Monitoring Urban Streams:
Strategies and Protocols for Humid-Region Lowland Systems

{Running title: Monitoring Urban Streams}

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ABSTRACT

Governmental mandates and public awareness have forced progressively smaller and less sophisticated agencies and organizations to initiate stream monitoring programs, particularly in urban and urbanizing areas. Yet many of these monitoring efforts lack either a coherent conceptual framework or appropriately chosen methods, and they rely on monitoring techniques that are simply infeasible for these institutional settings. We identify a monitoring strategy, and specific existing monitoring protocols, that will be useful for the management and rehabilitation of streams in urbanizing watersheds.

A monitoring strategy must be developed by 1) identifying the management question(s) being addressed, 2) determining the institutional level of effort required (and available) to make particular kinds of measurements effectively, and 3) identifying what specific parameters should and can be measured. Only a limited set of parameters show much utility or feasibility in addressing the most common management questions being faced by municipalities in urbanizing, humid-area regions of the United States. These include measures of riparian canopy, bank erosion and bank hardening, and in-stream large woody debris. With some additional expertise useful data can also be included on channel gradient, substrate composition, and pools. Nearly all of the other myriad physical parameters that have historically been measured on rivers and streams show little apparent value in these watershed and institutional settings.

BACKGROUND

Monitoring of stream systems has moved from a rarefied, academic pursuit to an activity required of progressively smaller and less sophisticated government agencies and non-governmental organizations. These efforts are commonly being implemented as a consequence of legislative mandates, from the state or Federal level, or as a condition of construction permits. Public agencies and citizen groups are thus actively measuring a variety of stream parameters, either to evaluate the “health” of these systems or to track their environmental conditions over time. Yet many of these monitoring efforts lack either a coherent conceptual framework or appropriately chosen methods, and, as such, do not produce adequate information to reach their intended goals. Furthermore, monitoring techniques developed in research settings or by large Federal agencies are simply not feasible for the vast majority of municipalities that are now initiating these programs. As a result, an unprecedented opportunity to record and to analyze the effects of land-use changes on aquatic ecosystems, driven by rapid urbanization and growing public awareness of downstream consequences, is being lost.

Our intent here is to articulate a strategy for urban stream monitoring that acknowledges not only the geomorphic and hydrologic characteristics of the fluvial system, but also the typical range of institutional needs and constraints under which that monitoring is likely to occur. It is not sufficient for a monitoring plan to identify only parameters that can characterize the condition of a system; it must also ensure that the data can be collected feasibly and reproducibly within the institutional setting that the monitoring will occur. The assessment here is based on the current monitoring theory and practice in lowland watersheds of western Washington State (USA), where recent listings of anadromous salmon under the federal Endangered Species Act directly affect management of stream channels also being affected by the region's rapid urban growth. These watersheds have become the primary focus of monitoring by local municipalities and citizen volunteer groups, because they contain biologically significant and typically fish-bearing streams that are undergoing rapid and readily visible degradation. They range in drainage area from about 10^0 to 10^2 km^2, supporting perennial streams with typical bankfull widths of about 1-10 m on channel gradients of 0.10 percent for headwater systems down to about 0.005 percent for the mainstem channels.

Although substantial resources are being directed towards ecosystem monitoring, neither funding agencies nor implementing agencies have received much guidance in designing an appropriate monitoring program. The problem is not with executing specific monitoring protocols—many guidance documents exist that specify proper techniques for data collection, and so these issues are mentioned here only briefly. Instead, the major shortcoming is in choosing an *approach* that will provide sufficient data to answer particular management questions and that is feasible for the institutional context and available resources. The approach articulated here does not, and should not, lead to the same monitoring program for every stream in every institutional setting. It can, however, provide the basis for crafting the most appropriate monitoring program across a variety of settings. It also leads to a set of "typical" monitoring activities that should prove useful in many applications that have become commonplace in urbanizing regions of the United States.

Our goal is to identify a monitoring strategy, and specific existing monitoring protocols, that will be useful for the management and rehabilitation of streams in urbanizing watersheds. We have subdivided this goal into several tasks:

1. Establish the monitoring strategy. This consists of
    - recognizing what management question(s) are being addressed by the monitoring;
    - determining the level of effort required to make particular kinds of measurements effectively; and
    - identifying what to measure.
2. Evaluate the utility of individual monitoring parameters currently being used to characterize particular features of the channel, as measures of stream health.
3. Recommend a set of stream-monitoring protocols that will meet the most common needs of agency monitoring programs in urban and urbanizing areas.

