to noise ratios for physical habitat variables, grouped according to the types of habitat attributes assessed. Measurement class codes: CHMR – channel morphology, HBCL – channel habitat unit classification, SUB -- substrate, FCV – fish cover, HDIS – human disturbance, and RBPH – Rapid Bioassessment Protocol habitat scores. Heavy bar = median; box = 25th to 75th percentiles, whiskers = 10th and 90th percentiles.



A) Mid-Atlantic Region



B) Oregon

Figure 6. Frequency distribution of signal to noise ratios for physical habitat metrics, grouped according to the measurement approach. Measurement classes: QMS -- Quantitative measurement of stable and easily defined features, F_QM – Quantitative measurement of flow-dependent or difficult-to-define features, SQM – Semi-quantitative measurements or determinations of presence-absence, VSC – Visual estimates of areal cover, F_HB – Visual determinations of flow-sensitive channel unit class, and JUD – Visual assessments requiring field judgements of habitat quality. Heavy bar = median; box = 25th to 75th percentiles, whiskers = 10th and 90th percentiles.

two quantitative measurement groups. Precision relative to regional variation (S/N) generally declined from moderate to low in the three remaining measurement groups: visual estimations of areal cover (VSC), flow-sensitive habitat classifications (F_HB), and field judgements of habitat quality (JUD).

Our findings are in general agreement with those of Wang et al. (1996), who evaluated among-observer precision based on replicate observations by six observers in three Wisconsin streams. They found that ". . . stream width and water depth were estimated most precisely; these were followed by substrate composition, cover for fish, and bank susceptibility to erosion. Estimates of bank vegetation or land use and gravel embeddedness were the least precise. . .". Platts (1981) and Hogle et al. (1993) found that precision and accuracy of habitat measurements were related to the clarity and detail of habitat definitions and measurement procedures. Platts (1981), Hogle et al. (1993), Ralph et al. (1994), Poole et al. (1997), and Wang et al. (1996) generally advocated measurements over visual observations or judgements for most habitat attributes. However, Wang et al. (1996) found, as we did, that visual determinations of some attributes, such as substrate cover, can be reasonably precise if these observations are repeated over a length of reach and the spatial boundaries of these observations are tightly controlled. Ralph et al. (1991, 1994) and Poole et al. (1997) caution that habitat unit classifications, even when carried out under the same flow conditions, are not sufficiently repeatable to be used in trend monitoring applications, due to the subjectivity of these types of observations. Poole et al. (1997) argue that, while they can be used in regional trend and status estimates, their lack of precision unnecessarily complicates data analysis and interpretation.

An unexpected result from our analysis was that a substantial number of repeat field samples (20 to 70) were required to reliably determine values of σ_{rep} and S/N, though statisticians advocate sample sizes of 40 to 50 for variance estimates (Scott Urquhart, personal communication). Values of these measures of precision determined on the basis of < 20 pairs of within-season field revisits were surprisingly variable (Table 17). As a typical example, estimates of σ_{rep} for the metric SDDEPTH ranged from 1.0 cm to 1.7 cm with 7 to 15 pairs of within-season repeat visits each year in the Mid-Atlantic region, and from 1.0 cm to 5.4 cm with 6 to 8 pairs in Oregon. Similarly, with identical methods and training, S/N ratios ranged from 11 to 47 in the various years of surveying Mid-Atlantic streams, and from 4 to 73 in Oregon. Both σ_{rep} and S/N can be substantially overestimated or underestimated when based on 6 to 15 pairs of repeat samples. We are led to the conclusion that an adequate evaluation of precision requires 20 to 50 pairs of within-season repeat samples, and that these pairs should be spread across several years. In addition,

TABLE 17. CONTRASTING PRECISION OF SDDEPTH IN SEPARATE AND COMBINED SURVEYS OF STREAMS IN THE MID-ATLANTIC REGION AND THE WILLAMETTE BASIN IN OREGON

Source of Variation	Degrees of freedom			RMSE (σ_{rep}) (cm)	S/N = $\sigma^2_{st(yr)}/\sigma^2_{rep}$
	Repeats	Model	Total		
Mid-Atlantic Region					
1993 Stream(year)	7	80	87	1.0	47
1994 Stream(year)	13	86	99	2.2	11
1995 Stream(year)	15	15	30	1.7	20
1996 Stream(year)	15	14	29	1.5	18
1993-96 Stream(year)	49	199	248	1.7	16
Willamette Basin, Oregon					
1993 Stream(year)	6	43	49	1.0	73
1994 Stream(year)	8	7	15	5.4	4
1995 Stream(year)	8	7	15	1.4	53
1996 Stream(year)	0	33	33	—	—
1993-96 Stream(year)	22	33	115	3.4	6

some of these stream visits should be to the same streams over several years, if the interannual component of variance is to be determined.

4.4 IMPLICATIONS OF HABITAT MEASUREMENT PRECISION

4.4.1 Effects on Estimates of Regional Population Distributions

The population variance observed in a regional survey in any given year (σ^2_{obs}) is the sum of the "true", or "signal" variance among streams during that year ($\sigma^2_{st(yr)}$), plus within-season replicate "noise" variance (σ^2_{rep}) that results from short-term temporal variation or measurement variation occurring within the sampling "window". For that year, $\sigma^2_{obs} = \sigma^2_{st(yr)} + \sigma^2_{rep}$. The effect of σ^2_{rep} is to distort the observed frequency distribution of the habitat metric across streams in the region. For example, this effect can be envisioned graphically as an increase in the outward spread of a normal bell-shaped curve from its mean (Overton ,1989: Paulsen et al., 1991: Larsen and Urquhart, 1993). As long as the habitat metric noise variance is normal and homogeneous (and the measurements themselves are unbiased), the mean and median habitat metric values of the regional stream population are estimated without bias, no matter how imprecise the measurements. Estimates of other stream population percentiles (e.g., the 10th, 25th, and 75th percentiles) have insignificant absolute bias when the signal-to-noise ratio is ≥ 10 (Overton, 1989). However, percentiles other than the median acquire progressively greater biases with declines in the ratio of signal to noise (Overton, 1989; Paulsen et al., 1991). Paulsen et al. (1991) show, for example, that when noise variance of a metric is equal to signal variance ($S/N = \sigma^2_{st(yr)}/\sigma^2_{rep} = 1.0$), the apparent value of $SD_{st(yr)}$ for that metric is inflated by a factor of 1.29. In a population with an underlying normal distribution, a survey using that metric would overestimate the percentage of streams with habitat metric values greater than the mean + $1(SD_{st(yr)})$ at 24%—considerably greater than the true value of 16% (these percentages are taken from normal distribution tables). If this metric value were the threshold of “acceptability,” then the survey would overestimate the number of streams with acceptable habitat quality by a factor of 1.5.

In general, if metric measurement variance is greater than about 50% of the variance among streams (i.e., $S/N = \sigma^2_{st(yr)}/\sigma^2_{rep} < 2.0$), and we believe that the regional sample of streams spans an ecologically meaningful range of the metric, then the metric may be too imprecise to answer with confidence certain kinds of questions posed concerning the proportions of the stream population within stated ranges of the metric (Paulsen et al., 1991). In such cases, we must either refrain from making high-resolution statements, seek a more precise metric, or achieve greater precision in the original metric. It might also be possible to correct the population estimates after-the-fact by “deconvoluting” population distribution functions (Stefanski and Bay, 1996), assuming the components of variance are quantified. Even though one can increase the precision of stream measurements by revisiting all streams two or more times and averaging the results, this is usually an expensive alternative. As long as temporal variation within the summer season is not the major source of uncertainty, the precision of physical habitat characterization of stream reaches could be increased either by increasing the number of within-reach habitat observation points, or by reducing the uncertainty of observations at each observation point. If most of the variance of a metric is the result of substantial uncertainty in the classifications or measurements themselves at a given position on a reach (rather than short-term temporal variation in the true value of the habitat parameter being measured), then little is gained by increasing the number of measurements. In this case one is better advised to increase the precision of the measurements themselves, or to develop more precise metrics by changing calculation or aggregation procedures (e.g., see Section 4.2.4 and Hughes et al., 1998).

4.4.2 Effects on Associations Between Variables

In addition to its effects on survey estimates of the regional population distributions, measurement imprecision can have predictable, but often unappreciated effects on our ability to detect correlation between variables and our ability to assess the amount of variation that can be attributed to a potential causal factor in using regression analysis. To illustrate, consider a biological measurement ("Variable 1") and ancillary habitat measurement ("Variable 2"). The Pearson product-moment correlation coefficient, **r**, measures the proportion of the total variation of two variables that is shared between the two variables (Snedecor and Cochran 1980):

$$\mathbf{r} = \frac{\sigma_{1,2}}{\sigma_1 \sigma_2} \qquad \textbf{(19)}$$

where

$\sigma_{1,2}$ is the covariance between the two variables,
σ_1 is the standard deviation of Variable 1,
σ_2 is the standard deviation of Variable 2.

We apply assumptions made by Allen et al. (1999) to evaluate the effect of measurement error on correlations. Assume for a moment that in reality, the underlying characteristics that we attempt to measure with Variables 1 and 2 are perfectly correlated, but the variables themselves are subject to random, unbiased measurement errors that are uncorrelated between the two variables. If those assumptions hold, then:

$$\mathbf{r} = \frac{\sigma_{\mathbf{1,2,st(yr)}}}{\left(\sqrt{\sigma^{\mathbf{2}}_{\mathbf{1,st(yr)}} + \sigma^{\mathbf{2}}_{\mathbf{1,\,rep}}} \times \sqrt{\sigma^{\mathbf{2}}_{\mathbf{2,st(yr)}} + \sigma^{\mathbf{2}}_{\mathbf{2,rep}}}\right)} \qquad \textbf{(20)}$$

