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Lower Columbia Region Monitoring Implementation Plan

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Cover photo: Clockwise from top left: East Fork Lewis River (photo courtesy of Stephanie Brock, Ecology); agriculture along the Columbia River Gorge (photo courtesy gorgelodging.com); view from Oregon Port of Longview (photo courtesy of Castle Rock Business Park); map of Lower Columbia region (photo courtesy of LCFRB).

ABBREVIATIONS AND ACRONYMS

This list contains abbreviations and acronyms used frequently in this document. Other abbreviations and acronyms are used infrequently and defined only in the text.

Term	Definition
AREMP	Aquatic and Riparian Effectiveness Monitoring Plan
BFW	Bankfull Width
B-IBI	Benthic Index of Biotic Integrity
CHaMP	Columbia Habitat Monitoring Program
COC	Chain of Custody
CPR	Cardiopulmonary Resuscitation
DEM	Digital Elevation Model
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency
EPT	The EPT Index is named for three orders of aquatic insects that are common in the benthic macroinvertebrate community: Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies).
ESA	Endangered Species Act
ESU	Evolutionarily Significant Units
FPW	Floodprone Width
GC-MS	Gas Chromatography-Mass Spectrometry
GIS	Geographic Information System
GPS	Global Positioning System
HDPE	High Density Polyethylene
HSTM	Habitat and Water Quality Status and Trends Monitoring
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
ISTM	Integrated Status and Trends Monitoring
LCFRB	Lower Columbia Fish Recovery Board
LCMS	Lower Columbia Master Sample
LTER	Long-Tem Ecological Research
LWD	Large Woody Debris
MQO	Measurement Quality Objectives
NAWQA	National Water-Quality Assessment Program
NLCD	National Land Cover Database
NO_3	Nitrate
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
ODFW	Oregon Department of Fish and Wildlife
O/E	Observed-to-Expected
OHW	Ordinary High Water
OSWER	Office of Solid Waste and Emergency Response
PAH	Polycyclic Aromatic Hydrocarbons
PFC	Properly Functioning Conditions
PFD	Personal Flotation Device
PNAMP	Pacific Northwest and Aquatic Monitoring Partnership
PPE	Personal Protective Equipment
QA	Quality Assurance

Term	Definition
Qa/QC	Quality Assurance/Quality Control
Qa/Qx	Water Quality and Water Flow (Quantity)
QAMP	Quality Assurance Monitoring Plan
QAPP	Quality Assurance Project Plan
QC	Quality Check
RPD	Relevant Percent Difference
RSD	Relative Standard Deviation
RSMP	Regional Stormwater Monitoring Program (Puget Sound Region)
SOP	Standard Operating Protocol
SRFB	Salmon Recovery Funding Board
SRM	Standard Reference Material
SRMD	Standard Reference Material and Data
TN	Total Nitrogen
TOC	Total Organic Carbon
UGA	Urban Growth Area
USEPA	United States Environmental Protection Agency
USDA Forest Service	United States Department of Agriculture Forest Service
USGS	United States Geological Survey
VWI	Valley Width Index
WA	Washington
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation

Table of Contents

Tables

Figures

Appendices

EXECUTIVE SUMMARY

In 2012, the Lower Columbia Fish Recovery Board (LCFRB) and the City of Longview initiated a collaborative project to design and implement an integrated Habitat and Water Quality Status and Trends Monitoring project (HSTM) in the Lower Columbia Region. Pursuit of such integration is motivated by two monitoring needs that face the region: supporting the recovery of watershed health and salmonid species listed as threatened or endangered under the Endangered Species Act (Chinook, coho, chum, and steelhead), and addressing anticipated future monitoring requirements under municipal stormwater National Pollutant Discharge Elimination System (NPDES) permits for eight jurisdictions in southwest Washington. By developing a coordinated strategy across these two monitoring programs, fiscal efficiencies and more robust and meaningful regional assessments should be achieved.

The primary goal of the HSTM project is to complete a monitoring design to meet the status and trends monitoring needs of the Washington State Department of Ecology (Ecology), southwest Washington municipal stormwater permittees, LCFRB, and other partners of the Pacific Northwest Aquatic Monitoring Partnership's program for Integrated Status and Trends Monitoring. This Implementation Report represents the culmination of past and present efforts conducted over the past year, representing "Phase 3" of this three-phase effort. Phase 1, completed in June 2013, developed the overarching framework for the coordinated strategy. Subsequently, Phase 2 produced the Monitoring Design Report (February 2015) that articulated the goals and objectives for the integrated monitoring project, and it specified the target populations, sampling stratification, and indicators to be used. This Implementation Report, the product of Phase 3, has refined the pragmatic details necessary for the actual initiation of monitoring—site selection, measurement protocols, data analyses, data management, and reporting—all of which are essential for successful on-the-ground execution.

The project study area includes all of the Lower Columbia Region Recovery domain, also referenced as the Lower Columbia Evolutionarily Significant Unit (ESU), which comprises the Columbia River mainstem from its mouth up to Bonneville Dam, and all Columbia River tributary subbasins from the mouth of the Columbia River up to and including the White Salmon River in Washington and the Hood River in Oregon, and the Willamette River up to Willamette Falls. The project currently addresses only the monitoring design for tributaries in the Washington portion of the ESU. Future phases hope to include the Oregon portion of the Region upon participation and funding by Oregon agencies, and to incorporate monitoring of the Columbia River mainstem and tidally influenced habitats, in order to generate a more complete picture of the landscape and its habitats. At present, the project also addresses the need for status and trends monitoring by the one Phase I and seven Phase II NPDES permittees in western Washington under anticipated requirement of their 2018 municipal stormwater permits.

Project Planning and Management

Project planning was largely accomplished through Phases 1 and 2 of the HSTM program; the focus of the Implementation Plan is on the refinement of prior guidance to ensure a robust, implementable program. The guiding questions and objectives developed during Phase 2 have been affirmed, although number of the objectives are unlikely to be fully satisfied within the first several years of implementation given the inherent variability of the parameters being measured and the complexity of addressing all of the objectives.

At the regional scale, the key monitoring questions are:

Question 1: What are the status and trends of water quality and stream flow in surface waters?

Question 2: What are the status and trends of water quality in surface waters draining watersheds with a substantial fraction of land that has been cleared for agriculture or recent (<20 years) forest harvests?

Question 3: What are the status and trends of instream biological health and instream/riparian habitat conditions (in terms of both quality and quantity)?

Question 4: Do instream biological health and instream/riparian habitat conditions correlate to changes in abundance, productivity, spatial structure, and diversity of the natural-origin fish in this population at the reach/subwatershed scale?

Question 5: Where on the landscape are key potential land-use activities occurring, and in what watersheds are one or another of these activities dominant?

Question 6: Are land-cover changes occurring at detectable rates across the Lower Columbia Region, and if so where are they occurring?

The monitoring recommended to characterize regional-scale water quality conditions (termed "Qa/Qx monitoring" in the reports and covered by Questions 1 and 2) has been significantly reduced from that originally envisioned, in light of cost and feasibility concerns. Stream temperature and benthic macroinvertebrates will be the only non-habitat indicators collected at these regional sites, but they should nonetheless provide useful characterization of these conditions and any significant trends over one or more ten-year periods of annual monitoring. The physical habitat indicators also to be collected at these sites, in total, are sufficiently comprehensive to address Question 3 over a similar period. They will also provide a basis to address Question 4 if fish population data are also available. Questions relating to landscape-level changes (Questions 5 and 6) have been answered to the extent that their characterization was needed to implement other elements of the program; documentation of other current conditions and determination of future change has been deferred for future reporting and implementation.

At the scale of urban areas, particularly those subject to stormwater NPDES permiting:

Question 7: What are the status and trends of water quality and stream flow in surface waters draining subwatersheds that are primarily within the jurisdiction of municipal stormwater NPDES permittees?

Question 8: What is the status and trends of water quality and stream flow in surface waters that are being affected by stormwater discharges from urban areas first developed under requirements of the 2013 Phase I and Phase II Western Washington Municipal Stormwater Permits?

Question 9: What are the status and trends of instream biological health and instream/riparian habitat conditions that are primarily within the jurisdiction of municipal stormwater permittees (in terms of both quality and quantity)?

Question 10: Do instream biological health and habitat conditions correlate to changes in observed abundance, productivity, spatial structure, and diversity of the natural-origin fish in this population (reach/subwatershed scale)?

The flow and water quality indicators recommended in Phase 2 have been affirmed as adequately balancing the need to assess the status and trends of these conditions (Question 7) with the cost of implementing a systematic, statistically rigorous sampling program. In addition to this "base program," the caucus of stakeholders comprising the stormwater permittees of the Lower Columbia Region have also advanced an "enhanced monitoring program" that can provide them with additional information (by collecting additional indicators, at additional cost) judged important for the management of their respective programs. Although not a part of the Phase 2 design, the details of this augmented water quality monitoring are included as an appendix to the Quality Assurance Program Plan for the HSTM program. Habitat monitoring within the urban areas of the Region (Questions 9 and 10) is included as a stratum within the regional-scale monitoring (see above), and as such it provide answers of equivalent resolution and timeliness as for Questions 3 and 4.

The HSTM project, once initiated, is expected to be implemented through one or two caucuses (currently meeting as the "Habitat Caucus" and the "Stormwater Caucus"). Their roles and responsibilities are outlined in appendices to this Implementation Plan, which span activities that include overall program management, fund acquisition and management, collection and analysis of data (either directly or via contractors), reporting, and maintaining stakeholder engagement and communication. Preliminary budgets for both Qa/Qx and habitat monitoring have been developed and total approximately $68,000 per year for base Qa/Qx monitoring at the urban sites addressing NPDES permit requirements and potentially about ten times that amount for habitat monitoring, region-wide.

Sample Site Selection

A preliminary set of sample sites for both the urban areas (termed "urban+NPDES sites") and the Region as a whole (termed "regional sites") have been selected via a two-step process. The first step involved the stratification of the target population of previously identified points along stream channels in the Lower Columbia Region (known as the "Master Sample") into physically meaningful strata, appropriate to the monitoring activities and intended uses of the data, by use of GIS characterization of the stream and watershed characteristics associated with each point in the Master Sample. These strata were defined in the Phase 2 Design Report and refined as part of this Implementation Plan:

For urban+NPDES sites: one stratum combination, consisting of stream segments with watersheds draining 2.5-50 km^2 draining watersheds with predominately urban land cover, as determined from the 2011 National Land Cover Database. There are about 25 such stream segments that meet these criteria.

For regional sites: 270 potential unique strata combinations, based on watershed area (5 categories), stream gradient (3 categories), number of primary salmonid populations in the subwatershed (3 categories, to ensure that the most biologically diverse streams are well-represented in the final random site selection), jurisdictional setting (inside or outside of urban+ NPDES areas) (2 categories), and predominant watershed land cover (3 categories). Many of these strata combinations, however, lack a sufficient number of Master Sample points (or, in some instances, *any* such points) to be viable strata combinations; indeed, only 45 strata combination have a sufficient number of points (minimum of 15), on the basis of statistical considerations, to be further considered for this sampling effort. This results in the potential for 675 (i.e., 45 × 15) regional monitoring sites.

Given the great disparity in the number of candidate sites for the two monitoring elements, the approach to the sampling design differs between the urban+NPDES sites and the regional sites. For the former, five or six sites (nearly all of which having preexisting data collection) will be monitored continuously and visited annually throughout the duration of the program. The remaining sites will be visiting under a 5-year rotating panel design, where 20% of the remaining sites will be monitoring for a single year and then left while the next panel is sampled. This is a true census design, insofar as every stream meeting the stratification criteria will be sampled. In contrast, there are far too many habitat sites to do more than take a random and presumably representative subsample of the entire population. These habitat sites so selected will be monitored on a strict 5-year rotating panel design in which 20% of the selected sites will be visited in any given year with repeat visits starting in year 6 and beyond. No habitat sites will be visited every year.

Indicators

The indicators recommended for this HSTM program have been identified on the basis of historic utilization and regional experience, prior recommendations from Phase 1 of this project, known issues with data quality and variability, cost of implementation, and direct relevance to the monitoring questions that are guiding this program. Because the habitat and water quality status and trend monitoring (HSTM) focus is to characterize the physical and water-quality status and trends of the streams and rivers of the Lower Columbia Region, the parameters of concern could be any and all that might contribute to that characterization. However, limitations on the technical feasibility of collecting certain parameters and on the overall scope of an affordable monitoring program have required great selectivity in the choice of monitoring parameters to actually measure.

The final suite of recommended parameters listed below comprises a range of water-quality, physical-habitat, and biological conditions that are closely linked to a variety of known or potential threats to aquatic resources: limiting habitat conditions for the Region's ESA-listed salmonid species and other biota, and impairment of watershed-specific beneficial uses.

Physical Habitat

Sample reach length
Channel type
Reach slope
Sinuosity
Bank modification
Density of habitat types
Bankfull width/depth
Pools per unit length
Floodplain width
Side channel habitat
Flow category
Residual Pool depth
Bank stability
Relative bed stability
Density/distribution instream wood
Substrate particle size
Shade
Riparian canopy
Riparian understory

Water Quality and Flow (Qa/Qx)

Water temperature[1]
Conductivity
Stage
Sediment metals
Sediment polycyclic aromatic hydrocarbons

Biological

Benthic macroinvertebrates[2]

The parameters were selected based on (1) the specific monitoring needs for addressing the program-specific questions and objectives, (2) the relative value of some parameters over others in their ability to detect meaningful changes, (3) the instream changes that land-use change (both

[1]Also collected during habitat monitoring
[2] Collected with both habitat and water quality monitoring

positive and negative) may potentially create, (4) regulatory requirements, and (5) financial constraints.

With respect to the recommended water-quality monitoring elements of this program, its most noteworthy aspects relative to prior efforts are its emphasis on continuously monitored (or otherwise integrative) indicators, and the overall brevity of the indicator list. These outcomes are driven by considerations long-articulated by project partners and stakeholders: statistical and scientific rigor of the chosen indicators, and feasible cost of implementation. It is anticipated that these indicators will meet the requirements of the upcoming 2018 NPDES Municipal Stormwater Permit's Special Condition S8.B, and their implementation will satisfy Ecology's need for a statistically valid stormwater status and trends monitoring program. In this Implementation Report their collection and analysis is referenced as the "base program" for water quality at urban+NPDES sites.

Stakeholders have also expressed the desire to gain further value from the HSTM monitoring program by collecting an expanded list of indicators. They have defined what is herein referenced as an "extended monitoring component" that will be implemented at the same sites, and following the same panel design as for the base indicators, to the extent that sufficient funds are available. Monitoring of these indicators will be conducted under the exclusive guidance of the steering committee that is established to manage the stormwater monitoring program once implemented, and it will be supported on a funding-available basis from the pooled monitoring funds once the costs associated with collection and interpretation of the base indicators have been fully covered:

EXTENDED MONITORING COMPONENT INDICATORS	
Water temperature	X^m
Conductivity	X^m
Dissolved oxygen	X^m
pH	X^m
Turbidity	X^m
Total suspended solids	X^m
Total solids	X^m
Total nitrogen	X^m
Nitrate + nitrite-nitrogen	X^m
Total phosphorus	X^m
Dissolved copper	X^m
Dissolved zinc	X^m
Fecal coliform bacteria	X^m

X^m = monthly sampling

Summary Guidance

It is not possible to fully anticipate the types of analyses that will be most useful for stakeholders in the HSTM program as it develops. Some of its components, particularly the emphasis on relatively low-cost, continuously monitored water quality indicators, are not widely established across the region and so unanticipated findings (or a lack of anticipated findings) are likely to result. Based on analyses of preexisting Qa/Qx data sets, particularly from urban and urbanizing watersheds of the Puget Sound region, it is likely that the sampling and monitoring approach will successfully discriminate overall conditions of water quality across the urban+NPDES sites, but they will require one (or more) decades of data collection to identify statistically significant trends (if any) in these data. The recommended cost-saving measure of collecting stage data as a surrogate for discharge, but not spending the additional field and analytical time to construct and maintain a discharge rating curve, appears to be justified with some caveats to preserve the accuracy and precision of the underlying gage data. A limited suite of hydrologic metrics can discriminate relative levels of urbanization with fairly good reliability; detecting trends, however, will depending on significant changes to watershed hydrology: either very rapid rates of additional urban development or aggressive (and effective) efforts at stormwater management from existing urban areas. Trends in the other continuously monitoring indictors, temperature and conductivity, appear to be relatively subtle and may not yield reliable results for several decades regardless of land-use changes or management activities.

The recommended habitat indicators were selected to be well-suited for comparison to the Properly Functioning Conditions (PFCs) established by NOAA for the freshwater and anadromous fish found in the Lower Columbia Region. The protocols for collecting the data are compatible with these PFCs and should provide a comprehensive, regional perspective on the status of the stream systems throughout the Region. Detecting trends over time will require a long-term commitment to this program, because specific sites will only be revisited on 5-year intervals. Although the randomly selected set of sites should provide a "representative" picture of habitat conditions in every year, the unavoidable variability imposed by a rotating panel design suggests that any Region-wide changes in habitat will likely require one to several decades to detect.

INTRODUCTION

In 2012, the Lower Columbia Fish Recovery Board (LCFRB) initiated a collaborative project to design and implement an integrated Habitat and Water Quality Status and Trends Monitoring project (HSTM) in the Lower Columbia Region. Pursuit of such integration was motivated by two monitoring needs that face the region: supporting the recovery of salmonid species listed as threatened or endangered under the Endangered Species Act (Chinook, coho, chum, and steelhead) and addressing anticipated future monitoring requirements under municipal stormwater National Pollutant Discharge Elimination System (NPDES) permits for eight jurisdictions in southwest Washington. The project has built on the progress of the Pacific Northwest Aquatic Monitoring Partnership's (PNAMP) Integrated Statues and Trends Monitoring (ISTM) Project, which sought ways to design and implement more coordinated, efficient, and effective aquatic ecosystem monitoring than under the independence by which the various monitoring program had historically been conducted. By integrating status and trends monitoring related to municipal stormwater permits with other existing monitoring efforts in the WA Lower Columbia ESU, the intent is to gain fiscal efficiencies and more robust and meaningful regional assessments than could be achieved by either program in isolation.

The primary goal of the HSTM project is to complete a monitoring design to meet the status and trends monitoring needs of Ecology, southwest Washington municipal stormwater permittees, LCFRB, and other partners of the Pacific Northwest Aquatic Monitoring Partnership's program for Integrated Status and Trends Monitoring. It has been executed in three phases, of which the first established the framework of the program (Tetra Tech 2013) and the second refined the monitoring design (Stillwater Sciences 2015a). This Implementation Plan, based on Ecology guidance (Ecology 2006), represents the final step of this HSTM program and contains the pragmatic details necessary for the actual initiation of monitoring—site selection, measurement protocols, data analyses, data management, and reporting—all of which are essential for successful on-the-ground execution. Detailed monitoring plans have been developed in tandem with this report and are documented in the Quality Assurance Project Plan (QAPP) (Stillwater Sciences 2016).

1 PART 1: PROJECT PLANNING AND MANAGEMENT

1.1 Background

1.1.1 Study area and surroundings

The project study area includes the Lower Columbia Region, comprising all Columbia River tributary subbasins from the mouth of the Columbia River up to the White Salmon River in Washington (WRIAs 25, 26, 27, 28 and 29) and the Hood River in Oregon, and the Willamette River up to Willamette Falls (Figure 1). This phase of the project was focused on the Washington portion of the Region with intent to include the Oregon portion of the Region at a later time, subject to participation and funding by Oregon agencies. This project also addresses the anticipated future needs for status and trends monitoring by the southwest Washington municipal stormwater NPDES permittees within the Lower Columbia Region.

The study area has had European settlements for well over a century, first concentrated along the valley of the Columbia River, with first agricultural and then urban development progressively expanding north and south along the Willamette/Puget Lowland trough. Today, major transportation links are primarily north/south through the west-central part of the region, and east/west along the Columbia River. Access is relatively good in the western two-thirds of the Region but almost entirely blocked by the Cascade Range to the east, whose crest forms the eastern edge of the study area.

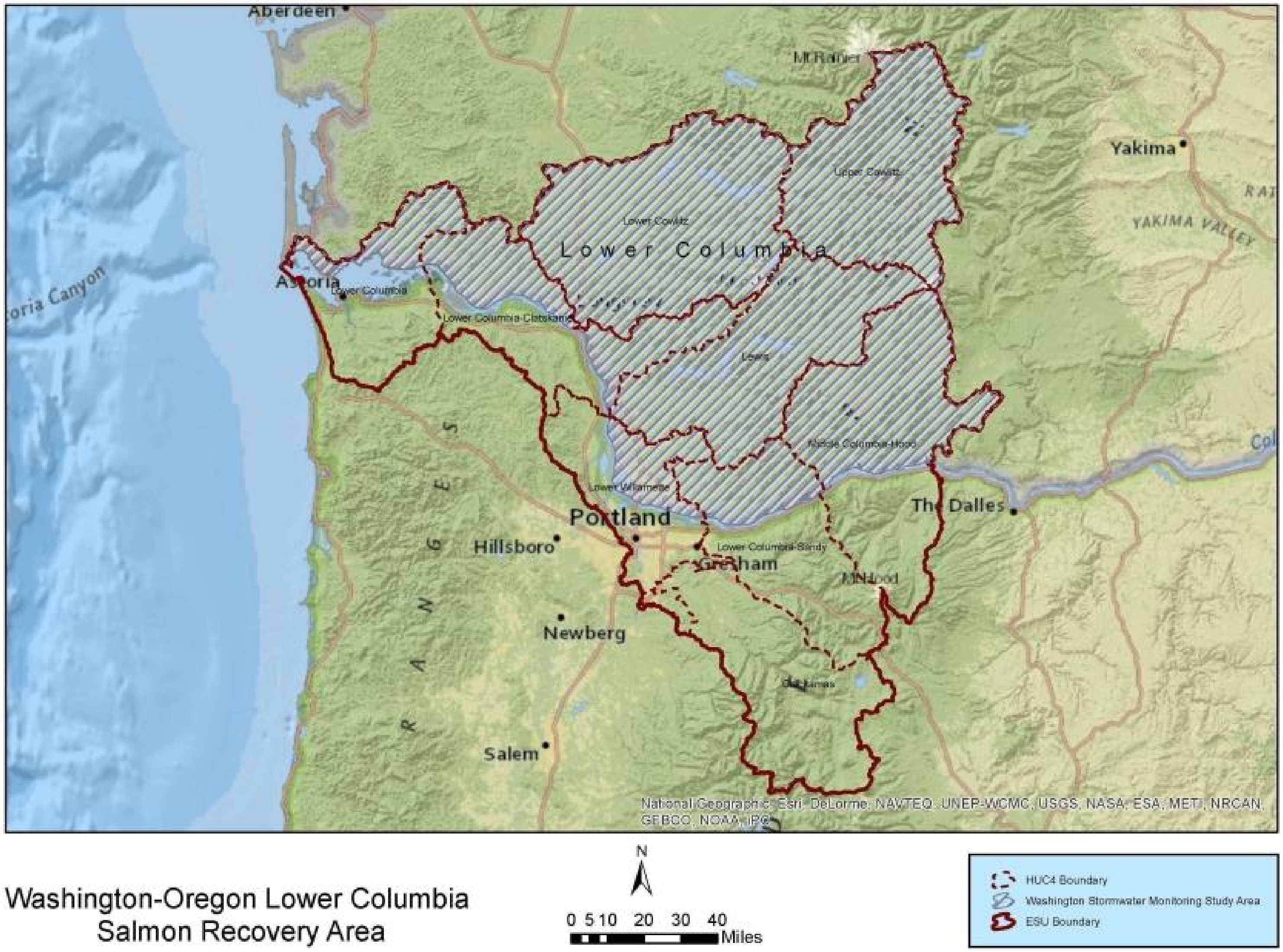


Figure 1. Lower Columbia Region boundary, highlighting the Washington portion of the Region. Source: LCFRB.

1.1.2 Logistical considerations

Conditions across the study area are generally representative of those throughout all of western Washington, presenting typical opportunities and constraints for monitoring coverage and field access. Urban areas are well covered by road networks, permitting ready access to streams and other watercourses but posing some potential limitations as a result of private property restrictions. Farther east, in the Cascade Range foothills and mountains, direct access to potential sites are much more constrained by limited roads and rugged topography, which are likely to impose some restrictions on site access. Elsewhere, agricultural and rural residential land uses are also likely to impose local challenges to access, as a consequence of both limited roads and private property, which are likely to necessitate adjustment to the sampling strategy once implementation actually begins.

1.1.3 Parameters of concern

Because the habitat and water quality status and trend monitoring (HSTM) focus is to characterize the physical and water-quality status and trends of the streams and rivers of the Lower Columbia Region, the parameters of concern could be any and all that might contribute to that characterization. However, limitations on the technical feasibility of collecting certain parameters and on the overall scope of an affordable monitoring program have required great selectivity in the choice of monitoring parameters to actually measure. The final suite of recommended parameters listed below comprises a range of water-quality, physical-habitat, and biological conditions that are closely linked to a variety of known or potential threats to aquatic resources: limiting habitat conditions for the Region's ESA-listed salmonid species and other biota, and impairment of watershed-specific beneficial uses.

Habitat
Sample reach length
Channel type
Reach slope
Sinuosity
Bank modification
Density of habitat types
Bankfull width/depth
Pools per unit length
Floodplain width
Side channel habitat
Flow category
Residual Pool depth
Bank stability
Relative bed stability
Density/distribution instream wood
Substrate particle size
Shade
Riparian canopy
Riparian understory

Water Quality
Water temperature[3]
Conductivity
Stage
Sediment metals
Sediment polycyclic aromatic hydrocarbons

Biological
Benthic macroinvertebrates[4]

[3]Also collected during habitat monitoring
[4] Collected with both habitat and Qa/Qx monitoring

The parameters were selected based on (1) the specific monitoring needs for addressing the program-specific questions and objectives, (2) the relative value of some parameters over others in their ability to detect meaningful changes, (3) the instream changes that land-use change (both positive and negative) may potentially create, (4) regulatory requirements, and (5) financial constraints. There are no known toxic sources or areas of toxic contamination within the Region that are explicitly being targeted by this monitoring program.

Parameters of interest have been referred to as “metrics” throughout the development of this HSTM program. That term warrants clarification as the parameters are not explicitly metrics (i.e., a system or standard of measurement). Furthermore, most monitoring programs commonly collect a broad array of metrics and then subsequently identify the metrics of greatest value for a given set of questions. The resulting subset of metrics are then each termed “indicators.” However, the development of the Lower Columbia HSTM program sought to identify only the most meaningful and feasible parameters to collect from the outset, rather than a broad array of indictors. As such, and for the sake of clarity and consistency, this document will use the term “indicators” from this point forward to reflect the parameters of interest.

1.1.4 Previous studies

This report represents the third phase of an envisioned three-phase project to design and implement a coordinated Habitat Status and Trends Monitoring program for the Lower Columbia Region. Phase 1 of the project, summarized in Tetra Tech (2013), developed preliminary recommendations for the coordinated monitoring strategy that included recommendations regarding the choice of habitat indicators, water quality indicators, and stratification of prospective sampling sites. It also supported completion of the Lower Columbia Master Sample, a GIS-based database of over 100,000 potential sampling points that constitutes the target population for the study as a whole. Phase 2 of the project, the HSTM design, articulated the final goals and objectives for the integrated monitoring project for water quality and habitat, and specified the target populations, sampling stratification, and proposed indicators.

A multitude of other studies that relate to water-quality and fish-habitat monitoring in the Pacific Northwest and beyond have been completed and published, and these were consulted extensively in the course of preparing the reports for both Phase 1 (Tetra Tech 2013) and Phase 2 (Stillwater Sciences 2015), although only a few refer directly to status and trends monitoring in the Lower Columbia Region. A notable exception was the ISTM Habitat Objectives 1&2 report, a summary to compare the goals, objectives, protocols, and inference domains of habitat status and trends monitoring programs in the Lower Columbia Region (Puls et al. 2014). This work was spearheaded by the Pacific Northwest Aquatic Monitoring Partnership (PNAMP), with help from regional partners. In addition to identifying the measurements and metrics that seven Lower Columbia monitoring programs had in common, an effort was made to determine the “shareability” of the most commonly calculated site-level metrics. For the full results, see the final report here: http://www.pnamp.org/document/4769.

A second effort, the Puget Sound area’s Regional Stormwater Monitoring Program (RSMP), has also been particularly valuable in the preparation of this document. The RSMP is a collaborative monitoring program between western Washington municipal stormwater permittees and additional state agencies, initiated as the “Stormwater Work Group” in 2010 and fully operational as of its first summer season of field sampling in 2015. The choice of indicators, sampling protocols, and Qa/QC procedures for the RSMP were consulted extensively during the design and implementation phases of the Southwest Washington HSTM, and both the insights and many of the specific implementation elements provided by this example has been invaluable in specifying and refining the recommended program here.

1.1.5 Related criteria or standards

A number of the monitoring questions and objectives for the HSTM program seek to evaluate the status and trends of physical, chemical, and biological parameters in relationship to published standards for beneficial uses (WAC 173-201A-602) and for Properly Functioning Conditions (PFC) (NOAA 1996). This is not compliance monitoring, however—a different and more extensive program would be needed to diagnose the causes of any failures to meet standards in receiving waters in a regulatory sense. More severe standards, such as for acute or chronic toxicity in water-column constituents, do exist but are not anticipated to be approached by any sample at any of the sites that are eventually selected for monitoring.

Concerns have been raised regarding the suitability of applying PFCs. For example, they do not distinguish variable target conditions across gradients that are known to have natural variation. However, it is a widely applied set of standards for physical, chemical and biological parameters that works well in many of the environments found in the Lower Columbia Region. In order to address the stakeholder concerns and potential limitations of PFC criteria, documentation of appropriate use and constraints are in development by NOAA staff.

Additional criteria or standards are also needed to link to instream biological health and habitat conditions to changes in observed abundance, productivity, spatial structure, and diversity of the natural-origin fish. Although studies have proposed such linkages (e.g., Beechie et al. 2015), no criteria currently exists (Jeff Anderson, NOAA, pers. comm. 2016). This is noteworthy because such linkages are one of the specific program questions to be answered by this study (Question 10 in the following section). In the absence of explicit criteria or standards, we recommend that positive progress towards achieving Properly Functioning Conditions for a given monitoring indicator will serve as a surrogate for explicit criteria by which to evaluate trends. Furthermore, Section 4 of this report proposes key physical, chemical and biological indicators and their association with fish population parameters.

1.2 Project Description

1.2.1 Questions and objectives

The project is designed to present an integrated, coordinated design to monitor the status and trends of natural rivers and streams in the Lower Columbia Region of southwest Washington, with a robust design that will allow region-wide, statistically supported inferences about instream habitat and water-quality conditions throughout the region. It is also intended to inform future Phase I and Phase II Western Washington Municipal Stormwater Permit requirements for permittees in the Lower Columbia River Region by producing a monitoring design that addresses multi-scale questions about status and trends of physical, chemical and biological attributes, including those influenced by stormwater. The project built on the progress of the Pacific Northwest Aquatic Monitoring Partnership's (PNAMP) Integrated Status and Trends Monitoring (ISTM) Project, which explored design and implementation alternatives in pursuit of more coordinated, efficient, and effective aquatic ecosystem monitoring. The intent of integrating status and trends monitoring mandated by municipal stormwater permits with other existing monitoring efforts in the WA Lower Columbia Region is to gain fiscal efficiencies and more robust and meaningful regional assessments.

The monitoring objectives, which underlie the purpose for the monitoring, have been developed in the context of 10 monitoring "questions." They are reproduced below from the Monitoring Design (Stillwater Sciences 2015a) in order to provide a full context for the reader, together with some discussion of their feasibility given constraints imposed by the final monitoring design and its anticipated implementation (as described in this report). They are organized at their highest level by the spatial scale of the monitoring, either Region-wide or focused more specifically on the urban areas associated with the municipal stormwater permittees' jurisdictions.

1.2.1.1 Regional-scale questions and objectives

Water quality and water quantity (Qa/Qx)

Question 1 (TR3, p. 14): What are the status and trends of water quality and stream flow in surface waters?

Objective 1.1 (status): In wadeable and non-wadeable streams, as stratified by predominant land-use categories in their contributing watersheds[5], evaluate whether water-quality conditions generally support the waterbody-specific beneficial uses identified in WAC 173-201A-602 (http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-602) and meet the "Properly Functioning" conditions of NOAA (1996), using the metrics recommended in Section 3.5 of this report.

Objective 1.2 (trends): For the population of sites measured under Objective 1.1, evaluate whether measured water-quality metrics show a statistically significant trend over a 10-year period towards the best conditions represented by the population of sites in the random draw from the Master Sample, and as described as "Properly Functioning" in NOAA (1996).

DISCUSSION: Based on recommendations of the Stormwater and Habitat caucuses that considered cost and feasibility, regional-scale Qa/Qx monitoring has been significantly reduced from the originally anticipated design. Stream flow will not be monitored and the sole water-quality indicator planned for measurement is water temperature. In addition, benthic macroinvertebrates will be collected at each site to provide an integrative biological indicator (e.g., B-IBI) of overall aquatic-system health. Although both temperature and indices of macroinvertebrates are widely used to evaluate general aquatic-system conditions, these indicators alone will be insufficient to evaluate more broad progress towards (or attainment of) beneficial uses or properly functioning conditions (Objective 1.1). Ten years should be sufficient to detect significant trends, if any, in these two parameters; and because the direction of "best conditions" (i.e., cooler water, higher B-IBI scores) is well known, it should be possible to meet Objective 1.2.

Question 2: What are the status and trends of water quality in surface waters draining watersheds with a substantial fraction of land that has been cleared for agriculture or recent (<20 years) forest harvests? (In other words, are our forest practices or agricultural BMPs making a difference in the status and trends of these working landscapes?)

[5] From Tetra Tech (2013), p. 28: "A subwatershed would be assigned to either the forested land use/class category, or a combined urban/suburban/rural land use/class category, based on the category with at least 51% cover in that subwatershed."

Objective 2.1 (status): In wadeable and non-wadeable streams primarily draining agricultural areas outside of Urban Growth Areas, evaluate whether measured water-quality metrics generally support the waterbody-specific beneficial uses identified in WAC 173-201A-602 (http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-602).

Objective 2.2 (trends): In wadeable and non-wadeable streams primarily draining subwatershed(s) with recent (<20 years) forest harvest area(s), evaluate whether measured water-quality metrics show a statistically significant trend over a 10-year period towards reference conditions.

DISCUSSION: As with the objectives under Question 1, the limited number of Qa/Qx metrics similarly narrows the degree to which these objectives can be addressed. Because there are a sufficient number of Master Sample points that drain predominately agricultural watersheds, addressing Objective 2.1 to the same degree as for Objective 1.1 (see above discussion) should be possible, although only for wadeable streams. There is an insufficient number of sites along larger, non-wadeable rivers to meet the predominant agricultural land-cover criterion. As of yet, it is unknown whether sufficient Master Sample points will be selected to provide adequate statistical power to address Objective 2.2.

Habitat

Question 3: What are the status and trends of in-stream biological health and in-stream/riparian habitat conditions (in terms of both quality and quantity)?

Objective 3.1 (status): In wadeable and non-wadeable streams, as stratified by predominant land-use categories in their contributing watersheds, evaluate the status of biological and habitat conditions relative to Properly Functioning Conditions (Appendix A).

Objective 3.2 (trends): Analyze for statistically significant spatial and temporal trends of biological and habitat metrics (annually.

DISCUSSION: The suite of habitat indictors adopted for regional monitoring sites address many of the "Habitat Elements" contained in NOAA's (1996) table of Properly Functioning Conditions (PFC's). Additional key indicators were also identified that provide value to understanding the status and trends of in-stream biological health and in-stream/riparian habitat conditions. Together, they should be sufficient to characterize most conditions relative to regional standards (Objective 3.1) and demonstrate statistically significant changes in these PFC's (Objective 3.2). An exception exists for low-gradient floodplain habitats that are not well represented by PFC criteria. This uncertainty will require additional reference conditions to be considered during evaluation of low-gradient sites. Furthermore, some of the indicators are slow to change and may require one or more decades to detect a significant change in the absence of major disturbances to the watershed.

Question 4: Do in-stream biological health and in-stream/riparian habitat conditions correlate to changes in abundance, productivity, spatial structure, and diversity of the natural-origin fish in this population at the reach/subwatershed scale?

Objective 4.1 (trends): Identify statistically significant correlations between trends in select habitat metrics and trends in fish population metrics being conducted by other monitoring programs.

DISCUSSION: Attaining Objective 4.1 is dependent in part on the availability of fish population metrics, whose collection and dissemination lie outside of the domain of this project. It also requires linkages between habitat indicators and fish population metrics, which are in development by NOAA. Despite these significant constraints, this objective remains of primary concern to addressing watershed health and salmon recovery. Correlations between fish metrics and habitat indicators collected under the HSTM program are most likely to emerge from the most integrative of indicators being collected here (i.e., B-IBI) and will undoubtedly require one or more decades to emerge in the absence of major watershed disturbances.

Landscape

Question 5: Where on the landscape are key potential land-use activities occurring, and in what watersheds are one or another of these activities dominant?

Objective 5.1 (status): Identify subwatersheds of the Lower Columbia Region at a suitable size to support other monitoring efforts under this program having "dominant" land uses of urban, agriculture, or recent (<20 year) forest harvest; identify subwatersheds with dominant intact (>20 year old) forest cover.

DISCUSSION: Elements of this objective have already been satisfied (specifically, the identification of Master Sample points with watersheds draining predominately urban or agricultural land cover) in order to support other element of the HSTM program implementation. The methodology for implementing the other elements of this objective is included in this Implementation Report (see Section 3.3.1) but their execution has been suspended until such time that their findings are required.

Question 6: Are land-cover changes occurring at detectable rates across the Lower Columbia Region, and if so where are they occurring?

Objective 6.1 (trends): Identify and quantify areas of land-cover change in subwatersheds of the Lower Columbia Region that drain to habitat and/or Qa/Qx monitoring sites at 5-year intervals.

Objective 6.2 (trends): Identify and quantify how land cover is changing within a selected buffer zone (e.g., 60 m) around channels included in the Qa/Qx and habitat monitoring elements at 5-year intervals.

DISCUSSION: The methodology for implementing the elements of these objectives is also included in this Implementation Report (Section 3.3.1) but their execution has been suspended until such time that their findings are required.

1.2.1.2 Municipal stormwater NPDES permit-related questions and objectives

Water quality and water quantity (Qa/Qx)

Question 7: What are the status and trends of water quality and stream flow in surface waters draining subwatersheds that are primarily within the jurisdiction of municipal stormwater NPDES permittees?

Objective 7.1 (status): In streams in urban NPDES areas, evaluate whether water-quality conditions generally support the watershed-specific beneficial uses identified in WAC 173-201A-602 (http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-602).

Objective 7.2 (trends): For the population of sites measured under Objective 7.1, evaluate whether measured water-quality metrics show statistically significant trends over a 10-year period towards the best conditions.

DISCUSSION: The design for Qa/Qx monitoring in urban+NPDES areas has sought to balance the competing interests of comprehensiveness, economy, and utility to regulators, permittees, and other stakeholders. The basic suite of indicators emphasize time-integrative parameters that should minimize random variability introduced by episodic sampling; the rotating panel design will allow the entire population of streams within the identified stratum (2.5-50 km^2 drainage area, predominately urban watershed land cover) to be sampled at least twice in a 10-year period, with a sufficient range of indicators to provide some general indication of the attainment of beneficial uses but not to systematically evaluate every criterion. The expanded suite of indicators will provide a richer array of indicators at a subset of these locations and allow a more complete determination of whether those uses are being achieved, at least for some locations and some parameters. In aggregate they should provide a robust characterization of overall conditions (Objective 7.1) of water quality and stream flow throughout the urban portions of the Lower Columbia Region. Based on prior studies, these data should also be sufficient to demonstrate any significant trends in those conditions over the course of one to two decades, and for which the "direction" of improving quality is well known (Objective 7.2).

Question 8: What are the status and trends of water quality and stream flow in surface waters that are being affected by stormwater discharges from urban areas first developed under requirements of the 2013 municipal stormwater permits?

Objective 8.1 (status): In streams whose catchment areas now drain primarily non-urbanized areas within Urban Growth Areas, evaluate whether water quality generally supports the watershed-specific beneficial uses identified in WAC 173-201A-602 (http://apps.leg.wa.gov/WAC/default.aspx?cite=173-201A-602) and meet the "Properly Functioning" conditions of NOAA (1996).

Objective 8.2 (trends): In the sample population of Objective 8.1, evaluate whether measured water-quality and flow (i.e., stage) metrics show statistically significant trends over a 10-year period in those subwatersheds that have experienced measureable land-use changes while under provisions of the 2013 (or later) municipal stormwater permit.

DISCUSSION: This question, and its associated objectives, begin to explore the boundary between "status and trends" monitoring and "effectiveness" monitoring, because they are targeting those locations where a particular activity (i.e., land development) is anticipated to have a potentially causal relationship with measured indicators. Given the rates and distribution of newly developed (and developing) land, however, it is unlikely that a statistically robust number of sites (i.e., 15 or more) is likely to be identified over the course of even a decade. Although worthy in principle, these objectives are likely to be answered only with indications of conditions or of trends that might have a meaningful association with upstream development, but which will require more targeted evaluation beyond the scope of the HSTM program to conduct.

Habitat

Question 9: What are the status and trends of in-stream biological health and in-stream/riparian habitat conditions that are primarily within the jurisdiction of NPDES stormwater permittees (in terms of both quality and quantity)?

Objective 9.1 (status): In streams in urban NPDES areas, evaluate the status of biological and habitat conditions according to the habitat metrics (Section 3.5.2) relative to Properly Functioning Conditions (NOAA 1996).

Objective 9.2 (trends): Analyze for statistically significant spatial and temporal trends of biological and habitat metrics (annually) in urban NPDES areas.

DISCUSSION: Given the narrow scope of habitat monitoring at urban+NPDES sites (i.e., width/depth and substrate), the comprehensive coverage of these streams will provide insufficient insight into physical conditions to address either objective. The habitat monitoring at a regional scale, however, includes a strata combination that will incorporate many of the streams within the urban+NPDES area, and which should address these two objectives to a similar degree, and over a similar time frame, as Objectives 3.1 and 3.2.

Question 10: Do in-stream biological health and habitat conditions correlate to changes in observed abundance, productivity, spatial structure, and diversity of the natural-origin fish in this population (reach/subwatershed scale)?

Objective 10.1 (trends): Identify statistically significant correlation between trends in select habitat metrics and trends in fish population metrics (e.g., abundance, productivity, spatial structure, and diversity) being conducted by other monitoring programs.

DISCUSSION: Because the spatial scale of the urban+NPDES monitoring sites is significantly less than that of the fish populations of interest in the Lower Columbia Region, this objective is likely to be less easily or successfully addressed than its regional counterpart (Objective 4.1). At best, correlations may emerge between these locally collected indictors and more localized fish presence/absence data. However, it is not known whether those fish data are being systematically collected by others in a spatial domain that would prove relevant to this objective, and so its potential for attainment through even a decade (or more) of HSTM implementation is unknown at this time.

1.2.2 Information and data to meet objectives

In order to address the project objectives, which broadly seek to characterize the status and trends of stream conditions across the Lower Columbia Region, a set of indicators will need to be measured with sufficient precision and statistical rigor to adequately characterize “status,” and over a sufficient period of time to discern any “trends.” Developing the specific approaches to meet these requirements was the primary task of the Design Report; specifying the procedures, timing, and locations for executing those approaches is the primary task of this Implementation Report, as described in the subsections that follow.

1.2.3 Target populations

The target populations differ for the two major types of monitoring activities described in this plan: namely, water-quality and quantity sampling (hereafter, "Qa/Qx sampling") and physical habitat sampling. A third monitoring type, biological monitoring of benthic macroinvertebrates, occurs at both Qa/Qx and habitat sampling locations.

The Qa/Qx target population will take advantage of the "continuity" of flowing water, under the assumption that most water-quality parameters vary only gradually, if at all, along a given reach in the absence of tributary or manmade inputs. Thus, the population of Qa/Qx sites from which sampling locations will be drawn will be *segments* having a specified range of drainage areas (see below). Within each selected segment, the location chosen for sampling should have only modest influence on the collected data, and thus ancillary considerations (such as site access or the reoccupation of legacy sampling sites that are located within the selected segments) can be incorporated without undermining the random spatial design. Thus, all Lower Columbia Master Sample sites within a specified range of drainage areas will be used to define stream segments as potential Qa/Qx sampling sites. To maintain data independence, however, no selected site should drain into any other selected site.

For habitat monitoring, more localized stream *reaches* are the appropriate target population for assessing habitat. Sampling sites will be located in reaches of continuous, freshwater streams with non-constructed channels and lotic, perennial flow. To adequately represent variability across stream reaches throughout the Region for wadeable and non wadeable streams, habitat monitoring will sample randomly chosen sites selected from all stream reaches that meet a specific set of strata-based selection criteria (see below).

1.2.4 Study boundaries and sample stratification

Although the sampling domain is the entire Lower Columbia Region within Washington state, adequate coverage of the diverse habitats and conditions with a relatively limited number of samples requires some degree of stratification. Stratifying a sample population is necessary to ensure that "like" is being compared to "like," and that a subset of that population can provide a credible representation of the group as a whole. For example, published reference conditions for large woody debris loading distinguish between values for wide rivers and narrow streams; pool frequency is not equivalent in low-gradient meandering streams and steep cascade channels. Thus, subdividing the population of sample sites on the basis of physical attributes is commonly necessary. In addition, stakeholders wanted to ensuring that the random selection of sites would ensure sufficient representation of key areas (such as the Lewis River subbasin, which supports a large number of ESA-listed salmonid species) on the basis of jurisdictional or regulatory considerations (e.g., recovery planning). Thus, this stratification was also included.

Based on considerations of geographic distribution, variability of channel types, and future management needs, the following strata have been defined:

For Qa/Qx sampling *within* the urbanized or designated UGAs of an NPDES municipal stormwater permittee, stream segments should have a predominant urban land cover in their contributing watershed with drainage areas between 2.5 and 50 km^2. Thus, this "urban+NPDES" Qa/Qx sampling is not further stratified and includes only a single category of sites.

Qa/Qx sampling *outside* of urban areas was included as a separate category of sampling in the Design Report; based on input from the Stormwater and Habitat Caucuses, however, a subset of Qa/Qx parameters have now simply been integrated into habitat sampling sites.

For habitat sampling, the following strata and categories are defined:

- Within the urban+NPDES areas, and "regional sites" that lie outside of all urban areas = **2 categories**
- Drainage area (0.6-2.5, 2.5-50, 50-200, 200-1000, >1000 km^2) = **5 categories**
- Stream gradient groups (<1.5%, 1.5-3%, 3-7.5%) = **3 categories**
- Predominant watershed land cover (forested, agricultural, urban) = **3 categories**
- Number of salmonid Primary Populations in the subbasin (0-2 and 3+) = **2 categories** (only applied outside of urban areas)

This stratification represents a reduction in two categories from the Phase 2 monitoring design. Stakeholders determined that three categories of gradient and two categories of Primary Populations would adequately represent the range of conditions and in support of management needs in the Lower Columbia Region. As such, the two strata were removed to avoid unnecessary excessive stratification and associated monitoring costs.

In addition to Qa/Qx and habitat sampling, a third type—biological sampling of benthic macroinvertebrates—will occur at all selected sites where either Qa/Qx or habitat sampling is implemented (i.e., at both the urban+NPDES and regional monitoring sites).

1.2.5 Practical constraints on the study design

As noted in the Background section, the Region is a patchwork of public and private land ownership, and of transportation networks of widely varying density and coverage. Not every site that is randomly selected will be accessible. Such circumstances were recognized in the Design Report as needing to be addressed during implementation. This should prove to be constraints only if a particular combination of strata have so few members that the necessary exclusion of a subset of points would result in too few remaining members for statistically robust sampling and representation of the population as a whole.

Affordability and the commitment from stakeholders to fund the HSTM are other practical constraints to be resolved. With limited resources and existing monitoring programs already in place, agencies and permittees are still in the process of determining their level of engagement as part of the development of this Implementation Plan. This has imposed modifications to the original Phase 2 Monitoring Design, which have been noted in Section 3 of this report. Such modifications are likely to continue throughout the implementation of this program.

Lastly, one of the primary goals of the HSTM for the Lower Columbia Region was to engage the Oregon portion of the Region and the associated stakeholders. That remains an incomplete goal and practical constraint on the study design, which is currently restricted to the Washington portion of the Region.

1.2.6 Summary of tasks needed to collect data

To collect data under the HSTM program, the roles and responsibilities for financing and implementing both the water quality and habitat components have been identified by their respective caucuses (see Appendices A and B). With these agreements and understandings in hand, the sequence of tasks required to collect data can be broadly summarized as follows:

- Identify the specific candidate sites at which monitoring will occur (specific sampling locations are provided with this report in the form of separate digital files - *forthcoming*).
- Identify the 5-year sampling schedule.
- Field-evaluate candidate sites for a given year based on access logistics and site security (for equipment deployment). Fifteen viable sites per strata should be identified.
- Acquire field sampling equipment and permanently installed sensors.
- Deploy sensors at sites where continuous monitoring will occur, and initiate regular maintenance schedule.
- Plan and implement summer-season site visits to Qa/Qx and habitat sites.

1.2.7 Decisions that could be made using data

Because sampling under the HSTM project has not yet begun and data have not yet been analyzed, how the monitoring data will be used by project partners has not been fully determined and will likely evolve throughout the lifetime of this program. The primary purpose of the data is to answer the program questions set forth in the Design Report (Stillwater Sciences 2015) and reiterated in Section 1.2.1 above. In general they are summarized as follows:

- Satisfying future municipal stormwater permit requirements for status and trends monitoring;
- Tracking the status and trends of regional watershed health known to support ESA-listed salmonid species; and
- Inferring the potential value and success of various salmon-recovery and stormwater-management efforts at a broad, landscape scale.

Based on the experience of other such status and trends monitoring program that are already implemented, potential approaches to analyzing and interpreting data to be collected by this program are discussed in Section 4 of this report.

1.3 Organization and Schedule

1.3.1 Project leadership

Project leadership and decision-making for the HSTM is conducted by the collective efforts of a Grant Core Team (a.k.a. the Core Team), Leadership Team and Stakeholders.

1.3.1.1 Core team

The Core Team roles and responsibilities included the following:

- Attend weekly team meetings as needed to discuss progress on tasks, resolve issues encountered, and plan for next steps
- Create documents, presentations, and other informational/outreach materials
- Review documents, presentations, and other informational/outreach materials created by other task team members
- Report progress to Leadership Team; recommend changes if necessary

- Revise work plan as necessary

Core Team members include:

Karen Adams, formerly LCFRB
Steve Manlow, LCFRB
Jeff Breckel, LCFRB
Jody Lando, Stillwater Sciences
Amy Puls, USGS/PNAMP
Jennifer Bayer, USGS/PNAMP
Megan Dethloff, USGS/PNAMP

1.3.1.2 Leadership team

The Leadership Team roles and responsibilities include the following:

- Attend monthly team meetings
- Vet the work of the Core Team
- Provide updates on the various caucus developments
- Provide guidance to the Core Team when needed
- Ensure project is meeting expectations

Leadership Team members are:

Steve Manlow, LCFRB
Karen Adams, formerly LCFRB
Scott Anderson, NOAA
Jennifer Bayer, USGS/PNAMP
Derek Booth, Stillwater Sciences
Jeff Breckel, LCFRB
Jeff Cameron, City of Longview
Megan Dethloff, USGS
Karen Dinicola, WA Ecology
Jeffrey Fisher, NOAA
Dick Gersib, WSDOT
Patrick Harbison, Cowlitz County
Steve Haubner, City of Longview
Jody Lando, Stillwater Sciences
Chad Larson, WA Ecology
Amy Puls, USGS/PNAMP
Brett Raunig, WA Ecology
Jeff Schnabel, Clark County
Dorie Sutton, City of Vancouver
Rod Swanson, Clark County
Melody Tereski, LCFRB
Steve Warner, City of Longview

1.3.1.3 Stakeholders

The level of involvement from stakeholders will depend on individual interest and availability. Suggested means of participation include:

- Attend workshops and technical work sessions
- Review documents pertaining to the study design and implementation plan and provide feedback regarding feasibility and scientific merit
- Represent agencies or interest groups on the Leadership and Task Teams

Stakeholders include:

Stormwater Permittees (Phase I, Phase II, and Secondary permittees), including but not limited to City of Battle Ground, City of Camas, City of Kelso, City of Longview, City of Vancouver, City of Washougal, Clark County, Consolidated Diking Improvement District 1, Cowlitz County, Kelso School District, Longview School District, Lower Columbia College, Port of Olympia, Port of Vancouver, Washington State University-Vancouver, and WSDOT.

PNAMP ISTM partners, including representatives from the following monitoring programs: Columbia Habitat Monitoring Program, Oregon Department of Environmental Quality National Rivers and Streams Assessment, Oregon Department of Fish and Wildlife Aquatic Inventory, Washington State's Salmon Recovery Funding Board Action Effectiveness Monitoring, US Forest Service and Bureau of Land Management Aquatic and Riparian Effectiveness Monitoring Plan, and Washington Department of Ecology Monitoring for Watershed Health and Salmon Recovery.

1.3.2 Participating organizations

For habitat monitoring, the regional program will be guided by a Steering committee composed of representatives from the regional habitat and water quality monitoring agencies and organizations (see Appendix B). Membership should include, at a minimum, representatives from:

- NOAA
- USDA Forest Service
- U.S. Fish and Wildlife Service
- USGS Pacific Northwest Aquatic Monitoring Partnership
- Washington Department of Fish and Wildlife
- Washington Department of Ecology's Environmental Assessment Program
- Washington Department of Ecology's Water Quality Programs
- Representative from SW Washington Stormwater Permittees
- Washington Salmon Recovery Funding Board
- Oregon Department of Fish and Wildlife
- Oregon Department of Environmental Quality
- Oregon Watershed Enhancement Board

A Technical Review committee will also be formed to provide feedback on annual reports and performance of the protocols. The feedback from the Technical Review committee will inform program management decisions by the Steering committee. Based on feedback from the Habitat Caucus members, the following agencies are interested in serving on the Technical Review committee:

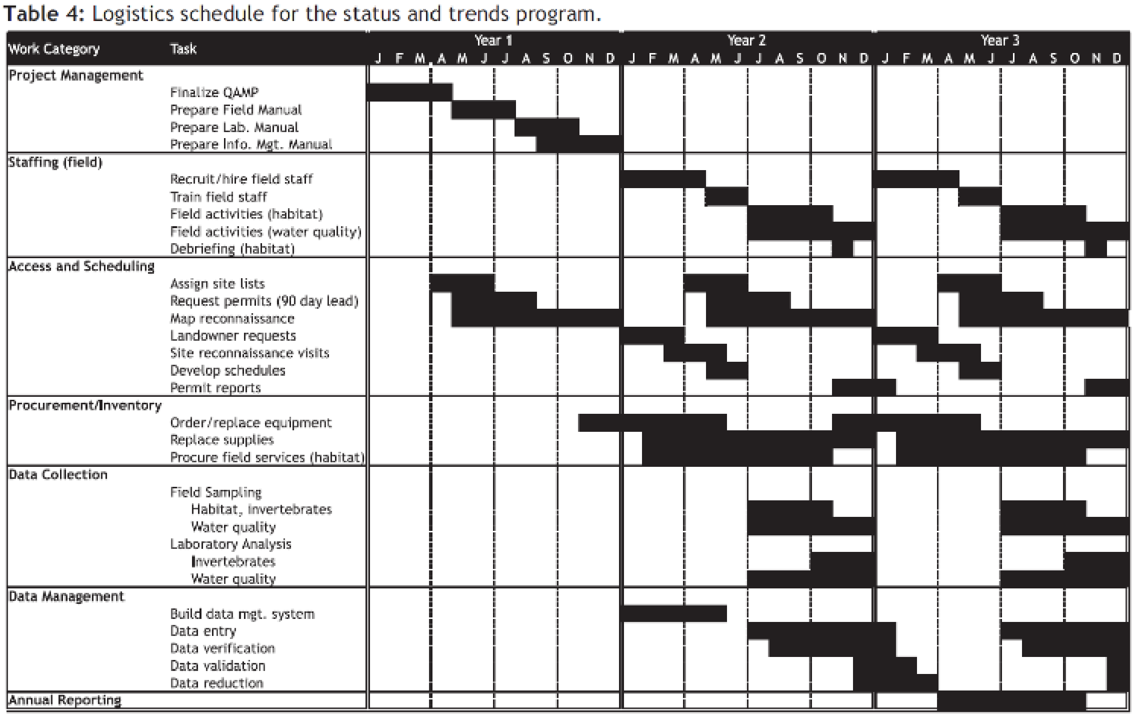
- NOAA
- U.S. Geologic Survey
- USDA Forest Service
- U.S. Fish and Wildlife Service
- Washington Ecology's Environmental Assessment Program
- Oregon Department of Fish and Wildlife

For the Qa/Qx monitoring of urban areas under the municipal stormwater NPDES permit, direction will be provided by the Stormwater Caucus, with Roles and Responsibilities detailed in Appendix A of this report.

1.3.3 Project schedule and limitations

Detailed program schedules will be developed by Program Managers responsible for water quality, habitat and biological monitoring. Table 4 from Ecology's Quality Assurance Monitoring Program guidance document (Ecology 2006) is a useful example of what should result from this forthcoming effort:

Table 4: Logistics schedule for the status and trends program.



Regional monitoring prescribed in the Habitat Roles and Responsibilities document (Appendix B) includes the following recommendations

- Site reconnaissance—begin in March to ensure landowner approval, site access, and monitoring feasibility.
- Field training workshop—prepare field crews by the end of May. All field personnel should participate in trainings every year.
- Data collection—July 1–September 30th annually to capture low flow conditions, ensure field crew safety and avoid spawning fish and emerging fry in Lower Columbia tributaries. Sites at higher elevation should be sampled later in the season to allow flows to decrease following snowmelt.

1.3.4 Budget information for the project

1.3.4.1 Urban+NPDES monitoring

Based on cost data and experience from the Puget Sound RSMP, recent small-stream monitoring for Clean Water Services (Stillwater Sciences 2015b), and prior experience from Clark County, the estimated cost of the recommended base Qa/Qx urban+NPDES monitoring as described in this Implementation Plan is approximately $68,000 per year (Table 1; see Section 3.1.1 for the list of base indicators). This cost compares favorably with prior estimates of population-adjusted costs relative to status and trends monitoring in the Puget Sound area under the RSMP. This cost estimate was prepared by the Stormwater Caucus and includes monthly maintenance of continuous data-recording installations and amortizes the equipment and installation costs over a presumed 5-year period of the NPDES permit cycle. It assumes that labor will be provided by Clark County staff at a fully burdened rate, and it draws on that program's monitoring experience to apply realistic unit costs. Based on one year of implementation of the Puget Sound RSMP, an additional contingency fund should probably be added to these totals, but that has not yet been included. Other modifications to this budget may include the establishment of an initial start-up year, in which equipment is purchased and program management is finalized but no data collection occurs.

The Stormwater Caucus has also developed an extended monitoring component to the Qa/Qx monitoring at urban+NPDES sites to address additional needs of the participating jurisdictions. Although not part of the primary monitoring of the HSTM program, the list of additional indicators is included in this Implementation Report (see Section 3.1.1) and the cost of their collection and analysis has been identified (about $59,000 per year, which would result in an annual combined monitoring cost [base+extended] of $127,000), using the same approach and assumptions as for the suite of monitoring indicators described above. The detailed cost spreadsheet for this extended program is included with its associated QAPP and provided as an appendix to the QAPP for the HSTM program.

Table 1. Annual monitoring costs to implement the base Qa/Qx urban+NPDES monitoring program.

Stream Monitoring Task Group	Phase II Base Annual Monitoring Costs	
	Annual / Site	All 10 Sites / Yr~
Data Collection		
One-Time Equipment Purchases		
One (1) Onset / Hobo BoxCar Pro 4.3 Starter Kit	$125	
One (1) Hobo Waterproof Data Shuttle	$249	
Ten (12) Hobo U20L Water Level Logger (extra for atmosph. press.)	$2,990	
Ten (10) Hobo U24 Conductivity / Temperature Data Logger	$7,500	
First year, one-time Equipment Purchases Subtotal		**$10,864**
Water Quality and Stage Monitoring		
monthly field hours (Base: loggers download / Expanded :sampling)	1	
# of staff	1	
rate	$109	
annual trips	12	
lab cost per monthly trip		
annual labor subtotal per site (includes equipment installation & maintenance)	$1,309	
annual lab subtotal per site		
WQ Monitoring Subtotal (Expanded includes 10% QC sampling rate)	**$1,309**	**$13,088**
BIBI: Bugs as Overall Indicator of Aquatic Health		
annual field hours	4	
# of staff	2	
rate	$109	
annual samples	1	
lab cost per site sample	$250	
annual labor subtotal	$873	
annual lab subtotal	$250	
Bug Monitoring Subtotal	**$1,123**	**$11,225**
Sediment Monitoring		
field hours (immediately prior to single monthly WQ field work)	1	
# of staff	1	
rate	$109	
annual samples	1	
annual lab cost (assumes just total metals and PAH parameters)	$353	
annual labor subtotal	$109	
annual lab subtotal	$353	
First Year Sediment Monitoring Subtotal (subsequent years' are 55% less)	**$462**	**$4,621**
Data Collection Subtotal		**$39,798**
Data Management, Analyses, and Reporting		
Data Management - Office Work		
monthly continuous stage data transfer, adjustments, and storage in Aquarius database	1	
monthly water temperature and conductivity data maintenance in Aquarius database	0.5	
total monthly office hours per station	1.5	
# of staff	1	
rate	$109	
applicable months	12	
annual office labor subtotal per station	$1,963	
Data Management Total	**$1,963**	**$19,632**
Annual Data Analyses and Reporting - All Sites		
data QC / finalization	8	
upload continuous data to state EIM	8	
data analyses - summary statistics, WQ metric calculations, tables and graphics	16	
status (trend -after 5 yrs.) reportiing	16	
total annual office hours - analyses and reporting	48	
# of staff	1	
rate	$109	
annual office labor subtotal	$5,235	
Data Analyses and Reporting Total		**$5,235**
Data Management, Analyses, and Reporting Subtotal		**$24,867**
Project Administration		
Project Management and Administration Total (5%)		**$3,233**
Annual Overall Total Cost		**$67,899**

** Assumes Clark County performing the monitoring on 6 trend (fixed) stream sites and 4 rotating panel streams sites per year*

1.3.4.2 Regional monitoring

Based on cost data and experience from ongoing monitoring programs (Ecology, WDFW and USGS), the estimated staff cost of the recommended regional monitoring as described in this implementation plan is approximately $709,000 per year (Table 2). This assumption presumes two 2-person crews will sample up to 70 sites/year/crew with a 5-year rotation of sites. This estimate does not yet include travel expenses (e.g., equipment, gas, lodging, meals), which is likely to increase the total cost by about 10%, depending on the final location of sites and where crews are based.

Table 2. Annual monitoring costs to implement regional sampling.

	Staff	Annual hours	Rate	Total
Project management	1		10% total budget	$ 64,432
Data collection	4	1520	$76	$ 62,080
Data management	1	320	$76	$ 24,320
Data analysis	1	520	$112	$ 58,240
	1	520	$76	$ 39,520
Reporting	1	320	$112	$ 35,840
	1	320	$76	$ 24,320
				$ 708,752

1.4 Quality Objectives

1.4.1 Decision quality objectives

"At the level of the decision, there is a need to specify tolerable limits of making decision errors. These tolerable limits are required, along with other information, to determine the numbers and locations of samples from the site that must be collected and analyzed." (from Ecology 2004, page B-2) [http://www.ecy.wa.gov/biblio/0403030.html]

Principles established during Phase 1 of the HSTM project have specified that basing future management on the results of monitoring will require a robust statistical design. This is being accomplished through: (1) use of the Master Sample for the Lower Columbia Region, which applied a probabilistic site selection algorithm to generate a spatially-balanced set of sites, to implement status and trends monitoring; and (2) ensuring a sufficient number of sites in each unique monitoring strata combination that that a specified level of statistical confidence can be achieved (95% confidence and 80% power for water quality and 90% confidence and 80% power for habitat and biological indicators). In addition to these two criteria, a third has been added, namely that individual indicators should have a signal to noise ratio that is at least of "moderate" precision (Kaufmann et al. 1999), in order to improve the statistical likelihood that identified trends in the data are reflecting true changes in environmental variables and not just random fluctuations or errors in measurement.

1.4.2 Measurement quality objectives

"At the level of measurements used to support the decision or study question, quality objectives are expressed as measurement quality objectives or MQOs. The MQOs are performance or acceptance criteria for the data quality indicators precision, bias, and sensitivity." (Ecology 2004, page B-2)

Because the HSTM program includes a wide variety of indicators, measurement quality objectives vary significantly between the various categories. An overarching focus for indicator selection has been to use only those metrics with relatively high levels of measurement precision and signal-to-noise. For parameters measured with on-site sensors or laboratory analysis (water temperature, sediment metals, conductivity, stage), typical values are within a few percent (and are specified more precisely in Section 3). For field methods (i.e., habitat indicators), commonly reported values for the precision of replicate values for those indicators recommended for inclusion in this program are on the order of 10% (e.g., Kaufmann et al. 1999).

1.5 Sampling Design

1.5.1 Experimental design and sampling locations

The experimental design for this project will follow two distinct approaches: one for the urban+NPDES sample sites, at which primarily Qa/Qx indicators will be collected; and the other for the regional sites, at which primarily habitat indicators will be collected. Both, however, share the same basic elements and underlying principles to guide site selection and data acquisition:

- Sites are drawn from the Master Sample for the Lower Columbia Region within Washington state
- The entire population of prospective sites will be stratified into categories that are scientifically relevant for the parameters being measured
- Within each unique combination of strata and categories, at least 15 sites will be sampled to ensure an sufficient level of statistical significance to support the decisions being made on the basis of the results
- Care will be taken to avoid sites that are affected by Columbia River backwater or tidal fluctuation

For the prospective sites that lie within the urbanized area or designated UGA of a municipal stormwater permittee (i.e., urban+NPDES areas), sampling for the Qa/Qx indicators will be limited to those that drain watersheds of 2.5-50 km^2 with predominantly (i.e., >50%) "urban" land cover (see Section 3.3). Although the Phase 2 Design Report included a provision for identifying sites outside of urban+NPDES areas (i.e., "regional" sites) that would be sampled exclusively for Qa/Qx indicators, decisions by the Stormwater and Habitat Caucuses during preparation of this implementation plan changed that element of the design. Instead, a single Qa/Qx indicator (temperature) will be collected at the regional sites as part of the habitat sampling effort (see below).

For habitat monitoring, the sample population will be stratified first on the basis of whether or not a site lies within the urbanized or designated UGA of a municipal stormwater permittee (i.e., the same "urban+NPDES" areas noted above). Within these areas, monitoring sites will be selected from strata defined by categories of drainage area size (0.6-2.5 km^2, 2.5-50 km^2, 50-200 km^2, 200-1000 km^2, >1000 km^2), stream gradient (<1.5%, 1.5-3%, 3-7.5%), and predominant land cover in the contributing watershed (forested, agricultural, urban). For those habitat sites outside the urban areas (i.e., not in a designated UGA or other urban area), an additional stratification will be added for the number of Primary Populations within the contributing subbasin (two categories, namely 0-2 or 3+ Primary Populations).

This sampling design has been motivated entirely by the measurements required to answer the ten monitoring questions, and by scientific understanding of how various chemical and physical attributes of streams vary with location and with watershed characteristics.

1.5.2 Representativeness

"Representativeness" is a property of both the region being assessed and the parameter being measured (Ecology 2006). The probabilistic sampling design is intended to achieve statistically valid spatial representations of stream status and trends at the scale of the entire Lower Columbia Region. Most field measurements (except for those made by continuous data-collecting sensors) will be conducted in the summer, a period when hydrologic, physical, and biological conditions are most stable and the likelihood of confounding high flows is low. Ensuring that the laboratory measurements of field-collected samples are representative of those field conditions, established procedures for sample holding time, equipment calibration, and analytical duplicates as described for each parameter below.

Representativeness of water-quality parameters is particularly enhanced by the Phase 2 Design Report's emphasis on collecting continuous parameters in real time, eliminating the otherwise inescapable uncertainties associated with the time-varying nature of most water-column constituents.

1.5.2.1 Field measurements

Most of the field measurement and data collection for Qa/Qx monitoring will be conducted at the downstream-most location of an identified stream segment that meet criteria for feasible logistics for access and site security. Most of the indicators are in the water column and are not anticipated to vary greatly throughout the stream segment. For those with collection at specific locations and with particular site requirements (i.e., sediment metals and PAHs and macroinvertebrates), the conditions necessary for representative field measurements are specified in this document as part of the measurement protocols.

Most of the field measurements conducted at habitat sampling locations are conducted throughout the entire 20×-bankfull-width-long reach, ensuring that results are truly "representative" of the reach. This distance is designed to include multiple pool-riffle or step-pool sequences in an alluvial channel coupled with measurements at 11 transects to avoid overrepresenting unique characteristics of any one segment. Variability will be reduced through refinement of site selection and rotating panel designs. Field personnel will record where samples are measured and note general descriptions of physical conditions of the channel, gradient, habitat types, water velocity, weather, and other parameters or unique local features that could influence data quality. These narrative field notes can be used to qualitatively assess how well the data represent the conditions characterized by this study, should any questions later arise about the representativeness and accuracy of the measured indicators.

1.5.2.2 Laboratory measurements

Typical protocols to ensure the representativeness of lab data is to provide triplicates of every 20th sample, with a goal of <5% variability as the standard. This provides a high confidence that each sample accurately reflects a representative value of the measured parameter. Because each year's sampling under this program will only include nine sediment samples, however, this guidance should be modified to randomly select one of those nine samples for triplicate measurement.

1.5.3 Comparability

All sites with once-per-year measurements will be visited during summer low-flow conditions, and the field methods will be documented in sufficient detail to ensure comparable results. The selection of indicators has been guided by the need to avoid those with recognized high levels of observer variability, and so many of the problems of (in)comparability that plague other such monitoring efforts have been addressed through the initial design. For sites with continuous data collection, field sensors will be similar or identical at all sites, and episodic calibration with hand-held sensors will ensure that the data are equivalent across all sites.

1.5.4 Completeness

Completeness will be calculated as a percentage of the number of valid samples that should have been collected relative to the number that actually are obtained. The standard for completeness is 90% in order that the data can be determined as valid in proportion to the goals for the project as a whole.

1.6 Signal to Noise Analysis

The first phase of Signal to Noise analysis was conducted for all metrics to support the selection of protocols based in part on the predictive strength of given metric and the shareability of data. However additional work and stakeholder input was needed to determine the best course of action regarding the shareability of data. As a result, Phase 2 of the Signal to Noise analysis was conducted as part of this Implementation Plan.

Signal to noise (S/N) analyses compare the magnitude of "true" change in a metric with the magnitude of its random (or otherwise irreducible) variability. The knowledge and management of such information is critical to ensuring a successful HSTM program because "High noise in habitat descriptions relative to the signal (i.e., low *S/N*) diminishes statistical power to detect differences among subpopulations" (Kaufmann et al. 2014).

Given the desire to manage the program development with S/N consideration, research was conducted to explore S/N data gaps and to work closely with the Stormwater and Habitat Caucuses to evaluate methods, S/N ratings, protocol selection and data shareability. The resulting ratings are listed below (Table 3). As explained in the Monitoring Design, the rating system can be interpreted as follows:

- S/N >10: negligible adverse effects of noise variance in environmental monitoring;
- S/N 6-10: minor adverse effects of noise variance in environmental monitoring,
- S/N 2-6: moderate adverse effects of noise variance in environmental monitoring
- S/N <2: severely limiting adverse effects of noise variance in environmental monitoring

Such information is highly valuable when considering the suitability of a given metric to detect meaningful signals (trends). It is also useful to evaluate the potential for monitoring programs to share data. Although some monitoring programs may find their data to be sharable based on standard protocols, if one program produces high S/N ratios and the other low S/N ratios, it would be ill-advised to pool such data. Because the HSTM program includes a wide variety of indicators, measurement quality objectives vary significantly between the various categories. Nevertheless, a program goal was set forth to identify only those indicators with relatively high levels of measurement precision and signal-to-noise.

Protocol discussion and selection by the stakeholders was supported by S/N ratings. For example, the Habitat Caucus used a decision matrix developed by Stillwater Sciences to evaluate the range of methodologies known for each indicator, the associated S/N ratings and recommendations for caucus consideration. The caucus reviewed and discussed the decision matrix during multiple meetings before arriving at consensus for field data collection methods that are presented in details within this report.

S/N studies reviewed for this effort included the following monitoring programs and organizations:

AREMP—Northwest Forest Plan Aquatic and Riparian Effectiveness Monitoring Program;
CDFG—California Department of Fish and Game Protocols;
ECOLOGY—Washington State Department of Ecology
EMAP—EPA Environmental Monitoring and Assessment Program;
NIFC—Northwest Indian Fisheries Commission;
ODFW—Oregon Department of Fish and Wildlife;
PIBO—USDA Forest Service-BLM (effectiveness monitoring program for PACFISH/INFISH biological opinion);
UC—Upper Columbia Monitoring Strategy.

Table 3. Habitat indicators and Signal/Noise ratings from various sources.

Indicators*	**Signal to Noise Rating**							
Program	**AREMP[1]**	**CDFG[1]**	**EMAP[1]**	**NIFC[1]**	**ODFW[1]**	**PIBO[1]**	**UC[1]**	**Ecology[2]**
Temperature[W,NW]								B
Conductivity[W]								A
Stage[W]								
Sediment metals[W]								
Sediment PAHs[W]								
Sample reach length[W,NW]	C[3]		B[3]			B[3]		
Channel type[W,NW]								
Reach slope[W,NW]	B[3] A[4]	C[4]	B[4] A[4] A[5]		A[4]	A[3] A[4]	A[4]	
Sinuosity[W,NW]	D[3] A[4]		B[4] D[5]			C[3] D[4]	C[4]	
Bank modification[W,NW]								
Density of habitat types (% pools)[W]	F[3]		D[3] C[5]			B[3]		C
Bankfull width/depth[W,NW]	F[3] C[4]	D[4]	D[4] B[5]	B[4]	C[4]	C[3] D[4]	D[4]	A
Pools per unit length[W]	D[4]	F[4]	D[4]	D[4]	C[4]	F[4]	D[4]	
Floodplain width[W,NW]								
Side channel habitat[W,NW]								
Flow category[W,NW]								
Benthic macroinvertebrates[W]								C
Residual Pool depth[W]	B[4]	F[4]	B[4] B[5]	C[4]	C[4]	A[3] B[4]	A[4]	A
Bank stability[W]								F,F
Relative bed stability[W]								
Density / distribution instream wood[W,NW]	B[3]A[4]	C[4]	F[3]A[4]	A[4]	A[4]	D[3] A[4]	A[4]	B,D
Particle size (D50)	B[3] C[4]		C[3] B[4]			B[3] B[4]	C[4]	
Particle size (percent fines)	A[3] C[4]	F[4]	A[3] C[4]		C[4]	A[3] B[4]	D[4]	
Shade[W]								D,A
Riparian canopy[W,NW]								
Riparian understory[W]								

* Indicators were previously labeled “metrics” in the Monitoring Design Report
Blank cells indicate no applicable signal to noise ratios or ratings identified
W Wadeable
NW Non-wadeable
1 S:N ratios converted to letter grades from Merritt and Hartman, 2012. If a log transformation improved S:N ratios, the letter grades for the transformed data are reported
2 Merritt and Hartmann 2012. When two grades are present from the same source document, the first is for wadeable streams and the second is nonwadeable rivers
3 Whitacre et al. 2007
4 Roper et al. 2010
5 Kauffman et al. 1999

1.7 Sampling Procedure Guidelines for Habitat and Biological Indicators

The sampling procedures for collection of habitat and biological indicators are based on numerous existing protocols. The Puget Sound Water Quality Action Team published a compilation of water quality procedures for environmental sampling and analysis (Puget Sound Protocols and Guidelines http://www.psat.wa.gov/Publications/protocols/protocol.html). In addition, Puls et al. (2014) documented seven primary monitoring programs in the Lower Columbia, each with associated protocols and sampling procedures:

1. Aquatic and Riparian Effectiveness Monitoring (US Forest Service and Bureau of Land Management)
2. Columbia Habitat Monitoring Program (Bonneville Power Administration)
3. Long-term Index Site Monitoring (Clark County, WA)
4. National Rivers and Streams Assessment (Oregon Department of Environmental Quality)
5. ODFW Aquatic Inventory (Oregon Department of Fish and Wildlife)
6. Reach-Scale Effectiveness Monitoring (Salmon Recovery Funding Board)
7. Watershed Health and Salmon Recovery (Washington Department of Ecology)

Table 4 indicates which protocol the sampling procedures for each indicator (described in detail in Section 3.2) draws from most heavily.

Table 4. Habitat and biological indicators and the protocol the procedures follow most closely.

Habitat and biological indicators*	Protocol the procedures follow most closely
Sample reach length[W,NW]	Ecology[1]
Channel type[W,NW]	Ecology modified to apply Montgomery and Buffington, (1997) categories
Reach slope[W,NW]	EMAP[2]
Sinuosity[W,NW]	None
Bank modification[W,NW]	EMAP
Density of habitat types	EMAP
Bankfull width/depth[W,NW]	ODFW[3], EMAP
Pools per unit length[W]	Ecology
Floodplain width[W,NW]	ODFW, Rapp and Abbe (2003)
Side channel habitat	CHaMP[4]
Flow Category	ODFW
Benthic macroinvertebrates	Ecology
Residual pool depth	ODFW
Bank stability	EMAP
Relative bed stability	Kaufmann et al. (2008)
Density/distribution instream wood	AREMP[5]
Substrate particle size (% comp by particle size category)	CHaMP
Shade[W]	Ecology
Riparian canopy (% cover) [W,NW]	Ecology
Riparian understory (% cover) [W]	Ecology
Temperature	CHaMP

* Indicators were previously labeled "metrics" in the Monitoring Design Report

[W,NW] Wadeable, Non-Wadeable

[1] Merritt, 2009, Merritt et al. 2010

[2] Lazorchak, et al. 1998

[3] Moore et al. 2014

[4] CHaMP 2015

[5] AREMP 2010

1.7.1 General field safety considerations

In any field data collection effort, there can be significant risks. It is the responsibility of each crew member, not just the crew lead, to insure the health and safety of crew members. A written health and safety plan must be prepared prior to the commencement of field activities. The health and safety plan must include at a minimum: phone numbers and a communication tree for notification should an emergency occur; maps to the nearest hospital, fire station, and/or emergency response facility; and the enumeration of the anticipated potential hazards.

All crew members must review and sign the health and safety plan during a field work "tailgate" kick-off meeting. During the tailgate meeting, the crew lead will summarize the potential hazards and ensure that all crew members are aware of safety procedures and appropriate lines of communication.

At least two crew members must be present during all field sampling activities. In areas where water or sediment contamination is known or suspected, exposure to water and sediments should be minimized. Crews may encounter hazardous materials, or sample preservatives may be hazardous if handled inappropriately. Crews should not disturb or retrieve improperly disposed hazardous materials. Field personnel should be familiar with the signs of heat stroke and hypothermia, and there should always be at least one person trained in first aid and CPR on every field crew.

1.7.1.1 Wadeable streams

Common hazards in wadeable streams include slip, trip and fall hazards; submerged objects; poisonous snakes, insects, and plants; and adverse weather conditions.

- Field crews must wear appropriate personal protective equipment (PPE), including waders (or at a minimum neoprene booties), hats, sunglasses (or safety goggles as needed), and should use sunscreen on exposed skin. When waders are worn, they must be equipped with a belt
- Extreme care should be used when walking on rip rap as rocks can easily shift
- LWD must be navigated carefully to avoid falls or getting pinned between pieces of debris
- First aid kits must be available at all times
- Appropriate gloves must be worn when agitating substrate for the collection of benthic macroinvertebrates
- Personnel with allergies to bees, other insects, poison oak, etc., must take proper precautions and have needed medications at the ready
- Motor vehicles must be operated with care and in observance of all applicable laws and regulations.
- Crews in remote locations must be equipped with radios or satellite phones
- Crew leads must ensure that all equipment is in safe working order
- Sampling should be discontinued during thunderstorms

1.7.1.2 Non-wadeable streams

In addition to the above hazards, non-wadeable streams present an additional level of danger.

- All crew members must wear a personal flotation device (PFD) when operating or working from a boat
- The boat operator should have a “kill switch” clipped to their person to avoid a runaway boat should they fall overboard
- All boats must be equipped with fire extinguishers, horns (on-board or compressed air), flares, and floatation cushions or ring buoys

1.7.2 Benthic collection methods; sample containers, identification, transportation, and chain of custody

Sampling will follow established State of Washington protocols (Appendix G in Merritt 2009). This method describes how to collect benthic macroinvertebrate samples for conducting community level assessments in Washington’s Status and Trends Program.

Benthic macroinvertebrate samples should be stored in sample jars with ethanol. All sample bottles should be clearly labeled, and chain-of-custody procedures described in Section 3.1.2 should be followed to avoid any loss or mis-assignment of data.

1.8 Sampling Procedure Guidelines (Field) for Water Quality

The indicators recommended for measurement at each urban+NPDES site for water quality and biology are as follows (Table 5):

Table 5. Water quality indicators for the recommended base monitoring program.

Water quality indicators*	Recommendation
Water temperature	X^c
Sediment metals	X^5
Sediment PAHs	X^5
Conductivity	X^c
Other indicators	
Stage (surrogate for flow)	X^c
Macroinvertebrate Index (EPT Percent)	X^a
Habitat indicators at Qa/Qx sites	
Bankfull width, depth	X^5
Wetted width, depth	each visit
Substrate composition	X^5

* Indicators were previously labeled "metrics" in the Monitoring Design Report
X^5 = data collection once per 5-yr permit cycle
X^a = annual data collection
X^c = continuous collection

Other parameters recommended for consideration in future years of the program are chloride and periphyton. Their incremental benefits for characterizing the status and trends of streams of the Region are uncertain at present, but they may be informed by the findings of other programs' efforts in future years and should be (re)considered as additional data and conclusions from other relevant studies across the region become available.

1.8.1 Scientific collection permits

The necessary permits for sampling macroinvertebrates will be obtained from the Washington Department of Fish and Wildlife (http://wdfw.wa.gov/licensing/scp). None of the other sampling recommended in this Implementation Plan is anticipated to require collection permits.

1.8.2 Field considerations

As with field data collection for habitat metrics (Section 1.7), matters of field safety should be carefully attended to for any such activity. Specific to the collection of samples under this program, sediment samples for PAH and metals analysis should be collected in glass containers and stored in a cooler held to 6°C or less for no more than one week (USEPA 1982). Benthic macroinvertebrate samples should be stored in sample jars with ethanol. All sample bottles should be clearly labeled, and chain-of-custody procedures described in Section 3.1.2 should be followed to avoid any loss or mis-assignment of data.

1.9 Measurement Procedures (lab) for Water Quality and Biological Indicators

Ecology's Laboratory Accreditation Program maintains a searchable database of accredited laboratories that may be accessed from this website: http://www.ecy.wa.gov/programs/eap/labs/lab-accreditation.html.

1.9.1 Sediment metals and PAHs

Sediment metal analyses will be conducted at a laboratory to be determined in consultation with the Steering Committee and Technical Review Community. Ecology's Laboratory Accreditation Program maintains a searchable database that may be accessed from this website: http://www.ecy.wa.gov/programs/eap/labs/lab-accreditation.html. (Laboratory methods and reporting limits are listed in the Quality Control section).

1.9.2 Benthic macroinvertebrates

Taxonomic identification will be conducted by a lab that employs taxonomists certified by the Society for Freshwater Science with experience with the freshwater macroinvertebrates of the Pacific Northwest. Based on guidance from the habitat caucus and to be consistent with other regional monitoring programs, the target subsample size will be 500 and identification will be conducted according to Level 2 of the Northwest Standard of Taxonomic Effort http://www.pnamp.org/project/4210.

1.10 Quality Control Procedures

1.10.1 Field (water quality, habitat, and biological)

An overarching focus for indicator selection has been to use only those indicators with relatively high levels of measurement precision and signal-to-noise. For water quality indicators measured with on-site sensors (water temperature, conductivity, stage), typical values for data quality and bias are within a few percent. The accuracy and instrument bias of each sensor will be verified through post-deployment calibration checks following the procedures described in Swanson (2007) and with deployment, retrieval, and monthly grab check samples collected as described in Ward (2007).

For those samples that are field-collected and transported to a laboratory (benthic macroinvertebrates and sediment), established procedures for preservation, holding times, and chain-of-custody will be followed. Field replicates will be used to evaluate the representativeness of the data. Habitat indicators will be measured using established, field-tested protocols (Section 3.2) by trained crews, with multiple checks during the recording, transferring, and data entry of field-collected information.

1.10.2 Laboratory (water quality, biological)

Sediment and benthic and macroinvertebrate samples are the only samples that will need to be analyzed by a laboratory. To ensure the quality and consistency of sample collections, equipment maintenance and sample collection protocols described in the appendices of this report will be followed. For the laboratory measurement of sediment PAHs and metals, bias and precision values should be less than 20–40% depending on the indicator (see Section 3.14) and will be checked through replicate samples. All laboratories used for the analyses will have their own approved internal quality-control procedures, which will be confirmed and documented prior to sample submission.

1.11 Data Management

Effective data management is an essential component of a successful monitoring program. For field-collected indicators, data will be entered onto field data sheets and checked for any errors on-site. Field sheets will be entered into Excel spreadsheets in the office, with a different team member comparing field sheets with the Excel files. For laboratory-reported indicators, original electronic spreadsheets will be archived and used to cross-checked against any subsequent analyses and reports.

Short-term data storage will occur through an access database. Final selection of a data management system is still pending. Following selection of a system, metadata, parameter formats and standard coding systems will be developed for site and geographic data, field data, laboratory analyses and data transfer. The format for reporting and recording of all data should be suitable for entry into the Environmental Information Management (EIM) system developed by Ecology and will be formatted consistent with that platform. In this way, data generated in this monitoring program can be recorded simultaneously in Ecology's data management system.

1.12 Data Verification and Validation

Data verification should occur at multiple steps in the process of collecting and analyzing monitoring data. In the field, all data recording sheets should be reviewed by all crew members before leaving the site. Analyses performed by an environmental laboratory will follow their own established procedures to ensure that results being reported are accurate. Both field and laboratory data records, following initial data entry should be verified against field forms and laboratory reports prior to final validation in the electronic database. Missing data are identified to ensure that values were not mistakenly overlooked during the data entry process. Printed copies of all stored environmental data should be made to ensure permanent records are available.

Incomplete or missing data are not anticipated to be a significant problem if data verification procedures are followed. Lost field forms could require a site revisit, but once entered into the database and a digital backup created, the risk of lost information is minimized. Lost laboratory samples are also very uncommon for accredited labs, and in the context of the overall HSTM program any such event would be unlikely to compromise the validity of the overall results unless criteria for completeness are not achieved.

1.13 Quality (Usability) Assessment

Following verification and validation, the variability, accuracy, and precision of the collected data will be compared with project objectives using professional judgment. If results do not meet criteria established at the beginning of the project, this will be explicitly stated in the annual reporting. Based upon data accuracy criteria, some data may be discarded. If this is found to be necessary, then the problems associated with data collection and analysis, reasons data were discarded, and potential ways to correct sampling problems will be reported. In some cases accuracy project criteria may be modified. Should that be necessary, the justification for modification, problems associated with collecting and analyzing data, as well as potential solutions will be reported.

1.14 Data Analysis, Audits and Reports

Data analysis procedures, roles, timing, and reporting recommendations were drafted for the Stormwater and Habitat Caucus Roles and Responsibilities report (Appendices A and B).

1.14.1 Data analysis

The program manager in consultation with the Steering Committee and Technical Review Committee will identify a data analysis manager in charge of data analysis and reporting. To accommodate contracting needs, interagency agreements for data analysis should be secured on a 5 year basis consistent with the reporting cycle of the program. This agreement should recognize the biennial funding cycle of most government agencies by inserting a clause related to funding contingencies.

Standard data analysis methodologies and reporting requirements are detailed in Section 3 of this report. The data analysis manager is responsible for analyzing the data on an annual basis between December and April, and providing a brief status update of those findings. Analysis and reporting should be a combined activity so that staff writing the report know the caveats and limitations of the data and corresponding analyses. This will increase the chances that the data is properly interpreted.

1.14.2 Audits

Audits ensure that quality assurance (QA) monitoring plan elements are implemented correctly. The quality of the data must be determined to be acceptable, and corrective actions must be implemented in a timely manner. There are two components of the auditing process:

- The Technical Systems Audit is a qualitative audit of conformance to the QA monitoring plan. The audit will be conducted soon after work has commenced so that corrective actions can be implemented early in the project. These evaluations include field collection activities, sample transport, laboratory processing, and data management components of the program.
- Proficiency Testing is the quantitative determination of an analyte in a blind standard to evaluate the proficiency of the analyst or laboratory. This audit is included for analysis of water quality samples as a routine procedure in the accredited laboratory. This type of testing is not possible for measurement of physical habitat variables using the suggested protocols.

1.14.3 Compiling/Disseminating reports and results

Compiling results and disseminating reports will be the responsibility of this data analysis and reporting manager. Once complete, the reports will be sent to the Program Manager for dissemination among the Technical Review committee for their review and comment prior to posting online and dissemination to the Steering Committee and interested parties.

The program manager will post annual status updates and 5-year status and trends reports to the program webpage. Findings will be disseminated by the program manager to NOAA, the Salmon Recovery Funding Board, Washington Department of Ecology, and other interested parties identified during the implementation phase of program development through distribution of an email with links. Links or copies of the reports should be posted on the PNAMP website to reach a broader regional audience.

Annual status updates will be generated by the data analysis and reporting manager between December and April of the year following data collection. This will allow some time for adaptive responses to the monitoring protocol before the coming field season. Five-year Status and Trends reports will be generated by the data analysis and reporting manager between December and July following every 5th year of data collection.

A more detailed report of both year-5 status and overall trends (from inception of monitoring to current year) on a regional basis will be generated between December and July every 5 years, consistent with the guidance in the implementation plan. Final updates and reports should be submitted to the program manager for review by the Technical Review committee. Upon incorporation of the Technical Review committee's comments, the program manager will finalize the document, post it online (program webpage and PNAMP), and send email notification to the Steering committee and interested parties.

2 PART 2: SAMPLE SITE SELECTION

2.1 Sampling Site Selection and Evaluation

2.1.1 Evaluation under the sampling design

Sample site selection and evaluation occurs at two levels in this program. The first level, described in Section 1.5, involved the stratification of the target population into physically meaningful strata, appropriate to the monitoring activities and intended uses of the data, by use of GIS characterization of the stream and watershed characteristics associated with each point in the Master Sample. The second level, the actual determination of whether monitoring can occur at the designated location, is covered below (Section 2.1.3).

Within each unique strata combination (bin), 15 "viable" monitoring sites are needed to meet the statistical objectives. Because of recognized challenges with site access, a working assumption based on experience in the RSMP program is that about twice as many "provisional" sites need to be identified and evaluated in order to meet the final target number. In other words, individual strata combinations should have at least 30 points initially identified. To be conservative, we increased that recommendation and identified 45 candidate sites from the Master Sample for each bin (Appendix C). The 45 "provisional" sites should be sufficient to identify 15 "viable" monitoring sites within a bin. A bin must have at least 15 possible candidate sites in order to be included in the random draw. It is also important to consider the fact that sites must be physically independent of one another. This is unlikely to be an issue for the forested parts of the Region, given the vast number of channel segments. Due to a small number of sites that drain watersheds with predominately urban or agricultural land cover, however, it is likely that more than one regional monitoring site could be selected within the same stream segment. To avoid such clustering of sample locations and ensure the best possible distribution of sites, only one regional monitoring site will be sampled per stream segment. If 15 sites are ultimately not monitored for a viable bin, a detailed list will be kept of the sites not sampled and reasons for not sampling will be used when adjusting the sample weights prior to statistical data analysis.