MONITORING STRATEGY

Addressing Management Questions

We recognize three common questions that depend on characterizing the health of streams in urbanizing watersheds:

1) What are the trends in stream condition?
2) What is the current stream health?
3) How should planned stream restoration or rehabilitation efforts be ranked?

Although related, these questions require different types of measurements at different levels of detail and precision. The first is the simplest to answer, because it requires only a set of measurements that show a response to watershed changes, repeated at the same location over time. The measurements need not be transferable, only reproducible.

In contrast, the second question (and commonly the third) carries an implicit or explicit comparison to some reference condition that is presumed to be "good." This requires not only that the measurements be accurate and transferable from one stream to another, but also that the chosen reference is truly applicable. Accordingly, some method of stream stratification or classification is required in order to select appropriate comparisons from the tremendous variety of natural stream types. Any monitoring with this goal requires such a framework, either implicitly or explicitly stated—criteria for a "good" boulder-strewn cascade, for example, will be dramatically different than for a languid lowland creek.

The third question for monitoring, how to rank prospective rehabilitation efforts, adds additional dimensions—how bad are conditions now? How good might they become? What elements of a healthy stream are most degraded? Can they be repaired? This demands the most comprehensive view of the channel, because streams can be degraded in many different ways. Although we find some similarities among many urban channels, no single strategy for rehabilitation will be effective in every case. Accordingly, part of the task for a monitoring program is to gather data that will help identify the most likely approach for success.

Level of Monitoring Effort

Many monitoring programs include unrealistically complex protocols for the level of staff or volunteers available. To provide a basis for comparison, we have used the following assumed scale of institutional "levels of effort":

1 = Rapid, low cost, but likely to generate only qualitative or imprecise quantitative data. Level 1 measures are single snapshot evaluations and typically have modest utility because they can reliably offer only a coarse discrimination of aquatic-system quality or health. However, they may be useful in evaluating gross conditions ("good" vs. "bad"), and they are suitable for a wide range of volunteers with only minimal training.

2 = Nominal equipment, relatively rapid, and likely to generate reproducible (albeit coarse) quantitative results. These techniques require trained volunteers or professionals. At this level of effort, measures can be useful to classify a stream or reach, or to characterize

conditions relative to some reference condition. As such, they can be used for both one-time and continuous monitoring programs, but most parameters will require substantial change for any difference to be detected.

3 = Similar requirements and applications as Level 2 but requiring more time and training in order to yield more precise results; discrimination of trends should be commensurately improved.

What to Measure

Finally, effective monitoring requires knowledge of *what* to measure. This analysis addresses only selected *physical* element of the stream system, despite the historic regulatory-driven emphasis on chemical parameters and the growing attention to in-stream biota. We have chosen this emphasis for several reasons:

- In a majority of settings, the most rapid and severe stream degradation is a consequence of physical effects, particularly high flows and riparian alteration, not chemical contamination (Horner et al., 1997). For most (but not all) monitoring assessments, collecting a statistically meaningful set of chemical data is simply not worth the substantial effort needed.
- Biological monitoring techniques have seen tremendous recent development; current articulation of their methodologies and application are readily available elsewhere (e.g., Fore and others, 1996; Karr and Chu, 1999).
- Unlike most chemical and biological evaluations, these measurements are relatively quick and easy to make; most can be accomplished during any time of the year and at all but the highest of stream discharges.

In acknowledgement of this focus, we recognize six physical *channel features* of particular importance, based on a growing understanding of how lowland channels respond to urbanization (Hollis, 1975; Dunne and Leopold, 1978; Booth, 1991; Horner et al., 1997; Booth and Jackson, 1997):

1. channel geometry,
2. stream corridor vegetation,
3. channel erosion and bank stability,
4. large woody debris,
5. channel-bed sediment, and
6. instream physical habitat.

Where comparison of these channel features to a reference condition is required by the management question(s), stratification is needed. We recommend the geomorphologically based approach of Montgomery and Buffington (1997), developed for forested mountain drainage basins in the Pacific Northwest, because it displays a clear relationships between channel “type” and channel behavior that is often lacking in more purely descriptive approaches (e.g. Rosgen, 1994). They define a range of stream types, of which four are particularly relevant to a humid-region, lowland setting. Certain monitoring parameters, discussed subsequently, can discriminate between these types; others simply vary so much between types that any unstratified comparisons would produce meaningless comparisons.