The effect of measurement imprecision on statistical correlation is clear from this expression. The greater the proportion of measurement error, σ^2_{rep}, the smaller will be the observed **r** value, and the smaller will be the proportion of variance (**r**^{2}) explained by a regression predicting Variable 1 from Variable 2. Standardizing variances and retaining the assumptions above, a rearrangement of Equation 20 yields a useful expression to relate the magnitude of $\sigma^2_{st(yr)}/\sigma^2_{rep}$ to the maximum observable values of **r** and **r**^{2} that could be obtained in correlations and regressions between two variables:

$$\mathbf{r_{max}} = \sqrt{\frac{\sigma^2_{1,st(yr)}}{\left(\frac{\sigma^2_{1,st(yr)}}{\sigma^2_{1,rep}}\right)}} \times \sqrt{\frac{\sigma^2_{2,st(yr)}}{\left(\frac{\sigma^2_{2,st(yr)}}{\sigma^2_{2,rep}}\right)}} \qquad \mathbf{(21a)}$$

$$\mathbf{r_{max}} = \sqrt{\frac{\left(\frac{\sigma^2_{1,st(yr)}}{\sigma^2_{1,rep}}\right)}{\left(1+\frac{\sigma^2_{1,st(yr)}}{\sigma^2_{1,rep}}\right)}} \times \sqrt{\frac{\left(\frac{\sigma^2_{2,st(yr)}}{\sigma^2_{2,rep}}\right)}{\left(1+\frac{\sigma^2_{2,st(yr)}}{\sigma^2_{2,rep}}\right)}} \qquad \mathbf{(21b)}$$

$$\mathbf{r_{max}} = \sqrt{\frac{\frac{S_1}{N_1}}{1+\frac{S_1}{N_1}}} \times \sqrt{\frac{\frac{S_2}{N_2}}{1+\frac{S_2}{N_2}}} \qquad \mathbf{(21c)}$$

Under the stated assumptions, if two variables have S/N values of 3, for example, we would not expect to observe a correlation between them higher than $\mathbf{r}_{\mathbf{max}} = [3/(1 + 3)]^{½} \times [3/(3 + 1)]^{½} = 0.75$, even if in truth, the attributes measured by these variables are more closely associated. When linear regression is used to predict Variable 1 from Variable 2, we would expect a regression model to explain no more than 56% of the variance in variable 2 ($\mathbf{r}^2_{\mathbf{max}} = 0.56$). For convenience in interpreting the implications of differing S/N values of metrics discussed in this report, Table 18 compares the predicted values of r_{max} for various combinations of measurement precision. If the S/N values of two variables are both 1, a true underlying correlation of **r**=1.00 will be observed as a correlation of **r**=0.50; similarly, only when two variables have S/N $\geq$ 10 (or one has 5 and the other > 25) does the observed correlation exceed **r**=0.90. Furthermore, if the less precise of two variables in an association analysis has S/N $\leq$ 2, the highest correlation coefficient (**r**) expected with the other variable is 0.81, regardless of how precise the other variable is. Similarly, the highest coefficient of determination ($\mathbf{r}^2$) expected in this case is 0.67. These observations have

TABLE 18. THEORETICAL MAXIMUM OBSERVED CORRELATION COEFFICIENTS (r) BETWEEN TWO METRICS OF VARYING PRECISION, AS MEASURED BY S/N ($\sigma^2_{st(yr)}/\sigma^2_{rep}$)[a]

	S/N =							
S/N =	**1**	**2**	**3**	**5**	**10**	**25**	**50**	**100**
1	0.50	-	-	-	-	-	-	-
2	0.58	0.67	-	-	-	-	-	-
3	0.61	0.70	0.75	-	-	-	-	-
5	0.65	0.75	0.79	0.83	-	-	-	-
10	0.67	0.78	0.83	0.87	0.91	-	-	-
25	0.69	0.80	0.85	0.90	0.93	0.96	-	-
50	0.70	0.81	0.86	0.90	0.94	0.97	0.98	-
100	0.70	0.81	0.86	0.91	0.95	0.98	0.99	0.99

[a] Assuming the underlying correlation between attributes measured by the two metrics is 1.

important implications for correlation and regression analyses. The “strength” of the underlying relationship suggested by observed association should be based on the maximum explainable variation ("discarding” measurement variance, or “noise”). However, this should **not** be interpreted as a rationale for embracing field approaches that have inherently high measurement variability.

4.5 GENERALIZATIONS AND RECOMMENDATIONS CONCERNING METRIC PRECISION

Based on our results, we make the following generalizations concerning the precision of habitat measurement and assessment approaches:

1) Measurements are more precise than visual estimates, but carefully-designed visual estimation procedures can be nearly as precise as measurements. To enhance precision, these visual observations are limited to measurable characteristics (e.g., cover or presence), rather than judgements of habitat quality, and they are made at multiple locations within a reach.

2) Flow-sensitivity and complex definitions of habitat features can degrade precision of quantitative measurements (e.g., bankfull height and incision).

3) Flow-sensitivity and subjectivity in habitat-unit classifications (e.g., %Pool) can seriously limit their usefulness in contrasting stream habitat among streams or in tracking changes in habitat through time.

4) The precision of multiple visual cover-class determinations can be improved by re-interpreting this information as extent of presence-absence of some defined feature (e.g., summed vegetation cover in two layers reinterpreted as percent of observations in which cover is > 0% in both layers), but perhaps at the expense of decreased sensitivity to stress.

5) The precision of separate metrics can be improved by combining them into more integrated metrics. For example, the precision of %Substrate <16mm diameter is more precise than the separate metrics of %Fine Gravel, %Sand, or %Fines; the precision of %(Pools + Glides) is more precise than %Pools. However, the gain in precision may be at the expense of decreased sensitivity to stress.

6) While visual judgement methods are attractive because of their rapidity in the field and in data reduction, their lack of precision limits their use in many applications.

7) At least 20 within-season pairs of repeat visits to 8 to 20 field sites spread over several years are required for confident assessment of within-season precision in physical habitat metrics. These repeat samples are ideally drawn as a random or stratified random sub-sample from a regional probability sample of stream reaches.

8) Metrics with S/N < 2.0 distort estimates of regional distributions based on survey results, and severely limit analyses of associations by regression and correlation.

9) When metric S/N variance ratios are $10, field measurement variance and short-term temporal fluctuations cause relatively insignificant error and distortion in estimates of regional population distribution functions, and offer relatively insignificant obstacles to analyses of association using regression and correlation.

4.6 OTHER CONSIDERATIONS IN SELECTING PHYSICAL HABITAT METRICS

At the beginning of this chapter, we emphasized the importance of accuracy, precision, and ecological relevance in characterizing physical habitat. When initially selecting a physical habitat measurement approach, the additional dimensions of practicality, effort and cost come in to play. If the variables have already been measured and the data is in-hand, one can choose the best set of variables to use in a particular analysis, regardless of their cost. When selecting variables, it is obviously important that those variables are accurate, faithfully depicting the attribute of habitat that we intend or understand them to depict. Secondly, it is important that they be precise, sufficiently repeatable so that measurement variation does not eclipse differences we want to be able to detect. As we discuss earlier in this chapter, lack of precision can severely limit the utility of a variable, but precision must be viewed relative to the magnitude of difference (or change) one wants to detect. The S/N ratios we calculated compare measurement precision with the variation of a metric across a region, adopting the observed range as a surrogate for the range of "important" variation. Expected ranges of condition or magnitudes of temporal change in any particular variable may differ substantially among regions, or in the same region viewed at different scales. For this reason, *S/N ratios should be viewed only as predictions of the ability of a variable to discern "important" differences within the* ***same*** *region from which they were calculated*. Furthermore, *S/N ratios calculated from a particular survey (e.g. MAHA or Oregon) should be viewed only as approximations of what the precision of measurements would likely be in a* ***different*** *region*. For this reason, we chose not to exclude or drop variables from consideration in a national monitoring program solely on the basis of poor precision in a given region.

The final measure of the utility of a habitat characterization approach is whether it contains useful information for interpreting controls on biota or impacts of human activity. In regional surveys, or in temporal series, this measure of performance is demonstrated through analysis of associations among variables. As with precision, this aspect of habitat metric utility is also region-specific, and dependent on the type of biological assemblage and the type of human disturbances present. However, we can offer some guidance based on our own research and that of others who have used EMAP habitat data. Table 19 lists the variables used most often in variety of multivariate and other types of analyses associating habitat with fish assemblages (Herlihy et al., 1997; Hughes et al., 1998; McCormick et al., in review; Howlin et al., in preparation), macroinvertebrate assemblages (Bryce et al., 1999; Li et al., in review; Griffiths et al., in review), periphyton assemblages (Hill et al., in review; Pan et al., 1999; Griffiths et al., in review), benthic metabolism (Hill et al., 1998), and landscape disturbance (Bryce et al., 1999). It is evident that the list includes representatives from each

TABLE 19. PHYSICAL HABITAT VARIABLES MOST FREQUENTLY USED

VARIABLE[a]:	DESCRIPTION:
	Channel Morphology:
XDEPTH	Mean thalweg depth (cm)
SDDEPTH	Standard deviation of thalweg depth (cm)
XWIDTH	Mean wetted width (m)
XWXD	Mean wetted width × depth (m^2)
RP100	Mean residual depth (m^2/100 m reach length) =cm
XBKF_W	Mean bankfull width (m)
XBKF_H	Mean bankfull height (m)
XINC_H	Mean incision height (m)
SINU	Channel Sinuosity
XSLOPE	Water surface gradient over reach (%)
	Substrate:
LSUB_DMM	Log$_{10}$[estimated geometric mean substrate diameter (mm)]
XEMBED	Substrate mean embeddedness -- channel + margin (%)
PCT_FN	Substrate % fine (silt/clay)
PCT_SA	Substrate % sand (0.6 to 2mm)
PCT_RC	Substrate % concrete
PCT_HP	Substrate % hard pan
PCT_SAFN	Substrate % sand + fines (< 2 mm)
PCT_SFGF	Substrate % fine gravel and smaller (# 16mm)
PCT_BIGR	Substrate % coarse gravel and larger (> 16mm)
PCT_BDRK	Substrate % bedrock
LTEST	Log$_{10}$ [Erodible substrate diameter (mm)] -- Estimate 1 (see text)
LRBS_TST	Log$_{10}$ [Relative Bed Stability] -- Estimate 1 (see text)
LDMB_BW4	Log$_{10}$ [Erodible substrate diameter (mm)] -- Estimate 2 (see text)
LRBS_BW4	Log$_{10}$ [Relative Bed Stability] -- Estimate 2 (see text)
	Fish Cover and Woody Debris:
XFC_ALG	Filamentous algae areal cover
XFC_AQM	Aquatic macrophyte areal cover
XFC_LWD	Large woody debris areal cover
XFC_BRS	Brush and small woody debris areal cover
XFC_OHV	Overhanging vegetation areal cover
XFC_BIG	Sum of cover from large wood, boulders, over-hanging banks and human structures
XFC_NAT	Sum of cover from large wood, brush, overhanging vegetation, boulders and undercut banks
V1W_MSQ	LWD volume in active channel (m^3/m^2) – size classes 1 to 5)
V1TM100	LWD volume in and above active channel (m^3/100m) – size classes 1 to 5)

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[a] Variable names in **bold** are considered to be most important.