Within the urban+NPDES areas of the region, the selection of a single stratum (stream segments with watersheds draining 2.5-50 km^2 and predominately urban land cover) and the presence of preexisting sampling locations (the legacy sites of Clark County and the City of Vancouver) results in a modified approach to site selection. First, the total number of segments meeting these criteria is 25, and so with a suitable rotating panel design they can all be sampled within a five-year period: this leads to true *census* sampling rather than *representative* sampling. Second, 20% of the sites already have known access (i.e., the legacy sites), and virtually all of the others like in close proximity to roads, bridge crossings, or other likely access points. Thus, well more than half of these sites are anticipated to be accessible at some point along the stream segment that contains them. For purposes of this Implementation Report, it is assumed that all will prove to be feasible.

Across the regional sites, however, these conditions generally do not apply, and access to sites will undoubtedly be a limiting (or at least logistically challenging) factor for many of those that are selected by random draw from their respective strata. This may require a revisit and augmented selection from the Lower Columbia Master Sample to acquire a sufficient number of actual monitoring sites. The process of initial random selection, the outcome of site evaluations, and any subsequent re-drawing of additional points from the Master Sample will be documented in the initial report write-ups for the first year's implementation of the program. In particular, the basis for site rejection will be highlighted.

Site evaluations, including a field visit to each candidate site, will be used to determine the suitability of each site for monitoring to meet the HSTM goals. Site suitability will be determined by selection criteria related to accessibility, hydrologic and geomorphic characteristics (flow, physical features, and salinity), and location relative to a candidate sites' original coordinates (see below).

In order to maximize the statistical rigor of the monitoring program and to be consistent with other regional monitoring designs (e.g., AREMP), regional monitoring sites will be visited in a rotating panel design as illustrated in the graphic below such that 1/5th of the sites would be visited each year and the full region will be sampled within a 5-year time period. To enable "repeat visits", the sites monitored in years 1–5 will be resampled according to the same annual schedule in years 6–10, 11–15 and so on. Given this implementation approach, regional status can be assessed annually for sites sampled in any given year, whereas trends will be evaluated at "repeat sites" on a 5-year rotation beginning in year 6.

	Year									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Group A	X					X				
Group B		X					X			
Group C			X					X		
Group D				X					X	
Group E					X					X

Desktop evaluation of candidate regional sites will be performed in advance of the initial site evaluation visit, and will include comparing candidate site coordinates to existing information on such items as surficial geology, parcel/property ownership, NHD waterbody type, historical stream flow and/or water quality data, and aerial photographs. For all of the initial candidate sites deemed unsuitable for monitoring, additional candidate sites for the relevant assessment region will be evaluated in the numerical order listed in the Master Sample Site list (from lowest to highest in the ORDER column).

For the special case of identifying locations for sampling Qa/Qx parameters within the urban+NPDES areas of the Region, “sites” are considered the entire stream segment along which the criteria of drainage area and land cover are met (see Figure 2 for their graphical display). Where a legacy site exists along a designated segment, it will presumably function as the actual monitoring location for this program. For those designated segments without a legacy site, desktop identification of prospective sampling location(s) should proceed from downstream to upstream, targeting the most promising locations for subsequent field checking. Preference should be given to the downstream-most location that meets all criteria for access, safety, and flow suitability (Section 2.1.3).

The locations of potential sampling sites is difficult to display because the full population of >100,000 Master Sample points cannot be shown on a single page. Thus, only partial representations are possible in a written report. Several such examples are shown below (Figure 2 through Figure 5); specific sampling locations are provided as separate digital files as part of the Implementation Plan.

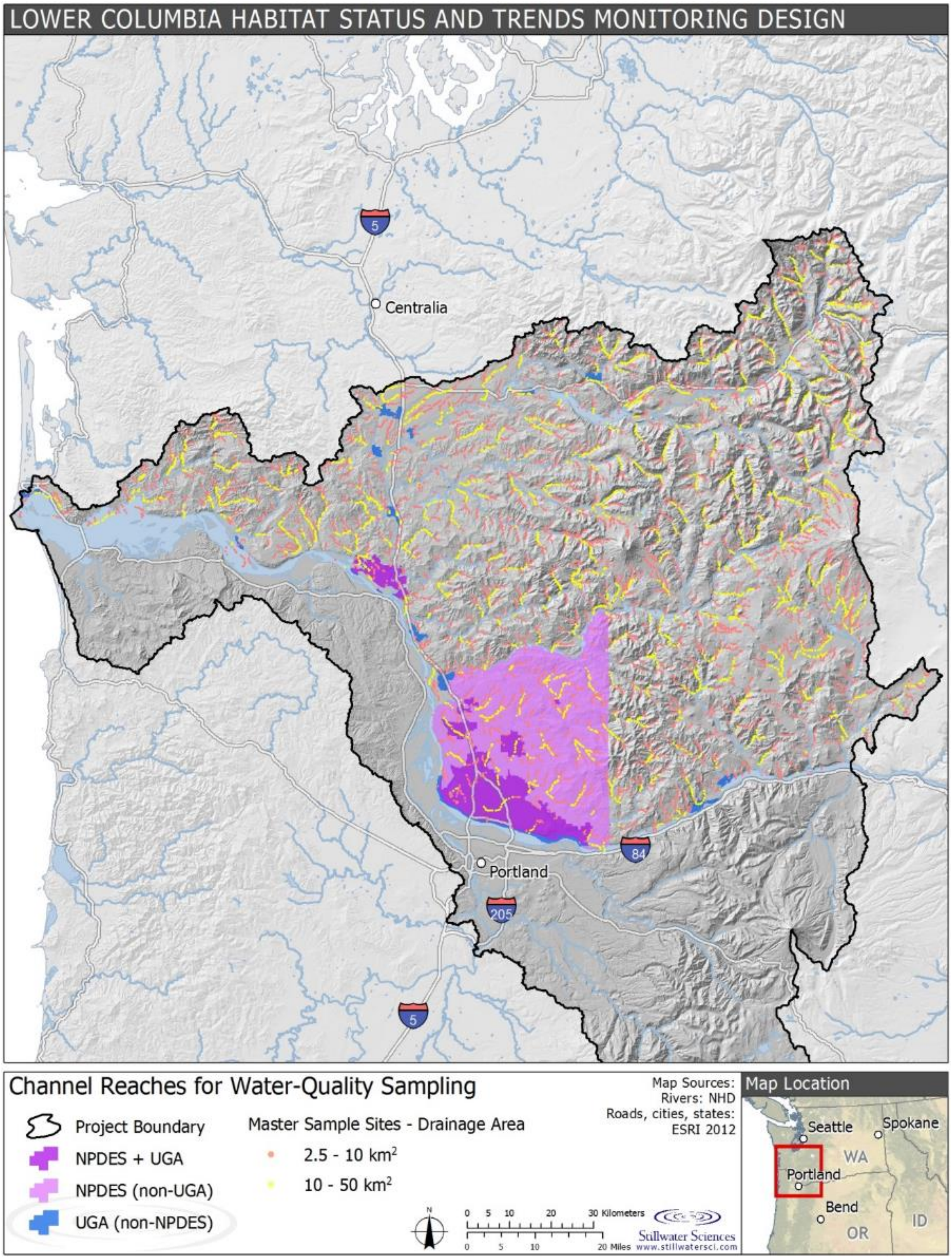


Figure 2. Stream segments that contain Master Sample points meeting the drainage-area criteria of 2.5-10 km^2 (red) or 10-50 km^2 (yellow).

The example below shows the distribution of legacy sampling sites in Clark County relative to only those Master Sample points that meet the criteria of having drainage areas between 2.5 and 50 km^2 and that drain watersheds with predominately urban land cover.

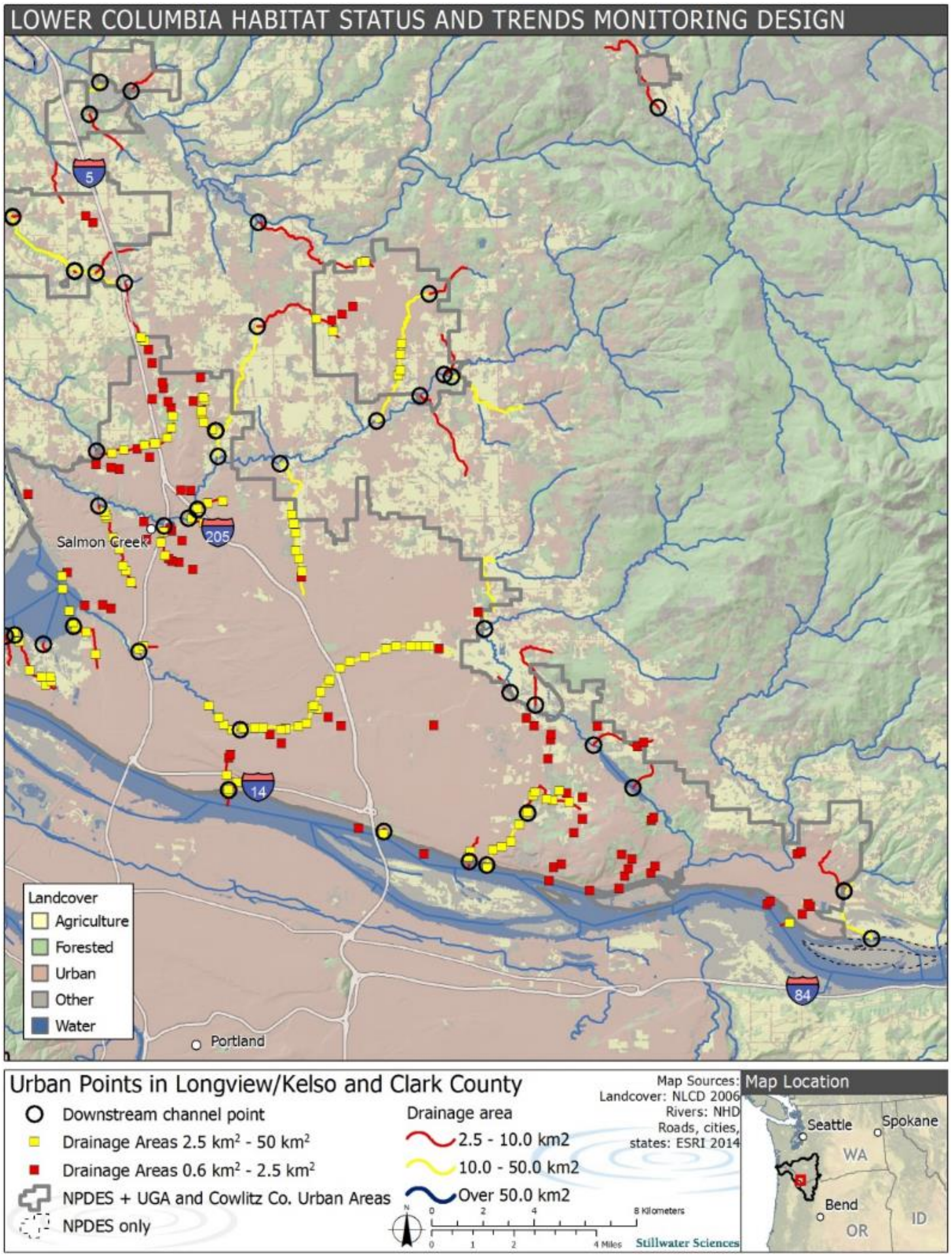


Figure 3. GIS view of the Master Sample points in Clark County (dark pink area). Individual points meeting the recommended drainage-area criteria and that drain watersheds with predominately urban land cover are indicated by red squares (2.5-10 km^2 drainage area) or yellow squares (10-50 km^2). All such locations that correspond to a qualifying master sample point (i.e., red or yellow square) constitute the set of "trend" urban+NPDES sampling sites referenced in this report, with their downstream-most locations indicated by black circles.

Two additional examples show the distribution of Master Sample sites draining watersheds with predominately urban (Figure 4) and agricultural (Figure 5) land uses, providing the basis for selecting sites within these land-cover categories for the regional sampling.

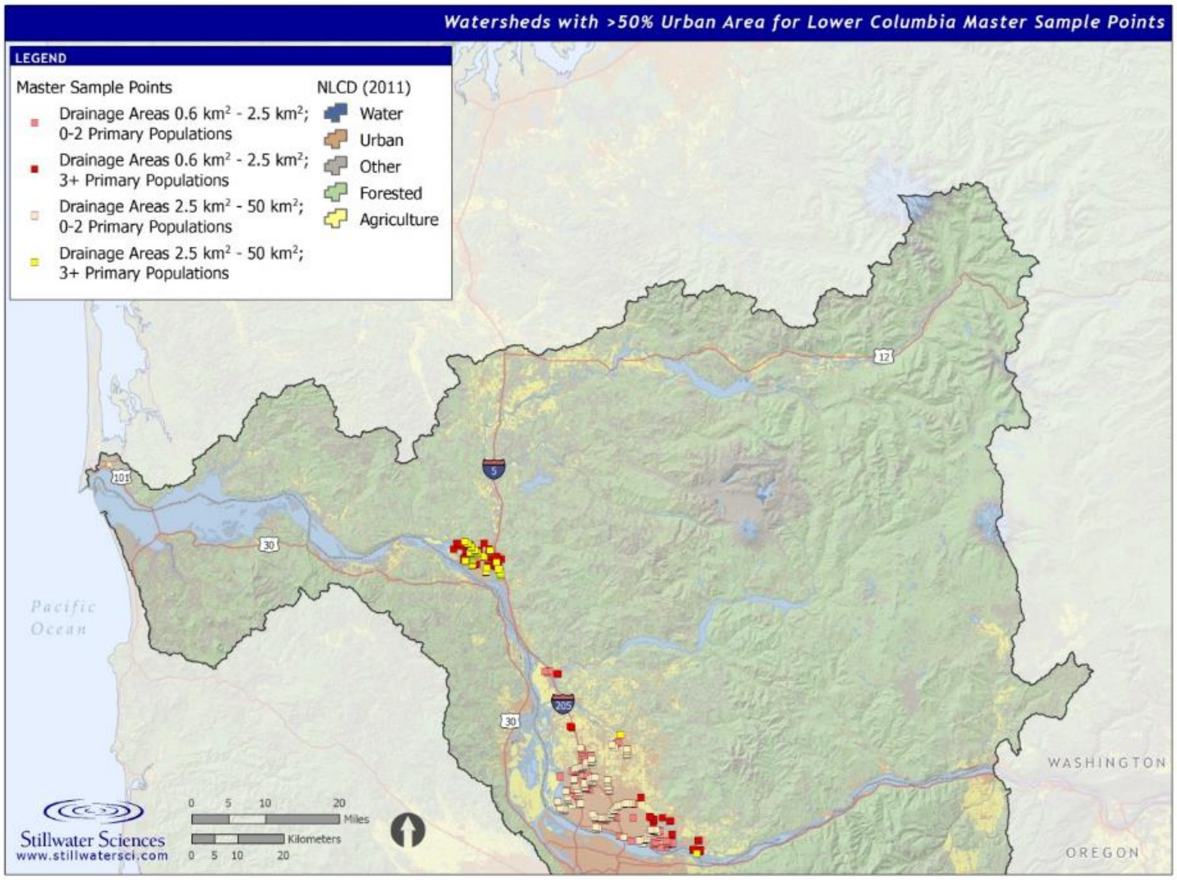


Figure 4. Master sample points draining watersheds with predominately urban land cover. Points are stratified with respect to drainage area and number of primary populations associated with the larger watershed within which they are located. Note the near-absence of such points outside of urban+NPDES areas.

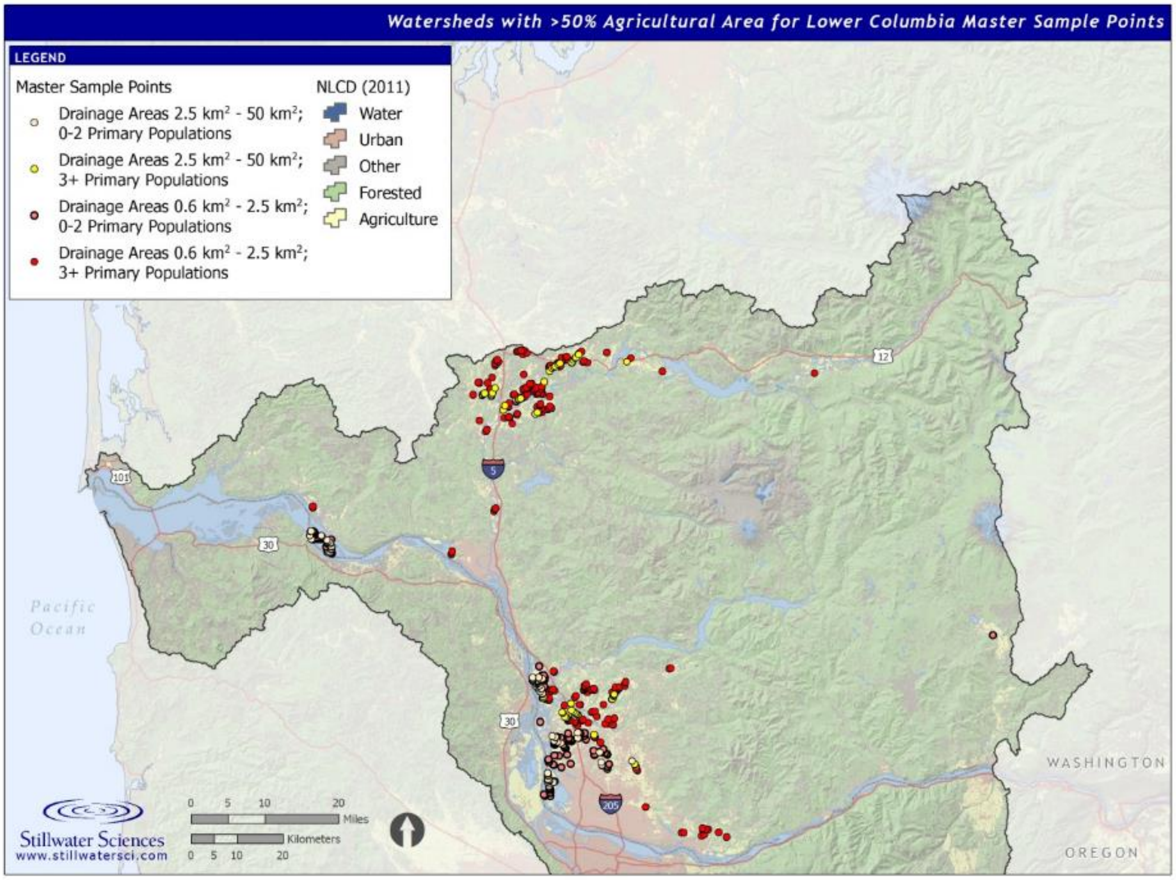


Figure 5. Master sample points draining watersheds with predominately agricultural land cover. Points are stratified with respect to drainage area and number of primary populations associated with the larger watershed within which they are located.

Due to the large number of sites in the master sample (>100,000), it was infeasible to calculate the dominant watershed drainage for all potential sample sites. However because there are only a limited number of sites that meet the criterion of having a predominate watershed land cover of "urban" or "agriculture," a GIS analysis was run to determine how many of the strata combinations will have a sufficient number of Master Sample points to have sufficient master sample points to merit inclusion in the final implementation Tables 6 and 7). Such data were also used to generate the costs estimates in Section 1.3.4.

Table 6. Monitoring sites within urban+NPDES areas that also drain watersheds with predominately urban landcover. Strata combinations that meet the minimum site number criteria (≥15 sites) are shaded.

0-2 Primary Populations

Drainage area	<1.5%	Gradient class	
		1.5–3%	3–7.5%
0.6–2.5 km^2	25	14	15
2.5–50 km^2	83	14	7

3+ Primary Populations

Drainage area	<1.5%	Gradient class	
		1.5–3%	3–7.5%
0.6–2.5 km^2	46	8	3
2.5–50 km^2	33	0	2

Table 7. Monitoring sites outside of urban+NPDES areas that also drain watersheds with predominately agricultural landcover. Strata that meet the minimum site number criteria (≥15 sites) are shaded.

0-2 Primary Populations

Drainage area	<1.5%	Gradient class	
		1.5–3%	3–7.5%
0.6–2.5 km^2	88	8	3
2.5–50 km^2	59	6	0

3+ Primary Populations

Drainage area	<1.5%	Gradient class	
		1.5–3%	3–7.5%
0.6–2.5 km^2	136	27	44
2.5–50 km^2	46	13	0

For the remaining sites that are not classified as urban or agricultural, the project team will run a GIS analysis on the 45 sites/strata randomly selected from the Master Sample (Appendix C) to confirm that they are in fact sites that drain watersheds with predominantly forested land cover, with the expectation that this will overwhelmingly be the case. Despite the absence of such analysis at present, the forest land cover classification provided in the Design Report to reliably infer that 26 strata combinations meet the minimum site criteria (Table 8).

Table 8. Monitoring sites outside urban+NPDES areas classified as forested. Strata that meet the minimum site criteria (≥15 sites) are shaded.

Drainage area	Slope	Urban+NPDES	Regional	
		Primary population categories		
		0–2	0–2	3+
0.6–2.5 km^2	<1.5%	9	68	320
	1.5–3%	7	115	362
	3–7.5%	9	434	1257
2.5–50 km^2	<1.5%	15	199	794
	1.5–3%	13	285	753
	3–7.5%	2	687	1627
50–200 km^2	<1.5%	6	97	337
	1.5–3%	1	98	195
	3–7.5%	1	44	169
200–1,000 km^2	<1.5%	1	135	197
	1.5–3%	0	33	43
	3–7.5%	0	33	15
>1,000 km^2	<1.5%	0	2	44
	1.5–3%	0	0	5
	3–7.5%	0	0	3

Note that there are no strata with 15 or more Master Sample points with predominate watershed land cover of "urban" outside the urban+NPDES area. Likewise, there are no strata with 15 or more Master Sample points with predominant watershed land cover of "agricultural" inside the urban+NPDES area. The results (Tables 6, 7, and 8) thus indicate that no more than 37 strata combinations (i.e., 5 urban, 6 agricultural, 26 forested) will meet the minimum-number criterion in the Lower Columbia Region, which has significant cost implications for the final design of the regional sampling program—37 strata with 15 sites/strata results in 555 regional monitoring sites.

This sampling design has been motivated entirely by the measurements required to answer the ten monitoring questions presented in Section 1.2.1, and by the scientific understanding of how various physical, chemical and biological attributes of streams vary by location and watershed characteristics.

2.1.2 Mid-study changes affecting site suitability

If a site becomes unsuitable for sampling during the course of the study, the Monitoring Coordinator will be notified. Reasons a site may be come unsuitable include, but are not limited to: a stream goes dry; the adjacent parcel(s) change ownership, and the new owner does not grant permission; or natural causes such as mudslides or animals make the site no longer safe to access. A decision about whether to simply discontinue the site or to identify a replacement site within the same strata combination will be made by project partners on the basis of its position in the rotating panel design, the amount of data already collected, and whether the strata combination would become underrepresented if the site (and, potentially others) were simply discontinued without replacement.

2.1.3 Field criteria for selecting a suitable sampling site

The process may need to continue through the sampling season as necessitated by potential changes in site conditions that affect suitability for sampling. Selection criteria for determining the suitability of a candidate site for monitoring to meet the HSTM goals are described below.

2.1.3.1 Accessibility criteria

These criteria concern whether land owners permit access to a site, and if the site can be safely accessed and sampled throughout the year. A site may also be deemed unsuitable or impractical for sampling certain if more than one hour is required to access the site from the nearest parking location.

If a candidate site is not obviously accessible through public property, property owners and/or tenants whose property will need to be accessed will, if feasible, be contacted prior to site evaluation. Parcel information gained from the desktop evaluation will be researched and a good faith effort to contact owners or tenants will be made. A site will be deemed unsuitable for sampling if permission has been denied by all land owners, tenants, or resource managers along the entire hydrologic reach. The Washington State Department of Natural Resources (WDNR, 2010) describes how to discern public and state-owned waters.

Overall safety conditions for access and sampling will be assessed prior to sampling, based on state and federal law and organizational policy. But it is ultimately the responsibility of the field crew at each time of arrival to decide if it is safe to enter the stream to conduct the sampling. Appropriate reasons for disqualifying a site from sampling may include:

- Flow is too swift or too deep
- Route of entry is unstable
- Hostile people or animals are present

2.1.3.2 Flow, physical, and salinity criteria

These criteria concern the conditions of the stream and streambed with regard to the specific types of data desired. To be considered a suitable sampling site, the waterbody at the candidate site coordinates must be on a stream or small wadeable river, and not on a lake, pond, wetland, or estuary. Specifically, the waterbody must have:

- A net flow of water that is unidirectional
- Defined left and right banks readily discernible from mid-stream
- Uninterrupted surface-water flow for more than half the length of approximately 20 bankfull widths or a minimum of 150 meters surrounding the candidate site coordinates
- Perennial flow (as best as can be determined at the time of the site visit)
- Flow in a natural channel that might have been highly modified, but was not constructed (such as canals, ditches, or pipelines)
- Natural substrate on the channel bottom
- Freshwater, as defined by a water column with more than 95 percent of its depth with less than 1 part per thousand salinity at any time during the year. Multiple lines of evidence

may be used to make this estimation (*e.g.*, vegetation, proximity to a known estuary, or salinity measurement). As noted in the Design Report, streams subject to backwater from the Columbia River are not considered suitable sampling sites for this program.

2.1.3.3 Location criteria

The following location rules apply such that the site reflects the intended probabilistic stream characteristics.

- During the site evaluation field visit, the field crew will attempt to access the site at the given coordinates or as nearby as possible, with recognition of the challenges of sampling in urban areas, particularly in gaining access to discretely defined locations. Ideally, a suitable sampling location will be located within 250 meters of the given candidate site coordinates.
- If access, flow, physical, and chemical criteria are not met within this distance, the field crew may continue to investigate locations upstream and downstream of the initial reach with the objective finding a suitable site that maintains the original candidate site characteristics.
- Suitable sampling sites upstream and downstream of the candidate site coordinates must fall within these constraints:
  - the final site is the same size class of the original candidate site;
  - there are no continuous surface-water inflows in excess of approximately 25 percent of the flow already in the reach; and
  - either :
    - there is no substantial, abrupt change in adjacent land use such as from residential to industrial, or from native vegetation to developed conditions; or
    - the final site is less than 500 m from the original candidate site coordinates.

2.1.4 Representativeness

"Representativeness" is a property of both the region being assessed and the parameter being measured (Ecology 2006). The probabilistic sampling design is intended to achieve statistically valid spatial representations of stream status and trends at the scale of the entire Lower Columbia Region. Most field measurements (except for those made by continuous data-collecting sensors) will be conducted in the summer, a period when hydrologic, physical, and biological conditions are most stable and the likelihood of confounding high flows is low. Ensuring that the laboratory measurements of field-collected samples are representative of those field conditions, established procedures for sample holding time, equipment calibration, and analytical duplicates as described for each parameter below.

Representativeness of water-quality parameters is particularly enhanced by the Phase 2 Design Report's emphasis on collecting continuous parameters in real time, eliminating the uncertainties associated with the time-varying nature of most water-column constituents.

2.1.4.1 Field measurements

Most of the field measurement and data collection for Qa/Qx monitoring will be conducted at the downstream-most location of an identified stream segment that meet criteria for feasible logistics for access and site security. Most of the indicators are in the water column and are not anticipated to vary greatly throughout the stream segment. For those with collection at specific locations and with particular site requirements (i.e., sediment metals and PAHs, and macroinvertebrates), the conditions necessary for representative field measurements are specified in this document as part of the measurement protocols.

Most of the field measurements conducted at habitat sampling locations are conducted throughout the entire 20×-bankfull-width-long reach, ensuring that results are truly "representative" of the reach. This distance is designed to include multiple pool-riffle or step-pool sequences in an alluvial channel coupled with measurements at 11 transects to avoid overrepresenting unique characteristics of any one segment. Variability will be reduced through refinement of site selection and rotating panel designs. Field personnel will record where samples are measured and note general descriptions of physical conditions of the channel, gradient, habitat types, water velocity, weather, and other parameters or unique local features that could influence data quality. These narrative field notes can be used to qualitatively assess how well the data represent the conditions characterized by this study, should any questions later arise about the representativeness and accuracy of the measured indicators.

2.1.4.2 Laboratory measurements

Typical protocols to ensure the representativeness of lab data is to provide triplicates of every 20th sample, with a goal of <5% variability as the standard. This provides a high confidence that each sample accurately reflects a representative value of the measured parameter. Because each year's sampling under this program will only include nine water-quality samples for laboratory analysis, however, this guidance should be modified to randomly select one of those nine samples for triplicate measurement.

2.1.5 Comparability

All sites with once-per-year measurements will be visited during summer low-flow conditions, and the field methods will be documented in sufficient detail to ensure comparable results. The selection of indicators has been guided by the need to avoid those with recognized high levels of observer variability, and so many of the problems of (in) comparability that plague other such monitoring efforts have been addressed through the initial design. For sites with continuous data collection, field sensors will be similar or identical at all sites, and episodic calibration with hand-held sensors will ensure that the data are equivalent across all sites.

2.1.6 Completeness

Completeness will be calculated as a percentage of the number of valid samples that should have been collected relative to the number that actually are obtained. The standard for completeness is 90% in order that the data can be determined as valid in proportion to the goals for the project as a whole.

2.2 Candidate Site List for Monitoring Sites

A candidate site list is provided in Appendix C with 45 sites for each viable strata combination. As detailed in Section 2.1.3 of this report, sites will be evaluated according to selection criteria for suitability. The first 15 sites, of the listed 45, that meet sampling criteria will be identified as the monitoring sites for a given strata.

3 PART 3: INDICATORS

3.1 Water Quality Indicators for urban+NPDES Sites

3.1.1 List of base indicators

The Qa/Qx indicators recommended for this HSTM program have been identified on the basis of historic utilization and regional experience, prior recommendations from Phase 1 of this project (and archived in Tetra Tech 2013), known issues with data quality and variability, cost of implementation, and direct relevance to the monitoring questions that are guiding this program. Relative to many other water-quality monitoring programs, the most noteworthy aspects of this recommended program are its emphasis on continuously monitored (or otherwise integrative) indicators, and the overall brevity of the list. These outcomes are driven by considerations long-articulated by project partners and stakeholders: statistical and scientific rigor of the chosen indicators, and feasible cost of implementation.

A rigorous, defensible indicator that is useful for regional status and trends monitoring needs to meet several goals: it should not be subject to significant variability that is dependent only on the vagaries of the day or hour when it is measured, its variability due to watershed and in-stream conditions should be high relative to the random or non-systematic variability that cannot be eliminated by the sampling protocol (i.e., a high signal-to-noise ratio), it should be responsive to the environmental stressors of greatest concern to resource managers, and its collection and analysis should be affordable.

Many traditional water-quality indicators, including many considered in earlier stages of this project, are challenged by one or more of these criteria. Most problematic are those that have been long-accepted as part of a “normal” or “conventional” stormwater monitoring program (e.g., National Research Council 2009), but which are known either to have high random variability (e.g., total phosphorus, total suspended solids, pH; Merritt and Hartman 2012) or to express instantaneous conditions that would require continuous water-column sampling that is likely cost-prohibitive because of the required degree of site maintenance (e.g., dissolved oxygen, dissolved metals, dissolved nutrients, turbidity) to generate useful data on regional status and trends.

Based on these considerations of both suitability and cost efficiency, a list of indicators recommended for measurement at each of these sites was presented in the Phase 2 Design Report and are described in Table 9. It is anticipated that these indicators will meet the requirements of the upcoming 2018 NPDES Municipal Stormwater Permit’s Special Condition S8.B, and their implementation will satisfy Ecology’s need for a statistically valid stormwater status and trends monitoring program. In this Implementation Report their collection and analysis is referenced as the “base program” for water quality at urban+NPDES sites.

However, stakeholders have also expressed the desire to gain further value from the HSTM monitoring program by collecting an expanded list of indicators. They have defined what is herein referenced as an “extended monitoring component” that will be implemented at the same sites, and following the same panel design as for the base indicators, to the extent that sufficient funds are available. The list of extended indicators is also presented in Table 9. Monitoring of these indicators will be conducted under the exclusive guidance of the Steering committee that is established to manage the stormwater monitoring program once implemented, and it will be supported on a funding-available basis from the pooled monitoring funds once the costs associated with collection and interpretation of the base indicators have been fully covered. The Quality Assurance Program Plan (QAPP) for the extended monitoring program, which includes the details of field and laboratory methods, is included as an appendix to the QAPP of this Implementation Plan.

Table 9. Water quality indicators recommended for measurement.

PRIMARY INDICATORS	
Water quality indicators*	**Recommendation**
Water temperature	X^c
Conductivity	X^c
Sediment metals	X^5
Sediment PAHs	X^5
Other indicators	
Stage (surrogate for discharge)	X^c
Macroinvertebrate index (EPT Percent)	X^a
Habitat indicators at Qa/Qx sites	
Bankfull width, depth	X^5
Wetted width, depth	each visit
Substrate composition	X^5
EXTENDED MONITORING COMPONENT INDICATORS	
Water temperature	X^m
Conductivity	X^m
Dissolved oxygen	X^m
pH	X^m
Turbidity	X^m
Total suspended solids	X^m
Total solids	X^m
Total nitrogen	X^m
Nitrate + nitrite-nitrogen	X^m
Total phosphorus	X^m
Dissolved copper	X^m
Dissolved zinc	X^m
Fecal coliform bacteria	X^m

* Indicators were previously labeled “metrics” in the Monitoring Design Report
X^5 = data collection once per 5-yr permit cycle
X^a = annual data collection
X^c = continuous collection
X^m = monthly collection (field meter or grab sample)

Other parameters recommended for consideration in future years of the program are chloride and periphyton. Their incremental benefits for characterizing the status and trends of streams of the Region are uncertain at present, but they may be informed by the findings of other programs’ efforts in future years and should be (re)considered as additional data and conclusions from other relevant studies across the region become available.

The overarching justification for nearly all of the indicators recommended for the Qa/Qx program was summarized by the Puget Sound RSMP, which provides a useful synopsis that is equally relevant to the Lower Columbia Region (Table 10, modified from Ecology 2011). Further discussion of this topic is provided in Section 4.

Table 10. Water quality indicators and associated rationale.

Indicators*	Rationale
Stage/discharge	Discriminating low-flow from high-flow periods is fundamental to interpreting other continuous parameters; alterations to the frequency and rate of change of stage/discharge is widely recognized as a (or *the*) major impact of land-use change on aquatic systems (e.g., NRC 2009).
Specific Conductance	Easily measured and correlates to the total dissolved solids.
Temperature	Key parameter affecting the health and survival of biological communities. Subject to state water quality criteria.
Sediment metals	A group of ecologically consequential heavy metals with defined sediment management standards in WA. Heavy metals contribute to toxic effects on aquatic life and impact the beneficial use of a water body.
Sediment polycyclic aromatic hydrocarbons	Associated with urban runoff and characteristic ensure for roadway impacts. Can accumulate in aquatic organisms and are known to be toxic at low concentrations. Can be persistent in sediments for long periods, resulting in adverse impacts on benthic community diversity and abundance.
Aquatic macroinvertebrates (B-IBI)	Integrates water quality and habitat impacts from stormwater over time (Karr 1998; Karr and Rossano 2001; Fore et al. 2001).
Physical Habitat (Slope and bearing, wetted width, bankfull width, bar width, substrate size, substrate depth, shade, human influence, riparian vegetation, large woody debris).	Urban development can alter basin hydrology and adversely affect stream channels (e.g., accelerated bank erosion, loss of LWD, reduced baseflow). Will aid in trend detection, interpretation of biological parameters, and stressor identification.

* Indicators were previously labeled “metrics” in the Monitoring Design Report

3.1.2 Field sampling procedures

Even before field measurements are taken, established procedures are required to ensure the highest degree of data quality. Field equipment will undergo routine cleaning, calibrations, and maintenance at the recommended frequency specified by each manufacturer and described in SOPs. For samples that require laboratory analysis (sediment metals, sediment PAHs, and benthic macroinvertebrates), chain-of-custody (COC) procedures are necessary to ensure thorough documentation of handling for each sample, from field collection to laboratory analysis. The purpose of this procedure is to minimize errors, maintain sample integrity, and protect the quality of data collected. A COC form will accompany each cooler of samples sent to a laboratory. Individuals who manipulate or handle these samples are required to log their activities on the form. When the laboratory receives a cooler of samples, it will assume responsibility for samples and maintenance of the COC forms. The laboratory will then conduct its procedures for sample receipt, storage, holding times, tracking, and submittal of final data to the responsible parties.

3.1.2.1 Continuous parameters

The sampling procedures will follow the detailed descriptions in Appendix D. Loggers will be deployed in locations where representative data may be obtained throughout the entire monitoring period. Combination probes for all three continuous parameters listed below may prove to be the most economical and feasible approach. All loggers will be deployed inside a ~2-foot-long piece of 1.5-inch camouflage-painted PVC pipe to shade them from sunlight and to prevent them from being found and vandalized. In addition, each deployment location will be photographed and have site-specific survey information documented on a standardized form.

- Water Temperature: Temperature loggers (e.g., VEMCO Minilog-II-T-351133) will be installed following manufacturer's instructions and downloaded on a regular basis, as determined by battery life and memory capacity. Spot checks during each visit will be made of temperature using a hand-held thermometer, with the time and temperature recorded in a field notebook for subsequent checking with the downloaded data to ensure that data-quality objectives are being met. The sampling protocols will follow the procedures described in the *Continuous Temperature Sampling Protocols for the Environmental Monitoring and Trends Section* (Ward, 2003) and in *the TFW Stream Temperature Survey Manual* (Schuett-Hames et al. 1999).
- Stage: Stage will be collected by permanent installation of a pressure transducer, following the manufacturer's instructions (e.g., those for the Solinst Leveloggers are available at http://www.solinst.com/Prod/3001/Levelogger-User-Guide/10-Levelogger-Installation-Maintenance/10-Installation.html). Manual stage measurements are also needed so data are available to confirm/correct the pressure transducer data (Appendix E5 of RSMP QAPP). Barologgers could be deployed to monitor atmospheric pressure conditions at each site, although the added expense is likely unnecessary given the intended uses of the stage data (see Section 4) and the relative magnitude and rate of change of the atmospheric correction.
- Conductivity: A conductivity probe (e.g., YSI 600LS) will be installed following manufacturer's instructions and maintained as described above.

3.1.2.2 Sediment metals and PAHs

This section draws on sediment sampling protocols for sampling and sieving composite sediment samples in streams from USGS National Field Manual (USGS, 2005) and NAWQA protocols (USGS, 1994) (Appendix C4 in RSMP QAPP). Procedures are derived from methods described in Johnson (1997), Blakley (2008a), and Manchester Environmental Laboratory (2008), with the additional sieving procedures described by Radke (2005) and Shelton and Capel (1994).

A composite sample will be collected at each stream segment, composed of 5 individual shallow-water sub-stations. Specific locations within a Qa/Qx sampling segment will be identified by field inspection to identify locations of water-deposited fine sand and silt-sized material, typically in alcoves and backwater areas, that have not been directly affected by local bank erosion. The composite sample will be delivered to the lab, where it will be processed (sieved) to make two unique samples. The first sample will be sieved to less than 2.0 mm and analyzed for multiple organic compounds (PAHs). The second sample will be sieved to less than 63 µm and analyzed for metals (arsenic, cadmium, chromium, copper, lead, silver and zinc). Prior to use, all equipment will be cleaned for organics and all sediment samples will be collected and handled with Teflon scoops, scrapers, and spatulas. Samples will be stored in glass only, held in coolers with ice after collection to maintain a temperature ≤6°C, and delivered to the lab within 7 days following the chain-of-custody procedures outlined above (USEPA 1982).

Specifications for minimum volumes of collected sediment will be made in conjunction with the determination of analytical laboratories to process the material. This will be about 10 g (dry weight) of sieved sediment.

3.1.2.3 Benthic macroinvertebrates

Sampling will follow established State of Washington protocols (Appendix D; Merritt 2009). This method describes how to collect benthic macroinvertebrate samples for conducting community level assessments in Washington’s Status and Trends Program.

Invertebrate sampling is one of the first methods to be performed on-site, after site verification and layout. It starts concurrently with water sampling, with initial components of the benthos sample collected downstream of the water sample. Working upstream, one kick sample is collected at each of 8 randomly selected transects, half of which are located mid-channel and half located within the margins of the stream. Each kick sample will be added to a composite sample for the site.

A different procedure is needed for the collection of each kick sample depending upon whether the station sits within flowing water or slack water. Flowing water is where the stream current can sweep organisms into the net; slack water is where water is so slow that active net movement is required to collect organisms.

- For sampling at flowing water stations, position a D-frame kick net and quickly and securely on the stream bottom to eliminate gaps under the frame. Collect benthic macroinvertebrates from a 1ft² (0.9 m²) quadrat located directly in front of the frame mouth. Work from the upstream edge of the quadrat backward and carefully pick up and rub stones directly in front of the net to remove attached animals. Quickly inspect each stone to make sure you have dislodged everything and then set it aside.
- For sampling at slack water stations, visually define a rectangular quadrat with an area of 1 ft² (0.09 m²). Inspect the stream bottom within the quadrat for any heavy organisms, such as mussels and snails. Remove these organisms by hand and place them into the sample jar. Pick up any loose rocks or other larger substrate particles within the quadrat and rub any clinging organisms off of rocks or other pieces of larger substrate (especially those covered with algae or other debris) into the net. Vigorously kick the remaining finer substrate within the quadrat with your feet while dragging the net repeatedly through the disturbed area just above the bottom.

For preservation, ethanol will be added to each sample jar so that the resulting solution consists of 1/3 sample and 2/3 ethanol. The sample jars will be stored by field crews and delivered *en masse* to the analytical laboratory at the end of the field season.

3.1.2.4 Monthly instantaneous and grab samples

The extended monitoring component of the Qa/Qx sampling includes eleven indicators that will be sampled during monthly field visits (Table 9), either by hand-held meter (water temperature and conductivity) or by grab sampling. Sampling procedures are discussed in the separate QAPP for that program.

3.1.3 Laboratory measurement procedures

This section discusses the laboratory QC procedures that will be implemented to provide high quality data. Field QC procedures were previously described as part of the Quality Control Procedures – Field section of this report. QC will be monitored throughout the duration of the study. The quality of raw, unprocessed, and processed data is subject to review according to established protocols in the Measurement Procedures section of this report.

This section discusses QC procedures that will be implemented by the contracted analytical laboratory to provide high quality chemical and physical analyses that meet these QAPP requirements. Contract laboratories will make every effort to meet sample holding times and target reporting limits for all parameters. Laboratory QC procedures and results will be closely monitored throughout the duration of the permit-mandated sampling. The quality of laboratory data is subject to review via the established protocols in the Measurement Procedures section. A typical schedule for laboratory QC samples is shown in Table 11 and, at a minimum, includes:

- Laboratory duplicates
- Matrix spikes
- Matrix spike duplicates
- Method/instrument blanks
- References (lab standards/surrogate standards/internal standards)

Table 11. A typical schedule for laboratory QC samples.

Quality control sample[1]	Analysis type	Frequency[2]	Corrective action
Laboratory Duplicates	Metals	5% of total samples or 1 per batch (method-specific)	Evaluate procedure; reanalyze or qualify affected data
	Conventional		
	Microbiology		
Matrix Spikes (full constituent list)	Metals	5% of total samples or 1 per batch	Evaluate procedure and assess potential matrix effects; reanalyze or qualify data
	Conventional	5% of total samples or 1 per batch	
	Organics	5% of total samples or 1 per batch	Evaluate duplicates and surrogate recoveries and assess matrix effects; evaluate or qualify affected data
Matrix Spike Duplicates[3]	Metals and Organics	At least 1 samples per year; Metals can be run either by MSD or lab duplicates at otherwise; 5% of total samples or 1 per batch	Evaluate procedure and assess potential matrix effects; reanalyze or qualify data
Method Blanks	Metals	5% of total samples or 1 per batch (method-specific)	Blank concentration may be used to define a new reporting limit. Evaluate procedure; ID contaminant source; reanalyze samples if blanks are within 10x concentration. No action necessary if samples are >10x blank concentrations
	Conventional		
	Organics		
	Microbiology		
Spiked (or Fortified) Blanks	Metals, Organics and Conventionals	5% of total samples or 1 per batch (primarily water)	Evaluate matrix spike recoveries; assess efficiency of extraction method; flag affected data
References (lab control standard, lab control sample, or standard reference materials)	Metals	5% of total samples or 1 per batch (spiked blank). If available, solid batches only: LCSs at 10% of total samples or 2 per batch (SRM/SRMD).	Evaluate lab duplicates/matrix spike recoveries; assess efficiency of extraction method; evaluate or qualify affected data
	Conventional	5% of total samples or 1 per batch	
	Organics	5% of total samples or 1 per batch (spiked blank). If available, solid batches only: SRMs at 10% of total samples or 2 per batch (SRM/SRMD).	
Surrogates	Organics	Surrogates frequency is 100%	Evaluate results; qualify or reanalyze or re-prep/reanalyze samples.
Internal Standards	Metals and Organics	Internal Standard frequency is 100% for GC/MS and ICPMS methods	Evaluate results; dilute samples, reassign internal standards or flag data.

[1] Quality control samples may be from different projects for frequencies on a per-batch basis.
[2] Frequencies may be determined from the study number of samples collected by the permittee.
[3] The lab may use either a matrix spike duplicate or laboratory duplicate to evaluate precision based on the method.

Typical protocols to ensure the representativeness of lab data is to provide triplicates of every 20th sample, with a goal of <5% variability as the standard. This provides a high confidence that each sample accurately reflects a representative value of the measured parameter. Because each year's sampling under this program will only include nine sediment samples, however, this guidance should be modified to randomly select one of those nine samples for triplicate measurement.

Biological samples

QC procedures for biological samples are currently limited to field replicates precision and laboratory duplicates for accuracy for benthic macroinvertebrates. Contract laboratories will make every effort to ensure accurate identification of specimens.

3.1.3.1 Instrument calibration

The instrumentation used by the chosen laboratories will meet or exceed manufacturers' specifications for use and maintenance. Maintenance of this equipment will be conducted in a manner specified by the manufacturer or by the QA guidelines established by the chosen laboratory.

3.1.3.2 Duplicate/splits

Laboratory duplicate samples will be analyzed regularly to verify that the laboratory's analytical methods are maintaining their precision. The laboratory should perform "random" duplicate selection on submitted samples that meet volume requirements. After a sample is randomly selected, the laboratory should homogenize the sample and divide it into two identical "split" samples. To verify method precision, identical analyses of these lab splits should be performed and reported. Some parameters may require a double volume for the parameter to be analyzed as the laboratory duplicate. Matrix spike duplicates may be used to satisfy frequencies for laboratory duplicates.

3.1.3.3 Matrix spikes and matrix spike duplicates

Matrix spike samples are triple-volume field samples (per parameter tested) to which method-specific target analytes are added or spiked into two of the field samples, and then analyzed under the same conditions as the field sample. A matrix spike provides a measure of the recovery efficiency and accuracy for the analytical methods being used. Matrix spikes can be analyzed in duplicate (matrix spike/matrix spike duplicate [ms/msd]) to determine method accuracy and precision. Matrix spikes will be prepared and analyzed at a rate of 1/20 (five percent) samples collected or one for each analytical batch, whichever is most frequent. Use of ms/msd at the frequency of 5% of the total number of samples is common practice. For the purposes of permit monitoring, these frequencies meet the expectations.

3.1.3.4 Blanks and standards

Laboratory blanks are useful for instrument calibrations and method verifications, as well as for determining whether any contamination is present in laboratory handling and processing of samples.

Laboratory standards

Laboratory standards (reference standards) are objects or substances that can be used as a measurement base for similar objects or substances. In many instances, laboratories using digital or optical equipment will purchase from an outside accredited source a solid, powdered, or liquid standard to determine high-level or low-level quantities of a specific analyte. These standards are accompanied by acceptance criteria and are used to test the accuracy of the laboratory's methods. Laboratory standards are typically used after calibration of an instrument and prior to sample analysis.

Surrogate and internal standards

Surrogate standards are used to process and analyze extractable organic compounds (PAHs). A surrogate standard is added before extraction, and it monitors the efficiency of the extraction methods. Internal standards are added to organic compounds and metal digests to verify instrument operation when using inductively coupled plasma mass spectrometry (ICP-MS) analysis and gas chromatography-mass spectrometry (GC-MS) analyses.

Method blanks

Method blanks are designed to determine whether contamination sources may be associated with laboratory processing and analysis. Method blanks are prepared in the laboratory using the same reagents, solvents, glassware, and equipment as the field samples. These method blanks will accompany the field samples through analysis.

Instrument blank

An instrument blank is used to "zero" analytical equipment used in the laboratory's procedures. Instrument blanks usually consist of laboratory-pure water and any other method-appropriate reagents, and they are used to zero instrumentation.

3.1.3.5 Inter-laboratory comparison

There is a recognized need to conduct an inter-laboratory comparison study if multiple laboratories will be analyzing samples. If so, the study will target 10% of the total samples (sediment metals and PAHs) for inter-lab comparison sediment samples (because only 9 sediment samples are collected under the present design per year, this will require just one such comparison per year).

3.1.4 Measurement quality objectives

MQOs specifically are used to address instrument and analytical performance. "At the level of measurements used to support the decision or study question, quality objectives are expressed as measurement quality objectives or MQOs. The MQOs are performance or acceptance criteria for the data quality indicators precision, bias, and sensitivity." (from Ecology, 2004 page B-2). Because the HSTM program includes a wide variety of indicators, measurement quality objectives vary significantly between the various categories. An overarching focus for indicator selection has been to use only those metrics with relatively high levels of measurement precision and signal-to-noise. For parameters measured with on-site sensors or laboratory analysis (water temperature, sediment metals, conductivity, stage), typical values are within a few percent (and will be specified more precisely following implantation, when specific laboratory protocols and instrument types are identified). Table 12 shows the acceptance thresholds for metals and PAH data collected through sediment sampling.

Table 12. Acceptance thresholds for metals and PAH data.

Sediment parameters for bioassessment	Analysis methods in sediment MQO	Reporting limit target	Lab replicate (RPD)[1]	Matrix spike[2] (% recovery)	Matrix spike duplicate (RPD)[1]	Control standard/ surrogate (% recovery)
		Sensitivity	Bias and precision	Bias and accuracy	Bias and precision	Bias and accuracy
Grain Size on <2 mm sieved sediment	PSEP, 1986 sieve and pipette or ASTM D422	Sensitivity = 1.0%	≤20%	n/a	n/a	n/a
Metals[4]: (Ag, As, Cd, Cr, Cu, Pb, Zn)	EPA Method 6020A or 200.8 (ICP-MS)	(0.1, 0.2, 0.1, 2.0, 0.5, 0.5, 5.0) mg/kg dw	≤20%	75–125	≤20%	85-115 (spiked blank) ERA Soil[5] 80-120 (As, Cd, Cu, Pb, Zn) 74-126 (Ag) 79-120 (Cr)
Polycyclic aromatic hydrocarbon (PAH) compounds[4]	EPA 8270D (GC-MS)	70 µg/kg dw	Compound specific ≤40%	Compound Specific 50–150	≤40%	Spiked Blank Compound Specific 50–150[3] SRM 1944 Compound Specific 40–200[6]

EPA: Environmental Protection Agency Method (http://water.epa.gov/scitech/methods/cwa/methods_index.cfm).
SM: *Standard Methods for the Examination of Water and Wastewater* (www.standardmethods.org).
PAH compounds include: 1-methylnaphthalene, 2-methylnaphthalene, 2-chloronaphthalene, acenaphthylene, acenaphthene anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b, j and k) fluoranthene, benzo(ghi)perylene, dibenzo(a,h)anthracene, dibenzofuran, carbazole, chrysene, fluoranthene, fluorene, indeno (1,2,3-cd)pyrene, naphthalene, phenanthrene, pyrene, and retene.
RPD: Relative percent difference.

1 The relative percent difference (RPD) is calculated when at least one of the result values is above the practical quantitation limit; if both values are below then the RPD is not calculated.
2 For inorganics, the *Laboratory Program Functional Guidelines* state that the spike recovery limits do not apply when the sample concentration exceeds the spike concentration by a factor of 4 or more (EPA, 2010).
3 Semivolatile surrogate recoveries are compound specific. MQOs are based on Johnson (2005) and Dutch et al. (2010).
4 This parameter is part of the inter-laboratory comparison study between KCEL and MEL
5 ERA solid LCS, "Metals in Soil". The catalogue number is 540; the lot number for the current KCEL aliquot in-house is e D081-540.
6 SRM 1944, "New York/New Jersey Waterway Sediment".

For continuous parameters (stage, temperature, and conductivity), the accuracy and instrument bias measurement quality objectives (MQOs) of each sonde and/or sensor is verified through post-deployment calibration checks following the manufacturer's procedures (Swanson, 2007).

In addition, deployment, mid-deployment, and retrieval measurements using hand-held probes at the deployment location will be used to evaluate the accuracy criteria in Table 13. Note that the accuracy criteria also include errors associated with the instantaneous measurement results. Grab sample data may be used to first correct continuous data for linear drift or a constant offset. This will be done prior to evaluating accuracy and precision if the mean difference between grab sample and LDO results is greater than 2%.

Table 13. Accuracy and precision limits.

Parameter	Accuracy	Precision (% relative standard deviation)
Stage	±0.1 ft	10
Temperature	±0.4°C	10
Conductivity	±µS/cm or 10%, whichever is greater	10

Continuous data will be compared to post-calibration checks and grab sample results. Differences not meeting criteria in Table 13 may result in the affected data set being qualified or rejected, depending on the amount of difference and the number of checks that failed to meet the criterion.

Precision MQOs are to be compared against the average relative standard deviation of data pairs collected during a deployment (Mathieu, 2006). Because sensors will frequently be deployed in association with stream-side flow monitoring equipment, there is a potential for sampling bias relative to average cross-section conditions.

3.1.5 Quality control

Field quality control procedures for water quality sampling
The accuracy and instrument bias of each sensor will be verified through post-deployment calibration checks following the procedures described in Swanson (2007) and with deployment, retrieval, and monthly grab check samples collected as described in Ward (2007).

Field quality control procedures for sediment and benthic macroinvertebrate sampling
Sediment and benthic and macroinvertebrate samples are the only samples that will need to be analyzed by a laboratory. To ensure the quality and consistency of sample collections, equipment maintenance and sample collection protocols described in the appendices of this report will be followed.

Sample holding times
Holding times are the maximum allowable length of time between sample collection and laboratory manipulation. Holding times are different for each analyte and are in place to maximize analytical accuracy and representativeness. Each sample collected will be packaged in a container and labeled accordingly. If necessary, sample collection should be coordinated with the analytical laboratory to ensure samples can be transported, received, and processed during non-business hours. Sample containers will be transported or sent by the field team to the

analytical laboratory, following established sample handling and chain-of-custody procedures. At the laboratory, samples may be further divided for analysis or storage.

Tables 14 lists sample volumes, holding times, containers, and preservation requirements for sediment and biological samples collected. Appendix D elaborates on the bottles and other equipment needed for biological samples.

Table 14. Sample containers, amounts, holding times, and preservation for samples (reproduced from Table 12 of the RSMP QAPP).

Analysis	Container[1]	Holding time	Preservative[2]
Metals (Ag, As, Cd, Cr, Cu, Pb, Zn)	4 oz glass[3] or HDPE jar	6 months	Cool to ≤6°C
PAHs	8 oz glass jar[3]	14 days/1 year if frozen	Cool to ≤6°C; PSEP standard (1986): may freeze at ≤ –18°C at lab
Macroinvertebrates	3.8 L wide-mouth poly jars	Indefinitely	Field preserved with ethanol, store in quiescent location.

1 No additional sample volume is needed for analysis and QC samples if the jar is filled.
2 Preservation needs to be done in the field, unless otherwise noted. Ice will be used to cool samples to approximately 4-6°C.
3 Glass containers with Teflon-lined lids, certified clean by manufacturer or laboratory in accordance with OSWER Cleaning Protocol #9240.0-05 (MEL, 2008).

Documentation
Field data measurements will be recorded in the field; example data sheets are provided in Appendix E for biological, habitat, and sediment monitoring. These forms will be used as print documents and taken into the field for recording.

Forms and documentation will include the station visit/maintenance sheet, meter calibration, and chain-of-custody forms. All entries on field documents will be made in pencil or permanent pen and will list the field technician name(s). Any errors or typos will be crossed out and rewritten by the technician who recorded the data. All corrections will be initialed and dated when made. Paper documents will be stored in an organized central filing location.

If field sampling or procedural errors are discovered, action will be taken to manage and correct those errors. Corrections may occur with corrective editing, relabeling, or, if warranted, flagging, discarding, and re-sampling. If a consistent error persists, an amendment to the sampling procedures may be required.

Composite/grab field replicate samples
Field replicates will be collected for the composited benthic macroinvertebrate and sediment field replicate samples (Table 15). Field replicates will be collected by splitting composited samples. The sediment samples will undergo a rigorous field homogenization to ensure adequate sample mixing prior to splitting. All field replicates will be labeled similar to other samples, so that the sample has its own unique number. These replicate samples will be submitted blind to the laboratory, with all other field samples.

Table 15. Field quality control schedule for benthic macroinvertebrate and sediment samples collected (reproduced from Table 14 of the RSMP QAPP).

Field sample collected	Frequency	Control limit	Corrective action
Composited benthic macroinvertebrate	Once	Qualitative control – Assess representativeness, comparability, and field variability	Review procedures; alter if needed
Composited sediment field replicates	10% of total samples	Qualitative control – Assess representativeness, comparability, and field variability	Review procedures; alter if needed

3.1.6 Data management, review and validation

Effective data management is an essential component of a successful monitoring program. The HSTM program manager will identify a data manager in charge of data QA, data entry, and data export to support the routine data analysis or in response to data requests.

For field-collected indicators, data will be entered onto field data sheets. Both field team members will ensure that the forms are completed and check for any errors, on-site. Field sheets will be entered into Excel spreadsheets, and a different team member will compare at least 50% of the field and laboratory data sheets with the Excel files. If any errors are found they will be corrected, and the project manager will check all of the remaining field and laboratory data sheets with the Excel files. This process will be repeated until all errors are eliminated. For laboratory-reported indicators, original electronic spreadsheets will be archived and then re-formatted, as needed, for subsequent analyses. Final results will be cross-checked against the original archived lab forms to verify consistency.

3.1.6.1 Database design

In accordance with the Stormwater Roles and Responsibilities document (Appendix A), near-term storage will occur through an access database, with a long term vision to secure funding in order to develop and maintain an online database website. The database will store raw data, as well as calculated indicators and indices. This is a labor intensive and thus expensive endeavor. If possible, database development could be streamlined by modeling or coupling with an existing database management system such as the Washington Department of Ecology's Environmental Information Management (EIM) database.

3.1.6.2 Data compilation

Final selection of a data management system is still pending. Following selection of a system, metadata, parameter formats and standard coding systems will be developed for the following:

- Site and Geographic Data—Sampling reaches will be identified with GPS coordinates at the upstream and downstream ends and with a narrative description of their location (i.e. East Fork Lewis River, extending 1,500 meters upstream from the NE 82nd Avenue/Daybreak Road bridge). Having both GPS coordinates and a narrative description will provide redundancy and insure that the sampling reaches can be re-located.
- Field Data Collection and Transfer—Draft data sheets will be developed and reviewed by all implementing agencies prior to the initiation of the first data collection event. This will

ensure that all field crews are collecting the same data in the same way. Some implementing agencies may choose to use an electronic platform for field data collection. These electronic tablet-based systems have advantages in that they can be designed in such a way that they include field QA/QC procedures insuring that all required data is collected (for instance, data collection fields can be designed so that crews cannot move on to the next field until data has been entered in the preceding field). Electronic data collection platforms also streamline data compilation and analysis, and eliminate transcription errors when transferring data into Microsoft Access or other database programs. Should an implementing agency choose to use an electronic data collection platform, precautions must be taken to insure that all data included on the approved data sheets is collected in an identical way.

- Methods for collection and transfer of field information differ based on the selection of a data management system. Automated systems exist (and are in use by Ecology) that scan paper data sheets and automatically enter the scanned data into a database. Specific data transfer and handling methodologies will be developed upon the adoption of a data management system. Data manually transferred from paper data sheets will require more extensive QA/QC procedures, such as being entered and checked by two different people, or by entering twice and comparing the two data sets.
- Laboratory Analyses and Data Transfer—Accredited laboratories will be used for all data analysis. Such laboratories have rigorous data analysis and transfer methodologies, and offer reporting of water quality data (including sediment metals, sediment PAHs and benthic macroinvertebrate community metrics) in electronic form. These data will be reported using a standard set of information that addresses the needs for quality assurance checks, verification, and other auditing requirements. The format for reporting and recording of water quality information will follow a similar design to that of the Environmental Information Management system developed by Ecology. In this way, data generated in this monitoring program can be recorded simultaneously in Ecology's data management system.

3.1.6.3 Data verification and validation

Data verification should occur at multiple steps in the process of collecting and analyzing monitoring data. In the field, all data recording sheets should be reviewed by all crew members before leaving the site. Analyses performed by an environmental laboratory will follow their own established procedures to ensure that results being reported are accurate. Both field and laboratory data records, following initial data entry should be verified against field forms and laboratory reports prior to final validation in the electronic database. Missing data are identified to ensure that values were not mistakenly overlooked during the data entry process. Printed copies of all stored environmental data should be made to ensure permanent records are available.

Incomplete or missing data are not anticipated to be a significant problem if data verification procedures are followed. Lost field forms could require a site revisit, but once entered into the database and a digital back up created, the risk of lost information is minimized. Lost laboratory samples are also very uncommon for accredited labs, and in the context of the overall HSTM program any such event would be unlikely to compromise the validity of the overall results unless criteria for completeness are not achieved.

3.2 Habitat Indicators – Physical and Biological

3.2.1 List and rationale

Habitat indicators proposed in the Monitoring Design were carefully vetted by the Habitat Caucus to determine the most appropriate protocols based on a desire to balance efficiency, accuracy and shareability. In the process of making such decisions, two of the recommended indicators were deemed non-essential (embeddedness and thalweg depth) given the cost of measurement and their value relative to other indicators. The remaining indicators (Table 4 in Section 1.7 above, and Table 16 below) were determined to be the minimum set necessary to document and track the status and trends of habitat conditions in the Lower Columbia Region. The indicators also include a subset of contextual data to characterize the monitoring site, but not expected to change over time. In an effort to be consistent with other regional monitoring programs, we advised following existing protocols to the extent possible.

Table 16. Habitat indicators and their associated metrics.

Indicators	Contextual?	Metric
1. Sample reach length[W,NW]	X	NA
2. Channel type[W,NW]	X	NA
3. Reach slope[W,NW]	X	Length-weighted average of individual slope measurements
4. Sinuosity[W,NW]	X	Ratio of centerline/straight-line lengths
5. Bank modification[W,NW]		Percent total
6. Density of habitat types[W]		Percent habitat for each type
7. Bankfull width/depth[W,NW]		Average of the unambiguous measurements for both bankfull width and bankfull depth.
8. Pools per unit length[W]		Pools per unit length
9. Floodplain width[W,NW]		Categorize the floodplain width into categories scaled by bankfull width (e.g., 0-1 W_{bkfl}; >1 W_{bkfl}) (bins TBD)
10. Side channel habitat[W,NW]		Qualifying channels – side channel length in meters; width and temperature measurements (upstream, midpoint and downstream); degree of connectivity to the mainstem (%) Nonqualifying – document presence only
11. Flow category[W,NW]		dry, puddled, low, moderate, high, bankfull, flood as defined by ODFW protocols. Modify "Low Flow" to include surface water flowing across <75% of active channel surface
12. Benthic Macroinvertebrates[W]		Samples processed to provide summary statistics/models (e.g. O/E and BIBI). Use Level 2 standard nomenclature http://www.pnamp.org/project/4210 as developed by the Macroinvertebrate Planning Group
13. Residual Pool depth[W]		Maximum pool depth minus pool crest depth
14. Bank stability[W]		Median of the 22 transect-specific measurements. The result is a categoric (not a decimal) value for the entire reach
15. Relative bed stability[W]		Ratio of reach D_{50} to [(average bankfull depth)×(reach slope)]; apply roughness correction if/as indicated by selected protocol.
16. Density / distribution instream wood[W,NW]		Number of pieces and total wood volume (m^3) per unit length
17. Substrate particle size[W]		Median grain size (D_{50}); also D_{84}, D_{16} for the entire reach.
18. Shade[W]		Shade score; could be reported as percent shade
19. Riparian canopy[W,NW]		% cover of vegetation > 5 m height
20. Riparian understory [W]		% cover of vegetation 0.5 – 5 m height
21.Temperature[W,NW]		7-day moving average maximum temp, daily maximum temp, average daily temp

W Wadeable
NW Non-wadeable

During the first or initial 5-year monitoring cycle, data on all 21 habitat indicators would be collected at each site. Four of these indicators (sample reach length, channel type, reach slope, sinuosity) are contextual and would be collected only during the initial 5-year monitoring cycle.

During the second and subsequent 5-year monitoring cycles, the same sites would be revisited in the same sequence utilized during the first 5-year cycle. Only data on the 17 non-contextual indicators would be collected during these subsequent monitoring cycles.

3.2.2 Field sampling procedures

Field sampling procedures are based on existing protocols. In some cases, the existing protocols are used without modification; in some cases existing protocols were modified to meet specific project goals; and in some cases entirely new protocols were developed when applicable pre-existing protocols were not available. Table 17 outlines the proposed indicators, a description of the data to be collected, the programs with similar (and potentially cross-shareable) data collected, and the protocol that serves as the basis for the data collection procedures. Text following Table 17 provides additional specifics on the collection methodologies for each indicator.

Table 17. Habitat and water quality indicators, data to be collected, recommended protocols and programs with potentially shareable data.

Indicators[1]	Method/Measurement	Recommended protocols and programs with potentially shareable data
1. Sample reach length^{W,NW}	Reach length (m). 20x BFW, 150m minimum, 500 m^{W}/2000 m^{NW} maximum Use air photo for initial designation, followed by field confirmation	AREMP, CHaMP, EMAP, ODFW, SRFB, **Ecology***
2. Channel type^{W,NW}	Bedrock, colluvial, cascade, step pool, forced step pool, plane bed, pool-riffle, forced pool-riffle, regime (Montgomery and Buffington 1997)	Ecology*
3. Reach slope^{W,NW}	Direct reading(s) of water-surface slopes using hand-held clinometer from top of reach to bottom (minimum number of segments as needed to visually span reach)	AREMP, CHaMP, EMAP*, ODFW, SRFB, Ecology
4. Sinuosity^{W,NW}	1) Centerline channel length of the entire reach (measured by airphoto if possible; using field-measured thalweg profile [see below] if not) (2) straight-line distance between the starting and ending points of the thalweg/centerline measurement	AREMP, EMAP, ODFW
5. Bank modification^{W,NW}	% of human modified bank—both sides	**EMAP***
6. Density of habitat types^{W}	Length and width for distinct habitat types meeting minimum size criteria—pool, step pool, riffle, cascade habitat, falls, run/glide, dry channel	CHaMP, EMAP, ODFW, Ecology
7. Bankfull width/depth^{W,NW}	Lengths of the bankfull width and depth, as identified using standard field indicators, at each of the 11 transects in a reach (measurements should be omitted at transects with ambiguous indicators)	AREMP, CHaMP, EMAP, ODFW*, SRFB, Ecology
8. Pools per unit length^{W}	Number of minimum-sized pools identified during habitat mapping, and total reach length	AREMP, CHaMP, EMAP, ODFW, **Ecology***

Indicators[1]	Method/Measurement	Recommended protocols and programs with potentially shareable data
9. Floodplain width[W,NW]	Employ field-based estimates; supplement with air photos for non-wadeable streams. Estimate width of the alluvial surface beyond the bankfull channel[W,NW]; document presence of additional off-channel features such as scroll bars, oxbow lakes, etc.	EMAP, ODFW* Rapp and Abbe (2003)
10. Side channel habitat[W,NW]	Determine "qualifying" vs. "nonqualifying" side channels (defined by CHaMP) Length, width, temperature, connectivity to mainstem	CHaMP*
11. Flow category[W,NW]	Visual estimate of flow conditions at time of survey	**ODFW***
12. Benthic Macroinvertebrates[W]	Employ Ecology's transect-based methods – one kick sample at 8 of the 11 transects for either flowing or slack water. Details found in https://fortress.wa.gov/ecy/publications/documents/1003109.pdf	**Ecology***, AREMP, CHaMP, EMAP, ODFW, SRFB
13. Residual Pool depth[W]	Maximum pool depth, pool crest depth	AREMP, CHaMP, EMAP, ODFW*, SRFB, Ecology
14. Bank stability[W]	Categorize bank condition at each end of each transect, integrating the conditions observed along the bank from the transect point up- and downstream half-way to the next adjacent transect (22 measurements)	**EMAP***
15. Relative bed stability[W]	None, computation based on data from substrate particle size and, bankfull depth and reach slope	EMAP and Ecology
16. Density / distribution instream wood[W,NW]	Number and size of individual qualifying logs (AREMP protocol-minimum 15 cm dia., 3 m length). 1st ten pieces measured, then every 5th up to 35 pieces, then every 10th piece, size and location of accumulations and jams. Other pieces visually estimated; location of wood recorded (mid, bar, side, etc.)	**AREMP***, CHaMP, EMAP, ODFW, SRFB, Ecology
17. Substrate particle size[W]	Randomly selected, "first-touch" grains across the entire bankfull channel along fast-water (i.e., riffle) transects only. Count number of grains per transect to achieve at least 200 grains counted per entire reach. Record b-axis length in 1/2-phi intervals; subdivide <4 mm grains into "sand" and "fines"	CHaMP*
18. Shade[W]	Canopy cover measured with densiometer (Mulvey et al. 1992 as cited by Ecology) on left bank and right bank for 11 transects and in 4 directions at each location	EMAP, SRFB, Ecology*
19. Riparian canopy (% cover) [W,NW]	Visually estimated for different vegetation types (see Ecology protocol) in a 10 x 10 m plot at 11 transects	CHaMP, EMAP, ODFW, SRFB, **Ecology***

Indicators[1]	Method/Measurement	Recommended protocols and programs with potentially shareable data
20. Riparian understory (% cover) [W]	Visually estimated for different vegetation types (see Ecology protocol) in a 10 x 10 m plot on both banks at 11 transects	CHaMP, EMAP, ODFW, SRFB, **Ecology***
21.Temperature[W,NW]	Temperature logged with hobo or similar data loggers at one representative location in the reach at half-hour intervals	AREMP, **CHaMP***, EMAP, ODFW, SRFB, Ecology

1 Indicators were previously labeled "metrics" in the Monitoring Design Report

* Asterisked program names reflect protocols with similar and potentially sharable field methods. If the asterisked program name is **bold**, that protocol is recommended without modification.

W Wadeable

NW Non-wadeable

The specific field methods for each of the indicators above are provided below. In some cases, additional detail from the source protocols is provided in Appendix D as needed. However, the source protocols are not reproduced in their entirety in Appendix D.

1) **Sample reach length.** Methods for determining the sample reach length are based on the Washington Department of Ecology (Ecology) protocols (for wadeable and non-wadeable streams), which are included in Appendix D. The sample reach length is based on the bankfull width. Bankfull width (see number 7 below) should be estimated off of aerial photographs prior to the initiation of field work. That way, crews will have an estimate of the length of the survey reach (and thus the level of effort) prior to deploying. Once in the field, first establish an "index station" and record its GPS coordinates. The index station is a transect near the access point or near the center of the survey reach. Measure the bankfull width (see number 7 below for methods of measuring bankfull width) at five locations near the index station:
   a) The Index Station (X)
   b) 1 bankfull width upstream from X
   c) 2 bankfull widths upstream from X
   d) 1 bankfull width downstream from X
   e) 2 bankfull widths downstream from X

   Record the average (nearest meter) of these 5 bankfull width measurements. Width measurements can be made using either a 50-m tape, a measuring rod, or (if the channel is wide and/or non-wadeable) with a laser rangefinder.

   Establish the length of the sample reach by multiplying the average bankfull width by 20. If the resultant length is less than 150 m or more than 500 meters (wadeable streams)/2000 meters (non-wadeable streams), set the reach length to those minimum (150 m) or maximum (500/2000 m) values.

Once the sample reach length has been determined, establish 11 transects (A-K) across the main channel only. Use orange flagging and a permanent marker to mark each of the 11 equidistant transects. Measure the distance between transects using either a 50-m tape, a range finder, or a measuring rod, by following the thalweg of the stream. The distance between flags should be 1/10th of the site length (or 2 times the estimated bankfull width at the index station). GPS coordinates should be recorded for the upstream and downstream ends of each sampling reach.

2) **Channel type**. Determination of channel type is based on Ecology protocols and Montgomery and Buffington (1997), both included in Appendix D. Investigators will need to be familiar with the definitions of the below terms and channel classifications from Montgomery and Buffington (1997).

   First decide whether the sample reach is predominantly colluvial, bedrock, or alluvial.

   a) Colluvial streams have a low chance of being sampled by this Status and Trends program, because we are limiting our sample to perennial streams.
   b) Bedrock streams are confined locations with little depositional material present.
   c) Alluvial streams transport and sort sediment supplied from upslope, and can have many different channel forms. If the site is predominantly alluvial, decide which one of the following sub-classifications can be used to describe the site.
      i) Cascade: cascade channel types have boulder substrates and tumbling flow. They occur on steep slopes, in narrow valleys. Pool spacing tends to be <1 channel width.
      ii) Step-pool: step pool channels have cobble and boulder substrates, and are characterized by longitudinal steps formed by large clasts in discreet channel spanning accumulations. Pool spacing is every 1-4 channel widths.
      iii) Forced step-pool: A forced step-pool morphology is one in which LWD forms most channel spanning steps that define the stream morphology (rather than the steps being formed by boulder and cobble).
      iv) Plane-bed: plane-bed channels have gravel and cobble substrates, and typically do not contain pools. Instead, they tend to have long stretches of generally featureless beds.
      v) Pool-riffle: Pool-riffle channels have an undulating bed with a sequence of bars, pools and riffles. They have gravel substrates, and pools every 5 to 7 channel widths.
      vi) Forced pool-riffle: A forced pool-riffle morphology is one in which most pools and bars are forced (formed) by large woody debris, rather than being geologically formed.
      vii) Dune ripple: dune-ripple morphology is most often associated with large, low-gradient, sand-bed channels (and are unlikely to be encountered at most sites in this monitoring program). The morphology is depth- and flow-dependent, but can have sand waves, dunes, and plane beds. Pools typically occur every 5 to 7 channel widths.

3) **Reach slope**. The reach slope methodology is a modification of the EMAP and Ecology protocols. These protocols record both slope and bearing, and thus, references to measuring bearing in Appendix D should be disregarded. In non-wadeable streams, slope will be estimated using a GIS-based approach.

Slope is measured by two people, each having a surveyor's rod or pole that is marked at the same height. Alternatively, the second person can be "flagged" on their person at the eye level of the person doing the backsiting (the "surveyor"). The surveyor's eye height must be marked on the other person prior to commencing the survey, while standing on level ground. The surveyor must sight their eye height when backsiting to their coworker or coworker's survey rod. When two marked poles are used, the surveyor should site from the mark on one pole (which is not necessarily set at their eye height) to the mark on the other. Also, be sure that the second person is standing (or holding the marked pole) at the water's edge or in the same depth of water as the surveyor. The intent is to get a measure of the **water surface slope**, which may not necessarily be the same as the bottom slope.

The surveyor reads both percent slope and degrees of the slope angle off the clinometer; being careful to read and record percent slope. Percent slope is the scale on the right-hand side as you look through most clinometers. Verify this by comparing the two scales. Percent slope is always a higher number than degrees of slope angle (e.g., 100% slope=45/ angle). For slopes > 2%, read the clinometer to the nearest 0.5%. For slopes < 2%, read to the nearest 0.25%. If the clinometer reading is 0%, but water is moving, record the slope as 0.1%. If the clinometer reading is 0% and water is not moving, record the slope as 0%.

It may not be possible to read the water surface slope along the entire reach length from one position. In such a case, the crew should record the slope for the minimum number of segments needed to visually span the reach. Backsites should be done from one pre-determined transect to another downstream transect (measurements need not be taken between each transect). Record the distance and percent slope for each reading. During data processing and analysis, the slope of the entire reach will be calculated as a length-weighted average of the individual slope measurements.

4) **Sinuosity.** Sinuosity is a desk-top calculation conducted during data analysis and processing. It is measured as the centerline channel length of the entire reach (measured by aerial photograph if possible; or alternatively from the field-measured thalweg lengths of all habitat units combined); divided by the straight-line distance between the starting and ending points of the sample reach (based on an aerial photo measurement).

5) **Bank modification.** The bank modification measure is the % (based on visual estimates) of the bank with human modification and is based on the EMAP protocol. For the left and right banks at each of the 11 detailed Channel and Riparian Cross-Sections, evaluate the presence/absence and the proximity of 11 categories of human influences:
   a) walls, dikes, revetments, riprap, and dams
   b) buildings
   c) pavement (e.g., parking lot, foundation)
   d) roads or railroads
   e) inlet or outlet pipes
   f) landfills or trash (e.g., cans, bottles, trash heaps
   g) parks or maintained lawns
   h) row crops
   i) pastures, rangeland, or hay fields
   j) logging

k) mining (including gravel mining)

Additional detail is provided by the EMAP protocol (Appendix D). Field crews will relate their observations and proximity evaluations to the stream and riparian area within 5 m upstream and 5 m downstream from the transect. Four proximity classes are used:

- In the stream or on the bank within 5 m upstream or downstream of the cross-section transect
- Present within the 10 m × 10 m riparian plot but not in the stream or on the bank
- Present outside of the riparian plot
- Absent.

If a disturbance is within more than one proximity class, crews will record the one that is closest to the stream. A particular influence may be observed outside of more than one riparian observation plot (e.g., at both transects "D" and "E"). Record it as present at every transect where you can see it without having to sight through another transect or its 10 m × 10 m riparian plot (see number 19 below).

6) **Density of habitat types/units**. Channel/habitat units are relatively homogeneous lengths of stream channel with consistent water surface gradient, bedform profile (channel topography), substrate composition, and flow characteristics. The identification of habitat units provides the context for the survey of fish habitat attributes and channel topography. The proposed habitat typing methodology has elements of the EMAP, Ecology, and ODFW protocols, but is not identical to any of them. Unlike the EMAP and Ecology protocols, habitat typing is NOT to be done in conjunction with a thalweg protocol. The proposed methodology is most aligned with the ODFW protocol, but has fewer habitat type categories. The proposed habitat types and their definitions are as follows:

Habitat type	Defining characteristics
Pool (P)	Pools (Figure 6) are laterally and longitudinally concave, with sorted finer substrate or bedrock, and laminar (non-turbulent) flow. Pools differ from runs/glides in being more concave, with a clear control feature (shallow "tail crest") on the downstream end. Pools are typically broken into multiple sub-types (scour pools, dammed pools, trench pools, etc.), but for this protocol, any concave feature with a smooth water surface and generally finer substrates than adjacent units, will be typed simply as a "pool," regardless of how and where they are formed. In order to qualify as a pool, the maximum depth must be at least 1.5 times the tail crest depth.
Step pool (STP)	Step pools (Figure 7) are a series of three or more steplike pools separated by short turbulent water. The length of the turbulent water cannot exceed the average wetted width. If the stretches of the turbulent water separating the pools are longer than they are wide, both the turbulent water and pools are typed and measured separately. Step pools were adopted as the only subtype of pool because the short intervening cascades are difficult and time consuming to measure.
Riffle (RFL)	Riffles (Figure 8) are fast, turbulent, shallow water, over submerged or partially submerged substrates. They are generally broad and uniform in cross section. The gradient of riffles is < 4%.
Run/glide (RG)	Runs/glides (Figure 9) have uniform depth, low gradients, and low morphological complexity. They generally have small cobble, gravel, or fine substrate, along with smooth, even (laminar) flow, and no surface turbulence. Runs/glides differ from riffles in their greater depth and lack of surface turbulence, and differ from pools in being not convex and lacking in an obvious downstream control feature.
Cascade (CAS)	Cascades (Figure 10) are high gradient riffles with large substrate, and often high water velocities. The gradient of cascades is typically 4-8% or more. Cascades differ from step pools in that they lack defined intervening "steps."
Falls (FLS)	Falls differ from cascades in that they have a single hydraulic drop, whereas cascades have multiple hydraulic drops, often separated grouped or individual boulders.
Dry channel (DC)	A dry channel is a channel of any morphology, lacking water at the time of the survey. During high flows, dry channels could possess any of the other geomorphological units.

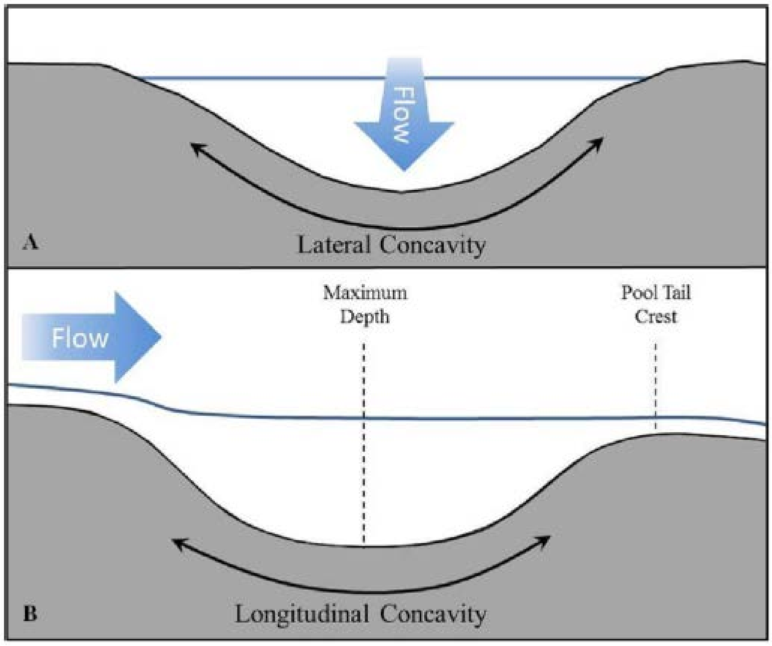


Figure 6. Diagrams showing (A) Cross sectional (lateral) and (B) longitudinal concavity of pools (from CHaMP 2013).

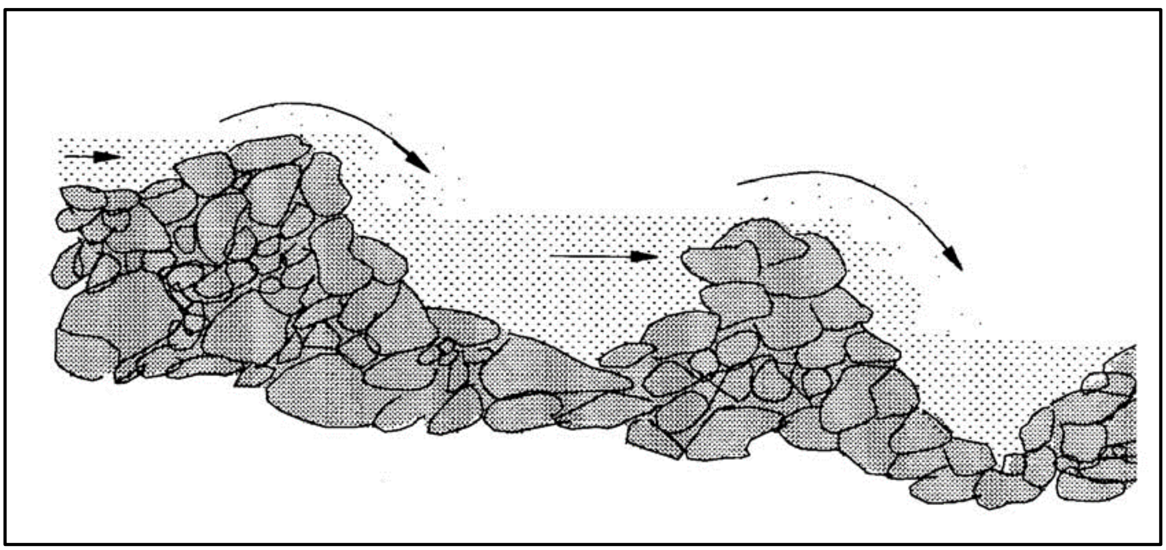


Figure 7. Step pools are a series of pools separated by short riffles or cascades. Generally found in high- gradient, confined mountain streams dominated by boulder substrate. (from Flosi et al. 2010).

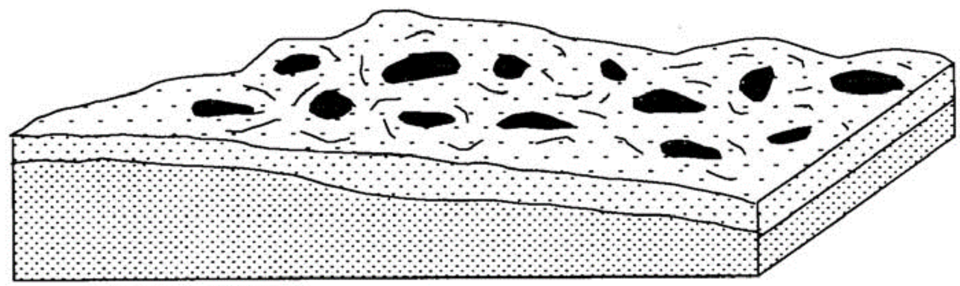


Figure 8. Riffles are shallow reaches with swiftly flowing, turbulent water with some partially exposed substrate. Gradient < 4%, substrate is usually cobble dominated. (from Flosi et al. 2010).

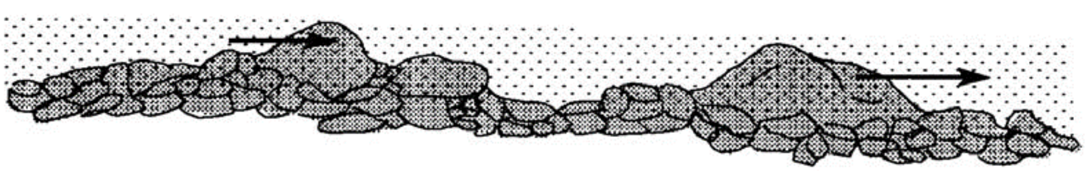


Figure 9. Run/glide habitat generally has a uniform to slightly varied stream bed and low to moderate velocities, lacking pronounced turbulence. Substrate usually consists of cobble, gravel, and sand (from Flosi et al. 2010).

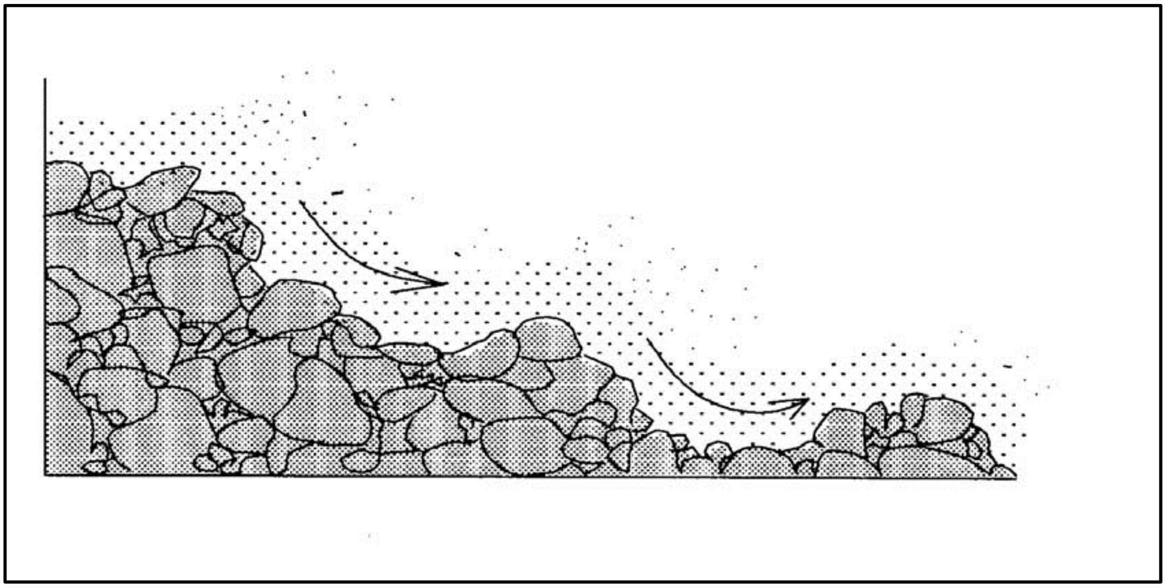


Figure 10. Cascades are steep riffle habitat, with a gradient of 4–8%, and boulder or bedrock substrate. (from Flosi et al. 2010).

Field crews will begin habitat typing at the downstream end of the survey reach. The reach will be delineated into the above habitat unit types and each unit will be assigned a unique number as crews proceed upstream. Streams will be given a unique identifier, which will be easily recognizable. Generally this will be the first few letters of the stream name, but the specific naming scheme is left up to the discretion of the implementing agencies. The habitat unit numbering scheme will simply be sequential from downstream to upstream, followed by the 1- to 3-letter code for the habitat unit type. Figure 11 illustrates the numbering scheme for the East Fork Lewis River.

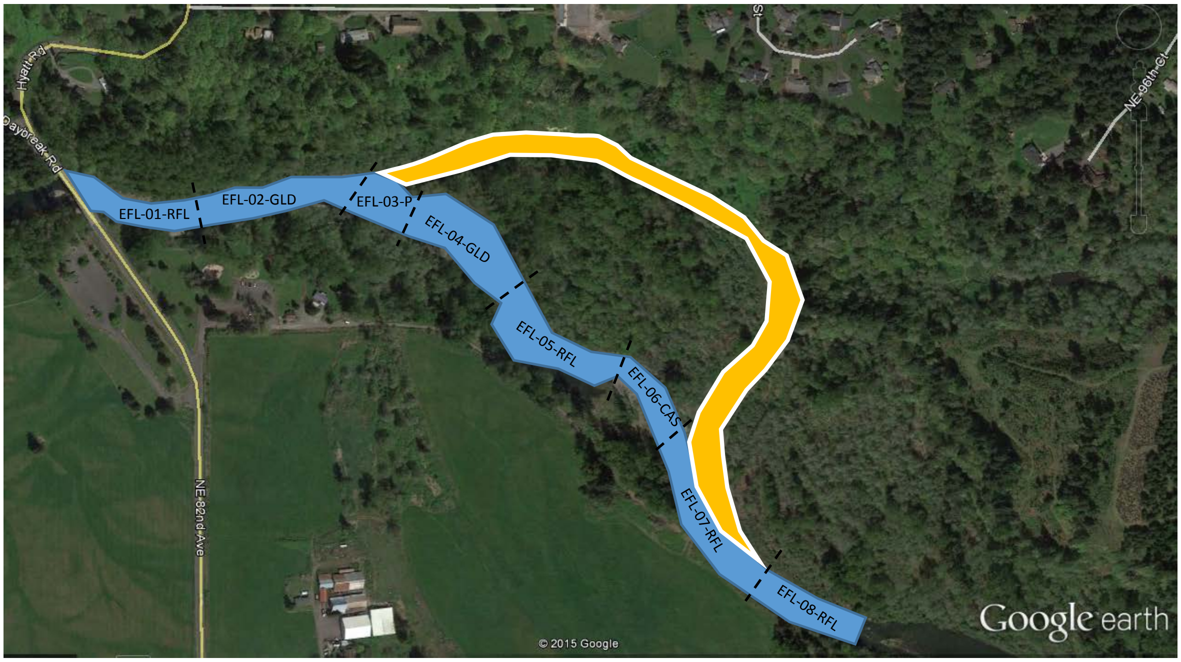


Figure 11. Example numbering scheme for a sample reach, in this case on the East Fork Lewis River. The qualifying side channel (in yellow) is not delineated into habitat units. Stream flow is from right to left.

In the habitat units crews will collect:

a) Length of the unit down the thalweg
b) Three wetted width measurements
c) Depth at thalweg at each wetted width transect
d) Maximum depth (pool units only)
e) Pool tail crest depth (pool units only)

Measurements are to be made with a 50-meter tape or a laser range finder (accurate to within one meter), and a metric surveyor's rod. In narrow channels (less than 20 meters) a tape or range finder with a higher degree of accuracy (than one meter resolution) should be used.