Of the alluvial channels encountered in lowland watersheds and their headwater tributaries, ***cascade channels*** are the steepest, characterized by large clasts that form the primary roughness elements and impose a strongly three-dimensional structure to the flow. Tumbling flow around individual boulders dissipates most of the energy of the flow; bed morphology is disorganized with at most small pools that span a fraction of the total channel width. ***Step-pool channels***, in contrast, display full-width-spanning accumulations of coarse sediment that form a sequence of steps, typically one to four channel-widths apart, that separate low-gradient pools filled with finer sediment. The step-forming sediment is mobile but only at very high discharges. ***Plane-bed channels*** lack well-defined bedforms and instead display long, and commonly channel-wide, reaches of uniform “riffles” or “glides.” In contrast to the steeper channels any flow oscillation is generally horizontal, not vertical, but the lateral variations are insufficient to produce pronounced meanders and associated pools. The most common of the lowland stream channels, ***pool-riffle channels***, have laterally oscillating flow that produces a sequence of pools at the outside of bends with corresponding bars on the inside of bends. The classification discriminates between “free” pool-riffle channels, where this distinctive morphology forms simply by virtue of the inertial characteristics of the water moving in a sinuous or meandering channel; and “forced” pool-riffle channels, where the presence of pools is closely tied to obstructions such as large woody debris.

We endorse Karr’s (1998) postulate that the ultimate goal of most stream evaluation and subsequent rehabilitation is improved biological health. Physical conditions are but a subset of what determines biological health, and so measuring only physical parameters cannot provide an accurate characterization of biological conditions. In consort with careful biological monitoring, however, these measurements can efficiently provide both evaluation of overall stream “health” and guidance on the most likely causative factors in urban and urbanizing systems.

CHANNEL FEATURES AND MONITORING PARAMETERS

1. Channel Geometry

Channel geometry describes the physical structure of a stream channel. Several different elements are included here, and a variety of parameters are currently used to measure this channel feature (Table I).

Table I. Parameters used to assess channel geometry. (L = not useful for the identified management question at the specified level of effort; M = moderately useful; H = very useful). The management applications ("Trends," "Current Health," and "Ranking") correspond to the three questions posed earlier:

- ❖ What are the trends in stream condition?
- ❖ What is the current stream health?
- ❖ How should planned stream restoration or rehabilitation efforts be ranked?

Parameter	**Method of Measurement**	**Level of Effort**	**Trends**	**Current Health**	**Ranking**
Wetted Width	Measured at specified distances	**1**	**L**	**L**	**L**
Cross sections	Monumented survey of cross-channel profile	**2**	**H**	**L**	**L**
Gradient	Various methods using different instruments for different degrees of precision	**2 or 3**	**L**	**H**	**H**
Bankfull Width and Depth	Determined using visual observations and/or channel profiles; taken at specified distances	**3**	**M**	**M**	**H**
"Flood-prone width" or valley confinement	Determined using visual observations or defined as the flow width at a specified multiple (usually 2x) of the bankfull depth	**3**	**L**	**L**	**H**

The most useful measure of channel geometry is bankfull channel dimension, such as given by cross-section measurements, and in particular the bankfull width. There are several reasons for this:

- Bankfull width and depth measurements can be measured quickly and require limited equipment. These measures are the primary variables for relating channel size to watershed parameters such as area, flood frequency, or level of development. However, experience is necessary to identify bankfull height consistently because a variety of indicators are needed to identify it reliably (Williams, 1978), and some uncertainty in reported bankfull channel dimensions is almost inescapable (Johnson and Heil, 1996).
- Documented channel changes are can be very useful in trend analysis. For example, cross section data can be used to identify changes in channel geomorphology over time (Leopold, 1973; Booth, 1997; Booth and Henshaw, in press) with almost no risk of subjective mis-

interpretation. Bankfull channel dimensions can be measured more rapidly than full cross sections, but documenting change in bankfull channel dimensions requires a greater magnitude of channel change than for cross sections.

- With an adequate regional compilation of channel dimensions, these measurements can show the relative deviation of channel geometry from anticipated undisturbed conditions (Dunne and Leopold, 1978; Booth and Jackson, 1997). They can therefore help evaluate current conditions and prioritize streams for rehabilitation.
- Several other measures of channel geometry, particularly gradient and valley confinement, do not discriminate “good” from “degraded” channels and are unlikely to change significantly over time. They are not useful, therefore, for one-time evaluations or for trend analyses, but they provide necessary information for the design of rehabilitation projects. As such they are relevant to one of our three management questions, even though they may not be part of the “monitoring” effort itself.