(continued)

TABLE 19 (Continued)

VARIABLE[a]:	**DESCRIPTION:**
	Riparian Vegetation Cover and Structure:
XCDENBK	Mean % canopy density at bank
XCDENMID	Mean % canopy density midstream
XCL	Riparian canopy (> 5 m high) cover - trees > 0.3 m DBH (diameter at breast height)
XGB	Riparian ground-layer (< 0.5 m high) bare ground cover
XC	Riparian canopy cover (XCL+XCS)
XCM	Riparian canopy + mid-layer cover (XC + XM)
XCMGW	Riparian woody cover, sum of 3 layers (XC + XMW + XGW)
XPCAN	Riparian canopy presence (proportion of reach)
XPCM	Riparian canopy and mid-layer presence (proportion of reach)
XPCMG	3-layer riparian vegetation presence (proportion of reach)
PCAN_C	Coniferous riparian canopy presence (proportion of reach)
	Human Disturbances:
W1H_WALL	Riparian Human disturbance -- Channel revetment (proximity-weighted index)
W1H_LOG	Riparian Human disturbance -- Logging (proximity-weighted index)
W1_HALL	Riparian Human Disturbance Index (proximity-weighted sum)
W1_HNOAG	Riparian Human Disturbance Index -- Non-agricultural types (proximity-weighted sum)
W1_HAG	Riparian Human Disturbance Index -- Agricultural types (proximity-weighted sum)

[a] Variable names in **bold** are considered to be most important.

of the seven aspects of habitat presented in the Introduction to this report. Of the 49 variables, we highlight a balanced set of 18 variables that we consider generally the most important, but recommend that researchers examine the suite of variables in Table 6 and take into consideration their precision (Tables 7 through 15), the region, type of biota, and their own particular research objectives.

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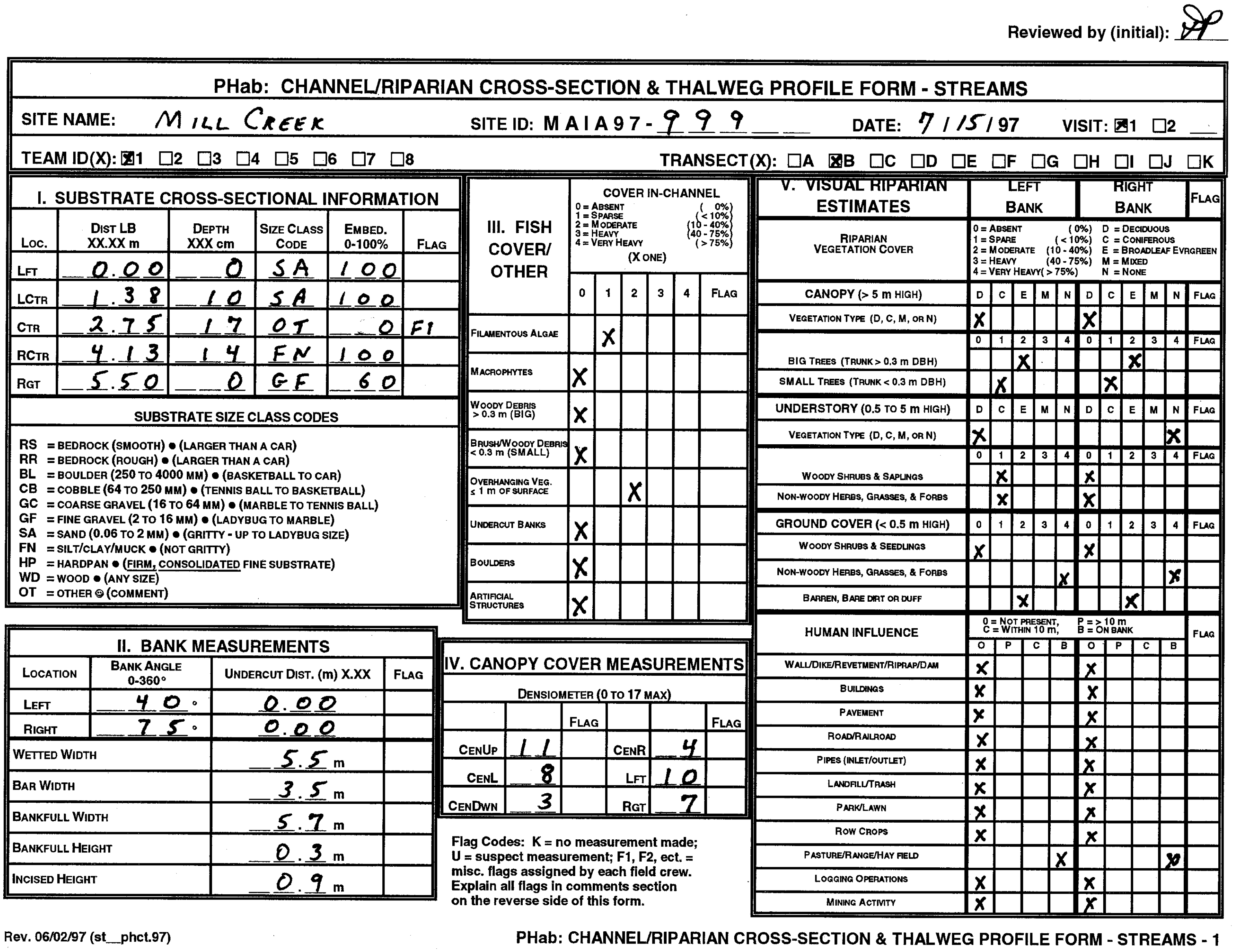
APPENDIX A. COMPLETED EXAMPLES OF FIELD DATA FORMS FOR PHYSICAL HABITAT CHARACTERIZATION

A completed set of EMAP field data forms for physical habitat characterization is included here. These forms are the same as those presented in the EMAP-Surface Waters field operations manual for wadeable streams (Lazorchak et al., 1998). Figure A-1 illustrates the form used to record instream and riparian measurement data at each cross-section transect. Figure A-2 shows the data form used to record measurement data collected along the longitudinal thalweg profile. Figure A-3 is an example of the form used to record backsighted slope and bearing measurements. Physical habitat data from one sample reach would be contained on 12 sheets. The cross-section and longitudinal thalweg profile data occupy the front and back sides of 11 sheets, one for each transect. The slope and bearing data for all transects of a reach are contained on one sheet.



Reviewed by (initial): ___

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

SITE NAME: Mill Creek SITE ID: M A I A 9 7 - 9 9 9 DATE: 7 / 15 / 97 VISIT: ☒1 ☐2

TEAM ID(X): ☒1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8 TRANSECT(X): ☐A ☒B ☐C ☐D ☐E ☐F ☐G ☐H ☐I ☐J ☐K

I. SUBSTRATE CROSS-SECTIONAL INFORMATION

Loc.	Dist LB XX.XX m	Depth XXX cm	Size Class Code	Embed. 0-100%	Flag
Lft	0.00	0	SA	100	
LCtr	1.38	10	SA	100	
Ctr	2.75	17	OT	0	F1
RCtr	4.13	14	FN	100	
Rgt	5.50	0	GF	60	

SUBSTRATE SIZE CLASS CODES

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

II. BANK MEASUREMENTS

Location	Bank Angle 0-360°	Undercut Dist. (m) X.XX	Flag
Left	40°	0.00	
Right	75°	0.00	
Wetted Width		5.5 m	
Bar Width		3.5 m	
Bankfull Width		5.7 m	
Bankfull Height		0.3 m	
Incised Height		0.9 m	

III. FISH COVER/ OTHER

COVER IN-CHANNEL
0 = Absent (0%)
1 = Sparse (< 10%)
2 = Moderate (10 - 40%)
3 = Heavy (40 - 75%)
4 = Very Heavy (> 75%)
(X ONE)

	0	1	2	3	4	Flag
Filamentous Algae		X				
Macrophytes	X					
Woody Debris > 0.3 m (BIG)	X					
Brush/Woody Debris < 0.3 m (SMALL)	X					
Overhanging Veg. ≤ 1 m of Surface			X			
Undercut Banks	X					
Boulders	X					
Artificial Structures	X					

IV. CANOPY COVER MEASUREMENTS

Densiometer (0 to 17 max)

		Flag			Flag
CenUp	11		CenR	4	
CenL	8		Lft	10	
CenDwn	3		Rgt	7	

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

V. VISUAL RIPARIAN ESTIMATES

Riparian Vegetation Cover
0 = Absent (0%) D = Deciduous
1 = Spare (< 10%) C = Coniferous
2 = Moderate (10 - 40%) E = Broadleaf Evrgreen
3 = Heavy (40 - 75%) M = Mixed
4 = Very Heavy(> 75%) N = None

	Left Bank					Right Bank					Flag
CANOPY (> 5 m HIGH)	D	C	E	M	N	D	C	E	M	N	Flag
Vegetation Type (D, C, M, or N)	X					X					
	0	1	2	3	4	0	1	2	3	4	Flag
BIG Trees (Trunk > 0.3 m DBH)			X					X			
SMALL Trees (Trunk < 0.3 m DBH)		X					X				
UNDERSTORY (0.5 to 5 m HIGH)	D	C	E	M	N	D	C	E	M	N	Flag
Vegetation Type (D, C, M, or N)	X									X	
	0	1	2	3	4	0	1	2	3	4	Flag
Woody Shrubs & Saplings		X				X					
Non-woody Herbs, Grasses, & Forbs		X				X					
GROUND COVER (< 0.5 m HIGH)	0	1	2	3	4	0	1	2	3	4	Flag
Woody Shrubs & Seedlings	X					X					
Non-woody Herbs, Grasses, & Forbs					X					X	
Barren, Bare Dirt or Duff			X					X			

HUMAN INFLUENCE: 0 = Not present, C = Within 10 m, P = > 10 m, B = On bank

HUMAN INFLUENCE	O	P	C	B	O	P	C	B	Flag
Wall/Dike/Revetment/Riprap/Dam	X				X				
Buildings	X				X				
Pavement	X				X				
Road/Railroad	X				X				
Pipes (Inlet/Outlet)	X				X				
Landfill/Trash	X				X				
Park/Lawn	X				X				
Row Crops	X				X				
Pasture/Range/Hay Field				X				X	
Logging Operations	X				X				
Mining Activity	X				X				