The mean wetted width and mean depth of all units will be calculated, along with the residual pool depth (see Number 13 below), and number of pools per unit length during data processing and analysis. The percentage by surface area of each habitat unit type present in the reach will also be calculated.

7) **Bankfull width and depth**. Bankfull width and depth will be collected at each of the eleven transects established in Number 1 above. This protocol is a modification of the ODFW protocol for bankfull width and depth (note that ODFW refers to the bankfull level as the "active channel height" and includes some additional measurements).

In unconstrained channels, bankfull level is the point where over bank flow begins during a flood event (with a 1.5 - 2-year recurrence interval). This level can be identified by interpreting evidence of bankfull flow atop the stream's banks (Figure 12). The most consistent indicators of bankfull flow are areas of deposition, as the top of these deposits (i.e., gravel bars) typically define the active floodplain (USDA Forest Service 2006). Other bankfull indicators include:

- a change in vegetation (i.e., from none to some, or from herbaceous to woody);
- a change in bank topography (a change in slope of the bank above the water's edge);
- a change in the particle size of bank material, such as the boundary between coarse cobble or gravel and fine-grained sand or silt;
- a line defining the lower limit of lichen colonization on boulders or bedrock;
- a stain line visible on bare substrate such as bedrock;
- a defined scour line (exposed roots, etc.); and
- a line of organic debris on the ground (but not debris hanging in vegetation) (USDA Forest Service 2006).

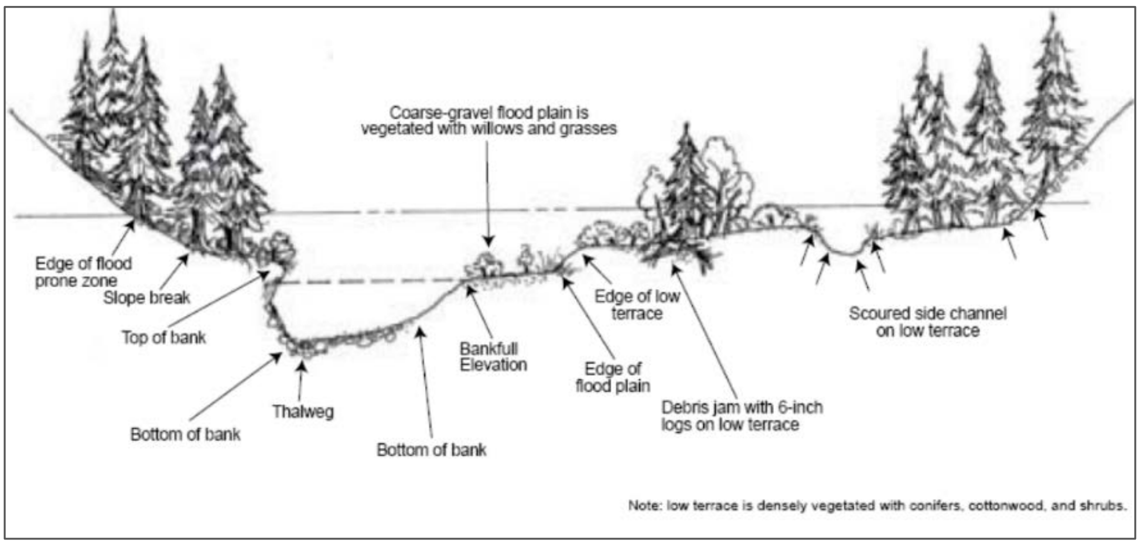


Figure 12. Illustration of bankfull width and other stream features (adapted from Groenier and Gubernick 2010).

Refer to Harrelson et al. (1994) for additional discussion of bankfull indicators.

Bankfull depth will be measured with a clinometer or laser rangefinder (equipped with a level) and a survey rod. One crew member (the surveyor) will record elevations (or rod heights) of the channel thalweg and bankfull level, while the other crew member (the rod holder) holds the rod. Steps for estimating bankfull depth include:

a. Identify locations of the thalweg and bankfull elevation at the transect using the indicators described above.
b. The surveyor will then stand straight-up, in a location higher than the bankfull elevation where he or she can see both the bankfull elevation and the adjacent thalweg of the transect.
c. The rod holder will then place the survey rod on the stream bottom at the thalweg and hold it vertically (#1 in Figure 13).

d. The surveyor will view the survey rod through a clinometer or rangefinder and record the height of the rod that is level with their eye height.
e. Next, the rod holder will move and place the survey rod at the bankfull elevation of the transect (#2 in Figure 13).
f. Without moving, the surveyor will look at the rod through a clinometer or rangefinder and record the rod height at the bankfull elevation that is level with their eye height.
g. Finally, the bankfull depth will be calculated by subtracting the rod height at bankfull elevation from the rod height at the thalweg elevation.
h. Measure the bankfull width with a tape or laser range finder. Bankfull width is the distance between the left bank and right bank at the point where over-bank flow begins during a flood event (bankfull elevation), or at the OHW level in a constrained channel.

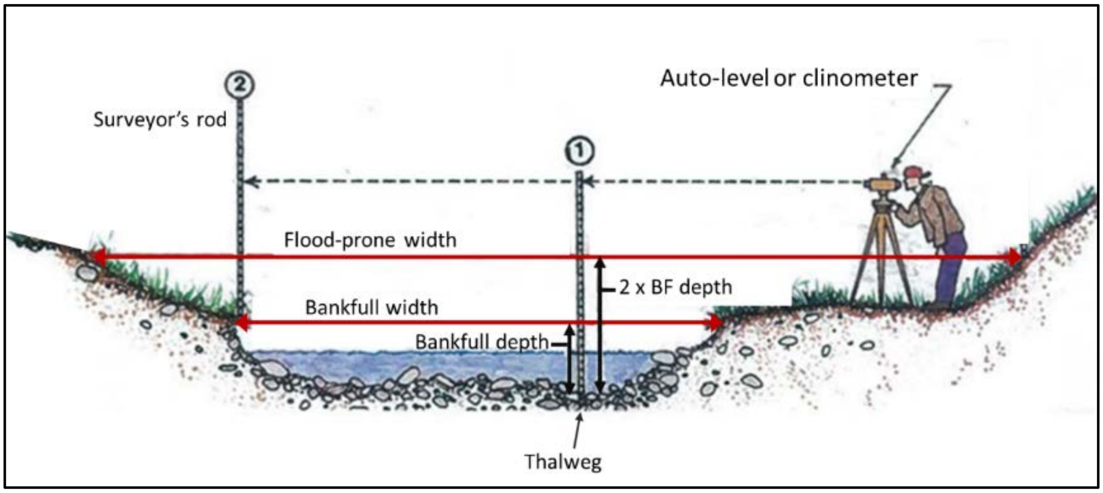


Figure 13. Measuring bankfull depth and bankfull and flood-prone widths (modified from Rosgen and Silvey 1998).

8) **Pools per unit length.** The number of pools (excluding step pool sequences) per unit length (entire sample reach length) will be calculated from data collected during #6 above. This calculation will be done during data analysis and processing.
9) **Floodplain width.** If LiDAR imagery is available, the floodplain width will be estimated based on visible erosional or depositional features, such as side channels and scroll bars at elevations similar to that of the main river. The field measurement of floodplain width, feasible only on small wadeable channels, is a modification of the ODFW protocol (Appendix D; note that in ODFW terminology, Bankfull depth = Active Channel Height), which presumes that the floodplain (i.e., the flat depositional geomorphic surface adjacent to the river) can be approximated by the *floodprone* area. This is commonly defined as the portion of the valley floor submerged during a 50-year flood, approximated by all areas adjacent to the channel at an elevation above the channel bottom no more than two times the bankfull depth (i.e., submerged by flows that are twice as deep as the bankfull flow). Estimating the floodprone width in the field is accomplished by first moving up or down the bank until the surveyor's eye height (as viewed through a clinometer held level) is twice their eye height on level ground, and then using a laser range finder (or tape) and a clinometer to identify its boundaries. During data processing, the ratio of floodprone to bankfull width is determined to quantify entrenchment: <2.5 for narrow valley floor channel types and >2.5 for

broad valley floor streams. This measurement is akin to the ODFW Valley Width Index [VWI].

Particularly on large, non-wadeable channels, the floodplain width is best determined from aerial photographs or LiDAR imagery if available.

10) **Side channel habitat.** The determination of whether a side channel is "qualifying" or "non-qualifying" is based on definitions in CHaMP, and discussed in detail in Appendix D. The below is a simplification of the CHaMP protocol; if more detail is needed, refer to Appendix D:
    a) First, Identify side channels.
        i) Side channel: To be considered a side channel, the channel must be separated from another channel by an island that is ≥ the bankfull elevation for a length ≥ the average bankfull width. Side channels that do not meet these qualifications should be considered part of the main channel
    b) Second, identify side channel type.
        i) Determine if side channel is qualifying or non-qualifying.
            (1) Qualifying side channel: Channel is located within the active bankfull channel and separated from another channel by an island ≥ the average bankfull width.
            (2) All other side channels are "non-qualifying." Non-qualifying side channels may lack a defined streambed, contain terrestrial vegetation, or be above the bankfull width of the main channel.
    c) Determine whether qualifying side channel is large or small based on its portion of total stream discharge.
        i) Visually estimate stream flow at both the upstream and downstream ends of the side channel as a percentage of the total flow at the site.
            (1) Large side channel: Has between 16% and 49% flow at either end.
            (2) Small side channel: Has < 16% flow at both ends.

For all small qualifying side channels, crews will record the following:

- Length (along the thalweg)
- Width (in three locations: near the head, confluence, and mid-distance)
- Connectivity to the mainstem (as an estimated percentage of total stream discharge)
- Temperature. Spot temperatures will be taken in three locations (at each width transect) in the side channel. The downstream width transect should be far enough upstream to avoid any back-water effects from the mainstem. These temperatures will be compared to the mainstem temperatures collected by the long-term data loggers.

11) **Flow category.** The flow at the time of the survey will be binned into one of the following categories (modified from ODFW):
    a) Dry
    b) Puddled (series of isolated pools connected by surface trickle or subsurface flow)
    c) Low (surface water flowing across less than 75% of the water-scoured [i.e., "active"] channel surface)
    d) Moderate (surface water flowing across 75-90 percent of the active channel surface)
    e) High (Stream flow completely inundating the active channel surface)

Sample reach surveys will ideally be conducted during summer low flow periods and should be avoided at flows above "moderate."

12) **Benthic macroinvertebrates.** Benthic macroinvertebrates will be collected using the Ecology protocol (kick samples taken at 8 of the 11 transects in either flowing or slack water). The specific macroinvertebrate protocol is included in Section 3.1.2.3 above.

13) **Residual pool depth.** Residual pool depth will be calculated for all pools based on the maximum depth and pool tail crest depth recorded during Number 6 above. The minimum, maximum, and average residual pool depth for the sampling reach will be calculated and reported.

14) **Bank stability.** Bank stability is defined by the degree of erosion and is based on the characterization in the EMAP protocol. Steep banks are more likely to collapse and suffer from erosion than are gently sloping banks and are therefore considered to be unstable. Signs of erosion include crumbling, unvegetated banks, exposed tree roots, and exposed soil. The banks will be categorized at each end of each transect, and each measurement will be indicated with the transect letter (A-K from downstream to upstream) followed by an "LB" or "RB" for left bank and right bank (note that left and right are determined while facing downstream). The bank conditions will be characterized for a segment halfway between each of the two adjacent transects. Bank condition will be characterized in one of four qualitative categories (poor, marginal, sub-optimal and optima) based on a visual estimate (see Table 18).

Table 18. Bank condition categories.

Optimal	Sub-optimal	Marginal	Poor
Banks stable; no evidence of erosion or bank failure.	Banks moderately stable; infrequent, small areas of erosion mostly healed over.	Moderately unstable; up to 60% of banks in reach have areas of erosion.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; on side slopes, 60 to 100% of bank has erosional scars.

15) **Relative bed stability.** The relative bed stability will be calculated during data processing and analysis based on the ratio of the D_{50} particle size (see Number 17 below) to [(average bankfull depth) X (reach slope)]. Roughness correction based large woody debris volume will be applied as necessary (see Kaufmann et al. 2008).

16) **Density/distribution of instream wood.** The Large Woody Debris (LWD) protocol is unmodified from the AREMP protocol in Appendix D, with two exceptions: (1) wood in qualifying side channels will not be tallied, and (2) as listed in Appendix D, the minimum size for a qualifying piece of LWD in the published AREMP protocol is 30 cm. AREMP modified this criteria downward to 15 cm. Therefore for this implementation plan, qualifying pieces of LWD will be those at least 15 cm in diameter and at least 3 meters in length. LWD will be assessed/tallied within the whole sample reach; ***not*** independently within each habitat unit.

The sampling method for assessing LWD follows (refer to Appendix D for figures illustrating the methodology described below):

a) In order to be counted, each piece must meet all of the following criteria.
   i) Each piece must be greater than 3 meters in length and at least 15 cm in diameter one-third of its length from the base or largest end.
   ii) Only include standing trees that lean within the bankfull channel if they are dead. Dead trees are defined as being devoid of needles or leaves, or where ALL of the needles and leaves have turned brown. Consider it living if the leaves or needles are green.
      (1) Note: Use caution when assessing the condition of a tree or fallen log. Nurse logs can appear to have living branches when seedlings or saplings are growing on them.
   iii) Wood that is embedded within the stream bank is counted if the exposed portion meets the length and width requirements.
   iv) Do not count a piece if only the roots (but not the stem/bole) extend within the bankfull channel.
   v) Some pieces crack or break when they fall. Include the entire length when the two pieces are still touching at any point along the break (Only count as one piece if they are from the same original piece of wood). Treat them separately if they are no longer touching along the break. Count only the portion within the bankfull channel when they are no longer touching.

b) Record the piece number, length (nearest 10 cm) and width (nearest cm) of all pieces in in the sample reach.

c) While the size of all wood pieces will be recorded, length and diameter will not always be measured for each piece, but may instead be estimated based on the procedure below. The same person should always be the estimator. A subset of pieces will be measured at sites with more than 10 qualifying pieces of wood (with the remainder estimated).
   i) For sites estimated to have between 11 and 100 pieces, measure the first 10 pieces of wood encountered. Starting at piece number 11, measure every 5th piece of wood up to and including the 35th piece of wood. All subsequent pieces of wood will be measured every 10th piece (starting with number 45).
   ii) For sites estimated to have over 100 pieces, measure the first ten pieces, then starting at the 11th piece only measure every 10th piece.

d) If the piece of wood designated for measurement cannot be measured safely; then measure the next piece of qualifying wood. Then continue measuring as specified above.

e) Measure the length of the main trunk and not branches or roots. Begin measurements where the roots attach to the base of the trunk when the roots are still connected.

f) Do not measure (just estimate) standing dead trees, pieces buried in log jams, or pieces that are unsafe to measure.

g) In assemblages, begin counting from the bottom up when pieces are stacked on each other.

h) Wood in qualifying side channels ***will not*** be tallied.

i) The percent of the wood submerged at bankfull is an estimate of how much of the piece of wood will be underwater when the stream reaches its bankfull height.

j) Record the number of pieces touching, wood location and wood type. Evaluate wood location relative to the bankfull channel (refer to Appendix D for diagrams and data collection sheets).

17) **Substrate particle size**. Bed surface substrate is measured using a modified Wolman Pebble Count procedure described in Harrelson et al. (1994). Of the protocols reviewed and used as a basis for this implementation plan, CHaMP using a modified pebble count to characterize substrate particle size. However, the CHaMP procedure differs significantly from that in Harrelson et al. (1994) and from that proposed in this implementation plan. Pebble counts will be conducted at each of the 11 transects that crosses a riffle. At least one pebble count must be conducted per reach. If no riffles are present in the reach, pebble counts will be conducted in at least one other unit. Unit types for pebble counts in order of preference include: riffles, runs/glides, and pools. To conduct the pebble count, a two-person crew (a measurer and a note taker) start at a randomly selected point on the riffle transect by tossing a pebble into the stream from one of the bankfull elevations (not necessarily the present water level). With the measurer averting their gaze, he/she should pick up the first particle touched by the tip of their index finger at the toe of their boot. Using a ruler or gravelometer, measure the intermediate axis (neither the longest nor shortest of the three mutually perpendicular sides of each particle picked up). Measure embedded particles or those too large to be moved in place. For these, measure the smaller of the two exposed axes. The measurer will call out the measurement, and a note taker will tally the measurement by size class (1/2 phi intervals, Table 19). Particles <4 mm will be subdivided into “sand” and “fines” (silt and clay) on the basis of their “grittiness” between the fingers. The measurer will then take one step across the channel in the direction of the opposite bank and repeat the process, continuing until they reach the bankfull elevation on the opposite bank. All riffle transects should be assessed until at least 200 particles have been measured. If not enough riffle transects are present to collect 200 particle measurements, the measurer should double back across the transect. Be sure that all elevations are representatively sampled. The measurer may have to duck under bank-top vegetation or reach down through brush to get a spatially representative count. The measurer should move upstream or and make additional transects to sample a total of at least 200 particles. During data analysis and processing, the data will be plotted by size class and frequency to determine the D_{16}, D_{50} and D_{84} for the entire reach.

Table 19. Half-phi intervals to be used when characterizing substrate particle size.

Category	Size (mm)
Silt/clay	<0.062
Sand	0.062–4.0 (appx)
Gravels	4–5.6
	5.6–8
	8–11
	11–16
	16–22
	22–32
	32–45
	45–64
Cobbles	64–90
	90–128
	128–180
	180–256
Boulders	256–362
	362–512
	512–1,024
	1,024–2,048
	2,048–4,096
Bedrock	

18) **Shade**. Canopy cover will be measured as a proxy for shade using a densiometer facing upstream, downstream, left and right on the right and left banks at each of the 11 transects. This methodology is modified from the Ecology protocol in Appendix D. Changes made to the ecology protocol include only taking densiometer readings only on the stream banks (rather than the stream banks and in the center of the channel), and including four directional readings at each bank (rather than just two). The specific sampling methodology follows:
    a) Hold a modified convex densiometer (modified such that just 17 of the grid intersections are contained within a taped "V"—see Appendix D) 30 cm above the ground or wetted surface at the bankfull location. Readings are taken close to the ground so that they will record shade provided by low-growing vegetation
    b) Record how many of the 17 cross-hairs have shade over them. Do this for each of four directions at the bankfull elevation on both the right and left banks at each transect:
        i) Facing left
        ii) Facing right
        iii) Facing upstream
        iv) Facing downstream

19) **Riparian canopy cover.** The percentage of riparian canopy and understory cover (Indicator 20) will be recorded using an un-modified Ecology protocol, included in Appendix D. On each transect of the main channel, assess a plot on each bank. Each plot extends 5 meters downstream, 5 meters upstream, and 10 meters back from the bankfull margin. The riparian

plot dimensions can be estimated rather than measured. On steeply sloping channel margins, plot boundaries are defined as if they were projected down from an aerial view. The specific sampling methodology includes:

a) Conceptually divide the riparian vegetation into three layers:
   - i) Canopy (> 5 m high),
   - ii) Understory (0.5 to 5 m high),
   - iii) Ground Cover layer (< 0.5 m high).

b) Within each layer, consider the type of vegetation present and the amount of cover provided. Do this independently of what is contained in higher layers.
   - i) Cover quantity is coded as follows:
     - (1) 0—absent
     - (2) 1—sparse (< 10% cover)
     - (3) 2—moderate (10–40% cover)
     - (4) 3—heavy (40-75% cover)
     - (5) 4—very heavy (> 75% cover)
   - ii) The maximum cover in each layer is 100%, so the sum of the cover for the combined three layers could add up to 300%.

c) Determine the type and quantity of cover for each of the three layers: Canopy, Understory and Ground Cover:
   - i) Canopy
     - (1) Determine appropriate dominant vegetation type (Deciduous, Coniferous, Broadleaf Evergreen, Mixed or None)
     - (2) Indicate the appropriate cover quantity code (0—absent, 1—sparse [<10%], 2—moderate [10–40%], 3—heavy [40–75%], or 4—very heavy [>75%]) for each of 2 classes:
       - (a) Big trees—trees having trunks larger than 0.3 m diameter (at breast height)
       - (b) Small trees—trees having trunks smaller than 0.3 m diameter (at breast height)
   - ii) Understory
     - (1) Determine appropriate dominant vegetation type code (Deciduous, Coniferous, Broadleaf Evergreen, Mixed or None
     - (2) Indicate the appropriate cover quantity code (0—absent, 1-sparse [<10%], 2—moderate [10–40%], 3—heavy [40–75%], or 4—very heavy [>75%]) for each of 2 classes:
       - (a) Woody vegetation—such as shrubs or saplings
       - (b) Non-woody vegetation—such as herbs, grasses, or forbs
   - iii) Ground Cover
     - (1) Indicate the appropriate cover quantity code (0—absent, 1-sparse [<10%], 2—moderate [10–40%], 3—heavy [40–75%], or 4—very heavy [>75%]) for each of 2 classes:
       - (a) Woody (living)
       - (b) Non-woody (living)
       - (c) Bare dirt (or decomposing debris)

iv) The sum of cover quantity ranges for these 3 types of ground cover should include 100%.

20) **Riparian understory.** (see above)

21) **Temperature.** The methodology for collecting long-term temperature data is included in Section 3.1.2.1 above.

3.2.3 Laboratory measurement procedures

Laboratory measurements procedures for benthic macroinvertebrates are presented in Section 3.1.3 above. No other laboratory analysis is required for habitat indicators.

3.2.4 Measurement quality objectives

Because the HSTM program includes a wide variety of indicators, measurement quality objectives vary significantly between the various categories. An overarching focus for indicator selection has been to use only those parameters with relatively high levels of measurement precision and signal-to-noise. For field methods (i.e., habitat indicators), commonly reported values for the precision of replicate values for those indicators recommended for inclusion in this program are on the order of 10% (e.g., Kaufmann et al. 1999).

3.2.5 Quality control

Most of the field measurements conducted at habitat sampling locations are conducted throughout the entire 20x-bankfull-width-long reach, ensuring that results are truly "representative" of the reach. This distance lies at the high end of typically specified reach lengths (10-20x bankfull widths are common in the literature), which is designed to include multiple pool-riffle or step-pool sequences in an alluvial channel and so avoid over representing any unique characteristics of any one segment. Variability will be reduced through refinement of site selection and local phenomenon based on physical criteria. Field personnel will record where samples are measured and note general descriptions of physical conditions of the channel, gradient, habitat types, water velocity, weather, and other parameters or unique local features that could influence data quality. These narrative field notes can be used to qualitatively assess how well the data represent the conditions characterized by this study, should any questions later arise about the representativeness and accuracy of the measured indicators.

Specific quality control procedures will include having a crew member other than the initial recorder review the data sheets prior to crews leaving the field. It is important to QC the data sheets in the field prior to leaving, in order to insure that all required data has been collected. When data collection requires crews to make visual estimates (for instance on riparian and understory cover percentages), individual crew members will independently make estimates, compare their results, and come to consensus.

3.2.6 Data management, review and validation

As recommended in the habitat Roles and Responsibilities document (Appendix B of this report), the HSTM program manager will identify a data manager in charge of data QA, data entry, and data export to support the routine data analysis or in response to data requests.

Data management review and validation procedures specific to habitat indicators include:

Raw Data

- Data entry and QA will occur between July and December of each year.
- Each organization collecting data will QA their data sheets in the field before departure from the site (see above).
- Organizations will submit the datasheets on an at least weekly basis to the program manager in digital format for distribution to the data manager. Submittals can include scanned images from the data sheets, data from the data sheets entered into a database program, or digital files from a field tablet or other electronic data collection platform. If paper datasheets are used, original datasheets should be mailed to the program manager for archiving on a weekly basis.
- The program manager will forward the data to the data manager, who will either enter the data into the database upon arrival. Or (in the case of digital files) check the data for completeness and accuracy. Any discrepancies will be reported as they are encountered to the program manager.
- The data manager will QA the data upon entry.

Calculation of Indicators

- Data entry will occur between December and April of each year.
- The analysis manager (discussed in Section 1.11), will provide any calculated indicators to the data manager for entry into the database and inclusion in reports. The analysis manager should automate the calculation of Indicators from the field data as much as possible so that as data accumulates from each year to the next, the analysis is consistent across years and reporting organizations.

3.3 Landscape Indicators

Several of the monitoring questions and objectives of the Design Report invoked a “landscape” analysis:

- Question 5: Where on the landscape are key potential land-use activities occurring?
- Question 6: Are land-cover changes occurring at detectable rates across the Lower Columbia Region, and if so where are they occurring?

They were included in the Design Report because the results of such analyses provide necessary support to other monitoring objectives, and the stratification of sampling points by the dominant land cover in their contributing watersheds provides necessary context for much of the in-stream monitoring data being collected under both the Qa/Qx and habitat elements. In addition, characterizing the status and trends of key attributes in the surrounding landscape can help separate the regional influence of natural variability from the more localized impacts (both positive and negative) of human actions.

The most feasible of these landscape attributes to monitor systematically over time are those relating to land cover, which has been systematically characterized across the entire Lower Columbia Region by the National Land Cover Database, and has compiled categorized land-cover coverage for 1992, 2001, 2006, and (most recently) 2011 (Homer et al. 2015). This data set, fully downloadable from the Multi-Resolution Land Characterization Consortium (www.mrlc.gov), provides the basis for all landscape-level analyses conducted for the HSTM project.

3.3.1 List and rationale

To maximize the accuracy of land-cover categorization and because determining the influence of particular landscape-level attributes on in-stream conditions is not a goal of status and trends monitoring, the following coarse land-cover categories were used to process and analyze the NLCD data, hereafter termed the "aggregated 2011 NLCD" (see http://www.mrlc.gov/nlcd11_leg.php for the full list of categories):

- "Urban" includes NLCD categories 21 ("Developed, Open Space"), 22 ("Developed, Low Intensity"), 23 ("Developed, Medium Intensity"), and 24 ("Developed High Intensity");
- "Agriculture" includes NLCD categories 81 ("Pasture/Hay") and 82 ("Cultivated Crops");
- "Forest" includes NLCD categories 41 ("Deciduous Forest"), 42 ("Evergreen Forest"); and 43 ("Mixed Forest");
- "Other" includes all other categories, particularly water, wetlands, ice and snow, and barren land.

These indicators were used to address those objectives of the landscape questions (see Section 1.2.1) that are critical to the implementation of the HSTM program as described in this report. Other questions and their associated objectives that were raised in the Design Report could enhance the ultimate interpretation of the monitoring data but are not essential for the program's implementation. The effort necessary to address those objectives is also substantial, and beyond both the scope of the current effort to develop the Implementation Plan and the resources presently available from project partners. Should such resources become available, however, the following list of monitoring questions and objectives articulated in the Design Report, and their associated technical approaches should be useful:

- Watershed landcover change: What areas of the 2011 NLCD are changed from the 2006 NLCD? What is the minimum magnitude of change so identified that is likely to constitute a "true" change, given unavoidable errors in classification? (Supports Objective 6.1. of the Design Report)

  The process to make this analysis would be to (a) register both grids to one another so that pixels from both datasets overlay exactly; (b) compare the pixel change between both years (both total change and change between classes); and (c) include some error or uncertainty report either based on published information or selecting a set of points from detailed imagery from either year. There is a confidence value of 70% for changes between 2001 and 2011 NLCD (Fry et al. 2008).

- Stream buffer landcover change: What areas of the 2011 NLCD are changed from the 2006 NLCD within 60-m-wide buffer zones for 1 and/or 5 km upstream of identified sampling site? (Supports Objective 6.2.)

  The process to make this analysis would be to (a) select a set of sampling sites, (b) identify its location on the NHD High dataset, (c) "travel" upstream 1 or 5 km and define the upstream point, (d) split and buffer the lines, and (e) overlay the buffers with the land cover change dataset obtained in (a).

- Discriminate "recent" (less than ~20 years) forest harvest areas using the NLCD. What watersheds have this as a dominant land cover? (Supports Objective 2.2.); identify "mature" (greater than ~20 years) forested areas using the NLCD (i.e., distinct from other "forested" areas? (Supports Objective 5.1.)

  For these two evaluations, use of the 2002 NLCD dataset would be most appropriate to use. Using the Land Cover change developed in the first analysis, comparison of the two classified images would provide answers to these questions.

- Identify subwatersheds in the range of 2.5-50 km^2 with a single "dominant" land cover type (i.e., >50% urban, forested, or agriculture) over the entire Lower Columbia Region. (Supports Objective 5.1.)

  This analysis has already been run on spatially restricted areas within the Lower Columbia Region to identify those Master Sample points draining watersheds with predominately "urban" or "agricultural" land cover. It has also been run on those points randomly selected for sampling. To comprehensively apply the same analysis to all 28,000 Master Sample points with drainage areas >0.6 km^2, prior experience suggests that it would require about one week of GIS processing time.

- Are there other potentially useful land-cover class aggregations that yield more information than our 4 basic categories? (Supports Objectives 6.1 and 6.2.)

  There appears to be no identified applications for which more detailed land classification schemes would be warranted on a region-wide basis. The 20 categories of the NLCD coverage, from which our four aggregated land-cover categories were derived, could provide a readily generated greater level of detail; other approaches could provide even greater discrimination but would require airphoto interpretation and a substantial investment of time (e.g., Lucchetti et al. 2014).

3.3.2 Data sources

The NLCD coverages (all years) are available for free download at http://www.mrlc.gov/finddata.php. This was the source of all land-cover data used in the analyses for the HSTM project.

3.3.3 Known magnitude of classification/locational errors

Extensive evaluation of land-cover classification accuracy typically returns values of up to 80% or better accuracy, with the best classifications found for the coarsest (i.e., most aggregated) classes, such as used in this report. For example, see Homer et al. (2007) and associated references for specific evaluations of the 2006 classification; Jin et al. (2013) offers some preliminary evaluations of the 2011 classification.

3.3.4 Analytical procedures

For the Design Report, a preliminary determination of the land cover associated with individual Master Sample points was made by evaluating the local land cover, as represented by the aggregated 2011 NLCD, at the location of the point itself. On this basis, some preliminary determinations were made regarding which strata combinations were likely to lack sufficient members (e.g., very large watersheds with a predominantly "urban" land cover) to require sampling. For actual implementation, however, the key attribute is the land cover of the *contributing watershed*, which requires a more extensive analysis. For this purpose, a script was written in ArcMap that delineated the entire watershed to a specified point, aggregated the underlying NLCD pixels, and tabulated the percentage land cover in each of four categories (urban, agriculture, forest, other).

Since the original 2011 NLCD dataset was for the conterminous 48 US states, a subset for the Lower Columbia Region was extracted and pixel-matched to the original dataset. Watershed size comparisons included comparing the watershed-generated areas to those of each Master Sample point to which they included contributed the area. Small discrepancies occurred due to the need to snap to the DEM-generated stream networks to prevent false (and typically very small) watersheds from being generated.

For the stratifications required by the Qa/Qx and habitat sampling design (see Section 1.2.4), Master Sample points with predominant (i.e., >50%) watershed land coverage of "urban" or "agriculture" were identified by first visually outlining areas where these land cover types are present in sufficient area to provide the possibility of such an outcome (for each, this was <10% of the total area of the Lower Columbia Region) and then running the script on all Master Sample points so contained. Many such points do not have a dominant land cover of urban or agriculture; only those that do (275 for "urban" and 430 for "agriculture") have been retained for subsequent inclusion in their appropriate strata).

Identifying "forest"-dominated points, however, requires a different procedure because the total number of points in the Lower Columbia Region is so large (>28,000 for just those draining watersheds larger than 0.6 km^2), and simply running the watershed land-cover script for all such points is not feasible at present. Fortunately, the vast majority of such points have a dominant "forest" land cover, and so it is also not necessary. Thus, alternative methods were employed: for the strata combinations requiring "urban" or "agriculture" land covers, Master Sample points were drawn from their respective subsamples; but those requiring "forest" land cover were drawn from the entire Master Sample (as appropriately stratified for drainage area, channel slope, etc.) without pre-determination of land cover. Only those so selected were then evaluated as to their watershed land cover. Those that are not "forest" were discarded and replaced with additional randomly drawn points (which themselves were tested for watershed land cover, repeating as necessary until full complements of points meeting each strata combination were identified).

3.3.5 Validation and quality control

Quality control of the underlying land-cover data relies on the processing that occurred prior to its posting on the Internet, and no additional evaluation was made for this project. A variety of quality-control procedures were made for the identification of watershed land-cover tallies, including visual comparisons of watershed outlines with land-cover layers in GIS and tabulation of watershed sizes with those having dominant urban or agriculture land covers (given the limited extent of these land uses throughout the Lower Columbia Region).

3.3.6 Data management

The NLCD data and ArcGIS file geodatabases are stored on servers that are backed up daily. Metadata is written when a dataset is finalized and includes source datasets, methods and changes made to the original dataset. LCFRB and project partners have received copies of the finalized datasets with metadata, including the source data and descriptions of processes done on them to allow full understanding of how the final versions were derived.

4 SUMMARY GUIDANCE

Because no part of the HSTM program has been implemented to date (April 2016) according to the study design, the full range of analyses and interpretations that the monitoring data may ultimately support cannot be known with certainty. However, the program is built on a rich legacy of monitoring aquatic resources across the Pacific Northwest and beyond, and so a variety of potential uses of the indicator data can be anticipated.

Fundamental to the design of the HSTM program, including the target populations, stratification, and choice of indicators is the *purpose* of status and trends monitoring. Its various definitions over the last several decades largely echo one another:

> "Status, the current state of the resource, can be characterized in terms of its extent, its productivity, or its condition. Each of these attributes can be investigated with regard to its trend, or its change with time." (Olsen et al. 1999)
>
> "Status monitoring assesses the current condition of a population or environmental condition across an area. Monitoring for trends aims at monitoring changes in populations or environmental condition through time." (Maas-Hebner et al. 2015)
>
> And, as summarized by Ecology for the Puget Sound RSMP, the goal of measuring status and trends in receiving waters is "to measure whether things are getting better or worse and identify patterns in healthy and impaired Puget Lowland streams and Puget Sound urban shoreline areas" (http://www.ecy.wa.gov/programs/wq/stormwater/municipal/rsmp/status.html).

Of critical importance to the design and implementation of a status and trends monitoring program is the recognition of what is, and is not, included. Common to all of these definitions is the clear articulation that the primary goal of such programs is to provide a broad characterization of conditions across the target population. Conversely, there is no attempt through status and trends monitoring to diagnose direct cause-and-effect relationships between stressors and their effects on the environment. Recognizing this distinction can avoid the pitfall of trying to meet both goals with a single design, and ultimately accomplishing neither. Although elements of a status and trends monitoring design can serve to support a more diagnostic effort, diverting resources to the identification of specific impacts (or its inverse, directly evaluating the effectiveness of remedial measures on environmental conditions) would inherently reduce the scope (or increase the cost) of the regional characterization.

Through the history of the Lower Columbia HSTM program, this distinction has been largely, but not entirely, acknowledged. So, for example, the Phase 1 Report for this project articulated suitable monitoring questions for a status and trends program (e.g., "What are the status and trends of in-stream biological health and both in-stream and riparian habitat conditions?" "What is the status and trends of water quality and stream flow in surface waters?"), but it also raised important management questions that nonetheless lie outside of what such a monitoring program can answer ("Are there significant effects of habitat degradation or improvement on the observed abundance, productivity, spatial structure, and diversity of the natural-origin fish in this population?").

Thus, any planned analysis or interpretation of the monitoring data collected under this program needs to maintain a focus on what these data were originally designed to accomplish: provide a statistically rigorous characterization of the physical, chemical, and biological conditions in the rivers and streams of the Region, respecting limitations on both the intensity of sampling and the number of indicators that are imposed by financial practicalities while still accomplishing this fundamental goal. Stratification of the target population, particularly with respect to the specific upcoming requirements for municipal stormwater NPDES permittees, can provide useful and cost-efficient guidance on where to invest additional monitoring resources into diagnosing observed or inferred impairments to receiving waters, or in evaluating the effectiveness of existing or future stormwater-management techniques. A status and trends monitoring program can do no more than highlight problematic areas and suggest fruitful next steps—it must fall to other programs to take those next steps.

4.1 Interpreting Qa/Qx Indicators within the Urban+NPDES Areas

Within the urban+NPDES areas, all streams draining 2.5-50 km^2 with predominately "urban" watershed land cover will be sampled during the course of the five-year rotating panel design (which presumably will correspond to the next NPDES permit cycle). Five of these sites also correspond to "legacy" sites that have been monitored for various parameters by the City of Vancouver or Clark County for between 1 and 10 years, of which those that include long-term macroinvertebrate sampling will be most directly applicable to the data subsequently collected under this program. In addition, there are likely four strata combinations with enough master sample points within the urban+NPDES area to support the collection of habitat indicators according to the regional monitoring design.

Most integrative of the indicators being measured at all of these sites will be the benthic macroinvertebrates, which can provide a coarsely integrative but biologically relevant characterization of conditions. Impacts can influence any of the primary "water features" of the urban environment (i.e., hydrology, water quality, physical habitat, biotic interactions, and energy fluxes; Booth et al. 2004, Karr and Yoder 2004), and this indicator has shown little success in clearly discriminating amongst those potential sources of stress. However, its value as a high-level indicator of overall conditions, of relevance to both stormwater and fisheries managers, has become well-established in the Pacific Northwest.

Less local experience is available on the value and interpretation of sediment metals and PAHs, although they have been utilized in monitoring programs throughout the nation for many years. They are time-integrative by virtue of the residence time of fine sediment, although the history of prior sediment-transporting storms undoubtedly imposes year-to-year variability. The contaminants are largely specific to urban activity—particularly automobiles, roadways, and the incomplete combustion of fuels (e.g., Huang and Foster 2006), and so these indicators not only provide an indication of the status of biologically significant compounds in these receiving waters but also offer the ancillary benefit of narrowing the list of possible stressors on these systems.

The final set of indicators, the monitoring of stage, temperature, and conductivity, addresses the related problems of sampling rapidly varying parameters by collecting the raw data at a greater frequency than that underlying variability. Useful processing of these data, and their interpretation, differs somewhat for each.

Stage has been long measured as a surrogate for discharge, which is broadly recognized as one of the key drivers of both physical and biological instream conditions. It is also particularly sensitive to watershed urbanization and is probably the single best indicator of stormwater impacts to lotic receiving waters (NRC 2009). “Conversion” of stage (i.e., water depth) to discharge is accomplished by a rating curve, whose construction requires episodic field visits to the measurement station to manually measure discharge (flow width, depth, and velocity) in order to correlate the observed depth with the measured discharge. Multiple such measurements, spanning a wide range of discharges, are necessary to construct a reliable rating curve, and it must be updated whenever flow events or other changes to the channel geometry are likely to have altered the stage–discharge relationship. These activities typically result in significant cost.

Although absolute discharge is a critical parameter for such applications as flood studies, stage alone should be nearly as useful for exploring the patterns of discharge over time, both short-term and long-term. An example from an urban watershed with a long-term gage record (Mercer Creek, in the Puget Sound region just east of Lake Washington, illustrates this well (Figure 14).

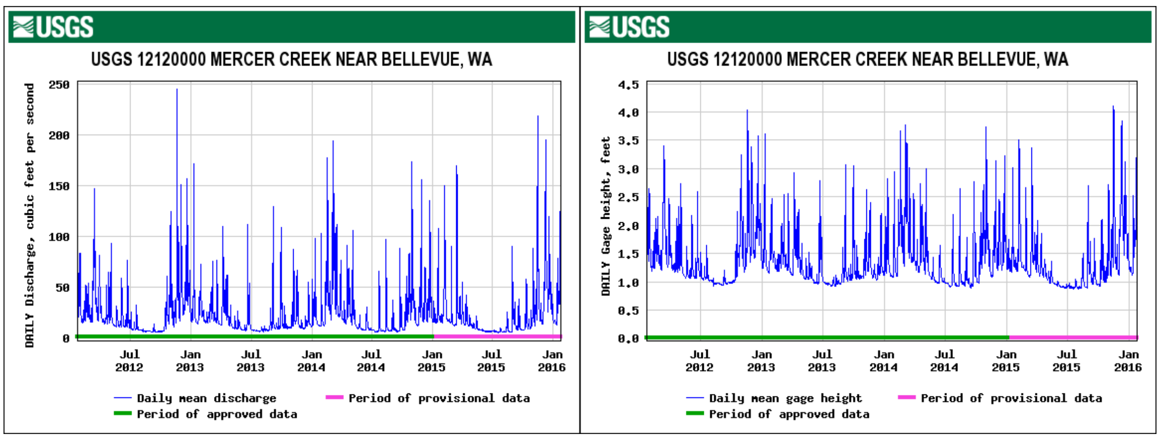


Figure 14. Discharge (left) and stage (right) for the past four years at Mercer Creek, Washington. Although the relationship between the two parameters is not identical over the full range of flows, the differences are clearly minimal and suggest that either could provide a useful basis for analysis of hydrologic patterns and trends.

Although constructing and maintaining a rating curve is not precluded by this monitoring design for the sites where stage data will be collected, it is not specifically recommended in recognition of the additional staff cost in collecting and analyzing the stage–discharge data. Primary indicators of hydrologic condition and alteration can be evaluated on stage data as easily as on discharge data, and both their range of values relative to regional conditions (see King County 2015) and their change over time can be used to characterize both the status and the trend of hydrologic conditions. Recommended indicators are focused on those anticipated to have the greatest relevance to both land-use changes and biological response (Konrad and Booth 2005), such as T_{Qmean} (e.g., Konrad and Booth 2002, DeGasperi et al. 2009) or the Richards-Baker Flashiness Index (Baker et al. 2004). See Appendix F for further discussion of hydrologic indicators and their application for the HSTM program.

Temperature is another water quality parameter that has a long history of collection using continuous data sensors, in recognition of the critical biological importance of water temperature, the wide range of stream channels that are impaired by overly high temperatures, and the rapid (diurnal) fluctuations of this indicator. Obviously, high water temperatures occur almost exclusively during the summer, suggesting that this indicator need only be collected during a portion of the year, and final implementation of the monitoring plan can elect to terminate the downloading of temperature data for the coolest 7 or 8 months of each year without significant loss of information (Figure 15). The *causes* of high temperature are varied, including (but not necessarily limited to) poor riparian cover, low groundwater input, and infrequent summertime stormwater discharges, which complicates any direct diagnostic value of this indicator for guiding immediate response by stormwater management programs. The value of this indicator in *evaluating* the status and trends of instream conditions, however, is widely recognized. See Appendix G for further discussion of this indicator.

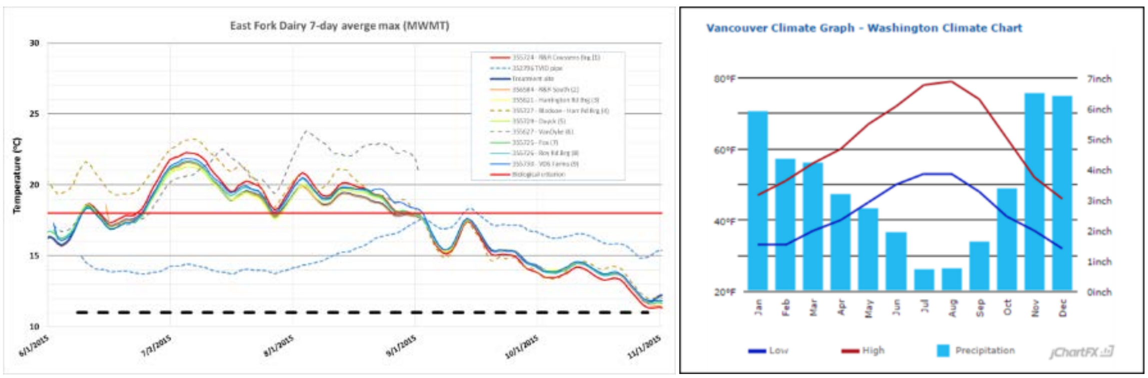


Figure 15. Left panel: Temperature variation in a small lowland stream in the Tualatin Basin, western Oregon (about 20 miles west of urban areas of the Lower Columbia Region). In 2015, biologically critical temperatures were reached at multiple locations in mid-June and persisted into September (data courtesy of Clean Water Services). Right panel: Distribution of rainfall at Vancouver, WA, with bar graph indicating that about 4 to 5 inches of potentially run-off-generating rainfall (about 10–15% of the annual total) falls during the period of the year when instream temperatures have the potential to reach ecologically problematic levels (data courtesy of HSTM Stormwater Caucus).

The final continuously collected indicator recommended by the Monitoring Design, conductivity, is only slightly less common as a broad-based indicator of instream conditions. “Conductivity” (or its temperature-corrected correlative, specific conductance) is widely recognized as a useful, easy-to-measure surrogate for total dissolved solids (TDS) (e.g., Minton 2003; Ecology 2011). As with temperature, causes of high TDS are varied and range from natural sources, particularly groundwater with a high mineral content, to stormwater inputs containing a range inorganic salts such as calcium, magnesium, potassium and sodium, and anions such as carbonates, nitrates, bicarbonates, chlorides and sulfates (GeoSyntec Consultants and Wright Water Engineers 2011). Natural waters in most settings have low TDS and thus low conductivity; elevated levels from human activity include wash-off from streets, fertilizers, industrial discharges, and soil erosion (see, for example, http://bcn.boulder.co.us/basin/data/NEW/info/TDS.html or http://www.epa.gov/your-drinking-water/table-regulated-drinking-water-contaminants).

The potentially greatest value of this indicator, however, is its ease of collection and its high correlation to other sediment-related measures (Miguntanna et al. 2010), particularly total suspended solids, which in turn has widely recognized ecological impacts at elevated levels and can be driven both directly by land-use activities i.e., (land-surface erosion) and indirectly via hydrologic alteration (resulting in stream-channel erosion from high flows). As with temperature, determining the precise *cause* of elevated sediment loading in a particular stream, whether measured directly or by a surrogate indicator, lies beyond the scope of a status and trends monitoring program. Characterizing the conditions, however, is a fundamental first step in effectively guiding subsequent management actions. See Appendix H for further discussion of this indicator.

4.2 Interpreting Indicators at Regional Sites throughout the Lower Columbia Region

Monitoring of streams across the region comprises annual measures of a range of physical habitat indicators together with collection and analysis of continuous temperature and benthic macroinvertebrates. The status of watershed health will be reported annually with trends available starting in year 6. As discussed in Section 1.1.5 of this report, Properly Functioning Conditions will be used to rate and assess the status and trends of specific indicators. This summary information will aid resource managers in succinctly communicating program results. Although PFCs are not explicitly linked to changes in fish abundance, productivity, spatial structure, and diversity, they do serve as reasonable surrogates until additional guidance becomes available. The following seven indicators are those most closely aligned to PFC criteria:

1. Temperature
2. Substrate particle size
3. Density/distribution instream wood
4. Pools per unit length
5. Residual Pool depth
6. Bankfull width/depth
7. Bank stability

Remaining indicators not currently included in PFC criteria will be used for additional interpretation in regional status and trend evaluation.

- Bank modification
- Density of habitat types
- Floodplain width
- Side channel habitat
- Relative bed stability
- Shade
- Riparian canopy
- Riparian understory
- Benthic macroinvertebrates

In some cases, data analysis and presentation methods are self-evident from the methodologies for collecting habitat indicators in Section 3.2 above. The following are suggested data analyses, potential benchmarks and presentation guidelines that will provide for easier applicability across programs in the region.

Given the ongoing advancement in benchmark development, we have provided recommendations rather than prescriptions. For technical as well as management purposes, these benchmarks may require refinement through the course of program implementation. For instance, many programs such as the U.S. Forest Service are either investigating or adopting reference conditions, rather than strict numerical benchmarks. The use of reference sites from within the study area can provide a more suitable, fine-scale basis for comparison of indicator results than regionally based benchmarks. Reference sites are defined as those that have been least disturbed by anthropogenic stress; data from these reference sites are then used to develop management targets for protection and restoration of aquatic resources. However, reference sites would need to be independently developed for specific strata, and thus, only more broadly applicable benchmarks to use for gross site characterization are presented below.

1. Temperature. The seven-day running average of maximum daily temperature is typically calculated. This number can then be compared to applicable benchmark criteria. NMFS defines a PFC to be water temperatures between 50º and 57ºF (10º and 14ºC). "At Risk" temperature conditions are defined by NMFS as 14ºC to 15.5ºC for spawning and 14ºC to 17.8ºC for rearing and migration. In Washington State, streams are designated in the following beneficial use categories (benchmark temperatures in parentheses) (Water Quality Standards for Surface Waters of the State of Washington, Chapter 173-201A WAC):
    a. Char spawning and rearing (12ºC)
    b. Core summer salmonid habitat (16ºC)
    c. Salmonid spawning, rearing, and migration (17.5ºC)
    d. Salmonid rearing, & migration only (17.5ºC)
    e. Non-anadromous Interior Redband Trout (18°C)
    f. Indigenous Warm Water Species (20°C)
2. Substrate particle size. Substrate metrics frequently reported include percentage of gravels and cobbles (suitable for spawning) and percent of sand and fines. Sand and fines can fill the interstices of gravels, reducing their suitability as spawning and rearing habitat. The percent of sand and fines can be compared to published criteria. NMFS (1996) states that a properly functioning condition is <12% fines; an at risk conditions is 12–17% (west side of the Cascades) or 12–20% (east side of the Cascades); and not properly functioning conditions are above these benchmarks. During data analysis and processing, the data can also be plotted by size class and frequency to determine the D_{16}, D_{50} and D_{84} for the entire reach (i.e., the sediment diameter that is coarser than 16, 50, and 84% of the total population). Shifts in the size of D_{16}, D_{50} and D_{84} signal a corresponding coarsening or fining of the substrate.
3. Density and distribution of instream wood. The total volume of LWD should be calculated and reported, and the number of "key pieces" should be tallied. The number of key pieces present could then be compared to applicable benchmarks. Key pieces are defined in different ways, depending on protocol. NMFS PFCs, as well as the USDA Forest Service interim Riparian Management Objectives (RMO) (Quigley et al. 1997) define key pieces in coastal areas as >24 inch diameter; >50 foot length, and for areas east of the Cascades as >35 feet length and >12 inches diameter. The key piece benchmark RMOs and PFCs are >12 key pieces per km (>20 key pieces per mile) east of the Cascades, and >50 pieces per km (80 pieces per mile) elsewhere.
4. Pools per unit length. Pools per unit length should be calculated from the number of pools identified and the total reach length. NMFS PFCs for pool frequency are based on channel width:

Channel width (feet)	Minimum # pools/mile for PFCs
5	184
10	96
15	70
20	56
25	47
50	26
75	23
100	18

Other pool metrics that could be reported are the percentage of habitat units and/or habitat area as pools, and number of channel widths per pool. These values could then be compared to applicable benchmark values. NMFS does not provide a PFC for percentage of pool habitat or pool frequency; in Oregon, however, benchmark values for "desirable" salmonid habitat conditions are >35% of the stream area comprised of pool habitat, and pool frequency of at least one pool every five to eight channel widths (ODFW 2014). "Undesirable" salmonid habitat conditions includes streams with <10% of total area in pools, and pool frequency >20 channel widths per pool (ibid).

5. Residual pool depth. As stated in Section 3.2 above, the minimum, maximum, and average residual pool depth for the sampling reach should be calculated and reported. The primary metric of interest related to residual pool depth is the number of pools greater than 1 meter (3 feet) deep. These deep pools tend to be more uncommon and serve as important holding habitat for adult salmonids. However, there is no established numerical criteria for the number of deep pools required per unit length of stream.
6. Bankfull width/depth. The average bankfull width and depth can be calculated from the data obtained at transects. The width:depth ratio could then also be determined. The width-to-depth ratio is a metric that can indicate the loss of pools, accelerated streambank erosion rates, high sediment supply and channel aggradation, channel over-widening due to direct mechanical impacts, and other causes. The NMFS PFC for width:depth ratio is the same as the USDA Forest Service interim RMOs (Quigley et al. 1997): <10.
7. Bank Stability. The percentage of each bank that is stable should be calculated from the data collected at the transects. According to NMFS, a properly functioning condition with regard bank stability is >90% stable; i.e., on average, less than 10% of banks are actively eroding. "At risk" conditions are 80–90% stable, and "not properly functioning" conditions are <80% stable banks.

While the preceding seven indicators can be compared across locations to pre-existing benchmarks or other established criteria, the remaining nine indicators are (in general) more appropriate for monitoring longer-term trends within a particular site, rather than making comparisons between sites. Exceptions to this statement are discussed below.

- Bank modification. The visual estimate of the percentage of each bank occupied by human-modified morphologies (i.e., pavement, rip-rap, etc.) can be compared within sites over time (if restoration activities return banks to a more natural state) or across sites. More remotes site (those in locations with less human impact), will obviously have a lesser degree of bank modification, but there are no guidelines for a comparison of what constitutes a desirable condition (other than the fact that less human modification is generally considered more desirable).

- Density of habitat types. The prevalence of different habitat types (geomorphic habitat units) should be calculated by unit length (i.e. the percentage of each habitat type per 1000 meters of surveyed stream length). The prevalence of different habitat types should also be reported by area (using the average length and width of each habitat unit to calculate cumulative and individual habitat area). The importance of different habitat types varies by species and life stage of fish utilizing the surveyed streams. The only frequently cited bench marks for the prevalence of different habitat types are related to the prevalence of pools, as discussed above. However, when reported on a percent of available habitat basis, this data can be used to draw broad comparisons between sites, and can be used to track changes within a site over time.
- Floodplain width. Floodplain width is normally an intrinsic property of a reach, determined by topographic confinement. Thus it has no value as an intrinsic indicator of stream "quality" except insofar as human infrastructure may have restricted access to part or all of that area. For purposes of evaluating actual or potential opportunities for off-channel habitat, surveyed reaches could be categorized into bins for comparison with each other, as streams with wide floodplains have different inherent qualities and evolve differently over time that streams with restricted floodplains. We recommend that investigators identify natural breaks in floodplain width within their monitored watersheds as a first step in identifying relative quality and potential for habitat development.
- Side-channel habitat. Side channels can provide important off-channel habitat for rearing salmonids. The length, average width, degree of connectivity to the mainstem and spot temperatures in the side channel vs. those in the main channel at the time of the survey should be reported. The length of side channels as a percentage of length of the main channel (or as a percent of total channel length, main channels and side channels combined) could also be reported, and gives an indication of habitat complexity in the surveyed reach.
- Relative bed stability (RBS). As described in the Monitoring Design (Stillwater Sciences 2015a), RBS is the ratio of the discharge predicted to move the median grain-size sediment on the bed of a channel to the bankfull discharge. For the RBS to be meaningful, the channel in question needs to have a reasonably well-defined bankfull level, and it needs to have a mixed-grain-size, gravel-bed substrate (these conditions are common, although not ubiquitous, across the Lower Columbia Region). An RBS score less than one predicts a relatively unstable streambed, because a progressively lower value indicates that the median bed sediment can be mobilized by flows progressively less (and so progressively more frequent) than the bankfull discharge. In relatively undisturbed coastal watersheds in the Pacific Northwest, Kaufmann et al. (2009) reported RBS values that ranged from 0.15 to 1.65. These results suggest that RBS values from suitable channels that are lower than this range should be considered indicative of ecological stress.
- Shade. The amount of shade recorded at each of the readings within a transect could be averaged for each individual transect, and an average calculated for the stream as a whole (average of all transects in the reach). Both of these numbers could then be reported and compared among sites and over time. The amount of channel shading is dependent on the width of the channel, channel morphology (if shade is provided by landforms rather than riparian vegetation), and the size and amount of riparian vegetation. In the absence of tree harvest, fire or other disturbance, channel shade should increase over time, but it is not an indicator that responds rapidly.
- Riparian canopy and riparian understory. Results for the riparian canopy, understory and groundcover should each be reported separately with the range and average of values for each transect. Results for the right and left banks could be lumped, but additional detail

would be provided if they were reported separately. An example data summary could read: "Of the 22 assessed locations (right and left banks at each of 11 transects) two were dominated by deciduous trees, three were mixed and the remaining 16 were evergreen dominated. For large trees, the canopy cover categories ranged from two to four, with an average of 3.5 (40–75% coverage). Canopy cover of small trees was much less, ranging from one to two, with an average of 1.1 (approximately 10% coverage)."

- Benthic macroinvertebrates. Data analysis of benthic macroinvertebrate samples will be conducted by the contracted laboratory. Typically, contracting laboratories will report multimetric models (such as a benthic Index of Biotic Integrity [B-IBI], and also typically, at least the EPT [Ephemera, Plecoptera, Tricoptera] Index) as well as multivariate (Observed/Expected [O/E]) models. Both multimetric and multivariate models can be used to compare among sampled sites, and within sampled sites over time. Different B-IBI scoring systems have different categories which constitute "good" to "poor" or "more disturbed" to "least disturbed" habitat. Examples can be found at the Puget Sound Stream Benthos site: http://pugetsoundstreambenthos.org/BIBI-Scoring-Types.aspx.

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Appendices

Appendix A

Stormwater Roles and Responsibilities

D R A F T
Recommendations for Implementing Stormwater Status and Trends Monitoring in the Lower Columbia Region under the 2018 NPDES Permits

Lower Columbia Stormwater Caucus Recommendations to Ecology
April 7, 2016

Contents

Introduction

The Lower Columbia Habitat Status and Trends Integrated Monitoring (HSTM) Phase 2 design was presented in February 2015 and submitted to the Washington Department of Ecology (Ecology) in fulfillment of requirements of a Grant of Regional and Statewide Significance.

The Lower Columbia HSTM monitoring design was collaboratively developed by local, state and federal stakeholders with diverse interests in impacts to habitat, designated uses, overall watershed health, and promoting salmon recovery.

As the first step in the implementation phase, the stakeholders formed caucuses to develop recommendations for developing a monitoring program based on the Phase 2 design. The Stormwater Caucus (Caucus) represents the eight local governments in the Lower Columbia Basin and the Washington State Department of Transportation (WSDOT) that have responsibilities for stormwater management and will have a NPDES MS4 permit requirement for status and trends monitoring effective in the next permit cycle.

Since June of 2015, the Caucus has worked to address the following questions and issues:

- Roles and Responsibilities:
  - Who are the primary program participants
  - How will the program be funded by the stormwater permittees
  - Who will manage the program
  - Who will conduct the monitoring and perform the data analysis and reporting
  - How other stakeholders will be able to participate in project implementation
- Data Collection:
  - Stream segment identification and selection
  - The use of legacy sites
  - Expected timing and frequency of the data collection
  - Parameters and metrics
  - Protocols to be used

- Data Management:
  - Data sharing objectives and mechanics (Why share? How to use the data? Who will use the data? What do they actually want to use?)
  - Database design
- Data Analysis and Reporting:
  - Who should analyze the data
  - How should the findings be reported including indicators to be used to answer the overall project questions and objectives for the urban stormwater management areas
- Scaling:
  - How the monitoring effort can be scaled (sites and frequency) to adequately answer management questions within available funding resources.

The group developed this set of recommendations and made decisions based on a consensus approach (Table 1).

This document contains the recommendations for the logistical roles and responsibilities for implementation of the Urban+NPDES stormwater portion of the Lower Columbia HSTM plan. A full overview of the plan and additional technical aspects of implementation planning can be found in the implementation plan report and QAPP document.

Table 1. Definition of Consensus

<table>
<tr><td colspan="7">Consensus is defined in terms of agreement along a continuum. Caucus members may register the degree of their agreement with the language in any of the first six columns:</td></tr>
<tr><td>Endorse</td><td>Endorse with a minor point of contention</td><td>Agree with reservation</td><td>Abstain</td><td>Stand aside</td><td>Formal disagreement but will go with the majority</td><td>Block</td></tr>
<tr><td>"I like it"</td><td>"Basically I like it"</td><td>"I can live with it"</td><td>"I have no opinion"</td><td>"I don't like it but I don't want to hold up the group"</td><td>"I want my disagreement to be noted in writing but I'll support the decision"</td><td>"I veto this proposal"</td></tr>
<tr><td colspan="7">The last (shaded) column on the right side of the continuum is not considered acceptable for consensus in this process.

However, anything to the left has been considered "agreement by consensus."</td></tr>
</table>

Recommendations

The Lower Columbia Stormwater Caucus (Caucus) has endorsed, with full consensus, the following recommendations for supporting and funding monitoring in the NPDES MS4-permited jurisdictions and respective Urban Growth Areas (UGA's) in the Lower Columbia Region.

Roles and Responsibilities

Program Partners

The primary program partners for the Lower Columbia NPDES+Urban stormwater component of the HSTM program will consist of the eight NPDES municipal stormwater permittees in the Lower Columbia Basin as well as WSDOT:

- City of Battle Ground
- City of Camas
- City of Kelso
- City of Longview
- City of Vancouver
- City of Washougal
- Clark County
- Cowlitz County
- Washington State Department of Transportation (WSDOT)

These nine entities will fund and guide the work of the program, and comprise a Steering Committee that will make key decisions in conjunction with the Program Manager (the entity managing the monitoring program, which is described below) on the program scope and budget administration. Additional agencies, organizations and stakeholders will be invited to participate on the program's Technical Advisory Committee (TAC) which will provide peer review and advise the Steering Committee.

Funding for Status and Trends Monitoring

The Caucus recommends that the program be funded by a cost-sharing formula based on population of the eight NPDES municipal stormwater permittees. WSDOT would be considered a medium-sized jurisdiction and pay a commensurate contribution. Funding for the program would be capped at $125,618 annually based on the population-based allocation method and per capita rate used in the current permit for Puget Sound status and trends monitoring.

Permittee contributions would be paid directly to Ecology to fulfill the Permit S8 requirement for status and trends monitoring. Ecology will serve as a pass-through of these funds to the Program Manager.

Who Will Manage the Program and Who Should Conduct the Monitoring

The Program Manager will be responsible for field work and sample collection, lab analyses, data management, QA/QC, and data analysis and reporting. The Caucus recommends that Clark County serve as the Program Manager.

Program Administration and Oversight

The Steering Committee comprised of the nine funding entities will make key decisions on the administration of the program scope and budget in conjunction with the Program Manager. A Technical Advisory Committee (TAC) will include additional agencies, organizations and stakeholders who have an interest in the program and will provide peer review of program activities and annual reports. The TAC will also provide feedback to the Steering Committee on the monitoring results and propose adaptive management of the program to address technical and/or budgetary issues.

Data Collection

Monitoring Program Overview

The Caucus recommends an implementation of the HSTM Phase 2 monitoring design utilizing a census-based approach to monitoring candidate stream sites within the Urban+NPDES strata in Clark and Cowlitz counties. Four stream segments ("status" sites) would be selected for the program each year, rotating through a set of 20 candidate segments within a 5-year period. In addition, the program would perform monitoring at a separate set of six non-rotating stream segments ("trend" sites) during the 5-year period. The total program of 26 stream segments meets the HSTM project's criteria of 10-20 sites per strata for statistical analyses.

Monitoring Indicators

The Caucus recommends the following parameters be collected at each of the status and trend sites in the monitoring program:

- Temperature
- Conductivity
- Stage
- Dissolved Oxygen (DO)
- pH
- Turbidity
- Total Suspended Solids (TSS)
- Total Solids (TS)
- Total Nitrogen (TN)
- Nitrate+Nitrite (NO_3+NO_2)
- Total Phosphorus (TP)
- Dissolved Copper (Cu)
- Dissolved Zinc (Zn)
- Fecal Coliform Bacteria
- Sediment Metals
- Sediment PAHs
- Benthic Macro-invertebrates

Site Identification and Selection

The potential program stream segment candidates for the NPDES MS4-permited jurisdictions and respective Urban Growth Areas (UGA's) were developed from the Lower Columbia Master Sample, following the framework developed for this project.

The prospective pool of stream segments includes 24 stream segments in Clark County and 6 segments in Cowlitz County which have their contributing watershed either partially or wholly within NPDES jurisdictions or UGA's. It is anticipated that 2-4 of the program's 20 status sites and one of the six trend sites be selected from the candidate stream segments in Cowlitz County.

Stream segments not selected for the program will be retained as alternates if preferred sites prove infeasible for meeting program objectives.

The Use of Legacy Sites

Legacy sites are those that have been sampled in the past and have a longer data record that might be useful in establishing long-term trends. Historical water quality monitoring and streamflow measurements have been performed in NPDES MS4-permited jurisdictions and respective Urban Growth Areas (UGA's) by Clark County, the City of Vancouver, and the Washington Department of Ecology.

The Caucus recommends that the program's six trend sites be located at legacy sites, as practicable, in order to leverage the existing trend data at these locations and build upon existing analyses.

Recommendations for Expected Timing and Frequency of Data Collection

The Caucus recommends that each of the status and trend sites be visited monthly to allow for site maintenance and downloading continuous parameter logger data, as well as the collection of field measurements and grab samples for other parameters.

Benthic macroinvertebrates will be assayed annually at each site (once at status sites and five times at trend sites, within the 5-year period). Sediment chemistry samples (PAHs and metals) will be collected once at each site within the 5-year period. Yearly QC reports and data summaries will be provided by the Program Manager.

Recommendations for Expected Timing and Frequency of Reporting

The Caucus recommends that reporting occur once every five years to provide a picture of stream status and trends in the Lower Columbia region. Report timing will likely depend on the expected timing and frequency of data collection (see above).

Methods Used to Collect Data

All parameters will be collected from data loggers, field measurements or grab samples, and analyzed by an accredited lab according to established protocols in the program Quality Assurance Project Plan (QAPP).

See the QAPP for a full discussion on methods for collecting the data for each indicator.

Data Management

Data Sharing Objectives and Mechanics

The Caucus recommends that the data be managed by the Program Manager, which will be responsible for performing QA/QC on all data and uploading the data to the Ecology's EIM database.

The Caucus expects this data will be shared among permittees, as well as other monitoring partners and stakeholders.

Database Design

The Caucus recommends that all data collected under the program be stored in Ecology's EIM database. Clark County currently manages data in its water quality database built under an Ecology grant in the early 2000's, which is capable of managing water quality and macroinvertebrate data collected under the program, and could serve as an alternative database. Clark County uses the Aquarius software to manage stage and flow data.

Data Analysis and Reporting

Who Should Analyze the Data

The Caucus recommends that the Program Manager be responsible for analyzing and interpreting the data collected under the program. Results collected under the program could potentially be pooled with data and analyses from the Puget Sound RSMP and PNAMP partners.

How Should the Findings be Reported

Data analysis and interpretation would be provided by the Program Manager in a report at the end of each 5-year permit term and provided for access and review to permittees and other stakeholders.

Scaling the Monitoring Effort

Scaling the Monitoring Effort to Answer Management Questions within Available Resources

The Caucus recommends the full funding of the "base" portion of the program (which includes continuous temperature, conductivity and stage data, sediment PAHs and metals and benthic macroinvertebrates), including an appropriate contingency buffer, before funding the collection and analysis of "extended" program parameters which include DO, pH, turbidity, TSS, TS, TN, NO_3+NO_2, TP, Cu, Zn and fecal coliform bacteria.

If funding is insufficient to fully implement the extended monitoring, the scope of extended monitoring would be reduced to stay within the funding cap and/or additional funding would be sought.

If enough funding is available, the collection of additional continuous parameters such as DO and TN may be considered.

Stormwater Caucus Members

Entities

- City of Battle Ground
- City of Camas
- City of Kelso
- City of Longview
- City of Vancouver
- City of Washougal
- Clark County
- Cowlitz County
- Washington State Department of Transportation (WSDOT)

Participants

- Sam Adams – City of Camas
- Anita Ashton – City of Camas
- Fred Bergdolt – WSDOT
- Jeff Cameron – City of Longview
- Rob Charles – City of Washougal
- Dick Gersib – WSDOT
- Annette Griffy – City of Vancouver
- Patrick Harbison – Cowlitz County
- Steve Haubner – City of Longview
- Van McKay – City of Kelso
- Jeff Schnabel – Clark County
- Dorie Sutton – City of Vancouver
- Rod Swanson – Clark County
- Kelly Uhacz – City of Battle Ground
- Steve Warner – City of Longview

Appendix B

Habitat Roles and Responsibilities

D R A F T

Recommendations for Implementing Habitat Status and Trends Monitoring in the Lower Columbia Region

Lower Columbia Habitat Caucus Recommendations to Ecology
January 7, 2016

Contents

D R A F T

Recommendations for Implementing Habitat Status and Trends Monitoring in the Lower Columbia Region

Introduction

The Lower Columbia Habitat Status and Trends Integrated Monitoring Design was finalized in February of 2015 and submitted to the Washington Department of Ecology in fulfillment of requirements of a Grant of Regional and Statewide Significance. This monitoring design was collaboratively developed by local entities with interests in stormwater impacts to habitat, watershed health, and salmon recovery. As a step toward implementation planning, those entities have broken out into caucuses to develop recommendations for how the design will be implemented.

Since August of 2015, the Habitat Caucus has worked to address the following issues:

- Partners;
  - Who will collect the data
  - How the collective resources of the habitat monitoring partners in the Lower Columbia should be pooled to support the effort
  - How agencies will participate in project implementation
- Data Collection;
  - Site identification and selection
  - The use of legacy sites
  - Expected timing and frequency of the data collection
  - The protocols to be used
- Data Management;
  - Data sharing objectives and mechanics (Why share? How to use the data? Who will use the data? What do they actually want to use?)
  - Database design
- Data Analysis;
  - Who should analyze the data
  - How should the findings be reported including indicators to be used
- Scaling;
  - How the monitoring effort can be scaled to adequately answer management questions within available resources

Stillwater Sciences assisted the caucus by providing various resources to consider as a starting point for caucus members to engage and contribute their ideas before arriving at a recommendation. The group developed these recommendations based on consensus (Table 1). Disagreements with any decision and the resolution to those disagreements will be documented in Appendix 1 of this report. At the time of this draft, there have been no disagreements among the Caucus.

This report represents only the portion of the full implementation plan that required logistical input. The technical aspects of implementation planning are found in the main body of the implementation plan report.

Table 1. Definition of Consensus

Consensus is defined in terms of agreement along a continuum. Caucus members may register the degree of their agreement with the language in any of the first six columns:

Endorse	Endorse with a minor point of contention	Agree with reservation	Abstain	Stand aside	Formal disagreement but will go with the majority	Block
"I like it"	"Basically I like it"	"I can live with it"	"I have no opinion"	"I don't like it but I don't want to hold up the group"	"I want my disagreement to be noted in writing but I'll support the decision"	"I veto this proposal"

The last (shaded) column on the right side of the continuum is *not* considered acceptable for consensus in this process.

However, anything to the left has been considered "agreement by consensus."

Recommendations

The Lower Columbia Habitat Caucus has endorsed the following recommendations for supporting and funding habitat monitoring in the Lower Columbia Region.

Partners

Structure of the Integrated Habitat Status and Trends Monitoring Program

In order to maintain momentum and keep the partners engaged, this program will be guided by a Steering committee composed of representatives from the regional habitat and water quality monitoring agencies and organizations. This steering committee would meet quarterly to provide an authoritative body to this multi-partner organization. In cooperation with the program manager, they would continue to foster partnerships in regional monitoring, continue to seek funding necessary to support the project, resolve obstacles and review methods to improve the program, and communicate results with stakeholders. Membership should include, at a minimum, representatives from:

- NOAA
- US Forest Service
- US Fish and Wildlife Service
- USGS Pacific Northwest Aquatic Monitoring Partnership
- Washington Department of Fish and Wildlife
- Washington Department of Ecology’s Environmental Assessment Program

- Washington Department of Ecology's Water Quality Programs
- Representative from SW Washington Stormwater Permittees
- Washington Salmon Recovery Funding Board
- Oregon Department of Fish and Wildlife
- Oregon Department of Environmental Quality
- Oregon Watershed Enhancement Board

In addition, a Technical Review committee will meet quarterly to provide feedback on annual reports and performance of the protocols. The feedback from the Technical Review committee will inform program management decisions by the Steering committee. Based on feedback from the Habitat Caucus members, the following agencies are interested in serving on the Technical Review committee:

- NOAA
- US Geologic Survey
- US Forest Service
- US Fish and Wildlife Service
- Washington Ecology's Environmental Assessment Program
- Oregon Department of Fish and Wildlife

How will agencies participate in monitoring implementation

The habitat caucus has identified a number of organizations in the Lower Columbia region that have an interest in habitat conditions, many of which are members of the Caucus. Some of these organizations have existing habitat monitoring programs that were designed to answer questions other than status and trends. Ideally, these agencies could also contribute to this monitoring program in a number of ways including:

- Staff – for field work, data management, analysis and reporting
- Funds to support implementation of the program
- Technical advice – participation in the habitat caucus and future program support
- Field equipment donation
- Serving on the Technical Review Committee
- Serving on the Steering Committee

Who Will Manage the Program

It is the recommendation of the Caucus that the Lower Columbia Fish Recovery Board manage the status and trends monitoring effort for both habitat and regional water quality monitoring tasks. This position could rotate or shift over time among the partners as negotiated by the Steering Committee. The Steering Committee would ultimately be in charge of appointing a program manager. To accommodate contracting needs, interagency agreements for program management should be secured on a 5 year basis consistent with the reporting cycle of the program. This agreement should recognize the biennial funding cycle of most government agencies by inserting a clause related to funding contingencies.

The Program Manager will work under the guidance of the Steering Committee to facilitate and coordinate the execution of data collection, management, analysis, and reporting through the combined efforts of the regional monitoring partners and contracted work. They will develop an annual work plan, convene the Steering Committee, organize and convene the Technical Review Committee, secure funding from regional monitoring partners, and provide a webpage to convey results and project information.

Who Should Conduct the Monitoring

Monitoring will be conducted by regional monitoring partners to the extent possible under their existing monitoring programs, and supplemented where necessary by contract labor. To date, we have heard verbal communications with NOAA, USFS AREMP, and Washington DNR, that they would be able to provide staff and equipment to visit a small number of sites each year. NOAA has the capacity to start with 2 sites a year. Washington DNR has stated that they could provide site visits, though the number and locations will be determined upon implementation. USFS/AREMP has the capacity to visit sites within the Gifford Pinchot National Forest. The program manager and steering committee will maintain an open policy for partners to conduct monitoring or contribute funding toward program operations as resources become available. To accommodate contracting needs, interagency agreements for data collection should be secured on a 5 year basis consistent with the reporting cycle of the program. This agreement should recognize the biennial funding cycle of most government agencies by inserting a clause related to funding contingencies.

Data Collection

Site Identification and Selection

As part of the Implementation Plan, 15 “viable” monitoring sites for each unique strata combination (bin) are needed. Given the challenges of site access and landowner approval, up to 45 provisional sites for each unique strata combination (bin) will be identified by random draw from the Lower Columbia Master Sample, following the framework developed in Phase 2 of this project (LCFRB, 2015). A bin must have at least 15 possible candidate sites in order to be included in the random draw. The 45 “provisional” sites should be sufficient to identify 15 “viable” monitoring sites within a bin.

Sites must physically independent of one another. Given the vast number of channel segments, this is unlikely to be an issue for the forested parts of the Region. However, due to the small number of sites that drain watersheds with predominately urban or agricultural land cover, it is likely that more than one regional monitoring site could be selected within the same stream segment. To avoid such clustering of sample locations and ensure the best possible distribution of sites, only one regional monitoring site will be sampled per stream segment.

The Use of Legacy Sites

Legacy sites are those that have been sampled in the past and have a longer data record that might be useful in establishing longer term trends. Legacy sites have been incorporated into the Lower Columbia HSTM Master Sample to allow the possibility of incorporating data from those sites. Legacy sites are not guaranteed to be included in the sample draw, but have equal probability of being “selected” as any other site in the Master Sample. If a legacy site is drawn and a partner has plans to visit that site in a subsequent year, another site will be drawn so that the legacy site is visited in the year that corresponds with the partner’s field schedule.

Recommendations for Expected Timing and Frequency of Data Collection

The sites will be visited in a rotating panel design such that 1/5th of the sites would be visited each year, covering the region over a 5 year period. This 5 year cycle is consistent with the reporting cycle used by NOAA in their 5 year status reviews for Salmon Recovery in the Lower Columbia. Site reconnaissance should begin in March to verify access permission from landowners and make a brief site visit to ensure the location is still accessible and safe to enter. A field training workshop should be held by the end of May to prepare field crews. All field personnel should participate in trainings every year. Data should be collected during the low flow months between July 1 and September 30th. Considerations behind this recommendation include the accuracy at which measurements can be taken at low flows, the safety of the field crew, and the relative absence of spawning fish and emerging fry in Lower Columbia tributaries. Sampling within the region should be timed in consideration of conditions within strata. For example, sampling at sites at higher elevation should occur later in the season to allow flows to decrease after snow melt.

During the first or initial 5-year monitoring cycle, data on 21 habitat indicators would be collected at each site. These habitat indicators are equivalent to the habitat metrics identified in the HSTM monitoring design. Four of these indicators (sample reach length, channel type, reach slope, sinuosity) are contextual and would be collected only during the initial 5-year monitoring cycle. During the second and subsequent 5-year monitoring cycles, the same sites would be revisited in the same sequence utilized during the first 5-year cycle. Only data on the 17 non-contextual indicators would be collected during these subsequent monitoring cycles. These indicators include:

- Bankfull width/depth
- Pools per unit channel length
- Floodplain area
- Side channel habitat
- Density of habitat type
- Flow category
- Residual Pool Depth
- Bank Stability
- Relative bed stability
- Density/distribution of instream wood
- Substrate particle size
- Shade
- Riparian Canopy
- Riparian understory
- Temperature (continuous measurements during summer season)
- Metrics associated with macroinvertebrate communities.

Regional status will be evaluated annually based on the sites sampled in a given year. Regional trends within and across stratum will be reported starting in year 6 based on a 5-year schedule for resampling. This monitoring approach maximizes the utility of the sites sampled for multiple purposes over a broad spatial extent.

Recommendations for Expected Timing and Frequency of Reporting

The caucus considered what would be useful for timing of reporting for the users of the data. NOAA reports on habitat condition with their 5-year status review. The LCFRB updates the Recovery Plan on a 6-year cycle that is tied in with fish cohort and life cycles. No other reporting needs were brought forward. The group recommends that the Lower Columbia HSTM program conduct reporting at two different scales and time cycles. A basic annual report will be generated to present data analysis on status, completed during the winter following each field season. A more detailed report on the analysis of both status and trends will be generated on a 5-year schedule. This report should be adequate to support both needs. If necessary, individual organizations could create interim reports derived from a summary of the most recent 5-year HSTM report, and the additional annual status reports needed to support their own reporting needs.

Methods Used to Collect Data

Stillwater Sciences compiled the methodologies of 7 active monitoring programs in the region to develop a decision matrix displayed, in part, in Table 1. This matrix documented the following for each measurement:

- the method from each program
- its associated signal to noise (where available)
- recommendations for caucus consideration regarding which method might be used

The Caucus reviewed the decision matrix and discussed additional suggestions to arrive at the recommendations for field data collection methods. By consensus, the habitat caucus recommends using the methods cited in Table 2 to collect data for each indicator. The actual methodologies are provided in an appendix of the Implementation Plan report. Monitoring partners are asked to use the HSTM protocols and methods to collect data to inform this program. The implementation report identifies methods that result in potentially sharable data. If the partner's methods are listed as sharable, then they may choose to use their methods to collect data to contribute to the HSTM program. If it is not possible to use the established methods, and the partners methods are not among those identified in the implementation report as potentially sharable, then participation in this capacity may not be appropriate.

Table 1. Excerpt from the decision matrix used by the Habitat Caucus in 2015 to discuss recommendations for data collection methodology of the Lower Columbia HSTM program.

Indicator[1] signal to noise grade*	**Methods currently used in Lower Columbia (Puls et al. 2014)***	**Notes on methods**	**Cost-effective method to implement? (high, med, low)**	**Protocol recommendation and justification**
Substrate particle size 1=A,C; 3,4=A,B		all measure or estimate particle size in some way. Different categories.	low	
	1	do pebble counts and visually estimate percent fines in pool tails.	low	
	2	pebble counts	low	**
	3,4,6	modified pebble counts on transects	low	**
	5	% distribution in 6 size classes visually estimated	low	
	7	modified pebble count, 12 substrate classes	low	
Embeddedness an intrinsically noisy metric	1, 5	not measured or estimated	low	
	2	For all cobbles selected in pebble count estimate % buried, and % fine sediments in immediate surroundings	low	
	3,4	Estimate for gravel, cobble and boulder from pebble counts. Four categories	low	**
	6, 7	estimate 10cm around pebble count	medium	

* Indicators were previously labeled "metrics" in the Monitoring Design Report

*1. AREMP
2. CHaMP
3. Clark Co.
4. ODEQ
5. ODFW
6. SRFB
7. WADOE

** Preliminary recommendation

Table 2. Summary of methods for data collection selected by consensus of the Habitat Caucus in 2015.

Monitoring Design Indicator*	Method/Measurement	Metric	Programs with potentially shareable protocols
1. Sample reach length[W,NW]	Reach length (m). 20x BFW, 150m minimum, 500m[W]/2000m[NW] maximum Use air photo for initial designation, followed by field confirmation	NA	AREMP, CHaMP, EMAP, ODFW, SRFB, Ecology
2. Channel type[W,NW]	Bedrock, colluvial, cascade, step pool, forced step pool, plane bed, pool-riffle, forced pool-riffle, regime (Montgomery and Buffington 1997)	NA	Ecology
3. Reach slope[W,NW]	Direct reading(s) of water-surface slopes using hand-held clinometer from top of reach to bottom (minimum number of segments as need to visually span reach)	Length-weighted average of individual slope measurements	AREMP, CHaMP, EMAP, ODFW, SRFB, Ecology
4. Sinuosity[W,NW]	1) Centerline channel length of the entire reach (measured by airphoto if possible; using field-measured thalweg profile [see below] if not) (2) straight-line distance between the starting and ending points of the thalweg/centerline measurement	Ratio of centerline/straight-line lengths	AREMP, EMAP, ODFW
5. Bank modification[W,NW]	% of human modified bank – both sides	Percent total	
6. Density of habitat types[W]	Length and width for distinct habitat types meeting minimum size criteria—pool, step pool, riffle, cascade habitat, falls, run/glide, dry channel	Percent habitat for each type	CHaMP, EMAP, ODFW, Ecology
7. Bankfull width/depth[W,NW]	Lengths of the bankfull width and depth, as identified using standard field indicators, at each of the 11 transects in a reach (measurements should be omitted at transects with ambiguous indicators).	Average of the unambiguous measurements for both bankfull width and bankfull depth.	AREMP, CHaMP, EMAP, ODFW, SRFB, Ecology
8. Pools per unit length[W]	Number of minimum-sized pools identified during habitat mapping, and total reach length	Pools per unit length	AREMP, CHaMP, EMAP, ODFW, Ecology

Monitoring Design Indicator*	Method/Measurement	Metric	Programs with potentially shareable protocols
9. Floodplain width[W,NW]	Employ field-based estimates; supplement with air photos for non-wadeable streams. Estimate width of the alluvial surface beyond the bankfull channel[W,NW]; document presence of additional off-channel features such as scroll bars, oxbow lakes, etc.	Categorize the floodplain width into categories scaled by bankfull width (e.g., 0-1 W_{bkfl}; >1 W_{bkfl}) (bins TBD)	EMAP
10. Side channel habitat[W,NW]	Determine "qualifying" vs. "nonqualifying" side channels (defined by CHaMP) Length, width, temperature, connectivity to mainstem	Qualifying channels – side channel length in meters; width and temperature measurements (upstream, midpoint and downstream); degree of connectivity to the mainstem (%) Nonqualifying – document presence only	
11. Flow category[W,NW]	Visual estimate of flow conditions at time of survey	dry, puddled, low, moderate, high, bankfull, flood as defined by ODFW protocols. Modify "Low Flow" to include surface water flowing across <75% of active channel surface	ODFW
12. Benthic Macroinvertebrates[W]	Employ Ecology's transect-based methods – one kick sample at 8 of the 11 transects for either flowing or slack water. Details found in https://fortress.wa.gov/ecy/publications/documents/1003109.pdf	Samples processed to provide summary statistics/models (e.g. O/E and BIBI). Use Level 2 standard nomenclature http://www.pnamp.org/project/4210 as developed by the Macroinvertebrate Planning Group.	Ecology, AREMP, CHaMP, EMAP, ODFW, SRFB
13. Residual Pool depth[W]	Maximum pool depth, pool crest depth	Maximum pool depth minus pool crest depth	AREMP, CHaMP, EMAP, ODFW, SRFB, Ecology

Monitoring Design Indicator*	Method/Measurement	Metric	Programs with potentially shareable protocols
14. Bank stability[W]	Categorize bank condition at each end of each transect, integrating the conditions observed along the bank from the transect point up- and downstream half-way to the next adjacent transect (22 measurements).	Median of the 22 transect-specific measurements. The result is a categoric (not a decimal) value for the entire reach.	EMAP
15. Relative bed stability[W]	None	Ratio of reach D50 to [(average bankfull depth) × (reach slope)]; apply roughness correction if/as indicated by selected protocol.	EMAP and Ecology
16. Density / distribution instream wood[W,NW]	Number and size of individual qualifying logs (AREMP protocol-minimum 15 cm dia., 3 m length). 1st ten pieces measured, then every fifth up to 35th pieces, then every 10th piece, size and location of accumulations and jams. Other pieces visually estimated; location of wood recorded (mid, bar, side, etc…)	Number of pieces and total wood volume (m^3) per unit length	AREMP, possibly others…
17. Substrate particle size[W]	Randomly selected, "first-touch" grains across the entire bankfull channel along fast-water (i.e., riffle) transects only. Count number of grains per transect to achieve at least 200 grains counted per entire reach. Record b-axis length in 1/2-phi intervals; subidivde <4 mm grains into "sand" and "fines".	Median grain size (D50); also D84, D16 for the entire reach.	CHaMP
18. Shade[W]	Canopy cover measured with densiometer (Mulvey et al. 1992 as cited by Ecology) on left bank and right bank for 11 transects and in 4 directions at each location	Shade score; could be reported as percent shade	EMAP, SRFB, Ecology
19. Riparian canopy (% cover) [W,NW]	Visually estimated for different vegetation types (see Ecology protocol) in a 10x10m plot at 11 transects	% cover of vegetation > 5m height	CHaMP, EMAP, ODFW, SRFB, Ecology
20. Riparian understory (% cover) [W]	Visually estimated for different vegetation types (see Ecology protocol) in a 10x10m plot on both banks at 11 transects	% cover of vegetation 0.5 - 5m height	CHaMP, EMAP, ODFW, SRFB, Ecology

Monitoring Design Indicator*	Method/Measurement	Metric	Programs with potentially shareable protocols
21.Temperature[W,NW]	Temperature logged with hobo or similar data loggers at one representative location at each selected site at half hour intervals. Hobos will be deployed, retrieved and downloaded by the Field Reconnaissance crew, and the data sent to the Data Manager.	7-day moving average maximum temp, daily maximum temp, average daily temp	AREMP, CHaMP, EMAP, ODFW, SRFB, Ecology

* Indicators were previously labeled “metrics” in the Monitoring Design Report

W Wadeable

NW Non-wadeable

Data Management

Data Sharing Objectives and Mechanics

The program manager in consultation with the Steering Committee and Technical Review Committee will identify a data manager in charge of data QA, entry to a database, and data export to support the analysis manager or in response to data requests. To accommodate contracting needs, interagency agreements for data management should be secured on a 5 year basis consistent with the reporting cycle of the program. This agreement should recognize the biennial funding cycle of most government agencies by inserting a clause related to funding contingencies.

Data flow will occur as follows:

Raw Data

- Data entry and QA will occur between July and December of each year.
- Each organization collecting data will QA their data sheets in the field or lab before departure from the site.
- Data collectors will submit data on a weekly basis to the data manager in digital format (either scanned images of datasheets or digital files from a field tablet) and copy the Program Manager. If paper datasheets are used, original datasheets should be mailed to the program manager for archiving on a weekly basis.
- The data manager will enter the data into the database upon arrival. A long term goal would be to develop an online database with clear guidance on data entry to allow monitoring partners to enter data themselves. The data manager would focus on QA of incoming data.
- The data manager will QA the data upon entry.

Indicators and Indices

- Entry of indicators and indices will occur between December and April of each year.
- The analysis manager (discussed below) will provide any calculated indicators and indices to the data manager for entry into the database. A long-term goal would be to have database functionality to generate those values on the fly.

Database Design

The caucus recommends that near-term storage occurs through an access database, however the long term vision is to secure funding to develop and maintain an online database website. The database will store raw data, as well as calculated indicators and indices. At this time, protocols for data sharing and upload to the database are simple. The data manager will input and extract data. Upon development of a more sophisticated database, more elaborate rules should be developed to facilitate multiple partners uploading and extracting data at will.

Data Analysis

Who Should Analyze the Data

The program manager in consultation with the Steering Committee and Technical Review Committee will identify a data analysis manager in charge of data analysis and reporting. To accommodate contracting needs, interagency agreements for data analysis should be secured on a 5 year basis consistent with the reporting cycle of the program. This agreement should recognize the biennial funding cycle of most government agencies by inserting a clause related to funding contingencies.

Analysis and reporting should be a combined activity. This should increase the chances that the data is properly interpreted. The person writing the report would then know the caveats and limitations of the data and analyses.

The data analysis manager should analyze the data on an annual basis between December and April, and provide a brief status update of those findings. A more detailed report of both year 5 status and overall trends (from inception of monitoring to current year) on a regional basis will be generated between December and July every 5 years, consistent with the guidance in the implementation plan. Final updates and reports should be submitted to the program manager for review by the Technical Review committee. Upon incorporation of the Technical Review Committee's comments, the program manager will finalize the document, post it online (program webpage and PNAMP), and send email notification to the Steering Committee and interested parties.

How Should the Findings be Reported including Indicators to be Used

Annual status updates will be generated by the data analysis and reporting manager between December and April of the year following data collection. This will allow some time for adaptive responses to the monitoring protocol before the coming field season. 5 year Status and Trends reports will be generated by the data analysis and reporting manager between December and July following every 5th year of data collection. These reports will be sent to the Program Manager for dissemination among the Technical Review committee for their review and comment prior to posting online and dissemination to the Steering Committee and interested parties.

The program manager will post annual status updates and 5 year status and trends reports to the program webpage. Findings will be disseminated by the program manager to NOAA, the Salmon Recovery Funding Board, Washington Department of Ecology, and other interested parties identified during the implementation phase of program development through distribution of an email with links. Links or copies of the reports should be posted on the PNAMP website to reach a broader regional audience.

Because the metrics selected for measurement are those that are most meaningful for describing habitat conditions, the metrics themselves are the primary indicators to be reported. For the macroinvertebrates, a multi-metric index and a multivariate index (O/E model) will be used. Details about these metrics are provided in the Implementation Report authored by Stillwater Sciences.

Scaling

Scaling the Monitoring Effort to Answer Management Questions within Available Resources

The following options were explored to provide a mechanism for reducing the overall magnitude and financial requirements of the monitoring effort:

- Determine the variability in habitat data to see if fewer sites would still support a robust assessment.
- Reduce statistical power/confidence
- Reduce the number of strata
- Condense and truncate strata categories
- Use remotely sensed data to collect some metrics
- Reduce the annual effort by adopting a rotating panel sampling design.

After consideration it was found that only three of these options were realistic:

- Reduce the level of statistical confidence required
- Condense and truncate strata categories
- Reduce the annual effort by adopting a rotating panel sampling design.

Investigations into acceptable levels of confidence for biological and ecological measurements indicate that there is precedent for lowering our level of confidence from 95% to 90%. There are at least 3 regional programs that conduct monitoring in the Lower Columbia that use a 90% confidence level to detect changes in environmental data. This shift does not result in a recommendation for a reduction in magnitude or financial requirements to support this program, however, it does allow us to detect changes with high confidence in a shorter time frame.

It was recommended that the least problematic reduction of strata categories could be accomplished by removing those sites that are in areas of >7.5% gradient, and by condensing the subbasin/primary population strata from 3 to 2 categories, combining the bins for those subbasins that support 3 primary populations and those that support 4 or more. This will reduce our effort by nearly 100 site visits per year.

Reducing the annual effort by adopting a rotating panel would provide savings on an annual basis, and make it a more manageable funding amount. It would allow us to visit fewer sites per year. However, there are implications for reporting, namely that a complete, statistically robust picture of regional habitat status would not be generated as quickly.