By comparison, some other common measurements are not as effective in characterizing the physical dimensions of the channel. For example, measurements of the wetted width vary with rising and falling stage, and this parameter may change by a factor of two or more in the course of a single day. Thus although useful for certain fisheries applications, it is not reliable for trend analysis and does not provide information needed to prioritize restoration projects.

2. Stream Corridor Vegetation

Stream corridor vegetation describes the amount of area above and adjacent to the stream (the riparian corridor) occupied by vegetation (Table II).

Table II. Parameters used to assess stream corridor vegetation.

Parameter	**Method of Measurement**	**Level of Effort**	**Trends**	**Current Health**	**Ranking**
Canopy	Numerical rankings (*e.g.* “low,” “medium,” and “high”); observer judgment	**1**	**L**	**M**	**H**
Shade percentage	Gridded mirror (densiometer) used to measure percent shade	**2**	**H**	**H**	**H**
Ground Cover	Three verbal rankings of "low", "medium" or "high"; observer judgment	**2**	**L**	**L**	**L**
Shrub Layer	Three verbal rankings of "low", "medium" or "high"; observer judgment	**2**	**L**	**M**	**L**

Numerous studies have demonstrated a close correlation between intact riparian corridor and good instream conditions (*e.g.*, Steedman, 1988; May, 1996; Horner and others, 1997) in both agricultural and urbanizing environments, and so this feature has particularly high utility. Shade percentage and canopy measurements collected using a spherical densiometer have greater precision and replicability than unaided visual estimates because they provide a calibrated means of measuring vegetation within the stream corridor. For this reason, use of this instrument is standard in forest practices (Lemmon, 1957). Characterization of riparian vegetation using this parameter can be readily used to accurately describe both current conditions and long-term trends within the stream corridor. However, use of a densiometer does require some training and may be unnecessarily time consuming for some applications (such as those where the majority of riparian shade has already been removed through management activities).

Canopy estimates made using several percentage classes (*e.g.*, 0-25%, 25-50%, etc.) are adequate for many applications. These measurements can be performed readily in the field with fair replicability and limited training. However, unaided estimates of percent canopy are prone to some observer error and are less precise than measurements made with a densiometer, and so they will not be nearly as sensitive to changes over time.

3. Channel Erosion and Bank Stability

Channel erosion and bank stability describe the health of the stream bank by characterizing the amount of bank erosion present and the relative stability of the bank. Measuring bank erosion, particularly in urban areas, is a critical parameter for assessing channel health and for guiding rehabilitation, because it is one of the few ways available to recognize the hydrologic disturbance that typically accompanies urban development (Hollis, 1975; Booth, 1991) (Table III).

Table III. Parameters used to assess bank erosion and bank stability.

Parameter	Method of Measurement	Level of Effort	Trends	Current Health	Ranking
Bank Erosion	Photographic record of the erosion and estimated location on map	**1**	**M**	**M**	**H**
	Presence/absence by map location or by reach; observer judgement	**1**	**L**	**M**	**M**
	Verbal rankings for magnitude of bank erosion, located by reach	**2**	**M**	**H**	**H**
	Distance from beginning of habitat unit to location of erosion; left/right of channel. Letter codes for type of slope failure, determined from comparison with pictures and written descriptions; judgement of observer.	**3**	**M**	**H**	**H**
Bank Hardening	Description or photographic record; location by reach or plotted on map	**2**	**M**	**M**	**M**

We recommend using methods of verbal ranking, with or without a photographic record, as this information requires minimal effort, generally describes current conditions, is useful for some level of trend analysis, and can locate areas for habitat restoration. Established channel-assessment methods typically divide the observed range of bank (in)stability into several distinct categories of descriptive conditions, which appears to be a useful and replicable degree of detail. Henshaw (1999) has developed a descriptive characterization based in part on Galli (1996a, b) with particularly good applicability and tested replicability (Table IV).

Table IV. Streambank stability classification criteria (from Henshaw, 1999).