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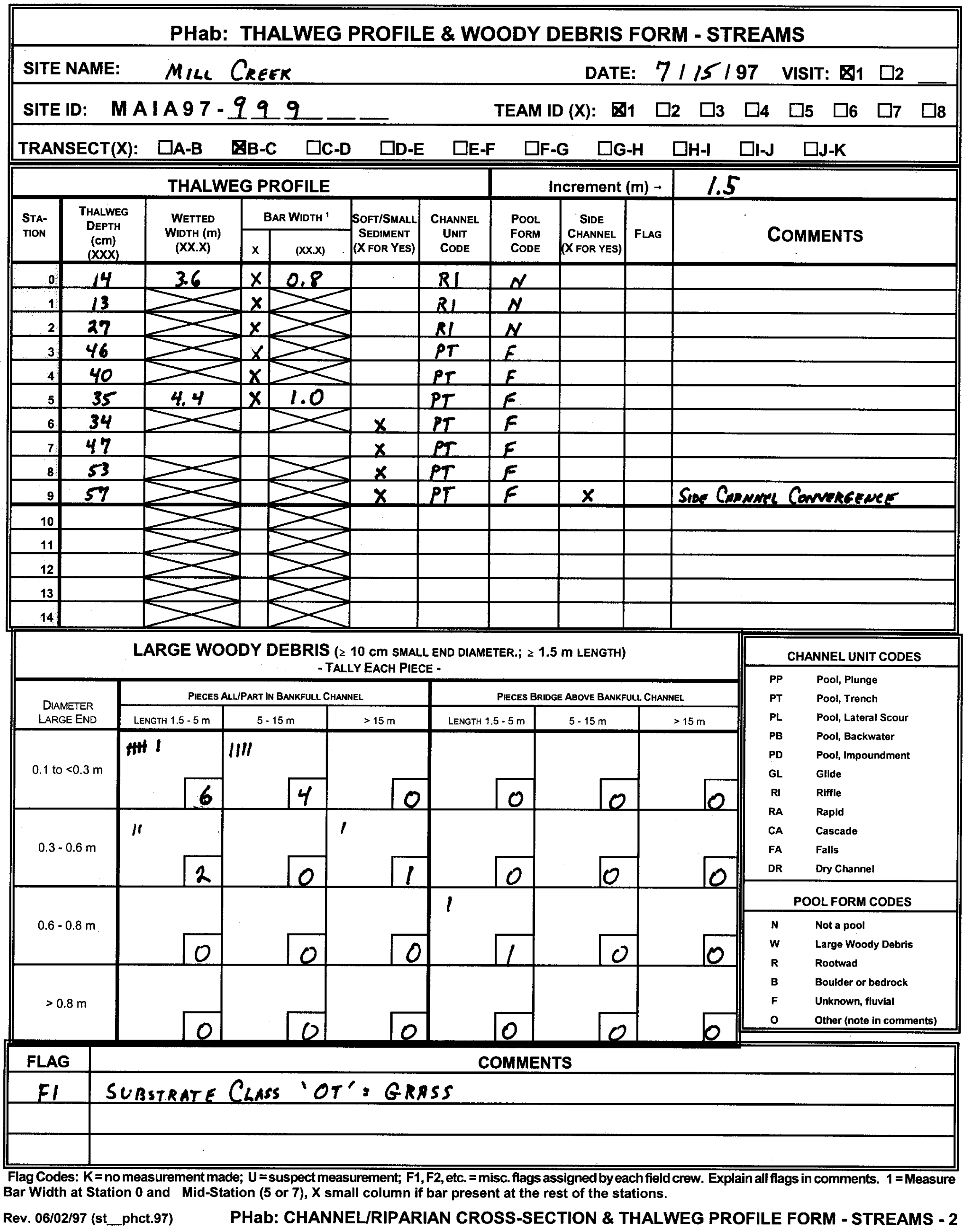
PHab: CHANNEL/RIPARIAN CROSS-SECTION & THALWEG PROFILE FORM - STREAMS - 1

Figure A-1. **Channel/Riparian Cross Section form.** From Kaufmann and Robison (1998).



Reviewed by (initial):

PHab: THALWEG PROFILE & WOODY DEBRIS FORM - STREAMS

SITE NAME: Mill Creek DATE: 7 / 15 / 97 VISIT: ☒1 ☐2

SITE ID: M A I A 9 7 - 9 9 9 TEAM ID (X): ☒1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8

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

THALWEG PROFILE Increment (m) → 1.5

STATION	THALWEG DEPTH (cm) (XXX)	WETTED WIDTH (m) (XX.X)	BAR WIDTH¹ X	BAR WIDTH¹ (XX.X)	SOFT/SMALL SEDIMENT (X FOR YES)	CHANNEL UNIT CODE	POOL FORM CODE	SIDE CHANNEL (X FOR YES)	FLAG	COMMENTS
0	14	3.6	X	0.8		RI	N			
1	13		X			RI	N			
2	27		X			RI	N			
3	46		X			PT	F			
4	40		X			PT	F			
5	35	4.4	X	1.0		PT	F			
6	34				X	PT	F			
7	47				X	PT	F			
8	53				X	PT	F			
9	57				X	PT	F	X		Side Channel Convergence
10										
11										
12										
13										
14										

LARGE WOODY DEBRIS (≥ 10 cm SMALL END DIAMETER.; ≥ 1.5 m LENGTH)
- TALLY EACH PIECE -

DIAMETER LARGE END	PIECES ALL/PART IN BANKFULL CHANNEL			PIECES BRIDGE ABOVE BANKFULL CHANNEL		
	LENGTH 1.5 - 5 m	5 - 15 m	> 15 m	LENGTH 1.5 - 5 m	5 - 15 m	> 15 m
0.1 to <0.3 m	𝍸 I 6	IIII 4	0	0	0	0
0.3 - 0.6 m	II 2	0	I 1	0	0	0
0.6 - 0.8 m	0	0	0	I 1	0	0
> 0.8 m	0	0	0	0	0	0

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

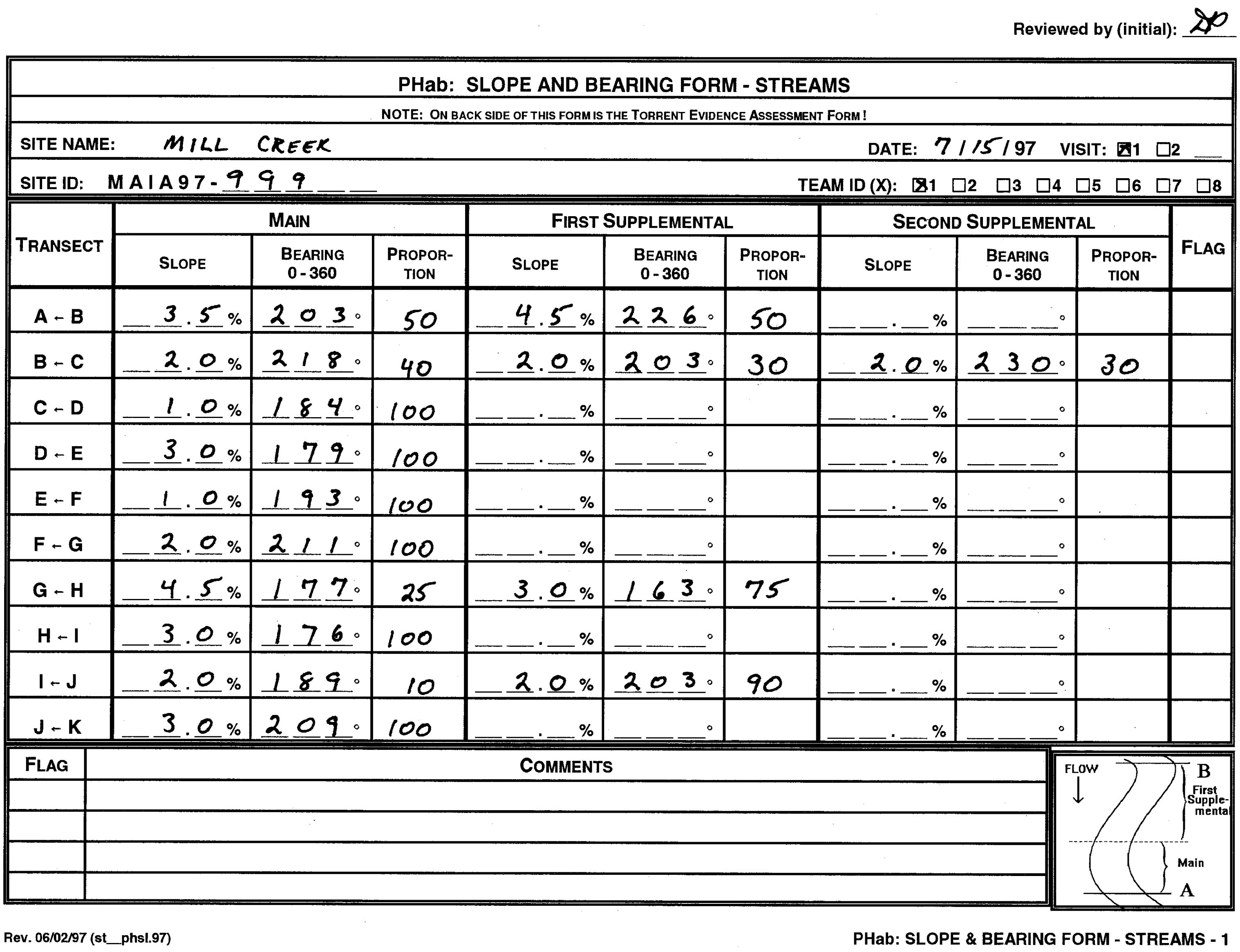
POOL FORM CODES	
N	Not a pool
W	Large Woody Debris
R	Rootwad
B	Boulder or bedrock
F	Unknown, fluvial
O	Other (note in comments)

FLAG	COMMENTS
F1	Substrate Class 'OT' : Grass

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

Rev. 06/02/97 (st__phct.97) PHab: CHANNEL/RIPARIAN CROSS-SECTION & THALWEG PROFILE FORM - STREAMS - 2

Figure A-2. Thalweg Profile and Woody Debris Form. From Kaufmann and Robison (1998).



Reviewed by (initial):

PHab: SLOPE AND BEARING FORM - STREAMS

NOTE: ON BACK SIDE OF THIS FORM IS THE TORRENT EVIDENCE ASSESSMENT FORM!