Available Resources

Currently, there is no designated funding for the habitat component of the Lower Columbia HSTM monitoring program. The LCFRB and others will present the completed monitoring package (Design and Implementation Plan) to potential funding sources to find funding for this effort. The discussion of the estimated resources necessary to support this program can be found in the implementation plan report.

Appendix 1: Resolution of Disagreements

At this time, the Caucus has not experienced any disagreement during our discussion.

Appendix 2: Habitat Caucus Members

Affiliation	First Name	Last Name	Active	Inactive
Bureau of Land Management/AREMP	Stephanie	Miller	X	
City of Vancouver	Dorie	Sutton	X	
Cowlitz Indian Tribe	Rudy	Salakory		X
Cowlitz Indian Tribe	Shannon	Wills		X
Lower Columbia Fish Recovery Board	Karen	Adams	X	
Lower Columbia Fish Recovery Board	Jeff	Breckel	X	
Lower Columbia Fish Recovery Board	Steve	Manlow		X
Lower Columbia Fish Recovery Board	Melody	Tereski		X
Lower Columbia Estuary Partnership	Amanda	Hanson		X
Lower Columbia Estuary Partnership	Matthew	Schwartz		X
Natural Systems Design	Jennifer	O'Neal		X
NOAA	Scott	Anderson	X	
NOAA	Jeffrey	Fisher	X	
NOAA	Scott	Rumsey		X
Oregon Deparment of Environmental Quality	Shannon	Hubler	X	
Oregon Department of Environmental Quality/ Northwest Region	Wade	Peerman		X
Oregon Department of Fish and Wildlife	Kara	Anlauf-Dunn		X
Oregon Department of Fish and Wildlife	Jamie	Anthony		X
Oregon Department of Fish and Wildlife	Charlie	Stein		X
Stillwater Sciences	Jody	Lando	X	
TetraTech/SRFB	Tricia	Gross		X
US Forest Service	Jim	Capurso		X
US Forest Service Gifford Pinchot National Forest	Baker	Holden		X

US Forest Service Gifford Pinchot National Forest	Ruth	Tracy		X
US Forest Service/AREMP	Mark	Raggon	X	
US Fish and Wildlife Service	Sam	Lohr		X
USFWS	Ron	Rhew	X	
US Geologic Survey	Ian	Waite	X	
US Geologic Survey Pacific Northwest Aquatic Monitoring Partnership	Jennifer	Bayer	X	
US Geologic Survey Pacific Northwest Aquatic Monitoring Partnership	Meg	Dethloff	X	
US Geologic Survey Pacific Northwest Aquatic Monitoring Partnership	Amy	Puls	X	
Washington Department of Natural Resources	Abby	Barnes	X	
Washington Department of Natural Resources	Allen	Lebovitz		X
Washington Department of Ecology	Chad	Larson	X	
Washington Department of Ecology	Glenn	Merritt		X
Washington Department of Fish and Wildlife	Emelie	McKain		X
Washington Department of Fish and Wildlife	Steve	West	X	
Washington Department of Fish and Wildlife	Dave	Howe		X
Washington Department of Natural Resources	James	Huinker	X	
Yakama Nation	Jeanette	Burkhardt		X
Yakama Nation	Lee	Carlson	X	
Yakama Nation	Michelle	Steg-Geltner		X
Yakama Nation	Paul	Ward		X

Appendix C

Candidate Monitoring Sites

Region	within Urban + NPDES area	within Urban + NPDES area	within Urban + NPDES area	within Urban + NPDES area	within Urban + NPDES area	within Urban + NPDES area
Drainage Area	0.6-2.5 km^2	0.6-2.5 km^2	0.6-2.5 km^2	0.6-2.5 km^2	2.5-50 km^2	2.5-50 km^2
Stream Gradient Groups	<1.5%	<1.5%	1.5-3%	3-7.5%	<1.5%	<1.5%
Predominant watershed land cover	forested	urban	urban	urban	forested	urban
Number of Primary Populations in the sub-basin	N/A	N/A	N/A	N/A	N/A	N/A
1	0.027027411	0.038944978	0.02111823	0.011684626	0.003930439	0.008067669
2	0.124613033	0.075407463	0.050757246	0.142972405	0.027752797	0.016642372
3	0.162746777	0.090307883	0.053617026	0.171033488	0.048775001	0.018918203
4	0.240815676	0.098726002	0.275184476	0.193857856	0.055871743	0.019079885
5	0.243179578	0.113492622	0.289596306	0.200768486	0.059944796	0.028232985
6	0.280025553	0.116859458	0.351109663	0.236162401	0.078855948	0.052029842
7	0.422037479	0.12309498	0.409584816	0.268909205	0.09669869	0.066233585
8	0.449516558	0.136847685	0.4132796	0.283764328	0.106079536	0.07120579
9	0.461732294	0.144106884	0.511653519	0.362012488	0.167658909	0.079082072
10	0.526551227	0.14516492	0.557339758	0.396692873	0.186943637	0.088703902
11	0.548502237	0.152703792	0.595228067	0.46616033	0.187016836	0.105541181
12	0.563127434	0.160406733	0.629835121	0.486787688	0.190810795	0.11776189
13	0.703367263	0.184334655	0.66199515	0.501768837	0.202943277	0.129280622
14	0.95599524	0.188479242	0.699580138	0.528925213	0.213892661	0.136216543
15	0.97721755	0.198605333	0.79373803	0.561653248	0.224239573	0.140539322
16		0.206465932	0.835041053	0.689164466	0.231081191	0.143499072
17		0.212471575	0.87358492	0.709696361	0.267983364	0.149709736
18		0.218446397	0.918657619	0.76493954	0.271366673	0.16839901
19		0.222523998	0.922930053	0.819939902	0.285508713	0.180025431
20		0.225149746	0.95443207	0.886588596	0.301539744	0.183303323
21		0.230507414	0.958352594		0.313632891	0.193157808
22		0.233689464	0.976553954		0.322848846	0.200117487
23		0.238970146			0.332265534	0.201758974
24		0.286933602			0.347249081	0.206284311
25		0.303385984			0.355976975	0.214070896
26		0.319141442			0.35904915	0.218918545
27		0.325063923			0.381445352	0.221885423
28		0.327237587			0.389111343	0.230365448
29		0.359878193			0.409295647	0.23073233
30		0.383574985			0.432485775	0.239395419
31		0.396371887			0.436830935	0.249305036
32		0.434135612			0.451348526	0.252608441
33		0.478925982			0.459762545	0.271728892
34		0.481888517			0.468364293	0.278909031
35		0.483254208			0.473607384	0.279853039
36		0.49159997			0.51489323	0.28025171
37		0.510712376			0.522919302	0.302691233
38		0.543826702			0.5304807	0.318326258
39		0.547303459			0.531160236	0.323185939
40		0.576816293			0.532407976	0.341762035
41		0.580209038			0.532645088	0.343254018
42		0.580718336			0.549605783	0.351713856
43		0.595553344			0.552462953	0.360081461
44		0.598212447			0.55451956	0.386182053
45		0.605123271			0.555762604	0.387623143

Region	within Urban + NPDES area	within Urban + NPDES area	within Urban + NPDES area	within Urban + NPDES area	Regional Area	Regional Area
Drainage Area	2.5-50 km^2	50-200 km^2	200-1000 km^2	>1000 km^2	0.6-2.5 km^2	0.6-2.5 km^2
Stream Gradient Groups	1.5-3%	<1.5%	<1.5%	<1.5%	<1.5%	<1.5%
Predominant watershed land cover	urban	forested	forested	forested	forested	forested
Number of Primary Populations in the sub-basin	N/A	N/A	N/A	N/A	0-2	3+
1	0.015736983	0.029845414	0.017790007	0.098437634	0.003562193	0.002349811
2	0.034718323	0.041960821	0.038564489	0.118669762	0.010396024	0.005395623
3	0.035360159	0.050762504	0.063354582	0.119794257	0.01939652	0.005953147
4	0.067768551	0.052810022	0.106664981	0.121388528	0.022306918	0.006313301
5	0.144032452	0.055293663	0.129602548	0.228469578	0.022439825	0.0063635
6	0.250103439	0.062944648	0.138358509	0.246910878	0.029532055	0.007216101
7	0.25751067	0.092239082	0.154821282	0.266339024	0.03321327	0.007325334
8	0.352264713	0.133769557	0.183031221	0.276189655	0.033846861	0.008176153
9	0.364893814	0.1341709	0.203546494	0.287766805	0.034247693	0.008746158
10	0.503530688	0.171617799	0.210157235	0.293978729	0.048977467	0.009281953
11	0.536598844	0.173971397	0.210420917	0.310171457	0.057392816	0.010554521
12	0.573787846	0.181676269	0.216428441	0.364695001	0.05864663	0.01215536
13	0.601958329	0.184172404	0.231982134	0.394413622	0.059213488	0.0141539
14	0.603613364	0.237046442	0.24950215	0.431462019	0.06337805	0.014174196
15	0.770990196	0.266064588	0.279533141	0.447471884	0.065558016	0.014815211
16	0.85849782	0.279690415	0.322533467	0.494256155	0.066744251	0.015731744
17		0.281819632	0.374997929	0.53273877	0.072005984	0.016342265
18		0.304246713	0.447043295	0.540893904	0.0740976	0.016582279
19		0.325285113	0.4687324	0.545397316	0.07987184	0.01675355
20		0.354370072	0.471575071	0.549041181	0.082897902	0.017679229
21		0.361194019	0.484635949	0.554387325	0.101744858	0.018044474
22		0.395308799	0.491407825	0.573162903	0.10230479	0.018372925
23		0.401465036	0.503216577	0.587784715	0.103121266	0.018535026
24		0.408132147	0.517648644	0.608532326	0.104100095	0.018824648
25		0.444438234	0.549922562	0.611918319	0.112276884	0.022426844
26		0.446712203	0.550948743	0.65198971	0.112669954	0.023274749
27		0.474401619	0.561788598	0.673047194	0.113456975	0.024459708
28		0.479597768	0.610929619	0.678531446	0.116974502	0.026144886
29		0.480527299	0.624212019	0.688173593	0.120681638	0.026870261
30		0.514974957	0.639915653	0.689626047	0.124992912	0.027569825
31		0.557490296	0.651642568	0.692355317	0.129923626	0.028113183
32		0.578687097	0.65367476	0.70117316	0.137370353	0.029052849
33		0.583754987	0.679375657	0.731061815	0.139570556	0.029078021
34		0.586048769	0.711272257	0.73187348	0.166005186	0.029701409
35		0.593629456	0.736841629	0.736816565	0.17240427	0.031433214
36		0.596703618	0.743171966	0.776729946	0.181802995	0.032225253
37		0.602472981	0.756931921	0.777317804	0.182193317	0.032617658
38		0.615274987	0.761696555	0.80464753	0.182545446	0.034842224
39		0.648309154	0.797064509	0.848574863	0.187724029	0.03514303
40		0.648767702	0.828319595	0.857942733	0.189034232	0.035399919
41		0.669941357	0.840440475	0.869295451	0.199482475	0.03655093
42		0.67834063	0.847096653	0.888040941	0.200895862	0.03757378
43		0.685441459	0.862025458	0.959098933	0.202360751	0.038025377
44		0.68663985	0.862233122	0.982428919	0.213306893	0.038363385
45		0.696308856	0.872099833	0.999294051	0.215285989	0.038808701

Region	Regional Area	Regional Area	Regional Area	Regional Area	Regional Area	Regional Area
Drainage Area	0.6-2.5 km^2	0.6-2.5 km^2	0.6-2.5 km^2	0.6-2.5 km^2	0.6-2.5 km^2	0.6-2.5 km^2
Stream Gradient Groups	<1.5%	<1.5%	1.5-3%	1.5-3%	1.5-3%	3-7.5%
Predominant watershed land cover	agricultural	agricultural	forested	forested	agricultural	forested
Number of Primary Populations in the sub-basin	0-2	3+	0-2	3+	3+	0-2
1	0.016862929	0.000474616	0.006753578	9.01434E-05	0.005626583	0.001913734
2	0.018483369	0.000607575	0.007615334	0.002173091	0.026303367	0.003878532
3	0.034335698	0.009967572	0.011380505	0.005068521	0.070377501	0.003964094
4	0.064532073	0.017193051	0.014137681	0.005403876	0.078794363	0.014457385
5	0.070786327	0.042776414	0.019722474	0.00602658	0.097482339	0.015602095
6	0.096461465	0.053186027	0.020329774	0.00763353	0.163694913	0.017383888
7	0.100836446	0.064506401	0.02223585	0.007659329	0.176566775	0.017566039
8	0.165288854	0.066290149	0.023984134	0.008472925	0.182778097	0.017996321
9	0.167148679	0.086842103	0.038236395	0.011227852	0.250846324	0.018900962
10	0.177801216	0.098654047	0.048715056	0.011557383	0.327243601	0.019141133
11	0.19466486	0.116781452	0.056235625	0.014551147	0.334554687	0.019284034
12	0.202781444	0.12322817	0.062359386	0.016348286	0.459045615	0.019638997
13	0.223645863	0.12384384	0.067393465	0.016870243	0.490687869	0.02036922
14	0.238580404	0.12700829	0.068011692	0.020600075	0.549506001	0.020422945
15	0.266341367	0.136182168	0.07687506	0.021778158	0.55995356	0.021043068
16	0.26967124	0.136284868	0.081311797	0.025418349	0.572476115	0.021065368
17	0.276893365	0.153097122	0.081925719	0.027059617	0.674153854	0.021792046
18	0.279068349	0.178336313	0.086043013	0.029854587	0.70643917	0.023468845
19	0.285208288	0.179862726	0.092659649	0.030653251	0.710373203	0.027127392
20	0.287390589	0.194026147	0.094909042	0.033398261	0.71277661	0.030352639
21	0.28885567	0.195046579	0.103421655	0.034696119	0.748409033	0.030937169
22	0.380979379	0.222314816	0.105532957	0.036418042	0.819671789	0.034263223
23	0.413595092	0.238987233	0.112169148	0.03768152	0.825664357	0.034662406
24	0.429207979	0.244397831	0.114635204	0.041082845	0.882230306	0.040139626
25	0.436678026	0.250482626	0.116585552	0.043081753	0.893772785	0.04459582
26	0.437089508	0.251763255	0.122855614	0.043217613	0.91833603	0.045648227
27	0.437236031	0.256641689	0.123182359	0.044407384	0.947734763	0.048037542
28	0.461310128	0.259464729	0.124725294	0.045731057		0.04932051
29	0.478249224	0.269853584	0.126088232	0.046150198		0.049996817
30	0.488706755	0.270137307	0.134396118	0.046602417		0.055608147
31	0.524032664	0.277592406	0.139917625	0.048831699		0.058417025
32	0.530012933	0.280480915	0.144299612	0.049093219		0.058908099
33	0.535981606	0.282569334	0.148204492	0.051207332		0.059622013
34	0.536010609	0.28269536	0.149852893	0.051535509		0.061166065
35	0.538644283	0.28647351	0.152112843	0.052302868		0.061247386
36	0.557952761	0.29292794	0.156031921	0.05323355		0.06467975
37	0.565181768	0.295934135	0.157308234	0.054998241		0.066383603
38	0.567176573	0.297844841	0.159454236	0.056567292		0.068380691
39	0.574705431	0.30056406	0.164410591	0.057491512		0.068416185
40	0.590727537	0.302294366	0.164881252	0.060245305		0.070166838
41	0.644464963	0.315969144	0.16672539	0.063484767		0.072577436
42	0.651953067	0.324685665	0.186443761	0.06442875		0.07305045
43	0.661596501	0.325778156	0.18684864	0.065631011		0.074261398
44	0.669906954	0.326532067	0.188261483	0.066672009		0.078294679
45	0.693239008	0.332305065	0.192008592	0.066966902		0.081341014

Region	Regional Area	Regional Area	Regional Area	Regional Area	Regional Area	Regional Area
Drainage Area	0.6-2.5 km^2	0.6-2.5 km^2	0.6-2.5 km^2	0.6-2.5 km^2	2.5-50 km^2	2.5-50 km^2
Stream Gradient Groups	3-7.5%	3-7.5%	>7.5%	>7.5%	<1.5%	<1.5%
Predominant watershed land cover	forested	agricultural	forested	forested	forested	forested
Number of Primary Populations in the sub-basin	3+	3+	0-2	3+	0-2	3+
1	0.001819322	0.02406907	4.38764E-05	8.82713E-05	0.988177773	0.00117785
2	0.002173788	0.050393102	0.000551688	0.000242864	0.006741517	0.001557915
3	0.00220634	0.074880166	0.001076559	0.000277818	0.7361029	0.001772315
4	0.00252122	0.075739688	0.001300832	0.000510335	0.835307405	0.002182845
5	0.002916451	0.081038053	0.002811753	0.000567114	0.688948195	0.002375396
6	0.003418562	0.129641013	0.003728354	0.000621062	0.276912584	0.003346996
7	0.003436176	0.132587913	0.003836804	0.000844757	0.095073094	0.004243781
8	0.003566455	0.187486374	0.004459346	0.000977224	0.13568794	0.004346258
9	0.005151473	0.200776676	0.00550899	0.001078212	0.65148519	0.004447005
10	0.006509626	0.217866581	0.005850543	0.001294975	0.130225241	0.004916987
11	0.007175776	0.224637434	0.005868603	0.001349659	0.453646526	0.00563866
12	0.00914519	0.227340306	0.005951171	0.001500736	0.770591477	0.007076235
13	0.009278548	0.239381971	0.006297273	0.001972618	0.157706599	0.007613274
14	0.009627583	0.250132649	0.006450889	0.002222814	0.992782964	0.007734771
15	0.010089126	0.286624437	0.007257968	0.002296048	0.454556875	0.007738111
16	0.010303473	0.301361887	0.008782972	0.002320938	0.306964286	0.009008955
17	0.010830747	0.320564631	0.009547727	0.002592846	0.514090718	0.009993964
18	0.010914898	0.372375407	0.009799399	0.003104648	0.85110682	0.010314666
19	0.011962784	0.37632737	0.010021514	0.003105357	0.201589273	0.01159128
20	0.012601689	0.388688772	0.010459708	0.003471562	0.26887025	0.011626078
21	0.013704293	0.447511321	0.01204479	0.003587661	0.741078022	0.011924089
22	0.014301592	0.470326687	0.012176601	0.003600831	0.994594577	0.012328353
23	0.014433393	0.475363939	0.013871833	0.003689782	0.407541096	0.01245007
24	0.0146385	0.558631724	0.015480528	0.0038858	0.751350029	0.012788796
25	0.016391704	0.560295406	0.015592542	0.003894457	0.239297832	0.013157242
26	0.018236983	0.568545589	0.017311273	0.004086817	0.438039218	0.013294874
27	0.018281358	0.630733695	0.017710632	0.004153296	0.336084196	0.014040246
28	0.018478068	0.663733284	0.017843339	0.004201172	0.49150758	0.015519345
29	0.018959177	0.668024832	0.017911033	0.004371705	0.960734731	0.016256627
30	0.019648471	0.669802305	0.018288842	0.004456229	0.518228807	0.016376286
31	0.019872636	0.70260183	0.018590357	0.004475831	0.834174344	0.016568481
32	0.021625833	0.773989491	0.018708008	0.005013577	0.398147492	0.016705079
33	0.021745733	0.791946668	0.019059448	0.005201074	0.352979778	0.017071828
34	0.022441271	0.884649731	0.019589241	0.005282667	0.661758006	0.017526962
35	0.02444575	0.891864409	0.019635524	0.005313497	0.365421743	0.019191084
36	0.024576047	0.903274001	0.020510278	0.005398651	0.084709337	0.0191922
37	0.025367392	0.94984514	0.020692191	0.005473309	0.711620387	0.019620379
38	0.025390368	0.978217331	0.020752389	0.005565463	0.226952395	0.019731374
39	0.025858878	0.992469685	0.02134678	0.006062954	0.035848096	0.020092451
40	0.026593343		0.02152053	0.006101464	0.035540773	0.020238999
41	0.026710566		0.021886903	0.006114802	0.062061742	0.020517448
42	0.027045414		0.021961147	0.006167591	0.701517093	0.020997085
43	0.027202845		0.021968096	0.006190328	0.484824104	0.021697962
44	0.027398438		0.022223643	0.006252697	0.743591515	0.022266408
45	0.02802763		0.022414544	0.006369885	0.776002196	0.022839094

Region	Regional Area	Regional Area	Regional Area	Regional Area	Regional Area	Regional Area
Drainage Area	2.5-50 km^2	2.5-50 km^2	2.5-50 km^2	2.5-50 km^2	2.5-50 km^2	2.5-50 km^2
Stream Gradient Groups	<1.5%	<1.5%	1.5-3%	1.5-3%	3-7.5%	3-7.5%
Predominant watershed land cover	agricultural	agricultural	forested	forested	forested	forested
Number of Primary Populations in the sub-basin	0-2	3+	0-2	3+	0-2	3+
1	0.010842045	0.067408351	0.004592167	0.000603574	0.001241193	0.000393545
2	0.037929293	0.10806462	0.005800715	0.001892227	0.00626912	0.000622413
3	0.125364047	0.149039239	0.0165655	0.002000057	0.006654685	0.000642952
4	0.211535766	0.159366922	0.016959574	0.002119548	0.00683055	0.001018305
5	0.218147363	0.185716498	0.017119582	0.00242981	0.007313975	0.001275097
6	0.235190547	0.199247174	0.018988223	0.002717372	0.00867816	0.001683308
7	0.248804971	0.200710238	0.019466627	0.00347487	0.009615122	0.001731608
8	0.276538214	0.209404899	0.021372308	0.003482863	0.010433746	0.003422362
9	0.336495375	0.233404943	0.022762496	0.00710036	0.010461012	0.004025224
10	0.352913882	0.265406454	0.022776689	0.010182073	0.010470005	0.004902344
11	0.358087386	0.277208755	0.028005998	0.010217477	0.010835061	0.005413581
12	0.379895149	0.292433309	0.029960548	0.010698609	0.011232215	0.005514761
13	0.381614562	0.293057008	0.0316297	0.012063316	0.013110848	0.00595295
14	0.38532493	0.302907314	0.031989107	0.012603427	0.016201751	0.006587112
15	0.388407228	0.304361145	0.034996759	0.012753359	0.017087141	0.006622953
16	0.393458069	0.321977379	0.042031349	0.013956921	0.018301612	0.006880843
17	0.397491197	0.407521119	0.043012431	0.016100234	0.018389475	0.006970729
18	0.398786121	0.412990184	0.045101471	0.018128924	0.018776537	0.007433764
19	0.42903183	0.482653097	0.045736568	0.019263205	0.01900658	0.007476949
20	0.478937927	0.512931739	0.045990901	0.022036142	0.019523535	0.007613924
21	0.506459681	0.524336937	0.048467417	0.022576551	0.019864339	0.007696769
22	0.562117792	0.563778263	0.051371691	0.023216944	0.019890949	0.008026485
23	0.577064164	0.573451047	0.054274732	0.023958787	0.020499134	0.008534831
24	0.632961024	0.611834322	0.05496896	0.025549009	0.021231057	0.008751173
25	0.637424195	0.656390872	0.057729394	0.026342634	0.021446049	0.008990354
26	0.652563532	0.66622653	0.058184373	0.02724071	0.022864099	0.009096912
27	0.674784932	0.669751497	0.058499736	0.029698509	0.023080043	0.009395882
28	0.692538098	0.675499669	0.062089998	0.031054516	0.023274707	0.009420818
29	0.748000913	0.710648614	0.066738978	0.031249854	0.024058177	0.009449291
30	0.754723022	0.726207872	0.072295422	0.032566281	0.026097158	0.009870512
31	0.759608077	0.782774961	0.07321798	0.032858036	0.028294319	0.010275798
32	0.780883842	0.799000601	0.07392148	0.033076014	0.029961988	0.010908316
33	0.879856061	0.802769459	0.074613135	0.033961675	0.031450439	0.010936919
34	0.892243087	0.852647315	0.07467088	0.034560839	0.031714329	0.011756446
35	0.901973699	0.864557242	0.076553828	0.035681998	0.031731993	0.012321981
36	0.912527149	0.884838487	0.08036326	0.03570472	0.032081923	0.012730293
37	0.920856084	0.893301888	0.083553579	0.036734717	0.03327157	0.012842059
38	0.922401105	0.924634989	0.085657505	0.036998062	0.035510592	0.013226628
39	0.926405112	0.925701969	0.090107277	0.037644192	0.036654347	0.013320795
40	0.945013251	0.975055472	0.090566738	0.038710005	0.037792272	0.013327366
41	0.948602952	0.994342508	0.092605727	0.038967544	0.038606965	0.014851172
42	0.965234538		0.094205064	0.03909836	0.038967121	0.014998495
43			0.099109944	0.039715567	0.039749272	0.015726171
44			0.099432949	0.040580837	0.040299628	0.015979691
45			0.105591887	0.04226005	0.040403495	0.016392104

Region	Regional Area	Regional Area	Regional Area	Regional Area	Regional Area	Regional Area
Drainage Area	2.5-50 km^2	2.5-50 km^2	50-200 km^2	50-200 km^2	50-200 km^2	50-200 km^2
Stream Gradient Groups	>7.5%	>7.5%	<1.5%	<1.5%	1.5-3%	1.5-3%
Predominant watershed land cover	forested	forested	forested	forested	forested	forested
Number of Primary Populations in the sub-basin	0-2	3+	0-2	3+	0-2	3+
1	0.001615559	0.000373434	0.004420272	0.002849397	0.00437349	0.001706896
2	0.001685613	0.000828251	0.017674745	0.00295811	0.017905316	0.002948566
3	0.004601452	0.001412726	0.017773284	0.003250324	0.044303683	0.013661919
4	0.004654775	0.001587972	0.02110425	0.003716519	0.047963815	0.016613218
5	0.007544072	0.001677227	0.0243536	0.015115881	0.05037106	0.018784898
6	0.007640235	0.001882605	0.02476379	0.016094764	0.053895331	0.025003195
7	0.007864125	0.002643478	0.03070086	0.018000722	0.054960721	0.032484099
8	0.008794827	0.002876306	0.031043841	0.018408264	0.062170519	0.032712593
9	0.010739469	0.003454282	0.037046772	0.019176042	0.065015689	0.035027596
10	0.01314504	0.003476774	0.040275568	0.019584415	0.068665858	0.040280562
11	0.013435289	0.004853883	0.045777839	0.019929917	0.073020256	0.041428606
12	0.018562853	0.005861215	0.052270166	0.022553158	0.074053372	0.041442962
13	0.020711159	0.007040939	0.052946174	0.023399754	0.088095528	0.044874903
14	0.020967455	0.007055688	0.057564899	0.025816436	0.088884374	0.046782599
15	0.022491722	0.007182691	0.058717401	0.025855192	0.103421005	0.048618385
16	0.027304713	0.008628062	0.066388766	0.028272163	0.105658347	0.050015633
17	0.029689914	0.008919371	0.069270545	0.028394993	0.120134011	0.055512793
18	0.029705843	0.009151594	0.07891098	0.029211316	0.120996148	0.058638434
19	0.030514435	0.009362196	0.084931623	0.029617861	0.135766136	0.064300854
20	0.036017583	0.009437434	0.087976795	0.029739058	0.14738819	0.065457379
21	0.038850152	0.009466159	0.093375075	0.030033353	0.149878876	0.067111544
22	0.03909411	0.010178719	0.094424015	0.031632253	0.165983518	0.068709799
23	0.041640353	0.010601233	0.094896313	0.032794313	0.171021775	0.071567853
24	0.041675895	0.010654658	0.112557676	0.033475509	0.178000525	0.078716028
25	0.041762811	0.010812435	0.114343127	0.034420622	0.178515359	0.080499189
26	0.041773497	0.010857161	0.117459478	0.037808566	0.18087004	0.082945114
27	0.042658685	0.011199733	0.117780169	0.038404819	0.185733911	0.089472687
28	0.044918096	0.011472511	0.120401075	0.039084965	0.18745631	0.097308938
29	0.045265255	0.011791014	0.120983609	0.044507427	0.19088288	0.101189745
30	0.045754969	0.011826192	0.126438543	0.045105191	0.20385569	0.102406369
31	0.046196808	0.013461922	0.132191298	0.046188045	0.209297841	0.102721946
32	0.047442563	0.013960736	0.133883835	0.047423272	0.217540044	0.103461
33	0.04776333	0.014207879	0.143464113	0.0502152	0.234985953	0.103972899
34	0.050224774	0.014287341	0.149871123	0.050747135	0.235712175	0.104317762
35	0.051070602	0.014310951	0.150194446	0.051389017	0.250129576	0.113619906
36	0.051181382	0.01437065	0.153128812	0.053125933	0.265397296	0.115407449
37	0.052043175	0.014421124	0.154544791	0.053970297	0.268940343	0.123915336
38	0.0528853	0.014664427	0.157456283	0.054582072	0.270504507	0.124871777
39	0.054781535	0.014921161	0.158917153	0.056633231	0.274935213	0.125524657
40	0.060775392	0.015722206	0.160693362	0.058006198	0.282801418	0.130927135
41	0.061026892	0.016312822	0.16689943	0.061219362	0.299890136	0.132952946
42	0.061188266	0.016314294	0.167134967	0.061287659	0.304223571	0.133957204
43	0.061859556	0.016795783	0.169010425	0.061367938	0.30741952	0.139865995
44	0.064645753	0.017193435	0.178287658	0.063052782	0.30906594	0.143113036
45	0.065021616	0.017273198	0.178515713	0.063842121	0.333790044	0.145348939

Region	Regional Area	Regional Area	Regional Area	Regional Area	Regional Area	Regional Area
Drainage Area	50-200 km^2	50-200 km^2	50-200 km^2	50-200 km^2	200-1000 km^2	200-1000 km^2
Stream Gradient Groups	3-7.5%	3-7.5%	>7.5%	>7.5%	<1.5%	<1.5%
Predominant watershed land cover	forested	forested	forested	forested	forested	forested
Number of Primary Populations in the sub-basin	0-2	3+	0-2	3+	0-2	3+
1	0.005242535	0.005553571	0.059552062	0.009413776	0.004759517	0.0030771
2	0.009076705	0.006788692	0.062577871	0.011771904	0.008197776	0.004782748
3	0.01201863	0.008731566	0.084317251	0.01502082	0.015956493	0.00503646
4	0.014470506	0.011828961	0.096936926	0.015126358	0.016287485	0.005097834
5	0.023816846	0.012228783	0.254110584	0.029522301	0.017956682	0.005673022
6	0.060491269	0.014263226	0.302575205	0.040310339	0.018001296	0.007652695
7	0.080325715	0.021910167	0.307145069	0.046969167	0.021515645	0.00962296
8	0.105019985	0.02578318	0.358873437	0.077710543	0.024084375	0.012706975
9	0.143970792	0.029520471	0.379737374	0.083802001	0.025739778	0.012870247
10	0.14440568	0.031423967	0.408830428	0.088117917	0.030437711	0.013648258
11	0.171768294	0.045565548	0.462317712	0.091251405	0.041197142	0.015438964
12	0.180160137	0.052512975	0.492528929	0.131000974	0.049103256	0.017033038
13	0.188827048	0.053187931	0.496848261	0.1428207	0.051387307	0.018358554
14	0.200188869	0.054374902	0.587113217	0.192561427	0.051569421	0.018360409
15	0.207747138	0.055046418	0.718307843	0.197580823	0.06799691	0.019510439
16	0.208862827	0.069160532	0.916630221	0.217332908	0.068186911	0.020005865
17	0.221495889	0.07068229	0.925835546	0.218053412	0.068526432	0.030072274
18	0.223276967	0.070729539		0.230313837	0.071334859	0.032318264
19	0.234950193	0.073648237		0.250118753	0.083256396	0.0325017
20	0.29679381	0.074337248		0.282763407	0.085198625	0.032780748
21	0.308437797	0.077143138		0.29457009	0.087435159	0.034942346
22	0.309294313	0.087776991		0.322568973	0.088861037	0.040355738
23	0.345334976	0.095197455		0.324536606	0.091438101	0.04313735
24	0.350540621	0.106045427		0.32936727	0.092499668	0.044283987
25	0.372509803	0.111521864		0.333216773	0.092611482	0.044879334
26	0.399759181	0.112831575		0.338422126	0.095418189	0.045141448
27	0.400075009	0.113470159		0.383711755	0.096404738	0.045860983
28	0.404588121	0.120123829		0.38589397	0.097816667	0.048182175
29	0.416676368	0.123449119		0.397069377	0.098149476	0.050096203
30	0.453294545	0.124158173		0.412044834	0.109559077	0.051453932
31	0.486027265	0.137439778		0.421426244	0.109747585	0.058528938
32	0.50110006	0.144663926		0.422098749	0.110171269	0.065475453
33	0.503448013	0.163025402		0.426412203	0.130996407	0.067597307
34	0.505743706	0.170041039		0.42749614	0.131442297	0.067901206
35	0.561044495	0.17085377		0.431272717	0.135633771	0.071337031
36	0.589772247	0.174127823		0.440185134	0.13619948	0.073230444
37	0.624997208	0.198257282		0.447122379	0.137330039	0.074037694
38	0.626216089	0.219624029		0.455639869	0.138188168	0.074457059
39	0.64632256	0.219872616		0.463981338	0.143114288	0.074570613
40	0.668684882	0.220278396		0.537439979	0.143347585	0.077671276
41	0.676689118	0.223924928		0.538700202	0.143726913	0.07786546
42	0.679974467	0.229865817		0.541623246	0.14568277	0.077939838
43	0.71655282	0.239482485		0.61318932	0.149954687	0.079235152
44	0.718527862	0.242629685		0.614287703	0.150531868	0.080572296
45	0.740024408	0.243648744		0.63507394	0.156992984	0.083002528

Region	Regional Area	Regional Area	Regional Area	Regional Area	Regional Area	Regional Area
Drainage Area	200-1000 km^2	200-1000 km^2	200-1000 km^2	200-1000 km^2	200-1000 km^2	200-1000 km^2
Stream Gradient Groups	1.5-3%	1.5-3%	3-7.5%	3-7.5%	3-7.5%	3-7.5%
Predominant watershed land cover	forested	forested	forested	forested	agricultural	urban
Number of Primary Populations in the sub-basin	0-2	3+	0-2	3+	3+	0-2
1	0.060757424	0.003000726	0.043329112	0.006122925	0.061304968	0.001141881
2	0.065267477	0.00747442	0.097379849	0.021367115	0.082538771	0.002274772
3	0.110222539	0.019476922	0.127116857	0.09489072	0.092775531	0.002902105
4	0.117873165	0.055933765	0.129039813	0.26243711	0.162072144	0.004128542
5	0.144327906	0.057576857	0.162750064	0.314566091	0.162348742	0.008300242
6	0.172100642	0.065248869	0.228057535	0.314714866	0.207182755	0.0091731
7	0.253688653	0.077964896	0.231478205	0.324480559	0.211452404	0.00937987
8	0.340276895	0.09934338	0.239722873	0.408277424	0.235336155	0.010568436
9	0.38647432	0.105379943	0.257437655	0.500779877	0.26033777	0.012836745
10	0.404147108	0.117839612	0.324251658	0.513163841	0.262952588	0.013183075
11	0.407137004	0.126369507	0.332206326	0.535423632	0.299302395	0.015066354
12	0.408482556	0.138296506	0.351867556	0.563878191	0.332555794	0.015096603
13	0.422376283	0.142156181	0.362140224	0.569005906	0.344693763	0.015605111
14	0.430388892	0.160442417	0.399128955	0.6124305	0.352580557	0.016242192
15	0.452694291	0.179700645	0.53572856	0.628485812	0.364244367	0.017529307
16	0.511857683	0.182087276	0.542023971	0.688577058	0.438753068	0.018155772
17	0.517082181	0.191367614	0.593306431	0.721730135	0.503649384	0.018166643
18	0.56279318	0.212886728	0.597509861	0.745613366	0.529275225	0.01864006
19	0.565356651	0.236394492	0.615300055	0.771586907	0.542005623	0.019096673
20	0.572153418	0.236760097	0.631161527	0.825730064	0.545028896	0.019194268
21	0.626412321	0.238435723	0.642224874	0.885111061	0.546877079	0.020946961
22	0.632023828	0.263361556	0.654507107	0.885131493	0.547352024	0.024603406
23	0.634803601	0.273813103	0.713951969	0.885365225	0.572615136	0.025488017
24	0.661473255	0.279904975	0.720354258	0.941701249	0.642525729	0.027763161
25	0.67077806	0.29377914	0.786011097	0.95385686	0.644428195	0.028229645
26	0.719082603	0.320213262	0.807324859	0.963618894	0.64826593	0.028533749
27	0.741314644	0.321223645	0.81601196	0.96486794	0.714811786	0.03050573
28	0.75285869	0.335109989	0.816910429		0.74160531	0.031272725
29	0.763030754	0.343034876	0.843414996		0.751742333	0.035505756
30	0.796377741	0.380137239	0.911210873		0.757205427	0.035731015
31	0.831455903	0.383705703	0.933992705		0.766078098	0.037424575
32	0.833658876	0.392758654	0.950789611		0.769167353	0.03764654
33	0.838491111	0.414502649	0.973344281		0.811581333	0.039312463
34	0.854169949	0.419877044			0.838983565	0.039483441
35	0.854452653	0.433831255			0.955281611	0.039667976
36	0.860360562	0.454421604			0.997251496	0.039751159
37	0.867088235	0.466588032				0.040609503
38	0.90584311	0.489715251				0.041082551
39	0.923580074	0.510122095				0.046230146
40	0.928595937	0.541233148				0.0488641
41	0.947271755	0.555225299				0.048913972
42	0.966142809	0.561492997				0.049700401
43	0.971867442	0.578728132				0.052692949
44	0.97413457	0.580496573				0.053830769
45		0.59274524				0.054258607

Region	Regional Area
Drainage Area	200-1000 km^2
Stream Gradient Groups	>7.5%
Predominant watershed land cover	forested
Number of Primary Populations in the sub-basin	3+
1	0.00366326
2	0.004557144
3	0.035242134
4	0.152027777
5	0.297042404
6	0.45593425
7	0.542817324
8	0.641676848
9	0.696577247
10	0.832134316
11	0.839238974
12	0.878345283
13	0.905499862
14	0.921671682
15	0.950795377
16	0.977328843
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Appendix D

Detailed Field-collection Protocols

Record Event Information

Next, on the *Site Verification Form* (Figure A-2), record the information below about the data collection event

Crew

Record the names of those who are in the crew. Also note the organization that each staff represents. The crew lead will be recorded in column 1. Staff sampling roles can be recorded later, after the day is done, by using the check boxes provided on the form.

Site

Bankfull Stage

Near the Index Station (X), visually estimate the bankfull stage. This is best done after considerable training. There are at least three good on-line sources of training materials for identifying bankfull stage:

1. http://preview.tinyurl.com/8aabbm (Buffington, 2007)
2. http://www.dnr.wa.gov/Publications/fp_bfw_video_pt1.wmv
   http://www.dnr.wa.gov/Publications/fp_bfw_video_pt2.wmv (Grizzel, 2008)
3. http://www.stream.fs.fed.us/publications/bankfull_west.html (Leopold et al, 1995)

Bankfull stage height is *not* a value that gets recorded on the *Site Verification Form*. The crew merely uses their visual estimate to help understand where to measure bankfull width.

Bankfull Width

Using the estimated bankfull level, measure the channel width at each of 5 transects near the Index Station:

1. The Index Station (X)
2. 1 bankfull width upstream from X
3. 2 bankfull widths upstream from X
4. 1 bankfull width downstream from X
5. 2 bankfull widths downstream from X

Record the average (nearest meter) of these 5 bankfull width measurements on the *Site Verification Form* (Figure A-2). Width measurements can be made using either a 50-m tape, a measuring rod, or (if the channel is wide) with a laser rangefinder.

Site Length

Sites must be no shorter than 150 m and no longer than 2000 m. Multiply the average bankfull width times 20. This value (whole meters) is the site length for a path that follows the main flow of the river. However, for any site with bankfull width less than 8 meters, the site length will be extended to 150 m; for any site with bankfull width over 100 m, reduce the length to 2000 m. Record the site length on the *Site Verification Form* (Figure A-2).

Sampling methods for waded streams are restricted to sites that are less than 25 meters wide (less than 500 m long). Larger sites can be waded if shallow, but will be sampled using raft protocols This rule will allow sampling on large streams to be accomplished within a single work day.

Relative position of the Index Station (X) within the site

The index station (X) is normally located at the middle of the site (i.e. at major transect F). On the *Site Verification Form* (Figure A-2), record the distance (tenths of meters) from X to the bottom of the site (i.e., to major transect A) and the distance from X to the top of the site (i.e., to major transect K). This distance is measured along the thalweg channel. Unless there is a reason to adjust the position of X, the distance will be equal to half the site length, in each direction.

The relative position of X can be adjusted for reasons such as

- to keep the top or bottom of the site in lands where permission has not been denied, or
- to keep from changing Strahler stream order (at the 1:100,000 scale), or
- to account for barriers such as lakes.

The location of the Index Station's coordinates can never be changed. These are pre-defined by the survey design. Although the site position can change relative to X (called "sliding" the site), the site must always contain X.

Bed Form

Assess the site for its predominant reach type according to Montgomery and Buffington (1993, 1997). Review the source materials hot-linked in the references to help understand the differences between bed forms. These references discuss details and provide images of examples.

First decide whether the site is predominated by a reach that is colluvial, alluvial, or bedrock. Colluvial streams have a low chance of being sampled by this Status and Trends program, because we are limiting our sample to perennial streams. Bedrock streams are confined locations with little depositional material present. Most streams sampled will be alluvial.

Next, if the site is predominantly alluvial, decide which one of the following sub-classifications can be used to describe the site.

- cascade
- step-pool
- plane-bed
- pool-riffle
- regime
- braided

Place an X in the appropriate box of the *Site Verification Form* (Figure A-2) to describe the predominant bed form within the site. Refer to the references (Montgomery and Buffington, 1993, 1997, 1998) and the definitions table (Table A-1) for help. Figures A-4 and A-5 might help.

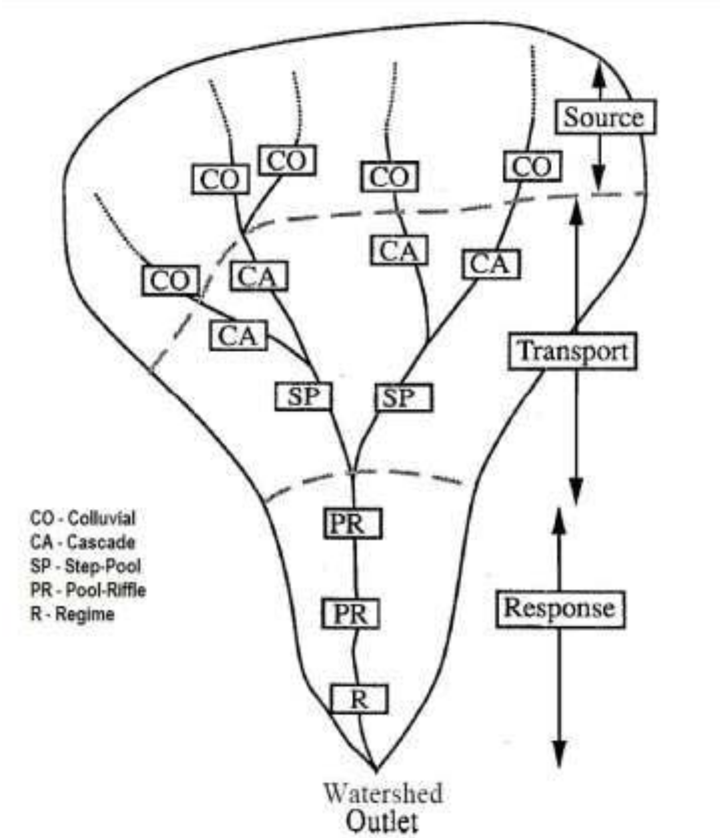

Figure A-4. Idealized positions (aerial view) of bed form types within a watershed. Modified from figure 22 of Montgomery and Buffington (1993).

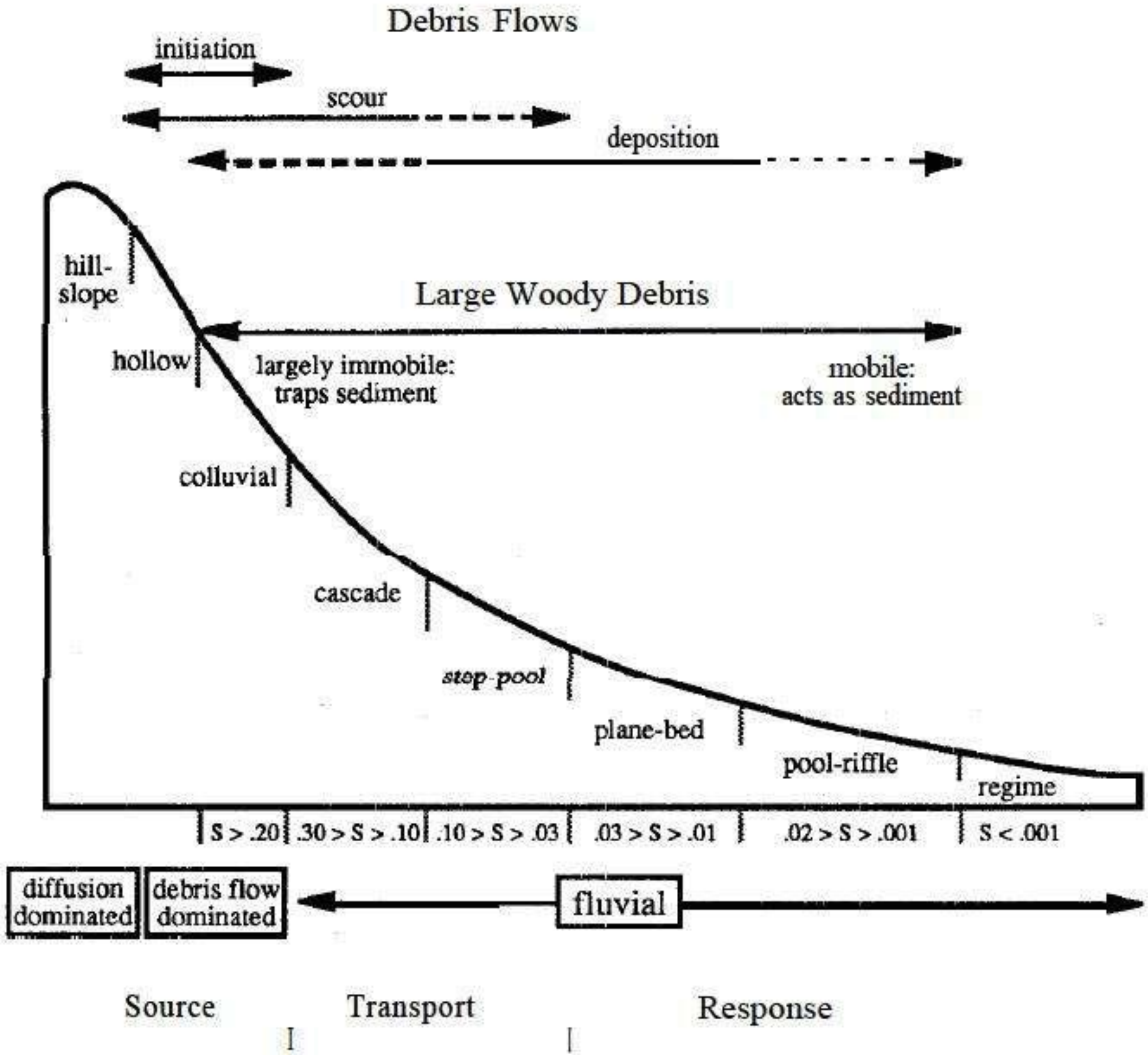

Figure A-5. Idealized positions (plan view) of bed form types within a watershed (from figure 16 of Montgomery and Buffington (1993)).

Layout the Reach

There are 3 types of transects that define the stream site (Table A-2): thalweg transects, major transects and minor transects.

Thalweg Transects

Conceptually divide the stream site length using 101 transects which are perpendicular to the thalweg. These are called Thalweg Transects. They occur at regular intervals (0.2 bankfull widths). Thalweg transects, except for those that are also major transects (see below), do not need to be marked. Thalweg transects are useful in concept for describing relative positions within the site.

Major transects

Use orange flagging and a permanent marker to mark each of the 11 equidistant major transects. The lowest is *transect A0*, the highest is *transect K0*. Measure the distance between transects using either a 50-m tape or a measuring rod, by following the thalweg of the stream. The distance between flags should be $1/10^{th}$ of the site length or (or 2 times the estimated bankfull width at the index station).

Minor Transects

Ten minor transects occur mid-way between the 11 major transects (Table A-2) The distance between major and minor transects is $1/5^{th}$ the site length (or 1 bankfull width). Minor transects don't need to be marked.

Table A-2. The relative position of all transects on a stream site.

Station	Thalweg Transect	Major Transect	Minor Transect	Distance from Bottom (Bankfull Widths *)
A0	Yes	Yes		0
A1	Yes			0.2
A2	Yes			0.4
A3	Yes			0.6
A4	Yes			0.8
A5	Yes		Yes	1
A6	Yes			1.2
A7	Yes			1.4
A8	Yes			1.6
A9	Yes			1.8
B0	Yes	Yes		2
B1	Yes			2.2
B2	Yes			2.4
B3	Yes			2.6
B4	Yes			2.8
B5	Yes		Yes	3
B6	Yes			3.2
B7	Yes			3.4
B8	Yes			3.6
B9	Yes			3.8
C0	Yes	Yes		4
C1	Yes			4.2
C2	Yes			4.4
C3	Yes			4.6
C4	Yes			4.8
C5	Yes		Yes	5
C6	Yes			5.2
C7	Yes			5.4
C8	Yes			5.6
C9	Yes			5.8
D0	Yes	Yes		6
D1	Yes			6.2
D2	Yes			6.4
D3	Yes			6.6
D4	Yes			6.8
D5	Yes		Yes	7
D6	Yes			7.2
D7	Yes			7.4

D8	Yes			7.6
D9	Yes			7.8
E0	Yes	Yes		8
E1	Yes			8.2
E2	Yes			8.4
E3	Yes			8.6
E4	Yes			8.8
E5	Yes		Yes	9
E6	Yes			9.2
E7	Yes			9.4
E8	Yes			9.6
E9	Yes			9.8
F0	Yes	Yes		10
F1	Yes			10.2
F2	Yes			10.4
F3	Yes			10.6
F4	Yes			10.8
F5	Yes		Yes	11
F6	Yes			11.2
F7	Yes			11.4
F8	Yes			11.6
F9	Yes			11.8
G0	Yes	Yes		12
G1	Yes			12.2
G2	Yes			12.4
G3	Yes			12.6
G4	Yes			12.8
G5	Yes		Yes	13
G6	Yes			13.2
G7	Yes			13.4
G8	Yes			13.6
G9	Yes			13.8
H0	Yes	Yes		14
H1	Yes			14.2
H2	Yes			14.4
H3	Yes			14.6
H4	Yes			14.8
H5	Yes		Yes	15
H6	Yes			15.2
H7	Yes			15.4
H8	Yes			15.6
H9	Yes			15.8

I0	Yes	Yes		16
I1	Yes			16.2
I2	Yes			16.4
I3	Yes			16.6
I4	Yes			16.8
I5	Yes		Yes	17
I6	Yes			17.2
I7	Yes			17.4
I8	Yes			17.6
I9	Yes			17.8
J0	Yes	Yes		18
J1	Yes			18.2
J2	Yes			18.4
J3	Yes			18.6
J4	Yes			18.8
J5	Yes		Yes	19
J6	Yes			19.2
J7	Yes			19.4
J8	Yes			19.6
J9	Yes			19.8
K0	Yes	Yes		20

* For very small or very large sites (with length of 150 m or 2000 m), the transect spacing is 1/100the of the site length, and might not be 0.2 bankfull widths.

Record Coordinates

Refer to *GPS Positions Form* (Figure A-1). Record the GPS-measured coordinates at the bottom of the site (transect A0), and at the top of the site (transect K0). Note the bank at which the GPS was used and the accuracy of the measurements. You might also record coordinates for other major transects too, but this is not required for the waded streams.

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Channel-reach morphology in mountain drainage basins

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ABSTRACT

A classification of channel-reach morphology in mountain drainage basins synthesizes stream morphologies into seven distinct reach types: colluvial, bedrock, and five alluvial channel types (cascade, step pool, plane bed, pool riffle, and dune ripple). Coupling reach-level channel processes with the spatial arrangement of reach morphologies, their links to hillslope processes, and external forcing by confinement, riparian vegetation, and woody debris defines a process-based framework within which to assess channel condition and response potential in mountain drainage basins. Field investigations demonstrate characteristic slope, grain size, shear stress, and roughness ranges for different reach types, observations consistent with our hypothesis that alluvial channel morphologies reflect specific roughness configurations adjusted to the relative magnitudes of sediment supply and transport capacity. Steep alluvial channels (cascade and step pool) have high ratios of transport capacity to sediment supply and are resilient to changes in discharge and sediment supply, whereas low-gradient alluvial channels (pool riffle and dune ripple) have lower transport capacity to supply ratios and thus exhibit significant and prolonged response to changes in sediment supply and discharge. General differences in the ratio of transport capacity to supply between channel types allow aggregation of reaches into source, transport, and response segments, the spatial distribution of which provides a watershed-level conceptual model linking reach morphology and channel processes. These two scales of channel network classification define a framework within which to investigate spatial and temporal patterns of channel response in mountain drainage basins.

INTRODUCTION

Geologists and engineers have long recognized fundamental differences between mountain channels and their lowland counterparts (e.g., Surell, 1841; Dana, 1850; Shaler, 1891). In contrast to self-formed flood-plain channels, the gradient and morphology of mountain channels are tremendously variable and prone to forcing by external influences. Although mountain channels provide important aquatic habitat (e.g., Nehlsen et al., 1991; Frissell, 1993), supply sediment to estuaries and the oceans (e.g., Milliman and Syvitski, 1992), and transmit land use disturbances from headwater areas down through drainage networks (e.g., Reid, 1993), they have received relatively little study compared to lowland rivers.

Improved ability to relate morphology and processes in mountain channels would facilitate understanding and predicting their response to both human and natural disturbance. Classification schemes can organize such understanding into conceptual models that provide further insight into channel processes (e.g., Schumm, 1977). With few exceptions (e.g., Paustian et al., 1992; Whiting and Bradley, 1993), classifications of mountain channels are not process based, which compromises their use for assessing channel condition, response potential, and relations to ecological processes.

In order to provide a useful general classification of mountain channels, a typology should be applicable on more than a regional basis, yet adaptable to regional variability; otherwise proliferation of regional channel classifications could impede rather than enhance communication and understanding. Moreover, a classification should rely on aspects of channel form that reflect channel processes. Furthermore, it should encompass the whole channel network, rather than consider only channels inhabited by desirable organisms or indicator species. A process-based understanding of spatial linkages within a watershed is essential for assessment of channel condition, prediction of channel response to disturbance, and interpretation of the causes of historical channel changes.

Herein we systematize a channel classification that expands on Schumm's (1977) general delineation of erosion, transport, and deposition reaches and provides a framework for examining channel processes in mountain drainage basins. We also report a field test of the classification using data from drainage basins in Oregon and Washington and propose a genetic explanation for the distinct channel morphologies that we recognize. The tie to channel processes and morphogenesis provides a defensible theoretical and conceptual framework within which to classify channel morphology, assess channel condition, and interpret response potential. In particular, coupling of process-based channel classification with landscape-specific spatial linkages can provide insight into how disturbances propagate through drainage basins. Our classification arose from field work in mountain drainage basins where we repeatedly observed the same general sequence of channel morphologies down through the channel network. Here we draw on previous work and our own field observations to discuss these morphologies and propose a theory for the origin of distinct alluvial channel types. Although developed based on literature review and field observations in the Pacific Northwest (Montgomery and Buffington, 1993), subsequent field work confirms the relevance of the classification in other mountainous regions.

Channel-reach Morphology

A voluminous literature on channel classification attests to the wide variety of morphologies exhibited by stream channels. No single classification can satisfy all possible purposes, or encompass all possible channel types; each of the channel classifications in common use have advantages and disadvantages for use in geological, engineering, and ecological applications (see discussion in Kondolf, 1995). Although stream channels possess a continuum of characteristics identifiable at spatial scales that range from individual channel units to entire drainage basins (Frissell et al., 1986), channel reaches of at least 10 to 20 channel widths in length define a useful scale over which to relate stream morphology to channel processes, response potential, and habitat characteristics.

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TABLE 1. DIAGNOSTIC FEATURES OF EACH CHANNEL TYPE

	Dune ripple	Pool riffle	Plane bed	Step pool	Cascade	Bedrock	Colluvial
Typical bed material	Sand	Gravel	Gravel-cobble	Cobble-boulder	Boulder	Rock	Variable
Bedform pattern	Multilayered	Laterally oscillatory	Featureless	Vertically oscillatory	Random	Irregular	Variable
Dominant roughness elements	Sinuosity, bedforms (dunes, ripples, bars) grains, banks	Bedforms (bars, pools), grains, sinuosity, banks	Grains, banks	Bedforms (steps, pools), grains, banks	Grains, banks	Boundaries (bed and banks)	Grains
Dominant sediment sources	Fluvial, bank failure	Fluvial, bank failure	Fluvial, bank failure, debris flows	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Fluvial, hillslope, debris flows	Hillslope, debris flows
Sediment storage elements	Overbank, bedforms	Overbank, bedforms	Overbank	Bedforms	Lee and stoss sides of flow obstructions	Pockets	Bed
Typical confinement	Unconfined	Unconfined	Variable	Confined	Confined	Confined	Confined
Typical pool spacing (channel widths)	5 to 7	5 to 7	None	1 to 4	<1	Variable	Unknown

We recognize three primary channel-reach substrates: bedrock, alluvium, and colluvium. Bedrock reaches lack a contiguous alluvial bed and reflect high transport capacities relative to sediment supply; they are typically confined by valley walls and have steep slopes. In contrast, alluvial channels exhibit a wide variety of morphologies and roughness configurations that vary with slope and position within the channel network, and may be either confined, with little to no associated flood plain, or unconfined, with a well-established flood plain. We recognize five distinct alluvial reach morphologies: cascade, step pool, plane bed, pool riffle, and dune ripple. Colluvial channels form an additional reach type that we recognize separately from alluvial channels, despite the common presence of a thin alluvial substrate. Colluvial channels typically are small headwater streams that flow over a colluvial valley fill and exhibit weak or ephemeral fluvial transport. Each of these channel types is distinguished by a distinctive channel-bed morphology, allowing rapid visual classification. Diagnostic features of each channel type are summarized in Table 1 and discussed below.

Cascade Channels

The term "cascade" connotes tumbling flow, although its specific morphologic definition varies and often is applied to both channel units and reaches (e.g., Bisson et al., 1982; Grant et al., 1990). Our delineation of cascade channels focuses on streams in which energy dissipation is dominated by continuous tumbling and jet-and-wake flow over and around individual large clasts (e.g., Peterson and Mohanty, 1960) (Fig. 1A). Cascade channels generally occur on steep slopes, are narrowly confined by valley walls, and are characterized by longitudinally and laterally disorganized bed material typically consisting of cobbles and boulders (Fig. 2A). Small, partially channel-spanning pools spaced less than a channel width apart are common in cascade channels. Tumbling flow over individual grain steps and turbulence associated with jet-and-wake flow around grains dissipates much of the mechanical energy of the flow (Fig. 3A).

Large particle size relative to flow depth makes the largest bed-forming material of cascade reaches effectively immobile during typical flows. Studies of steep-gradient channels report that large bed-forming grains typically become mobile only during infrequent (i.e., 50–100 yr) hydrologic events (Grant et al., 1990; Kondolf et al., 1991; Whittaker, 1987b). Mobilization of these larger clasts is accompanied by high sediment transport rates due to the release of finer sediment trapped under and around large grains (Sawada et al., 1983; Warburton, 1992). During lesser floods, gravel stored in low energy sites is mobilized and travels as bedload over larger bed-forming clasts (Griffiths, 1980; Schmidt and Ergenzinger, 1992). Gravel and finer material are locally stored on stoss and lee sides of flow obstructions (i.e., large grains and large woody debris) due to physical impoundment and generation of velocity shadows. One tracer study (Kondolf et al., 1991) showed that material in such depositional sites was completely mobilized during a seven-year recurrence-interval event, whereas no tracer movement was observed during flows of less than the annual recurrence interval.

These observations suggest that there are two thresholds for sediment transport in cascade channels. During moderate recurrence-interval flows, bedload material is rapidly and efficiently transported over the more stable bed-forming clasts, which have a higher mobility threshold corresponding to more infrequent events. The lack of significant in-channel storage (Kondolf et al., 1991) and the rapid scour of depositional sites during moderately frequent high flows suggest that sediment transport is effectively supply limited in cascade channels. Bedload transport studies demonstrate that steep channels in mountain drainage basins are typically supply limited, receiving seasonal or stochastic sediment inputs (Nanson, 1974; Griffiths, 1980; Ashida et al., 1981; Whittaker, 1987). Because of this high transport capacity relative to sediment supply, cascade channels function primarily as sediment transport zones that rapidly deliver sediment to lower-gradient channels.

Step-Pool Channels

Step-pool channels are characterized by longitudinal steps formed by large clasts organized into discrete channel-spanning accumulations that separate pools containing finer material (Figs. 1B and 2B) (Ashida et al., 1976, 1981; Griffiths, 1980; Whittaker and Jaeggi, 1982; Whittaker and Davies, 1982; Whittaker, 1987a, 1987b; Chin, 1989; Grant et al., 1990). Primary flow and channel bed oscillations in step-pool reaches are vertical, rather than lateral, as in pool-riffle channels (Fig. 3B). The stepped morphology of the bed results in alternating critical to supercritical flow over steps and subcritical flow in pools (Bowman, 1977; Chin, 1989). Step-pool channels exhibit a pool spacing of roughly one to four channel widths (Bowman, 1977; Whittaker, 1987b; Chin, 1989; Grant et al., 1990), significantly less than the five to seven channel widths that typify self-formed pool-riffle channels (Leopold et al., 1964; Keller and Melhorn, 1978). Steps provide much of the elevation drop and roughness in step-pool channels (Ashida et al., 1976; Whittaker and Jaeggi, 1982; Whittaker, 1987a, 1987b; Chin, 1989). Step-pool morphology generally is associated with steep gradients, small width to depth ratios, and pronounced confinement by valley walls. Although step-forming clast sizes typically are comparable to annual high flow depths, a stepped longitudinal profile also may develop in steep sand-bedded channels (G. E. Grant, 1996, personal commun.).

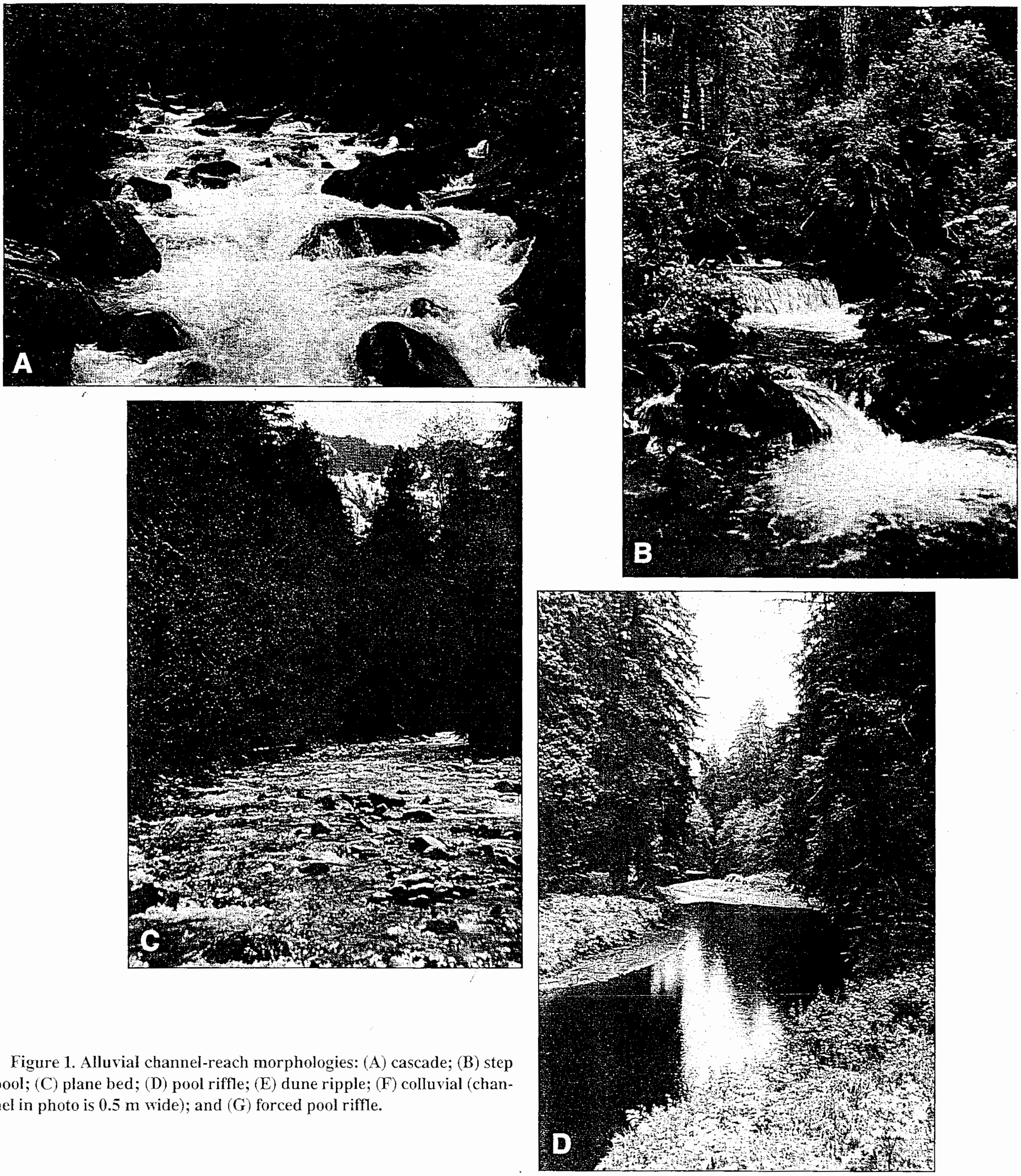
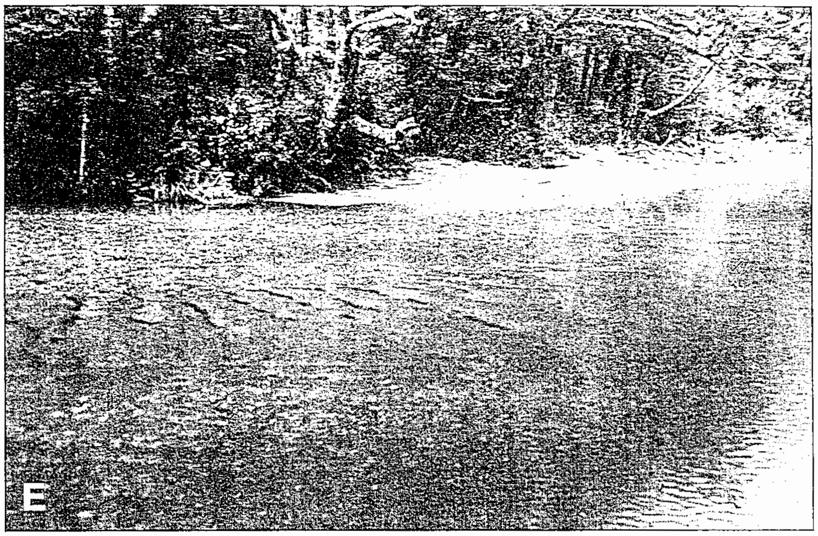
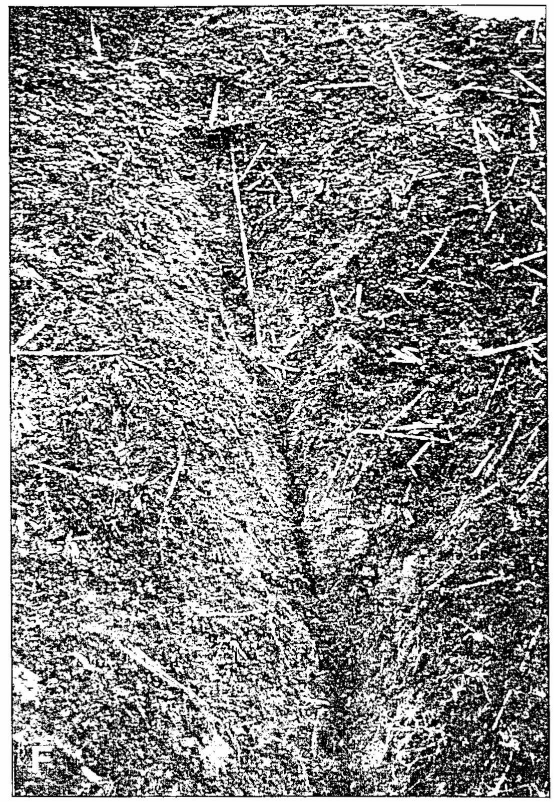


Figure 1. Alluvial channel-reach morphologies: (A) cascade; (B) step pool; (C) plane bed; (D) pool riffle; (E) dune ripple; (F) colluvial (channel in photo is 0.5 m wide); and (G) forced pool riffle.

Step-forming material may be viewed as either a kinematic wave (Langbein and Leopold, 1968), a congested zone of large grains that causes increased local flow resistance and further accumulation of large particles (Church and Jones, 1982), or as macroscale antidunes (McDonald and Banerjee, 1971; Shaw and Kellerhals, 1977; Grant and Mizuyama, 1991). Step-pool sequences form through armoring processes under high dis-





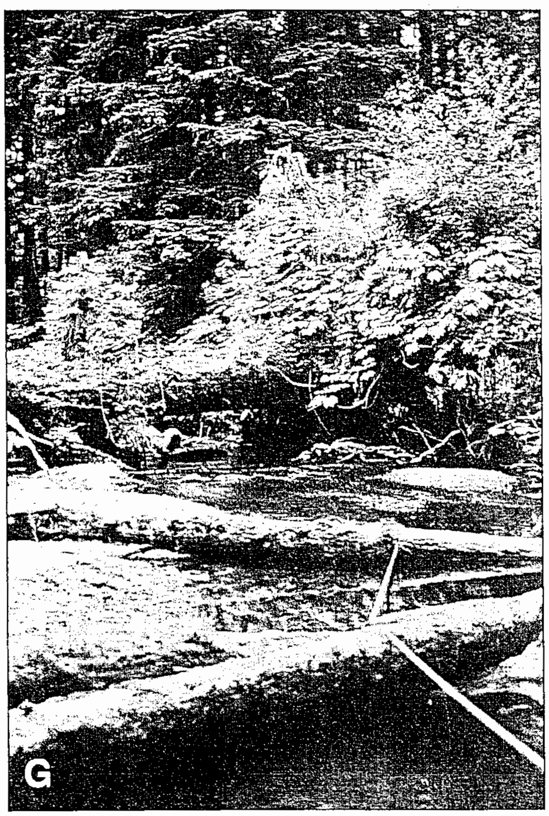


Figure 1. *(Continued—caption on facing page).*

charges and low sediment supply (Ashida et al., 1981; Whittaker and Jaeggi, 1982). Grant et al. (1990) suggested that low sediment supply and infrequent discharges capable of moving the coarsest sediment are required for development of stepped-bed morphology, and Grant and Mizuyama (1991) suggested that step-pool formation requires a heterogeneous bed mixture and near-critical flow. Furthermore, step spacing corresponds to maximum flow resistance, providing stability for a bed that would otherwise be mobile (Whittaker and Jaeggi, 1982; Abrahams et al., 1995).

Step-pool channels have several sediment transport thresholds. Large bed-forming material generally is mobile only during relatively infrequent hydrologic events (Whittaker, 1987a, 1987b; Grant et al., 1990), although Warburton (1992) showed that step-forming clasts in steep proglacial channels may be mobile annually. Significant movement of all grain sizes occurs during extreme floods, and step-pool morphology is reestablished during the falling limb of the hydrograph (Sawada et al., 1983; Whittaker, 1987b; Warbuton, 1992). During more frequent discharges, finer material stored in pools travels as bedload over stable bed-forming clasts (Ashida et al., 1981; Whittaker, 1987a, 1987b; Ergenzinger and Schmidt, 1990; Grant et al., 1990; Schmidt and Ergenzinger, 1992). In a series of tracer tests in a step-pool channel, Schmidt and Ergenzinger (1992) found that all of the tagged particles placed in pools mobilized during frequent, moderate discharges and were preferentially redeposited into pools. Transport of all the pool-filling material indicates that sediment transport of non–step-forming grains is supply limited. Bedload studies in step-pool channels demonstrate complex relations between discharge and sediment transport; transport rates are dependent on seasonal and stochastic sediment inputs, flow magnitude and duration, and antecedent events (Nanson, 1974; Griffiths, 1980; Ashida et al., 1981; Sawada et al., 1983; Whittaker, 1987a, 1987b; Warburton, 1992). Ashida et al. (1981), for example, observed a 10 hr lag between the hydrograph peak and onset of bedload transport for step-pool channels scoured of all pool-filling sediment during previous storms. Hydrograph peaks and bedload transport were, however, directly correlated during a subsequent storm due to the availability of sediment deposited in pools. Warburton (1992) suggested three phases of sediment transport in step-pool channels: a low-flow flushing of fines; frequent high-flow mobilization of pool-filling gravel (also noted by Sawada et al., 1983); and less-frequent higher-discharge mobilization of step-forming grains.

Although step-pool and cascade channel morphologies both reflect supply-limited transport, they are distinguished by differences in the spatial

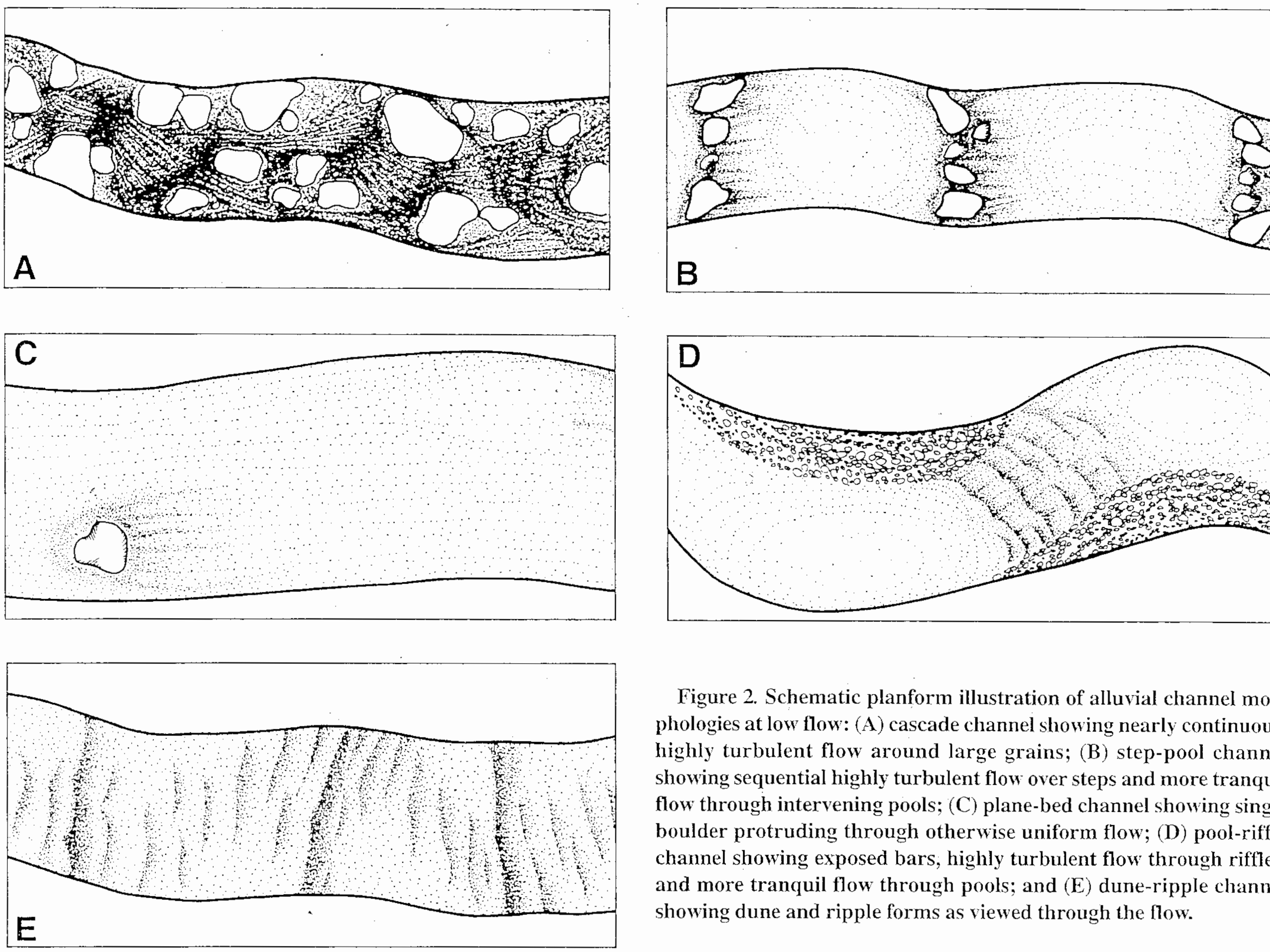


Figure 2. Schematic planform illustration of alluvial channel morphologies at low flow: (A) cascade channel showing nearly continuous, highly turbulent flow around large grains; (B) step-pool channel showing sequential highly turbulent flow over steps and more tranquil flow through intervening pools; (C) plane-bed channel showing single boulder protruding through otherwise uniform flow; (D) pool-riffle channel showing exposed bars, highly turbulent flow through riffles, and more tranquil flow through pools; and (E) dune-ripple channel showing dune and ripple forms as viewed through the flow.

density and organization of large clasts. Step-pool channels are defined by discrete channel-spanning steps less than a channel width in length that separate pools spaced every one to four channel widths. Cascade channels are defined by ubiquitous tumbling and jet-and-wake flow over a series of individual large clasts that together exceed a channel width in length, with small, irregularly placed pools spaced less than a channel width apart. The regular sequence of pools and steps in step-pool channels probably represents the emergence of a fluvially organized morphology in alluvial channels. In contrast, the disorganized large clasts of cascade channels may include lag deposits forced by nonfluvial processes (e.g., debris flows, glaciers, and rock falls).

Plane-Bed Channels

The term "plane bed" has been applied to both planar bed phases observed to form in sand-bed channels (Simons et al., 1965) and planar gravel and cobble-bed channels (Florsheim, 1985) like the coarse-grained, threshold canals described by Lane and Carlson (1953). Our use of the term refers to the latter and encompasses glide (run), riffle, and rapid morphologies described in the fisheries literature (e.g., Bisson et al., 1982). Plane-bed channels lack discrete bars, a condition that is associated with low width to depth ratios (Sukegawa, 1973; Ikeda, 1975, 1977) and large values of relative roughness (ratio of 90th percentile grain size to bankfull flow depth). Church and Jones (1982) considered bar formation unlikely at relative roughnesses of 0.3 to 1.0. Plane-bed reaches occur at moderate to high slopes in relatively straight channels that may be either unconfined or confined by valley walls. They typically are composed of sand to small boulder grain sizes, but are dominantly gravel to cobble bedded.

Plane-bed channels differ morphologically from both step-pool and pool-riffle channels in that they lack rhythmic bedforms and are characterized by long stretches of relatively featureless bed (Figs. 1C and 2C). The absence of tumbling flow and smaller relative roughness distinguish plane-bed reaches from cascade and step-pool channels (Fig. 3C). Plane-bed channels lack sufficient lateral flow convergence to develop pool-riffle morphology due to lower width to depth ratios and greater relative roughness, which may decompose lateral flow into smaller circulation cells. However, introduction of flow obstructions may force local pool and bar formation.

Plane-bed channels typically exhibit armored bed surfaces calculated to have a near-bankfull threshold for mobility, although elevated sediment loading can cause textural fining and a lower calculated mobility threshold (Buffington, 1995). Plane-bed channels with armored bed surfaces indicate a transport capacity greater than sediment supply (i.e., supply-limited conditions), whereas unarmored surfaces indicate a balance between transport capacity and sediment supply (Dietrich et al., 1989). Nevertheless, beyond

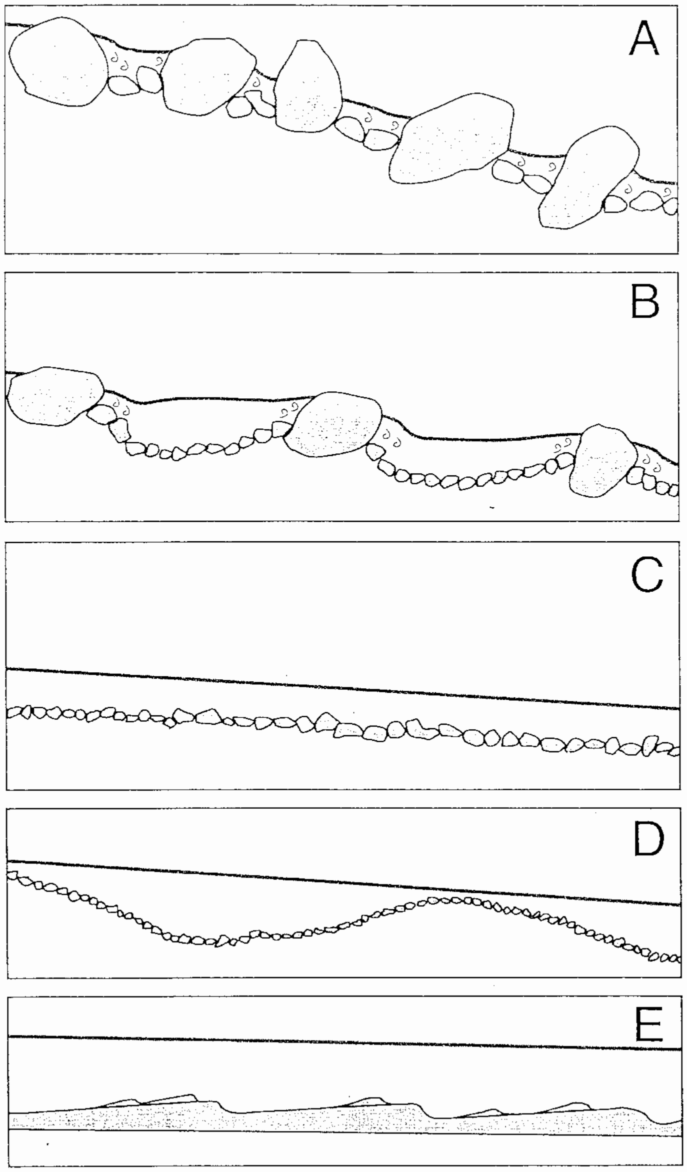


Figure 3. Schematic longitudinal profiles of alluvial channel morphologies at low flow: (A) cascade; (B) step pool; (C) plane bed; (D) pool riffle; and (E) dune ripple.

the threshold for significant bed-surface mobility, many armored gravel-bedded channels exhibit a general correspondence between bedload transport rate and discharge (e.g., Milhous, 1973; Jackson and Beschta, 1982; Sidle, 1988), implying transport-limited conditions. The above observations suggest that plane-bed channels are transitional between supply- and transport-limited morphologies.

Pool-Riffle Channels

Pool-riffle channels have an undulating bed that defines a sequence of bars, pools, and riffles (Leopold et al., 1964) (Fig. 1D). This lateral bedform oscillation distinguishes pool-riffle channels from the other channel types discussed above (Fig. 2D). Pools are topographic depressions within the channel and bars are corresponding high points (Fig. 3D); these bedforms are thus defined relative to each other (O'Neill and Abrahams, 1984). Pools are rhythmically spaced about every five to seven channel widths in self-formed, pool-riffle channels (Leopold et al., 1964; Keller and Mellhorn, 1978), but channels with a high loading of large woody debris exhibit smaller pool spacing (Montgomery et al., 1995). Pool-riffle channels occur at moderate to low gradients and are generally unconfined, and have well-established flood plains. Substrate size in pool-riffle streams varies from sand to cobble, but typically is gravel sized.

Bar and pool topography generated by local flow convergence and divergence may be either freely formed by cross-stream flow and sediment transport, or forced by channel bends and obstructions (e.g., Lisle, 1986). Free-formed pool-riffle sequences initially result from internal flow perturbation that causes flow convergence and scour on alternating banks of the channel; concordant downstream flow divergence results in local sediment accumulation in discrete bars. Topographically driven convective accelerations reinforce convergent and divergent flow patterns, and thus pool-riffle morphogenesis (Dietrich and Smith, 1983; Dietrich and Whiting, 1989; Nelson and Smith, 1989). Alluvial bar development requires a sufficiently large width to depth ratio and small grain sizes that are easily mobilized and stacked by the flow (Church and Jones, 1982). Bar formation in natural channels appears to be limited to gradients ≤0.02 (Ikeda, 1977; Florsheim, 1985), although flume studies indicate that alternate bars may form at steeper gradients (Bathurst et al., 1983; Lisle et al., 1991). Bedform and grain roughness provide the primary flow resistance in free-formed pool-riffle channels.

Pool-riffle channels have heterogeneous beds that exhibit a variety of sorting and packing, commonly with a coarse surface layer and a finer subsurface (Leopold et al., 1964; Milhous, 1973). Armored gravel-bed channels typically exhibit a near-bankfull threshold for general and significant bed-surface mobility (e.g., Parker et al., 1982; Jackson and Beschta, 1982; Andrews, 1984; Carling, 1988; Buffington, 1995). Movement of surface grains releases fine sediment trapped by larger grains and exposes finer subsurface sediment to the flow, contributing to a steep rise in bedload transport with increasing shear stress (Milhous, 1973; Jackson and Beschta, 1982; Emmett, 1984). Bed movement is sporadic and discontinuous, depending on grain protrusion (Fenton and Abbott, 1977; Kirchner et al., 1990), friction angle (Kirchner et al., 1990; Buffington et al., 1992), imbrication (Komar and Li, 1986), degree of burial (Hammond et al., 1984; Buffington et al., 1992), and turbulent high-velocity sweeps of the channel bed. Very rarely is the whole bed in motion, and material eroded from one riffle commonly is deposited on a proximal downstream riffle.

Pool-riffle channels, like plane-bed channels, exhibit a mixture of supply- and transport-limited characteristics depending on the degree of bed-surface armoring and consequent mobility thresholds. Unarmored pool-riffle channels indicate a balance between transport capacity and sediment supply, while armored surfaces represent supply-limited conditions (e.g., Dietrich et al., 1989). Nevertheless, during armor-breaching events, bedload transport rates are generally correlated with discharge, demonstrating that sediment transport is not limited by supply once the bed is mobilized. Considerable fluctuations in observed transport rates, however, reflect a stochastic component of grain mobility caused by grain interactions, turbulent sweeps, and transient grain entrapment by bedforms (Jackson and Beschta, 1982; Sidle, 1988). Magnitudes of bedload transport also may vary for similar discharge events, depending on the chronology of antecedent transport events (Milhous, 1973; Reid et al., 1985; Sidle, 1988). Although both pool-riffle and plane-bed channels display a mix of supply- and transport-limited characteristics, the presence of depositional barforms in pool-riffle channels suggests that they are generally more transport limited than plane-bed channels. The transport-limited character of both of these morphologies, however, contrasts with the more supply-limited character of step-pool and cascade channels.

Dune-Ripple Channels

Dune-ripple morphology is most commonly associated with low-gradient, sand-bed channels (Figs. 1E, 2E, and 3E). A flow regime–dependent succession of mobile bedforms provides the primary hydraulic resistance in dune-ripple channels (e.g., Kennedy, 1975). However, even gravel-bed channels can exhibit a succession of multiple-scale bedforms during extreme discharges (e.g., Griffiths, 1989; Dinehart, 1992; Pitlick, 1992). The bedform configuration of dune-ripple channels depends on flow depth, velocity, bed-surface grain size, and sediment transport rate (e.g., Gilbert, 1914; Middleton and Southard, 1984), but generally follows a well-known morphologic sequence with increasing flow depth and velocity: lower-regime plane bed, ripples, sand waves, dunes, upper-regime plane bed, and antidunes (Gilbert, 1914; Simons et al., 1965; Harms et al., 1975). In channels transporting moderately to poorly sorted sediment, migrating bedload sheets composed of thin accumulations of sediment also may develop (Whiting et al., 1988). Several scales of bedforms may coexist in a dune-ripple channel; ripples, bedload sheets, and small dunes may climb over larger mobile dunes. A complete theoretical explanation for the development of such multiple-scale bedforms does not yet exist, but they are typically associated with low relative roughness. Dune-ripple channels also exhibit point bars or other bedforms forced by channel geometry. In contrast to the threshold sediment transport of plane-bed and pool-riffle streams, dune-ripple channels exhibit "live bed" transport (e.g., Henderson, 1963), in which significant sediment transport occurs at most stages. Hence, dune-ripple channels are effectively transport limited. The frequency of bed mobility and the presence of ripples and/or dunes distinguish dune-ripple channels from pool-riffle channels.

Colluvial Channels

Colluvial channels are small headwater streams at the tips of a channel network that flow over a colluvial valley fill and exhibit weak or ephemeral fluvial transport (Fig. 1F). Little research has focused on colluvial channels, even though first-order channels compose approximately half of the total length of a channel network (Montgomery, 1991). Dietrich et al. (1982) recognized that shallow flows in headwater channels have little opportunity for scour, and therefore sediment delivered from neighboring hillslopes generally accumulates to form colluvial valley fills. Benda and Dunne (1987) examined sediment in steep headwater valleys in the Oregon Coast Range and concluded that beneath a water-worked coarse surface layer, the valley fill consists of relatively unsorted colluvium delivered from surrounding hillslopes. Shallow and ephemeral flow in colluvial channels appears insufficient to mobilize all of the colluvial sediment introduced to the channel, resulting in significant storage of this material (Dietrich and Dunne, 1978; Dietrich et al., 1982; Benda, 1990). Large clasts, woody debris, bedrock steps, and in-channel vegetation further reduce the energy available for sediment transport in colluvial channels. Intermittent flow may rework some portion of the surface of the accumulated material, but it does not govern deposition, sorting, or transport of the valley fill.

Episodic transport by debris flows may account for most of the sediment transport in steep headwater channels. A sediment budget for a small basin in northern California indicated that debris flows account for more than half of the long-term sediment yield (Lehre, 1982). Swanson et al. (1982) estimated that only 20% of the total sediment yield from a first-order channel in the Cascade Range is accommodated by fluvial transport. Hence, the long-term sediment flux from low-order channels in steep terrain appears to be dominated by debris-flow processes. Differences in channel profiles support the hypothesis that different processes dominate the erosion of steep headwater channels and lower-gradient alluvial channels in the Oregon Coast Range (Seidl and Dietrich, 1992).

Dietrich and Dunne (1978) recognized that the residence time of sediment in headwater debris-flow–prone channels was on the order of hundreds of years. Kelsey (1980) also estimated that the sediment stored in first- and second-order channels is scoured by debris flows every 300 to 500 yr. Benda (1990) proposed a conceptual model for the evolution of channel morphology in steep headwater channels that involves cyclical alteration of bed morphology from gravel to boulder to bedrock in response to episodic sediment inputs. The accumulation of colluvial valley fills during periods between catastrophic scouring events indicates that transport capacity, rather than sediment supply, limits fluvial transport in colluvial channels.

Bedrock Channels

Bedrock channels lack a continuous alluvial bed. Although some alluvial material may be temporarily stored in scour holes, or behind flow obstructions, there is little, if any, valley fill. Hence, bedrock channels generally are confined by valley walls. Evidence from both anthropogenic badlands and mountain drainage basins indicates that bedrock channels are steeper than alluvial channels having similar drainage areas (Howard and Kerby, 1983; Montgomery et al., 1996). It is reasonable to adopt Gilbert's (1914) hypothesis that bedrock channels lack an alluvial bed due to high transport capacity associated with steep channel gradients and/or deep flow. Although bedrock channels in low-gradient portions of a watershed reflect a high transport capacity relative to sediment supply, those in steep portions of a watershed may also reflect recent catastrophic scouring.