Class	Description
4	STABLE • perennial vegetation to waterline • no raw or undercut banks (some erosion on outside of meander bends OK) • no recently exposed roots • no recent tree falls
3	SLIGHTLY UNSTABLE • perennial vegetation to waterline in most places • some scalloping of banks • minor erosion and/or bank undercutting • recently exposed tree roots rare but present
2	MODERATELY UNSTABLE • perennial vegetation to waterline sparse (mainly scoured or stripped by lateral erosion) • bank held by hard points (trees, boulders) and eroded back elsewhere • extensive erosion and bank undercutting • recently exposed tree roots and fine root hairs common
1	COMPLETELY UNSTABLE • no perennial vegetation at waterline • banks held only by hard points • severe erosion of both banks • recently exposed tree roots common • tree falls and/or severely undercut trees common

In contrast, more laborious measurements of bank erosion are rarely of much use. For example, identifying the length and location of an erosional zone and plotting it on a map can increase the precision of the original measurements but requires substantially more training and more field time. The utility of such measurements is uncertain—unless the purpose is to identify specific sites for bank repair, such data are commonly used simply to indicate those reaches, in aggregate, that display a relatively high degree of erosion. If the specific sites themselves will never be resurveyed, the detailed description of their location or character will not be used for either current assessment or subsequent remediation.

4. Large Woody Debris

Large woody debris (LWD) is used as a general indicator of watershed condition in forested (and once-forested) watersheds. Low levels of LWD can result in a reduced number of pools, pool quality, gravel and organic debris levels, and habitat complexity (Bisson et al. 1987; Grette 1985; Harris 1987; Bilby and Bisson 1992). Good correlation has been demonstrated between the degree of watershed urbanization and the number of instream LWD pieces in urbanizing Pacific Northwest channels (May, 1996; Horner and others, 1997; Booth and others, 1997). Parameters used by local agencies to measure woody debris include the length and diameter of the LWD, length and diameter of small woody debris (SWD), location and stability of logs, percentage of wood covering and creating pools, rootwad diameter, and dimensions of LWD jams (Table V).

Table V. Parameters used to assess large woody debris (LWD).

Parameter	Method of Measurement	Level of Effort	Trends	Current Health	Ranking
Large Woody Debris (LWD)	Tally per length of stream reach	**1**	**H**	**H**	**H**
	Four numerical zones used to identify the location within the stream channel	**2**	**H**	**H**	**H**
	Distance from the beginning of the stream habitat unit to the location of the LWD	**3**	**M**	**L**	**M**
	Four numerical zones used to identify the stability of the LWD	**3**	**H**	**H**	**H**
	Pool forming	**3**	**M**	**H**	**M**
“Small” Woody Debris (SWD)	Tally per length of stream reach	**2**	**L**	**M**	**L**
LWD jams	Length, width, height, and number of individual wood pieces	**3**	**M**	**M**	**M**

The parameters and methods used to measure LWD generally provide useful information on current conditions, can be used in trend analyses, and are useful in prioritizing restoration projects. Similarly, all require some training to collect accurate field measurements. We recommend that specific minimum diameter and length criteria be used in counting LWD because they appear to improve accuracy and replicability while requiring little additional training. There are no absolute minimum size criteria for LWD, however; agencies contemplating cooperative data collection need to agree to a common standard. A minimum diameter of 25 cm (10 in) is a common criterion in the published literature. For example, Bilby and Ward (1989) do not report any stable LWD less than this size; Montgomery and others (1995), citing Swanson and others (1976), use this as their minimum diameter for LWD; and Oregon Department of Forestry (1995) do not allow logs of lesser diameter for their rehabilitation projects.

The minimum *length* of LWD, however, has less agreement. Bilby (1984) suggests that any piece shorter than 5 m may be unstable; Bilby and Ward (1989) counted none shorter than 4.5 m in their study; Montgomery and others (1995) counted any piece longer than 1 m; Oregon Department of Forestry (1995) requires a length double to that of the bankfull width. A minimum length of 3 m (10 ft), in combination with the minimum diameter criterion of 25 cm (10 in), is a defensible, appropriate, and easily remembered standard to use where none other has been agreed upon. However, restoration projects must consider stream size in determining the specific length and diameter of replacement LWD, and a monitoring program focusing on large rivers might elect to use different minimum size criteria than suggested here.

The remaining parameters sometimes used by agencies include length and diameter of "small" woody debris, location and stability of logs, percentage of wood covering and creating pools, rootwad diameter, and dimensions of LWD jams. Measuring these parameters may be useful for specific fish-habitat assessments, but in general they are too detailed and require more training than is necessary to assess LWD in urbanizing watersheds.

5. Channel-Bed Sediment

Although **channel-bed sediment** is critical to the physical and biological functioning of stream channels, most of the commonly measured parameters are not suitable for use in the type of monitoring program we are considering. In part, this is due to the difficulty in generating certain types of reliable, replicable data for this channel feature, and because there are few reliable correlations between channel-bed sediment and overall stream condition (Table VI).

Table VI. Parameters used to assess channel-bed sediment.