SITE NAME: MILL CREEK

DATE: 7 / 15 / 97 VISIT: ☒1 ☐2

SITE ID: MAIA97-999

TEAM ID (X): ☒1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8

TRANSECT	MAIN			FIRST SUPPLEMENTAL			SECOND SUPPLEMENTAL			FLAG
	SLOPE	BEARING 0-360	PROPOR-TION	SLOPE	BEARING 0-360	PROPOR-TION	SLOPE	BEARING 0-360	PROPOR-TION	
A - B	3.5 %	203°	50	4.5 %	226°	50	. %	°		
B - C	2.0 %	218°	40	2.0 %	203°	30	2.0 %	230°	30	
C - D	1.0 %	184°	100	. %	°		. %	°		
D - E	3.0 %	179°	100	. %	°		. %	°		
E - F	1.0 %	193°	100	. %	°		. %	°		
F - G	2.0 %	211°	100	. %	°		. %	°		
G - H	4.5 %	177°	25	3.0 %	163°	75	. %	°		
H - I	3.0 %	176°	100	. %	°		. %	°		
I - J	2.0 %	189°	10	2.0 %	203°	90	. %	°		
J - K	3.0 %	209°	100	. %	°		. %	°		

FLAG	COMMENTS

Rev. 06/02/97 (st__phsl.97)

PHab: SLOPE & BEARING FORM - STREAMS - 1

Figure A-3. Slope and Bearing data form. From Kaufmann and Robison (1998).

APPENDIX B. DATA ENTRY, VERIFICATION, AND DATABASE STRUCTURE

B.1 DATA STRUCTURE

B.1.1 Introduction and Typographical Conventions

Before beginning verification and validation (VerVal) of Physical Habitat (PHab) data it is advisable to be familiar with the sampling techniques and protocol used to collect the data. Of particular interest is the layout and structure of the sampling reach, as this directly determines the structure of the individual PHab data files. The general sampling scheme is discussed in Section 2 of the main body of this report (*Synopsis of EMAP Physical Habitat Field Methods)* and also the Physical Habitat chapter of EMAP's field operations and training manual (Kaufmann and Robison, 1998).

We use the following typographical conventions for identifying data file names, variable names, and VerVal computer code throughout this document:

- Data file names are written in lower case, bold italics, (e.g. ***sub_bank, thalweg***).
- PHab measurement and metric variable names are written in upper case letters, as are the names and values of location and identification variables (e.g. WT_WID, TRANSDIR, STRM_ID, PCT_SA, ORC38, ORST97-047).
- When referring to a particular part of this document we will use the term 'section', and italicize the name of the section we are referring to, (e.g., 'in the *structure check* section of this document').
- When referring to a piece of Statistical Applications Software (SAS) code we have included we will specify 'SAS code,' and name the code in upper case italics, or identify the code by description (e.g. '. . .in SAS code *MH_RP*', or 'Run the SAS code that examines the ***sub_bank*** data file.').

B.1.2 Structure of Data Collection

Every stream sampling reach is designated by a unique stream identification number, and delineated with eleven equally spaced sampling cross sections called TRANSECTs, which are labeled A through K. Habitat characteristics are measured according to one of four sampling location layouts relative to the reach and its 11 transects (Figure B-1):

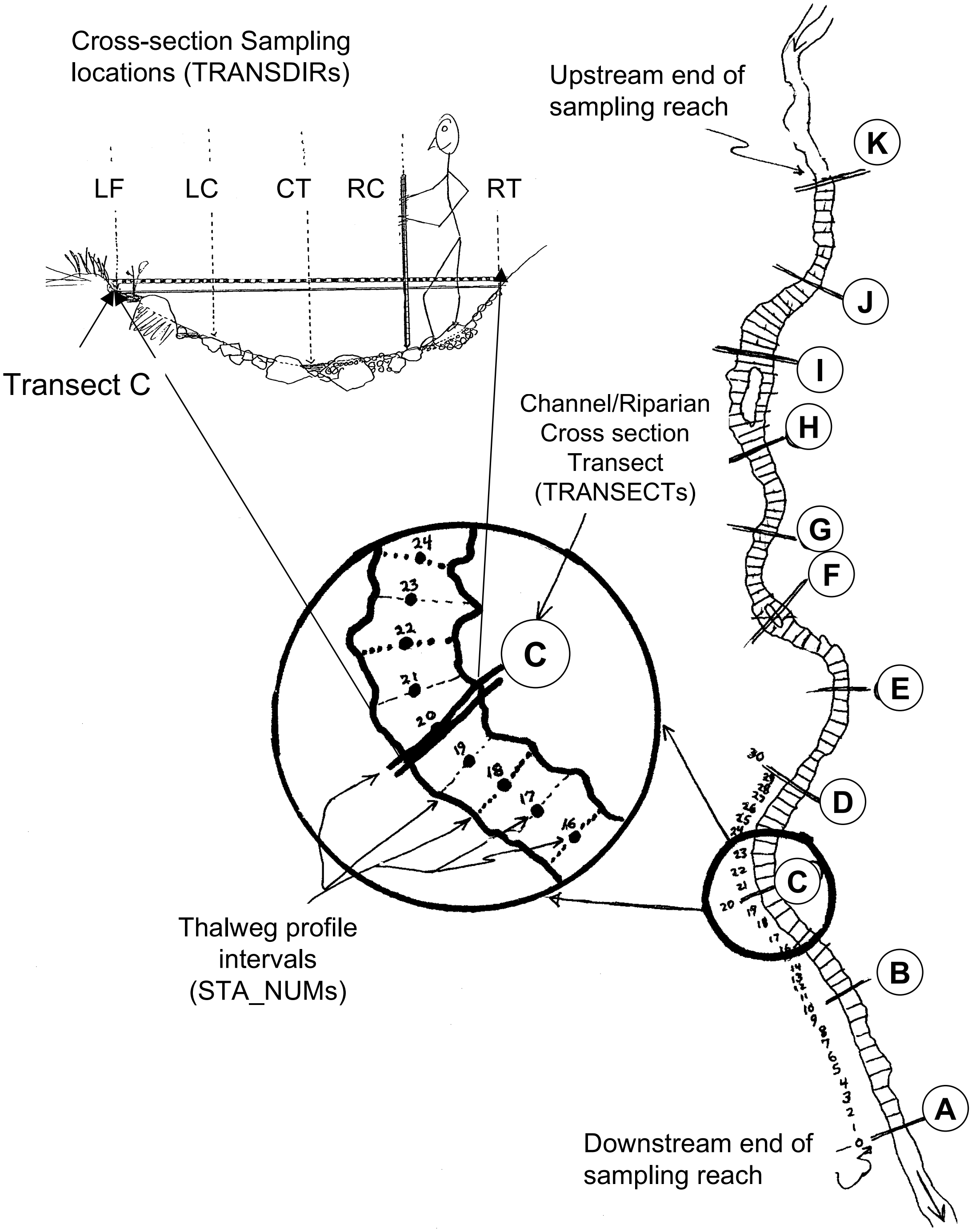


Figure B-1. Layout of sampling reach, showing sampling points across transects and thalweg measurement points.

- Substrate and depth data ***(sub_bank*** file) are collected at points called TRANSDIRs, arranged along the channel cross-section at each transect, as shown on the inset of Figure B-1.
- Canopy densiometer measurements (***canpycov*** file) are made at TRANSDIR positions LF and RT, and then in four directions from one mid-channel point, designated CU, CD, CL, and CR (denoting the left and right bank measurements and the four mid-channel measurements towards the upstream, downstream, left hand, and right hand directions.
- Fish cover is evaluated at 11 in-channel plots, each centered on a transect cross-section (***fishcov*** file).
- Visual riparian cover estimates and human disturbance tallies are evaluated on streamside plots on the left and right banks, centered on each of the 11 transect cross-sections (***riparian*** file).
- Thalweg profile data are collected along the mid-channel length of the sampling reach at points called STA_NUMs (station numbers), of which there are 10 or 15, equally spaced between each of the 11 transect cross sections (***thalweg*** file).

B.1.3 Data File Structure

Data files are arranged as matrices, with observations running in rows, and variables running in columns. Every observation is made up of individual cell entries containing data points / values for each variable.

In addition to the field comments file, ***phabcom***, there are six standard PHab data files containing measurements and observations entered from the PHab field forms: ***canpycov, fishcov, lgwoody, riparian, sub_bank*** and ***thalweg****.* The types of variables within these files are listed in Table 4 of the main body of this report. The data files are organized by individual stream sampling events. Each sampling event is identified by a unique set of identification variables consisting of STRM_ID, YEAR, VISIT_NO, DATE_COL and TEAM_ID. The number of observations within each sampling event is determined by what measurements were made in the field, and at what physical location they were made within the sampling reach. Variables in the PHab data files named TRANSECT, TRANSDIR and STA_NUM are called sampling location variables, and designate the specific location where a particular PHab measurement was made within the reach.

Every stream should have eleven TRANSECTs, labeled A through K. Within each TRANSECT there are varying numbers of observations based on which measurements were made in the field, and at what locations (TRANSDIRs or STA_NUMs) on the sampling reach they were made.

B.2 DATA VERIFICATION AND VALIDATION

B.2.1 Getting Started

We provide SAS Code files (Appendix C on the attached compact disk) to automate the VerVal process as much as possible. However, the code we have included is designed only as a structural guide for Verification and Validation of PHab data files. ***Do not rely solely on the SAS code provided for assuring the quality of PHab data files***. All possibilities can not reasonably be expected to be captured by any fixed VerVal procedure. Therefore keen observational skill and professional judgement will ***always*** be required to determine if particular values are possible, or logical within each individual context. It is also important to keep in mind that the code may need to be altered to accommodate differences in data entry, variable formatting, file names, and sometimes the field sampling protocols themselves. It is advisable to fix file format irregularities prior to using the metrics calculation codes. These calculations may be quite complex, making the code difficult to modify without introducing errors. File format irregularities can be fixed by modifying the VerVal code or by writing new programs.

For each region and year:

1) Obtain all requisite data files for a particular region and year (***canpycov, fishcov, lgwoody, riparian, sub_bank, thalweg, phabcom***).
2) Create a folder (directory) to hold the raw data for that region and year, and place these seven data files in it. A copy of the verified data files should be retained locally. One way to do this is by adding a “0" suffix to the file names. Alternatively, these files could be kept in a separate directory.
3) Create working copies of each data file. Name them by adding the suffix 1, 2, 3, etc., to the original file names, to designate successive versions created during VerVal. File names usually must be limited to 8 digits; for example we shortened names like ***riparian*** and ***canpycov*** to ***ripar*** and ***canpy***. To indicate the year of study, we typically alter the seven file names by shortening them to 6 digits, then adding the last two numbers of the study year to make 8-digit file names. Place all successive working files in the folder containing all data for the given region and year. <u>It is important to record in a log book or file all changes made when creating new or updated data files.</u>
4) Before beginning VerVal it is important to make sure that all PHab data files are present for each region and year, that these files have the correct structure, and that they contain the necessary identifying variables with the correct attributes.