Forced Morphologies

Flow obstructions can force a reach morphology that differs from the free-formed morphology for a similar sediment supply and transport capacity. In forested mountain drainage basins, for example, large woody debris may force local scour, flow divergence, and sediment impoundment that respectively form pools, bars, and steps (Fig. 1G). In an extreme example, Montgomery et al. (1996) found that log jams forced alluvial streambeds in otherwise bedrock reaches of a mountain channel network in western Washington.

Forced pool-riffle and step-pool channels are the most common obstruction-controlled morphologies in forested mountain drainage basins. A forced pool-riffle morphology is one in which most pools and bars are forced by obstructions such as large woody debris, and a forced step-pool channel is one in which large woody debris forms most of the channel-spanning steps that define the bed morphology. Forced morphologies can extend beyond the range of conditions characteristic of analogous free-formed morphologies (i.e., to steeper gradients and/or lower sediment supply). We recognize forced morphologies as distinct channel types because interpretation of whether such obstructions govern bed morphology is important for understanding channel response.

Intermediate and Other Morphologies

The channel types described above represent identifiable members along a continuum that includes several intermediate morphologies: riffle bar (pool riffle–plane bed); riffle step (plane bed–step pool); and cascade pool (step pool–cascade). Mixed alluvial and bedrock reaches exhibit subreach scale variations in alluvial cover. In our experience, however, it is simple to replicate identification of the seven basic reach types, even though they lie within a continuum of channel morphologies. Whether intermediate channel types are useful for classification purposes depends on the context of the application. Although our proposed classification does not cover all reach types in all environments (e.g., estuarine, cohesive-bed, or vegetated reaches), we have found it to be applicable in a variety of mountain environments.

TABLE 2. STUDY AREA CHARACTERISTICS

Study area	Geology	Drainage area (km^2)	Relief (m)	Land use
Finney Creek, Washington	Phyllite, greenschist, glacial sediments	128	1476	U.S. Forest Service, state forestry
Boulder River, Washington	Phyllite, glacial sediments	63	1985	U.S. Forest Service wilderness area
South Fork Hoh River, Washington	Sandstone, glacial sediments	129	>882	State forestry, national park
Deton Creek, Oregon	Sandstone	8	327	Private forestry

FIELD TEST

Process differences associated with reach morphology should result in distinct physical characteristics for each reach type. Data compiled from field studies in the Pacific Northwest reveal systematic association of channel types with slope, drainage area, relative roughness, and bed-surface grain size. Furthermore, these data suggest an explanation for the origin of distinct channel types.

Study Areas and Methods

Field surveys were conducted in four drainage basins in western Washington and coastal Oregon: Finney Creek, Boulder River, South Fork Hoh River, and Deton Creek (Table 2). In each study area, channel reaches 10–20 channel widths in length were surveyed throughout the drainage basin. Each reach was classified into one of the above-defined channel types. Reach slopes were surveyed using either an engineering level or a hand level and stadia rod. Topographic surveys and channel-spanning pebble counts of 100 grains (Wolman, 1954) were conducted at representative cross sections. Reach locations were mapped onto U.S. Geological Survey 1:24,000 scale topographic maps from which drainage areas were measured using a digital planimeter. Reach slopes were determined from topographic maps for some additional reaches where morphologies were mapped, but slope and grain-size measurements were not collected. We also included in our analysis data collected using similar field methods in related studies in western Washington and southeast Alaska (Montgomery et al., 1995; Buffington, 1995).

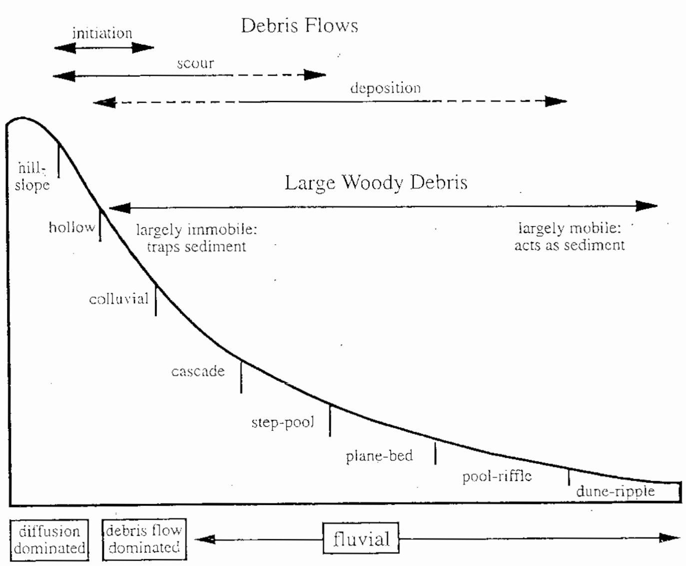


Figure 4. Idealized long profile from hillslopes and unchanneled hollows downslope through the channel network showing the general distribution of alluvial channel types and controls on channel processes in mountain drainage basins.

Results

In each study area, there is a general downstream progression of reach types that proceeds as colluvial, cascade, step pool, plane bed or forced pool riffle, and pool riffle (Fig. 4); we encountered no dune-ripple reaches in the study basins, although we observed them in neighboring areas. Bedrock reaches occur at locally steep locations throughout the channel networks, and not all of these channel types are present in each watershed. Furthermore, the specific downstream sequence of reach types observed in each drainage basin reflects local factors controlling channel slope, discharge, sediment supply, bedrock lithology, and disturbance history.

Data from alluvial, colluvial, and bedrock reaches within each study basin define distinct fields on a plot of drainage area versus reach slope (Fig. 5). These data provide further evidence that, for a given drainage area, bedrock reaches have greater slopes, and hence greater basal shear stress and stream power, than either alluvial or colluvial reaches (Howard and Kerby, 1983; Montgomery et al., 1996). Alluvial reaches occur on slopes less than about 0.2 to 0.3, and different alluvial channel types generally segregate within an inversely slope-dependent band within which pool-riffle and plane-bed channels occur at the lowest slopes, and step-pool and cascade channels occur on steeper slopes. Colluvial reaches occur at lower drainage areas and extend to steeper slopes. Data from colluvial reaches define a relation between drainage area and slope that contrasts with that of lower-gradient alluvial reaches. This general pattern holds for each of the study basins, implying consistent differences among colluvial, alluvial, and bedrock reaches in mountain drainage basins.

The different drainage area–slope relation for colluvial and alluvial channel reaches implies fundamental differences in sediment transport processes. For equilibrium channel profiles, channel slope (S) and drainage area (A) are related by

$$S = KA^{-m/n} \quad (1)$$

where K, m, and n are empirical variables that incorporate basin geology, climate, and erosional processes (e.g., Howard et al., 1994). A log-linear regression of reach slope and drainage area data from alluvial and colluvial channels in Finney Creek yields m/n values of 0.72 ± 0.08 ($R^2 = 0.72$) and 0.26 ± 0.05 ($R^2 = 0.58$), respectively, which implies long-term differences in sediment transport processes between these channel types. This correspondence between the inflection in the drainage area–slope relation and the transition from colluvial to alluvial channels is consistent with the interpretation that scour by debris flows is the dominant incisional process in colluvial channels (Benda, 1990; Seidl and Dietrich, 1992; Montgomery and Foufoula-Georgiou, 1993).

Although slope ranges of free-form alluvial channel types overlap, they have distinct medians and quartile ranges (Fig. 6). Examination of the composite slope distributions indicates that reaches with slopes of less than 0.015 are likely to have a pool-riffle morphology; reaches with slopes of

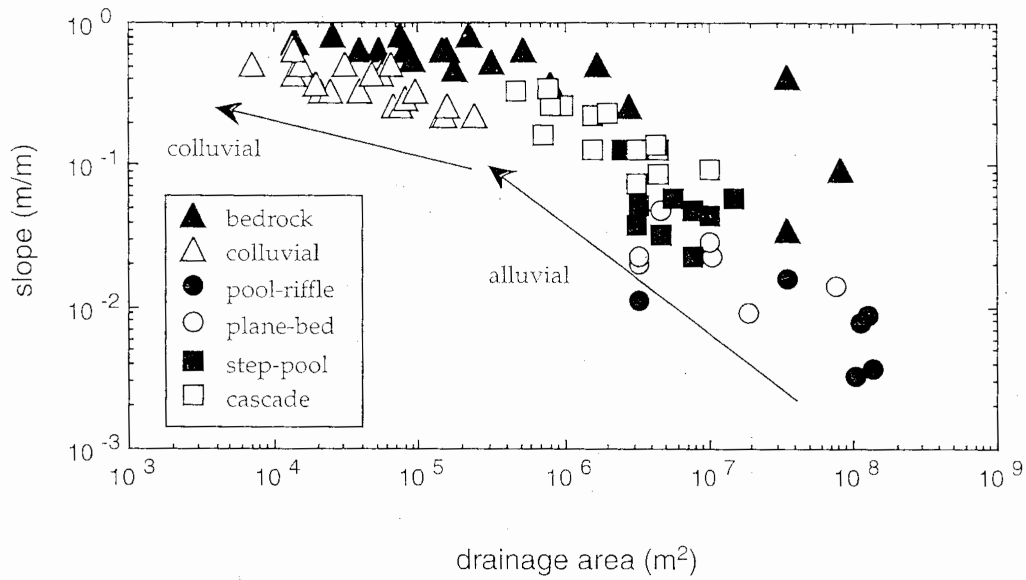


Figure 5. Drainage area versus reach slope for channels in the Finney Creek watershed, Washington.

0.015 to 0.03 typically have a plane-bed morphology; reaches with slopes of 0.03 to 0.065 are likely to have a step-pool morphology; and alluvial reaches with slopes greater than 0.065 typically have a cascade morphology. These core slope ranges define zones over which each channel type is the most likely to occur; however, the distributions overlap and channel type is not uniquely related to reach slope. Furthermore, forced pool-riffle reaches span the slope ranges for pool-riffle and plane-bed reaches, indicating that introduction of large woody debris can extend a forced morphology to slopes where such a morphology would not be expected under low woody debris loading (Montgomery et al., 1995). Nonetheless, the general segregation of reach type by slope allows prediction of likely channel morphology from topographic maps or digital elevation models.

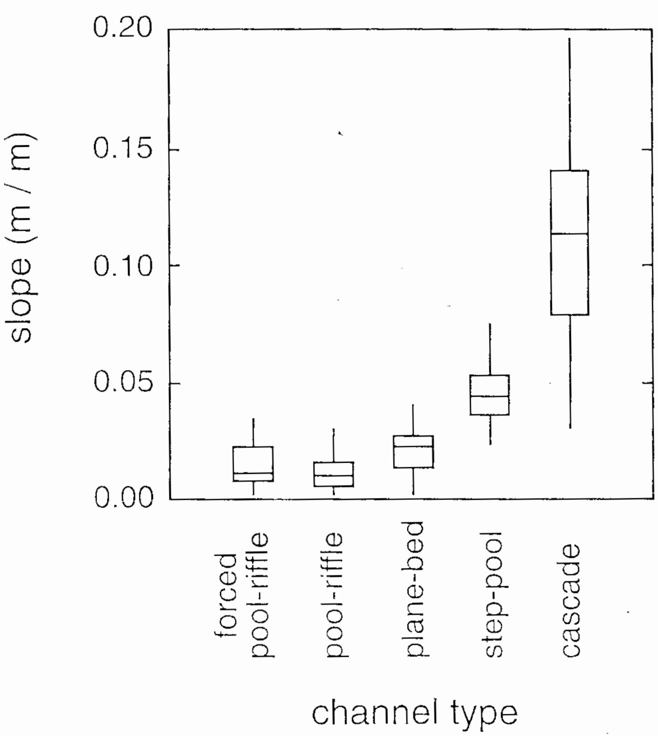


Figure 6. Composite slope distributions for channel reaches surveyed in this and related studies (Buffington, 1995; Montgomery et al., 1995); boxes represent inner and outer quartiles; vertical lines represent inner and outer tenths.

Relative roughness (the ratio of the ninetieth percentile grain size to the bankfull flow depth [d_{90}/D]) and reach slope together differentiate alluvial reach types (Fig. 7): pool-riffle channels have relative roughness less than about 0.3 and occur on slopes <0.03; plane-bed channels exhibit relative roughness of roughly 0.2 to 0.8 on slopes of 0.01 to 0.04; step-pool reaches occur on steeper slopes and have relative roughness of 0.3 to 0.8; and the size of the largest clasts on the bed of steeper cascade reaches can approach those of bankfull flow depth. Relative roughness and reach slope together provide a reasonable stratification of channel morphology. In pool-riffle and plane-bed channels relative roughness increases rapidly with increasing slope, whereas there is little relation between relative roughness and slope for steeper step-pool and cascade reaches.

Composite bed-surface grain-size distributions for pebble counts from different channel types exhibit systematic coarsening from pool-riffle through cascade channels. For reaches in the Finney Creek watershed (Fig. 8), the median grain size increases from 17 mm for pool-riffle channels to 80 mm for cascade morphologies, and d_{84} increases from 57 mm to 250 mm. These systematic changes in bed-surface grain-size distributions indicate that progressive fining of the bed material accompanies the formation of different channel types downstream through a channel network.

The data reported above demonstrate that qualitatively defined channel types exhibit quantitatively distinguishable characteristics. Our data further indicate that channel morphology is related to reach-average bankfull shear stress (Fig. 9). Bedrock channels occur in reaches with the greatest shear stress; cascade and step-pool reaches plot at lower values, which in turn are greater than those for plane-bed and pool-riffle channels. Hence, it appears that, in part, local flow hydraulics influence the general distribution of channel types in a watershed.

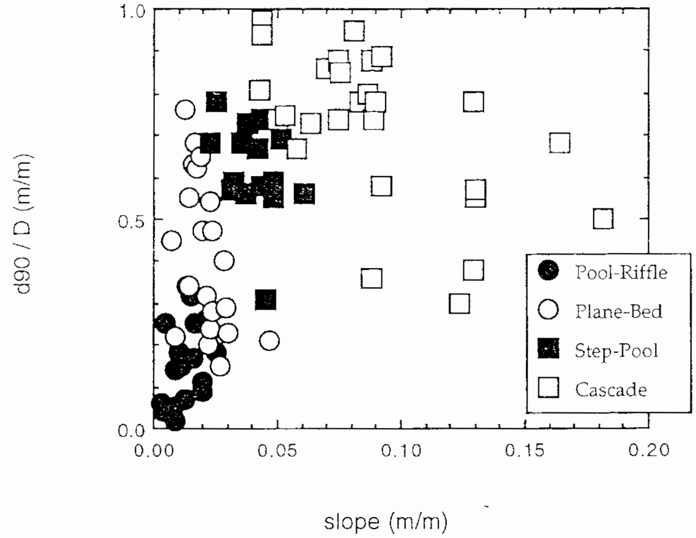


Figure 7. Composite plot of relative roughness (d_{90}/D) versus field surveyed reach slope for data from alluvial reaches in our study areas.

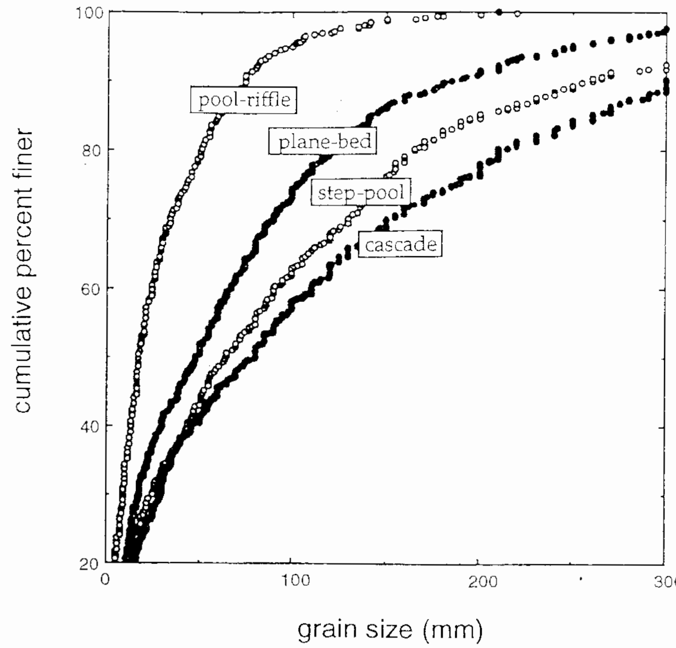


Figure 8. Aggregated cumulative grain-size distributions for alluvial channels of reaches with different bed morphologies in the Finney Creek watershed.

ORIGIN OF REACH-LEVEL MORPHOLOGIES

The typical downstream sequence of channel morphologies (Fig. 4) is accompanied by a progressive decrease in valley-wall confinement, which in stream-formed valleys may reflect opposing downstream trends of sediment supply (Q_s) and transport capacity (Q_c). Transport capacity is defined here as a function of the total boundary shear stress and is distinguished from the effective transport capacity (Q_c'), which is a function of the effective shear stress available for sediment transport after correction for shear stress dissipation caused by hydraulic roughness elements. Transport capacity generally decreases downstream due to the slope decreasing faster than the depth increases, whereas total sediment supply generally increases with drainage area, even though sediment yield per unit area often decreases (Fig. 10). This combination may result in long-term patterns of downstream deposition and development of wide flood plains and unconfined valleys. Insignificant sediment storage in a valley segment indicates that virtually all of the material delivered to the channel is transported downstream. In contrast, thick alluvial valley-fill deposits imply either a long-term excess of sediment supply over transport capacity, or an inherited valley fill.

These general patterns and our field observations discussed above lead us to propose that distinctive channel morphologies reflect the relative magnitude of transport capacity to sediment supply, which may be expressed as the ratio $q_r = Q_c/Q_s$. Colluvial channels are transport limited ($q_r << 1$), as in-

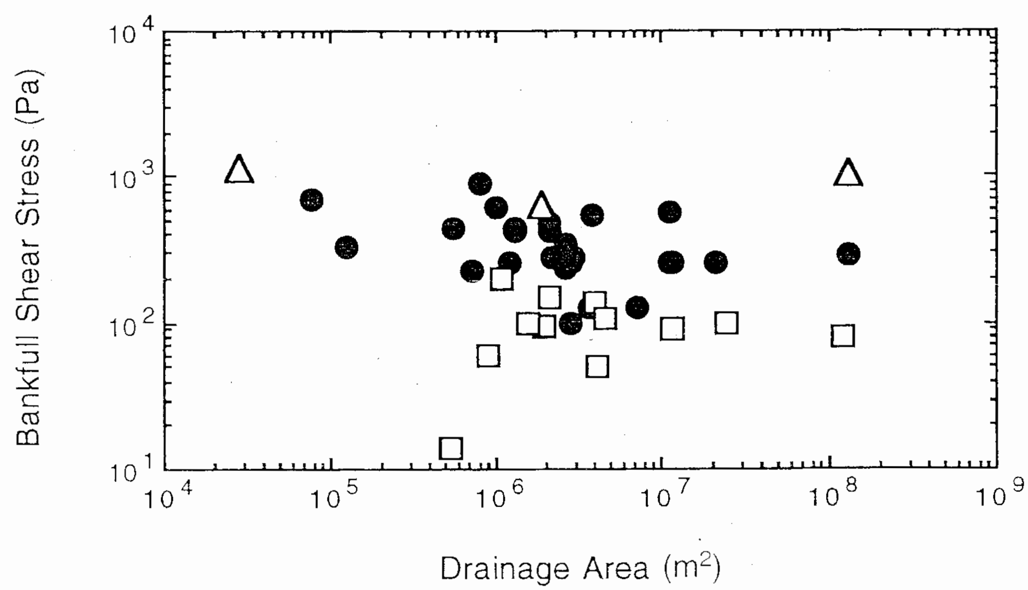


Figure 9. Plot of drainage area versus reach. Average shear stress for bedrock (triangles), cascade and step-pool (circles), and plane-bed and pool-riffle (squares) channel morphologies are from the South Fork Hoh River study area.

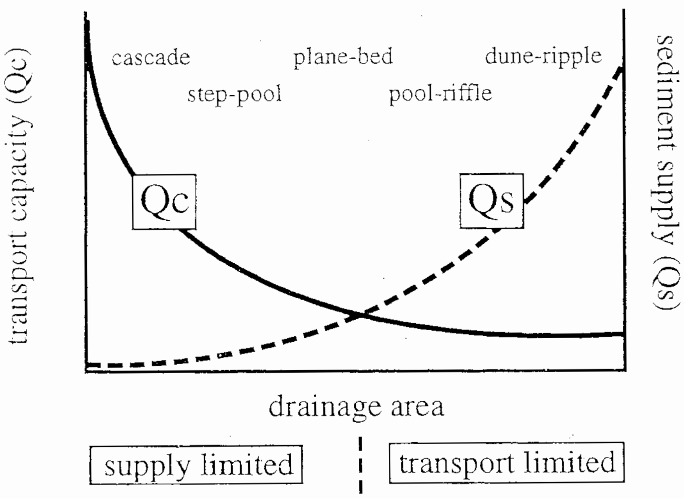


Figure 10. Schematic illustration of generalized relative trends in sediment supply (Q_s) and transport capacity (Q_c) in mountain drainage basins.

dicated by the accumulation of colluvium within valley bottoms. In contrast, the lack of an alluvial bed indicates that bedrock channels are supply limited ($q_r >> 1$). For a given drainage area (and thus Q_s), bedrock reaches have greater slopes and shear stresses (Figs. 5 and 9), implying that they have higher transport capacities and thus greater q_r values than other channel types. Alluvial channels, however, probably represent a broad range of q_r: steep alluvial channels (cascade and step-pool) have higher shear stresses (Fig. 9) and thus higher Q_c and q_r values for a given drainage area and sediment supply; the lower-gradient plane-bed and pool-riffle channels are transitional between $q_r > 1$ and $q_r \approx 1$, depending on the degree of armoring (e.g., Dietrich et al., 1989) and the frequency of bed-surface mobility; and the live-bed mobility of dune-ripple channels indicates that $q_r \leq 1$. The variety of alluvial channel morphologies probably reflects a broad spectrum of q_r expressed through fining and organization of the bedload (Fig. 11), which leads to formation of distinct alluvial bed morphologies that represent the stable bed form for the imposed q_r. This hypothesized relation between q_r and stable channel morphologies in mountain drainage basins provides a genetic framework for explaining reach-level morphologies that elaborates on Lindley's (1919) regime concept. An alluvial channel with $q_r > 1$ will become stable when the bed morphology and consequent hydraulic roughness produce an effective transport capacity that matches the sediment supply ($Q_c' \approx Q_s$).

Different channel types are stabilized by different roughness configurations that provide resistance to flow. In steep channels energy is dissipated primarily by hydraulic jumps and jet-and-wake turbulence. This style of energy dissipation is pervasive in cascade channels and periodic in step-pool channels. Skin friction and local turbulence associated with moderate particle sizes are sufficient to stabilize the bed for lower shear stresses characteristic of plane-bed channels. In pool-riffle channels, skin friction and bedform drag dominate energy dissipation. Particle roughness in dune-ripple channels is small due to the low relative roughness, and bedforms govern hydraulic resistance. The importance of bank roughness varies with channel type, depending on the width to depth ratio and vegetative influences, but in steep channels bank resistance is less important compared to energy dissipation caused by tumbling flow. These different roughness configurations represent a range in q_r values that varies from high in cascade reaches to low in dune-ripple channels.

Our hypothesis that different channel types represent stable roughness configurations for different q_r values implies that there should be an association of channel type and roughness. Even though the general correlation of morphology and slope (Fig. 6) implies discrete roughness characteristics among channel types, different channel morphologies occurring on the same slope should exhibit distinct roughness. Photographs and descriptions of channel morphology from previous studies in which roughness was determined from measured velocities (Barnes, 1967; Marcus et al., 1992) allow direct assessment of the roughness associated with different channel types. For similar slopes, plane-bed channels exhibit greater roughness than pool-riffle channels, and step-pool channels, in turn, appear to have greater roughness than plane-bed channels with comparable gradients (Fig. 12). Moreover, intermediate morphology reaches plot between their defining channel types. These systematic trends in roughness for a given slope strongly support the hypothesis that reach-level channel morphology reflects a dynamic adjustment of the bed surface to the imposed shear stress and sediment supply (i.e., the specific q_r value).

CHANNEL DISTURBANCE AND RESPONSE POTENTIAL

Natural and anthropogenic disturbances that change hydrology, sediment supply, riparian vegetation, or large woody debris loading can alter channel processes and morphology. The effect that watershed disturbance has on a particular channel reach depends on hillslope and channel coupling, the sequence of upstream channel types, and site-specific channel morphology. In particular, the variety and magnitude of possible morphologic responses to

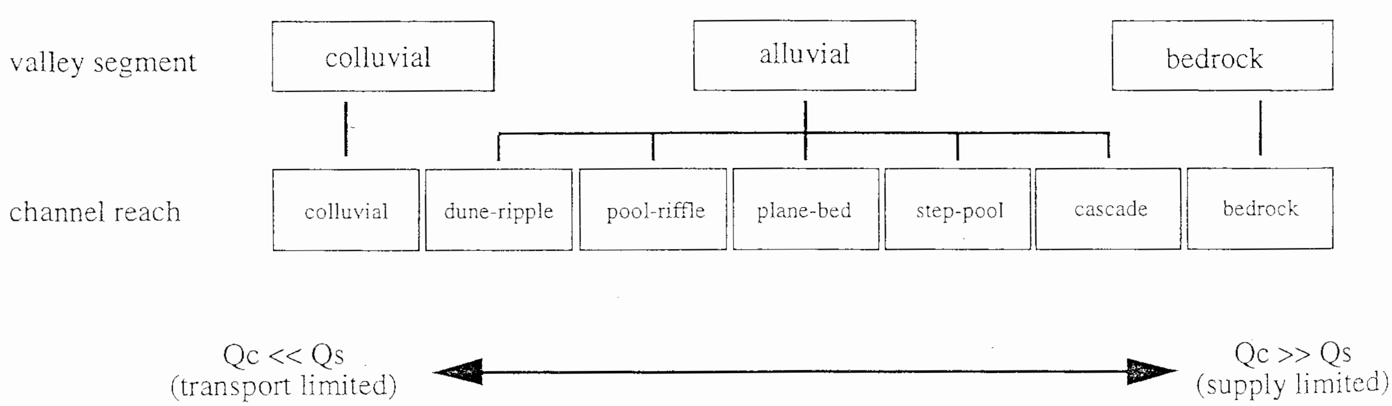


Figure 11. Schematic illustration of the transport capacities relative to sediment supply for reach-level channel types.

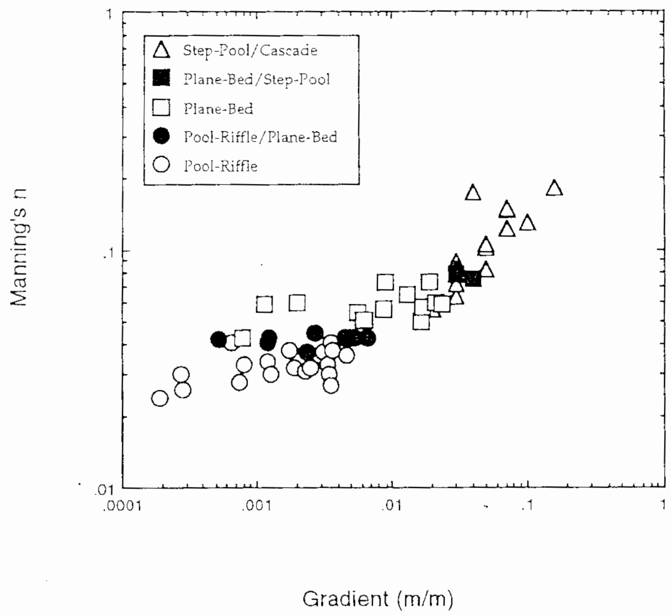


Figure 12. Plot of reach roughness coefficient (Manning's n) versus reach slope for channels classified according to our system using data and photographs in Barnes (1967) and Marcus et al. (1992). Note that channel types interpreted to reflect greater relative transport capacity have higher roughness over similar slopes.

a given disturbance depend on channel type, external influences (e.g., confinement, riparian vegetation, large woody debris), and disturbance history. Together these considerations provide an integrative approach for examining spatial and temporal patterns of channel disturbance and response in mountain watersheds.

Spatial Distribution of Channel Types

The spatial distribution of channel types and their coupling to both hillslopes and one another can strongly influence the potential for a channel to be affected by a disturbance. In general, the degree of hillslope-channel coupling changes downstream through mountain channel networks, resulting in changes in both the characteristics and delivery mechanisms of sediment supplied to a channel (e.g., Rice, 1994). Furthermore, the general downstream progression of channel morphologies in mountain drainage basins (Fig. 4) causes an association of hillslope coupling and channel type. Headwater colluvial channels are strongly coupled to adjacent hillslopes, and net sediment transport from these weakly fluvial reaches is affected by the frequency of upslope debris flows and mass movements. Valley-wall confinement allows direct sediment input by hillslope processes to cascade and step-pool channels, which makes them prone to periodic disturbance from hillslope failures. Debris flows can dominate the disturbance frequency in headwater portions of the basin, scouring high-gradient channels and aggrading the first downstream reach with a gradient low enough to cause deposition of the entrained material (e.g., Benda and Dunne, 1987). Consequently, the effects of debris-flow processes on channel morphology can be divided into those related to scour, transport, and deposition. Farther downstream, the coupling between hillslopes and lower-gradient channels (i.e., plane-bed, pool-riffle, and dune-ripple) is buffered by wider valleys and depositional flood plains, making these reaches less susceptible to direct disturbance from hillslope processes. Sediment characteristics, delivery, and transport are generally dominated by fluvial processes in these lower-gradient channels, although forcing by large woody debris and impingement of channels on valley walls can have a significant influence on the local transport capacity and sediment supply (e.g., Rice, 1994).

The downstream sequence in which channel types are arranged also affects the potential for a disturbance to impact a particular reach. Position within the network and differences between q_r values allow general aggregation of channel reaches into source, transport, and response segments. In steep landscapes, source segments are transport-limited, sediment-storage sites subject to intermittent debris-flow scour (i.e., colluvial channels). Transport segments are morphologically resilient channels with a high q_r (i.e., bedrock, cascade, and step-pool channels) that rapidly convey increased sediment loads. Response segments are channels with a low q_r (i.e., plane-bed, pool-riffle, and dune-ripple) in which significant morphologic adjustment occurs in response to increased sediment supply. These distinctions build upon Schumm's (1977) concept of erosion, transport, and deposition zones within a watershed to provide a conceptual model that allows identification of reach-specific response potential throughout a channel network.

The spatial distribution of source, transport, and response segments governs the distribution of potential impacts and recovery times within a watershed. Downstream transitions from transport to response reaches define locations where impacts from increased sediment supply may be both pronounced and persistent. Transport segments rapidly deliver increased sediment loads to the first downstream reach with insufficient transport capacity to accommodate the additional load. Consequently, the "cumulative" effects of upstream increases in sediment supply may be concentrated in response segments where longer time and/or significant morphological change is required to transport the additional sediment. In this regard, reach-level classification identifies areas most sensitive to increases in upstream sediment inputs. Hence, downstream transitions from transport to response segments can provide ideal locations to monitor network response and should serve as critical components of watershed monitoring studies. Most important, the relation between channel type and response potential provides a direct link between upstream sediment inputs and downstream response. Identification of source, transport, and response segments thereby provides a context for examining connections between watershed modifications, impacts on channel morphology, and biological response.

Influence of Channel Type

Differences in confinement, transport capacity relative to sediment supply, and channel morphology influence channel response to perturbations in sediment supply and discharge. Thus, it is important to assess channel response potential in the context of reach type and location within a watershed. An understanding of reach morphologies, processes, and environments allows reach-specific prediction of the likely degree and style of response to a particular perturbation. Small to moderate changes in discharge or sediment supply can alter channel attributes (e.g., grain size, slope, and channel geometry); large changes can transform reach-level channel types. On the basis of typical reach characteristics and locations within mountainous watersheds, we assessed the relative likelihood of specific morphologic responses to moderate perturbations in discharge and sediment supply for each channel type (Table 3).

Channels with different bed morphology and confinement may have different potential responses to similar changes in discharge or sediment supply. Changes in sediment storage dominate the response of colluvial channels to altered sediment supply because of transport-limited conditions and low fluvial transport capacities (Table 3); depending on the degree of valley fill, increased discharge can significantly change channel geometry. In contrast, bedrock, cascade, and step-pool channels are resilient to most discharge or

TABLE 3. INTERPRETED REACH-LEVEL CHANNEL RESPONSE POTENTIAL TO MODERATE CHANGES IN SEDIMENT SUPPLY AND DISCHARGE

	Width	Depth	Roughness	Scour depth	Grain size	Slope	Sediment storage
Dune ripple	+	+	+	+	o	+	+
Pool riffle	+	+	+	+	+	+	+
Plane bed	p	+	p	+	+	+	p
Step pool	o	p	p	p	p	p	p
Cascade	o	o	p	o	p	o	o
Bedrock	o	o	o	o	o	o	o
Colluvial	p	p	o	p	p	o	+

Notes: +—likely, o—unlikely, p—possible.

sediment-supply perturbations because of high transport capacities and generally supply-limited conditions. Many bedrock channels are insensitive to all but catastrophic changes in discharge and sediment load. Lateral confinement and large, relatively immobile, bed-forming clasts make channel incision or bank cutting unlikely responses to changes in sediment supply or discharge in most cascade and step-pool channels. Other potential responses in step-pool channels include changes in bedform frequency and geometry, grain size, and pool scour depths, whereas only limited textural response is likely in cascade channels. Lower gradient plane-bed, pool-riffle, and dune-ripple channels become progressively more responsive to altered discharge and sediment supply with decreasing q_r, smaller grain sizes, and less channel confinement. Because plane-bed channels occur in both confined and unconfined valleys, they may or may not be susceptible to channel widening or changes in valley-bottom sediment storage. Smaller, more mobile grain sizes in plane-bed and pool-riffle channels allow potentially greater response of bed-surface textures, scour depth, and slope compared to cascade and step-pool morphologies. Unconfined pool-riffle and dune-ripple channels generally have significant potential for channel geometry responses to perturbations in sediment supply and discharge. Changes in both channel and valley storage are also likely responses, as well as changes in channel roughness due to alteration of channel sinuosity and bedforms. There is less potential for textural response in dune-ripple than in pool-riffle and plane-bed channels simply because of smaller and more uniform grain sizes. At very high sediment supply, any of the above channel types may acquire a braided morphology (e.g., Mollard, 1973; Church, 1992). The general progression of alluvial channel types downstream through a channel network (Fig. 4) suggests that there is a systematic downstream increase in response potential to altered sediment supply or discharge.

The above predictions of response potential are largely conceptual, based on typical reach processes, characteristics, and locations within a drainage basin. Nevertheless, our approach provides a rational, process-based alternative to channel assessments based solely on descriptive typologic classification. For example, a channel-reach classification developed by Rosgen (1994) recognizes 7 major and 42 minor channel types primarily on the basis of bed material and slope; there is also the option of more detailed classification using entrenchment, sinuosity, width to depth ratio, and geomorphic environments. However, the classification lacks a basis in channel processes. The lack of an explanation of the rationale underlying Rosgen's (1994) assessment of response potential for each minor channel type emphasizes this shortcoming. Furthermore, Rosgen's (1994) classification combines reach morphologies that may have very different response potentials: Rosgen's (1994) C channels may include reaches with dune-ripple, pool-riffle, plane-bed, or forced pool-riffle morphologies; his B channels may include plane-bed, forced-pool riffle, and step-pool morphologies; and his A channels may include colluvial, cascade, and step-pool reaches. Although bed material and slope provide a convenient classification for many channels, the lack of a process-based methodology compromises such an approach to structuring channel assessments, predicting channel response, and investigating relations to ecological processes.

External Influences

Channel response potential also reflects external influences on channel morphology, the most prominent of which are confinement, riparian vegetation, and large woody debris loading. Valley-wall confinement limits changes in both channel width and flood-plain storage and maximizes channel response to increased discharge by limiting overbank flow. Although there is a general downstream correspondence between channel type and valley-wall confinement in many mountain watersheds, structural controls and geomorphic history can force confinement in any portion of the channel network.

Riparian vegetation influences channel morphology and response potential by providing root strength that contributes to bank stability (e.g., Shaler, 1891; Gilbert, 1914), especially in relatively noncohesive alluvial deposits. The effect of root strength on channel bank stability is greatest in low-gradient, unconfined reaches, where loss of bank reinforcement may result in dramatic channel widening (Smith, 1976). Riparian vegetation is also an important roughness source (e.g., Arcement and Schneider, 1989) that can mitigate the erosive action of high discharges.

Large woody debris provides significant control on the formation and physical characteristics of pools, bars, and steps (Heede, 1985; Lisle, 1986; Montgomery et al., 1995; Wood-Smith and Buffington, 1996), thereby influencing channel type and the potential for change in sediment storage and bedform roughness in response to altered sediment supply, discharge, or large woody debris loading. Woody debris may decrease the potential for channel widening by armoring stream banks; alternatively, it may aid bank erosion by directing flow and scour toward channel margins. Furthermore, bed-surface textures and their response potential are strongly controlled by hydraulic roughness resulting from in-channel wood and debris-forced bedforms (Buffington, 1995). Although large woody debris can force morphologic changes ranging from the scale of channel units to reaches, its impact depends on the amount, size, orientation, and position of debris, as well as channel size (Bilby and Ward, 1989; Montgomery et al., 1995) and rates of debris recruitment, transport, and decay (Bryant, 1980; Murphy and Koski, 1989). In general, individual pieces of wood can dominate the morphology of small channels, whereas debris jams are required to significantly influence channel morphology in larger rivers where individual pieces are mobile (Abbe and Montgomery, 1996). Thus, the relative importance of large woody debris in controlling channel morphology and response potential varies through a channel network.

Temporal Changes in Channel Morphology

The spatial pattern of channel types within a watershed provides a snapshot in time of a channel network, but history also influences the response potential of mountain channels, because past disturbance can condition channel response. Temporal variations in macroscopic channel morphology reflect (1) changes in large woody debris loading (e.g., Beschta, 1979;

Heede, 1985); (2) changes in discharge and sediment input (e.g., Hammer, 1972; Graf, 1975; Megahan et al., 1980; Coats et al., 1985); and (3) routing of sediment waves through the channel network (e.g., Gilbert, 1917; Kelsey, 1980; Church and Jones, 1982; Madej, 1982; Reid, 1982; Beschta, 1983).

Channels in which large woody debris forces pool formation and sediment storage are particularly sensitive to altered wood loading. For example, removal of large woody debris from forced pool-riffle channels may lead to either a pool-riffle or plane-bed morphology (Montgomery et al., 1995). Similarly, loss of large woody debris may transform a forced step-pool channel into a step-pool, cascade, or bedrock channel, depending on channel slope, discharge, and availability of coarse sediment.

Changes in reach-level channel type resulting from increased sediment supply typically represent a transient response to a pulsed input, although a longer-term response may result from sustained inputs. A landslide-related pulse of sediment may result in a transient change to a morphology with a lower q_r that subsequently relaxes toward the original morphology as the perturbation subsides. Pool-riffle reaches, for example, can develop a braided morphology while transmitting a pulse of sediment and subsequently revert to a single-thread pool-riffle morphology. Channel reaches with high q_r should recover quickly from increased sediment loading, because they are able to rapidly transport the load downslope. Reaches with a low q_r should exhibit more persistent morphologic response to a comparable increase in sediment supply. Transient morphologic change can also result from debris-flow scour of steep-gradient channels. For example, colluvial and cascade channels that are scoured to bedrock by a debris flow may slowly revert to their predisturbance morphologies.

The spatial pattern of channel types provides a template against which to assess channel response potential, but the disturbance history of a channel network also is important for understanding both current conditions and response potential. Reach-level channel morphology provides a general indication of differences in response potential, but specific responses depend on the nature, magnitude, and persistence of disturbance, as well as on local conditions, including riparian vegetation, in-channel large woody debris, bank materials, and the history of catastrophic events. Furthermore, concurrent multiple perturbations can cause opposing or constructive response, depending on both channel type and the direction and magnitude of change. Hence, assessment of either present channel conditions or the potential for future impacts in mountain drainage basins should consider both disturbance history and the influences of channel morphology, position in the network, and local external constraints.

CONCLUSIONS

Systematic variations in bed morphology in mountain drainage basins provide the basis for a classification of channel-reach morphology that reflects channel-forming processes, serves to illustrate process linkages within the channel network, and allows prediction of general channel response potential. The underlying hypothesis that alluvial bed morphology reflects a stable roughness configuration for the imposed sediment supply and transport capacity implies a fundamental link between channel processes and form. The association of reach types and ratios of transport capacity to sediment supply combined with identification of external influences and the spatial coupling of reaches with hillslopes and other channel types provides a conceptual framework within which to investigate channel processes, assess channel conditions, and examine spatially distributed responses to watershed disturbance. Integration of this approach into region-specific landform and valley segment classifications would provide a common language to studies of fluvial processes and response to disturbance. This classification, however, is not ideal for all purposes; characterization of river planforms, for example, is useful for classifying flood-plain rivers. The development of specific restoration designs requires further information on reach-specific characteristics. Our classification simply characterizes aspects of reach-level channel morphology useful for assessing channel condition and potential response to natural and anthropogenic disturbance in mountain drainage basins.

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Section 6
Physical Habitat Characterization—Non-wadeable Rivers

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

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

All of these attributes may be directly or indirectly altered by anthropogenic activities. Nevertheless, their expected values tend to vary systematically with river size (drainage area) and overall gradient (as measured from

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topographic maps). The relationships of specific physical habitat measurements described in this EMAP-SW field manual to these seven attributes are discussed by Kaufmann (1993). Aquatic macrophytes, riparian vegetation, and large woody debris are included in this and other physical habitat assessments because of their role in modifying habitat structure and light inputs, even though they are actually biological measures. The field physical habitat measurements from this field habitat characterization are used in the context of water chemistry, temperature, and other data sources (e.g., remote sensing of basin land use and land cover). The combined data analyses will more comprehensively describe additional habitat attributes and larger scales of physical habitat or human disturbance than are evaluated by the field assessment alone.

This protocol is intended for evaluating physical habitat in non-wadeable streams and rivers. Kaufmann and Robison (1998) describe other methods for use in smaller, wadeable streams. Like the methods for wadeable streams, these methods are most efficient during low flow conditions and when leaves are on terrestrial vegetation, but may be applied during other seasons and higher flows except as limited by safety considerations. It is designed for monitoring applications where robust, quantitative descriptions of reach-scale habitat are desired, but time is limited.

Like the wadeable streams protocol (Kaufmann and Robison 1998) this habitat characterization approach employs a randomized, systematic spatial sampling design to minimize bias in the placement and positioning of measurements. Measures are taken over defined channel areas and these sampling areas or points are placed systematically at spacings that are proportional to baseflow channel width. This systematic sampling design scales the sampling reach length and resolution in proportion to stream size. It also allows statistical and series analyses of the data that are not possible under other designs. We strive to make the protocol objective and repeatable by using easily learned, repeatable measures of physical habitat in place of estimation techniques wherever possible. Where estimation is employed, we direct the sampling crew to estimate attributes that are otherwise measurable, rather than estimating the quality or importance of the attribute to biota or its importance as an indicator of disturbance. We have included the more traditional visual classification of channel unit scale habitat types because they have been useful in past studies and enhance comparability with other work.

The time commitment to gain repeatability and precision is greater than that required for more qualitative methods. In our field trials, two people typically complete the specified channel, riparian, and discharge measurements in about three hours of field time. However, the time required can vary considerably with channel characteristics, flow conditions, and the location of boat launching areas.

The protocol defines the length of each sampling reach proportional to river wetted width and then systematically places measurements to statistically represent the entire reach. Stream thalweg depth measurements, habitat classification, and mid-channel substrate observations are made at very tightly spaced intervals; whereas channel "littoral" and riparian stations for measuring or observing substrate, fish cover, large woody debris, bank characteristics and riparian vegetation structure are spaced further apart. The tightly spaced depth measures allow calculation of indices of channel structural complexity, objective classification of channel units such as pools, and quantification of residual pool depth, pool volume, and total stream volume.

6.1 Components of the Field Habitat Assessment

Field data collection for the physical habitat assessment is accomplished in a single float down each river sample reach. Depending on the survey region, river sample reach lengths are defined as either 40 or 100 times the wetted width in the vicinity of the point of entry (Figure 6-1). In addition to physical habitat assessment, the 2-person habitat team of the field crew collects chemical, macroinvertebrate, and periphyton samples (if applicable). They may also recon the channel if they precede the electrofishing boat down the river. To characterize mid-channel habitat (Table 6-1), they measure a longitudinal thalweg (or mid-channel) depth profile, tally snags, classify channel habitat types, characterize mid-channel substrate, and locate the 11 systematic transect locations for littoral/riparian sampling and other habitat observations (Figures 6-1 and 6-2). At each of the 11 marked reach transect locations (A-K), they measure channel wetted width, bankfull channel dimensions, incision, channel constraint, bearing and gradient; then assess near-shore, shoreline, and riparian physical habitat characteristics by measuring or observing littoral depths, riparian canopy cover, substrate, large woody debris, fish cover, bank characteristics, riparian vegetation, and evidence of human activities (Table 6-1). They also collect benthic macroinvertebrates (Section 9), take benthic algal samples (if applicable), and measure conductivity and water temperature using procedures described in section 5.

Mid-channel habitat measurements and observations are recorded on multiple pages of the Thalweg Profile Form (Figure 6-3). Instructions for these mid-channel procedures are given in section 6.5. Measurements made while anchored or tied up to the 11 littoral/riparian plot stations ("transects") are recorded on 11 copies of the two sided Channel/Riparian Transect Form (Figures 6-4 and 6-5). Instructions for these transect or littoral/riparian assessment activities are discussed in subsection 6.6.

6.2 Habitat Sampling Locations On The Study Reach

Measurements are made at two scales of resolution along the mid-channel length of the reach; the results are later aggregated and expressed for the entire reach, a third level of resolution (Figure 6-1). We want to assess habitat and other river indices over river reach lengths that are long enough to incorporate the habitat variability due to river meandering and pool-riffle structure. To accommodate habitat variability in a way that adjusts for varying sizes of rivers, EMAP protocols specify sample reach lengths that are a multiple of their average wetted width (40 or 100 Channel-Widths). Water velocity, habitat complexity, fish abundance, and species richness may also affect capture efficiency and consequently the required sample reach length. In the Oregon river pilot, it was found that 85 channel widths is adequate for Oregon rivers (Hughes et al. In Review). In the Mid-Atlantic region, river reaches of 40 channel widths long were used in order to make this aspect of field methods consistent between wadeable and non-wadeable streams. For this field manual, we discuss the methods used to

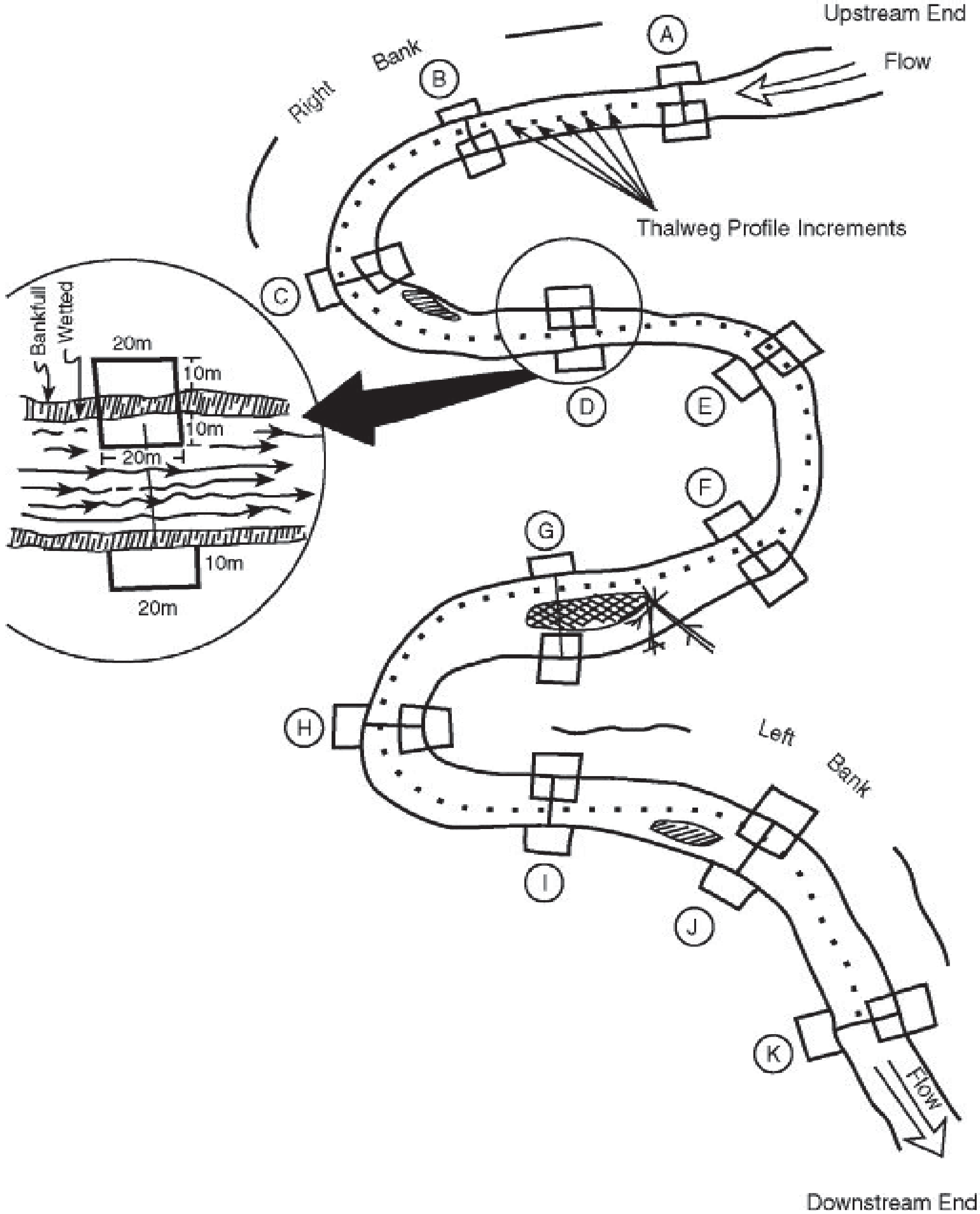


Figure 6-1. River reach sample layout.

Table 6-1. Components of River Physical Habitat Protocol.

1. Thalweg Profile:

At 10 equally spaced intervals between each of 11 channel cross-sections (100 along entire reach):

* Classify habitat type, record presence of backwater and off-channel habitats. (10 between cross sections, 100 total)
* Determine dominant substrate visually or using sounding rod. (10 between cross-sections, 100 total)

At 20 equally spaced intervals (for 100 ChW reach) or 10 equally spaced intervals (for 40 ChW reach) between each of 11 channel cross-sections:

* Tally mid-channel snags - 10 (or 20) between cross-sections, 100(or 200) total.
* Measure thalweg (maximum) depth using Sonar or rod - 10 (or 20) between cross-sections, 100(or 200) total.

2. Littoral/Riparian Cross-Sections: @ 11 stops ("transects") at equal intervals along reach length:

Measure/estimate from one chosen bank on 11 channel cross-sections:

* Gradient (clinometer or Abney level) between cross-section and next one downstream.
* Bearing (compass) between cross-section and next one downstream.
* Wetted width (laser range finder).
* Mid-channel bar width (laser range finder).
* Bankfull width and height (estimate).
* Incision height (estimate).
* Bank angle (estimate).
* Riparian canopy cover (densiometer) in four directions from chosen bank.
* Shoreline Substrate in the first 1m above waterline (est. dominant and subdominant size class).

In 20m long Littoral Plot extending streamward 10m from chosen bank:

* Littoral depth at 5 locations systematically-spaced within plot (Sonar or sounding rod).
* Dominant and Subdominant substrate size class at 5 systematically-spaced locations (visual or sounding rod).
* Tally large woody debris in littoral plot and in bankfull channel by size and length class.
* Areal cover class of fish concealment and other features, including:

filamentous algae	overhanging vegetation
aquatic macrophytes	undercut banks
large woody debris	boulders and rock ledges
brush and small woody debris	artificial structures

In 20m long Littoral Plot extending 10m landward starting at bankfull margin:[1]

* Estimate areal cover class and type (e.g., woody) of riparian vegetation in Canopy, Mid-Layer, and Ground Cover
* Observe and record human activities and disturbances and their proximity to the channel.

For largest visible Riparian Tree:

* Estimate diameter (Dbh), height, species, and distance from river edge.

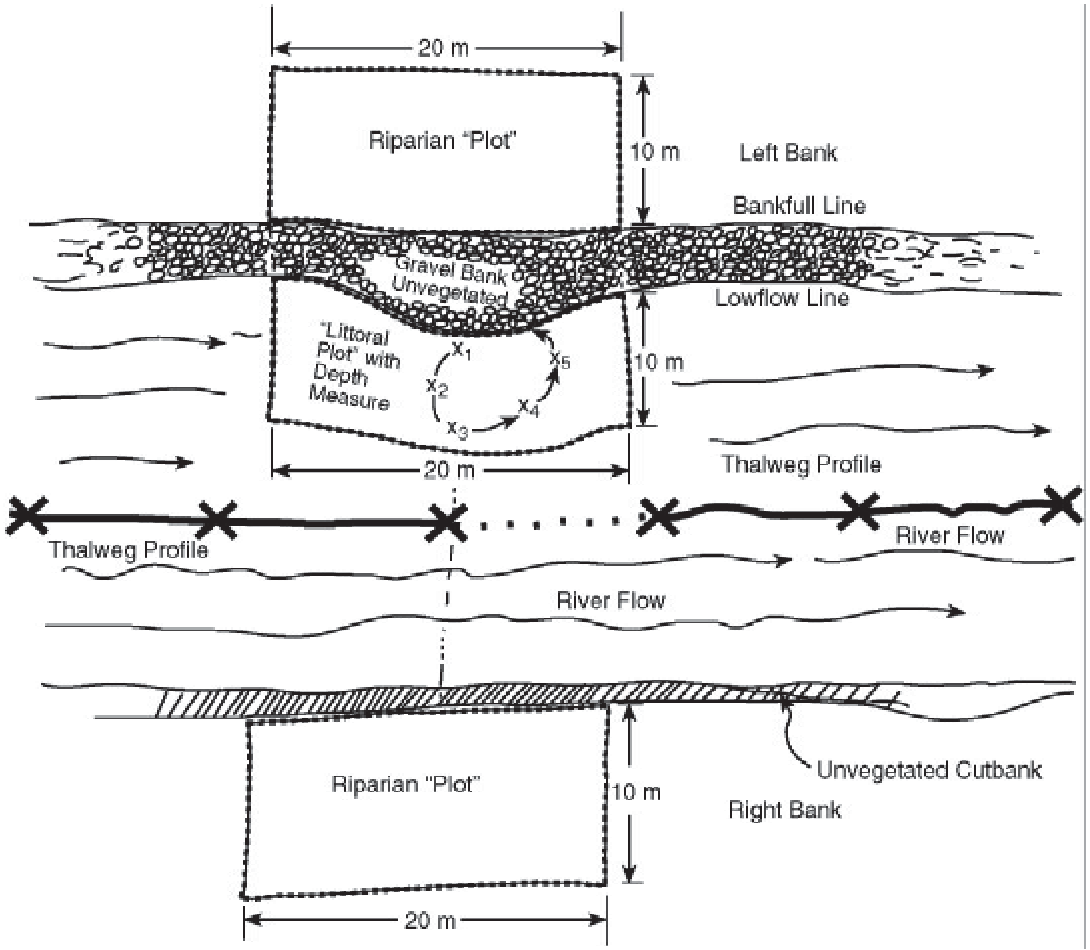


Figure 6-2. Littoral-Riparian Plots for characterizing riparian vegetation, human influences, fish cover, littoral substrate, and littoral depths.

sample reaches 40 times the mean wetted width at the vicinity of the launch point in Mid-Atlantic region streams and 100 times the mean wetted width in Oregon streams.

Section 4 describes the procedure for locating the X-site that defines the midpoint of the sample reach. This sampling location is already marked on a 1:24,000 map prior to going into the field. It has precise coordinates of latitude and longitude, and was selected by the EMAP design group using a randomized systematic sampling design. Subsections 6.3 and 6.4 describe the protocol for delineating a sample reach that is 40 or 100 times its width. Those sections also describe the protocol for measuring out (with a laser range finder) and locating the 11 littoral/riparian stations where many habitat measurements will be made. The distance between each of these stations is 1/10th the total length of the sample reach.

The thalweg profile measurements must be spaced as evenly as practicable over the entire sample reach length. In addition, they must be sufficiently close together that they do not "miss" deep areas and habitat units that are in a size range of about 1/3 to 1/2 of the average channel width distance. To set the

Reviewed by (initial) DKA

PHab: THALWEG PROFILE FORM - RIVERS

SITE NAME: BEAVER RIVER — DATE: 8 / 5 / 98 — VISIT ☐0 ☒1 ☐2 ☐3

SITE ID: ORRV 98-999 — TEAM ID (X): ☒1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8

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

SUBSTRATE CODES	CHANNELHABITAT CODES	OTHER
BH = Bedrock/Hardpan (smooth or rough) • (larger than a car) BL = Boulder (250 to 4000 mm) • (basketball to car) CB = Cobble (64 to 250) • (tennis ball to basketball) GR = Coarse to Fine Gravel (2 to 64) • (ladybug to tennis ball) SA = Sand (0.06 to 2 mm) • (gritty - up to ladybug size) FN = Silt/Clay/Muck • (not gritty) OT = Other ☺ (Comment Please)	PO = Pool GL= Glide RI = Riffle RA= Rapid CA= Cascade FA= Falls DR = Dry Channel	Off Ch. = Off Channel or Backwater
Circle One Substrate Code for Each Station	Circle One Channel Habitat Code for Each Station	X if Yes

REMEMBER: A = Upstream End of Reach and K = Downtown End of Reach

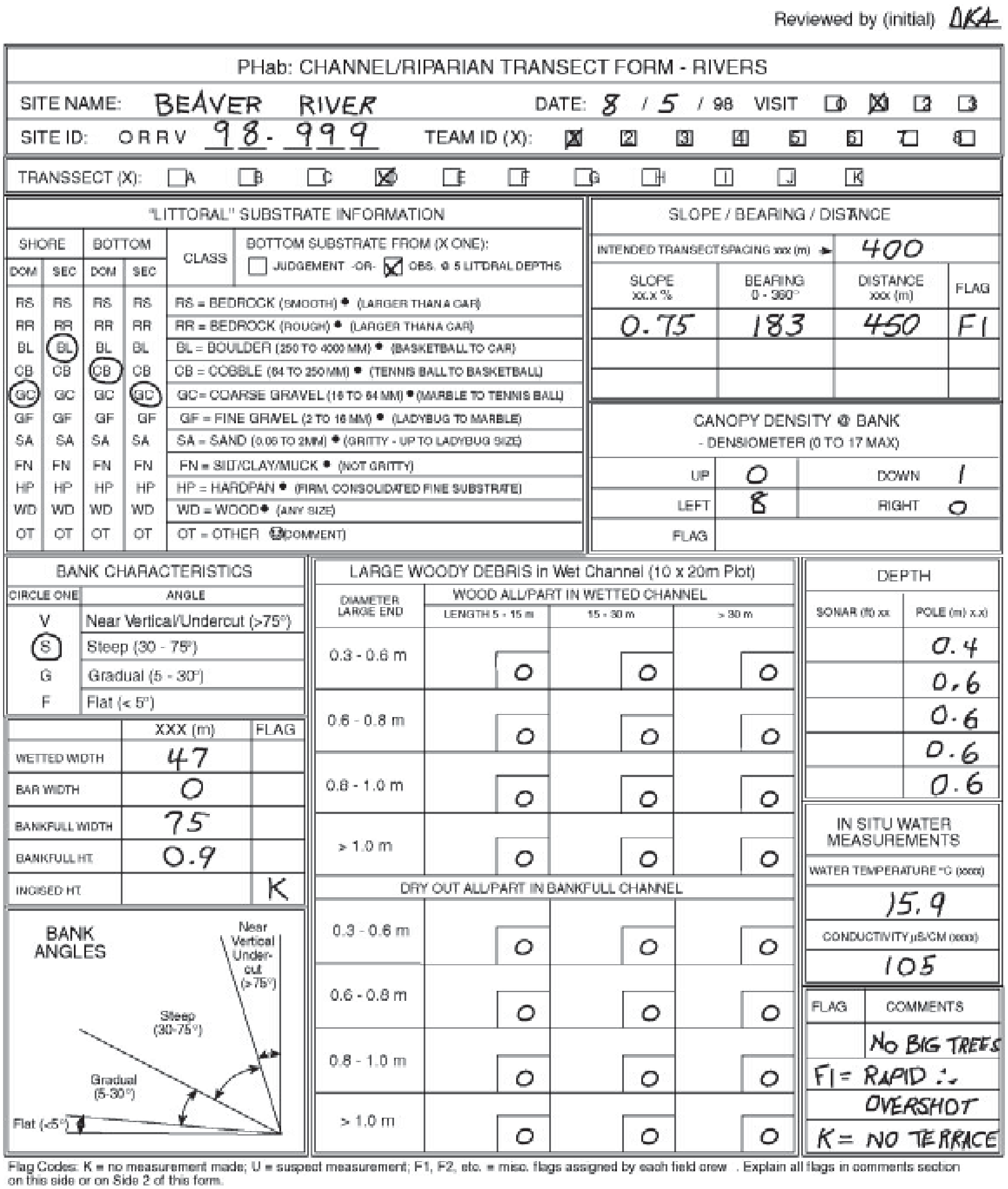
STATION	SNAG (X)	DEPTH (ETHER) SONAR (ft) xx	DEPTH (ETHER) POLE (m) x.x	SUBSTRATE (CIRCLE ONE)	CHANNEL HABITAT (CIRCLE ONE)	OFF CH. (X)	FLAG
1		12		BH (BL) CB GR SA FN OT	PO GL (RI) RA CA FA DR		
2		10					
3		9		BH (BL) CB GR SA FN OT	PO (GL) RI RA CA FA DR		
4		9					
5		6		BH (BL) CB GR SA FN OT	PO (GL) RI RA CA FA DR		
6		5					
7		4		BH (BL) CB GR SA FN OT	PO GL (RI) RA CA FA DR		
8		6					
9	X	3		BH (BL) CB GR SA FN OT	PO GL (RI) RA CA FA DR		
10		4					
11		5		BH (BL) CB GR SA FN OT	PO GL (RI) RA CA FA DR		
12		6					
13		8		BH (BL) CB GR SA FN OT	PO GL (RI) RA CA FA DR		
14		8					
15		7		BH (BL) CB GR SA FN OT	PO GL (RI) RA CA FA DR		F1
16							
17				BH BL CB GR SA FN OT	PO GL RI RA CA FA DR		
18							
19				BH BL CB GR SA FN OT	PO GL RI RA CA FA DR		
20							

Flag Codes: K = no measurement made; U = suspect measurement; F1, F2, etc. = misc. flags assigned by each field crew . Explain all flags on Comment Form.

F1 = STATIONS 1-15 SPREAD THROUGH PROFILE

Rev. 05/29/98 (_rvph_1.98) — PHab: THAWEG PROFILE FORM - RIVERS - 1

Figure 6-3. Thalweg Profile Form.



Reviewed by (initial) DKA

PHab: CHANNEL/RIPARIAN TRANSECT FORM - RIVERS

SITE NAME: BEAVER RIVER DATE: 8 / 5 / 98 VISIT ☐1 ☒2 ☐3 ☐3

SITE ID: ORRV 98-999 TEAM ID (X): ☒1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8

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

"LITTORAL" SUBSTRATE INFORMATION

BOTTOM SUBSTRATE FROM (X ONE): ☐ JUDGEMENT -OR- ☒ OBS. @ 5 LITTORAL DEPTHS

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

SLOPE / BEARING / DISTANCE

INTENDED TRANSECT SPACING xxx (m) → 400

SLOPE xx.x %	BEARING 0 - 360°	DISTANCE xxx (m)	FLAG
0.75	183	450	F1

CANOPY DENSITY @ BANK - DENSIOMETER (0 TO 17 MAX)

UP	0	DOWN	1
LEFT	8	RIGHT	0
FLAG			

BANK CHARACTERISTICS

CIRCLE ONE	ANGLE
V	Near Vertical/Undercut (>75°)
(S)	Steep (30 - 75°)
G	Gradual (5 - 30°)
F	Flat (< 5°)

	XXX (m)	FLAG
WETTED WIDTH	47	
BAR WIDTH	0	
BANKFULL WIDTH	75	
BANKFULL HT.	0.9	
INCISED HT.		K

BANK ANGLES: Near Vertical Under-cut (>75°); Steep (30-75°); Gradual (5-30°); Flat (<5°)

LARGE WOODY DEBRIS in Wet Channel (10 x 20m Plot)

DIAMETER LARGE END	LENGTH 5 - 15 m	15 - 30 m	> 30 m
WOOD ALL/PART IN WETTED CHANNEL			
0.3 - 0.6 m	0	0	0
0.6 - 0.8 m	0	0	0
0.8 - 1.0 m	0	0	0
> 1.0 m	0	0	0
DRY OUT ALL/PART IN BANKFULL CHANNEL			
0.3 - 0.6 m	0	0	0
0.6 - 0.8 m	0	0	0
0.8 - 1.0 m	0	0	0
> 1.0 m	0	0	0

DEPTH

SONAR (ft) xx	POLE (m) x.x
	0.4
	0.6
	0.6
	0.6
	0.6

IN SITU WATER MEASUREMENTS

WATER TEMPERATURE °C (xxxx): 15.9

CONDUCTIVITY µS/CM (xxxx): 105

FLAG	COMMENTS
	No BIG TREES
F1 =	RAPID ∴ OVERSHOT
K =	NO TERRACE

Flag Codes: K = no measurement made; U = suspect measurement; F1, F2, etc. = misc. flags assigned by each field crew . Explain all flags in comments section on this side or on Side 2 of this form.

Rev. 05/29/98 (_rvphc_.98) PHab: CHANNEL/RIPARIAN TRANSECT FORM - RIVERS - 1

Figure 6-4. Channel/Riparian transect form - page 1 (front side).

interval between thalweg profile measurements, measure the wetted channel width with a laser range finder at several locations near the upstream end of the reach and multiply it by 40 (100) to set the river sample reach length. Then divide that reach length by 100 (or 200) to set the thalweg increment distance. Following these guidelines, you will be making 100 or 200 evenly-spaced thalweg profile measurements, 10 or 20 between each detailed channel cross section where littoral/ riparian observations are made. The number and spacing of measurements are as follows for the two different sample reach lengths:

	40 Ch-W		100 Ch-W	
	number	spacing	number	spacing
Transects and Riparian Plots	10	4 Ch-W	10	10 Ch-W
Thalweg Depth measurements	100	0.4 Ch-W	200	0.5 Ch-W
Thalweg Substrate, Habitat Class	100	0.4 Ch-W	100	1.0 Ch-W

6.3 Logistics, Work Flow, and Defining Sample Locations

The two-person habitat assessment team uses the most nimble of the selection of watercraft judged capable of navigating the river reach. In a single midstream float down the 40 or 100 Channel-width reach, the team accomplishes a reconnaissance, a sonar/pole depth profile, and a pole-drag to tally snags and characterize mid-channel substrate. The float is interrupted by stops at 11 transect locations for littoral/riparian observations. They determine (and mark -- optional) the position of each successive downstream transect using a laser range finder to measure out and mentally note each new location 4 (or 10) channel-width's distance from the preceding transect immediately upstream. The crew then floats downstream along the thalweg to the new transect location, making thalweg profile measurements and observations at 10 (or 20) evenly-spaced increments along the way. When they reach the new downstream transect location, they stop to do cross-section, littoral, and riparian measurements. Equipping the boat with a bow or stern anchor to stop at transect locations can greatly ease the shore marking operation and shoreline measurement activities. In addition, while they are stopped at a cross-section station, the crew can fill out the habitat "typing" entries retrospectively and prospectively for the portion of the stream distance that is visible up- and downstream. They can also record reconnaissance and safety notes at this time. While stopped at the transect location, the crew makes the prescribed measurements and observations, collects biological samples, backsites slope and bearing towards the previous upstream transect, and sets or mentally notes eye-level flags or reference points on shore for subsequent backsites. The habitat crew also assists the electrofishing boat crew over jams and helps to conduct shuttles (this can take considerable time where put-ins and take-outs are distant).

6.4 Reconnaissance and Reach Marking

The purpose of the reconnaissance is to locate (and optionally mark) the reach sampling location and to inform the second boat of the route, craft, and safety precautions needed during its subsequent electrofishing activities. After finding adequate put-in and take-out locations, the team may opt to mark the upstream end of the sample reach end with colored flagging. Based on several channel width measurements using a laser range finder, they determine the sample reach length (40 x or 100 x Channel Width), the transect spacing (4 x or 10 x Channel Width) and thalweg sampling interval (0.5 x Channel Width). As the crew floats downstream, they stop (and optionally flag) 11 transect locations along the riverbank in the process of carrying out slope, bearing, and distance backsites. As the team floats downstream, they may choose and communicate to the electrofishing crew the most practical path to be used when fishing with a less maneuverable boat, taking into consideration multiple channels, blind channels, backwaters, alcoves, impassible riffles, rapids, jams, and hazards such as dams, bridges and power lines. They determine if and where tracking or portages are necessary.

6.5 Thalweg Profile

"Thalweg" refers to the flow path of the deepest water in a river channel. The thalweg profile is a longitudinal survey of maximum depth and several other selected characteristics at 100 (or 200) near-equally spaced points along the centerline of the river between the two ends of the river reach (Figure 6-1). For practical reasons, field crews will approximate a thalweg profile by sounding along the river course that they judge is deepest, but also safely navigable. Data from the thalweg profile allows calculation of indices of residual pool volume, river size, channel complexity, and the relative proportions of habitat types such as riffles and pools. The procedure for obtaining thalweg profile measurements is presented in Table 6-2. Record data on the Thalweg Profile Form as shown in Figure 6-3.

6.5.1 Thalweg Depth Profile

A thalweg depth profile of the entire 40 or 100 Channel-width reach shall be approximated by a sonar or sounding rod profile of depth while floating downstream along the deepest part of the channel (or the navigable or mid-channel path). In the absence of a recording fathometer (sonar depth sounder with strip-chart output or electronic data recorder), the crew records depths at frequent, relatively evenly-spaced downstream intervals while observing a sonar display and holding a surveyor's rod off the side of the boat (see subsection 6.5.2, below). The sonar screen is mounted so that the crew member can read depths on the sonar and the rod at the same time. The sonar sensor may need to be mounted at the opposite end of the boat to avoid mistaking the rod's echo for the bottom, though using a narrow beam (16 degree) Sonar transducer minimizes this problem. It is surprisingly easy to hold the sounding rod vertical when you are going at the same speed as the water. In our river trials, one measurement every half-channel-width (10 to 15 m) in current moving at about 0.5 m/s resulted in one measurement every 20 to 30 seconds. To facilitate accomplishing this work fast enough, the field form only requires "checks" for any observations other than depth measurements. To speed operations further, it may also be advantageous to mount a bracket on the boat to hold the clipboard.

6.5.2 Pole Drag for Snags and Substrate Characteristics

The procedure for obtaining pole drags for snags and substrate characteristics is presented in Table 6-2. While floating downstream, one crew member holds a calibrated PVC sounding tube or fiberglass surveying rod down vertically from the gunwale of the boat, dragging it lightly on the bottom to simultaneously "feel" the substrate, detect snags, and measure depth with the aid of sonar. The number of large snags hit by this rod shall be recorded as an index of fish cover complexity (modification of Bain's "snag drag"). While dragging the sounding rod along the bottom, the crew member shall record the dominant substrate type sensed by dragging the rod along the bottom (bedrock/hardpan, boulder, cobble, gravel, sand, silt & finer) (Figure 6-3). In shallow, "wild," fast-water situations, where pole-dragging might be hazardous, crews will estimate bottom conditions the best they can visually and by using paddles and oars. If unavoidable, suspend measurements until out of whitewater situations, but make notes and appropriately flag observations concerning your best judgements of depth and substrate.

6.5.3 Channel Habitat Classification

The crew will classify and record the channel habitat types shown in Figure 6-3 (fall, cascade, rapid, riffle, glide, pool, dry) and check presence of off-channel and backwater habitat at a spatial resolution of about 0.4 channel-widths on a 40 Channel-width reach. On a 100 Channel-width reach habitat classifications are made every 1.0 channel-widths and off-channel and backwater habitat presence is checked every 0.5 channel-width distance -- the same interval as thalweg depths. The resulting database of traditional visual habitat classifications will provide a bridge of common understanding with other studies. The procedures for classifying channel habitat are presented in Table 6-2. The designation of side channels, backwaters and other off-channel areas is independent of the main-channel habitat type. Main channel habitat units must meet a minimum size criteria in addition to the qualitative criteria listed in Table 6-3. Before being considered large enough to be identified as a channel-unit scale habitat feature, the unit should be at least as long as the channel is wide. For instance, if there is a small, deep (pool-like) area at the thalweg within a large riffle area, don't record it as a pool unless it occupies an area about as wide or long as the channel is wide.

Mid-Channel Bars, Islands, and Side Channels pose some problems for the sampler conducting a thalweg profile and necessitate some guidance. Mid-channel bars are defined here as channel features below the bankfull flow level that are dry during baseflow conditions (see Section 6.6.4 for definition of bankfull channel). Islands are channel features that are dry even when the river is at bankfull flow. If a mid-channel feature is as high as the surrounding flood plain, it is considered an island. Both mid-channel bars and islands cause the river to split into side channels. When a bar or island is encountered along the thalweg profile, choose to navigate and survey the channel that carries the most flow.

When side channels are present, the comments column of the Thalweg Profile form should reflect their presence by checking the "Off-Channel" column. These checkmarks will begin at the point of divergence from the main channel, continuing downstream to the point of where the side channel converges with the main channel. In the case of a slough or alcove, the "off-channel" checkmarks should continue from the point of divergence.

6.6 Channel Margin ("Littoral") And Riparian Measurements

Components of this section include slope and bearing, channel margin depth and sub-

Table 6-2. Thalweg Profile Procedure.

1. Determine the interval between measurement stations based on the wetted width used to determine the length of the sampling reach.
2. Complete the header information on the Thalweg Profile Form, noting the transect pair (upstream to downstream).
3. Begin at the upstream transect (station "1" of "20" or station "1" of "10").

Thalweg Depth Profile

a) While floating downstream along the thalweg, record depths at frequent, approximately even-spaced downstream intervals while observing a sonar display and holding a surveyor's rod off the side of the boat.

b) A depth recording approximately every 0.4 (or 0.5) channel-width distance is required, yielding 10 (or 20) measurements between channel/riparian cross-section transects.

c) If the depth is less than approximately 0.5 meters, or contains a lot of air bubbles, the sonar fathometer will not give reliable depth estimates. In this case, record depths using a calibrated measuring rod. In shallow, "wild," fast-water situations depths may have to be visually estimated to the nearest 0.5 meter.
d) Measure depths to nearest 0.1 m and record in the "SONAR" or "POLE" column on the Thalweg Profile Form.

Pole Drag for Snags and Substrate Characteristics

a) From the gunwale of the boat, hold a fiberglass surveying rod or calibrated PVC sounding tube down vertically into the water.
b) Lightly drag the rod on the river bottom to "feel" the substrate and detect snags.
c) Observations are taken at half the frequency as depth measurements (i.e., at every other depth measurement point on 100 Channel-Width reaches).
d) Record the number of snags hit by the rod and the dominant substrate type sensed by dragging the rod along the bottom.
e) On the Thalweg Profile Form, circle the appropriate "SUBSTRATE" type and tally the number of "SNAGS".

Channel Habitat Classification

a) Classify and record the channel habitat type at increments of every 1.0 channel width.
b) Check for off-channel and backwater habitat at increments of every 0.4 (or 0.5) channel width.
c) If channel is split by a bar or island, navigate and survey the channel with the most discharge.
d) When a side channel is encountered, check the "OFF-CHANNEL" column beginning with the point of divergence from the main channel, continuing downriver until the side channel converges with the main channel.
e) On the Thalweg Profile Form, circle the appropriate "CHANNEL HABITAT" and check the off-channel column as described in (d) above.

4. Proceed downriver to the next station ("2"), and repeat the above procedures.
5. Repeat the above procedures until you reach the next transect. Prepare a new Thalweg Profile Form, then repeat the above procedures for each of the reach segments, until you reach the downriver end of the sampling reach (Transect "K").

Table 6-3. Channel Unit Categories.

Class (Code)	Description
	Channel Unit Habitat Classes[a]
Pools (PO):	Still water, low velocity, smooth, glassy surface, usually deep compared to other parts of the channel:
Plunge Pool	Pool at base of plunging cascade or falls.
Trench Pool	Pool-like trench in the center of the stream
Lateral Scour Pool	Pool scoured along a bank.
Backwater Pool	Pool separated from main flow off the side of the channel.
Dam Pool	Pool formed by impoundment above dam or constriction.
Glide (GL)	Water moving slowly, with a 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 and breaking waves. Sound: continuous rushing, but not as loud as cascade.
Cascade (CA)	Water movement rapid and very turbulent over steep channel bottom. Most of the water surface is broken in short, irregular plunges, mostly whitewater. Sound: roaring.
Falls (FA)	Free falling water over a vertical or near vertical drop into plunge, water turbulent and white over high falls. Sound: from splash to roar.
Dry Channel (DR)	No water in the channel
Off-Channel Areas	Side-channels, sloughs, backwaters, and alcoves that are separated from the main channel.

[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.

strate, large woody debris, bank angle and channel cross-section morphology, canopy cover, riparian vegetation structure, fish cover, and human influences. All measurements are recorded on the two-sided Channel/Riparian Transect Form (Figures 6-4 and 6-5).

6.6.1 Slope and Bearing

The slope, or gradient, of the stream reach is useful in three different ways. First, the overall stream gradient is one of the ma-

Reviewed by (initial) DKA

PHab: CHANNEL/RIPARIAN TRANSECT FORM - RIVERS (continued)

SITE NAME: BEAVER RIVER DATE: 8 / 5 / 98 VISIT ☐0 ☒1 ☐2 ☐3

SITE ID: O R R V 98 - 999 TEAM ID (X): ☒1 ☐2 ☐3 ☐4 ☐5 ☐6 ☐7 ☐8

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

VISUAL RIPARIAN ESTIMATES	LEFT BANK	RIGHT BANK	FLAG
RIPARIAN VEGETATION COVER (10 m x 20 m Plot)	0 = ABSENT (0%) 1 = SPARSE (< 10%) 2 = MODERATE (10 - 40%) 3 = HEAVY (40 - 75%) 4 = VERY HEAVY (> 75%)	D = DECIDUOUS C = CONIFEROUS E = BROADLEAF EVERGREEN M = MIXED N = NONE	
CANOPY (> 5 m HIGH)			
VEGETATION TYPE	D C E M (N)	D C E M (N)	
BIG TREES (TRUNK > 0.3 m DBH)	(0) 1 2 3 4	(0) 1 2 3 4	
SMALL TREES (TRUNK > 0.3 m DBH)	(0) 1 2 3 4	(0) 1 2 3 4	
UNDERSTORY (0.5 to 5 m HIGH)			
VEGETATION TYPE	(D) C E M N	D C E M (N)	
WOODY SHRUBS & SAPLINGS	0 1 (2) 3 4	(0) 1 2 3 4	
NON-WOODY HERBS, GRASSES & FORBS	0 (1) 2 3 4	(0) 1 2 3 4	
GROUND COVER (< 0.5 m HIGH)			
WOODY SHRUBS & SEEDLINGS	0 (1) 2 3 4	0 (1) 2 3 4	
NON-WOODY HERBS, GRASSES & FORBS	0 1 (2) 3 4	0 1 2 3 (4)	
BARREN, BARE, DRY OR DUFF	0 (1) 2 3 4	(0) 1 2 3 4	

HUMAN INFLUENCE (10 m x 20 m Plot)	0 = NOT PRESENT P = > 10 m	C = WITHIN 10 m B = ON BANK	FLAG
WALL/DIKE/REVETMENT/RIPRAP/DAM	(0) P C B	(0) P C B	
BUILDINGS	(0) P C B	(0) P C B	
PAVEMENT	(0) P C B	(0) P C B	
ROAD/RAILROAD	0 (P) C B	0 (P) C B	F2
PIPES (INLET/OUTLET)	(0) P C B	(0) P C B	
LANDFILL/TRASH	(0) P C B	(0) P C B	
PARK/LAWN	(0) P C B	(0) P C B	
ROW CROPS	(0) P C B	(0) P C B	
PASTURE/RANGE/HAY FIELD	(0) P C B	(0) P C B	
LOGGING OPERATIONS	(0) P C B	(0) P C B	
MINING ACTIVITY	(0) P C B	(0) P C B	

FISH COVER/ OTHER (10 m X 20 m Plot)	COVER IN-CHANNEL: 0 = ABSENT (0%) 1 = SPARSE (< 10%) 2 = MODERATE (10 - 40%) 3 = HEAVY (40 - 75%) 4 = VERY HEAVY (> 75%) — CIRCLE ONE	FLAG
FILAMENTOUS ALGAE	(0) 1 2 3 4	
MACROPHYTES	0 (1) 2 3 4	
WOODY DEBRIS (> 0.3 m - BIG)	(0) 1 2 3 4	
BRUSH/WOODY DEBRIS (< 0.3 m - SMALL)	(0) 1 2 3 4	
OVERHANGING VEG. (≤ 1 m OF SURFACE)	(0) 1 2 3 4	
UNDERCUT BANKS	0 (1) 2 3 4	
BOULDERS/LEDGES	0 (1) 2 3 4	
ARTIFICIAL STRUCTURES	(0) 1 2 3 4	

CHANNEL CONSTRAINT

DISTANCE FROM SHORE TO RIPARIAN VEGETATION (XX).XX: 0

CIRCLE ONE	
(C)	CHANNEL IS CONSTRAINED.
U	CHANNEL IS UNCONSTRAINED IN BROAD VALLEY.
B	CHANNEL IS IN BROAD VALLEY BUT CONSTRAINED BY INCISION.
N	CHANNEL IS IN NARROW VALLEY BUT NOT VERY CONSTRAINED.

CIRCLE ONE	
(YES)	I COULD READILY SEE OVER THE BANK.
NO	I COULD NOT READILY SEE OVER THE BANK.

FLAG	COMMENTS (Additional space available on Side 1)
F2	RAILROAD GRADE

Flag Codes: K = no measurement made; U = suspect measurement; F1, F2, etc. = misc. flags assigned by each field crew . Explain all flags in comments section on this side or on Side 1 of this form.

Rev. 05/29/98 (_rvphc_.98) PHab: CHANNEL/RIPARIAN TRANSECT FORM - RIVERS - 2

Figure 6-5. Channel/Riparian transect form - page 2 (back side).

jor stream classification variables, giving an indication of potential water velocities and stream power; both of which are in turn 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), Robison and Kaufmann (1994), and Kaufmann et al., (1999), the water surface slope will allow us to compute residual pool depths and volumes from the multiple depth and width measurements taken in the thalweg profile (Subsection 6.5). Compass Bearings between cross section stations, along with the distance between stations, will allow us to estimate the sinuosity of the channel (ratio of the length of the reach divided by the straight line distance between the two reach ends).

Measure slope and bearing by "backsiting" upstream from cross-section station B to A, C to B, D to C, etc., down to the 11th cross section (Figure 6-1). To measure the slope and bearing between adjacent stations, use an Abney Level (or clinometer), and a bearing compass following the procedure presented in Table 6-4. Record data for slope and bearing in the Slope/Bearing/Distance section of the Channel/Riparian Transect Form (Figure 6-4).

It may be necessary to set up intermediate slope and bearing stations between the normal 11 stations if you do not have direct line-of-site along (and within) the channel between stations. This can happen if brush is too heavy or if there are tight meander bends or sharp slope breaks. To backsite upstream from supplemental stations, treat them just as you do a normal transect location in steps 1 to 6 of Table 6-4. Record supplemental slope, bearing, and distance backsites sequentially in the spaces provided on the field form.

6.6.2 Channel Margin Depth and Substrate

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

Channel margin depths are measured along the designated shoreline at each transect within the 10m swath of the 20m channel margin length that is centered on the transect location. Dominant and sub-dominant bottom substrates are determined and recorded at 5 systematically-spaced locations that are located by eye within the 10m x 20m plot. These methods are an adaptation of those used by the U.S.EPA for evaluating littoral substrates in lakes (Kaufmann and Whittier 1997), where the substrate size may be visually assessed or estimated by "feel" using the surveyors rod or PVC sounding tube in deep, turbid water. The procedure for obtaining channel margin depth and substrate measurements is described in more detail in Table 6-5. Record these measurements on the Channel/Riparian Transect Form as shown in Figure 6-4.

Table 6-4. Procedure for Obtaining Slope and Bearing Data.

1. Set eye-level flagging at upstream transect: Place flagging or mentally note a landmark at a standardized eye level along the shoreline at Transect A while doing shoreline measurements. To accomplish this, sit in the boat with your clinometer or Abney level held against your measuring rod at a comfortable, standardized height above the water surface (or designated place on bottom of boat). This shall be the same height you plan to use for all slope backsites from downstream. Site towards the nearby bank with the clinometer or Abney level indicating 0% slope. Note the level on the object sited and place flagging on it (optional). Accuracy of the clinometer measurements can be checked occasionally against a surveyors level.
2. Using the laser rangefinder, determine and record the intended location and distance of the next downstream Transect.
3. Float downstream (doing your thalweg profile measurements at 10 or 20 increments) to Transect B, where the next channel/riparian station is located.
4. Measure (w/ laser rangefinder) and record the distance back to the flagged upstream transect. (Note that, because of hazards and maneuvering problems, this distance may unavoidably differ from the "intended transect spacing" that is set at 4 (or 10) times the wetted width in the near vicinity of the furthest upstream transect (A).
5. Backsite the river gradient: While at the bank at Transect B, hold your Abney or clinometer at the same level on your measuring rod that you used at the previous station when you set up the eye-level flagging. Site back upstream at your flagging at Station A; read and record **percent** Slope on the field form. Be careful, the clinometer reads both percent slope and degrees of the slope angle. **Percent slope is the scale on the right hand side as you look through most clinometers. If using an Abney Level, insure that you are reading the scale marked "PERCENT."**
6. Backsite the compass bearing: From the bank at Station B, site back with your compass to the flagging you placed at Station A and record your compass bearing ("Azimuth"). It does not matter for these measurements whether or not you adjust your compass bearings for magnetic declination, but **it is important that you are consistent in the use of magnetic (unadjusted) or true (adjusted) bearings** throughout all the measurements you make on a given reach. Write on the field form which type of bearings you take. Also guard against recording "reciprocal" bearings (erroneous bearings 180 degrees from what they should be). The best way to do this is to know where the primary (cardinal) directions are in the field -- north (0 degrees), east (90 degrees), south (180 degrees), and west (270 degrees) -- and insure that your bearings "make sense."
7. Repeat step 1, setting your eye-level flagging at Transect B before floating down to a new downstream transect. Then repeat steps 2 through 7.

Again adapting methods developed for lake shorelines by Kaufmann and Whittier (1997), identify the dominant and subdominant substrate present along a shoreline swath 20 meters long and 1 meter back from the waterline. The substrate size class choices are as shown in Table 6-5.

6.6.3 Large Woody Debris

Methods for tallying large woody debris (LWD) are adapted from those described by Kaufmann and Robison (1998). This component of the EMAP Physical Habitat protocol allows estimates of the number, size, and total volume of large woody debris within the river reach. LWD is defined here as woody material with small end diameter of at least 30 cm (1ft) and length of at least 5 m (15 ft). These size criteria are larger than those used by Kaufmann and Robison (1998) in wadeable streams because of the lesser role that small wood plays in controlling velocity and morphology of larger rivers.

The procedure for tallying LWD is presented in Table 6-6. The tally includes all pieces of LWD that are at least partially in the baseflow channel (Wetted Channel). Sepa-

Table 6-5. Channel Margin Depth and Substrate Procedure.

1. If not already done, fill in the header information on page 1 of a Channel/Riparian Transect Form. Be sure to indicate the letter designating the transect location.

2. Measure depth and observe bottom substrates within a 10m swath along the 20m of the channel margin that is centered on each transect location.

3. Determine and record the depth and the dominant and subdominant substrate size class at 5 systematically-spaced locations estimated by eye within this 10m x 20m plot and 1m back from the waterline. **If the substrate particle is "artificial" (e.g. concrete or asphalt), choose the appropriate size class, flag the observation and note that it is artificial in the comment space.**

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

4. On page 1 of the Channel/Riparian Transect Form, circle the appropriate shore and bottom substrate type and record the depth measurements ("SONAR" or "POLE" columns).

5. Repeat Steps 1 through 4 at each new cross section transect.

rately tally wood that is presently dry but contained within the "Bankfull" or active channel (flood channel up to bankfull stage). Include wood that spans above the active channel or spanning above the active channel with the "Dry but within Bankfull" category. For each tally (Wetted Channel and Dry but within Bankfull), the field form (Figure 6-4) provides 12 entry boxes for tallying debris pieces visually estimated within three length and four diameter class combinations. Each LWD piece is tallied in only one box. Woody debris is not tallied in the area between channel cross sections, but the presence of large debris dams and accumulations should be mapped and noted in the comments.

For each LWD piece, first visually estimate its length and its large and small end diameters in order to place it in one of the diameter and length categories. The diameter classes on the field form (Figure 6-4) refer to the large end diameter. The diameter classes are 0.3m to <0.6m, 0.6m to <0.8m, and 0.8m to <1.0m and >1.0m. The length classes are 5m to <15m, 15m to <30m, and >30m. Sometimes LWD is not cylindrical, so it has no clear "diameter". In these cases visually estimate what the diameter would be for a piece of wood with circular cross section that would have the same volume. When evaluating length, include only the part of the LWD piece that has a diameter greater than 0.3m (1 ft).

Table 6-6. Procedure for Tallying Large Woody Debris.

Note: Tally pieces of large woody debris (LWD) within the 11 transects of the river reach at the same time the shoreline measurements are being determined. Include all pieces whose large end is located within the transect plot in the tally.

1. LWD in the active channel is tallied in 11 "plots" systematically spaced over the entire length of the stream reach. These plots are each 20 m long in the upstream-downstream direction. They are positioned along the chosen bank and extend from the shore in 10m towards mid-channel and then all the way to the bankfull margin.
2. Tally all LWD pieces within the plot that are at least partially within the baseflow channel. Also tally LWD that is dry but contained within the active channel. First, determine if a piece is large enough to be classified as LWD (small end diameter 30 cm [1 ft.]; length 5 m [15 ft.])
3. For each piece of LWD, determine its diameter class based on the diameter of the large end (0.3 m to < 0.6 m, 0.6 m to <0.8 m, 0.8 m to <1.0 m, or >1.0 m), and the length class of the LWD pieces based on the part of its length that has diameter 30 cm. Length classes are 5m to <15m, 15m to <30m, or >30m.
   - If the piece is not cylindrical, visually estimate what the diameter would be for a piece of wood with circular cross section that would have the same volume.
   - When estimating length, include only the part of the LWD piece that has a diameter greater than 0.3 m (1 ft.)
4. Place a tally mark in the appropriate diameter × length class tally box in the "WOOD All/Part in WETTED Channel" section of the Channel/Riparian Transect Form.
5. Tally all shoreline LWD pieces along the littoral plot that are at least partially within or above (bridging) the bankfull channel, but not in the wetted channel. For each piece, determine the diameter class based on the diameter of the large end (0.3 m to < 0.6 m, 0.6 m to <0.8 m, 0.8 m to <1.0 m, or >1.0 m), and the length class based on the length of the piece that has diameter 30 cm. Length classes are 5m to <15m, 15m to <30m, or >30m.
6. Place a tally mark for each piece in the appropriate diameter × length class tally box in the "DRY BUT ALL/PART IN Bankfull Channel" section of the Channel/Riparian Transect Form.
7. After all pieces within the segment have been tallied, write the total number of pieces for each diameter × length class in the small box at the lower right-hand corner of each tally box.
8. Repeat Steps 1 through 7 for the next river transect, using a new Channel/Riparian Transect Form.