Parameter	Method of Measurement	Level of Effort	Trends	Current Health	Ranking
Substrate Composition	Point and count method	**2**	**M**	**M**	**L**
	Six letter ranking codes for substrate size, based on single-particle estimation of diameter at ten equally-spaced points across the channel	**2**	**L**	**L**	**L**
Embedded-ness	Numerical ranking from 1 to 5; visual estimation of percent sediment and cover of gravel, boulders, rubble	**3**	**M**	**M**	**M**
	Measure % fines in gravel	**3**	**M**	**M**	**M**
Type of substrate (average over bed area)	Type of substrate (sand, silt, clay) based on visual estimation of particle size	**2**	**L**	**L**	**L**

The most common parameter (point counts of the substrate), is useful only if measurements are made in equivalent locations along a stream and between streams. Specifically, measurements should be made on upstream sides of point bars at low flow or in uniform channel-spanning riffles where no point bars are present (Reid and Dunne, 1996; Kondolf, 1997). Measuring this parameter therefore requires modest training. More importantly, *interpreting* the resulting data generally requires experience in sediment analysis that is beyond the scope of this evaluation. Variability in the channel gradient, source area, season of measurement, and history of recent high flows all can affect the measured values of this parameter without any corresponding influence from watershed disturbance. Suggestively, however, a study where channel conditions and sampling locations were reasonably consistent across a number of Puget Lowland streams showed a good correlation between substrate size and high-quality biological conditions (May 1996).

Embeddedness can also be a useful monitoring parameter, because it can be measured with moderate precision and clearly affects certain elements of channel health, particularly the viability of benthic animals and incubating fish eggs. However, it does not provide an unambiguous characterization, because different streams can have very different sediment characteristics as a consequence of different gradients and source areas. Thus a snapshot characterization of embeddedness might show if a channel had a suitable substrate for biota but would *not* necessarily demonstrate that the cause of poor conditions was from human disturbance. MacDonald and others (1991, p. 124) note that "Embeddedness has shown promise, but the immediate need for a monitoring technique has resulted in widespread use and adaptation before cobble embeddedness could be adequately field-tested and validated." Change in this parameter over time may guide protection or rehabilitation strategies, although Burns and Reis (1989) judged that five consecutive years of embeddedness data were necessary to evaluate trends in a mining district in Idaho. Galli (1996a,b) groups embeddedness fractions (% fines on the bed surface) into four categories (0-25%, 25-50%, etc.), but does not report the sensitivity of these groupings to changes in the channel or the watershed. Observations suggest that channels can fully span the range from 0 to 100 percent embeddedness and that the differences are well correlated both with human disturbance of the watershed and with biological utilization of the stream channel (May, 1996; Wydzga, 1997). However, we have no data on the rate at which such changes can occur and thus no basis to judge the predictive value of this parameter.

Other sediment parameters yield data with limited application in assessing urbanizing watersheds for a variety of reasons:

- Sediment sizes vary markedly between different morphologic units (e.g. between pools and riffles).   Characterization of the substrate without reference to the morphology of the channel will not provide replicable or comparable data, and so it will not be useable for establishing conditions or trends. If such data are needed, the point-counting method of Wolman (1954) is well established and is relatively quick and easy. Kondolf (1997) emphasizes that the various alternative methods of sampling, such as single-grain measurements or “zig-zag” sampling across and down a reach of channel (Bevenger and King, 1995) yield non-reproducible results with little or no predictive value.
- Use of visual substrate classifications is an unnecessary loss of accuracy (Chapman and McLeod, 1987; MacDonald and others, 1991).   For surface-sediment sampling, the pebble-count method of Wolman (1954) has good statistical replicability for only a modest expenditure of additional time.
- More detailed characterization of "substrate" requires not only the measurement of the surface sediment but also, for gravel-bedded channels, that of the sediment below the upper layer of (usually coarser) gravel. Such subsurface measurements are even more time-consuming, although with care they are useful in characterizing habitat suitability given the overall size distribution of the gravel and the percentage of void-filling fine sediment. However, the techniques available to make such measurements (Platts and others, 1983; Church and others, 1987) are beyond the scope of this evaluation.

6.   Instream Physical Habitat—Pools, Riffles, and Other Habitat Units

Characterizing **instream physical habitat** has a long history in undisturbed forested watersheds. This approach is intuitively well founded—if one of our primary interests is the ability of the channel to support aquatic organisms, what better way to assess that “ability” than to measure the features of the channel directly associated with biological use?