B.2.2 Preliminary Structure and Variable Attribute Check

With all the requisite data files available, run the VerVal overview computer code *AARDVARK.sas*, so named in order that it shows up first in an alphabetized directory listing, and also because it performs a miscellaneous variety of tasks. The computer code is thoroughly documented, so that a data manager can apply it and be clearly informed about what the code is doing to the data set. This section of code examines the entire set of data files checking for inconsistencies in variable naming and formatting, improper variable names, improper variable types (numeric or character). These problems should be fixed before proceeding. The code will add missing variables and set the variables values to their expected length. However, note that text variable values may be shortened, possibly truncating text data. Improper variable types are a condition which requires the individual attention of the user, and thus are not automatically changed in the code. Variables which are unexpected may exist in a data set either as a result of non-standard naming (e.g., STREAM instead of STRM_ID), or may be supplemental data specific to an individual study. In either case these conditions also require the attention of the user and are not deleted by the program. *AARDVARK.sas* also checks sampling date (DATE_COL) values within data files, noting irregularities in the output. It also creates a table to assist in checking for inconsistencies among data files and for determining values for important, but often unrecorded variables, such as REACHLEN and INCREMNT.

Among the formatting requirements of the metric calculation computer codes are the following:

1) All STRM_ID's should be for the correct region (e.g.. OR___, MA___, etc.), and in the correct form. In most cases STR _ID should be a multi-character string which uniquely identifies that a stream reach ('MA003S', 'ORC34', 'ORST97-038', '00028S'). If STRM_ID's are not in the right form, create a new version of data file making the necessary corrections.

2) All dates should be for the correct year and in the correct form (MM/DD/YYYY).

3) Variables appearing in more than one data file should have the same attributes. Variable name, type, and length should be the same in all data files for a given region. All data files should have appropriate ID and sampling location variables. ID variables may include STRM_ID, VISIT_NO, YEAR, DATE_COL and TEAM_ID. Sampling location variables are TRANSECT and TRANSDIR or TRANSECT and STA_NUM. (The ***thalweg*** data file has a sampling location variable called STA_NUM, while the ***sub_bank*** data file has a corresponding variable called TRANSDIR.). If variables are incorrectly named or missing, or if

variable attributes are inconsistent among data files, create a new version of the data file making the necessary corrections.

In addition to the general file formatting issues, there are segments of *AARDVARK.sas* that merge data (e.g. bearing and slope data are merged from ***slopebrg*** into ***thalweg***), and segments of code that put specific files into the format expected by the metric calculation codes that will later be applied to them. These segments may be run or modified as needed. Once these changes have been made, the data overview program should be rerun to check the changes made.

B.2.3 Verifying and Validating Individual Data Files

Many of the VerVal code files we provide are tailored to each of the PHab data files (***canpycov, fishcov, lgwoody, riparian, sub_bank, thalweg***), and each bears the name of the data file to which it pertains. To apply the code, the name of the data file to be checked should be typed where indicated near the beginning of the program text. The code should be run in sequence, one test section at a time. Before running each successive check, correct deficiencies indicated by the previous section. In order to confirm that corrections have been made, each section of code should be re-run on each data file after it is updated.

Each time changes are made to a PHab data file and an updated file version is created, it is important to reopen the data file (making the appropriate changes in the file name, if necessary), and re-run the previous *DATA* steps with the newly modified data before continuing to the next section of that VerVal SAS code. Otherwise changes to the data file will not be recognized by the code.

There are six general steps in verifying and validating PHab data files. It is vital that these be done in the prescribed order, and that each step be completed before proceeding to the next. The SAS code files included for VerVal of each PHab data file contain numbered sections that correspond to these six sequential steps, but not all steps apply to every data file. These six steps of verification/validation check the following aspects of the data: data file structure, missing values, values outside of an allowable range, unusual values, channel morphology visualizations, and internal logic among variables. These steps are generally described in Sections B.2.3.1 through B.2.3.6. Because some cross-checks are based on related variables among the PHAB data sets, we recommend validating the ***sub_bank*** data first, followed by the ***thalweg*** data.

B.2.3.1 Data File Structure--

The first section of each VerVal code aids validating and correcting data file structure, insuring that every stream visited has the correct ID number, the correct number of visits, transects, and observations within transects. This is a critical portion of VerVal, because each final data file must have a standardized structure that reflects the field sampling design in order for the habitat metric calculation code to run properly. Each data point or cell entry in a data file should reflect an individual measurement or observation recorded in the field.

Each subsection of "*Computer Code for VerVal of Individual Data File*s" begins with a brief description of the sampling design that gives rise to the structure of the data file. Subsections then list the identification variables and briefly explain how they relate to the data file structure. The identification variables (STRM_ID, YEAR, VISIT_NO, DATE_COL, TRANSECT, TRANSDIR, STA_NUM) should have exactly the number of cell entries listed in the "*Structure Check*" subsections within the subsequent section entitled "*Computer Code for VerVal of Individual Data Files*". Inequalities may indicate that data for a transect, station, etc, were not recorded in the field, not entered during data entry, assigned an incorrect identifying value, or that additional side channel observations were included in the survey. Discrepancies in the number of identification variable values present should be validated and corrected at this stage. The number of entries for the PHAB variables themselves (e.g. DENSIOM, UNDERCUT, etc.) may vary somewhat due to missing values in the data file. The number of non-missing values for these variables should equal, or be slightly lower than the number listed number in the individual data file "*Structure Check*" subsections. However, at the structure check step, it is not yet necessary to validate every entry for each PHAB variable, but rather to ensure that the overall structure and number of observations are correct.

B.2.3.2 Missing Values–

This section of code aids in identifying missing values. These should be verified by cross-checking with the data forms. Values which are present on the data forms, but missing from the data file, should be documented in the separate VerVal log book or file, and added to the data file. Values which are missing from the data files, but are found to be 0 on the field forms should likewise be corrected. Large woody debris tally data are an exception, as missing values indicate zero counts for a particular size/location class.

B.2.3.3 Values Outside Allowable Range–

This section of code lists observations in which variable values are outside of an allowable range. (example: ***riparian*** vegetation cover class: 0 - 4, DENSIOM: 0 - 17). Illegal values should be compared against the data forms. Values that cannot be reconciled should be documented, and changed to "missing" in the revised data file.

B.2.3.4 Unusual Values–

This section of code uses summary statistics to examine the range of continuous numerical data (example: DEPTH, WT_WID values). The unusual values identified by this examination should be verified by checking the field forms to ensure that they are not transcription errors. Remaining unusual values should be evaluated using professional judgement. They may be changed and documented, or left to stand accordingly. Impossible values (e.g., DEPTH=700m) that cannot be reconciled should be documented, and changed to missing values in a revised data file.

B.2.3.5 Channel Morphology–

This section of some of the VerVal codes graphs channel morphology values as transect or stream profiles so that one can visually determine if some values stand out as outliers, even though they may not be unusual relative to the whole data set. Values of many channel morphology measures need to be evaluated in a reach-specific and cross section-specific context. For example, a wetted width of 30 m may not stand out as unusual in a large data set. But it would be very unusual in a stream with all other widths < 3 m. Outliers should be verified and documented, and an attempt to reconcile them should be made using best professional judgement. If this is not possible, a decision must be made to remove outliers, or to leave them stand. Regardless which choice is made, proper documentation is essential.

B.2.3.6 Internal Logic--

This section of VerVal codes lists various instances where the data contains logical inconsistencies. Some examples are:

-The sum of cover class values within a vegetation layer should not convert to a cover percentage > 100% (e.g., class 3 + class 4 = 57.5% + 87.5% = 145%);
-Canopy type or densiometer cover indicate vegetation presence, but visual cover estimates are zeros (e.g. CANV = D,C,E, or M; but BTRE and STRE both equal 0 or missing).

Apparently illogical values that are identified and listed by the code should be checked against field forms, documented, and where possible, professional judgement should be used in reconciling values to specific guidelines listed in individual '*logic check*' sections of this document. When apparently illogical values cannot be reconciled, decide whether to replace the questionable values with missing values, or let them stand; then fully document these changes.

B.3 COMPUTER CODE FOR VER/VAL OF INDIVIDUAL DATA FILES

B.3.1 File *canpycov* Checks

Structure check:

Canopy cover is measured by taking a densiometer reading at six places, (TRANSDIRS) spaced along, and around each of eleven transects (see figure 2-1), resulting in 66 observations per stream visit.

Expected Frequencies of Variables:

STRM_ID , VISIT_NO, DATE_COL, TRANSECT - 66 for each stream visit.

TRANSDIR - 6 per TRANSECT, one for each value CD, CL, CR, CU, LF and RT.

DENSIOM - Canopy cover measurement should have a maximum of 66 values per stream visit.

Missing value check:

For DENSIOM - As described in *'Verifying and Validating Individual Data Files'* overview section.

Allowable range check:

DENSIOM should only have whole number values from 0 to 17.

B.3.2 File *fishcov* Checks

Structure check:

Areal cover available for fish from several different sources is estimated over a stream plot centered on each transect, resulting in eleven observations per stream visit.

Expected Frequencies of Variables:

STRM_ID , VISIT_NO, DATE_COL, TRANSECT - 11 for each stream visit.

Fish cover estimates for the PHAB variables ALGAE, BOULDR, BRUSH, MACPHY, STRUCT, OVRHNG, UNDCUT and WOODY each should have a maximum of 11 values per stream visit.

Missing value check:

For PHAB variables mentioned above: As described in *'Verifying and Validating Individual Data files'* overview section.

Allowable range check:

All fish cover variables should only have whole number values from 0 to 4.

B.3.3 File *riparian* Checks

Structure check:

At each transect, vegetation type and cover in three layers are estimated, and human influences are recorded within a riparian plot on each stream bank, resulting in 22 observations per stream visit.

Expected Frequencies of Variables:

STRM_ID, YEAR, VISIT_NO, DATE_COL, TRANSECT -- 22 for each stream visit.

TRANSDIR -- Two entries for each transect, one each of value LF and RT.

Canopy and understory vegetation type (CANV, UNDV) and cover (BTRE, STRE, WOOD, NONW, GCW, GCNW, and GCB), and human influences (WALL, BLDG, PVMT, ROAD, PIPE, LDFL, PARK, CROP, PSTR, LOG and MINACT) should have a maximum of 22 entries per stream visit.