Count each of the LWD pieces as one tally entry and include the whole piece when assessing dimensions, even if part of it is outside of the bankfull channel. If you encounter massive, complex debris jams, estimate their length, width, and height. Also estimate the diameter and length of large "key" pieces and judge the average diameter and length of the other pieces making up the jam. Record this information in the comments section of the form.

6.6.4 Bank Angle and Channel Cross-Section Morphology

Undercut, vertical, steep, and gradual bank angles are visually estimated as defined on the field form (Figure 6-4). Observations are made from the wetted channel margin up 5 m (a canoe's length) into the bankfull channel margin on the previously chosen side of the stream.

The channel dimensions to be measured or estimated are the wetted width, mid-channel bar width, bankfull height and width, the amount of incision, and the degree of channel constraint. These shall be assessed for the whole channel (left and right banks) at each of the 11 cross section transects. Each are recorded on the Channel/Riparian Transect Form (Figure 6-4). The procedure for obtaining bank angle and channel cross-section morphology measurements is presented in Table 6-7.

Table 6-7. Procedure for Bank Angle and Channel Cross-Section.

1. Visually estimate the bank angle (undercut, vertical, steep, gradual), as defined on the field form. Bank angle observations refer to the area from the wetted channel margin up 5 m (a canoe's length) into the bankfull channel margin on the **previously chosen side of the river**. Circle the range within which the observed band angle falls on the "Bank CHARACTERISTIC" section of the Channel/ Riparian Transect Field Form.
2. With a laser rangefinder at a cross-section transect, measure and record the **wetted width** value in the "Wetted Width" field in the bank characteristics section of the field data form. Also determine the **bankfull channel width** and the **width of exposed mid-channel bars (if present)** with the laser rangefinder and surveyor's rod. Record these values in the "Bank CHARACTERISTIC" section of the field data form.
3. To estimate bankfull height, hold the surveyor's rod vertical, with its base planted at the water's edge. Using the rod as a guide while examining both banks, estimate (by eye) the <u>height of bankfull flow above the present water level.</u> Look for evidence on one or both banks such as:
   - An obvious slope break that differentiates the channel from a relatively flat floodplain terrace higher than the channel.
   - A transition from exposed river sediments to terrestrial vegetation.
   - A transition from sorted river sediments to unsorted terrestrial soils.
   - Transition from bare rock to moss growth on rocks along the banks.
   - Presence of drift material caught on overhanging vegetation.
   - Transition from flood- and scour-tolerant vegetation to that which is relatively intolerant of these conditions.
4. Hold the surveyor's rod vertical, with its base planted at the water's edge. Using the surveyor's rod as a guide while examining both banks, estimate (by eye) the channel <u>incision as</u> the **height up from the water surface to the elevation of the first terrace of the valley floodplain** (Note this is at or above the bankfull channel height). Record this value in the "Incised Height" field of the Bank Characteristic section on the field data form.
5. Repeat Steps 1 through 4 at each cross-section transect. Record data for each transect on a separate field data form.

Wetted width refers to the width of the channel as defined by the presence of free-standing water; if greater than 15m, it can be measured with the laser range finder. Mid-channel bar width, the width of exposed mid-channel gravel or sand bars in the channel, is included within the wetted width, but is also recorded separately. In channel cross-section measurements, the wetted and active channel boundaries are considered to include mid-channel bars. Therefore, the wetted width shall be measured as the distance between wetted left and right banks. It is measured across and over mid-channel bars and boulders. If islands are present, treat them like bars, but flag these measurements and indicate in the comments that the "bar" is an island. If you are unable to see across the full width of the river when an island separates a side channel from the main channel, record the width of the main channel, flag the observation, and note in the comments section that the width pertains only to the main channel.

Bankfull height and width shall be estimated with the aid of the surveyor's rod and laser range finder. The "bankfull" or "active" channel is defined as the channel that is filled by moderate sized flood events that fill the channel to its flood banks. Measure bankfull width over and across mid-channel bars. Bankfull flows typically recur every 1 to 2 years and do not generally overtop the channel banks to inundate the valley floodplain. They are believed to be largely responsible for the observed channel dimensions in most rivers and streams. If the channel is not greatly incised, bankfull channel height and the amount of incision will be the same. However, if the channel is incised greatly, the bankfull level will be below the level of the first terrace of the valley floodplain, making "Bankfull Height" smaller than "Incision" (Figure 6-6). You will need to look for evidence of recent flows (within about 1 year) to distinguish bankfull and incision heights, though recent flooding of extraordinary magnitude may be misleading.

Estimating the level of bankfull flow during baseflow conditions requires judgement and practice; even then it remains somewhat subjective. In many cases there is an obvious slope break that differentiates the channel from a relatively flat floodplain terrace higher than the channel. Because scouring and inundation from bankfull flows are often frequent enough to inhibit many types of terrestrial vegetation, the bankfull channel may be evident by a transition from exposed river sediments and water-loving plants to upland ter-

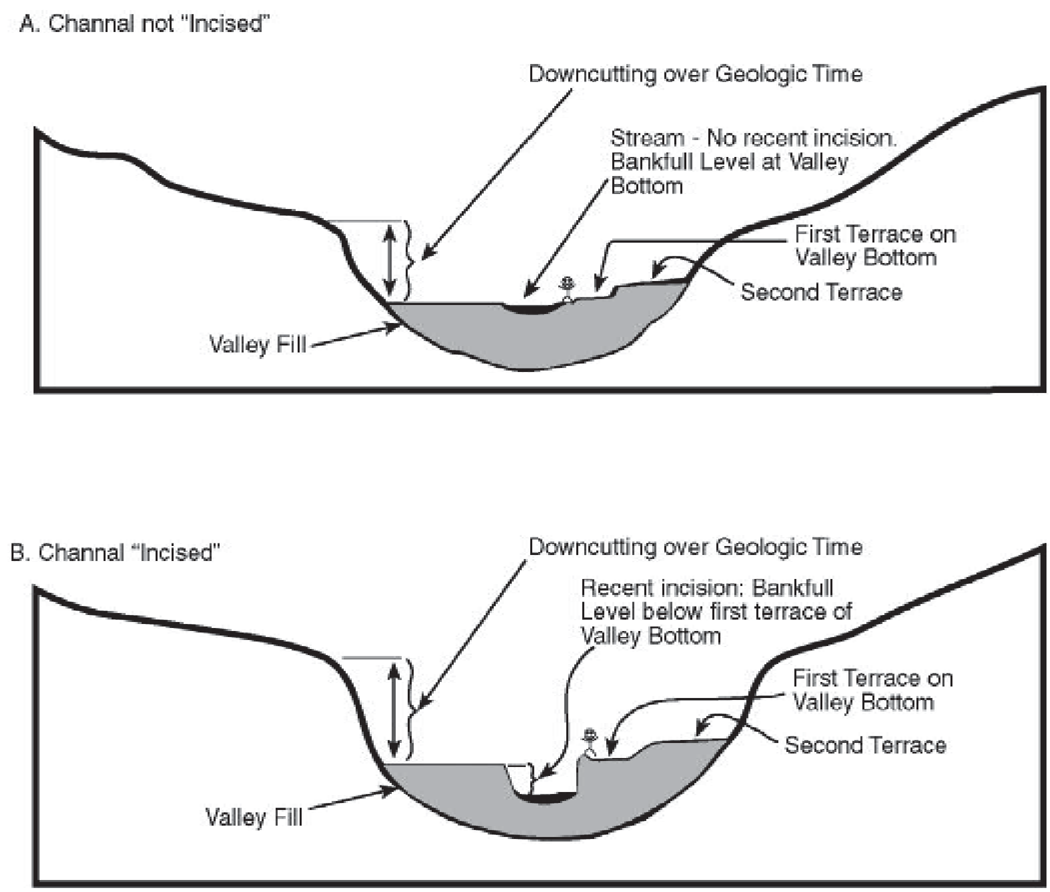


Figure 6-6. Schematic showing bankfull channel and incision for channels. (A) not recently incised, and (B) recently incised into valley bottom. Note level of bankfull stage relative to elevation of first terrace on valley bottom (Stick figure included for scale).

restrial vegetation. Similarly, it may be identified by noting where moss growth on rocks along the banks has been removed by flooding. The bankfull flow level may also be seen by the presence of drift material caught on overhanging vegetation.

As described in Table 6-7 and shown in Figure 6-6, examine both banks and estimate (by eye) the amount of channel incision from the water surface to the elevation of the first terrace of the valley floodplain. In cases where the channel is cutting a valley sideslope and has oversteepened and destabilized that slope, the bare "cutbank" is not necessarily an indication of recent incision. Examine both banks to make a more accurate determination of channel downcutting. Finally, assess the degree of river channel constraint by answering the four questions on the form (Figure 6-5) regarding the relationships among channel incision, valley sideslope, and width of the valley floodplain.

6.6.5 Canopy Cover (Densiometer)

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

Vegetative cover over the river margin shall be measured at the chosen bank at each of the 11 transect locations (A-K). This measurement employs the Convex Spherical Densiometer, model B (Lemmon, 1957). The densiometer must be taped exactly as shown in Figure 6-7 to limit the number of square grid intersections to 17. Densiometer readings can range from 0 (no canopy cover) to 17 (maximum canopy cover). Four measurements are obtained at each cross-section transect (upriver, downriver, left, and right). Concentrate on the 17 points of grid intersection on the densiometer. If the reflection of a tree or high branch or leaf overlies any of the intersection points, that particular intersection is counted as having cover. The measure to be recorded on the form is the count (from 0 to 17) of all the intersections that have vegetation covering them. Therefore, a higher number indicates greater canopy extent and density. In making this measurement, it is important that the densiometer be leveled using the bubble level (Figure 6-7).

The procedure for obtaining canopy cover data is presented in Table 6-8. These bank densiometer readings complement your visual estimates of vegetation structure and cover within the riparian zone (Section 6.6.6). For each of the four directions, count the number of covered densiometer intersection points. Record these counts in the "Canopy Density @ Bank" section of the Channel/Riparian Transect Form as shown in Figure 6-4.

6.6.6 Riparian Vegetation Structure

The previous section (6.6.5) described methods for quantifying the cover of canopy over the river margin. The following visual estimation procedures, adapted from Kaufmann and Robison (1998), are a semi-quantitative evaluation of riparian vegetation structure, the type and amount of different types of riparian vegetation. These field characterizations shall be used to supplement interpretations of riparian vegetation from aerial photos and satellite imagery. Together, they

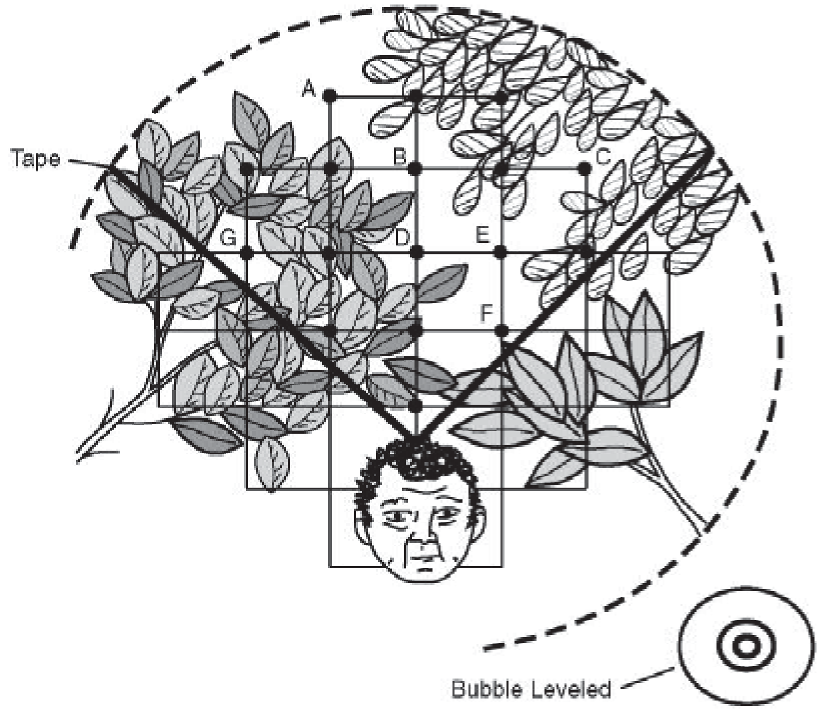


Figure 6-7. Schematic of modified convex spherical canopy densiometer (From Mulvey et al., 1992). In this example, 10 of the 17 intersections show canopy cover, giving a densiometer reading of 10. Note proper positioning with the bubble leveled and face reflected at the apex of the "V".

Table 6-8. Procedure for Canopy Cover Measurements.

1. Take densiometer readings at a cross-section transect while anchored or tied up at the river margin.
2. Hold the densiometer 0.3 m (1 ft) above the surface of the river. Holding the densiometer level using the bubble level, move it in front of you so your face is just below the apex of the taped "V".
3. At the channel margin measurement locations, count the number of grid intersection points within the "V" that are covered by either a tree, a leaf, a high branch, or the bank itself.
4. Take 1 reading each facing upstream (UP), downstream (DOWN), left bank (LEFT), and right bank (RIGHT). Right and left banks are defined with reference to an observer facing downstream.
5. Record the UP, DOWN, LEFT, and RIGHT values (0 to 17) in the "CANOPY COVER @ BANK" section of the Channel/Riparian Transect Form.
6. Repeat Steps 1 through 5 at each cross-section transect. Record data for each transect on a separate field data form.

are used to evaluate the health and level of disturbance of the river/riparian corridor. They also indicate the present and future potential for various types of organic inputs and shading. The cover and structure of riparian vegetation is estimated in three riparian layers within 10m x 20m plots along the river shoreline that are centered on the transect location with boundaries estimated by eye. As employed by Allen-Gill (unpublished manuscript), these plots shall be set back from the channel so that they describe vegetation above bankfull flow. As a result, gravel bars within the bankfull channel are not included in the vegetation plot (Figure 6-2).

Observations to assess riparian vegetation apply to the riparian area upstream 10 meters and downstream 10 meters from each of the 11 cross-section stations (Figure 6-2). They include the visible area from the river bankfull margin back a distance of 10m (30 ft) shoreward from both the left and right banks, creating a 10m X 20m riparian plot on each side of the river (Figure 6-2). The riparian plot dimensions are estimated, not measured. On steeply sloping channel margins, the 10m X 20m 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 shall be for each side of the channel, not the bar. If an island obscures the far bank of the main channel, assess riparian vegetation on the bank of the island.

Table 6-9 presents the procedure for characterizing riparian vegetation structure and composition. Figure 6-5 illustrates how measurement data are recorded in the "Visual Riparian Estimates" section of the field form. Conceptually divide the riparian vegetation into three layers: a CANOPY LAYER (>5m high), an UNDERSTORY (0.5 to 5m high), and a GROUND COVER layer (<0.5 high). Note that several vegetation types (eg. grasses or woody shrubs) can potentially occur in more than one layer. Similarly note that some things other than vegetation are possible entries for the "Ground Cover" layer (eg. barren ground and duff, which includes fallen leaves, needles and twigs).

Before estimating the areal coverage of the vegetation layers, record the type of vegetation (**D**eciduous, **C**oniferous, Broadleaf **E**vergreen **M**ixed, or **N**one) in each of the two taller layers (Canopy and Understory). Consider the layer "Mixed" if more than 10% of the areal coverage is made up of the alternate vegetation type.

You will estimate the areal cover separately in each of the three vegetation layers. Note that the areal cover can be thought of as the amount of shadow cast by a particular layer alone when the sun is directly overhead. The maximum cover in each layer is 100%, so the sum of the areal covers for the combined three layers could add up to 300%. The four entry choices for areal cover within each of the three vegetation layers are "0" (absent: zero cover), "1" (sparse: <10%), "2" (moderate: 10-40%), "3" (heavy: 40-75%), and "4" (very heavy: >75%). These ranges of percentage areal cover corresponding to each of these codes are also shown on the Field Form. When rating vegetation cover types, mixtures of two or more subdominant classes might all be given sparse ("1") moderate ("2") or heavy ("3") ratings. One very heavy cover class with no clear subdominant class might be rated "4" with all the remaining classes either moderate ("2"), sparse ("1") or absent ("0"). Two heavy classes with 40-75% cover can both be rated "3".

As an additional assessment of the "old growth" character of riparian zones, search for the largest riparian tree visible on either side of the river from the littoral-riparian station. Identify if possible the species or the taxonomic group of this tree and estimate its height, diameter (Dbh), and distance from the wetted river margin.

6.6.7 Fish Cover, Algae, Aquatic Macrophytes

This portion of the EMAP physical habitat protocol is a visual estimation procedure modified from methods developed for lake shorelines (Kaufmann and Whittier 1997) and for wadeable streams (Kaufmann and Robison 1998). The aim is to evaluate, semi-quantitatively, the type and amount of important types of cover for fish and macroinvertebrates. Over

Table 6-9. Procedure For Characterizing Riparian Vegetation Structure.

1. Anchor or tie up at the river margin at a cross-section transect; then make the following observations to characterize riparian vegetation structure.

2. Estimate the distance from the shore to the riparian vegetation plot; record it just below the title "Channel Constraint" on the field form.

3. Facing the left bank (left as you face downstream), estimate a distance of 10 m back into the riparian vegetation, beginning at the bankfull channel margin. Estimate the cover and structure of riparian vegetation in 3 riparian layers along the river shoreline within an estimated 10m x 20m plot centered on the transect, and beginning at the bankfull river margin along the river shoreline.

   - On steeply-sloping channel margins, estimate the distance into the riparian zone as if it were projected down from an aerial view.

4. Within this 10 m × 20 m area, conceptually divide the riparian vegetation into three layers: a CANOPY LAYER (>5m high), an UNDERSTORY (0.5 to 5 m high), and a GROUND COVER layer (<0.5 m high).

5. Within this 10 m × 20 m area, determine the dominant vegetation type for the CANOPY LAYER (vegetation > 5 m high) as either Deciduous, Coniferous, broadleaf Evergreen, Mixed, or None. Consider the layer "Mixed" if more than 10% of the areal coverage is made up of the alternate vegetation type. Indicate the appropriate vegetation type in the "Visual Riparian Estimates" section of the Channel/Riparian Cross-section and Thalweg Profile Form.

6. Determine separately the areal cover class of large trees (> 0.3 m [1 ft] diameter at breast height [DBH]) and small trees (< 0.3 m DBH) within the canopy layer. Estimate areal cover as the amount of shadow that would be cast by a particular layer alone if the sun were directly overhead. Record the appropriate cover class on the field data form ("0"=absent: zero cover, "1"=sparse: <10%, "2"=moderate: 10-40%, "3"=heavy: 40-75%, or "4"=very heavy: >75%).

7. Look at the UNDERSTORY layer (vegetation between 0.5 and 5 m high). Determine the dominant vegetation type for the understory layer as described in Step 5 for the canopy layer.

8. Determine the areal cover class for woody shrubs and saplings separately from non-woody vegetation within the understory, as described in Step 6 for the canopy layer.

9. Look at the GROUND COVER layer (vegetation < 0.5 m high). Determine the areal cover class for woody shrubs and seedlings, non-woody vegetation, and the amount of bare ground present as described in Step 6 for large canopy trees.

10. Repeat Steps 1 through 9 for the opposite bank.

11. Repeat Steps 1 through 10 for all cross-section transects, using a separate field data form for each transect.

a defined length and distance from shore at 11 systematically spaced plot locations, crews shall estimate by eye and by sounding the proportional cover of fish cover features and trophic level indicators including large woody debris, rootwads and snags, brush, undercut banks, overhanging vegetation, rock ledges, aquatic macrophytes, filamentous algae, and artificial structures. Alone and in combination with other metrics, this information is used to assess habitat complexity, fish cover, and channel disturbance.

The procedure to estimate the types and amounts of fish cover is outlined in Table 6-10. Data are recorded in the "Fish Cover/ Other" section of the Channel/Riparian Transect Form as shown in Figure 6-5. Crews will estimate the areal cover of all of the fish cover and other listed features that are in the water and on the banks within the 10m x 20m plot (refer to Figure 6-2).

Observations to assess fish cover and several other in-channel features apply to a 10 m x 20 m inundated area adjacent to the selected bank extending 10 m out from the channel margin, and then upstream 10 m and downstream 10 m from each of the 11 transect cross-sections (Figure 6-2). These plot dimensions are estimated by eye. The ranges of percentage areal cover corresponding to each of these codes are the same as for riparian vegetation cover (Section 6.6.6) and are also shown on the Field Form.

Table 6-10. Procedure For Estimating Fish Cover.

1. Stop at the designated shoreline at a cross-section transect and estimate a 10m distance upstream and downstream (20m total length), and a 10m distance out from the banks to define a 20m x 10m littoral plot.
2. Examine the water and the banks within the 20m x 10m littoral plot for the following features and types of fish cover: filamentous algae, aquatic macrophytes, large woody debris, brush and small woody debris, overhanging vegetation, undercut banks, boulders, and artificial structures.
3. For each cover type, estimate its areal cover by eye and/or by sounding with a pole. Record the appropriate cover class in the "Fish Cover/Other" section of the Channel/ Riparian Transect Form ("0"=absent: zero cover, "1"=sparse: <10%, "2"=moderate: 10-40%, "3"=heavy: 40-75%, or "4"=very heavy: >75%).
4. Repeat Steps 1 through 3 at each cross-section transect, recording data from each transect on a separate field data form.

Filamentous algae pertains to long streaming algae that often occur in slow moving waters. Aquatic macrophytes are water loving plants in the river, including mosses, that could provide cover for fish or macroinvertebrates. If the river channel contains live wetland grasses, include these as macrophytes. Woody debris includes the larger pieces of wood that can provide cover and influence river morphology (i.e., those pieces that would be included in the large woody debris tally [Section 6.6.3]). Brush/ woody debris pertains to the smaller wood that primarily affects cover but not morphology. The entry for trees or brush within one meter above the water surface is the amount of brush, twigs, small debris etc. that is not in the water but is close to the river and provides cover. Boulders are typically basketball to car sized particles. Many streams contain artificial structures designed for fish habitat enhancement. Streams may also have in-channel structures discarded (e.g. cars or tires) or purposefully placed for diversion, impoundment, channel stabilization, or other purposes. Record the cover of these structures on the form.

6.6.8 Human Influences

Field characterization of the presence and proximity of various important types of human activities, disturbances, and land use in the river riparian area is adapted from methods developed by Kaufmann and Robison (1998) for wadeable streams. This information shall be used in combination with riparian and watershed landuse information from aerial photos and satellite imagery to assess the potential degree of disturbance of the sample river reaches.

For the left and right banks at each of the 11 detailed Channel/Riparian Cross-Sections, evaluate the presence/absence and the proximity of 11 categories of human influences outlined in Table 6-11. Confine your observations to the river and riparian area within 10m upstream and 10m downstream from the cross-section transect (Figure 6-2). Four proximity classes are used: On the riverbank within 10m upriver or downriver of the cross-section transect, present within the 10m x 20m riparian plot, present outside of the riparian plot, and not present. Record human influences on the Channel/Riparian Transect Form (Figure 6-5).

You may mark "P" more than once for the same human influence observed outside of more than one riparian observation plot (e.g. at both Transect D and E). The rule is that you count human disturbance items as often as you see them, BUT NOT IF you have to site through a previously counted transect or its 10x20m riparian plot.

6.7 Summary of Workflow

Table 6-12 lists the activities performed at and between each transect for the physical habitat characterization. The activities are performed along the chosen river bank and mid-channel (thalweg profile).

6.8 Equipment and Supplies

Figure 6-8 lists the equipment and supplies required to conduct all the activities described for characterizing physical habitat. This checklist is similar to the checklist presented in Appendix A, which is used at the base location (Section 3) to ensure that all of the required equipment is brought to the river. Use this checklist to ensure that equipment and supplies are organized and available at

Table 6-11. Procedure for Estimating Human Influence.

1. Stop at the designated shoreline at a cross-section transect, look toward the left bank (left when facing downstream), and estimate a 10m distance upstream and downstream (20m total length). Also, estimate a distance of 10m back into the riparian zone to define a riparian plot area.
2. Examine the channel, bank and riparian plot area adjacent to the defined river segment for the following human influences: (1) walls, dikes, revetments, riprap, and dams; (2) buildings; (3) pavement (e.g., parking lot, foundation); (4) roads or railroads, (5) inlet or outlet pipes; (6) landfills or trash (e.g., cans, bottles, trash heaps); (7) parks or maintained lawns; (8) row crops; (9) pastures, rangeland, or hay fields; (10) logging; and (11) mining (including gravel mining).
3. For each type of influence, determine if it is present and what its proximity is to the river and riparian plot area. Consider human disturbance items as present if you can see them from the cross-section transect. Do not include them if you have to site through another transect or its 10m × 20m riparian plot.
4. For each type of influence, record the appropriate proximity class in the "Human Influence" part of the "Visual Riparian Estimates" section of the Channel/Riparian Transect Form. Proximity classes are:
   - B ("Bank") Present within the defined 20m river segment and located in the stream or on the wetted or bankfull bank.
   - C ("Close") Present within the 10 × 20m riparian plot area, but above the bankfull level.
   - P ("Present") Present, but observed outside the riparian plot area.
   - O ("Absent") Not present within or adjacent to the 20m river segment or the riparian plot area at the transect
5. Repeat Steps 1 through 4 for the opposite bank.
6. Repeat Steps 1 through 5 for each cross-section transect, recording data for each transect on a separate field form.

Table 6-12. Summary of Workflow - River Physical Habitat Characterization.

A. At the chosen bank on first transect (farthest upstream):

1. Move boat in a "loop" within 10 x 20 meter littoral plot, measuring five littoral depths and probing substrate.
2. Estimate dominant and subdominant littoral substrate, based on probing the five locations.
3. Estimate areal cover of fish concealment features in 10 x 20 meter littoral plot.
4. Tally LWD within or partially within the 10 x 20 meter littoral plot.
5. Measure water conductivity and temperature.
6. Do densiometer measurements at bank (facing upstream, downstream, left, right).
7. Choose bank angle class, estimate bankfull height, width and channel incision. (Note that width and incision estimates incorporate both left and right banks.).
8. Tally LWD entirely out of water but at least partially within the bankfull channel.
9. Estimate and record distance to riparian vegetation on the chosen bank.
10. Make visual riparian vegetation cover estimates for the 10 x 20 meter riparian plot on both sides of the channel. (Note that riparian plot starts at bankfull and continues back 10m away from the bankfull line).
11. Identify species, height, Dbh, and distance from riverbank of largest riparian tree within your vision.
12. Make visual human disturbance tally. It has the same plot dimensions as the riparian vegetation -- except if a disturbance item is observed in the river or within the bankfull channel, then the proximity code is "B", the closest rating. Disturbances within the plot get a rating of "C"; those visible beyond the plot are rated "P".
13. Siting clinometer level (0%) towards the near or far bank at the current transect, mark or remember an eye-level point to which you will be siting when backsiting from the next downstream transect.
14. Get out far enough from the bank so you can see downstream. Then use the laser rangefinder to site and record the distance to the intended position of the next downstream transect.

B. Thalweg Profile:

1. As soon as you get out from the bank after doing transect activities, take the first of 20 thalweg depth measurements and substrate/snag probes using sonar and pole -- also classify habitat type.
2. Estimate thalweg measurement distance increments by keeping track of boat lengths or channel-width distances traversed; each increment is 1/10th (or 1/20th) the distance between transects.
3. At the 20th thalweg measurement location, you are one increment upstream of the next transect. Backsite compass bearing mid-channel, then measure the distance and % slope back to your visual "mark" on the bank at the previous transect.

C. Repeat the Whole Process (for the remaining 10 transects and spaces in between).

the river site in order to conduct the activities efficiently.

6.9 Literature Cited

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Equipment and Supplies for Physical Habitat		
Qty.	Item	
1	Surveyor's telescoping leveling rod (round profile, fiberglass, metric scale, 7.5m extended)	
1	Clinometer (or Abney level) with percent and degree scales.	
1	Convex spherical canopy densiometer (Lemmon Model B), modified with taped "V"	
1	Bearing compass (Backpacking type)	
1 roll ea.	Colored surveyor's plastic flagging (2 colors)	
2	Covered clipboards (lightweight, with strap or lanyard to hang around neck)	
	Soft (#2) lead pencils (mechanical are acceptable)	
2 pair	Chest waders with felt-soled boots for safety and speed if waders are the neoprene "stocking" type	
1	Camera - waterproof 35mm with standard and wide angle lens	
	Film - 35mm color slide film, ASA 400 and 100	
1	Fiberglass Tape and reel (50m metric) with good hand crank and handle	
1	SONAR depth sounder - narrow beam (16 degrees)	
1	Laser rangefinder - 400 ft. distance range - and clear waterproof bag	
11 plus extras	Channel/Riparian Transect Forms	
11 plus extras	Thalweg Profile Forms	
1 copy	Field operations and methods manual	
1 set	Laminated sheets of procedure tables and/or quick reference guides for physical habitat characterization	

Figure 6-8. Checklist of equipment and supplies for physical habitat

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

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

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

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

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

7.1 COMPONENTS OF THE HABITAT CHARACTERIZATION

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

TABLE 7-1. COMPONENTS OF PHYSICAL HABITAT CHARACTERIZATION

Component	Description
Thalweg Profile: (Section 7.4.1)	• Measure maximum depth, classify habitat and pool-forming features, and determine presence of soft sediment at 10-15 equally spaced intervals between each of 11 channel cross-section transects (100 or 150 individual measurements along entire reach). • Measure wetted width at 11 channel cross-section transects and midway between them (21 measurements).
Woody Debris Tally: (Section 7.4.2)	• Between each of the channel cross sections, tally large woody debris numbers within and above the bankfull channel according to length and diameter classes (10 separate tallies).
Channel and Riparian Characterization: (Section 7.5)	• At 11 cross-section transects placed at equal intervals along reach length: - Measure: channel cross section dimensions, bank height, bank undercut distance, bank angle, slope and compass bearing (backsite), and riparian canopy density (densiometer). - Visually Estimate[a]: substrate size class and embeddedness; areal cover class and type (e.g., woody trees) of riparian vegetation in Canopy, Mid-Layer and Ground Cover; areal cover class of fish concealment features, aquatic macrophytes and filamentous algae. - Observe & Record[a]: human disturbances and their proximity to the channel.
Discharge: (see Section 6)	• In medium and large streams (defined in Section 6) measure water depth and velocity at 0.6 depth at 15 to 20 equally spaced intervals across one carefully chosen channel cross-section. • In very small streams, measure discharge by timing the filling of a bucket or timing the passage of a neutral buoyant object through a segment whose cross-sectional area has been estimated.

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

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

7.2 HABITAT SAMPLING LOCATIONS WITHIN THE SAMPLING REACH

Measurements are made at two scales of resolution along the length of the reach; the results are later aggregated and expressed for the entire reach, a third level of resolution. Figure 7-1 illustrates the locations within the sampling reach where data for the different components of the physical habitat characterization are obtained. We assess habitat over stream reach lengths that are approximately 40 times their average wetted width at base-flow, but not less than 150 m long. This allows us to adjust the sample reach length to accommodate varying sizes of streams (see Section 2). Many of the channel and riparian features are characterized on 11 cross-sections and pairs of riparian plots spaced at 4 channel-width intervals. The thalweg profile measurements must be spaced evenly over the entire sampling reach. In addition, they must be sufficiently close together that they do not "miss" deep areas and habitat units that are in a size range of about a to ½ of the average channel width. Follow these specifications for choosing the interval between thalweg profile measurements:

! **Channel Width < 2.5 m — interval = 1.0 m**
! **Channel Width 2.5-3.5 m — interval = 1.5 m**
! **Channel Width > 3.5 m — interval = 0.01 × (reach length)**

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

7.3 LOGISTICS AND WORK FLOW

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

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

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

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

2. <u>Channel/Riparian Cross-Sections (Section 7.5)</u>. One person proceeds with the channel cross-section dimension, substrate, bank, and canopy cover measurements. The second person records those measurements on the Channel/Riparian Cross-section and Thalweg Profile Form while making visual estimates of riparian vegetation structure, instream fish cover, and human disturbance specified on that form. Slope and bearing are determined together by backsiting to the previous transect. Intermediate flagging (of a different color) may have to be used if the stream is extremely brushy, sinuous, or steep to the point that you cannot site for slope and bearing measures between two adjacent transects. (Note that the crews could tally woody debris while doing the backsite, rather than during the thalweg profile measurements.)

3. <u>Discharge (Section 6)</u>. Discharge measurements are made after collecting the chemistry sample. They are done at a chosen optimal cross section (but not necessarily at a transect) near the X-site. However, do not use the electromagnetic current meter close to where electrofishing is taking place. Furthermore, if a lot of channel disruption is necessary and sediment must be stirred up, wait on this activity until all chemical and biological sampling has been completed.

7.4 THALWEG PROFILE AND LARGE WOODY DEBRIS MEASUREMENTS

7.4.1 Thalweg Profile

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

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

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

TABLE 7-2. THALWEG PROFILE PROCEDURE

1. Determine the interval between measurement stations based on the wetted width used to determine the length of the sampling reach.

   For widths < 2.5 m, establish stations every 1 m.
   For widths between 2.5 and 3.5 m, establish stations every 1.5 m
   For widths > 3.5 m, establish stations at increments equal to 0.01 times the sampling reach length.

2. Complete the header information on the thalweg profile and woody debris section of a Channel/Riparian Cross-section and Thalweg Profile Form, noting the transect pair (downstream to upstream). Record the interval distance determined in Step 1 in the "INCREMENT" field on the field data form.

   - NOTE: If a side channel is present, and contains between 16 and 49% of the total flow, establish secondary cross-section transects and thalweg measurement stations as necessary. Use separate field data forms to record data for the side channel, and designate each secondary transect as "X" followed by the primary transect letter (e.g., XA, XB, etc.). Collect all channel and riparian cross-section measurements from the side channel.

3. Begin at the downstream end (station "0") of the first transect 9Transect "A").

4. Measure the wetted width if you are at station "0", station "5" (if the stream width defining the reach length is • 2.5 m), or station "7" (if the stream width defining the reach length is < 2.5 m). Wetted width is measured across and over mid-channel bars and boulders. Record the width on the field data form to the nearest 0.1 m for widths up to about 3 meters, and to the nearest 5% for widths > 3 m. This is 0.2 m for widths of 4 to 6 m, 0.3 m for widths of 7 to 8 m, and 0.5 m for widths of 9 or 10 m, and so on. For dry and intermittent streams, where no water is in the channel, record zeros for wetted width.

   - NOTE: If a mid-channel bar is present at a station where wetted width is measured, measure the bar width and record it on the field data form.

5. At each thalweg profile station, use a meter ruler or a calibrated pole or rod to locate the deepest point (the "thalweg"), which may not always be located at mid-channel. Measure the thalweg depth to the nearest cm, and record it on the thalweg profile form. <u>Read the depth on the side of the ruler, rod, or pole</u> to avoid inaccuracies due to the wave formed by the rod in moving water.

   - NOTE: For dry and intermittent streams, where no water is in the channel, record zeros for depth.

   - NOTE: At stations where the thalweg is too deep to measure directly, stand in shallower water and extend the surveyor's rod or calibrated rod or pole at an angle to reach the thalweg. Determine the rod angle using the external scale of the clinometer. Leave the depth reading for the station blank, and record a "U" flag. Record the water level on the rod and the rod angle in the comments section of the field data form.

(continued)

TABLE 7-2 (Continued)

6. At the point where the thalweg depth is determined, observe whether small, loose, soft sediments are present directly beneath your ruler, rod, or pole. Soft/small sediments are defined here as fine gravel, sand, silt, clay or muck readily apparent by "feeling" the bottom with the staff. Record presence or absence in the “SOFT/SMALL SEDIMENT” field on the field data form.

7. Determine the channel unit code and pool forming element codes for the station. Record these on the field data form using the standard codes provided. For dry and intermittent streams, where no water is in the channel, record habitat type as dry channel (DR).

8. If the station cross-section intersects a mid-channel bar, Indicate the presence of the bar in the “BAR WIDTH” field on the field data form.

9. Record the presence or absence of a side channel at the station’s cross-section in the “SIDE CHANNEL” field on the field data form.

10. Proceed upstream to the next station, and repeat Steps 4 through 9.

11. Repeat Steps 4 through 10 until you reach the next transect. Prepare a new Channel/Riparian Cross-section and Thalweg Profile Form, then repeat Steps 2 through 10 for each of the reach segments, until you reach the upstream end of the sampling reach (Transect “K”).

Reviewed by (initial): JP

PHab: THALWEG PROFILE & WOODY DEBRIS FORM - STREAMS

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(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 Width[1] X	Bar Width[1] (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: Length 1.5 - 5 m	Pieces All/Part in Bankfull Channel: 5 - 15 m	Pieces All/Part in Bankfull Channel: > 15 m	Pieces Bridge Above Bankfull Channel: Length 1.5 - 5 m	Pieces Bridge Above Bankfull Channel: 5 - 15 m	Pieces Bridge Above Bankfull Channel: > 15 m
0.1 to <0.3 m	卌 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

Code	Description
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

Code	Description
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 7-2. Thalweg Profile and Woody Debris Form.

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

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

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

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

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

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

Channel Unit Habitat Classes[a]

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 the center of the stream
Lateral Scour Pool (PL)	Pool scoured along a bank.
Backwater Pool (PB)	Pool separated from main flow off the side of the channel.
Impoundment Pool (PD)	Pool formed by impoundment above dam or constriction.
Pool (P)	Pool (unspecified type).
Glide (GL)	Water moving slowly, with a 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 is broken in short, irregular plunges, mostly whitewater. Sound: roaring.
Falls (FA)	Free falling water over a vertical or near vertical drop into plunge, water turbulent and white over high falls. Sound: from splash to roar.
Dry Channel (DR)	No water in the channel

(continued)

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

TABLE 7-3 (Continued)

Categories of Pool-forming Elements[b]

Code	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 (describe in the comments section of field form)

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

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

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

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

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

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

7.4.2 Large Woody Debris Tally

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

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

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

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

TABLE 7-4. PROCEDURE FOR TALLYING LARGE WOODY DEBRIS

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

1. Scan the stream segment between the two cross-section transects where thalweg profile measurements are being made.

2. Tally all LWD pieces within the segment that are at least partially within the bankfull channel. Determine if a piece is LWD (**small end diameter • 10 cm [4 in.]; length • 1.5 m [5 ft.]**)

3. For each piece of LWD, determine the class **based on the diameter of the large end** (0.1 m to < 0.3 m, 0.3 m to <0.6 m, 0.6 m to <0.8 m, or >0.8 m, and the class based on the length of the piece (1.5m to <5.0m, 5m to <15m, or >15m).

    - If the piece is not cylindrical, visually estimate what the diameter would be for a piece of wood with circular cross section that would have the same volume.
    - When estimating length, include only the part of the LWD piece that has a diameter greater than 10 cm (4 in)

4. Place a tally mark in the appropriate diameter × length class tally box in the "PIECES ALL/PART IN BANKFULL CHANNEL" section of the Thalweg Profile and Woody Debris Form.

5. Tally all LWD pieces within the segment that are not actually within the bankfull channel, but are at least partially spanning (bridging) the bankfull channel. For each piece, determine the class based on the diameter of the **large end** (0.1 m to < 0.3 m, 0.3 m to <0.6 m, 0.6 m to <0.8 m, or >0.8 m), and the class based on the length of the piece (1.5 m to <5.0 m, 5 m to <15 m, or >15 m).

6. Place a tally mark for each piece in the appropriate diameter × length class tally box in the "PIECES BRIDGE ABOVE BANKFULL CHANNEL" section of the Thalweg Profile and Woody Debris Form.

7. After all pieces within the segment have been tallied, write the total number of pieces for each diameter × length class in the small box at the lower right-hand corner of each tally box.

8. Repeat Steps 1 through 7 for the next stream segment, using a new Thalweg Profile and Woody Debris Form.

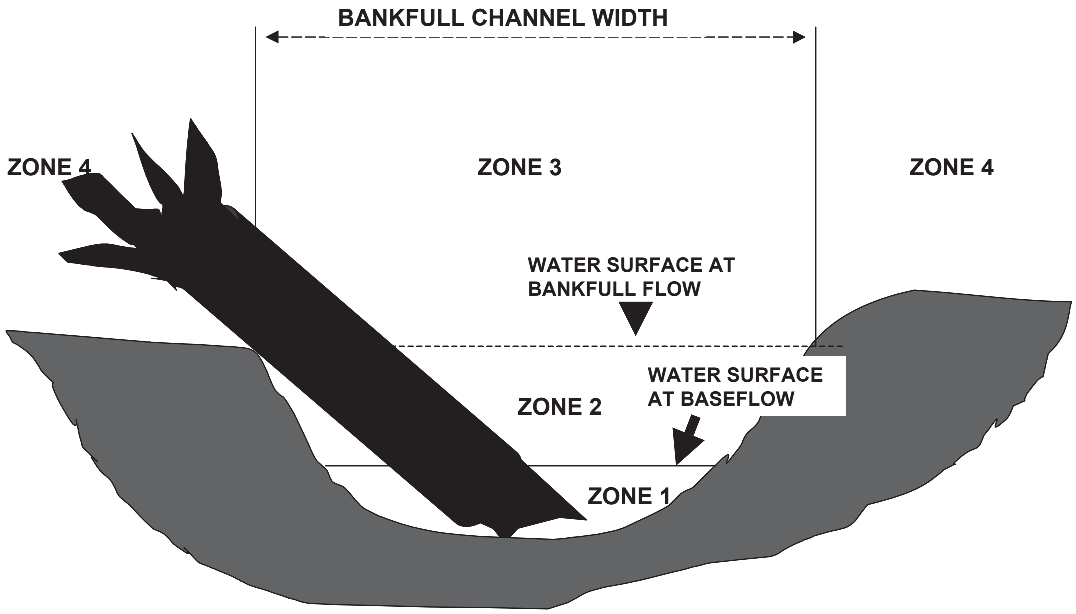


Figure 7-3. Large woody debris influence zones (modified from Robison and Beschta, 1990)

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

7.5 CHANNEL AND RIPARIAN MEASUREMENTS AT CROSS-SECTION TRANSECTS

7.5.1 Slope and Bearing

The slope, or gradient, of the stream reach is useful in three different ways. First, the overall stream gradient is one of the major stream classification variables, giving an indication of potential water velocities and stream power, which are in turn important 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 thalweg profile (Section 7.4.1). Compass bearings between cross section stations, along with the distance between stations, will allow us to estimate the sinuosity of the channel (ratio of the length of the reach divided by the straight line distance between the two reach ends).

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

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

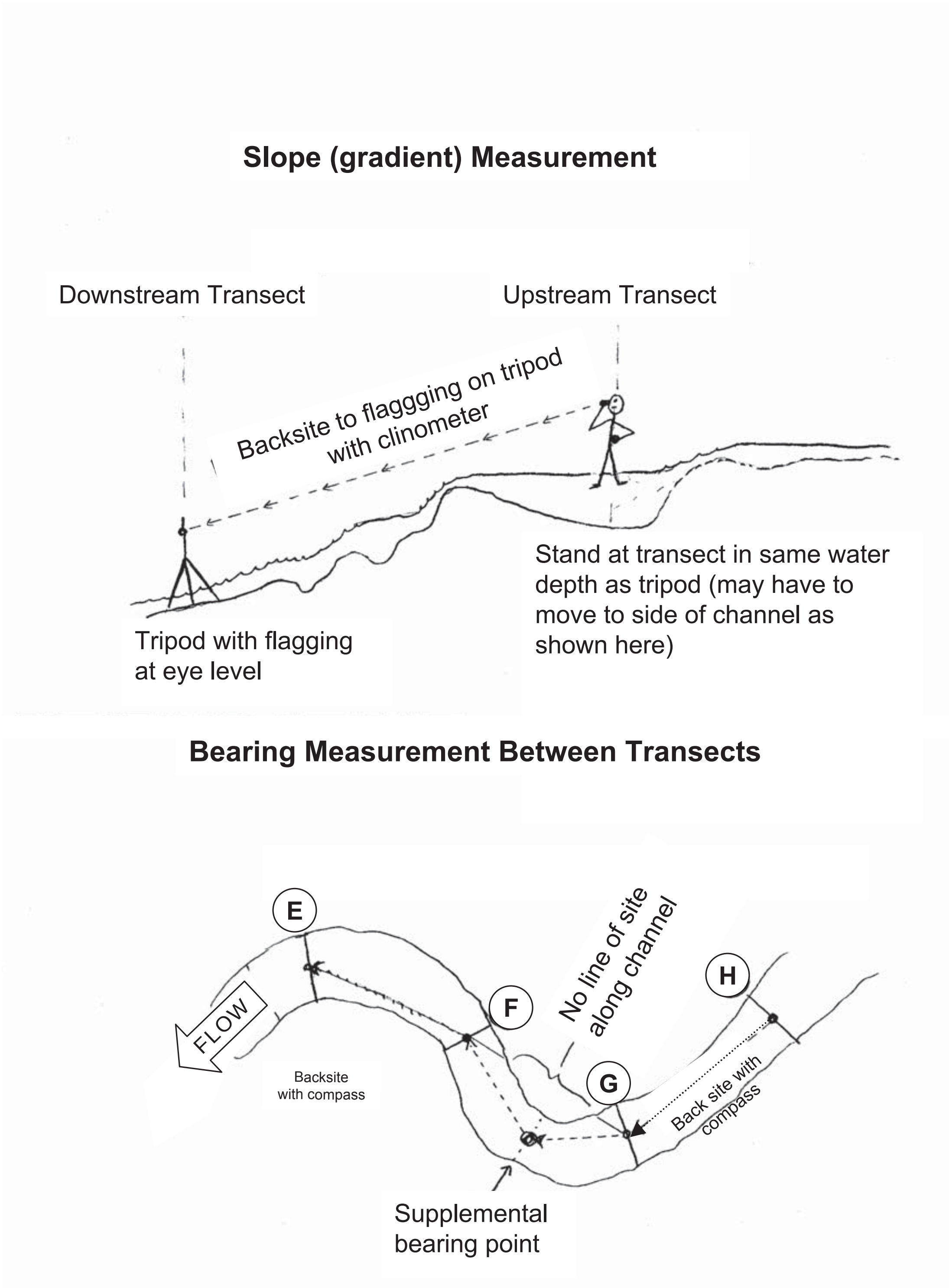


Figure 7-4. Channel slope and bearing measurements.

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

1. Stand in the center of the channel at the downstream cross-section transect. Determine if you can see the center of the channel at the next cross-section transect upstream. If not, you will have to take supplementary slope and bearing measurements.

2. Set up the tripod in shallow water or at the water's edge at the downstream cross-section transect (or at a supplemental point). Standing tall in a position with your feet as near as possible to the water surface elevation, set the tripod extension and mark it with a piece of flagging at your eye level. Remember the depth of water in which you are standing when you adjust the flagging to eye level.

   - On gradually sloped streams, it is advisable to use two people, each holding a pole marked with flagging at the same height on both poles.

3. Walk upstream to the next cross-section transect. Find a place to stand at the upstream transect (or at a supplemental point) that is at the same depth as where you stood at the downstream transect when you set up the eye-level flagging.

   - If you have determined in Step 1 that supplemental measurements are required for this segment, walk upstream to the furthest point where you can still see the center of the channel at the downstream cross-section transect from the center of the channel. Mark this location with a different color flagging than that used to mark the cross-section transects.

4. With the clinometer, site back downstream on your flagging at the downstream transect (or at the supplementary point). Read and record the **percent** slope in the "MAIN" section on the Slope and Bearing Form. Record the "PROPORTION" as 100%.

   - If two people are involved, place the base of each pole at the water level (or at the same depth at each transect). Then site with the clinometer (or Abney level) from the flagged height on upstream pole to the flagged height on the downstream pole.

   - If you are backsiting from a supplemental point, record the slope (%) and proportion (%) of the stream segment that is included in the measurement in the appropriate "SUPPLEMENTAL" section of the Slope and Bearing Form.

5. Stand in the middle of the channel at upstream transect (or at a supplemental point), and site back with your compass to the middle of the channel at the downstream transect (or at a supplemental point). Record the bearing (degrees) in the "MAIN" section of the Slope and Bearing Form.

   - If you are backsiting from a supplemental point, record the bearing in the appropriate "SUPPLEMENTAL" section of the Slope and Bearing Form.

6. Retrieve the tripod from the downstream cross section station (or from the supplemental point) and set it up at the next upstream transect (or at a supplemental point) as described in Step 2.

7. When you get to each new cross-section transect (or to a supplementary point), backsite on the previous transect (or the supplementary point), repeat Steps 2 through 6 above.

Reviewed by (initial): DP

PHab: SLOPE AND BEARING FORM - STREAMS

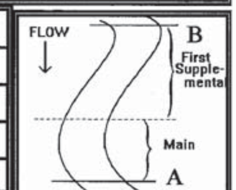
NOTE: ON BACK SIDE OF THIS FORM IS THE TORRENT EVIDENCE ASSESSMENT FORM!

SITE NAME: 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	PROPORTION	SLOPE	BEARING 0-360	PROPORTION	SLOPE	BEARING 0-360	PROPORTION	
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 7-5. Slope and Bearing Form.

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

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

7.5.2 Substrate Size and Channel Dimensions

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

In the EMAP protocol, substrate size and embeddedness are evaluated at each of the 11 cross-section transects (refer to Figure 7-1) using a combination of methods adapted from those described by Wolman (1954), Bain et al. (1985), Platts et al. (1983), and Plafkin et al. (1989). The basis of the protocol is a systematic selection of 5 substrate particles from each of 11 cross-section transects (Figure 7-6). In the process of measuring substrate particle sizes at each channel cross section, you also measure the wetted width of the channel and the water depth at each substrate sample point. If the wetted channel is split by a mid-channel bar (see Section 7.4.1), the five substrate points are centered between the wetted width boundaries regardless of the mid-channel bar in between. Consequently, substrate particles selected in some cross-sections may be "high and dry". For dry channels, make cross-section measurements across the unvegetated portion of the channel.

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

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

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

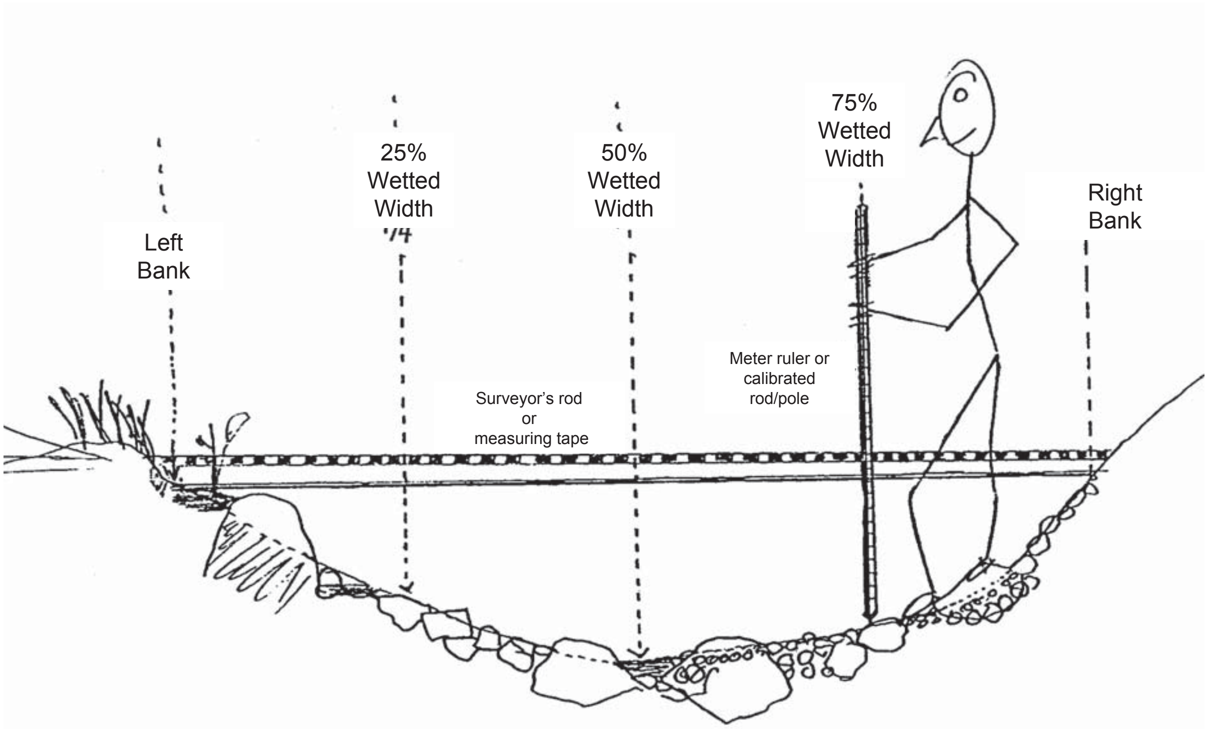


Figure 7-6. Substrate sampling cross-section.

7.5.3 Bank Characteristics

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

TABLE 7-6. SUBSTRATE MEASUREMENT PROCEDURE

1. Fill in the header information on page 1 of a Channel/Riparian Cross-section and Thalweg Profile Form. Indicate the cross-section transect. At the transect, extend the surveyor's rod across the channel perpendicular to the flow, with the "zero" end at the left bank (facing downstream). If the channel is too wide for the rod, stretch the metric tape in the same manner.

2. Divide the wetted width of the channel by 4 to obtain the locations of the substrate measurement points along the cross-section. In the "DISTLB" fields of the form, record the distances corresponding to 0% (LFT), 25% (LCTR), 50% (CTR), 75% (RCTR), and 100% (RGT) of the measured wetted width.

3. Place your sharp-ended meter stick or calibrated pole at the "LFT" location (0 m). Measure the depth and record it on the field data form.

   - Entries for the water's edge at the left and right banks may be 0 (zero) if the banks are gradual.
   - If the bank is nearly vertical, let the base of the measuring stick fall to the bottom, rather than holding it suspended at the water surface.

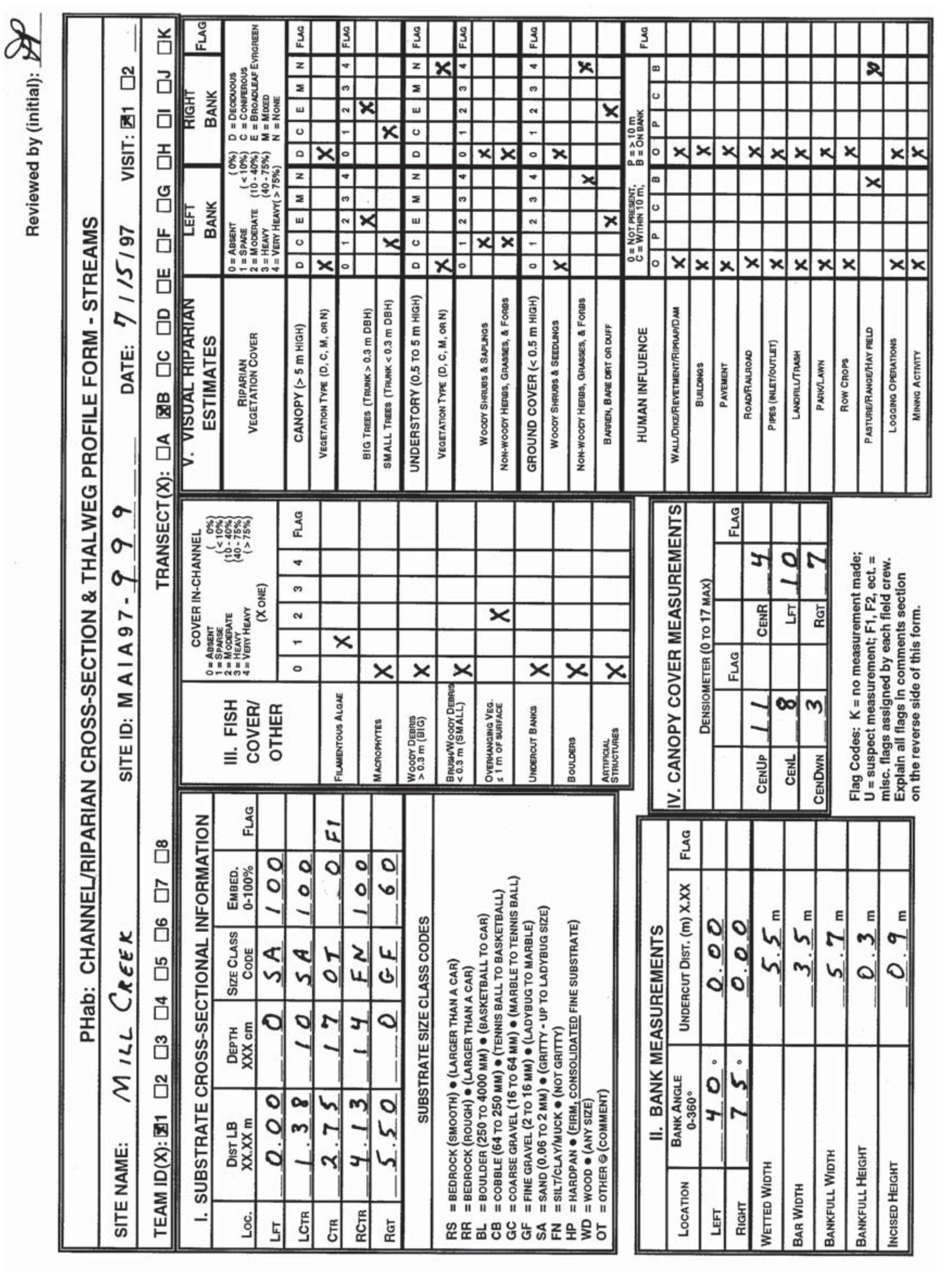
4. Pick up the substrate particle that is at the base of the meter stick (unless it is bedrock or boulder), and visually <u>estimate its particle size</u>, according to the following table. Classify the particle according to its "median" diameter (the middle dimension of its length, width, and depth). Record the size class code on the field data form.

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

5. For particles larger than sand, examine the surface for stains, markings, and algae. Estimate the average percentage embeddedness of particles in the 10 cm circle around the measuring rod. Record this value on the field data form. By definition, sand and fines are embedded 100 percent; bedrock and hardpan are embedded 0 percent.

6. Move successively to the next location along the cross section. Repeat steps 4 through 6 at each location.

7. Repeat Steps 1 through 6 at each new cross section transect.



Reviewed by (initial): [initials]

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

SITE NAME: Mill Creek — SITE ID: MAIA97-999 — DATE: 7/15/97 — VISIT: ☒1 ☐2

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

I. SUBSTRATE CROSS-SECTIONAL INFORMATION

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%); 1 = Sparse (<10%); 2 = Moderate (10-40%); 3 = Heavy (40-75%); 4 = Very Heavy (>75%). D = Deciduous; C = Coniferous; E = Broadleaf Evrgreen; M = Mixed; N = None

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

HUMAN INFLUENCE: 0 = Not Present, C = Within 10 m, P = > 10 m, B = On Bank

	Left Bank	Right Bank	Flag
Wall/Dike/Revetment/Riprap/Dam	0	0	
Buildings	0	0	
Pavement	0	0	
Road/Railroad	0	0	
Pipes (Inlet/Outlet)	0	0	
Landfill/Trash	0	0	
Park/Lawn	0	0	
Row Crops	0	0	
Pasture/Range/Hay Field	B	B	
Logging Operations	0	0	
Mining Activity	0	0	

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

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

TABLE 7-7. PROCEDURE FOR MEASURING BANK CHARACTERISTICS

1. To measure bank angle, lay the surveyor's rod or your meter ruler down against the left bank (determined as you face downstream), with one end at the water's edge. Lay the clinometer on the rod, read the bank angle in degrees from the external scale on the clinometer. Record the angle in the field for the left bank in the "BANK MEASUREMENT" section of the Channel/Riparian Cross-section and Thalweg Profile Form.

   - A vertical bank is 90 degrees; undercut banks have angles >90 degrees approaching 180 degrees, and more gradually sloped banks have angles <90 degrees. To measure bank angles >90 degrees, turn the clinometer (which only reads 0 to 90 degrees) over and subtract the angle reading from 180 degrees.

2. If the bank is undercut, measure the horizontal distance of the undercutting to the nearest 0.01 m. Record the distance on the field data form. The undercut distance is the distance from the water's edge out to the point where a vertical plumb line from the bank would hit the water's surface.

   - Measure submerged undercuts by thrusting the rod into the undercut and reading the length of the rod that is hidden by the undercutting.

3. Repeat Steps 1 and 2 on the right bank.

4. Hold the surveyor's rod vertical, with its base planted at the water's edge. Using the surveyor's rod as a guide while examining both banks, estimate (by eye) the channel incision as the height up from the water surface to elevation of the first terrace of the valley floodplain (Note this is at or above the bankfull channel height). Record this value in the "INCISED HEIGHT" field of the bank measurement section on the field data form.

5. Still holding the surveyor's rod as a guide, examine both banks to estimate and record the height of bankfull flow above the present water level. Look for evidence on one or both banks such as:

   - An obvious slope break that differentiates the channel from a relatively flat floodplain terrace higher than the channel.
   - A transition from exposed stream sediments to terrestrial vegetation.
   - Moss growth on rocks along the banks.
   - Presence of drift material caught on overhanging vegetation.
   - transition from flood- and scour-tolerant vegetation to that which is relatively intolerant of these conditions.

6. Record the wetted width value determined when locating substrate sampling points in the "WETTED WIDTH" field in the bank measurement section of the field data form. Also determine the bankfull channel width and the width of exposed mid-channel bars (if present). Record these values in the "BANK MEASUREMENT" section of the field data form.

7. Repeat Steps 1 through 6 at each cross-section transect. Record data for each transect on a separate field data form.

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

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

7.5.4 Canopy Cover Measurements

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

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

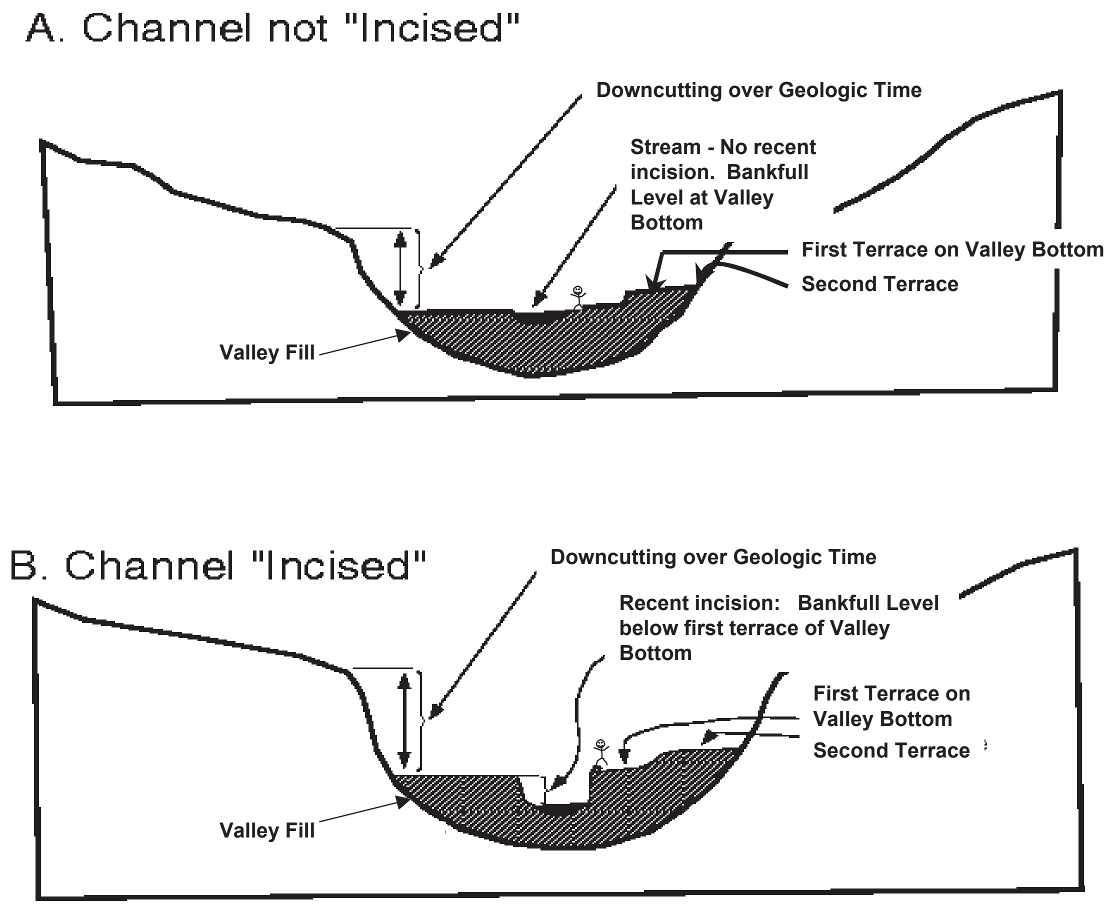

Figure 7-8. Schematic showing bankfull channel and incision for channels. (A) not recently incised, and (B) recently incised into valley bottom. Note level of bankfull stage relative to elevation of first terrace on valley bottom (Stick figure included for scale).

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

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

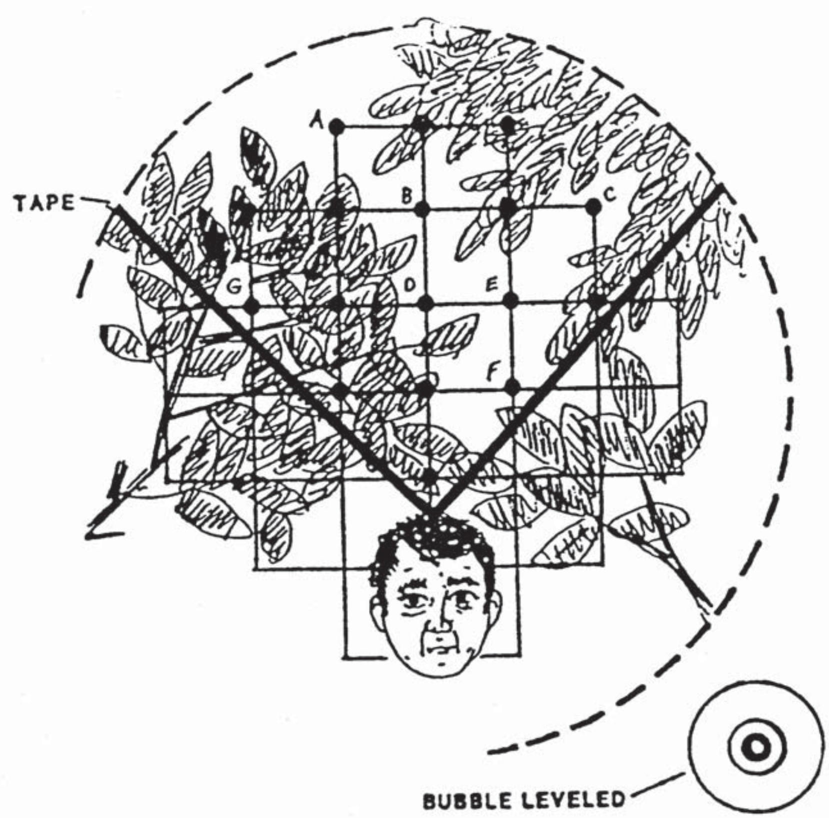

Figure 7-9. Schematic of modified convex spherical canopy densiometer (From Mulvey et al., 1992). In this example, 10 of the 17 intersections show canopy cover, giving a densiometer reading of 10. Note proper positioning with the bubble leveled and face reflected at the apex of the "V."

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

TABLE 7-8. PROCEDURE FOR CANOPY COVER MEASUREMENTS

1. At each cross-section transect, stand in the stream at mid-channel and face upstream.

2. Hold the densiometer 0.3 m (1 ft) above the surface of the stream. Hold the densiometer level using the bubble level. Move the densiometer in front of you so your face is just below the apex of the taped “V”.

3. Count the number of grid intersection points within the “V” that are covered by either a tree, a leaf, or a high branch. Record the value (0 to 17) in the “CENUP” field of the canopy cover measurement section of the Channel/Riparian Cross-section and Thalweg Profile Form.

4. Face toward the left bank (left as you face downstream). Repeat Steps 2 and 3, recording the value in the “CENL” field of the field data form.

5. Repeat Steps 2 and 3 facing downstream, and again while facing the right bank (right as you look downstream). Record the values in the “CENDWN” and “CENR” fields of the field data form.

6. Repeat Steps 2 and 3 again, this time facing the bank while standing first at the left bank, then the right bank. Record the values in the “LFT” and “RGT” fields of the field data form.

7. Repeat Steps 1 through 6 at each cross-section transect. Record data for each transect on a separate field data form.

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

7.5.5 Riparian Vegetation Structure

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

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

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

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

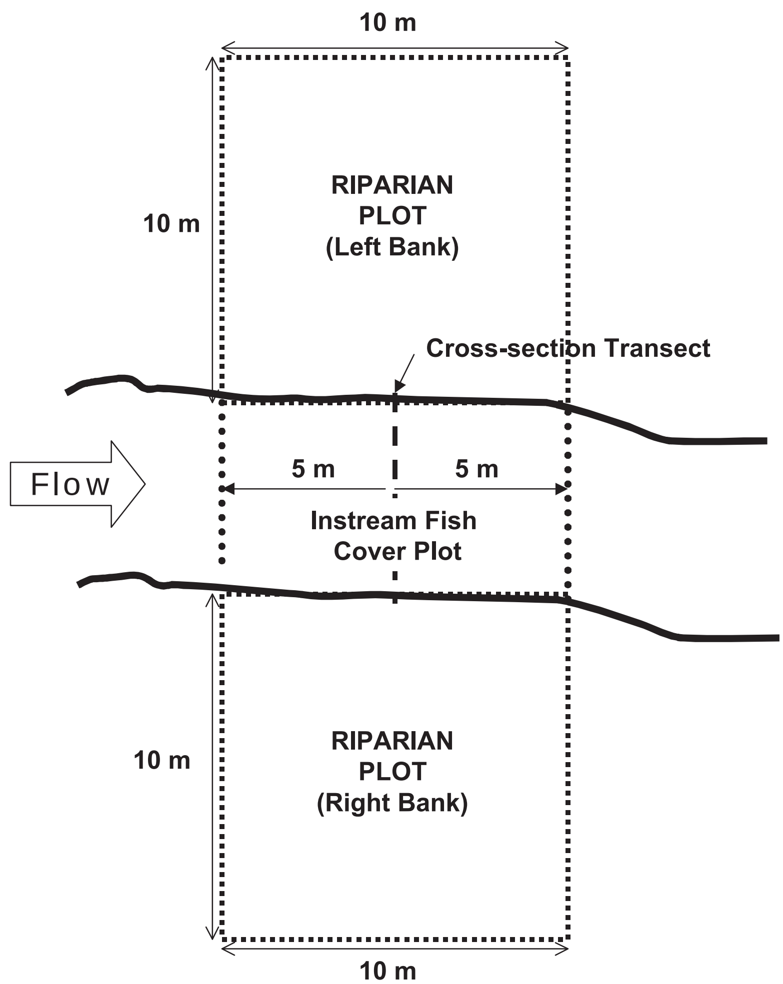

Figure 7-10. Boundaries for visual estimation of riparian vegetation, fish cover, and human influences.

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

TABLE 7-9. PROCEDURE FOR CHARACTERIZING RIPARIAN VEGETATION STRUCTURE

1. Standing in mid-channel at a cross-section transect, estimate a 5 m distance upstream and downstream (10 m total length).

2. Facing the left bank (left as you face downstream), estimate a distance of 10 m back into the riparian vegetation.

   - On steeply-sloping channel margins, estimate the distance into the riparian zone as if it were projected down from an aerial view.

3. Within this 10 m × 10 m area, conceptually divide the riparian vegetation into three layers: a CANOPY LAYER (>5m high), an UNDERSTORY (0.5 to 5 m high), and a GROUND COVER layer (<0.5 m high).

4. Within this 10 m × 10 m area, determine the dominant vegetation type for the CANOPY LAYER (vegetation > 5 m high) as either Deciduous, Coniferous, broadleaf Evergreen, Mixed, or None. Consider the layer "Mixed" if more than 10% of the areal coverage is made up of the alternate vegetation type. Indicate the appropriate vegetation type in the "VISUAL RIPARIAN ESTIMATES" section of the Channel/Riparian Cross-section and Thalweg Profile Form.

5. Determine separately the areal cover class of large trees (> 0.3 m [1 ft] diameter at breast height [DBH]) and small trees (< 0.3 m DBH) within the canopy layer. Estimate areal cover as the amount of shadow that would be cast by a particular layer alone if the sun were directly overhead. Record the appropriate cover class on the field data form ("0"=absent: zero cover, "1"=sparse: <10%, "2"=moderate: 10-40%, "3"=heavy: 40-75%, or "4"=very heavy: >75%).

6. Look at the UNDERSTORY layer (vegetation between 0.5 and 5 m high). Determine the dominant vegetation type for the understory layer as described in Step 4 for the canopy layer.

7. Determine the areal cover class for woody shrubs and saplings separately from non-woody vegetation within the understory, as described in Step 5 for the canopy layer.

8. Look at the GROUND COVER layer (vegetation < 0.5 m high). Determine the areal cover class for woody shrubs and seedlings, non-woody vegetation, and the amount of bare ground present as described in Step 5 for large canopy trees.

9. Repeat Steps 1 through 8 for the right bank.

10. Repeat Steps 1 through 9 for all cross-section transects, using a separate field data form for each transect.

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

7.5.6 Instream Fish Cover, Algae, and Aquatic Macrophytes

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

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

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

TABLE 7-10. PROCEDURE FOR ESTIMATING INSTREAM FISH COVER

1. Standing mid-channel at a cross-section transect, estimate a 5m distance upstream and downstream (10 m total length).

2. Examine the water and the banks within the 10-m segment of stream for the following features and types of fish cover: filamentous algae, aquatic macrophytes, large woody debris, brush and small woody debris, overhanging vegetation, undercut banks, boulders, and artificial structures.

3. For each cover type, estimate the areal cover. Record the appropriate cover class in the "FISH COVER/OTHER" section of the Channel/Riparian Cross-section and Thalweg Profile Form ("0"=absent: zero cover, "1"=sparse: <10%, "2"=moderate: 10-40%, "3"=heavy: 40-75%, or "4"=very heavy: >75%).

4. Repeat Steps 1 through 3 at each cross-section transect, recording data from each transect on a separate field data form.

7.5.7 Human Influence

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

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

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

7.6 EQUIPMENT AND SUPPLIES

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

TABLE 7-11. PROCEDURE FOR ESTIMATING HUMAN INFLUENCE

1. Standing mid-channel at a cross-section transect, look toward the left bank (left when facing downstream), and estimate a 5m distance upstream and downstream (10 m total length). Also, estimate a distance of 10 m back into the riparian zone to define a riparian plot area.

2. Examine the channel, bank and riparian plot area adjacent to the defined stream segment for the following human influences: (1) walls, dikes, revetments, riprap, and dams; (2) buildings; (3) pavement (e.g., parking lot, foundation); (4) roads or railroads, (5) inlet or outlet pipes; (6) landfills or trash (e.g., cans, bottles, trash heaps); (7) parks or maintained lawns; (8) row crops; (9) pastures, rangeland, or hay fields; (10) logging; and (11) mining (including gravel mining).

3. For each type of influence, determine if it is present and what its proximity is to the stream and riparian plot area. Consider human disturbance items as present if you can see them from the cross-section transect. Do not include them if you have to site through another transect or its 10 m ×10 m riparian plot.

4. For each type of influence, record the appropriate proximity class in the "HUMAN INFLUENCE" part of the "VISUAL RIPARIAN ESTIMATES" section of the Channel/Riparian Cross-section and Thalweg Profile Form. Proximity classes are:

   - B ("Bank") Present within the defined 10 m stream segment and located in the stream or on the stream bank.
   - C ("Close") Present within the 10 × 10 m riparian plot area, but away from the bank.
   - P ("Present") Present, but outside the riparian plot area.
   - O ("Absent") Not present within or adjacent to the10 m stream segment or the riparian plot area at the transect

5. Repeat Steps 1 through 4 for the right bank.

6. Repeat Steps 1 through 5 for each cross-section transect, recording data for each transect on a separate field form.

EQUIPMENT AND SUPPLIES FOR PHYSICAL HABITAT

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

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

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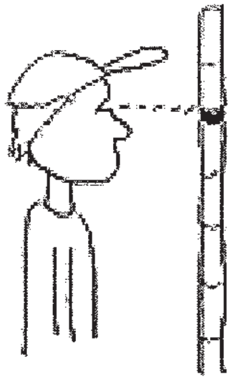
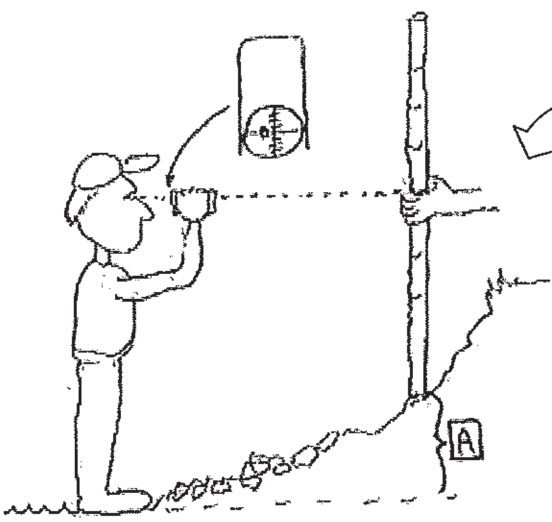
GUIDE TO MEASURING CHANNEL METRICS



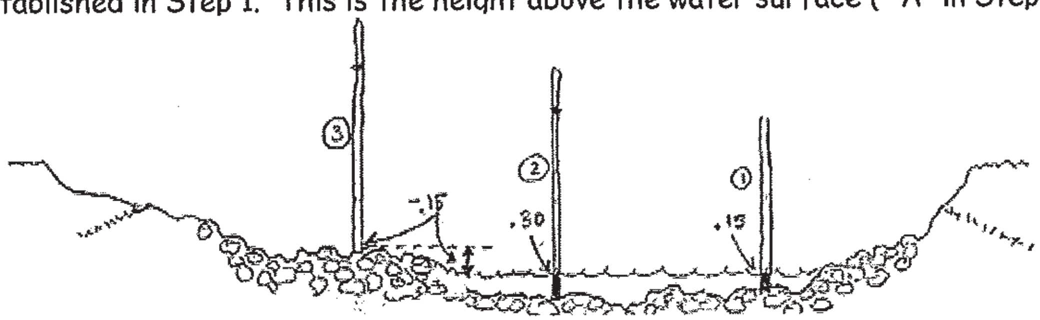
Step 1: Clinometer (CLINO) identifies his eye height on the depth staff.

Step 2: CLINO and survey partner (TAPE) discuss and agree on the active channel scour or margin on either side of the stream. **NOTE:** Channel metrics are to be conducted at the pool tail crest or at the top or bottom of a fast water unit type.



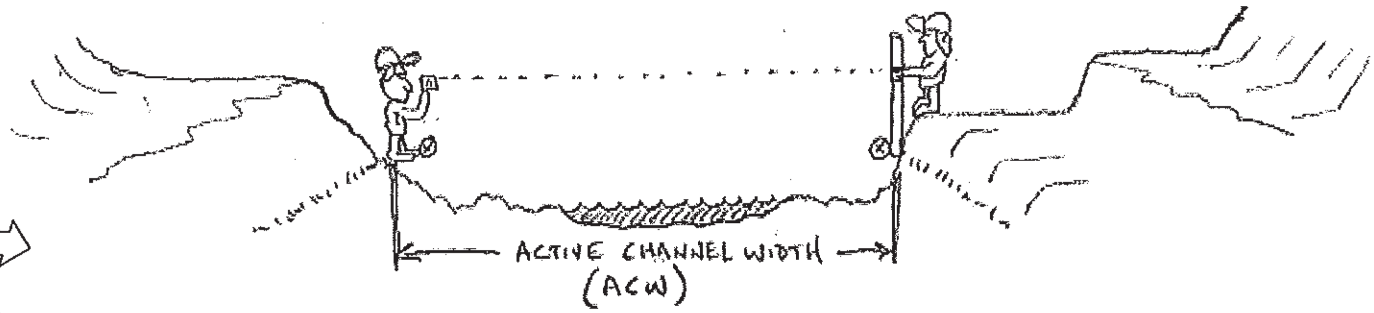
Step 3: TAPE places depth staff at top of the active channel. CLINO stands at the water surface. TAPE slides her hand down the depth staff until CLINO sees the hand come into view while keeping the clinometer on 0% slope.

Step 4: Subtract the height where CLINO saw the hand on the depth staff (Step 3) from the eye height established in Step 1. This is the height above the water surface ("A" in Step 3).

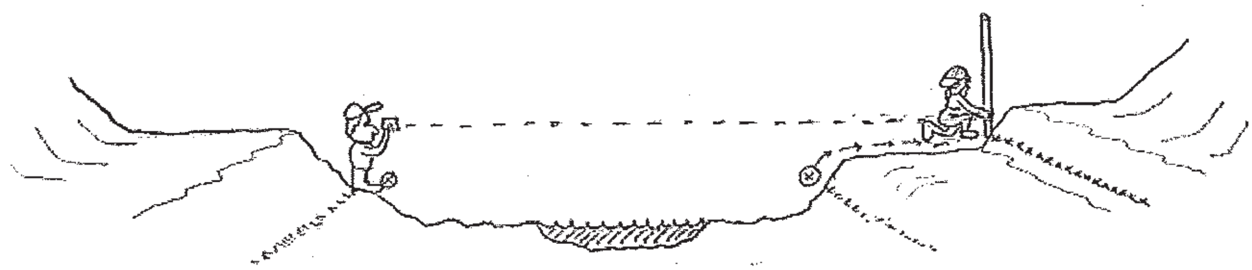


Step 5: CLINO takes the end of the tape measure and starts across the channel while TAPE stays at the active channel margin. CLINO takes 3 depth measurements at $\frac{1}{4}$, $\frac{1}{2}$, and $\frac{3}{4}$ distance of the active channel width while crossing the channel (the measurements are usually the water depth but occasionally can be an exposed gravel bar above the water surface - thus a negative value).

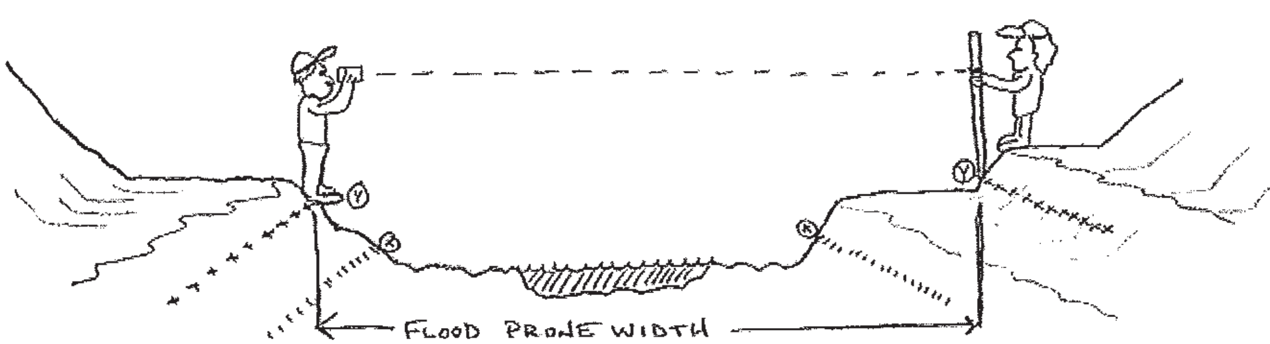
Step 6: Take the average of the three measurements. The example in Step 5 has the measurements 0.15, 0.30, and -0.15 (average = 0.10). Add this value to the measurement "A" obtained in Step 3. This sum is the Active Channel Height (ACH).



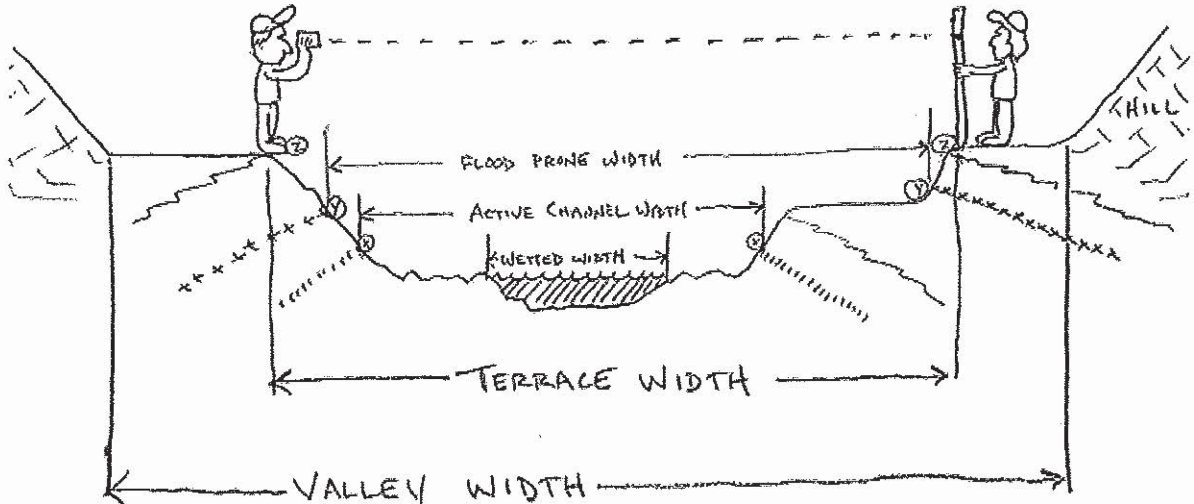
Step 7: TAPE repositions her hand at CLINO's eye height on the depth staff. On the other side of the stream, CLINO backs up the bank until his eye is level with TAPE's hand on the depth staff (using the clinometer at 0% slope). CLINO has now established the active channel margin on the other bank. The distance between CLINO and TAPE is the Active Channel Width (ACW) as **x** depicts above.



Step 8: TAPE subtracts the Active Channel Height value from CLINO's eye height on the depth staff. CLINO remains at the active channel margin with the clinometer at his eye on 0% slope. TAPE backs up the bank until her hand (at the new position) comes into CLINO's view. TAPE has now established the margin of the flood prone on her side of the stream.



Step 9: TAPE repositions her hand back to CLINO's eye height on the depth staff and does not move. CLINO backs up until his eye (clinometer on 0%) is looking at TAPE's hand. CLINO has now established the flood prone margin on his side of the stream. The measurement between CLINO and TAPE is the Flood Prone Width (FPW) as depicted by **y** in the above illustration. Flood Prone Height (FPH) is simply 2X the Active Channel Height.



<u>**Step 10:**</u> If a high terrace (terrace feature above FPH) exists within 4 active channel widths then measure a terrace height (TH) and terrace width (TW). TAPE backs up until she is on the edge of the high terrace lip while CLINO stays at the flood prone margin on his side of the stream. TAPE slides her hand down the depth staff until CLINO (with clinometer on 0%) sees TAPE's hand in view. Subtract this height from CLINO's eye height on the depth staff. Add this difference to the Flood Prone Height value. This sum is the Terrace Height (TH).

TAPE repositions her hand back to CLINO's eye height on the depth staff and stays at the terrace lip while CLINO moves back until his eye (on 0%) is looking at his corresponding eye height on TAPE's depth staff. The distance between them is the Terrace Width (TW) as **z** depicts above.

The Valley Width Index (VWI) is an estimate of how many <u>Active Channel Widths</u> can fit between the toe of the hillslope on one side of the valley to the toe of the slope on the other side of the valley. In the illustration above, if the Valley Width is 30 meters and the Active Channel Width is 15 meters, then the VWI is 2.0.

Definitions

Definitions of acronyms and other terms are found in Table P-1.

Table P-1. Definitions.

Term or Acronym	Definition
Bankfull stage	This stage is delineated by the elevation point of incipient flooding, indicated by deposits of sand or silt at the active scour mark, break in stream bank slope, perennial vegetation limit, rock discoloration, and root hair exposure (Endreny 2009).
Bankfull width	Horizontal distance between the bankfull stage on the left bank and the bankfull stage on the right bank. For Status and Trends, this is measured in tenth of meters.
Dammed pool	A pool formed by impounded water from complete or nearly complete channel blockage (Armantrout, 1998)
DCE	Data Collection Event. Data are indexed using this code which includes the SITE_ID, the date, and the time that the event began. It uses this format: **WAM06600-NNNNNN-dce-20YY-MMDD-HHMM** **NNNNNN** = the number portion of the SITE_ID. **YY** = the last two numeric digits of the year that the event occurred. **MM** = the two numeric digits for the month that the event occurred. **DD** = the two numeric digits for the day within the month that the event occurred. **HHMM** = the military time when the event began.
Dry channel	A habitat unit is designated as dry channel (DC) where flow is subsurface.
Fast non-turbulent	Habitat unit with smooth, laminar flow that is less deep than in pools. Examples include a sheet or run.
Fast turbulent	Habitat unit with supercritical flow, with hydraulic jumps sufficient to entrain air bubbles and create whitewater (Armantrout, 1998). Examples include water-falls, cascades, rapids, and riffles.
Habitat Unit	Habitat units are "quasi-discrete areas of relatively homogeneous depth and flow that are bounded by sharp physical gradients… Different types of units are usually in close enough proximity to one another that mobile stream organisms can select the type of unit that provides the most suitable habitat" (Hawkins et al. 1993). For Status and Trends, any unit (with two exceptions) must be at least **as long as *half* their wetted width** and they must include the thalweg. Plunge pools and dry channels are the exceptions. Plunge pools can be shorter than half their width. Dry channels have no wetted width and only need to extend 20% of a site's bankfull width (1/100th of the entire stream site's length).
Left bank	A person facing downstream will have the left bank on their left side.
Main channel	Channels in a stream are divided by islands (dry ground that rises above bankfull stage). Main channels contain the greatest proportion of flow.

	For this method it is called channel number 0.
major transect	A subset of the thalweg transects. Each of 11 equidistant transects across the length of a site. These are labeled as follows: A0 (lowest), B0, C0….K0 (highest).
minor transect	A subset of the thalweg transects. Each of 10 equidistant transects across the length of a site. These are situated mid-way between major transects and are labeled as follows: A5, B5, C5….K5.
Plunge pool	A pool created by water that passes over an obstruction and drops steeply to scour a basin in the streambed below (Armantrout 1998). This plunge type of scour pool is coded separately because its length criteria are different. Plunge pools can be shorter than half the wetted width.
Pool	For Status and Trends, this is a habitat unit that has a maximum depth at least 1.5 times its crest depth.
Pool crest depth (scour pools)	Thalweg depth at the shallowest tail-out (downstream) end of the pool.
Pool crest depth (dammed pools)	Thalweg depth at the shallowest upstream end of the pool.
Pool maximum depth	Deepest thalweg depth in a pool habitat unit.
Right bank	A person facing downstream will have the right bank on their right side.
Scour pool	Pool created by the scouring action of current flowing against an obstruction (Armantrout 1998). Examples include eddy pools, trench pools, mid-channel pools, convergence pools, and lateral scour pools.
Side channels	Channels that contain less flow than the main channels. These are identified and enumerated (1,2,3 etc.) as encountered (see the method for thalweg measurements) during the DCE.
Thalweg	Path of a stream that follows the deepest part of the channel (Armantrout, 1998).
Thalweg depth	Water depth along the path of the thalweg.
thalweg transect	The stream site is conceptually divided longitudinally into 100 segments, separated by 101 thalweg transects. Thalweg transects are separated by 0.2 (site average) bankfull widths from each other. The thalweg transects are labeled from the bottom of the site to the top as follows: A0, A1, A2, A3, A4, A5, A6, A7, A8, A9, B0…K0.

SECTION 6: CHANNEL SEGMENTS AND SIDE CHANNELS

Equipment: N/A

Objective: Identify and label the main channel and different side channel types.

6.1 Channel Segment Numbers and Side Channel Classification

Channel segment numbers are used to differentiate the main channel from side channels. Assign a unique channel segment number to the main channel and all qualifying side channels.