Two factors limit the utility of direct measures of channel habitat features. Although, researchers and field personnel have articulated these limitations for over a decade, the consequences of those limitations have not been consistently reflected in many monitoring programs:

1. The measurement or characterization of such features is imprecise and subject to substantial observer error. This is true of nearly all monitoring parameters, however, the magnitude of typical errors associated with habitat-unit inventories renders data inappropriate for between-stream or time-trend comparisons.
2. In-channel physical habitat features do not necessarily respond rapidly to human disturbance, and so even if a measurable change in such a monitoring parameter can be documented it may come far too late, if at all, to trigger an effective management response.

Both of these limitations are the subject of an extensive, recent literature review and analysis (Poole and others, 1997). Their conclusion is particularly germane to our current evaluation:

> "Habitat-unit classification was not designed to quantify or monitor aquatic habitat. At the level necessary for use as a stream habitat monitoring tool, the method is not precise, suffers from poor repeatability, cannot be precisely described or accurately transferred among investigators, can be insensitive to important human land-use activities, is affected by stream characteristics that vary naturally and frequently, and is not based on direct, quantitative measurements of the physical characteristics of interest. Relying on habitat-unit classification as a basis for time-trend monitoring is time-consuming, expensive, and ill-advised." (Poole and others, 1997, p. 894)

They base their conclusions in part on the work of four studies that specifically investigated observer bias (Platts and others, 1983; Hankin and Reeves, 1988; Ralph and others, 1991; Roper and Scarnecchia, 1995). For example, Roper and Scarnecchia (1995) found that five days of standardized training were ***in***sufficient to produce consistent results among different observers when a full range of habitat units (nine, in their study) was used. Even if high precision could be achieved, a variety of researchers have noted the relative insensitivity of habitat units to land-use changes or other human impacts (Warren and others, 1987; MacDonald and others, 1991; Ralph and others, 1994). We therefore anticipate that most such efforts will combine the unfortunate attributes of large time commitments, non-repeatable results, and limited predictive or management utility.

Despite the generally poor record for habitat assessment in monitoring programs, we recognize the underlying conceptual basis for including some aspect of these channel features among the list of monitoring parameters. Useful results are most likely where the number of habitat categories is small. Roper and Scarnecchia (1995) reported complete agreement among their multiple observers for only 25 percent of the classified units, using their full set of nine categories. In contrast, their observers achieved a more useful 75-percent agreement when only three units were being discriminated (pools, riffles, and glides). We recommend focusing on <u>pools</u>, because they show a crude but consistently inverse correlation with human watershed disturbance across a wide range of landscape types (*e.g.*, Booth, 1990; Peterson and others, 1992; Galli, 1996a; May, 1996) (Table VII).

Table VII. Evaluation of parameters used to assess pools.

Parameter	Method of Measurement	Level of Effort	Trends	Current Health	Ranking
Tally of "large" pools in reach	Identified using size criteria for residual depth and wetted channel width	**2**	**L**	**H**	**M**
Maximum depth	Deepest point in the pool	**2**	**L**	**M**	**L**
Principal cause of pool formation	Numerical ranking from 1 to 11, based on what is blocking the stream flow	**3**	**L**	**L**	**L**
Pool type	Pool types identified by comparison with written description; observer judgement.	**3**	**L**	**L**	**L**

We recommend measuring pool width and depth over any alternative parameters because they provide adequate assessment of current conditions and require only moderate training. In addition, these measurements can be quickly collected and they require little field equipment (see also Robison and Kaufman, 1994).

However, substantial observer variability, seasonal variability in flow, and variability caused by instream objects such as boulders or LWD (MacDonald and others, 1991; Myers and Swanson, 1997; Poole and others, 1997) make measuring and interpreting pool habitat problematic. Accordingly, monitoring pools is often not terribly useful for the specific tasks being evaluated in this report and so their overall value is modest at best. If the intent of the monitoring is to render a one-time evaluation of stream health, close attention to channel classification is also necessary, because the criteria for a "good" number and dimension of pools changes dramatically among the different channel types.

Habitat types other than pools do *not* appear to be suitable for use in the type of monitoring program we are considering. This is primarily because of the difficulty and expense in generating reliable, replicable data for these other habitat parameters, as much or more so than with pools. Information gathered during assessment of other channel features (e.g., channel geometry) can probably generate equivalent information with much greater reliability and greater insight into the *cause* of physical-habitat change (MacDonald and others, 1991; Poole and others, 1997).