Missing value check:

For PHAB variables mentioned above - As described in *'Verifying and Validating Individual Data Files*" overview section.

Allowable range check:

CANV and UNDV should only have values D, C, E, M, or N. BTRE, STRE, WOOD, NONW, GCW, GCNW and GCB should only have whole number values from 0 to 4. All human influence variables should only have values of 0, B, C or P.

Logic checks for Cover Class Variables:

Within each of the three layers of riparian vegetation cover, values should not add to more than the equivalent of 100%, assuming the mid-point % cover for each cover class entry. For each of the vegetation-layer categories, areal cover was estimated in four classes: absent (0), sparse (0–10%), moderate (10–40%), heavy (40%-75%) and very heavy (>75%). The mid-points of these cover classes are, respectively: 0%, 5%, 25%, 53%, and 87.5%. Therefore, the following combinations are violations of this logic:

1) If BTRE=4, then STRE cannot be 3 or 4, and vice-versa.
2) If WOOD=4, then NONW can not be 3 or 4, and vice-versa.
3) If any of GCW, GCNW or GCB=4, then none of the others can be 3 or 4.

Running section 6 of the SAS code for VerVal of PHAB data files lists violations of this rule of logic. In these cases each value should be reduced by one. For example, if BTRE and STRE both=4, then reduce both values by one. This will bring the equivalent total below 100%. If BTRE=4 and STRE=3, or vice-versa, then reduce both values by one. This will preserve the relationship of dominant and sub-dominant vegetation cover values, while also reducing the equivalent vegetation layer total to below 100%

Logic Checks for Cover Type Variables:

If CANV indicates there is no cover in the canopy vegetation layer (i.e. CANV = N), and there is a non-zero value for BTRE or STRE, then CANV should be changed to missing.

If UNDV indicates there is no cover in the understory vegetation layer (i.e. UNDV= N), and there is a non-zero value for WOOD or NONW, then UNDV should be changed to missing.

If BTRE and STRE both have values of zero, and CANV is not equal to N, then CANV should be changed to N.

If WOOD and NONW both have values of zero, and UNDV is not equal to N, then UNDV should be changed to N.

Comments Cross Check:

Occasionally, survey crews will list human influence factors in comments, but neglect to include them in the riparian data section of the field form. The comments cross-check section of code lists comments as well as all the human influence variables. If any human influences are listed in the comments, but have no values in the PHab variables, then document them, and add them as 'P' to a revised data file.

B.3.4 File *sub_bank* Checks

Structure Check:

Substrate information is measured at each of five points (TRANSDIRs) across each TRANSECT, resulting in 55 observations per stream visit. Bank characteristics are measured at both stream banks, at each TRANSECT, resulting in 22 values per stream visit. Width and bankfull characteristics are recorded once at each transect, resulting in eleven values for each stream visit.

Expected Frequencies of Variables:

STRM_ID, YEAR, VISIT_NO, DATE_COL, TRANSECT - 55 for each stream visit.

TRANSDIR - There should be five entries for each TRANSECT, one each of value LF, CL, CT, CR and RT.

Distance to the left bank (DIST_LB), water depth (DEPTH), substrate size class (SIZE_CLS) and embeddedness (EMBED) should have one entry per TRANSDIR for a total of 5 per transect and 55 per stream visit.

Bank angle (ANGLE) and undercut (UNDERCUT) should only have entries at TRANSDIRs LF and RT for each TRANSECT, totaling a maximum of 22 entries per stream visit. Wetted width (WT_WID), bankfull width (BANKWID) and height (BANKHT), stream incision (INCISED) and bar width (BARWID) should have one entry per TRANSECT, totaling a maximum of 11 entries per stream visit. These values should be listed at TRANSDIR=RT.

Missing Value Check:

UNDERCUT-- If an UNDERCUT value is missing, it should be compared with the UNDCUT value in the ***fishcov*** data file. If the UNDCUT value is 0, then the missing UNDERCUT (***sub_bank*** value) should be changed to 0. If the UNDCUT value in ***fishcov*** is not 0, then the missing ***sub_bank*** value must be left as missing.

BARWID – If a BARWID value is missing, it should be compared with the BARWID value in the ***thalweg*** data file for the same TRANSECT at STA_NUM=0. If there is a BARWID value at this location in the ***thalweg*** data, then the missing BARWID value in the ***sub_bank*** file may be replaced with that value.

For other PHAB variables: As described in '*Verifying and Validating Individual Data Files*' overview section.

Allowable Range Check:

SIZE_CLS can have values of RS, RR, RC, HP, BL, CB, GC, GF, SA, WD, FN, OT, or missing.

EMBED can have values of 0 to 100, inclusive.

ANGLE can have values from 0 to 180.

Unusual Value Check:

UNDERCUT values greater than 1 meter should be considered very unusual.

INCISION values greater than BANKHT + 5m should be considered very unusual.

BARWID values should be generally small (0 to 6, but always less than WT_WID).

Channel Morphology Checks:

This section graphs channel cross section and longitudinal profile plots for DIST_LB, DEPTH, WT_WID, BANKWID and BANKHT by stream visit. These plots should be examined for outliers, values that do not fall within a reasonable range for each individual stream.

Logic Checks:

Distance From Left Bank - DIST_LB values should be 0 (or very close to 0) when TRANSDIR=LF, then it should increase successively by 25% of the wetted width as measurement locations progress across the channel (TRANSDIR positions CL, CT, CR), until at TRANSDIR=RT, the value of DIST_LB=WET_WID. The first part of section 6 of the SAS code for VerVal of ***sub_bank*** data lists TRANSECTS where DIST_LB is not 0 at TRANSDIR=LF and/or where DIST_LB does not equal WT_WID at TRANSDIR=RT. The second part of this section of code identifies transects with irregular TRANSDIR spacings.

Incision, Bankfull Height and Wetted Width, Bankfull Width - BANKWID should be ≥ WT_WID. INCISED should be ≥ BANKHT. The VerVal code lists data that are counter to these rules. Occasionally field crews incorrectly record values of INCISED that are measurements of incision above bankfull height rather than from the water surface. In this case INCISED should be changed to the value of BANKHT plus INCISED. INCISED values are also sometimes mistakenly switched with BANKHT values.

Wetted Width, Depth - The VerVal code lists TRANSECTs where WT_WID =0 (most probably signifying a dry channel), but where a DEPTH value other than 0 is entered. Validation can be performed by cross checking with ***thalweg*** data. If CHANUNIT = DR at STA_NUM=0 (***thalweg*** data file), then WT_WID and DEPTH values ***(sub_bank)*** should both = 0. If ***thalweg*** data indicates that there was water flow at STA_NUM=0 for that TRANSECT then appropriate adjustments to ***sub_bank*** data must be made.

Bar Width, Wetted Width - In the EMAP field methods, a mid-channel bar is an in-channel feature. Therefore, BARWID cannot equal or exceed WT_WID; the VerVal code lists violations of this logic.

Comments Check - This section of VerVal code lists comments if SIZE_CL =OT, signifying “other”. Field surveyors are instructed to elaborate on atypical substrates in comments. If 'hardpan' or 'concrete' are listed, then SIZE_CL should be changed to 'HP' or 'RC', respectively.

By definition, bedrock and hardpan substrate size classes are not embedded (if SIZE_CLS=RR, RS, HP or RC then EMBED=0). Conversely, sand or smaller substrate size classes are by definition completely embedded (if SIZE_CLS=SA or FN then EMBED=100). These corrections should be made universally by running the last section of the VerVal code for ***sub_bank*** after the rest of the VerVal code for this data file has been completed.

B.3.5 File *thalweg* Checks

Structure Check:

Thalweg characteristics are measured at either ten or fifteen stations (depending on the width of the stream) equally spaced as STA_NUM=0 through 9 or 14 between each TRANSECT, A through K. There is only one station at the location of transect K. Stream width is recorded once at each transect (STA_NUM=0) A through K, and at the middle position (either STA_NUM=5 or 7) of each transect A through J. Stream slope and compass bearing backsights are recorded once at each TRANSECT from B to K. Slope and bearing data are originally entered in a file called ***slopebrg***, which is merged with ***thalweg*** data by the VerVal code *AARDVARK.sas*.

Expected Frequencies of Variables:

STRM_ID, YEAR, VISIT_NO, DATE_COL, TRANSECT -- either 101 or 151 for each stream visit. Data for STA_NUM ‘0' of TRANSECT ‘K’ are often not collected, so thalweg depth values typically number 100 or 150 per stream visit.

STA_NUM -- 10 or 15 for each of the ten TRANSECTs A through J, and one for TRANSECT=K.

Thalweg depth (DEPTH), presence of fine sediments (SEDIMENT), habitat unit (CHANUNIT), and pool forming agent (POOLFORM) should normally have either 10 or 15 values, one per STA_NUM, for TRANSECTS A through J, and one or zero for TRANSECT K, totalling a maximum of 100, 101, 150, or 151 entries per stream visit. Wetted width (WT_WID), and bar width (BARWID) should have a maximum of 20 or 21 entries per stream visit, with 2 entries (at station numbers 1 and either 5 or 7) at each transect A through J, and 1 or zero at transect K. The primary backsighted values for stream gradient (SLOPE), and bearing (BEARING) should have 10 entries per stream visit. These values should be listed at STA_NUM=0 for each transect B through K. Supplemental slope and bearing measurements may have 10 or fewer entries per stream visit. These supplemental measurement variables include SLOPE2, SLOPE3, BEAR2, BEAR3, PROPORT2, PROPORT3, and in older data sets: SUPSLOPE and SUPBEAR.

Missing Value Check:

In order to make this stage of data checking easier, the SAS code we break this section into several parts to handle groups of variables differently:

1) WT_WID, SLOPE, BEARING, PROPORTN, INCREMNT, REACHLEN, BARWID, SIDECHAN, CHANUNIT and POOLFORM: If WT_WID is missing and STA_NUM is 0, then replace WT_WID with the value of WT_WID from ***sub_bank*** data for the same transect. For other PHab variables, procedures are as described in the *"Verifying and Validating Individual Data Files"* overview section.