Step 1. Identify the main channel.

i. Main (primary) channel: Contains the greatest amount of stream flow at a site.

Step 2. Identify side channels.

i. Side channel: To be considered a side channel, the channel must be separated from another channel by an island that is ≥ the bankfull elevation for a length ≥ the average bankfull width. At small sites that are 120 m in length, an island must be ≥ 6 m to qualify.

   a. If a channel is separated from another channel by an island that is shorter than the average bankfull width (or < 6 m at small sites), then consider the channel part of the adjacent channel.

   b. If a channel is separated from another channel by a bar (< bankfull elevation) or boulder, then consider the side channel part of the adjacent channel.

Step 3. Identify side channel type.

i. Determine if side channel is qualifying or non-qualifying.

   a. Qualifying side channel: Channel is located within the active bankfull channel and separated from another channel by an island ≥ the average bankfull width.

      i. Qualifying side channels are further divided into large and small side channels (see Step 3, ii.).

      ii. Refer to the decision tree in Figure 17 regarding segment number and channel unit designations for qualifying side channels.

   b. Non-qualifying side channel: Channel is located outside the active bankfull channel or possesses one or more of the following characteristics:

      i. The elevation of the channel's streambed is above bankfull at any point.

      ii. Channel lacks a continuously defined streambed or developed streambanks.

      iii. Channel contains terrestrial vegetation.

ii. Determine whether qualifying side channel is large or small.

Visually estimate stream flow at both the upstream and downstream ends of the side channel as a percentage of the total flow at the site.

   a. Large side channel: Has between 16% and 49% flow at either end.

   b. Small side channel: Has < 16% flow at both ends.

Step 4. Assign segment numbers to channels.

i. The main channel is assigned "Segment 1" throughout the site (Figure 16).

ii. The first large or small side channel encountered when laying out the site (moving upstream) is designated as "Segment 2". Designate additional qualifying side channels sequentially (2, 3, 4, etc.) until all large and small side channels have been uniquely numbered (Figure 16).

iii. Do not assign segment numbers to non-qualifying side channels.

Note: If a qualifying side channel continues downstream beyond the bottom of site, begin surveying the side channel in line with the bottom of site. Likewise, end surveying a side channel in line with the top of site.

Note: If a large side channel splits and each channel contains > 16% of the total stream flow, assign the original segment number to the largest channel and assign a new segment number to the second channel. If a large side channel splits, and flow in either channel is < 16% of the total flow, assign the original channel segment number to the largest channel, and assign a new segment number to the smaller channel (now considered a small side channel).

Step 5. Record measurements. What to measure in each channel type:

i. <u>Main channel</u>:

   a. Classify channel units, collect all channel unit attributes, and conduct topographic survey.

ii. <u>Large side channels</u>:

   a. Classify channel units, collect all channel unit attributes, and conduct topo survey.

iii. <u>Small side channels</u>:

   a. Classify the entire side channel (both wet and dry portions) as a Small Side Channel unit (Figure 15C) and conduct topographic survey.

   b. Quantify Large Woody Debris (Section 8.4). Do not collect any additional channel unit attributes.

   c. Categorize the side channel as continuously wet, partially wet, or dry.

   d. Estimate the total length of the side channel centerline.

   e. Estimate the average bankfull width of the side channel.

   f. Estimate the percent of the bankfull channel area that is wet at the time of sampling.

iii. <u>Non-qualifying side channels</u>:

   a. Capture the area where the side channel enters/exits the adjacent channel in the topographic survey but <u>do not</u> conduct the topo survey throughout the side channel.

   b. Do not classify channel units, collect any channel unit attributes, or categorize it.

   c. Do not estimate side channel length, width, or percent wetted.

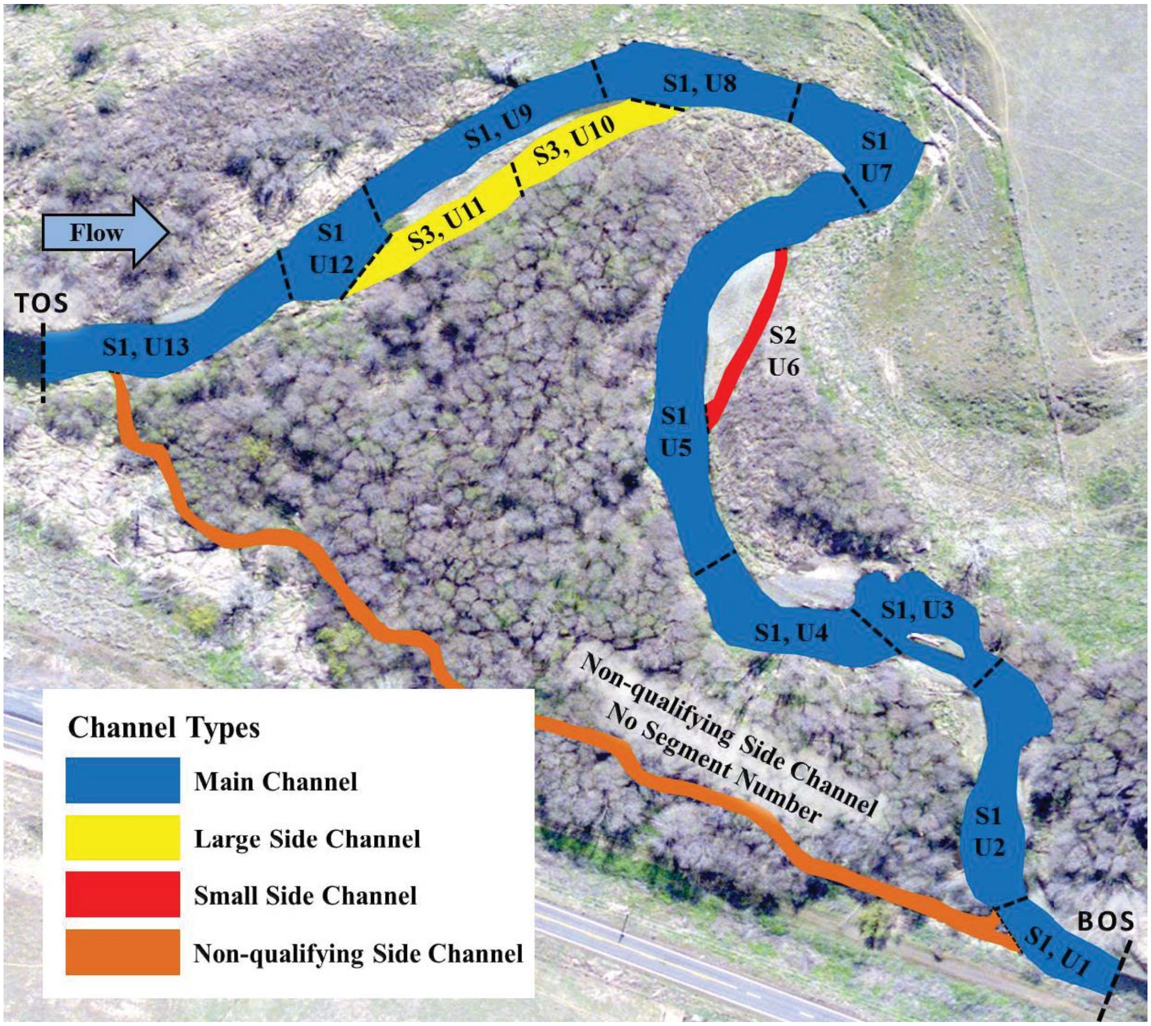


Figure 16. How to number channel segments within a site. The main channel is assigned segment 1 throughout the site. Both large and small side channels are assigned sequential segment numbers working upstream. In the figure, channel segment numbers are preceded with a "S" (S1-S3) and channel unit numbers with a "U" (U1-13).

Qualifying Side Channel Decision Tree

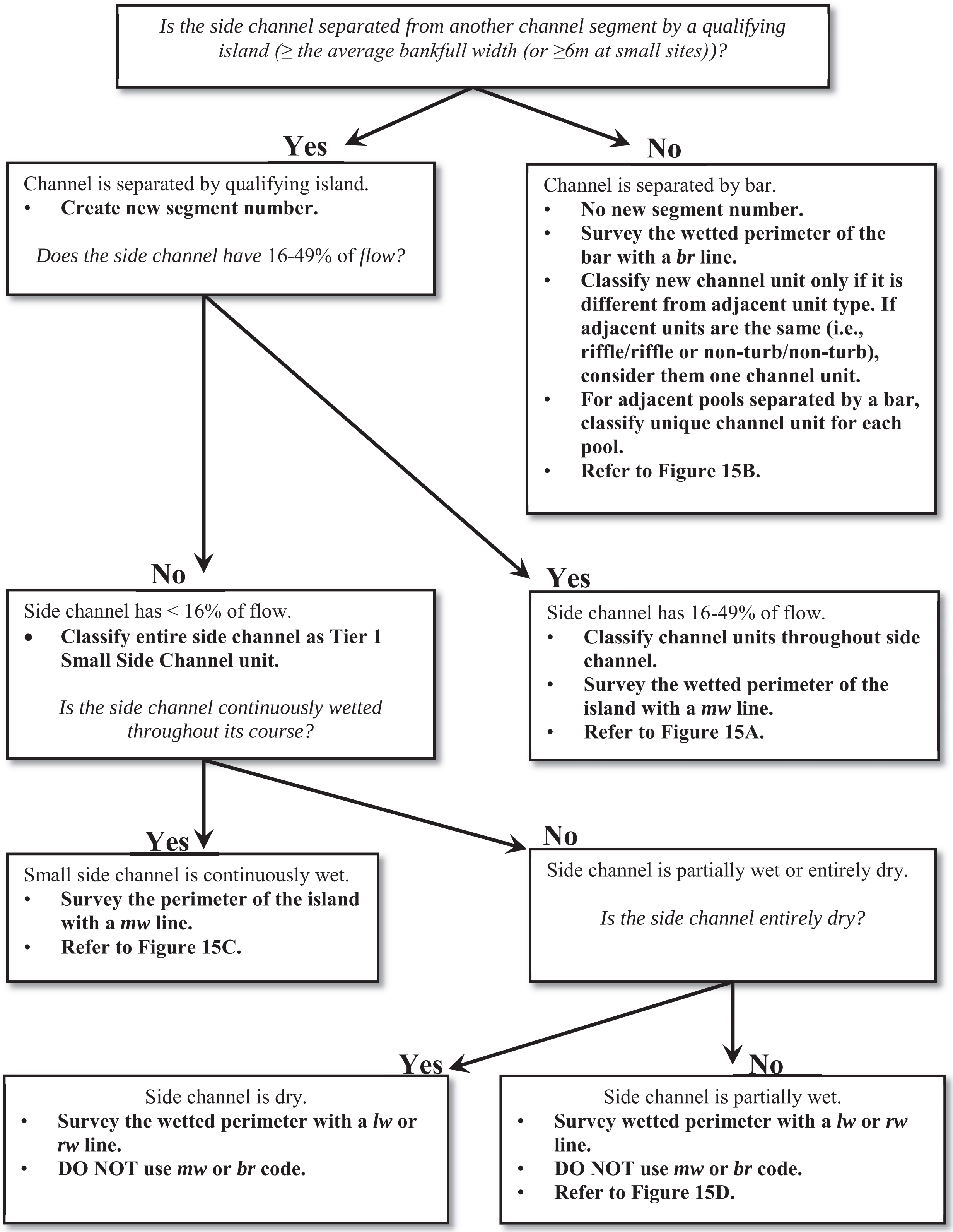


Figure 17. Decision tree outlining segment number and channel unit designations, along with topographic codes for qualifying side channels and islands.

Land Uses continued

BK **B**ug **K**ill. Eastside forests with > 60% mortality from pests and diseases. Enter bug kill as a comment on the unit sheet when it is observed in small patches.
LG **L**ight **G**razing Pressure. Grasses, forbs and shrubs present, banks not broken down, animal presence obvious only at limited points such as water crossings. Cow pies evident.
HG **H**eavy **G**razing Pressure. Broken banks, well established cow paths. Primarily bare earth or early successional stages of grasses and forbs present.
EX **EX**closure. Fenced area that excludes cattle from a portion of rangeland
GN **G**ree**N** way. Designated Green Way areas, Parks (city, county, state).
UR **UR**ban
RR **R**ural **R**esidential
IN **IN**dustrial
DW **D**omestic **W**ater supply watershed.
CR **C**onservation area or wildlife **R**efuge.
GF **G**ol**F** course.
MI **MI**ning
WA Designated **W**ilderness **A**rea or Wilderness Study Area
WL **W**et**L**and.
NU **N**o **U**se identified.
WS **W**ild and **S**cenic Area

9. **Water Temperature.** Stream temperature recorded at each reach change or a minimum of once per page of data. Record the time as well. Note if the temperature is measured in °C or °F.

   At named tributaries, record the stream temperature of the tributary **and** in the mainstem stream upstream from the tributary confluence. Identify and record each temperature in the appropriate line of the Note column.

10. **Stream Flow.** Description of observed discharge condition. Best observed in riffles. If a gauging station is present, be sure to record the stage height.

DR **DR**y
PD **P**u**D**dled. Series of isolated pools connected by surface trickle or subsurface flow.
LF **L**ow **F**low. Surface water flowing across 50 to 75 percent of the active channel surface. Consider general indications of low flow conditions.
MF **M**oderate **F**low. Surface water flowing across 75 to 90 percent of the active channel surface.
HF **H**igh **F**low. Stream flowing completely across active channel surface but not at bankfull.
BF **B**ankfull **F**low. Stream flowing at the upper level of the active channel bank.
FF **F**lood **F**low. Stream flowing over banks onto low terraces or flood plain.

11. **Location.** Township, range, section and quarter at the start of the reach. Use the following example as the format: T10S-R05W-S22SE.

Appendix G

Sampling Benthos in Wadeable Streams

Purpose and Scope

This method describes how to collect benthic macroinvertebrate samples for conducting community level assessments in Washington's Status and Trends Program. Data will be used to describe biological integrity and ecological quality (or taxonomic loss). It applies to waded streams. This method requires measurement of the associated physical and chemical environmental variables described in other methods within this protocol.

Definitions

Definitions of acronyms and other terms are found in Table G-2.

Table G-2. Definitions.

Term or Accronym	**Definition**
Biological Integrity	"The ability to support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity and functional organization comparable to those of natural habitats within a region" (Karr and Dudley, 1981).
Ecological Quality	For this method, ecological quality refers to the ratio of observed to expected natural taxa (Wright et al 2000). This is the observed number of native taxa collected relative to the number of taxa predicted based on a model of reference condition.
Kick	One of the 8 components to a site's composite benthos sample. One kick is collected at each of 8 transects within the site. The area of a kick is 1 ft^2 (0.743 m^2) of stream bottom.

Personnel Responsibilities

One person or more performs this activity. Staff performing this method must have been trained.

Equipment, Reagents, Supplies

- Wide-mouth polyethylene jar (128 oz or 3.8 L)
- D-Frame kick net with these characteristics
    - Frame mouth that is 1 ft (30.5 cm) wide by 1 ft tall.
    - 500-µm mesh net
- 95% Ethanol (add 3 parts by volume for each part sample)
- Label (waterproof) for jar exterior
- Label (waterproof) for jar interior
- Soft-lead pencil
- Clear tape
- Electrical tape
- Pocket knife
- Wading gear

Summary of Procedure

Invertebrate sampling is one of the first methods to be performed on-site, after site verification and layout. It starts concurrently with water sampling, with initial components of the benthos sample collected downstream of the water sample. One kick sample is collected at each of 8 transects and added to the composite sample for the site. This method is taken from Hayslip (2007) with some details provided by Peck et al (2006).

Choose transects

Randomly choose 8 transect stations out of these 11:
- A0
- B0
- C0
- D0
- E0
- F0
- G0
- H0
- I0
- J0
- K0

Identify kick stations

Start at the lowest transect and work upstream. At each transect, visually estimate the distance from left to right where the stream bottom will be sampled (Table G-1). Half the stations are in mid-channel. Half are in margins. If the water is too deep to sample at any station, collect the sample from the nearest feasible location. The kick net normally allows sampling up to about 50 cm depths.

Table G-1. Components of the macroinvertebrate composite sample.

Kick Station	Distance across wetted channel (left to right)
1st	25%
2nd	50%
3rd	75%
4th	50%
5th	25%
6th	50%
7th	75%
8th	50%

Collect each kick

A different procedure is needed depending upon whether the station sits within flowing water or slack water. Flowing water is where the stream current can sweep organisms into the net. Slack water is where water is so slow that active net movement is required to collect organisms.

Flowing water stations

Once the kick station is determined, place the net opening into the face of flow. Position the net quickly and securely on the stream bottom to eliminate gaps under the frame. Collect benthic macroinvertebrates from a 1ft² (0.9 m²) quadrat located directly in front of the frame mouth.

Work from the upstream edge of the quadrat backward and carefully pick up and rub stones directly in front of the net to remove attached animals. Quickly inspect each stone to make sure you have dislodged everything and then set it aside. If a rock is lodged in the stream bottom, rub it a few times concentrating on any cracks or indentations.

After removing all large stones, keeping the sampler securely in position, starting at the upstream end of the quadrat, kick the top 4 to 5 cm of the remaining finer substrate within the quadrat for 30 seconds.

Pull the net up out of the water. Immerse the net in the stream several times or splash the outside of the net with stream water to remove fine sediments and to concentrate organisms at the end of the net. After completing the sample, hold the net vertically and rinse material to the bottom of the net.

After taking a sample, examine the contents of the net. Pick out coarse rocks and sticks. Closely examine them for clinging organisms; pick these animals off of the debris and place them into the sample jar. Discard the debris and empty the net's remaining contents into the sample jar.

Add enough ethanol to the sample jar so that the resulting solution consists of 1/3 sample and 2/3 ethanol (by volume).

Slack water stations

Visually define a rectangular quadrat with an area of 1 ft^2 (0.09 m^2). Inspect the stream bottom within the quadrat for any heavy organisms, such as mussels and snails. Remove these organisms by hand and place them into the sample jar. Pick up any loose rocks or other larger substrate particles within the quadrat and hold them in front of the net. Use your hands to rub any clinging organisms off of rocks or other pieces of larger substrate (especially those covered with algae or other debris) into the net. After scrubbing, place the larger substrate particles outside of the quadrat.

Vigorously kick the remaining finer substrate within the quadrat with your feet while dragging the net repeatedly through the disturbed area just above the bottom. Keep moving the net all the time so that the organisms trapped in the net will not escape. Continue kicking the substrate and moving the net for 30 seconds.

After 30 seconds, remove the net from the water with a quick upstream motion to wash the organisms to the bottom of the net.

After taking a sample, examine the contents of the net. Pick out coarse rocks and sticks. Closely examine them for clinging organisms; pick these animals off of the debris and place them into the sample jar. Discard the debris and empty the net's remaining contents into the sample jar.

Add enough ethanol to the sample jar so that the resulting solution consists of 1/3 sample and 2/3 ethanol (by volume).

Special circumstances

For samples located within dense beds of long, filamentous aquatic vegetation, kicking may not be effective. Use a knife to sample only the vegetation that lies ***within*** the quadrat. Don't include parts of the strands that extend beyond the quadrat.

Label and Seal the Composite sample

Using a number 2 pencil, complete two benthos jar labels (Figure G-1). Place one into the sample. Screw on the lid and seal it closed using electrical tape. Attach the other benthos label to the outside of the jar using clear tape. Record the DCE, which includes the Site_ID, and site arrival time (year, month, day, hour, and minute). It should match the DCE recorded on the Site Verification Form. Be sure to note which transects were sampled, and which of these were sampled using the slack water technique..

Figure G-1. The benthos jar label

500 μ D-frame kick	**Benthos Jar Label** Jar ___ of ___
Project	2009 Monitoring in the ______________________ STR
Stream	
Who collected? (full name)	
8 1-ft^2 Transects **(circle all sampled)**	A B C D E F G H I J Transects sampled using slack-water technique: ______________________
Collectors Notes	
DCE	WAM06600-__ __ __ __ __ __-dce-2009__ __ __ __-__ __ __ __ m m d d h h m m

UNIT-2 FORM

Information recorded by the "Numerator" member of each field crew.

1. **Unit Number.** Corresponds to number on "Estimator" sheet.

2. **Unit Type:** Corresponds to same type on "Estimator" sheet.

3. **Depth.** Maximum depth in pools, modal or typical depth in glides and fast water units. Measure to the nearest 0.05 meter as accurately as possible in pools. Probe the bottom with the depth staff to find the deepest point. Small differences in pool depth are significant.

4. **Depth at Pool Tail Crest:** The pool tail crest (PTC) location is where the water surface slope breaks into the downstream habitat unit. Measure the maximum depth to the nearest 0.01 meter along the hydraulic control feature that forms the pool. For beaver ponds unit type (BP) that do not have water flowing over the top of the dam yet there is subsurface flow through the sticks and logs of the dam, record the PTC depth as 0.01 meter. For subunit pools (BW, AL, IP), a PTC is not measured or recorded.

5. **Verified Length and Width.** Verified measurements only apply to Basin surveys. Refer to Appendix 2 for description and survey detail.

6. **Substrate.** Percent distribution by streambed area of substrate material in six size classes: silt and fine organic matter, sand, gravel (pea to baseball; 2-64mm), cobble (baseball to bowling ball; 64-256mm), boulders, and bedrock. Estimate distribution relative to the total area of the habitat unit (wetted area only). Round off each class to nearest 5 percent

   - Do not worry about totaling your estimates exactly to 100 percent; your values will be weighted accordingly during analysis.
   - Estimate the distribution of the <u>surrounding</u> and/or <u>supporting</u> substrate to the best of your ability at ***SS*** *(step over structure),* ***SL*** *(step over log), and* ***CC*** *(culvert crossing) units. For open-bottom culverts, estimate the substrate as for a normal habitat unit.*
   - Be sensitive to the difference between surface flocculants and other fine sediment. Fine sediment that <u>covers and embeds</u> gravel and cobble should be part of your estimate. A thin layer of low density fine material over bedrock or boulders should not.
   - Hardpan clay or conglomerate substrate has bedrock characteristics; therefore, it is classified as bedrock when estimating percent composition. Indicate this in the Note field.

7. **Boulder Count.** Count of boulders greater than 0.5 m in average diameter. Within this size class, include only the boulders that have any portion protruding above the water surface and those at the margin of the wetted channel. In dry units and dry channels, estimate the boulder count within the active channel.

8. **Bank Erosion.** Actively eroding, recently eroding, or collapsing banks that have the following characteristics: (1) exposed mineral soils and inorganic material, evidence of tension cracks, or active sloughing, **and** (2) lack of woody vegetation, roots, rocks (gravel, cobble, boulder), or logs. Eroding banks may contribute material slowly to the stream or collapse in large chunks. Determine if bank erosion is present from the top of the active channel and above, yet not to exceed the height of the floodprone. Record presence / absence if cumulatively over 25 percent of all bank length exhibits signs of erosion. If so, select the appropriate box on the PDA or write 'Y' (yes) or 'N' (no) on the paper data form.

9. **Undercut Bank.** The undercut must be at least 1 meter in length and have an average of 15 horizontal centimeters of immediate overhanging ceiling If present, select the appropriate box on the PDA or write 'Y' (yes) or 'N' (no) on the paper data form.

    Look for areas that provide good hiding cover for fish. Include areas undercut beneath root wads.

10. **Comment Codes.** Comments identifying important features. Enter as many codes as appropriate. For codes which apply to a specific bank, use a slash (/) to indicate the stream, and (when looking upstream) record those features originating on the left side of the stream on the left side of the slash, and like-wise for those features on the right.

AM **AM**phibian. Record species (if known) in Note field.
BC **B**ridge **C**rossing. Record road name or number in Note field.
BD **B**eaver **D**am. Include height of step/dam created by beavers.
BK **B**ug **K**ill. Patches of insect or disease tree mortality.
BV **B**ea**V**er Activity (beaver den, cut trees, chewings, pond, etc.) Indicate age of activity – very old, old, new, recent, fresh.
CC **C**ulvert **C**rossing. Stream passes through a culvert. Record road name or number, as well as culvert material and dimensions. There must be a matching CC unit type.
CE **C**ulvert **E**ntry. Applies to those tributaries a distance from the stream, usually for road drainage.
CS **C**hannelized **S**treambanks. Rip-rap or other artificial bank stabilization and stream control.
DJ **D**ebris **J**am. Accumulation of large woody debris that fills the majority of the stream channel and traps additional sediment and debris. These have potential to alter channel morphology.
FC **F**ence **C**rossing.
GS **G**auging **S**tation.
HS Artificial **H**abitat **S**tructure. Describe type: gabion, log weir, cabled wood, interlocking log jams, etc. If the habitat structure spans several habitat units, record it in the unit most affected by the structure. Identify the habitat units it spans in the NOTE field.
MI **Mi**ning. Dredging, sluicing, tailings (old or new), equipment, etc.
PA **P**otential **A**rtificial Barrier. Potential artificial or human-created barrier to upstream or downstream migration of fish.
PN **P**otential **N**atural Barrier. Potential natural barrier to upstream or downstream fish migration.

Natural and Artificial Barriers are relative to the stream size, fish species, and fish age class encountering them. Consider these variables when using this Comment Code.
Document the height, take photographs, and record in Notes.

Comment Codes continued

RF **R**oad **F**ord. Road that crosses within the active channel of the stream (no bridge).

SD **S**creened **D**iversion. Pump or canal diverting water. Give some indication of size or capacity.

SS **S**pring or **S**eep. Usually small amounts of flow (<5% of total flow) directly entering from hillslope. For large springs, estimate the contribution to flow. Springs do not have defined channels.

TJ **T**ributary **J**unction (both named and unnamed). Use the TJ class only for tributaries with clearly developed channels. Survey even if the trib is dry. Place this code on the primary (01) channel unit, and indicate the side of the stream where the trib is located. Place the tributary name on the tributary (11) channel unit. Record a temperature and the ACW in the Note column. Record the unit number of primary channel unit on the topo map.

UD **U**nscreened **D**iversion. Unscreened pump or canal diverting water. Give some indication of size or capacity.

WL **W**ild**L**ife use of stream or riparian zone. Identify species if possible. This code refers to everything except fish, amphibian, and shellfish species. Use the AM code for amphibian observations and record fish or shellfish observations only in the Note column.

If a code does not exist for an observation, do not invent a code. Add detail/describe in the Note column.

Mass Movement. A two-part Comment Code to identify the type and condition of mass movements. The first letter of the code identifies the type of mass movement failure. The second letter evaluates the apparent activity of the failure. (Example: AI = inactive debris avalanche.) Do not confuse mass movements with bank erosion. Mass movements are not immediate stream bank-associated scouring or degradation. If a mass movement spans across several habitat units <u>record it once</u>. Put the Comment Code in the unit most affected and record the other impacted units in the Notes column.

Type:

E **E**arthflow: general movement and encroachment of hillslope upon the channel. These can be identified by groups of unusually leaning trees on a hillslope

L **L**andslide: failure of locally adjacent hill slope. Usually steep, broad, often shaped like a half oval, with exposed soils.

A **A**valanche: failure of small, high-gradient trib. Often appear “spoon shaped” looking upslope. Water may flow in these intermittent or ephemeral channels that contribute alluvial soils debris.

Condition:

A **A**ctive: contributing material now.

I **I**nactive: evidence of contribution of material during previous winter or high flows.

S **S**tabilized: vegetated scars, no evidence of recent activity.

11. **Note.** Additional information to describe or identify the habitat unit, Comment Code, riparian vegetation, fish species, measurements of steps, culverts, barriers, etc.

TABLE 14-1. DESCRIPTIONS OF HABITAT PARAMETERS USED IN THE RAPID ASSESSMENT OF STREAMS

Habitat Parameter	Prevalent Habitat Type R=Riffle/run P=Pool/glide	Description and Rationale
1. Instream Cover (fish)	R P	Includes the relative quantity and variety of natural structures in the stream (e.g., fallen trees, logs, and branches, large rocks, and undercut banks) that are available for refugia, feeding, or spawning. A wide variety of submerged structures in the stream provide fish with a large number of niches, thus increasing assemblage diversity.
2. Epifaunal Substrate (benthic invertebrates)	R	Essentially the amount of niche space or hard substrates (rocks, snags) available for insects and snails. Numerous types of insect larvae attach themselves to rocks, logs, branches, or other submerged substrates. As with fish, the greater the variety and number of available niches or attachments, the greater the variety of insects in the stream. Rocky-bottom areas are critical for maintaining a healthy variety of insects in most high gradient streams.
	P	The abundance, distribution, and quality of substrate and other stable colonizing surfaces (e.g., old logs, snags, aquatic vegetation) that maximize the potential for colonization.
3A. Embeddedness	R	The extent to which rocks (gravel, cobble, and boulders) are covered or sunken into the silt, sand, or mud of the stream bottom. Generally, as rocks become embedded, the surface area available to macroinvertebrates and fish for shelter, spawning, and egg incubation is decreased. To estimate the percent of embeddedness, observe the amount of silt or finer sediments overlying and surrounding the rocks. If kicking does not dislodge the rocks or cobble, they may be greatly embedded. It is useful to observe the extent of the dark area on their underside of a few rocks.
3B. Pool Substrate Characterization	P	Evaluates the type and condition of bottom substrates found in pools. Firmer sediment types (e.g., gravel, sand) and rooted aquatic plants support a wider variety of organisms than a pool substrate dominated by mud or bedrock and no plants. In addition, a stream that has a uniform substrate in its pools will support far fewer types of organisms than a stream that has a variety of substrate types.
4A. Velocity and Depth Regimes	R	There are four primary current and depth combinations: (1) slow-deep, (2) slow-shallow, (3) fast-deep, and (4) fast-shallow. The best streams in high gradient regions will have all four combinations present. The presence or availability of these four habitats relates to the ability of the stream to provide and maintain a stable aquatic environment. In general use a depth of 0.5 m to separate shallow from deep and a current velocity of 0.3 m/sec to separate fast from slow.
4B. Pool Variability	P	Rates the overall mixture of pool types found in streams, according to size and depth. The four basic types of pools are large-shallow, large-deep, small-shallow, and small-deep. A stream with many pool types will support a wide variety of aquatic species. Rivers with low sinuosity (few bends) and monotonous pool characteristics do not have sufficient quantities and types of habitat to support a diverse aquatic community. As a general guideline, consider a pool deep if it is greater than 1 m deep, and large if its length, width, or oblique dimension is greater than half the stream width.

(continued)

TABLE 14-1 (Continued)

Habitat Parameter	Prevalent Habitat Type R=Riffle/run P=Pool/glide	Description and Rationale
5. Channel Alteration	R P	Basically a measure of large-scale changes in the shape of the stream channel. Many streams in urban and agricultural areas have been straightened, deepened, or diverted into concrete channels, often for flood control purposes. Such streams have far fewer natural habitats for fish, macroinvertebrates, and plants than do naturally meandering streams. Channel alteration is present when the stream runs through a concrete channel; when artificial embankments, riprap, and other forms of artificial bank stabilization or structures are present; when the stream is very straight for significant distances; when dams and bridges are present; and when other such changes have occurred.
6. Sediment Deposition	R P	The amount of sediment that has accumulated and the changes that have occurred to the stream bottom as a result of the deposition. Deposition occurs from large-scale movement of sediment caused by watershed erosion. Sediment deposition may cause the formation of islands, point bars (areas of increased deposition usually at the beginning of meanders that increase in size as the channel is diverted toward the outer bank) or shoals or result in the filling of pools. Increased sedimentation also results in increased deposition. Usually this is evident in areas that are obstructed by natural or man-made debris and areas where the stream flow decreases, such as bends. High levels of sediment deposition create an unstable and continually changing environment that becomes unsuitable for many organisms.
7A. Frequency of Riffles	R	The sequence of riffles occurring in a stream. Riffles are a source of high-quality habitat and diverse fauna, therefore, an increased frequency of occurrence greatly enhances the diversity of the stream community. For areas where riffles are uncommon, a run/bend ratio can be used as a measure of sinuosity. A large degree of sinuosity provides for diverse habitat and fauna, and the stream is better able to handle the high energy flows that result from storms than are relatively straight streams.
7B. Channel Sinuosity	P	Evaluates the meandering or relative frequency of bends of the stream. Streams that meander provide a variety of habitats for aquatic organisms, whereas straight stream segments are characterized by monotonous habitats that are prone to flooding. A high degree of sinuosity creates a variety of pools and reduces the energy from surges when the stream flow fluctuates. The absorption of this energy by bends protects the stream from excessive erosion and flooding. In "oxbow" streams of coastal areas and deltas, meanders are highly exaggerated and transient. Natural conditions are shifting channels and bends. Alteration of these streams is usually in the form of flow regulation and diversion.
8. Channel Flow Status	R P	The degree to which the channel is filled with water. The flow status will change as the channel enlarges or as flow decreases as a result of dams and other obstructions, diversions for irrigation, or drought. When water does not cover much of the streambed, the amount of useable substrate for aquatic organisms is limited.

(continued)

TABLE 14-1 (Continued)

Habitat Parameter	Prevalent Habitat Type R=Riffle/run P=Pool/glide	Description and Rationale
9. Condition of Banks	R P	The stream banks are eroded (or have the potential for erosion). Steep banks are more likely to collapse and suffer from erosion than are gently sloping banks and are therefore considered to be unstable. Signs of erosion include crumbling, unvegetated banks, exposed tree roots, and exposed soil
10. Bank Vegetative Protection	R P	The amount of the stream bank that is covered by vegetation. The root systems of plants growing on stream banks help hold soil in place, thereby reducing the amount of erosion that is likely to occur. This parameter supplies information on the ability of the bank to resist erosion, as well as some additional information on the uptake of nutrients by the plants, the control on instream scouring, and stream shading. Banks that have full, natural plant growth are better for fish and macroinvertebrates than are banks without vegetative protection or those shored up with concrete or riprap.
11. Grazing or Disruptive Pressure	R P	Disruptive changes to the riparian zone because of grazing or human interference (e.g., mowing). In areas of high grazing pressure from livestock or where residential and urban development activities disrupt the riparian zone, the growth of a natural plant community is impeded. Residential developments, urban centers, golf courses, and rangeland are the common causes of anthropogenic effects on the riparian zone.
12. Riparian Vegetated Zone Width	R P	The width of natural vegetation from the edge of the stream bank (riparian buffer zone). The riparian vegetative zone serves as a buffer zone to pollutants entering a stream from runoff, controls erosion, and provides stream habitat and nutrient input into the stream. A relatively undisturbed riparian zone reflects a healthy stream system; narrow, far less useful riparian zones occur when roads, parking lots, fields, lawns, bare soil, rocks, or buildings are near the stream bank. The presence of "old fields" (i.e., a previously developed field allowed to convert to natural conditions) will rate higher than fields in continuous or periodic use. Paths and walkways in an otherwise undisturbed riparian zone may be judged to be inconsequential to destruction of the riparian zone.

Reviewed by (initial): ______

RAPID HABITAT ASSESSMENT FORM: RIFFLE/RUN - STREAMS (continued)

SITE NAME:	DATE: / /	VISIT: G1 G2 ___	
SITE ID: ___ ___ ___ ___ ___ - ___ ___ ___ ___ ___	TEAM ID (X): G1 G2 G3 G4 G5 G6 G7 G8		

HABITAT PARAMETER	CATEGORY			
	OPTIMAL	SUB-OPTIMAL	MARGINAL	POOR
7. FREQUENCY OF RIFFLES	Occurrence of riffles is relatively frequent; the distance between riffles divided by the width of the stream equals 5 to 7; variety of habitat.	Occurrence of riffles is infrequent; distance between riffles divided by the width of the stream equals 7 to 15.	Occasional riffle or bend; bottom contours provide some habitat; distance between riffles divided by the width of the stream is between 15 to 25.	Generally all flat water or shallow riffles; poor habitat; distance between riffles divided by the width of the stream is greater than 25.
SCORE:	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
8. CHANNEL FLOW STATUS	Water reaches the base of both banks and a minimal area of channel substrate is exposed.	Water fills more than 75% of the available channel; or less than 25% of the channel substrate is exposed.	Water fill 25 to 75% of the available channel; and/or riffle substrates are mostly exposed.	Very little water in channel, and mostly present as standing pools.
SCORE:	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
9. CONDITION OF BANKS	Banks stable; no evidence of erosion or bank failure.	Banks moderately stable; infrequent, small areas of erosion mostly healed over.	Moderately unstable; up to 60% of banks in reach have areas of erosion.	Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; on side slopes, 60 to 100% of bank has erosional scars.
SCORE:	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
10. BANK VEGETATIVE PROTECTION	More than 90% of the stream bank surfaces are covered by vegetation.	70 to 90% of the stream bank surfaces are covered by vegetation.	50 to 70% of the stream bank surfaces are covered by vegetation.	Less than 50% of the stream bank surfaces are covered by vegetation.
SCORE:	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
11. GRAZING OR OTHER DISRUPTIVE PRESSURE	Vegetative disruption, through grazing or mowing is minimal or not evident; almost all plants are allowed to grow naturally.	Disruption is evident but is not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining.	Disruption is obvious; patches of bare soil or closely cropped vegetation are common; less than one-half of the potential plant stubble height remaining.	Disruption of stream bank vegetation is very high; vegetation has been removed to 2 inches or less in average stubble height.
SCORE:	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
12. RIPARIAN VEGETATION ZONE WIDTH (LEAST BUFFERED SIDE)	Width of riparian zone is greater than 18 m; human activities (i.e.; parking lots, roadbeds, clearcuts, lawns, or crops) have not impacted this zone.	Zone width is between 12 and 18 m; human activities have only minimally impacted this zone.	Zone width is between 6 and 12 m; human activities have impacted the zone a great deal.	Width of zone is less than 6 m; little or no riparian vegetation due to man-induced activities.
SCORE:	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Large Wood

Objective:

- Quantify the number and size of large wood pieces that are present within the bankfull channel, including qualifying side-channels.

Sampling method:

1. In order to be counted, each piece must meet **ALL** of the following criteria.
    a. Each piece must be greater than 3 meter in length and at least 30 cm in diameter one-third of the way up from the base, or largest end.
    b. Only include standing trees that lean within the bankfull channel if they are dead. Dead trees are defined as being devoid of needles or leaves, or where **ALL** of the needles and leaves have turned brown. Consider it living if the leaves or needles are green (Figure 15).

       Note: Use caution when assessing the condition of a tree or fallen log. Nurse logs can appear to have living branches when seedlings or saplings are growing on them.

    c. Wood that is embedded within the stream bank is counted if the exposed portion meets the length and width requirements.
    d. Do not count a piece if only the roots (but not the stem/bole) extend within the bankfull channel (Figure 16).
    e. Some pieces crack or break when they fall. Include the entire length when the two pieces are still touching at any point along the break (Only count as one piece if they are from the same original piece of wood). Treat them separately if they are no longer touching along the break. Count only the portion within the bankfull channel when they are no longer touching (Figures 17 &18).

2. Record the piece number, estimated length (nearest 10 cm), and estimated width (nearest cm) of all pieces in the site. The same person will make all estimates for a given site.
3. Also measure the length (nearest 10 cm) and diameter (nearest cm) of the first 10 pieces you encounter. The person estimating should not be made aware of the measured value.
4. A subset of pieces will be measured at sites with more than 10 qualifying pieces of wood.
    a. For sites estimated to have between 11 and 100 pieces, measure the first 10 pieces of wood encountered. Starting at piece number 11, measure every 5th piece of wood up to and including the 35th piece of wood. All subsequent pieces of wood will be measured every 10th piece (starting with number 45).
    b. For sites estimated to have over 100 pieces, measure the first ten pieces, then starting at the 11th piece only measure every 10th piece.

c. If the piece of wood designated for measurement can not be measured safely; then measure the next piece of qualifying wood. Then continue measuring as specified above in a and b.

5. Measure the length of the main stem and not branches or roots. Begin measurements where the roots attach to the base of the stem when the roots are still connected.
6. Do not measure (just estimate) standing dead trees, pieces buried in log jams, or pieces that are unsafe to measure.
7. Begin counting from the bottom up when pieces are stacked on each other.
8. For wood in qualifying side channels, count only the pieces that are within bankfull.
9. Percent of the wood submerged at bankfull is an estimate of how much of the piece of wood will be underwater when the stream reaches its **bankfull** height.
10. Number of pieces touching, wood location and wood type will be collected and recorded. Evaluate wood location relative to the bankfull channel (See Table 5 and Figure 19).

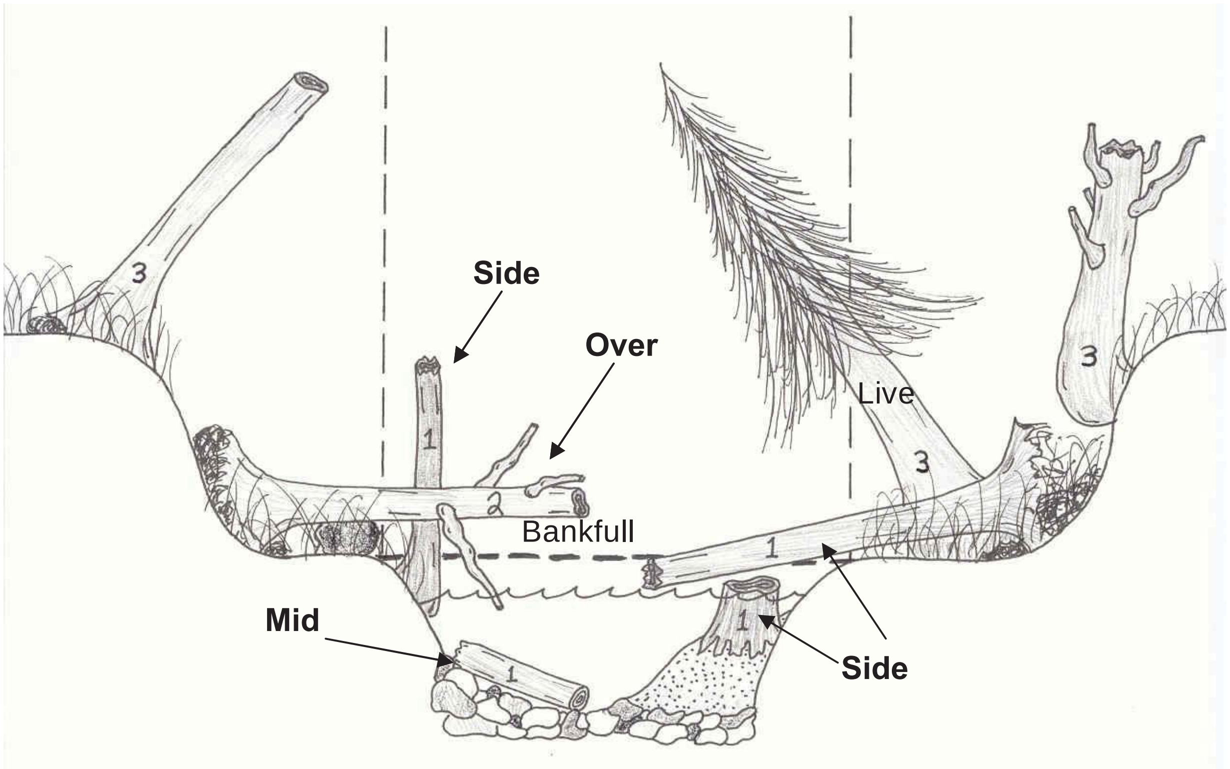


Figure 15. Illustration of large woody debris. Pieces numbered 1 and 2 would be included in the survey, while pieces numbered 3 would not be counted.

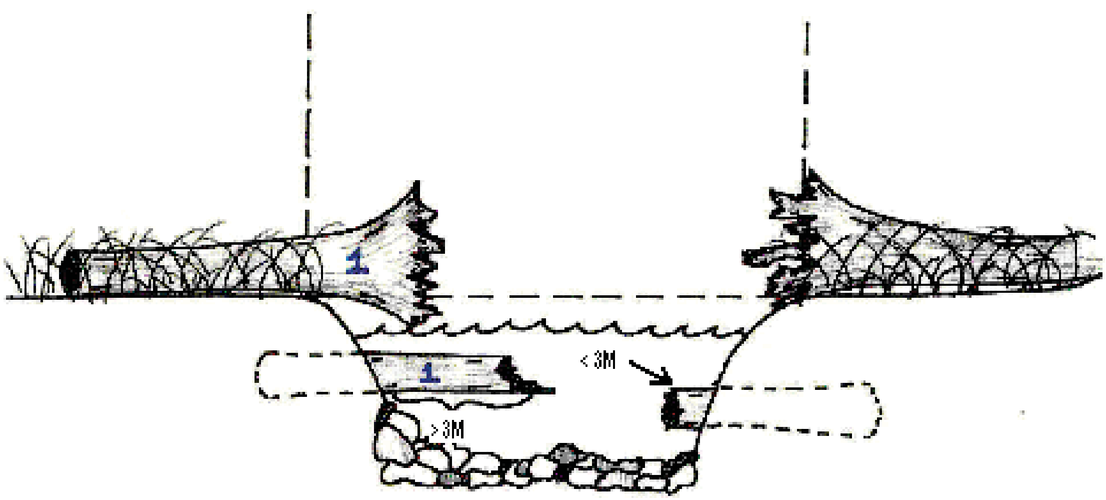


Figure 16. Examples of qualifying large woody debris (1). The pieces on the right side (3) are not counted because only the roots extend over the bankfull channel (upper) and the exposed section is < 3 m in length (lower).

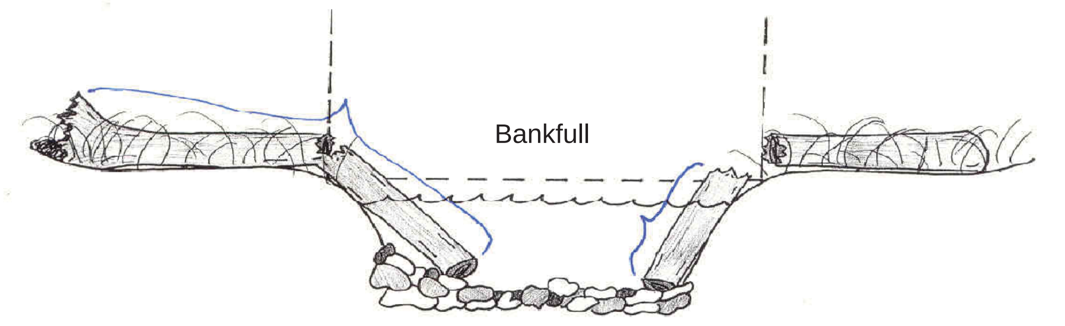


Figure 17. Examples of how to measure the length of broken pieces. Measure the length of the entire piece on the left (pieces still connected). Only measure the piece within the bankfull channel on the right.

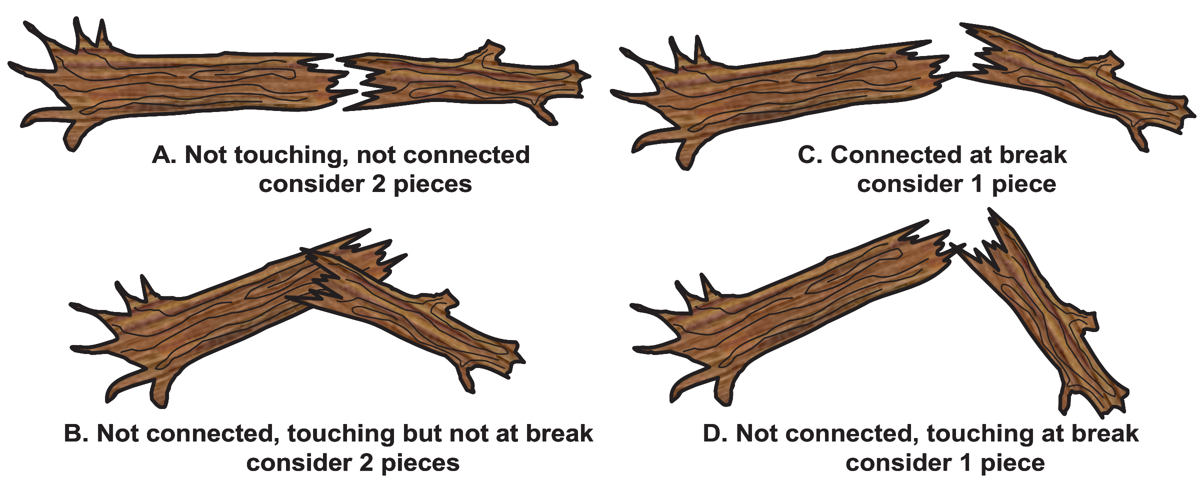


Figure 18. Variations of touching vs. not touching along the break.

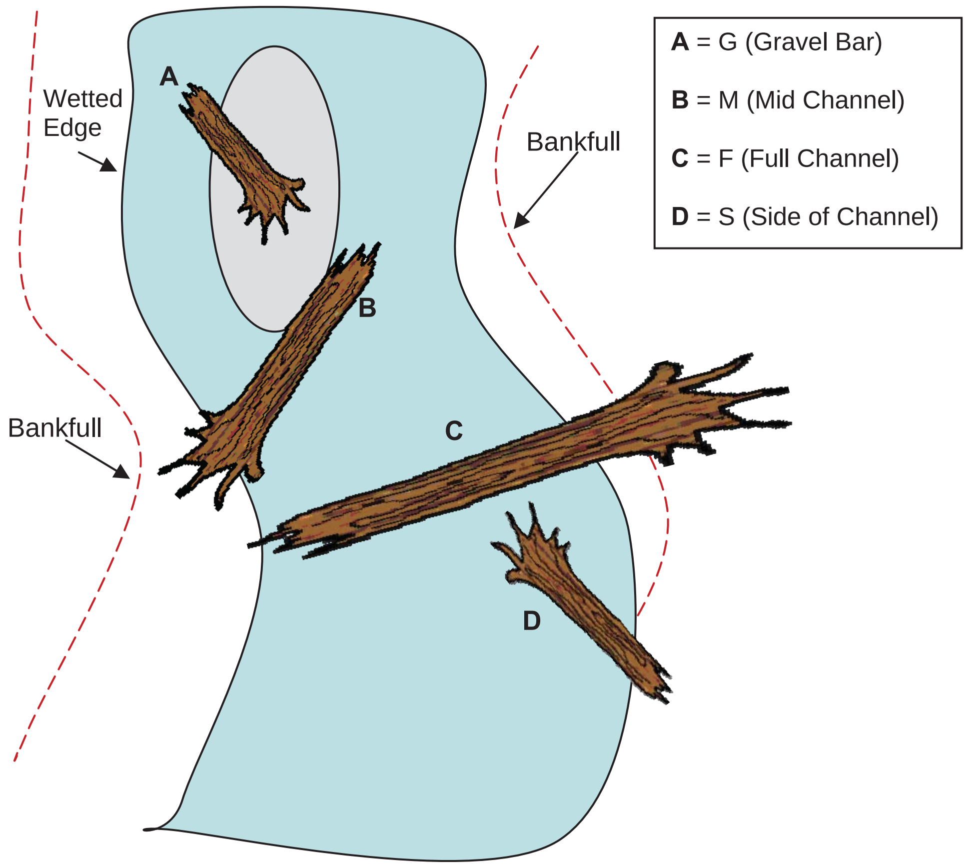


Figure 19. Example of wood locations in relation to the stream channel.

Table 5. Codes to be used with the wood data form.

Code Type	Definition
# Pieces Touching	
S →	**S**ingle piece
**A (1, 2, 3…) →	**A**ccumulation (2-4 pieces)
**J (1, 2, 3….) →	**J**am (≥5 pieces)
Wood Type	
N →	**N**atural (broken ends or entire trees)
C →	**C**ut end
A →	**A**rtificial (part of a man-made structure)
RN →	**R**oot wad attached to trunk with **N**atural end (broken or entire tree)
RC →	**R**oot wad with opposite end **C**ut
Wood Location	
S →	**S**ide of the channel - Piece of wood covers or extends over a small portion (0-25%) of the stream channel (near bankfull edge).
M →	**M**id channel - Wood is in the main flow of the channel at bankfull (can be any orientation, not exclusive to center of the channel).
G →	**G**ravel Bar- (Build up of sediment below bankfull elevation with water flowing on both sides.) - 50% or more of the piece of wood is located on the gravel bar
F →	**F**ull channel - Wood extends across 75% or more of the stream channel. Portions may extend beyond bankfull elevation.
O →	**O**ver the channel - Suspended over the active channel, above the bankfull elevation. Includes pieces with a suspended bole but the branches extend below bankfull elevation.
Percent Submerged	Categories:
A	0-25%
B	25-50%
C	50-75%
D	≥75%

****Jams and accumulations will be numbered sequentially, in the order that they are encountered.**

If you do not encounter any wood on a longitude, fill-in the datasheet with the longitude and add to comments that there is no wood on that particular longitude.

8.6 Particle Size Distribution and Cobble Embeddedness

Equipment: Gravelometer, depth rod.

Objective: Quantify the size distribution of substrate in fast water habitats and to estimate cobble embeddedness.

8.6.1 Particle Size Distribution

Step 1. Determine where to place cross-sections.

i. Count the number of Tier II riffle channel units that occur within the main channel and large side channels.

   a. If there are ≥10 riffles, place one cross-section in each of the first 10 riffles (working upstream).

   b. If there are less than 10 riffles, evenly distribute additional cross-sections into riffles according to the proportion of stream length that each unit comprises relative to the other riffles. If there is not enough space to conduct all measurements in riffles (see Step 1, ii, c), then evenly distribute remaining cross-sections into non-turbulent units (working upstream). If there is not enough space to conduct all measurements in riffles and non-turbulent units, then distribute remaining cross-sections into rapids.

ii. Cross-section location and spacing.

   a. When there is only one cross-section in a unit, place the cross-section at the midpoint of the unit.

   b. When there are multiple cross-sections in a unit, equally space the cross-sections throughout the unit (Figure 29). Cross-sections should be oriented perpendicular to the bankfull channel.

   c. Cross-sections should not be closer than $1/100^{th}$ of the site length apart. Move additional cross-sections to the next largest unit if too crowded. For example, the minimum spacing between cross-sections at a 120 m long site would be 1.2 m.

   d. Cross-sections should not cross two or more laterally adjacent channel units.

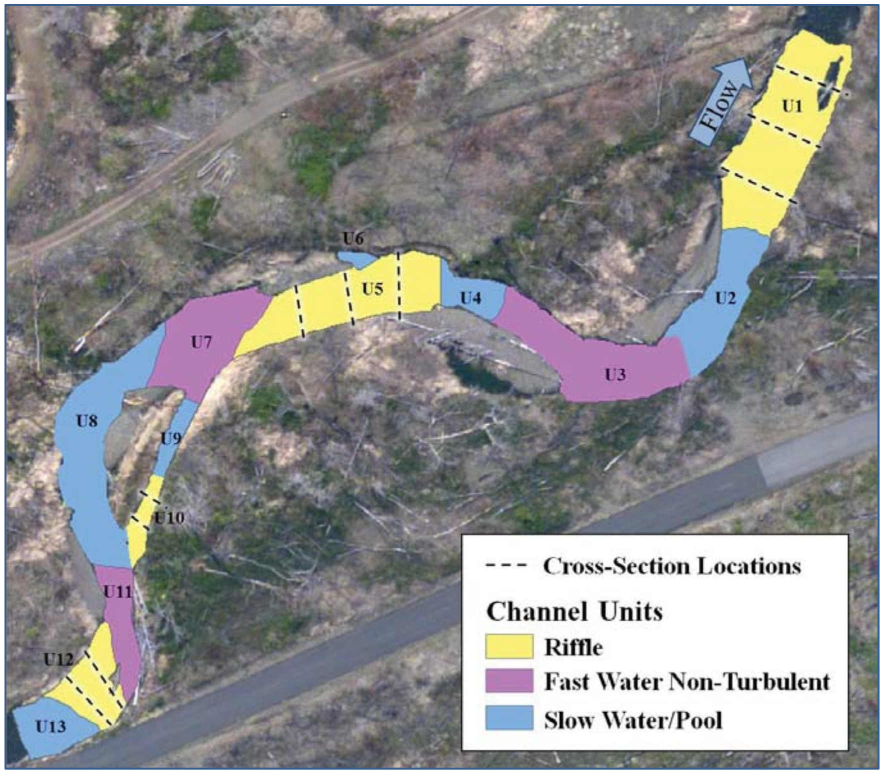


Figure 29. Example of how to distribute pebble count cross-sections at a site.

Step 2. Select 11 sampling points at each cross-section.

i. At each cross-section, visually divide the cross-section into 11 equally spaced sampling points running perpendicular to the stream channel, and spanning the width of the bankfull channel. (Figure 30).

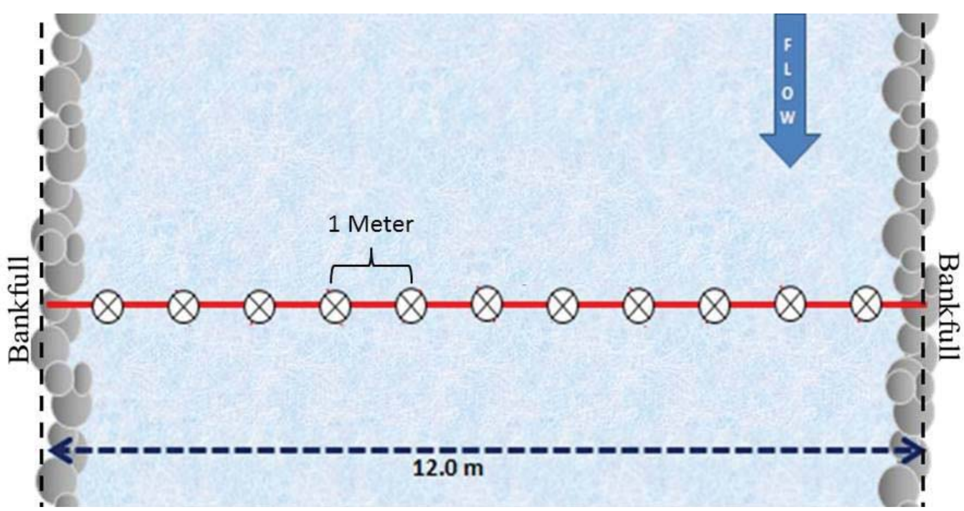


Figure 30. Example of a cross-section layout. In this example, distance between samples is 1 m, because the bankfull width is 12 m. Particle sample location is shown with a circle and crosshairs.

Step 3. Select and measure particles.

i. Select particles at sample points by turning your eye away and extending your finger down and picking up the first particle that you feel at the tip of your boot.

a. Use a gravelometer (Figure 31) to classify the b-axis of each particle. Record the size category (Table 8) for the largest square opening that the particle does not fit through. For example, if the particle fits through the 180 mm square but does not fit through the 128 mm square it is classified as the 128-180 mm size class.

b. Record silt and clay particles that are < 0.06 mm in the 0.0002-0.06 mm size class. Silt and clay particles are smooth when rubbed between the thumb and fingers whereas sand rolls between the fingers (is gritty).

c. Use the thin edge of the gravelometer to determine sand particles between 0.06 and 2 mm. (Note the thin edge of the gravelometer is 2 mm wide).

d. For particles > 128 mm and < 512 mm, measure the b-axis using the notches at the top of the gravelometer.

e. For particles > 512 mm, measure and record the length of the b-axis using the top edge of the gravelometer or a depth rod.

f. Record "bedrock" when encountered at sample points.

g. If your finger touches a thin layer of fine sediment covering a larger particle, then measure the fine sediment, not the larger particle. Conversely, if your finger touches a rock covered by individual fine sediment particles; measure the rock.

h. **Do not measure stream bank particles**.

i. For embedded particles that cannot be removed from the stream bed, use the notched edge of the gravelometer or the depth rod to measure the b-axis, and record the appropriate size class.

Figure 31. Gravelometer used to classify the b-axis of particles.

Table 8. Size categories for sediment in the range of silt/clay to bedrock. Record the size range that the particle falls within (e.g., 45-64).

Description of particle size		Size Range (mm) Lower	Upper
Bedrock		**n/a**	n/a
Boulder	mega	**> 4000**	n/a
	very large	**2896**	4000
		2048	2896
	large	**1448**	2048
		1024	1448
	medium	**724**	1024
		512	724
	small	**362**	512
		256	362
Cobble	large	**180**	256
		128	180
	small	**90**	128
		64	90
Gravel	very coarse	**45**	64
		32	45
	coarse	**22.6**	32
		16	22.6
	medium	**11.3**	16
		8	11.3
	fine	**5.7**	8
		4	5.7
	very fine	**2**	4
Sand		**0.06**	2
Silt/Clay		**0.0002**	0.06

8.6.2 Cobble Embeddedness

Cobble embeddedness is a measure of the degree to which a cobble is buried by fine sediment.

Embeddedness is the percentage of a cobble's surface that is surrounded by fine sediment (< 2 mm). High cobble embeddedness results in a reduction of interstitial spaces between particles and makes the substrate more difficult to move (think of a fish's tail).

i. Estimate embeddedness for all cobble-sized particles (64 mm – 256 mm) that are selected during particle size distribution sampling. Record estimates to the nearest 5%.

ii. Embeddedness is estimated as the product of two values:

   a. The percentage of the cobble's surface that is buried below the surface of the streambed (Figure 32A), and

   b. The percentage of fine sediment < 2 mm in the substrate immediately surrounding the cobble (Figure 32B).

Appendix J

Shade Measurements at Major Transects in Waded Streams

Purpose and Scope

This method explains how to measure shade for the Status and Trends Program at each of 11 equidistant transects at each site. Measurements in this procedure will be restricted to one main channel. This method must be preceded by the Major Transects Method.

Instruments included on the procedure include a distance measuring device (e.g., measuring rod), and a convex densiometer (modified according to Mulvey *et al.* (1992)).

Definitions

Definitions of acronyms and other terms are found in Table J-1.

Table J-1. Definitions.

Term or Accronym	Definition
bankfull channel width	Horizontal distance between the bankfull stage on the left bank and the bankfull stage on the right bank.
bankfull stage	This stage is delineated by the elevation point of incipient flooding, indicated by deposits of sand or silt at the active scour mark, break in stream bank slope, perennial vegetation limit, rock discoloration, and root hair exposure (Endreny 2009).
left bank	A person facing downstream will have the left bank on their left side.
main channel	Channels in a stream are divided by islands (dry ground that rises above bankfull stage). Main channels contain the greatest proportion of flow. For this method it is called channel number 0.
major transect	One of 11 equidistant transects across the length of a site. These are labeled as follows: A0 (lowest), B0,C0,….K0 (highest) A major transect will cross the main channel and side channels.
right bank	A person facing downstream will have the right bank on their right

	side.
station	Any location within the site where an observation is made or part of a sample is collected.
side channels	Channels that contain less flow than the main channels. These are identified and enumerated (1,2,3 etc.) as encountered (see the method for thalweg measurements) during the data collection event.
site	A site is defined by the coordinates provided to a sampling crew and the boundaries established by the site layout method. Typically, the site extends 10 bankfull widths downstream from the coordinates and 10 bankfull widths upstream. The site also includes all riparian plots examined during the *Data Collection Event*. The site consists of many stations at which measurements or samples are collected.
transect	A line of study that crosses the direction of flow, divided into intervals where observations are collected.

Personnel Responsibilities

This method is performed by 1 person. This method is applied at every DCE, at each major transect. Staff performing this method must have been trained.

Equipment, Reagents, Supplies

- No. 2 pencil
- *Major Transect Form*
- measuring rod or 50-m tape
- Modified convex densiometer

Summary of Procedure

Refer to the *Major Transect Form* (Figure J-1). At each of the major Transects (A0-K0), assess the main channel (channel number 0). Use a convex densiometer (Lemmon, 1957) that has been modified according to Mulvey *et al* (1992; figure J-2); it has 17 intersections.

DENSIOMETER MEASUREMENTS

(0-17Max)

		Flag			Flag
CenUp	5		CenR	9	
CenL	0		Left	0	
CenDwn	4		Right	17	

Figure J-1. Densiometer portion of The *Major Transects Form*, with example data.

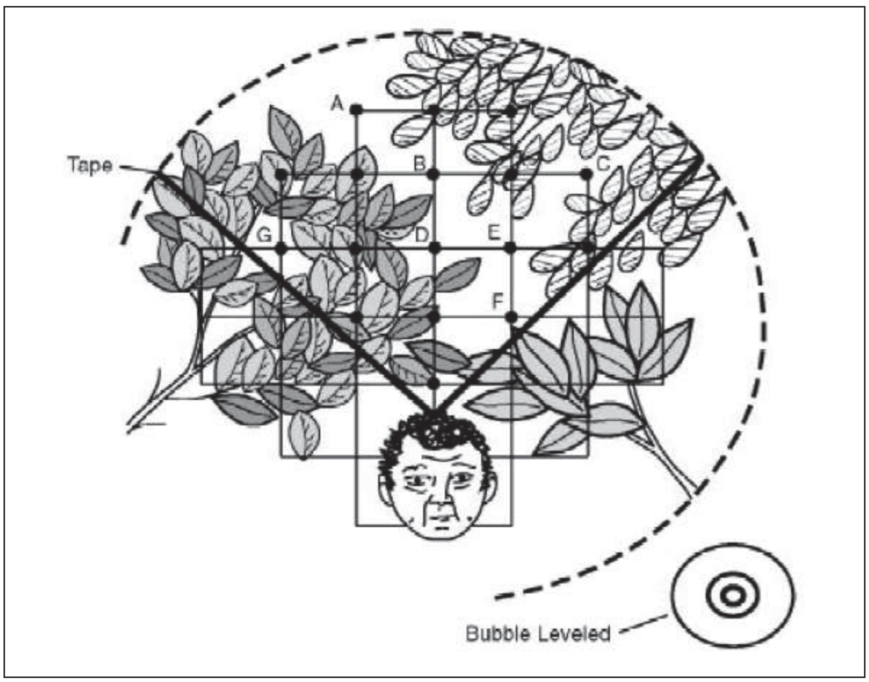


Figure J-2. An example reading from a modified convex densiometer. It shows 10 of 17 intersections with shade (a score of "10"). Note the proper positions of the bubble and head reflection (From Mulvey *et al*. 1992).

Record how many of the 17 cross-hairs have shade over them. Do this for each of six directions on the major transect (Figure J-3):

- Facing the left bankfull stage

- Facing the right bankfull stage
- Bankfull channel center, facing upstream
- Bankfull channel center, facing right
- Bankfull channel center, facing downstream
- Bankfull channel center, facing left

At each wetted station, hold the densiometer 30 cm above the water. At each dry station, hold the densiometer 30 cm above the ground. Bank readings should be able to detect shade from riparian understory vegetation such as ferns.

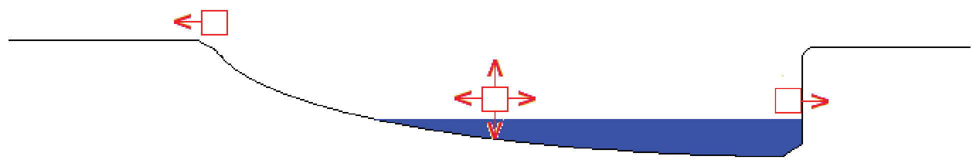


Figure J-3. Stations for densiometer measurement on each major transect. The densiometer is held level, and 30 cm above water for wet stations and 30 cm above ground for dry stations.

References

Endreny, T.A. 2009. *Fluvial Geomorphology Modules*, State University of New York College of Environmental Science and Forestry, National Oceanic and Atmospheric Administration, and the University Corporation for Atmospheric Research. www.fgmorph.com

Lemmon, P.E. 1957. A New Instrument for Measuring Forest Overstory Density. Journal of Forestry. 55(9):667-668.

Mulvey, M, L. Caton, and R. Hafele. 1992. Oregon Nonpoint Source Monitoring Protocols and Stream Bioassessment Field Manual for Macroinvertebrates and Habitat Assessment, Draft. Oregon Department of Environmental Quality, Portland, Oregon.

Appendix L

Riparian Vegetation Structure at Transects in Wide Streams & Rivers

Purpose and Scope

This method explains how to collect measurements for WHSR at each of 11 transects at each site. Observations in this procedure will be restricted to one main channel. This method must follow pre-season site layout.

Definitions

Definitions of acronyms and other terms are found in Table L-1.

Table L-1. Definitions.

Term or Acronym	Definition
Bankfull stage	This stage is delineated by the elevation point of incipient flooding, indicated by deposits of sand or silt at the active scour mark, break in stream bank slope, perennial vegetation limit, rock discoloration, and root hair exposure (Endreny 2009).
Broadleaf evergreen	Non-coniferous trees that maintain foliage through the seasons. A native example for Washington is the madrona (*Arbutus menziesii*)
Canopy	The functional definition for this method: Vegetation above 5 m high within a 10 m x 10 m riparian plot.
Coniferous	Any of various mostly needle-leaved or scale-leaved, chiefly evergreen, cone-bearing gymnospermous trees or shrubs such as pines, spruces, and firs. This includes larch.
Cover	This can be thought of as the amount of shadow cast by a particular layer alone when the sun is directly overhead. Conceptually remove vegetation from higher layers before estimating.
DCE	Data Collection Event. Data are indexed using this code which includes the SITE_ID, the date, and the time that the event began. It uses this format: **WAM06600-NNNNNN-dce-20YY-MMDD-HHMM** **NNNNNN** = the number portion of the SITE_ID. **YY** = the last two numeric digits of the year that the event occurred. **MM** = the two numeric digits for the month that the event occurred.

	DD = the two numeric digits for the day within the month that the event occurred. **HHMM** = the military time when the event began.
Deciduous	Non-coniferous trees that shed their leaves annually. Examples include alder, oak, maple, and cottonwood.
Duff	Organic matter in various stages of decomposition on the floor of the forest.
Forbs	A broad-leaved herb other than a grass, such as those that grow in a field, prairie, or meadow.
Ground cover	The functional definition for this method: Vegetation or bare ground below 0.5 m high within a 10 m x 10 m riparian plot.
Herbs	Plants whose stems do not produce woody, persistent tissue. They generally die back at the end of each growing season.
Left bank	A person facing downstream will have the left bank on their left side.
Main channel	Channels in a stream are divided by islands (dry ground that rises above bankfull stage). Main channels contain the greatest proportion of flow. For this method it is called channel number 0.
major transect	One of 11 equidistant transects across the length of a site. These are labeled as follows: A0 (lowest), B0,C0,….K0 (highest)
Mixed	Vegetation type if more than 10% of the cover is made up of an alternate type.
Right bank	A person facing downstream will have the right bank on their right side.
Side channels	Channels that contain less flow than the main channels. These are identified and enumerated (1,2,3 etc.) as encountered (see the method for thalweg measurements) during the DCE.
Understory	The functional definition for this method: Vegetation below 5 m high but above 0.5 m high within a 10 m x 10 m riparian plot.

Personnel Responsibilities

This method is performed by 1 person. This method is applied at every DCE, at each major transect. Observations are made at both banks of the main channel. Staff performing this method must have been trained.

Equipment, Reagents, Supplies

- No. 2 pencil
- *Major Transect Data Form*

Summary of Procedure

This procedure is derived from Peck et al. (2006) and Moberg (2007).

Refer to the *Major Transect Data Form* (Figure L-1). At each of the major Transects (A0-K0), in the main channel, evaluate a 10 m x 20 m riparian plot (Figure L-2) on the bank that was designated during pre-season site layout.. The riparian plot dimensions can be estimated rather than measured. On steeply sloping channel margins, plot boundaries are defined as if they were projected down from an aerial view.

Conceptually divide the riparian vegetation into three layers:

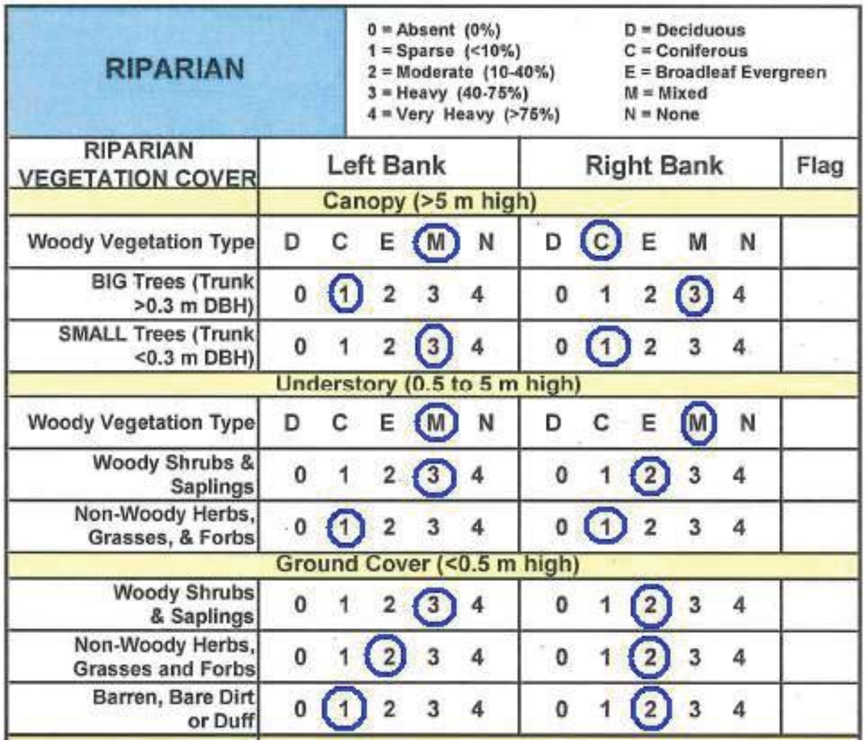
- Canopy (> 5 m high),
- Understory (0.5 to 5 m high),
- Ground Cover layer (< 0.5 m high).

Within each layer, consider the type of vegetation present and the amount of cover provided. Do this independently of what is contained in higher layers.

Cover quantity is coded on the field form (Figure L-1) as follows:

- 0 - absent
- 1- sparse (< 10% cover)
- 2 - moderate (10-40% cover)
- 3 - heavy (40-75% cover)
- 4 – very heavy (> 75% cover)

The maximum cover in each layer is 100%, so the sum of the cover for the combined three layers could add up to 300%. Ground cover scores must add to 100%.



RIPARIAN	0 = Absent (0%) 1 = Sparse (<10%) 2 = Moderate (10-40%) 3 = Heavy (40-75%) 4 = Very Heavy (>75%)	D = Deciduous C = Coniferous E = Broadleaf Evergreen M = Mixed N = None	
RIPARIAN VEGETATION COVER	Left Bank	Right Bank	Flag
Canopy (>5 m high)			
Woody Vegetation Type	D C E **(M)** N	D **(C)** E M N	
BIG Trees (Trunk >0.3 m DBH)	0 **(1)** 2 3 4	0 1 2 **(3)** 4	
SMALL Trees (Trunk <0.3 m DBH)	0 1 2 **(3)** 4	0 **(1)** 2 3 4	
Understory (0.5 to 5 m high)			
Woody Vegetation Type	D C E **(M)** N	D C E **(M)** N	
Woody Shrubs & Saplings	0 1 2 **(3)** 4	0 1 **(2)** 3 4	
Non-Woody Herbs, Grasses, & Forbs	0 **(1)** 2 3 4	0 **(1)** 2 3 4	
Ground Cover (<0.5 m high)			
Woody Shrubs & Saplings	0 1 2 **(3)** 4	0 1 **(2)** 3 4	
Non-Woody Herbs, Grasses and Forbs	0 1 **(2)** 3 4	0 1 **(2)** 3 4	
Barren, Bare Dirt or Duff	0 **(1)** 2 3 4	0 1 **(2)** 3 4	

Figure L-1. A portion of the *Major Transect Data Form*, with example data.

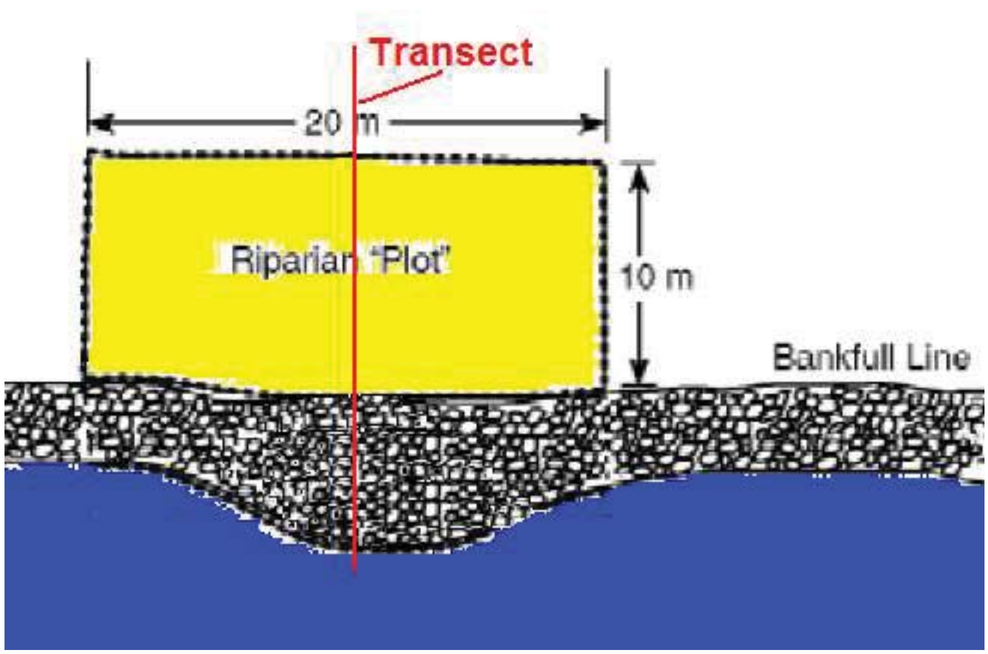


Figure L-2. One of two riparian plots at a transect.

Canopy

On the *Major Transect Form* (Figure L-1), circle the appropriate vegetation **type code** (D, C, E, M, or N). Type codes are defined on the form. The M (mixed) code means that there is any percentage of a second vegetation type.

Then circle the appropriate cover **quantity code** (0, 1, 2, 3, or 4) for each of 2 classes:

- Big trees – trees having trunks larger than 0.3 m diameter (at breast height)
- Small trees– trees having trunks smaller than 0.3 m diameter (at breast height)

Understory

On the *Major Transect Form* (Figure I-1), circle the appropriate vegetation **type code** (D, C, E, M, or N) for any *woody* vegetation that might be present. Then circle the appropriate cover **quantity code** (0, 1, 2, 3, or 4) for each of 2 classes:

- Woody vegetation - such as shrubs, saplings, or tree trunks
- Non-woody vegetation - such as herbs, grasses, or forbs

Ground Cover

Circle the appropriate cover **quantity code** (0, 1, 2, 3, or 4) for each of 3 classes:

- Woody (living)
- Non-woody (living)
- Bare dirt (or decomposing debris)

The sum of cover quantity ranges for these 3 types of ground cover should include 100%.

References

Endreny, T.A. 2009. *Fluvial Geomorphology Modules*, State University of New York College of Environmental Science and Forestry, National Oceanic and Atmospheric Administration, and the University Corporation for Atmospheric Research. www.fgmorph.com

Peck, D.V., Herlihy, A.T., Hill, B.H., Hughes, R.M., Kaufmann, P.R., Klemm, D.J., Lazorchak, J.M., McCormick, F.H., Peterson, S.A., Ringold, P.L., Magee, T., and Cappaert, M.R. Environmental Monitoring and Assessment Program-Surface Waters, Western Pilot Study, Field Operations Manual for Wadeable Streams. EPA/620/R-06/003. U.S. Environmental Protection Agency, Washington, D.C.
http://www.epa.gov/wed/pages/publications/authored/EPA620R-06003EMAPSWFieldOperationsManualPeck.pdf

Moberg, J. 2007. A field manual for the habitat protocols of the Upper Columbia Monitoring Strategy. Prepared for and funded by Bonneville Power Administration's Integrated Status and Effectiveness Monitoring Program. Terraqua, Inc. Wauconda, WA
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Appendix M

Riparian Vegetation Structure at Major Transects in Waded Streams

Purpose and Scope

This method explains how to collect measurements for the Status and Trends Program at each of 11 equidistant transects at each site. Observations in this procedure will be restricted to one main channel. This method must follow the method for establishing major transects.

Definitions

Definitions of acronyms and other terms are found in Table M-1.

Table M-1. Definitions.

Term or Acronym	Definition
Bankfull stage	This stage is delineated by the elevation point of incipient flooding, indicated by deposits of sand or silt at the active scour mark, break in stream bank slope, perennial vegetation limit, rock discoloration, and root hair exposure (Endreny 2009).
Broadleaf evergreen	Non-coniferous trees that maintain foliage through the seasons. A native example for Washington is the madrona (*Arbutus menziesii*)
Canopy	The functional definition for this method: Vegetation above 5 m high within a 10 m x 10 m riparian plot.
Coniferous	Any of various mostly needle-leaved or scale-leaved, chiefly evergreen, cone-bearing gymnospermous trees or shrubs such as pines, spruces, and firs. This includes larch.
Cover	This can be thought of as the amount of shadow cast by a particular layer alone when the sun is directly overhead. Conceptually remove vegetation from higher layers before estimating.
DCE	Data Collection Event. Data are indexed using this code which includes the SITE_ID, the date, and the time that the event began. It uses this format: **WAM06600-NNNNNN-dce-20YY-MMDD-HHMM** **NNNNNN** = the number portion of the SITE_ID. **YY** = the last two numeric digits of the year that the event occurred. **MM** = the two numeric digits for the month that the event occurred.

	DD = the two numeric digits for the day within the month that the event occurred. **HHMM** = the military time when the event began.
Deciduous	Non-coniferous trees that shed their leaves annually. Examples include alder, oak, maple, and cottonwood.
Duff	Organic matter in various stages of decomposition on the floor of the forest.
Forbs	A broad-leaved herb other than a grass, such as those that grow in a field, prairie, or meadow.
Ground cover	The functional definition for this method: Vegetation or bare ground below 0.5 m high within a 10 m x 10 m riparian plot.
Herbs	Plants whose stems do not produce woody, persistent tissue. They generally die back at the end of each growing season.
Left bank	A person facing downstream will have the left bank on their left side.
Main channel	Channels in a stream are divided by islands (dry ground that rises above bankfull stage). Main channels contain the greatest proportion of flow. For this method it is called channel number 0.
major transect	One of 11 equidistant transects across the length of a site. These are labeled as follows: A0 (lowest), B0,C0,….K0 (highest)
Mixed	Vegetation type if more than 10% of the cover is made up of an alternate type.
Right bank	A person facing downstream will have the right bank on their right side.
Side channels	Channels that contain less flow than the main channels. These are identified and enumerated (1,2,3 etc.) as encountered (see the method for thalweg measurements) during the DCE.
Understory	The functional definition for this method: Vegetation below 5 m high but above 0.5 m high within a 10 m x 10 m riparian plot.

Personnel Responsibilities

This method is performed by 1 person. This method is applied at every DCE, at each major transect. Observations are made at each bank of the main channel. Staff performing this method must have been trained.

Equipment, Reagents, Supplies

- No. 2 pencil
- *Major Transect Data Form*

Summary of Procedure

This procedure is derived from Peck et al. (2006) and Moberg (2007).

Refer to the *Major Transect Data Form* (Figure M-1).

RIPARIAN	0 = Absent (0%) 1 = Sparse (<10%) 2 = Moderate (10-40%) 3 = Heavy (40-75%) 4 = Very Heavy (>75%)	D = Deciduous C = Coniferous E = Broadleaf Evergreen M = Mixed N = None	
RIPARIAN VEGETATION COVER	**Left Bank**	**Right Bank**	**Flag**
	Canopy (>5 m high)		
Woody Vegetation Type	D C E **M** N	D **C** E M N	
BIG Trees (Trunk >0.3 m DBH)	0 **1** 2 3 4	0 1 2 **3** 4	
SMALL Trees (Trunk <0.3 m DBH)	0 1 2 **3** 4	0 **1** 2 3 4	
	Understory (0.5 to 5 m high)		
Woody Vegetation Type	D C E **M** N	D C E **M** N	
Woody Shrubs & Saplings	0 1 2 **3** 4	0 1 **2** 3 4	
Non-Woody Herbs, Grasses, & Forbs	0 **1** 2 3 4	0 **1** 2 3 4	
	Ground Cover (<0.5 m high)		
Woody Shrubs & Saplings	0 1 2 **3** 4	0 1 **2** 3 4	
Non-Woody Herbs, Grasses and Forbs	0 1 **2** 3 4	0 1 **2** 3 4	
Barren, Bare Dirt or Duff	0 **1** 2 3 4	0 1 **2** 3 4	

Figure M-1. A portion of the *Major Transect Data Form*, with example data.

On each major transect of the main channel, assess a plot on each bank. Each plot extends 5 meters downstream, 5 meters upstream, and 10 meters back from the bankfull margin. The riparian plot dimensions can be estimated rather than measured. On steeply sloping channel margins, plot boundaries are defined as if they were projected down from an aerial view.

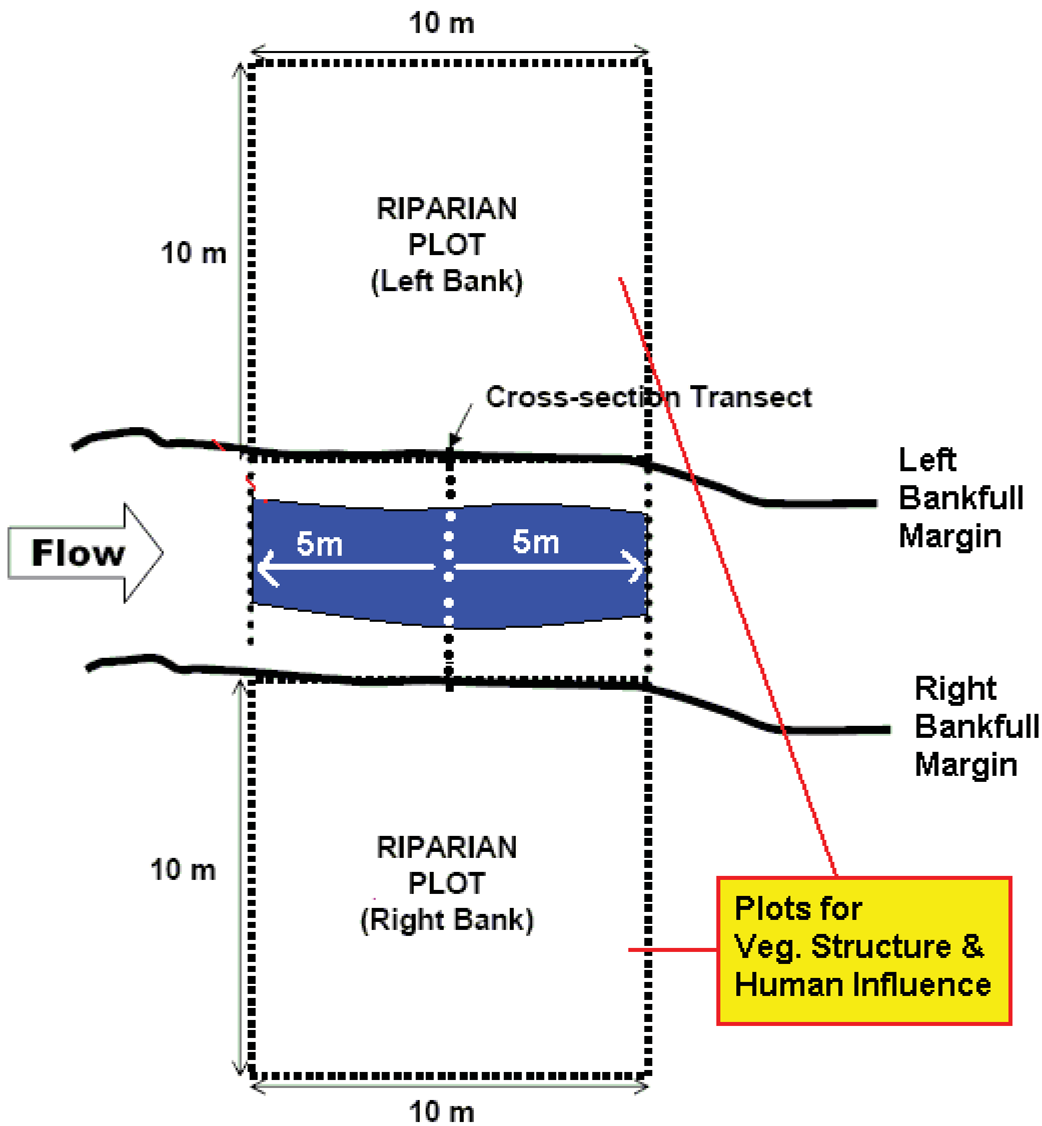

Figure M-2. Riparian plots

Conceptually divide the riparian vegetation into three layers:

- Canopy (> 5 m high),
- Understory (0.5 to 5 m high),
- Ground Cover layer (< 0.5 m high).

Within each layer, consider the type of vegetation present and the amount of cover provided. Do this independently of what is contained in higher layers.

Cover quantity is coded on the field form (Figure I-1) as follows:

- 0 - absent
- 1- sparse (< 10% cover)
- 2 - moderate (10-40% cover)
- 3 - heavy (40-75% cover)
- 4 – very heavy (> 75% cover)

The maximum cover in each layer is 100%, so the sum of the cover for the combined three layers could add up to 300%.

Canopy

On the *Major Transect Form* (Figure I-1), circle the appropriate vegetation **type code** (D, C, E, M, or N). Type codes are defined on the form.

Then circle the appropriate cover **quantity code** (0, 1, 2, 3, or 4) for each of 2 classes:

- Big trees – trees having trunks larger than 0.3 m diameter (at breast height)
- Small trees– trees having trunks smaller than 0.3 m diameter (at breast height)

Understory

On the *Major Transect Form* (Figure I-1), circle the appropriate vegetation **type code** (D, C, E, M, or N) for any *woody* vegetation that might be present. Then circle the appropriate cover **quantity code** (0, 1, 2, 3, or 4) for each of 2 classes:

- Woody vegetation - such as shrubs or saplings
- Non-woody vegetation - such as herbs, grasses, or forbs

Ground Cover

Circle the appropriate cover **quantity code** (0, 1, 2, 3, or 4) for each of 3 classes:

- Woody (living)
- Non-woody (living)
- Bare dirt (or decomposing debris)

The sum of cover quantity ranges for these 3 types of ground cover should include 100%.

References

Endreny, T.A. 2009. *Fluvial Geomorphology Modules*, State University of New York College of Environmental Science and Forestry, National Oceanic and Atmospheric Administration, and the University Corporation for Atmospheric Research. www.fgmorph.com

Moberg, J. 2007. A field manual for the habitat protocols of the Upper Columbia Monitoring Strategy. Prepared for and funded by Bonneville Power Administration's Integrated Status and Effectiveness Monitoring Program. Terraqua, Inc. Wauconda, WA http://www.nwfsc.noaa.gov/research/divisions/cbd/mathbio/isemp/docs/isemphabitatprotocolsfieldmanualdraft070615.pdf

Peck, D.V., Herlihy, A.T., Hill, B.H., Hughes, R.M., Kaufmann, P.R., Klemm, D.J., Lazorchak, J.M., McCormick, F.H., Peterson, S.A., Ringold, P.L., Magee, T., and Cappaert, M.R. Environmental Monitoring and Assessment Program-Surface Waters, Western Pilot Study, Field Operations Manual for Wadeable Streams. EPA/620/R-06/003. U.S. Environmental Protection Agency, Washington, D.C. http://www.epa.gov/wed/pages/publications/authored/EPA620R-06003EMAPSWFieldOperationsManualPeck.pdf

9.5 Water Temperature

Reference: Isaak et al. (2010).

Equipment: Onset TidbiT, PVC housing material/cables, epoxy, rubber gloves, underwater viewer.

Objective: Install year round water temperature sensors at sites using one of two installation methods.

Water temperature sensors will be placed at all annual and rotating panel sites within each CHaMP subbasin. At new sites where sensors have not been established, it is important that watershed leads make a concerted effort to install all sensors before high summer temperatures (approx. July 15). When early flow conditions do not permit installation with the epoxy method, use the wire method initially and have the crew members apply the epoxy method (where applicable) after flows have subsided. Temperature data should be downloaded in the fall and before high spring flows.