RECOMMENDED MONITORING FOR URBAN STREAM SYSTEMS

Although there is general agreement that the physical conditions of streams are important determinants of aquatic habitat quality, there is little agreement on the best way to measure or to characterize those physical conditions. Even though many agencies and volunteer groups may be collecting voluminous amounts of stream-condition data, no region can comprehensively assess the status of its entire aquatic systems. This problem is compounded in urban and urbanizing areas, because most of the monitoring protocols currently in use have been developed for other purposes or in other settings, notably the forested slopes of the adjacent mountains.

Based on this evaluation, we see a limited set of monitoring tasks appropriate to a rapid, low-cost effort ("Level 1" in the tables below), although the benefits of enhanced stewardship by involving volunteer monitoring far exceed any concerns about data imprecision at this level of effort. The measurements that are suggested by our analysis are given in Table VIII.

Table VIII. Summary of Recommended "Level 1" Measurements.

PARAMETER	**METHOD OF MEASUREMENT**
Canopy	Visual estimate of canopy cover, expressed as a percentage range (*e.g.*, 0-25%, 25-50%, 50-75%, 75-100%)
Bank erosion and bank hardening	Verbal rankings for magnitude of bank erosion, located by reach (and representative photographs if desired)
Large Woody Debris; minimum length > 3 m (10') and minimum diameter > 25 cm (10")	Tally of the number of pieces in the channel in a specified length or reach of stream.

This is a much shorter list than even the most low-effort monitoring plan typically includes, and we emphasize that there may be a number of reasons why an expanded list might be appropriate. If, however, the intended purpose is simply to provide useful information for guiding management decisions, we see little evidence that additional tasks executed at the lowest level of effort will produce any useable results. With these measurements, a coarse discrimination of stream quality is possible, and the worst channels—barren, raw channels with neither cover nor diversity—will be apparent. Detecting change over time, however, will be highly ***in***sensitive; damage will occur long before these methods can unequivocally identify it.

At a greater level of effort ("Level 2," requiring trained volunteers or professionals but minimal equipment and modest field time) the range of recommended tasks is greater and includes several of the activities that normally constitute many agencies' "stream monitoring program" (Table IX). However, some commonly executed tasks are absent from this recommendation. Those omitted tasks either require an even greater level of effort in order to produce reliable results, or there is no evidence that *any* level of effort applied to them can achieve practical guidance for our three management questions in the urban environment.

Level 2 measurements are useful because 1) they provide a more detailed and precise evaluation of stream quality than Level 1 measurements, 2) they offer the chance to detect modest changes in channel conditions over time, 3) they identify credible reference conditions, and 4) they generate some of the information needed to design a rehabilitation project. Further enhancement of monitoring is also possible ("Level 3"), requiring more time and effort but yielding more precise and (presumably, but not always) more useful results.

Table IX. Summary of Recommended "Levels 1 and 2" Measurements.

PARAMETER	**METHOD OF MEASUREMENT**
Gradient	Several alternative methods are available, with the use of hand-held equipment generally adequate.
Shade/canopy	Gridded mirror (densiometer) used to measure the percent shade, or visual estimate of canopy cover
Bank erosion and bank hardening	Verbal rankings for magnitude of bank erosion, located by reach
Large Woody Debris; minimum length > 3 m (10') and minimum diameter > 25 cm (10")	Tally of the number of pieces in the channel in a specified length or reach of stream; include four numerical zones used to identify the location within the stream channel *or* limit tally to those pieces within bankfull channel
Substrate composition	"Point and count" method with 100 randomly selected grains from upstream side of point bar or channel-spanning riffle
Pools (specify minimum depth for inclusion)	Tally and measurement of the number of pools in a specified length or reach of stream, using residual depth and wetted channel width to define minimum size

SUMMARY

We have evaluated the commonly used monitoring approaches and protocols for evaluating the physical condition of urban streams. Through this effort, we have found that the list of useful and feasible measurements is surprisingly short. The recommended parameters characterize, either directly or indirectly, many of the physical changes that befall urban streams. These include disrupted hydrology (measured here through its consequences on scour and bank erosion), loss of riparian corridor (canopy measurements), and the combined influence of high flows and increased upstream scour on in-stream sedimentation and habitat diversity (parameters for measuring sediment, LWD, and pools). Because these changes are interrelated, no simple set of measurements will give unequivocal guidance on the *cause*, and thus the most effective solution, of these problems. However, appropriately selected measurements should help define the kinds of rehabilitation approaches that should address the most seriously degraded elements of the urban stream system. If the institutional reason for the monitoring, and the institutional constraints on its execution, are clearly articulated and acknowledged throughout the process, the monitoring effort should yield genuinely useful data.

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