2) There is a separate section for the variable DEPTH. This variable is used in calculating residual pool statistics, which are degraded by missing values. (Field crews should be encouraged to make their best estimate for points where depth cannot be measured directly, and to flag these entries accordingly.) If a large number of depth values are missing, or there are several gaps in one reach, then it may be impossible to calculate residual pool statistics. For this reason extra care should be taken in verification, including the following suggestions:

    - If one depth value is missing, and there are values for depth at the adjacent station numbers, then the missing value may be replaced by interpolating between the two adjacent values.
    - If there are several depth values missing in a row it may be possible to evaluate residual pools based on an abbreviated reach segment. This will entail adjusting reach lengths in the residual pool statistic calculations.

3) This section of VerVal code lists missing fine substrate presence (SEDIMENT) values for those thalweg stations at the first STA_NUM of a transect separately from those between transects. This is because missing SEDIMENT values at the transect cross-section location (STA_NUM=0) can be inferred from SIZE_CL substrate data in the ***sub_bank*** data file:

    - If the observation at the first station of a transect is missing, then check the ***sub_bank*** data file value for SIZE_CL at the deepest TRANSDIR from the same TRANSECT. If this value is GF, SA or FN, then the missing value should be replaced with 'Y'. Otherwise the missing value should be replaced with 'N'.

- Missing SEDIMENT values between transects are checked as described in Section B.2.3 of this Appendix: *“Verifying and Validating Individual Data Files”*.

Allowable Range and Unusual Value Checks:

SEDIMENT should only have values of Y or N; but field crews frequently indicate fine sediment presence with Y and absence by a missing value.

CHANUNIT should only have values of PP, PT, PL, PB, PD, GL, RI, RA, CA, FA or DR.

POOLFORM should have values of N, W, R, B, F, or O, or a combination of these.

SIDECHAN can have values of either Y or N. If there is a missing value, it should be changed to N.

SLOPE, or any supplemental slope values greater than 20% are rare. Values between 0 and 0.1% should be examined to see that they were not recorded as 1/100th of the true slope.

BEARING, or any supplemental bearings should only have values from 0 to 359. PROPORTN, PROPORT2, AND PROPORT3 should have values from 0 to 100%, and should sum to 100%.

BARWID values should be generally small (0 to 6, but always less than WT_WID).

Channel Morphology Check:

This section of code produces, for each stream visit, a longitudinal profile of wetted width for the reach, and depth profiles for each of the reach segments between transects. These plots should be examined for obvious outliers that fall outside a reasonable range of variation within each individual stream and visit.

Logic Checks:

WT_WID, DEPTH, CHANUNIT - This section lists transects where WT_WID, DEPTH or CHANUNIT suggest a dry channel, but one or more of the other variables do not agree. (e.g., where CHANUNIT = DR, but DEPTH or WT_WID has a non-zero value). Validation can be aided by cross-checking with ***sub_bank*** data.

Bar Width, Wetted Width - The EMAP field methods define mid-channel bars as in-channel features. Therefore BARWID cannot be $ WT_WID. This section lists violations of this relationship.

Slope and Bearing - If no SLOPE, BEARING and/or PROPORTN values are listed, but there are (supplemental) values for SLOPE2, SLOPE3, BEAR2, BEAR3, PROPORT2, or PROPORT3, the missing primary value should be replaced with the supplementary value, and the supplementary value removed.

Increment and Reach Length - If each transect has 10 stations, then INCREMNT should be equal to, or approximately equal to REACHLEN ÷ 100. If each TRANSECT has 15 stations, then INCREMNT should be equal to, or approximately equal to REACHLEN ÷ 150.

Shift in Slope and Bearing Recordings -- If TRANSECT A has a value listed for SLOPE or BEARING, but TRANSECT K does not, then check if the slope and/or bearing recordings are all shifted by one TRANSECT (i.e., backsight at B was recorded at A, etc.). There should be one value listed for each TRANSECT from B to K, all located at STA_NUM=0.

Width to Depth Ratio - This section lists transects where (WT_WID/DEPTH) is > 50, or < 1. These values are suspect, and should be verified with ***sub_bank*** channel cross-section data.

B.3.6 File *lgwoody* Checks

<u>Structure Check</u>:

Pieces of wood greater than 0.1 m in diameter and 1.5 m in length are counted and recorded between every two transects, separated into 12 size classes each for pieces at least partially wet during bankful flows (PIEC_TYP='WET') and those within bankful width, but above bankful flows (PIEC_TYP=‘DRY’). The ***lgwoody*** data file may not contain observations for size classes in which LWD was not recorded. In this case, check field forms to determine when it is safe to assume that missing observations in any given size class are meant to be zeros. In these cases there may be significantly less than 240 observations per reach, but the metric calculation SAS code will run correctly regardless of missing observations.

Expected Frequencies of Variables:

STRM_ID, VISIT_NO, DATE_COL, TRANSECT - 240 per stream visit. There may be less than this number if zeros were omitted when no LWD was observed.

PIEC_LEN, PIEC_DIA and PIECES should all have 24 entries per transect totaling 240 entries per stream visit.

PIEC_TYP should have 12 values of 'WET' and 12 values of 'DRY' for each of the eleven TRANSECTs, totalling 240 entries for each stream visit

Missing Value Check:

For PHab variables mentioned above - As described in *"Verifying and Validating Individual Data Files"* overview section.

Unusual Value Check:

Extremely large numbers, or numbers which are disproportionately large for an individual stream reach should be checked against the field forms.

Data Restructuring:

This part of the VerVal code restructures the ***lgwoody*** data file to facilitate calculating reach level metrics. The resulting data file should be saved as the final ***lgwood**** data file.

B.3.7 Computer Code Involving More Than One Data File

There are several instances where values resulting from the same or similar measurements appear as the same or different variables, but in two different PHab data files. The VerVal code we provide will compare these values and generate a list of observations that do not agree. Values listed should be verified by examining the original data forms. Instances where values are found to be inconsistent should be reconciled and documented.

FISHSUB - This code compares undercut measurements in the ***sub_bank*** data file (UNDERCUT), with estimates of the areal cover of undercut from ***fishcov*** data (UNDCUT). It is logically possible for ***fishcov*** to have a positive value for UNDCUT, with ***sub_bank*** having a value of 0 for UNDERCUT. However if there is a positive value for UNDERCUT (***sub_bank***), and UNDCUT (***fishcov***) has a value of 0, then UNDCUT should be changed to 1, indicating that there is at least some bank undercut within the ***fishcov*** plot.

THALSUB - The first section of this code lists observations where ***thalweg*** values for WT_WID and/or BARWID do not match those for ***sub_bank.*** The second part of this code checks for situations where either ***thalweg*** or ***sub_bank*** data suggest a dry stream channel, but there are depth and/or wetted width values, and/or the CHANUNIT value is not DR.

LABELS - When all PHab data files have been thoroughly validated, verified and documented, variables should be labeled. At this point the sequential number of each final PHab data file should be added to the macro data lines at the end of the included *LABELS* SAS code. Running this code will automatically label all variables in the ***canpycov, fishcov, riparian, sub_bank, thalweg,*** and ***lgwoody*** data files.

B.4 FINAL DATA VALIDATION CONSIDERATIONS

A final level of quality assurance is accomplished by examining reach level metrics after they are calculated from the raw habitat measurement files (see Section 3 of main body of this report). Some errors within the various PHab data sets can be seen quite obviously from this overall vantage point. These types of checks include the following:

- Check metric variables that indicate how many values were used to calculate metrics (e.g. NBNK, N_BA, NSLP). Values deviating from the expected numbers may indicate data structure problems; if there are excessive numbers of missing values, a reach level metric value based on the remaining observations may be suspect.

- Particular ecoregions have predictable expectations for some variables, particularly for canopy and mid-layer cover types (for example, one would not expect high cover values for coniferous vegetation in the Great Plains region). Cases where data is contrary to expectations may indicate incorrect values in the physical habitat data file **riparian**. Similarly, metric values that are an order of magnitude higher or lower than the values from all other stream reaches in an ecoregion, or that look incongruent when compared to others, should be double-checked.

- If a metric value for a reach is equal to the minimum or maximum possible for the associated raw measurement variable, (e.g., if XCDENMID=0, or

XFC_ALG=1.00) then every observation for that variable in the raw physical habitat measurement data file would have to be at the minimum or maximum value (e.g., DENSIOM=0 and ALGAE=4) for the stream in question.

- If a metric variable indicating variance (e.g., VSLOPE, SDDEPTH) is equal to 0 in a particular stream reach, then all raw data values must be equal to the reach mean value (e.g., XSLOPE, XDEPTH) for all observations of the associated measurement variable in that stream (e.g., SLOPE and DEPTH in file **thalweg**).

To check sinuosity metrics, compare REACH and REACHLEN. If TRAN_N=10 (all bearing values were present and used in calculating sinuosity), then REACH should equal REACHLEN. If this is not the case, verify the number of bearing values used to calculate sinuosity for the stream visit in question.

Finally, errors are inevitably revealed during data analysis, as inconsistencies may be discovered in relationships such as those between slope and substrate size, or between depth variance and residual pool area. We hope that this guide helps to identify most errors and inconsistencies.

APPENDIX C. COMPUTER CODE FOR DATA VERIFICATION AND VALIDATION

Programs and thorough program documentation to assist with data verification and validation of EMAP Physical Habitat data (described in Appendix B) are included on the enclosed compact disk. They were developed for use with the Statistical Analysis System (SAS; Version 6.12 for Windows) software. These programs are formatted as plain ASCII text files, and so can be read and printed from any word processor. In SAS, a file is retrieved into the Program Editor window, modified as necessary, and submitted to run it. These programs and their updates may also be available in the future from the EMAP website (*http://www.epa.gov/emap*)
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APPENDIX D. COMPUTER CODE FOR PHYSICAL HABITAT METRIC CALCULATION

Programs and thorough program documentation to calculate the various metric variables from the individual measurement EMAP Physical Habitat variables (described in Section 4 of the main report) are included on the enclosed compact disk. They were developed for use with the Statistical Analysis System (SAS; Version 6.12 for Windows) software. These programs are formatted as plain ASCII text files, and so can be read and printed from any word processor. In SAS, a file is retrieved into the Program Editor window, modified as necessary, and submitted to run it. These programs and their updates may also be available in the future from the EMAP website (*http://www.epa.gov/emap*).

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APPENDIX E. ILLUSTRATION OF RAW DATA AND COMPLETED METRIC CALCULATIONS FOR SEVERAL STREAM REACHES

Included on the enclosed compact disk are files that provide an example raw data collected from several stream reaches, and the metric variables calculated using procedures described in this report. These data files are formatted as comma-delimited ASCII files and as SAS export files; we have included a program to convert to local SAS format. These files may also be available in the future from the EMAP website (*http://www.epa.gov/emap*)