9.5.1 Establishing New Sensors

Step 1. Identify sensor placement location.

i. Epoxy Method: Search for a large rock or boulder (charismatic megaboulders are best) that will be immobile during large floods and is easy for others to identify on subsequent site visits. Finding a good rock is the most important step to a successful sensor installation. If a suitable rock is not available, consider placement using the wire method.
    a. Optimal placement locations for rock and boulder secured sensors include:
        i. Rocks, boulders, or structures that will not move or be disturbed at high flows.
        ii. Boulders large enough that they protrude above the low flow water surface and wide enough that they can effectively shield the sensor from moving rocks or debris during high flows.
        iii. Areas downstream of large rocks in pockets of relatively calm water with smaller substrate sizes.
        iv. A relatively flat downstream attachment surface that is deep enough to remain submerged in flowing water for the entire year.

ii. Cable Method: If there is not a suitable rock or boulder within or in close proximity (100 m) to the site, identify a secure location such as the base of a tree or root wad to attach the sensor using a metal cable.
    a. Optimal placement locations for cable secured sensors include:
        i. Areas with sufficient stream flow that will maintain year-round flow, but outside of strong currents. Also consider whether the sensor attached to the wire will move at high flows and place sensor so that it will not get hung up in vegetation or left on the bank.
        ii. Locations away from seeps or steep banks on the side of stream in order to avoid groundwater influences.

iii. Camouflaged or inconspicuous locations at sites with high public use. In these instances, vegetation, grasses, or cobbles may be used to cover wire or hold wire in place.

b. Suitable locations for attaching sensors may be relatively rare within low-gradient, meadow reaches. In these instances, examine potential placement locations no more than 100 m upstream or downstream of the site and away from tributary influences.

Step 2. Install and record sensor location details.

i. After identifying a suitable sensor placement location:

a. Record sensor serial number.

b. Install sensor.

c. Take a GPS reading. Record UTM coordinates, accuracy, and the date and time installed.

d. Record the stream bank that the sensor is nearest to and the distance from that stream bank. If cable is attached to a tree on the bank, record the distance from bank as 0.

e. Record the attachment method as cable or epoxy.

f. Take a photo of the sensor location. Include enough of the surrounding environment in the photo to relocate the sensor.

g. Write a detailed description of the sensor location in the placement location field. Description should include distance from site bottom and any other pertinent information for relocating sensor at subsequent visits. The more detail the better. For example: Sensor attached to grey, rectangular boulder 1 m in diameter near river left (~1.5 m from bank), 5 m upstream from transect 12 OR Sensor is attached to the base of a small willow, ~ 6 m downstream from top of site on river right.

h. Note sensor location on site map.

i. After sensor has been in the water for approximately 1 hour, measure and record the instantaneous water temperature near the sensor using a handheld thermometer. Record the date and time instantaneous temperature is measured. It is preferable to measure the instantaneous water temperature at the top of the hour when the installed sensor will be recording information.

9.5.2 Previously Installed Sensors

Step 1. Locate previously installed sensor.

i. Use existing photographs, GPS coordinates, and site maps to locate the previously installed water temperature sensor.

a. If sensor location is found but sensor is missing, search downstream to see if sensor can be found. Note if sensor cannot be located. Establish a new sensor using the criteria outlined above.

Step 2. Download sensor data and record information

i. Remove the sensor from the housing unit and confirm that the correct sensor serial number was recorded when originally installed. Avoid removing sensor from the water when it will be recording one of its hourly temperature measurements (on the hour).

   a. Download sensor using the sensor shuttle (Appendix G).

   b. Note whether the red light on the sensor is blinking. If there is no blinking light, replace the sensor and notify the watershed lead.

   c. Record in the sensor condition field the current condition of the sensor as being submerged in flowing water, submerged in non-flowing water, dry, or missing.

   d. Record if the sensor has been left in place, removed, or moved to a more suitable location. Move the sensor if it is in non-flowing water or buried in sediment. Replace sensor with a new one if it is missing. Record action in the action field.

   e. Take a new GPS reading. Record UTM coordinates, accuracy, and the date and time sensor was downloaded or checked.

   f. Verify and update sensor location information as needed such as stream bank, distance from bank, attachment method, and location description.

   g. Take a new photo of the sensor.

   h. Measure and record the instantaneous water temperature near the sensor using a handheld thermometer. Record the date and time instantaneous temperature is measured. It is preferable to measurement the instantaneous water temperature at the top of the hour when the installed sensor will be recording information.

   i. Note the sensor location in the site map.

Appendix E

Example Data Sheets

LWD FORM

DCE:

Ch Un #	Piece ID	Large Wood Type	Diameter (m)	Length (m)	Method	Notes
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
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		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	
		WET *or* DRY			ESTIMATED *or* MEASURED	

Wolmann Pebble Count

Date ______________ Stream __________

Reach ______________ Crew __________

Unit # ______________ BFW (m) __________

Transect # ______________

	size (mm)	Count	Total #
Clay/Silt	<0.062		
Sand	0.062-4.0		
G	4 - 5.6		
R	5.6 - 8		
A	8-11		
V	11-16		
E	16 - 22		
L	22 – 32		
S	32 - 45		
	45 - 64		
C	64 - 90		
O	90 - 128		
B	128 - 180		
B	180 - 256		
B	256 - 362		
L	362 - 512		
D	512 - 1024		
R	1024 - 2048		
S	2048 - 4096		
Bdrck	Bedrock		

Total =

Comments:

Date ______________ Stream __________

Reach ______________ Crew __________

Unit # ______________ BFW (m) __________

Transect # ______________

	size (mm)	Count	Total #
Clay/silt	<0.062		
Sand	0.062-4.0		
G	4 - 5.6		
R	5.6 - 8		
A	8-11		
V	11-16		
E	16 - 22		
L	22 – 32		
S	32 - 45		
	45 - 64		
C	64 - 90		
O	90 - 128		
B	128 - 180		
B	180 - 256		
B	256 - 362		
L	362 - 512		
D	512 - 1024		
R	1024 - 2048		
S	2048 - 4096		
Bdrck	Bedrock		

Total =

Comments:

Transect Characteristics Datasheet

Date ________________ Crew ___________________________________ Page _____ of _____

Stream Name______________________Reach #_______Habitat Unit_________Transect #_______________

GPS Location (*US and DS end*) US DS

Waypoint:__________ -*or*- UTM (Zone 11T): Easting:___________________Northing:___________________

Channel form and constraining features

Channel Type (circle): *Colluvial* *Alluvial* *Bedrock*

Alluvial type (circle): *Cascade* *Step pool* *Forced step pool* *Plane bed*

Pool/riffle *Forced pool/riffle* *Dune-ripple*

Bank stability (circle) *Optimal* *Sub-optimal* *Marginal* *Poor*

Bank modification (% of each code)[1] LB ______________________________

RB ______________________________

Bankfull Depth (BFD):

Rod Height at Thalweg:________ Rod Height at Bankfull Elev.__________ Difference = BFD ___________

Bankfull Width:___________ Flood Prone Width:_____________

Riparian vegetation

Cover = (0 - absent, 1-sparse [<10%], 2-moderate [10-40%], 3-heavy [40-75%], or 4-very heavy [>75%])
Type = (D)eciduous, (C)oniferous, (B)road-leafed evergree, (M)ixed, (N)one

Left Bank

Canopy vegetation: Cover code A)_______B)_________Type code_______ A=big trees, B=small trees

Understory vegetation: Cover code A)_______B)______Type code________ A=woody, B=non-woody

Ground vegetation: Cover code A)____B)____C)____Type code________ A=woody, B=non-woody,C=bare dirt

Right Bank

Canopy vegetation: Cover code A)_______B)_________Type code_______ A=big trees, B=small trees

Understory vegetation: Cover code A)_______B)______Type code________ A=woody, B=non-woody

Ground vegetation: Cover code A)____B)____C)____Type code________ A=woody, B=non-woody,C=bare dirt

Stream canopy closure *(from channel)* *Indicate the number of covered grid intersections (0-17)*

UP _________ *Down* _________ *Right* _________

Left _________

Transect Notes

Transect Photos *(photograph channel looking upstream and downstream and both banks/riparian)*

Photo #	Description

[1]a) walls, dikes, revetments, riprap, and dams, b)buildings, c)pavement (e.g., parking lot, foundation), d) roads or railroads, e)inlet or outlet pipes, f)landfills or trash (e.g., cans, bottles, trash heaps, g)parks or maintained lawns, h) row crops, i) pastures, rangeland, or hay fields, j)logging, k)mining (including gravel mining)

Appendix F

Hydrology

Hydrologic Indicators

The HSTM design recommends the continuous collection of stage data at the Qa/Qx Urban+NPDES monitoring sites in order to characterize the status and trends of in-stream hydrology. This approach raises two issues: (1) to what degree is “stage” an adequate surrogate for “discharge,” the more typical parameter used to characterize hydrology; and (2) which specific indicators of hydrology are likely to be most useful to characterize conditions and track trends in these urban and urbanizing watersheds? These issues are best addressed in reverse order, because the utility of a stage–discharge substitution depends in part on the indicators being used in any subsequent evaluation.

Hydrologic indicators with utility for stormwater management

Land-cover changes have been long recognized to alter the hydrology of watersheds and the flow regime of streams, particularly small streams (e.g., Leopold 1968). However, there has been little consensus over the years about the “best” indicators of such alterations, or even what the “best” would constitute. The earliest studies tended to focus on the increased magnitude of floods of a particular recurrence interval, of which the compilation by Hollis (1975) remains one of the more robust characterizations of this widely-recognized phenomenon.

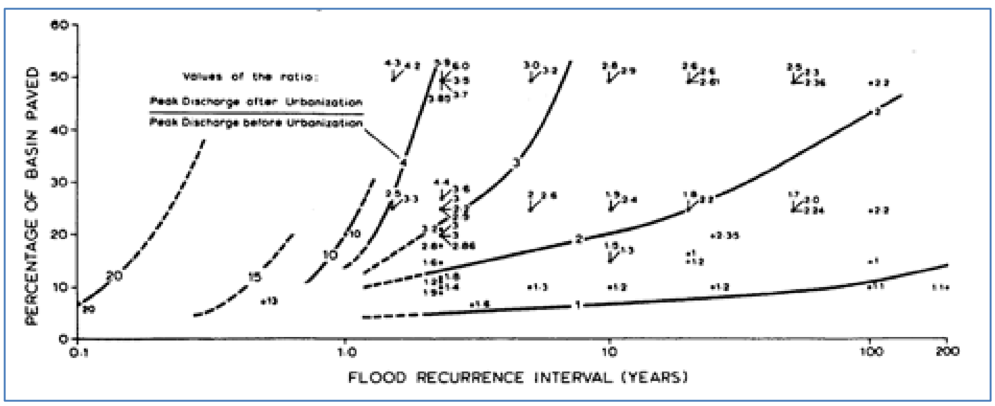

Figure F1. The compilation of Hollis (1975), displaying the results from multiple studies (individual labeled dots) that characterized the multiplicative increase in peak discharge (curved dark lines) for a given flood recurrence (x axis) in a watershed that has undergone a specified increase in impervious area (y axis). For those floods that tend to exceed infrastructure design standards and are large enough to cause damage (i.e., >10-year), typical suburban impervious-area percentages tend to increase peak discharges by 2- to 3-fold.

Subsequent work, most prominently developed in the Pacific Northwest by King County’s Basin Planning Program in the late 1980’s and later embraced more broadly (e.g., MacRae 1997), focused on the fractional increases in cumulative flow durations, producing graphs such as from the Soos Creek Basin Plan (Figure F2) that allowed for the calculation of long-term increases in sediment transport.

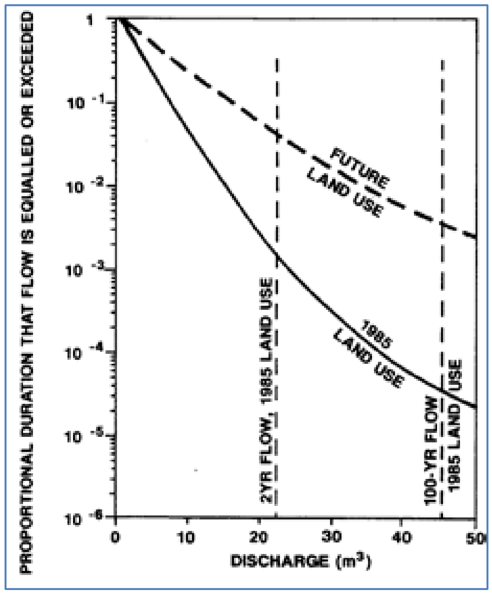

Figure F2. Flow-duration curve for Soosette Creek, developed for the Soos Creek Basin Plan (King County 2001). The hydrologic simulation program HSPF was used to predict runoff from the 14-km^2 watershed if all urban-zoned parcels were fully built out ("FUTURE LAND USE"). This graph indicates that flows exceeding the magnitude of the existing 2-year discharge (about 22 m^3/sec) will persist for more than 20 times longer under future land use (as compiled over a period of many decades). During the same interval, the 100-year discharge will be exceeded for more than 100 times longer.

Other indictors of flow change were also explored during the 1980's and 1990's, including the frequency at which discharge exceed a chosen threshold of presumed streambed disturbance or significant erosion. This indicator was identified under the assumption that it could highlight changes of particular importance to biota, particularly bottom-dwelling macroinvertebrates that depend on a relatively stable substrate for their livelihood (e.g., Figure F3).

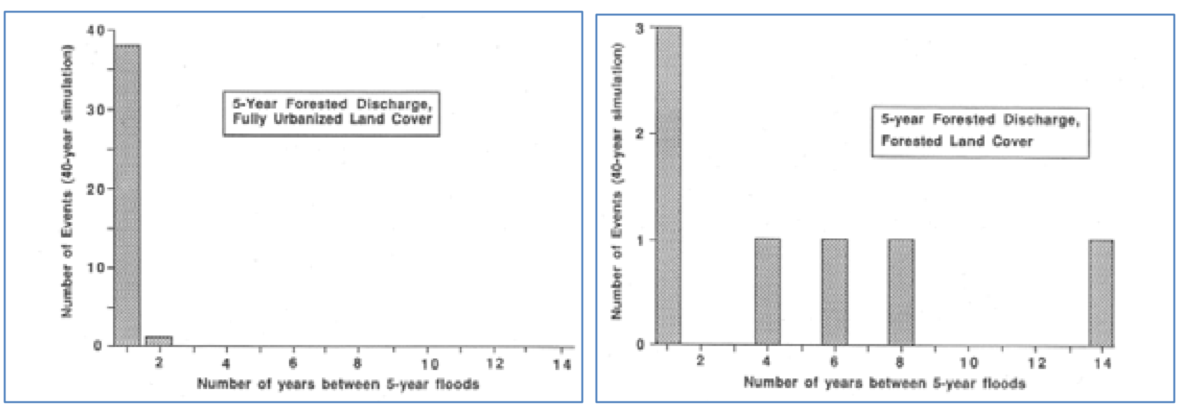

Figure F3. Interval between significant "disturbance events," here defined as a flow that exceeds the 5-year (predevelopment) discharge. Within a 40-year simulation period under forested land-cover conditions (left), three such floods occur the year following another one; but there is also an interval of 14 years with no such flow at all. Under the urban land-cover condition (right), only one year *lacks* such a flood; indeed, most years have multiple such events every winter (modified from Booth 1991).

Although national efforts were also developing a widely recognized set of indicators (e.g., the Indicators of Hydrologic Alteration, or IHA) (Richter et al. 1996), these were exhaustive in their treatment of flow and developed primarily with the changes in hydrology imposed on large rivers by dam regulation. A suite of indictors focused more explicitly on hydrologic changes caused by watershed urbanization were explored by Konrad and Booth (2002), who suggested that changes in flashiness, peak flow, and baseflow were all credible indicators. Focusing more explicitly on those attributes of the flow regime that would likely have biological effects, Konrad and Booth (2005) explored metrics that characterized the variability in high flows, low flows, daily flows, and the distribution of peak flows to baseflow. They tested these indicators on 13 small watersheds, nationwide—5 that had undergone little land-cover change over an 80-year gage record, and 8 that had seen substantial urbanization over the same period. Importantly, they found that no single metric reliably discriminated "urbanized" from "non-urbanized" watersheds; and no urbanized watershed showed a systematic change in every hydrologic metric. Thus, there is no "silver bullet" for detecting and characterizing the effects of watershed urbanization on flow regime, but many show promise, and a diverse suite is most likely to provide the most robust indications of hydrologic conditions and change.

DeGasperi et al. (2009) explored the relationship between B-IBI scores, watershed imperviousness, and hydrology through the investigation of eight hydrologic metrics (Low Pulse Count and Duration; High Pulse Count, Duration, and Range; Flow Reversals, T_{Qmean}, and R-B Index). This work was continued in King County (2012), which made use of the developed relationships between hydrologic metrics and B-IBI scores to evaluate the potential *biological* effectiveness of alternative stormwater management approaches to flow control. They considered eight metrics:

Metric name	**Description**
Low Pulse Count	Number of times each calendar year that discrete low flow pulses occurred
Low Pulse Duration	Annual average duration of low flow pulses during a calendar year
High Pulse Count	Number of days each water year that discrete high flow pulses occur
High Pulse Duration	Annual average duration of high flow pulses during a water year
High Pulse Range	Range in days between the start of the first high flow pulse and the end of the last high flow pulse during a water year
Flow Reversals	The number of times that the flow rate changed from an increase to a decrease or vice versa during a water year. Flow changes of less than 2% are not considered
T_{Qmean}	The fraction of time during a water year that the daily average flow rate is greater than the annual average flow rate of that year
R-B Index	Richards-Baker Index – A dimensionless index of flow oscillations relative to total flow, based on daily average discharge measured during a water year
Peak 2-yr:Winter Baseflow	Ratio of the estimated 2-year peak flow to winter baseflow (i.e., mean flow for October through April)

As with the results of Konrad and Booth (2005), all correlations between any given flow metric and B-IBI scores are imperfect, although the overall trends are as hydrologic theory and biological inference would anticipate. In the interest of reducing the list to a more tractable number of indicators for application in the HSTM program, two criteria were applied: strength of the biology–hydrology correlation, and the potential for common stormwater-management approaches to influence the value of the indicator over time. So, for example, the "High Pulse Range" shows a good correlation with B-IBI, but stormwater management is not as likely to influence this metric in an urban watershed as it would for a measure of within-storm flashiness or peak discharge.

With this rationale, three indicators from the above list of eight have been selected for use in the HSTM monitoring effort:

- T_{Qmean}
- R-B Index (henceforth, "RBI")
- Flow Reversals

T_{Qmean} is the aggregate fraction of time during a water year that a hydrograph lies above the mean discharge for that water year (Konrad and Booth 2002). Thus, a stream whose hydrograph is primarily a slowly varying baseflow and only limited peak flows may spend nearly half of the time above the mean discharge, resulting in indicator values at or above 0.40. In contrast, a very flashy hydrograph will have peaks that may greatly exceed the *magnitude* of the mean discharge, but the *duration* of those excursions may be rather brief. Thus, T_{Qmean} values for such systems may fall to values around 0.20.

The Richards-Baker Index (RBI) (Baker et al. 2004) is calculated for each water year as the sum of all day-to-day discharge differences (i.e., the absolute value of the difference between today's flow and yesterday's flow) divided by the sum of daily discharges. The numerator can be visualized as the length of the line making up a continuous average hydrograph, while the denominator would simply be the sum of all daily discharges stacked on top of one another.

Flow reversals are the simple tally of the number of days during the fall and winter seasons (specifically, October 1 through April 30) when the flow has changed from a rising or a falling trend to its opposite over the course of one day. A minimum threshold of change is commonly applied to avoid counting minor fluctuations; following King County (2012), that threshold was set at 2%. Thus, for example, a daily sequence of 90 à 100 à 95 cfs would count as a reversal, but 99 à 100 à 99 cfs would not.

For each of these indicators, their correlation with biological health (as measured by B-IBI) is relatively strong and monotonic (King County 2012). In these aquatic systems, more uniform and less flashy flow regimes are associated with more diverse species assemblages with a greater proportion of intolerant species. Thus, biologically "better" conditions are associated with higher values of T_{Qmean} and lower values of the R-B Index and the annual tally of fall/winter flow reversals. These relationships provide a clear basis to recognize the relative "status" of any given site on the basis of their flow indicators.

Evaluation of flow indicators in western Washington streams

Data source and the selection of test watersheds

Nearly all hydrologic data used in this evaluation were downloaded from the King County Hydrologic Information Center (http://green2.kingcounty.gov/hydrology/), selecting stations draining 2.5–50 km^2 to maximize their applicability to the HSTM Qa/QX Urban+NPDES monitoring sites, and with a relatively long period of record (at least 10 years of flow data for most) (Table 1). The sites in total span a wide range of urbanization, from nearly undeveloped watersheds to more than 70% urban land cover (Figure F4). The one non-King County gage site, that at Mercer Creek, was selected because it has the longest record (60 years) and the data are of equivalent quality and presentation.

Table 1. Site list. All data from King County, except Mercer Creek (USGS gage 12120000). The watersheds fall into three natural groups based on their 2011 urban land-cover percentage, and are so indicated by the shading. The three least urban watersheds (Webster, Griffen, and Fisher) serve as useful "control" sites insofar as they each have urban land cover less than 3%, forest cover greater than 60%, and essentially no discernable change in urbanization over the 10-year period covered by the 2001 and 2011 National Land Cover Databases.

GAGE	GAGE #	LATITUDE	LONGITUDE	Drainage Area (km^2)	Start date Q	Stop data Q	% Forest 2011	% Urban 2011	% Urban change 2001-->2011
Webster	31q	47.4164	-121.9195	4.64	WY 2010	WY 2015	93.3%	0	0.0%
Griffen	21a	47.6163	-121.9070	44.54	WY 2002	WY 2015	62.9%	0.3%	0.0%
Fisher	65B	47.3841	-122.4815	5.03	WY 2005	WY 2015	60.9%	2.7%	0.0%
Tahlequah	65A	47.3345	-122.5089	3.98	WY 2005	WY 2015	81.4%	4.5%	0.0%
Cherry trib.	05b	47.7410	-121.9409	3.75	WY 2009	WY 2015	63.9%	4.7%	0.0%
Judd	28a	47.4034	-122.4688	12.12	WY 2000	WY 2015	62.2%	4.7%	0.1%
Weiss	53e	47.6926	-121.9454	8.40	WY 2009	WY 2013	64.8%	8.9%	0.1%
Crisp	40d	47.2883	-122.0672	8.02	WY 1995	WY 2015	46.4%	15.8%	4.2%
Seidel	02o	47.7117	-122.0519	3.75	WY 2009	WY 2015	53.7%	16.9%	15.5%
Taylor U/S	31i	47.4090	-122.0254	9.43	WY 1992	WY 2015	38.6%	21.5%	0.9%
Taylor D/S	31h	47.4207	-122.0412	13.17	WY 1992	WY 2015	40.0%	22.4%	0.9%
L Jacobs	15c	47.5654	-122.0521	11.89	WY 1992	WY 2015	25.8%	46.0%	3.9%
L Jacobs	15c	47.5654	-122.0521	11.89	WY 2000	WY 2015	25.8%	46.0%	3.9%
Lakota	33b	47.3288	-122.3726	8.96	WY 1990	WY 2009	9.9%	71.6%	3.1%
Mercer	12120000	47.6031	-122.1797	32.30	WY 1956	WY 2015	12.0%	71.7%	1.2%
Juanita	27a	47.7077	-122.2149	16.99	WY 1993	WY 2015	10.0%	78.0%	2.0%
Miller	42a	47.4455	-122.3520	23.13	WY 1989	WY 2015	4.8%	80.7%	3.5%

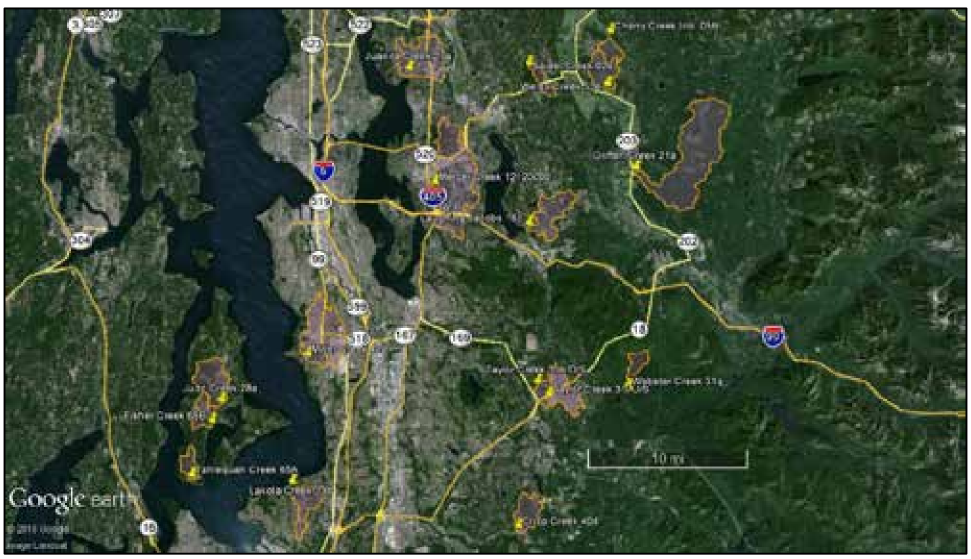

Figure F4. All sites used in the hydrologic indicator analysis for this section.

Results of analysis for hydrologic indicators

Of the 16 sites identified as candidate gage records, three were excluded from hydrologic analysis either because they had short (4-year) records and their level of urban land cover was close to other site(s) with lengthier records (Cherry tributary, Weiss), or because they were tributary to a farther downstream gage and so not independent (Taylor U/S). The remaining 13 sites in aggregate display the anticipated relationships between urban land cover and hydrology: with increasing levels of urbanization, the average-over-full-record values of T_{Qmean} decreased, the RBI increased, and the tally of annual fall/winter flow reversals increased (Figure F5). However, the significant scatter in the graphs of all indicators reinforces the long-standing recognition that "urban land cover" is a good but not perfect surrogate for hydrologic alteration of a watershed, and that each indicator responds differently within a given watershed setting.

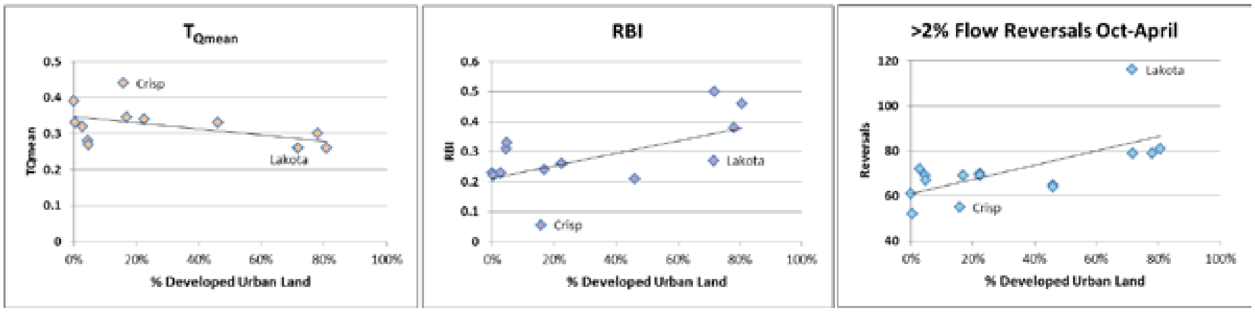

Figure F5. All sites with analyzed hydrologic data, with the specified indicator plotted against the 2011 watershed urban land cover. Plotted indicator values are those of each individual water year averaged over the full period of record. Two sites with somewhat anomalous relationships are labeled.

Examples of local disparities within an overall urban-driven trend are readily identified. For example, the flow of Crisp Creek, with a moderate 15.8% watershed urban land cover, is supported by abundant deep groundwater flow (which is why a tribal fish hatchery has made use of its cold, reliable flow since 1987). This site is an outlier on the plots for all three metrics, because the relatively high, steady groundwater flow damps the expression of urban flashiness. In contrast, Lakota Creek (71.6% urban land cover) is a steep tributary to Puget Sound that drains a largely suburban watershed in the city of Federal Way. It is fully "on-trend" with respect to T_{Qmean} relative to other watersheds of comparable urban land-cover percentages (for example, that of Mercer Creek is an identical 0.26 with an urban land cover of 71.7%), but its RBI is below the regional trend (i.e., less flashy) wheras its flow reversals are well above the corresponding trend (i.e., more flashy).

Comparisons between metrics

Differences between indicators at the same site can be assessed more systematically by comparing their pairwise behavior to one another. Figure F6 shows these comparisons, which demonstrate their overall good correspondence but with some informative differences.

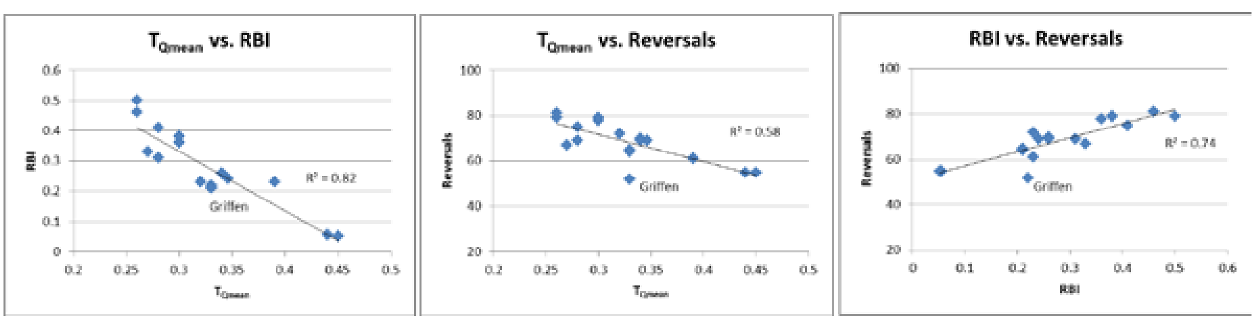

Figure F6. All sites with analyzed hydrologic data, with the specified indicators plotted against one another using the values for each individual water year averaged over the full period of record. The only systematically outlier is Griffen Creek, which has many fewer flow reversals then either of its other two indictors might otherwise suggest. Possible explanations for this behavior are that the watershed is the largest of this group, and with one of the largest fractions of wetlands (>5% watershed area) of any site.

Unlike the relationships between urban land cover and hydrologic indicators, each indicator is likely to be affected equivalently by the unique attributes of each watershed—not only urban land cover, but also baseflow contribution, hillslope and channel gradients, and watershed size. Thus, their relatively good correlation between indicators (particularly between T_{Qmean} and RBI, two related measures of the magnitude of high-flow peaks relative to more common, persistent flows) is not surprising. It also suggests that seeking yet additional indicators may not result in a commensurate increase in understanding.

Ability to detect trends

These datasets are also suitable to evaluate the ability of these indicators to detect changes over time, given the decade to multi-decade length for many of them and the parallel availability of land-cover data from both 2001 and 2011, a period covered by many of these records. The aggregated results, however, are not particularly encouraging (Figure F7). The range of "natural" variability, as expressed by the points plotting along the y-axis (i.e., with no detectable change in urban land cover over the 10-year period) fully encompasses the observed range of change for any degree of urban land cover increases at many of the other sites. For those that exceed the range of values expressed by the three sites with little/no change, most show very small or mixed responses over their period of record (e.g., Taylor D/S, with less flashy T_{Qmean} and RBI trends but more flashy reversals).

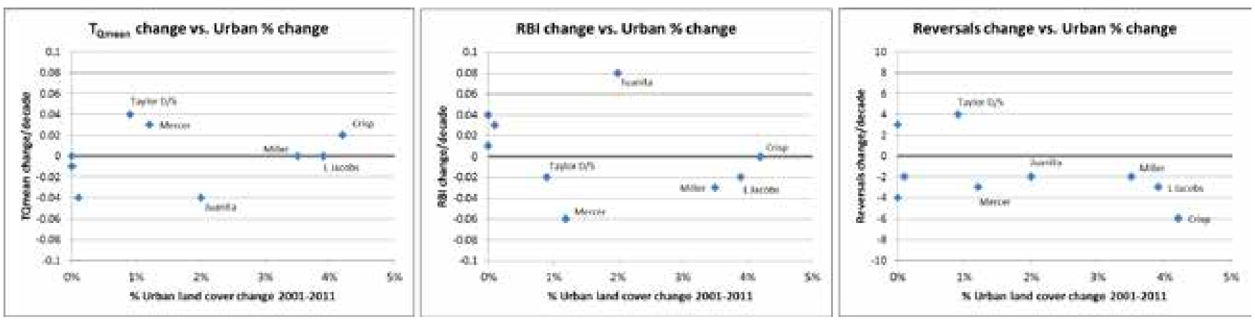

Figure F7. Rate of change in hydrologic indicators as a function of urban land-cover change. No site with active urbanization during the decade 2001-2011 shows a consistent pattern with respect to all three indicators; the three sites with no significant change that plot close or on the y-axis (and for which all have <5% urban land cover as of 2011) can be used to infer a range of natural variability, which suggests somewhat more flashy flows on the basis of T_{Qmean} and RBI (but not if considering flow reversals).

These results do not offer much promise for systematic detection of decadal-scale hydrologic trends, even for those watersheds with relatively rapid rates of change. Although several watersheds showed changes in specific indicators beyond the range defined by the near-"control" sites (those lying on or close to the y-axis of Figure F6, and which themselves suggest a somewhat inconsistent picture of greater natural flashiness in runoff over the period), no site shows a consistent response in all three indicators. Reversals at the control sites define the widest interval of natural variability, for which only Taylor and Crisp Creek exceed: and for those two, the apparent trend of Crisp Creek suggests a *less* flashy regime, despite its relatively high rate of urban land-cover change, whereas the trend for reversals at Taylor Creek contradicts those for T_{Qmean} and RBI.

More revealing is the behavior of two specific sites: Seidel Creek, with a relatively short hydrologic record (spanning 7 years in total but with data for only WYs 2009, 2010, 2011, 2012, and 2015) but the greatest change in urban land cover between 2001-2011 (15.5%, with an accompanying decrease in forest cover of 23.5%), and Mercer Creek, with more than a half-century of gage data. On Seidel Creek, rapid suburban development in the decade of the 2000's (Figure F8) resulted in significant hydrologic changes, although the relatively sparse data paint a somewhat ambiguous picture (Figure F9).

Figure F8. Aerial views of Seidel Creek watershed from 2002 (left) and 2014 (right). Imagery from Google Earth. Over one-half square kilometer (133 acres) of this 3.5 km^2 watershed converted to urban land cover during the decade 2001–2011.

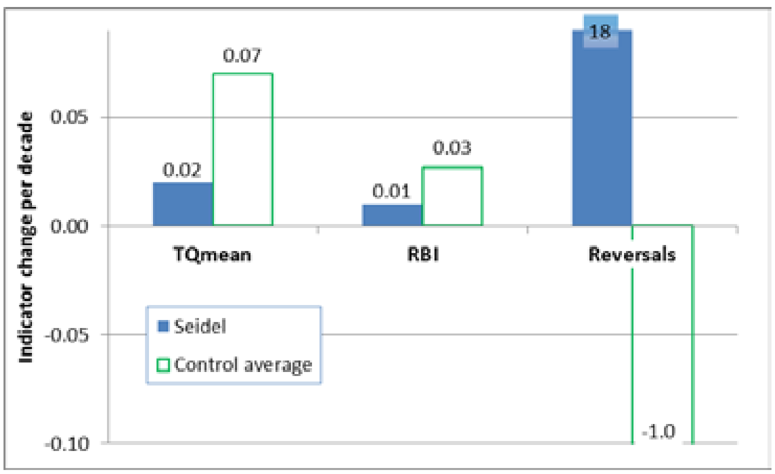

Figure F9. Decadal rate of change in hydrologic indicator values for Seidel, extrapolated from the period 2009–2015. Trends imply lower hydrologic changes than those expressed for the control sites using T_{Qmean} or RBI; however, the trend for reversals is dramatically more rapid (i.e., more urban) that for those same control sites.

Mercer Creek has the unique advantage of having a near-continuous 60-year hydrologic record, spanning a period when urban development was only just beginning in this 32-km^2 watershed up to its current condition with more than 70% urban land cover. The trends for all three hydrologic metrics are strong and consistent over the full period of record (Figure F10, Figure F11), which likely span a period when urban land cover would have been increasing as rapidly as any other site in this study over the last 10 years (i.e., >5%/decade). However, they also all suggest a possible reversal of these trends over the last ~10 years or so, particularly well-expressed by a reduction in the RBI but also displayed in T_{Qmean} (an increase) and in flow reversals (a less distinct reduction). These long-term records also suggest that the RBI has the lowest interannual variability and flow reversals the greatest—but even for the former, at least two to three decades of record would have been necessary to identify any consistent trends. Absent widespread and highly effective stormwater management, this is likely to be the minimum duration of monitoring that would be required to detect statistically meaningful trends in hydrologic indicators.

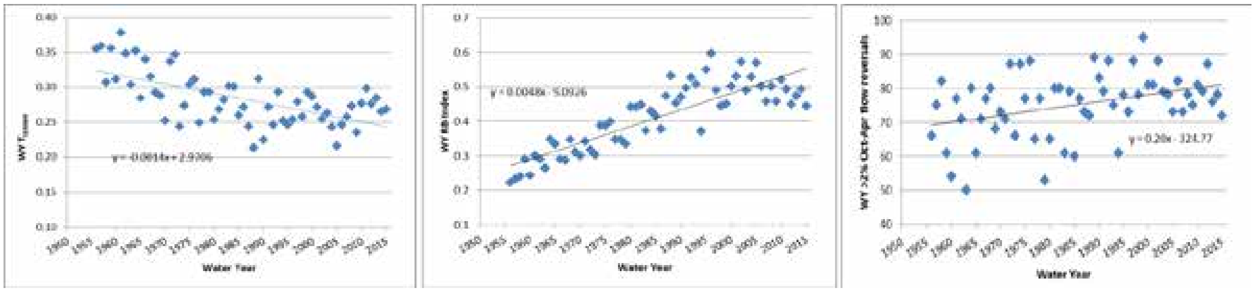

Figure F10. Water-year values of the three hydrologic indicators for Mercer Creek at USGS gage 12120000, the longest record in the data set.

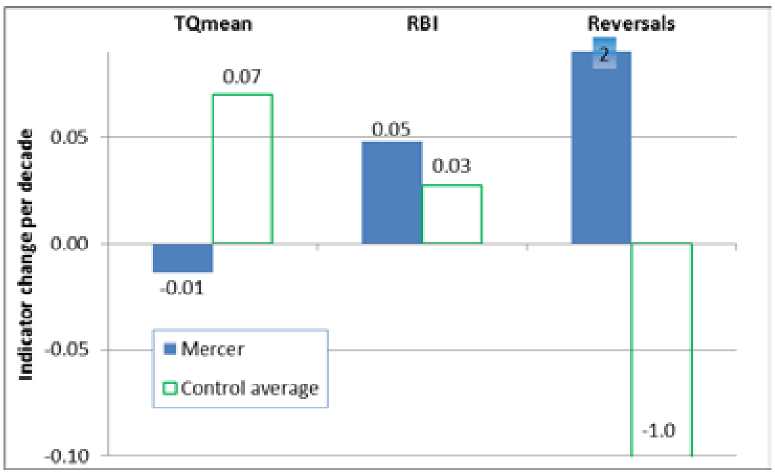

Figure F11. Average rate of change in hydrologic indicators for Mercer Creek over the full period of record (WY 1956–2016, with control-site averages from the last decade provided for reference). All Mercer Creek changes are of consistent direction, supporting an inference of long-term increase in flashiness corresponding to the multi-decadal period of urbanization in the watershed.

Suitability of stage as a surrogate for discharge

Rationale for substitution

Accurate stream gaging can require significant levels of both expertise and time/cost, because it requires not only the continuous recording of water level (stage) but also relatively frequent site visits to directly measure discharge. The resulting relationship between recorded stage and measured discharge (the rating curve) is generally considered accurate only within the range that discharges have been measured (i.e., it is reliable for interpolation but progressively less so for extrapolation), which requires site visits during times of high or peak flow. Of course, this will typically correspond to times when *every* such site is experiencing such flows, making measurement logistics difficult for a limited number of trained crews. In addition, the underlying relationship between stage and discharge can change, most commonly as a result of erosion or sediment deposition at the gaging site, and so rating curves must be developed anew following significant (or potentially significant) channel-altering events. These requirements all increase the cost of reliable discharge measurements.

However, for many applications the conversion of stage to discharge is unnecessary. Since discharge is normally a *calculated* value derived from stage, those parameters that depend on patterns or variations in discharge should actually be more accurately represented by direct evaluation of the raw (i.e., stage) data. Only for those applications that require a direct knowledge of the flow magnitude (e.g., culvert capacity, floodplain inundation) is the conversion to discharge mandatory. In addition, many of the issues associated with fluctuations in the flow, such as sediment transport or substrate disturbance, are only dependent on stage (because stage is the direct measure of flow depth, a key determinant of the tractive stress that mobilizes sediment); the absolute discharge is in fact irrelevant.

For these reasons, the use of stage data was explored as a surrogate for discharge in implementing the hydrologic monitoring components of this HSTM program. In general, hydrologic indicators have been developed and implemented solely on the basis of discharge, and so the purpose of this exploration was to determine the degree to which stage can be used effectively as a surrogate for discharge, and to identify any potential pitfalls to the naïve substitution of one measurement (i.e., stage) for another (discharge).

Approach
The same set of gage records from King County's Hydrologic Information Center (plus USGS 12120000) was mined for suitable data sets. Although stage must have been recorded for all dates with reported discharge, the data are not readily available for all such entries. From the population of gage records used to evaluate the hydrologic indicators, 10 have at least ten years of jointly reported daily stage–discharge data from which comparisons can be made. Evaluations of both individual years and record-averaged values and trends were made to determine the suitability, and the limitations, of using stage records without needing to invest the additional effort in developing and maintaining a rating curve.

Results
Comparison of the three indicators using both the discharge record and the stage record yield very mixed results (Figure F12). T_{Qmean} shows by far the most consistent relationship, suggesting that this indicator could be calculated and interpreted using either data set with only minimal uncertainty associated with its use or integration with prior studies. The other two indicators, however, have rather poor correlations between calculations using the two alternative data sets, and so which require further discussion.

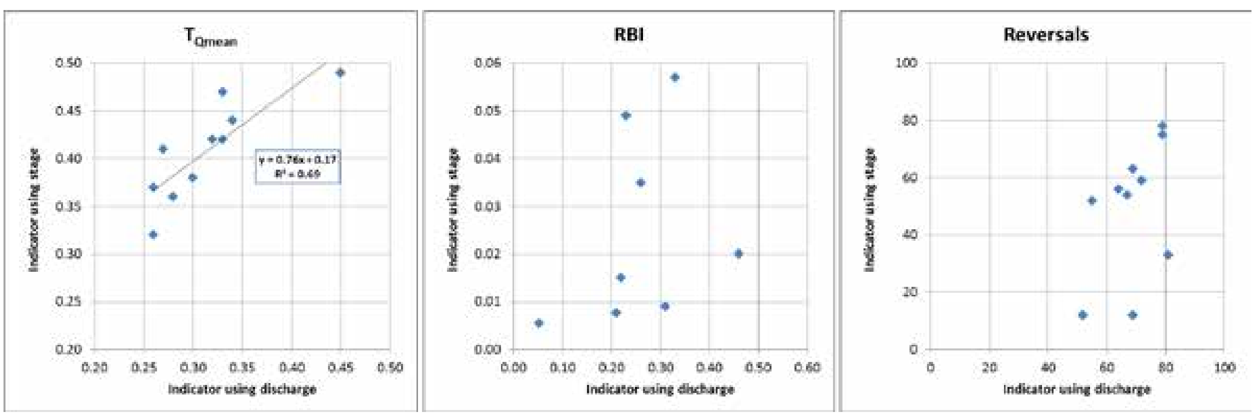

Figure F12. The three hydrologic indicators recommended for use in the HSTM program, comparing the decadal-averaged values for each site calculated using the discharge record (x axis) and the stage record (y axis). Only T_{Qmean} shows as a useful relationship with the data as it presently exists.

The Richards-Baker Index (RBI), the quotient of summed day-to-day discharge differences divided by the sum of daily discharges, depends not only on the magnitude of interday fluctuations (an intuitive measure of "flashiness," which is why the RBI is widely used) but also on the overall magnitude of the denominator. Using discharge data, this relationship is understandable: an interday fluctuation can be considered "large" only in the context of the overall magnitude of discharge. However, the "magnitude" of stage is entirely arbitrary, since the datum from which it is measured can be any value (and may well change from year to year, or even within a single water year) (Figure F13).

This result does not require that RBI be calculated only from discharge, but it does require that the actual flow *depth* (i.e., a physical measurement of the flow) be preserved from the original field measurements and pressure transducer record. This is not commonly done, and it would need to be incorporated into any procedure that sought to avoid the added time and expense of creating stage–discharge rating curves. Unlike stage, depth is not an "arbitrary" value, and fluctuations around an average depth are quite likely to have physical and biological importance. Without these data, however, extraction of a meaningful value of the RBI is not possible.

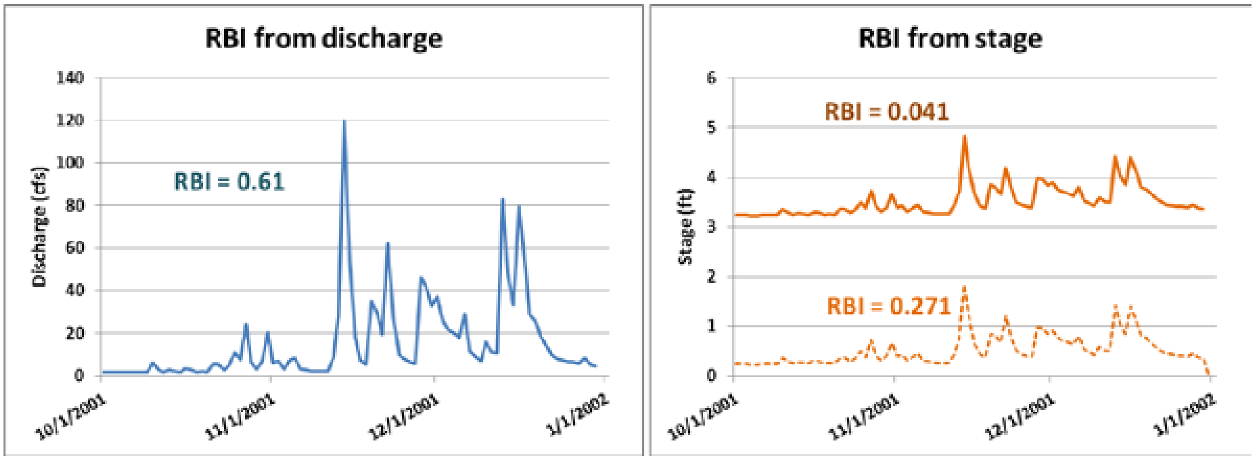

Figure F13. Comparison of discharge (left) and stage (right) records from Miller Creek (gage 42a) for the first three months of WY 2002. The stage record as reported is the upper curve on the right panel; the lower curve reflects an arbitrary 3′ lowering of the datum, as might occur after a scouring event in the channel or if the gage location were moved. Although no physical change exists between the two records, the calculated RBI from the "shifted" record is more than 5 times larger. This indicator shift would not occur if the data were of actual flow *depth*, rather than stage.

Flow reversals, the tally of daily flow reversals during the fall and winter seasons that exceed a specified threshold (here, 2%), should in principle be entirely unaffected by whether stage or discharge is the variable being used, since any discharge record is based on a monotonic function of stage (i.e., if stage increases then calculated discharge increases, and vice versa). The poor correlation between these two approaches (Figure F12, right) is therefore not an intrinsic shortcoming of the data but rather of its typical implementation. To avoid "counting" even miniscule reversals in the annual total, a minimum threshold of change is normally applied to include a day's reversal in the tally (King County 2012 recommends 2%). However, calculated discharge is commonly a power function of measured stage, such that a given change in discharge may reflect a somewhat smaller change in stage. In our data set, discharge reversals invariably exceeded stage reversals for every site, using the same 2% threshold for identifying a true reversal for both. This limitation can be significant reduced with a lower (or no) threshold for identifying reversals in the stage record (Figure F14), but they can be eliminated altogether only if the full precision of the recorded stage data is preserved throughout the calculating and archiving of these data. Typically, values are reported only to 2 or 3 significant digits, which may result in identical day-to-day records of the stage but nonetheless produce calculated changes in discharge.

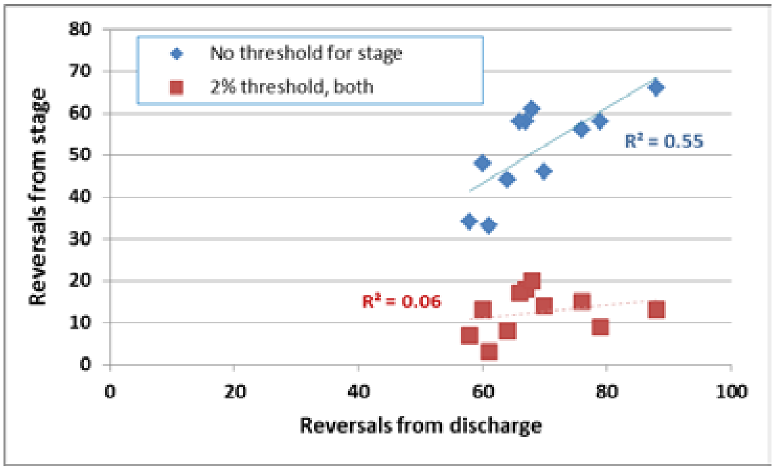

Figure F14. Comparison of alternative flow reversal records (from Tahlequah Creek [gage 65A], the site with the worst naïve correlation of reversal calculations). Using the 2% minimum day-to-day threshold for identifying flow reversals on both the (recorded) stage record and the (calculated) discharge record, there is essentially no correlation between the two indicators, with a five-fold (or greater) difference between them in any given year. Eliminating the threshold for identifying stage reversals results in a dramatically improved correlation. The remaining mismatch is almost certainly a consequence of rounding the reported stage values (which span only a 2-ft range over the period of record and are reported to the nearest 0.01′, whereas discharge spans an order of magnitude greater range of values but is also reported with a precision of 0.01).

Conclusions

We have explored the application, interpretation, and limitations of hydrologic indicators, using an unprecedented data set in terms of its quality, length, and applicability to urban and urbanizing watersheds of the Pacific Northwest. Three indicators previously identified for their utility in identifying hydrologic conditions that respond to watershed urbanization and with biological importance—T_{Qmean}, the Richards-Baker Index, and the annual tally of wet-season inter-day flow reversals—are all successful in stratifying watersheds across a range of urban development. The indicators are well correlated, and so in principle any one or two could provide nearly the same degree of understanding as the entire set. However, their calculation is straightforward and makes use of the same data, suggesting that the minimal savings in time is not worth the potential loss of insight. None of the indicators appear to reliably detect trends in watershed urbanization over the course of a single decade, at least given the rates of such development across the region over the past 10 to 20 years, but they all appear to respond with a reasonable degree of statistical significance to longer, multi-decadal trends. Use of stage as a surrogate for discharge in the calculation of these indicators appears plausible but cannot be implemented under current reporting practices. Instead, the original data for water depth would need to be preserved, along with the full precision of the original recorded data. With these caveats, there is every reason to expect that hydrologic indicators based on stage will prove as or more useful, at least in the context of status-and-trends monitoring, as those based on subsequent calculations of discharge.

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Appendix G

Temperature

Temperature as an indicator for HSTM Qa/Qx monitoring

Temperature

The influence of urbanization on the temperature of rivers and streams is widely recognized. Decades of study have investigated the causes, and the consequences, of warmed water in rivers and streams (Hannah et al., 2008), but their quantification in any given watershed is confounded by channel-network geometry, groundwater inflow and hyporheic exchange, and the interplay of stream orientation and sun angle, canopy cover, and air temperature (Smith, 1972; Poole and Berman 2001). Heat is added to and lost from a stream by radiation, sensible heat from inflows and outflows, latent heat by evaporation or condensation, bed conduction, and friction (e.g., Brown, 1969). Decades of measurements and models demonstrate that the most important term for streams is the net radiation, which in turn is determined by the sun angle, stream aspect, and canopy cover (Pluhowski, 1970; Poole and Berman, 2001). The least important are generally those of conduction and evaporation, while bed conduction and friction are sometimes ignored altogether.

Of the remaining terms, the types and magnitude of sensible heat inputs are quite variable. The presence and influence of cool groundwater inflows depend on both local and regional variations in subsurface geology, soil thickness and permeability, and upland land cover (e.g., Smith and Lavis, 1975; Tague et al., 2007). In contrast, prior studies of urban stream temperatures typically have focused on the sensible heat contribution of urban runoff, but they have almost exclusively been conducted in regions where thunderstorms fall on recently sun-warmed pavement surfaces that result in runoff up to 5-10°C warmer than the receiving stream, and with the highest runoff temperatures occurring in the mid-afternoon on sunny days during storm events with low total rainfall amounts (Herb et al., 2008). However, these climatological conditions are not ubiquitous, and they are particularly rare in the Pacific Northwest. Thus, prior work offers surprisingly little insight into a matter of significant regional environmental concern and regulatory attention.

Existing studies, both empirical and model-based, suggest the likely magnitude of stream-temperature changes resulting from human activity, particularly as a result of increased solar radiation on the water surface. Hewlett and Fortson (1982) reported typical water-temperature increases in the southeastern Piedmont of about 3ºC (± 3ºC) from riparian clearing (and up to about 7ºC during the hottest days of a Georgia summer). A pre- and post-clearcutting investigation of a small headwater stream in Pennsylvania (Rishel et al., 1982) showed the average monthly maximum stream-temperature increase to be 4.4ºC. Burton and Likens (1973) found increases of 4-5ºC in riparian-cleared areas of Hubbard Brook experimental forest, New Hampshire, a similar magnitude to the measured and modeled influence of shading in western Oregon (Risley et al., 2002). LeBlanc and others (1997) investigated various human-induced changes via a calibrated temperature model for a temperate mid-latitude site; they found typical simulated temperature increases from vegetation removal to be 2ºC from direct solar radiation augmented by increased channel width (resulting from urban-increased discharges) and baseflow reduction.

To address the paucity of urban-watershed temperature studies in the Pacific Northwest, a four-year data set of summertime stream temperatures collected across the Puget Lowland in 1998, 1999, 2000, and 2001 was recently analyzed (Booth et al. 2014). Four watershed variables presumed to be influential (total watershed area and the watershed percentages of urban development, upstream lakes, and permeable glacial outwash soils as an indicator of groundwater exchange) were significant predictors of stream temperature only when considered together, with the strongest influence identified for percent outwash followed by percent urban development and percent upstream lake area. Upstream lakes resulted in downstream warming of up to 3ºC; variability in riparian shading imposed a similar temperature range.

Thus, watershed urbanization itself is not the most important determining factor for summertime stream temperatures in this region, and even the long-recognized effects of riparian shading can be no more influential than those imposed by other local-scale and watershed-scale factors. These issues must be appreciated to make sense of instream temperature data, either as previously collected by other programs or as recommended here for the HSTM program. In reviewing the lessons provided by prior efforts this discussion focuses on maximum instream temperatures, insofar as these typically raise the greatest concerns for their influence on cold-water fish species in the Pacific Northwest.

To explore the potential value and interpretation of the temperature data that is recommended for collection under the HSTM program, a similar suite of data from King County Water and Land Resources Division was identified and analyzed. King County maintains a network of continuously recording stream temperature stations, distributed across streams that drain a range of watersheds form the urban lowlands to the forested Cascade foothills. Daily average temperature data were downloaded from the King County Hydrologic Information Center (http://green2.kingcounty.gov/hydrology/), choosing 11 sites that span a broad range of urbanization but with all draining watersheds within the range of 2.5–50 km^2 (Table 1). Record lengths varied from 5 to 20 years, with most spanning the period 2005–2015.

Table 1. List of King County gages used in evaluating the application of continuous stream temperature data. All sites duplicate gages with hydrologic data reported in Appendix H of this report (but not all hydrologic sites have recorded temperature data).

GAGE NAME GAGE #	Webster 31q	Griffen 21a	Fisher 65B	Tahlequah 65A	Cherry trib. 05b	Judd 28a	Crisp 40d	Taylor 31i	Laughing Jacobs 15c	Juanita 27a	Miller 42a
W'shed Area (km^2)	4.64	44.54	5.03	3.98	3.75	12.12	8.02	9.43	11.89	16.99	23.13
% Forest 2011	93.3%	62.9%	60.9%	81.4%	63.9%	62.2%	46.4%	38.6%	25.8%	10.0%	4.8%
% Urban 2011	0.0%	0.3%	2.7%	4.5%	4.7%	4.7%	15.8%	21.5%	46.0%	78.0%	80.7%
% Urban change 2001-->2011	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	4.2%	0.9%	3.9%	2.0%	3.5%
Start date T	2009	2005	2004	2004	2009	2000	1998	2009	1996	2000	2001
Stop data T	2013	2015	2015	2015	2012	2015	2015	2012	2015	2015	2015
	RURAL WATERSHEDS						SUBURBAN		SUBURBAN—URBAN		

For each gage, the full available record was downloaded at a daily time step and inspected for thermal maxima. An example of the data, using those from the gage with the longest record (Laughing Jacobs, gage 15c) displays many of the key features of these records (Figure G1):

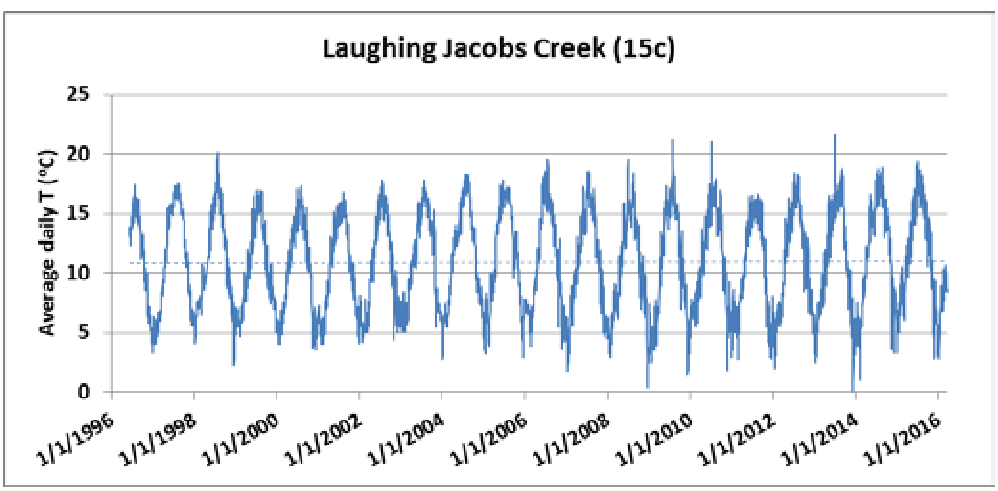

Figure G1. Daily thermograph for Laughing Jacobs Creek, expressing the full period of record. The average temperature trend line is plotted as a faint dotted line (about 11ºC), and it shows no trend over the 20 years of record.

Most apparent in these data is the annual cycle of stream temperature, which peaks in late July in most years (rarely, early August) and reaches its minimum around the turn of the year. There is some suggestion of a wider annual range of temperatures in the latter half of the record, but the linear best-fit trend (dashed blue line) is unchanged over the twenty-year period.

Although the annual averages are essentially unchanged, annual maximum temperatures show a fairly distinct pattern at this site. With the exception of 1999, all of the ten warmest maximum temperatures have occurred post-2006 (Figure G2).

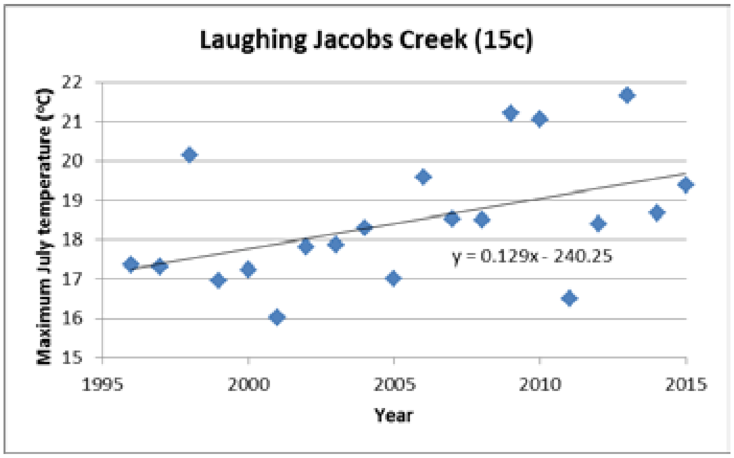

Figure G2. Annual maximum daily temperatures at Laughing Jacobs Creek. In contrast to the mean temperature, this record shows a relatively distinct (but irregular) increasing trend.

A variety of factor may explain the broad increase in maximum temperatures (about 1°C per decade) over this 20-year period, including random variability (the standard deviation of the data is only slightly less than that of the apparent trend), more widespread regional summertime warming, or the effects of increased urbanization over this period (a 3.9% increase in watershed urban land cover from 2001 to 2011, based on changes between the 2001 and 2011 National Land Cover Database).

Separating the influence of regional climate from that of more local human activity can be explored using six of the temperature stations from the King County dataset that have urban land cover values of less than 5% (as of 2011) and show an increase of no more than 0.1% in this parameter over the preceding decade (Figure G3). These “reference” sites suggest no systematic temperature change during their respective period(s) of record, suggesting that the Laughing Jacobs results are reflecting changes specific to that watershed and/or monitoring site (and that may or may not be related to watershed urbanization specifically)

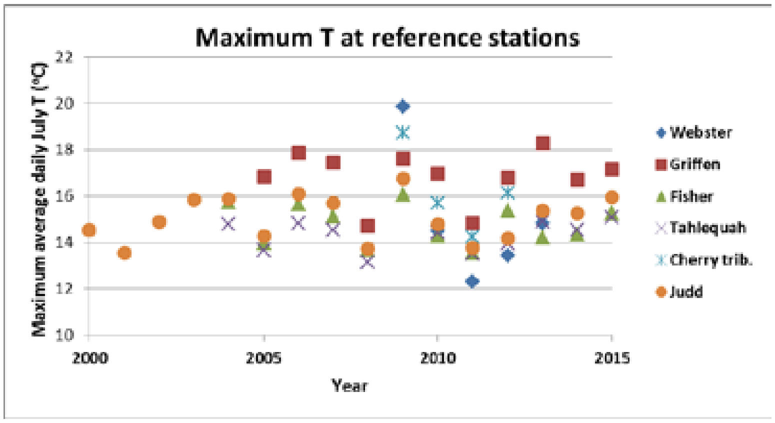

Figure G3. Annual maximum temperatures for six sites with low watershed urbanization and no significant increase in urban land cover during the period 2001–2011. Nearly 4ºC separate the warmest from the coolest of these "low-urban" sites, and none show any apparent trend during this period.

To further explore the potential influence of regional climate warming, daily maximum air temperatures for two long-term weather stations (SeaTac airport, in the center of the Puget Lowland; and Landsburg, in the Cascade foothills) were downloaded from http://weather-warehouse.com/. Annual maximum temperatures, maximum July temperatures (to maintain an analogous record to that of the stream temperatures), and the average of all July daily maxima were plotted and inspected for trends over both the full period of record (68 years in the case of SeaTac, 100 years in the case of Landsburg) and for the last two decades (Figure G4).

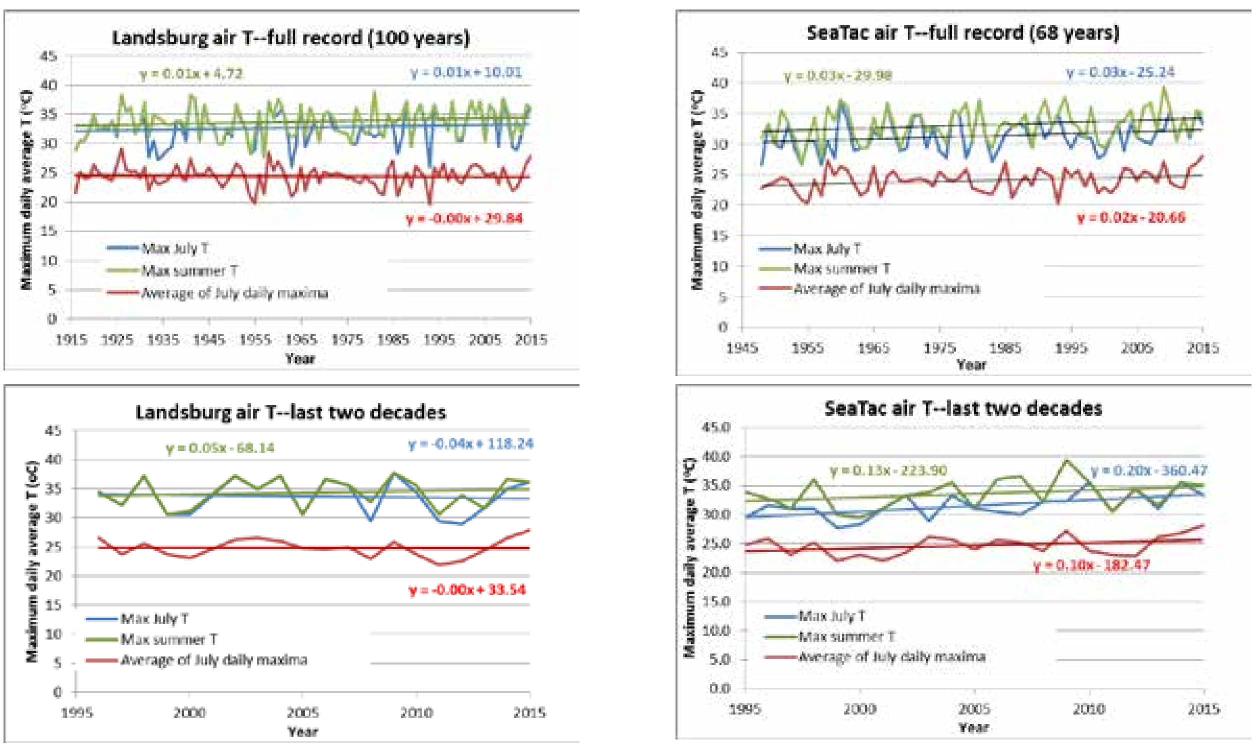

Figure G4. Regional air temperatures over the last 60+ years (top) and the last 20 years (bottom). Linear trends are given by the equations, which show the greatest increase in maximum summer temperatures over the last two decades (e.g., over 1ºC per decade in the case of SeaTac). Recent SeaTac changes are greatest, regardless of the specific metric being considered, and are lowest over the last century's record at Landsburg.

For Landsburg, well-separated from most urban development and other human activity, there is little discernable change in air temperature regardless of the metric or the period of investigation. The most prominent trend is the recent one-degree increase over the last two decades in maximum summertime temperature, although neither the average of all daily maxima shows nor the maxima of July temperatures show any such change. For SeaTac, comparable averages are about 1 degree *cooler* than at Landsburg, regardless of which period is compared, but the trends in temperature *change* are both stronger and more consistent than at Landsburg, with SeaTac temperature increases of 2 to 4 degrees over the last two decades regardless of which metric is evaluated (coincidentally, a rate quite similar to that of Laughing Jacobs Creek). These results suggest that there is both a regional climatic component and a more local, urban-related component to changes in ambient air-temperature maxima, which in turn are likely to exert a real (but ill-defined) influence on measured stream temperatures.

The effects of urbanization cannot be fully separated from the potential regional influences of geography in our existing data set, because urbanization is not randomly distributed across the landscape--in general, the more urban localities are lie east of Puget Sound towards the center of the Lowland, whereas the less urban sites are either farther east in the forested Cascade foothills or along the coastline of Vashon Island, immediately adjacent to Puget Sound. This confounding relationship notwithstanding, the existing King County stream stations with temperature data show a strong correlation between urbanization and maximum temperatures, whether for selected years or as averaged over the available records for all gages (Figure G5).

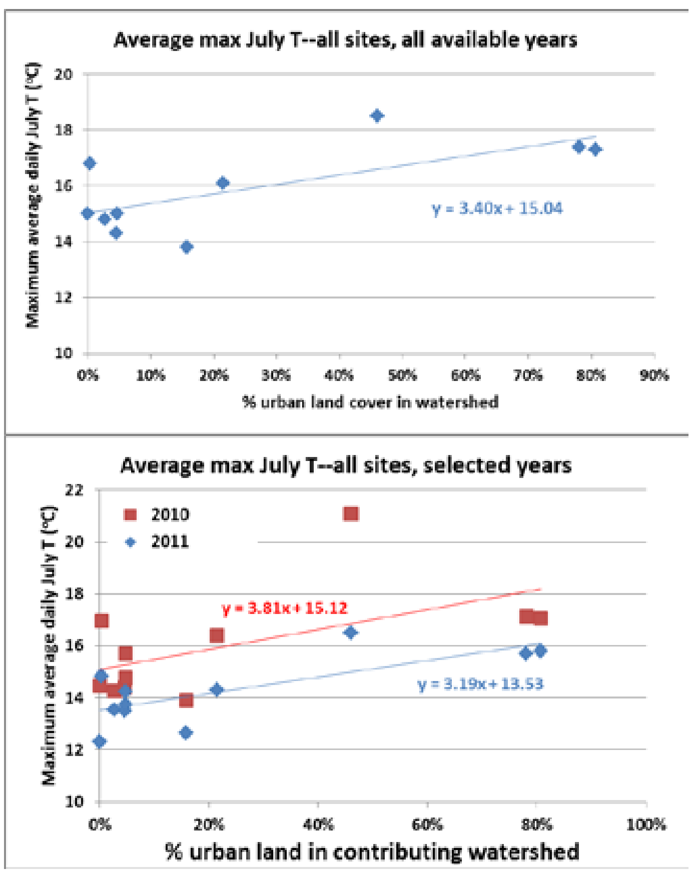

Figure G5. Relationships between watershed urban land cover and maximum stream temperatures. Top, average of maximum July temperatures over each site's entire period of record; bottom, maximum July temperature for two successive years at each site. Note that the full-record average plots close to that for 2010; 2011 was cooler by an average of about 2ºC across all sites.

Although the geographic location of the two long-term air temperature stations suggests that the eastern, low-urban sites might be up to one degree warmer, it is the most urban sites that are up to three degrees warmer than their more forested, less-developed counterparts. Of course, these data offer no insight into whether urbanization is the cause, or if so then what might cause these differences—reduced infiltration and so lower summertime flow, reduced riparian shading, and/or urban runoff across warmed surfaces from human activities (landscape watering, pavement washing, etc.) have all been suggested as possible agents. However, they do suggest that whatever the cause there are likely to be discernible effects of urbanization on stream temperatures; they can impose an effect that is as much as several degrees in magnitude; and they occur across a temperature range that is significant for the health of cold-water fisheries and so have potential biological consequences.

Are these data suitable for detecting trends in changing stream temperature more generally? The suburban station with the longest temperature record (Crisp Creek) also shows the greatest land-cover change between 2001 and 2011 (an increase of 4.2% in urban land cover, to a total of 15.8% in 2011). Unlike the reference sites it does shows a distinct trend of increasing maximum temperatures (Figure G6), although the summertime streamflow at this site is dominated by groundwater and the rate of warming (about 0.5°C per decade) is only half that of the air temperature rise at SeaTac. Based on the scatter of the data and the magnitude of the trend at this site, even though it has the greatest land-cover change it is unlikely to demonstrate statistically significant changes with only a single decade of measurement here.

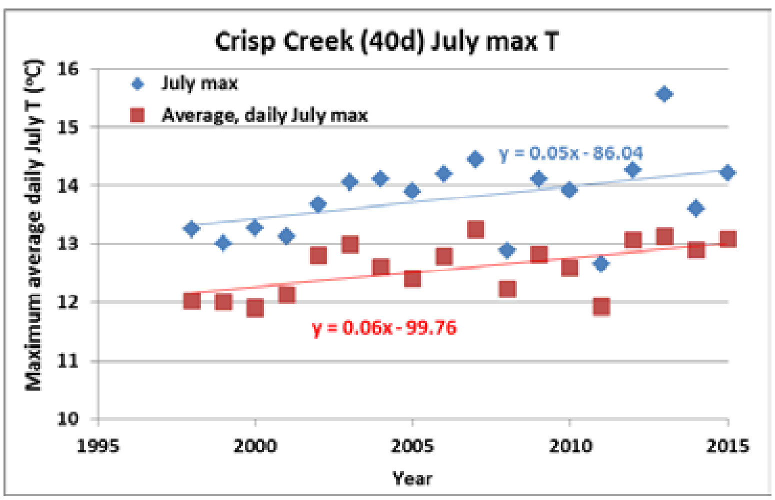

Figure G6. Temperature changes at Crisp Creek over its full period of record. Given the magnitude of change and the scatter of the data, a single decade of measurement probably do not demonstrate statistically significant change.

Conclusions

Long-term stream temperature data show intriguing patterns of decadal-scale warming, loosely correlated with the magnitude of urban development in the watershed. These results are broadly consistent with, and of the same magnitude as, prior studies in both western Washington and elsewhere about the potential range of effects of human activity on stream temperatures. However, those influences vary in both location and scale (e.g., local riparian clearing vs. watershed-scale land-cover change), and they can be dwarfed by intrinsic watershed conditions of geology and groundwater and the annual variability of climate that render any deterministic interpretation of such data challenging. Nonetheless, the widespread impairment of lowland streams from high summertime temperature, the importance that this parameter has for aquatic biota, and the potential for significant temperature changes to result from human activities and watershed management clearly justify its inclusion in any status-and-trends monitoring program.

Thermal “conditions” are likely to be identifiable, at least with respect to key biological thresholds, within a few years of continuous monitoring during July and August; detecting “trends” in a statistically defensible manner, however, is likely to require over a decade of such monitoring. Unravelling the co-varying influences of human activity, interannual weather variability, and climate change will require not only more targeted investigations of the watershed and riparian zone of interest but also the presence of a regional temperature monitoring framework that can reveal regional trends independent of local influences.

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Appendix H

Conductivity

Conductivity as an indicator for HSTM Qa/Qx monitoring

"Conductivity" (or its temperature-corrected correlative, specific conductance) is widely recognized as a useful, easy-to-measure surrogate for total dissolved solids (TDS) (e.g., Minton 2003; Ecology 2011). As with temperature, causes of high TDS are varied and include both natural sources and stormwater inputs. Natural waters in most settings have low TDS and thus low conductivity; elevated levels from human activity include wash-off from streets, fertilizers, industrial discharges, and soil erosion.

As summarized by the USEPA (https://www.epa.gov/national-aquatic-resource-surveys/indicators-conductivity):

> "Conductivity is a measure of the ability of water to pass an electrical current. Because dissolved salts and other inorganic chemicals conduct electrical current, conductivity increases as salinity increases. Organic compounds like oil do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity.
>
> "Conductivity is useful as a general measure of water quality. Each water body tends to have a relatively constant range of conductivity that, once established, can be used as a baseline for comparison with regular conductivity measurements. Significant changes in conductivity could then be an indicator that a discharge or some other source of pollution has entered the aquatic resource.
>
> "Significant changes (usually increases) in conductivity may indicate that a discharge or some other source of disturbance has decreased the relative condition or health of the water body and its associated biota. Generally, human disturbance tends to increase the amount of dissolved solids entering waters which results in increased conductivity. Water bodies with elevated conductivity may have other impaired or altered indicators as well."

The potentially greatest value of this indicator is its ease of collection and its high correlation to other sediment-related measures (Miguntanna et al. 2010), particularly total suspended solids, which in turn has widely recognized ecological impacts at elevated levels and can be driven both directly by land-use activities i.e., (land-surface erosion) and indirectly via hydrologic alteration (resulting in stream-channel erosion from high flows).

Roy et al. (2003) conducted a comprehensive assessment of physical, chemical, and biological conditions in 30 streams along a rural-to-urban gradient in the Piedmont region of the southeastern US. They emphasized the high degree to which specific conductance (i.e., conductivity normalized to 25^{o}C) correlated with both land use and to biological impairment. They parameterized SC as the annual average value of multiple baseflow measurements, and summarized their findings as follows:

> "The consistently strong relationships we observed between biotic indices and SC [specific conductance] indicate that increased SC may lead to biotic impairment of surface waters. Other studies have also found a strong relationship between SC and land cover (Ometo et al., 2000) and have determined predictive relationships between SC and changes in macroinvertebrate assemblages (Tate & Heiny, 1995; Imert & Stanford, 1996). Specific conductance might be a good indicator of sediment disturbance as a source of increased ions (in addition to ion input via catchment run off), as it was positively correlated with decreased riffle and emergent bar particle size. Thus, its inclusion in the regression models may partially be due to its relationship with these variables, or as a surrogate 'chemical signal' from increased non-point sources in the catchments (e.g. fertilisers, pesticides, sediment), as suggested by its relationships with forest land cover and ammonium concentration." (p. 340)

King County Water and Land Resources Division has maintained a modest set of continuously recording conductivity meters in small streams throughout the central Puget Lowland. Eight such sites have about four years of data; one additional site (Miller) has less than a single year, but its unique location (draining a significant portion of SeaTac Airport, and with the highest fraction of watershed urban land cover) make it an instructive example.

The raw data (available from the King County Hydrologic Information Center at http://green2.kingcounty.gov/hydrology/) expresses a well-understood phenomenon—when discharge increases, SC decreases through dilution. When plotted on appropriate scales, the hydrograph and the plot of SC over time are near-perfect inverses of each other (Figure H1).

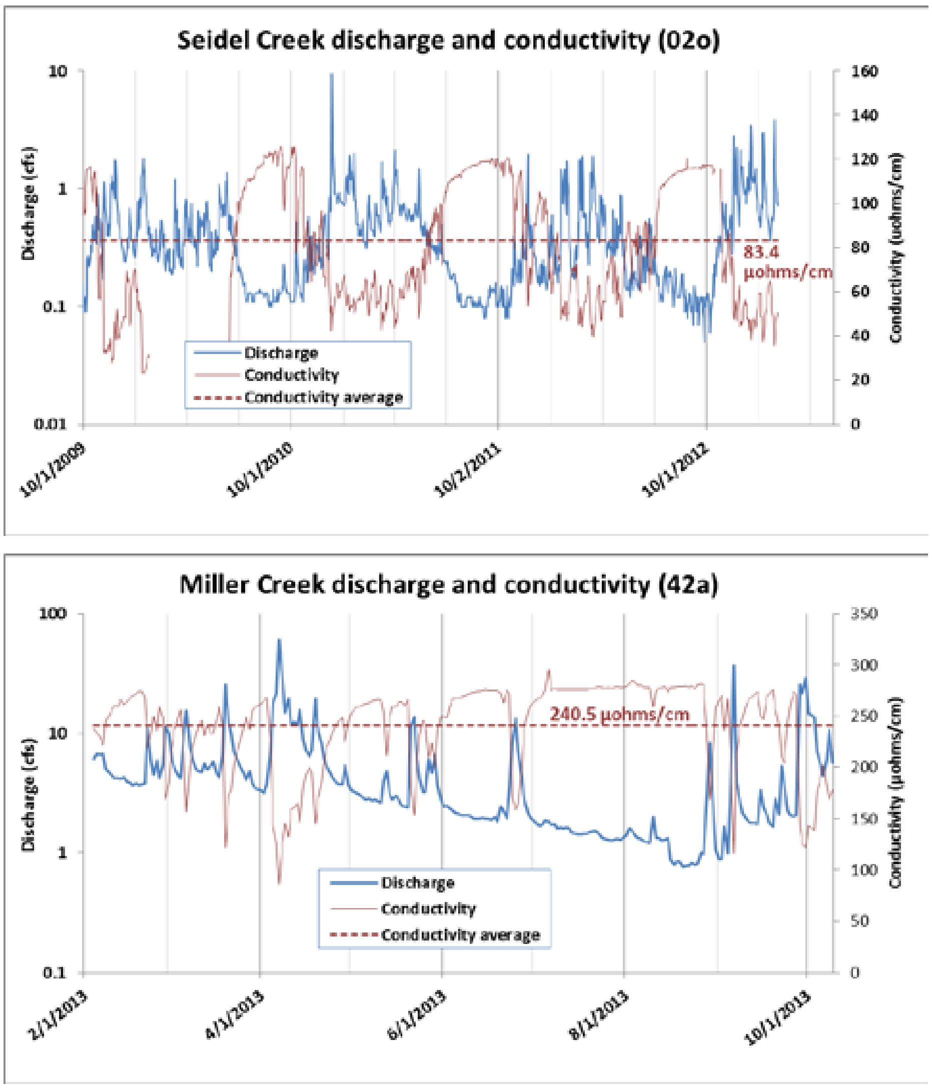

Figure H1. Example graphs of continuous conductivity measurements at two King County gage sites. Note the near-perfect opposite oscillations of conductivity and discharge, albeit on very different scales of measurement. The average value of conductivity over the period of record is shown by the dashed red line for each; they are markedly different for the suburban site (Seidel Creek) and the more intensively urban site (Miller Creek).

Most noteworthy is the substantial difference in average SC values for these two examples, presumably reflecting influences of both groundwater composition and contributions of urban runoff (Seidel Creek has 16.9% urban land cover, Miller Creek has 80.7%). Considering all nine gages. a broad pattern between watershed urbanization and conductivity (Figure H2), although the outlying position of Miller

Creek tends to drive any apparent relationship. The low-urban sites have values that range from about 30 to over 130 µohms/cm, suggesting that this range is indicative of regional conditions without significant human influence. Note, however, that even the moderate-urban sites (e.g., Talyor U/S, Seidel) also fall within this range.

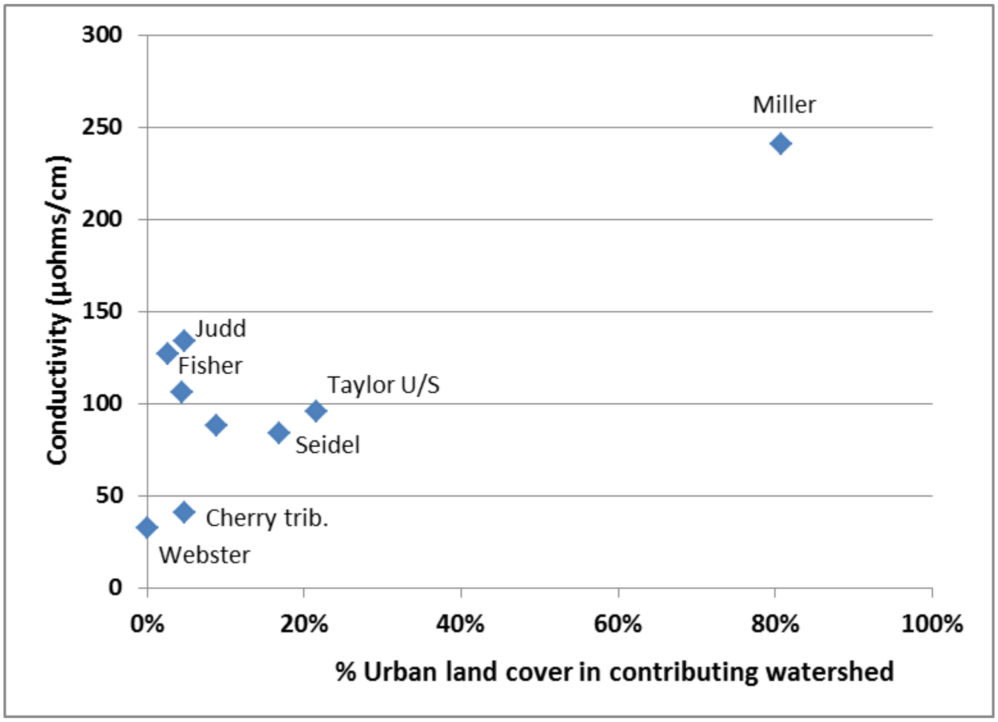

Figure H2. All sites with conductivity data, plotting their record-averaged conductivity value against their 2011 watershed urban land cover. There is no evident relationship except that the one high-urban site has a significantly greater conductivity value than the others.

Overall, there are no apparent trends across the period of record on any gage. Seidel Creek experienced the most rapid increase in urban land cover of all watersheds during the 2001-2011 period, but inspection of its conductivity graph (Figure C1, top) suggests no significant trend.

CONCLUSIONS

The relative paucity of existing data, and its apparent insensitivity to all but the largest of land-use differences or changes, suggest that monitoring for this parameter may only identify heavily impacted systems that are already recognizable by other means. It also suggests that trends as a result of incremental management or land-use changes are unlikely to be detected until an indeterminate (but undoubtedly large) number of years have passed. Nevertheless, its inclusion is supported by the ease of data collection, the previously recognized correlation of this parameter with both watershed impacts and biological health, and the potential for expanding what is currently a very limited data set to support a better regional understanding of such conditions.

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Appendix I

Comments and Responses to the Draft Implementation Plan Report

The following table documents stakeholder comments on the Implementation Plan Report provided in association with the February 9, 2016 workshop in Longview, Washington. Comments were provide during the workshop and electronically in the following week. Responses to each comment are provided by Stillwater Sciences and were used to guide the Implementation report.

Commenter, oranization	Comment	Response
Michelle Girts, EnTranRight, LLC	The identified objectives 1, 2, 3, 4, 7, and 8 render this study an "effects" study, using objectives 5 and 6 documented trends to associate effects with causes. It is thus essential that the monitoring plan and associated data analysis methodologies be established at the same time—and certainly before any cost estimates for the monitoring can be done. The initial data analysis step will of course be characterization of the distributions, variability, reproducibility, etc. for the target parameters, but there are enough numbers in the literature and held by USGS and others to have a strong sense of what these characteristics will be now - sufficient to base the monitoring plan on the sampling frequency, locations, and indicators that will give statistically valid conclusions when subjected to trend analysis. I haven't seen specifics about recommended data analysis methodology, and in the meeting it was stated that the statistical methods were left out because they were determined to be not relevant at this stage. That is a significant flaw, as it is quite possible that no statistically significant results will be derived from this monitoring program.	Thank you for this comment, which in part was echoed in the workshops and addressed in our final draft. The wording of each objective was chosen to avoid mistaking correlation (i.e., between watershed conditions and indicators), the essence of status-and-trends monitoring, from causality (which would be the the purpose of any subsequent effectiveness monitoring study). We do hope that identified impairments will motivate subsequent effectiveness studies and, ultimately, improvement in receiving-water quality; but this is not the purpose of the present study design. The comment is quite correct in noting the existence of abundant water-quality and habitat data sufficient to infer preliminary statistical properties. These data in fact long predate USGS efforts, and they were quoted extensively in the Design Report and used explicitly in establishing the initial design. Of course, there is no guarantee that local monitoring results will demonstrate statistically significant trends (since an absence of actual change is a possible condition beyond the control of any monitoring program), but achieving a robust characterization of status is fully incorporated into the design. Refinement of this characterization will surely occur once region-specific data have been collected, but assuming that no consideration of such issues has yet occurred is a reflection of unfamiliarity with the multi-year process of developing the HSTM program, not a "significant flaw" of the program itself.
Michelle Girts, EnTranRight, LLC	The recommendations for stormwater sampling provide neither worthwhile background information to characterize the stormwater assimilation capabilities and responses of a watershed and changes in same, nor whether regulatory compliance is furthered by management, planning, education, or engineering changes which are potentially controllable factors. The stormwater sampling program should be re-evaluated to provide such benefits to the utilities contributing to this study. Note that this recommendation goes far beyond a question of whether continuous or grab sampling have greater value in establishing status and trends.	Although "stormwater assimilation capabilities" and "regulatory compliance" are both topics worthy of investigation, neither lie within the scope of a status-and-trends monitoring program (stormwater or otherwise). The program is intentionally scoped at a much more basic level, as articulated by the Department of Ecology: "Are conditions getting better or worse?" If "worse," then permittees and regulators alike will have more work ahead of them to identify additional actions beyond what is already incorporated into stormwater-management programs to achieve desired outcomes. Many of these stormwater utilities are already investing in such measures, and we are optimistic that this status-and-trends program will identify areas more specifically (both geographical and topical) where such efforts could be applied to greatest benefit. We remind the comment-er, however, that providing the specific guidance necessary to achieve those benefits is beyond the scope of a status-and-trends monitoring program, and to include those elements here would have greatly increased the cost without a commensurate improvement in benefits.

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Michelle Girts, EnTranRight, LLC	There appears to be no plan to subject this program to initial or periodic review by a national or international panel of experts in the field. Considerable advances will take place in monitoring techniques and equipment, data management and analysis, and the associated science over each 5-year period (and changes will take place in the regulatory context, too). Given that this program is at least a $1M/year investment, I recommend that such a panel be convened to—if not review the final proposed program now - review the outcomes and the program against the backdrop of such advances when the first 5-year report is produced. Such feedback and other proposed changes that inevitably result from implementation can then be considered, and the program modified as an integrated whole for the next 5-year implementation.	During a stakeholder meeting, the Department of Ecology agreed to the merits of a peer reviewed Qa/Qx design, with the full support of the contractors and stakeholders. There is no question but that peer review, national or otherwise, almost invariably leads to improvements in any study or design, and the principle is fully embraced by all parties. The details of when and how the peer review will occur have yet to be determined.
Michelle Girts, EnTranRight, LLC	This monitoring plan could benefit greatly by offering opportunities to academic, government, and private research organizations, by flagging questions in need of further controlled or experimental research with outcomes that are potentially immediately applicable. By definition, a trend study takes place over time, and so there may be many such junctions between monitoring and research. I suggest that this program seize the opportunity and identify ways in which it might advance both talent and knowledge in these fields	See prior response. As with virtually all public-agency monitoring programs, methodology and data will be readily available to all, and participation by any/all 3rd parties will surely be welcomed. If the comment is advocating for additional cost to participants to fund the engagement of such parties, however, the response lies outside of the domain of the report authors.
Rich Doenges, WA Dept of Ecology	Several time during the presentation you mentioned that statistical significance was part of the evaluation process, can you summarize what's behind that and what sort of assumptions are important to maintain that statistical significance?	Given the absence of region-specific data at this stage of the plan's implementation, development of the monitoring design relied on the collective experience from prior studies to determine indicators and procedures most likely to produce statistically significant results in a 5- to 10-year period. Habitat indicators were selected that have consistently produced relatively low noise data (refer to the signal-to-noise analysis of the Design Report), using methods with a good record of reliability and reproducibility. Qa/Qx indicators were also selected to emphasize integrative measures that reduce the intrinsic variability of these data, and the guidance from many decades of water-quality sampling were applied to identify the number of sites per strata that would be necessary to detect a modest level of change over a decadal time scale. The monitoring design also relies on stratified random sampling to ensure unbiased representation of the larger population.

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Michelle Girts, EnTranRight, LLC	What statistical analyses do you have planned for the data?	"Suggested analyses were added to the report to provide guidance without prescription. Ultimately, the appropriate statistical analysis will be the responsibility of the data analyst for the HSTM implementation. However, the outline of such analyses can already be discerned. For the continuous Qa/Qx indicators, evaluation of variance can occur once a single year's data have been collected, and from that a determination of what magnitude of year-to-year change (at a site) or difference (from one site to another) will be needed to detect statistical significance. For the annual indicator (B-IBI), prior analyses have already defined the magnitude of change/difference needed to identify ""differences,"" although these findings will surely be reevaluated once multiple years of same-site data have been collected. For the once-in-5-year indicators, affirming the statistical significance of any detected trends will require at least several monitoring periods, since the regional/national understanding of their variability is not presently well developed. Discriminating "better" from "worse" sites will also likely require more than a single 5-year sample set and should be informed by other regional monitoring programs currently underway. "
James Martin, Washington State University - Vancouver	Regarding the cost estimates, what were the assumptions on baseline expectations about how each site would be sampled?	Additional detail and assumptions were provided by the Stormwater caucus and included in the Implementation Plan and QAPP
Fred Bergdolt, Wa Department of Transportation	What will managers be able to do with the status and trends data from this program?	Managers will be able to review both status and trend data to identify the condition of Lower Columbia habitat and water quality conditions as well as potential changes over time. Although managers have a wide range of potential applications and interest for status and trend data, in general, it can be used to highlight areas of greatest concern and the potential need for management changes. Results relative to evaluation criteria and general trends can be valuable for the purpose of communication and management.