Scientific Protocol for Salmonid Habitat Surveys within the Columbia Habitat Monitoring Program

2011 Training Version 1.1

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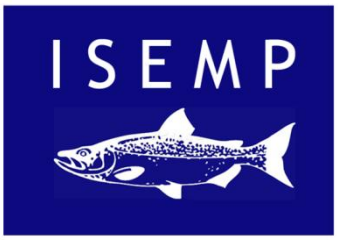
Bonneville Power Administration's
Integrated Status and Effectiveness Monitoring Program



for

Bonneville Power Administration's Columbia Habitat Monitoring Program

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SECTION 1: INTRODUCTION

This document is intended to explain the set of methods and associated metrics that will be collected and analyzed by the Columbia Habitat Monitoring Program (CHaMP) to an audience including salmon habitat scientists, data analysts, study designers, and monitoring practitioners. The background and objectives of CHaMP and its habitat protocol are described in Section 1. Section 2 describes the theoretical underpinnings of this approach to salmonid habitat monitoring and Section 3 summarizes the survey design and site selection process. Sections 4 through 9 describe the data collection methods and metadata requirements in sufficient detail that trained technicians can use this portion of the document as a field handbook. Section 10 describes how field data is processed into metrics that will be usable by natural resource managers and decision makers. Finally, Section 11 and the several appendices provide information that supports the protocol.

1.1 The Genesis of CHaMP

The 2008 Biological Opinion (BiOp) on the Federal Columbia River Power System (FCRPS) identified offsite mitigation actions, largely in the form of habitat restoration, as a means to offset mortality imposed by the FCRPS on anadromous salmonids. As such, the Bonneville Power Administration (BPA) is working with the National Oceanic and Atmospheric Administration (NOAA) and other regional fish management agencies to implement a tributary habitat action effectiveness strategy across the Columbia River basin (FCRPS BiOp RPA 56.3) which supports habitat restoration, rehabilitation, and conservation action performance assessments and adaptive management requirements of the 2008 FCRPS BiOp. In 2010, BPA began the development of CHaMP to meet FCRPS Action Agency (2010) programmatic prescriptions for habitat monitoring.

CHaMP is designed as a Columbia River basin-wide habitat status and trends monitoring program built around a single protocol with a programmatic approach to data collection and management (RM&E Workgroup 2010). CHaMP will result in the collection and analysis of systematic habitat status and trends information that will be used to assess basin-wide habitat conditions. When coupled with biological response indicators, this status and trends information will be used to evaluate habitat management strategies. This program will be integrated with ongoing Pacific Northwest Aquatic Monitoring Program (PNAMP) recovery planning efforts and will be part of the collaborative process across Columbia Basin fish management agencies and tribes and other state and federal agencies that are monitoring anadromous salmonids and/or their habitat. The implementation of CHaMP will characterize stream responses to watershed restoration and/or management actions in at least one population within each steelhead and spring Chinook Major Population Group (MPG) which have, or will have, “fish-in” and “fish-out” monitoring (identified in RPA 50.6), thereby meeting the requirements of Reasonable and Prudent Alternative (RPA) 56.3, RPA 57, and RPA 3. CHaMP was designed to deliver trends in habitat indicators and requires that monitoring occur for three cycles of a sampling panel (see section 1.6), at least 9 years.

During the process of developing CHaMP, BPA has been advised by the Integrated Status and Effectiveness Monitoring Program (ISEMP), which is a BPA-funded project

specifically tasked with assessing and developing standardized monitoring protocols for fish and fish habitat in the Columbia River Basin. In early 2010 BPA requested that ISEMP recommend a habitat protocol to be adopted by BPA-funded Columbia River Basin monitoring programs. Based on ISEMP's initial recommendations (Bouwes et al. 2010), BPA and several collaborating agencies, with technical and coordination assistance from ISEMP, began to build CHaMP through the development of a set of coordinated proposals to the 2010 Research, Monitoring and Evaluation (RM&E) and Artificial Production Categorical Review for the Columbia River Basin Fish and Wildlife Program in the spring of 2010. This set of proposals received favorable reviews by the Independent Scientific Review Panel (ISRP) for the Northwest Power and Conservation Council (NWPC; ISRP 2010a, ISRP 2010b; e.g., the proposed CHaMP monitoring program "is very comprehensive and ambitious" and would "represent a major step forward" in the implementation of basin-wide habitat restoration actions and pertinent effectiveness monitoring) which bolstered BPA's desire to continue development of CHaMP. By the end of 2010, BPA had taken concrete steps to further develop and implement CHaMP beginning in 2011. The ISEMP has been tasked with coordinating the development and implementation of CHaMP for at least its initial three years.

CHaMP is being built around a single habitat monitoring protocol (a protocol being a documented set of methods and associated metrics; Oakley et al. 2003) with a program-wide approach to data collection and management. The protocol is structured around a general understanding of the link between habitat attributes and how they directly relate to the specific life history requirements of the salmonid fishes managed under the 2008 BiOp. These fish are likely not only responding to watershed and reach conditions but also to the conditions of individual channel units within reaches. Recognizing the importance of how interactions at the channel unit scale affect fish performance has led to an increased emphasis on the quantification of this important scale of fish habitat in the CHaMP protocol. We adopted the Hawkins et al. (1993) hierarchical classification scheme that allows for summarization of information across multiple scales. This preserves the ability to summarize information at the site scale, as commonly practiced in major fish habitat monitoring programs throughout the Pacific Northwest, as well as at the smaller channel-unit and topographical feature scales. The protocol employs spatially continuous sampling strategies using well-established surveying techniques to conduct precise topographic surveys from which digital elevation models (DEMs) can be produced. These topographic surveys are augmented by auxiliary data (e.g., channel classification, fish cover, substrate composition, distribution and embeddedness, large woody debris (LWD), solar input and water temperature, stream discharge, water chemistry, riparian structure, and site-level human influence) that help to characterize aspects of channel units that influence site-scale fish production potential.

The CHaMP protocol draws together methods from many existing protocols as well as novel approaches to collecting and analyzing channel geomorphological data. The protocol is designed to maintain the rapid nature of existing stream habitat protocols and to collect data that fits within a geomorphological hierarchy spanning spatial scales ranging from within-unit topographical features to channel units to geomorphic reaches to watershed and subbasin scales.

1.2 CHaMP's Objective

The program's primary objective is to assess the quantity and quality of stream habitat for salmonids in wadeable, perennial streams below natural impassible barriers within Technical Recovery Team (TRT) population boundaries. The intention of the program is to generate standardized status and trend data for salmonid habitat in watersheds of the Columbia River Basin. Surveys will be conducted in watersheds with perceived large juvenile life-stage survival gaps due to habitat impairments or that are home to existing high quality fish monitoring infrastructure. Program implementation will occur on the spatial scale of the TRT populations with the intention for inference on habitat quality and quantity at the fish population level. The stream habitat data generated by CHaMP will be used in conjunction with salmonid growth, survival, abundance and productivity to estimate fish-habitat relationships across the Columbia River Basin. The CHaMP protocol is fish-centric, i.e., measuring habitat relevant to salmonids of interest under the BiOp. As such, it differs from other programs like the Aquatic and Riparian Effectiveness Monitoring Program (AREMP), which was designed to assess the condition of aquatic, riparian, and upslope ecosystems under the jurisdiction of the Northwest Forest Plan (Gallo 2001), or the PACFISH/INFISH Biological Opinion (PIBO) protocol, which was designed to determine whether a suite of biological and physical attributes, processes, and functions of upland, riparian, and aquatic systems are being degraded, maintained, or restored, particularly in reference to livestock grazing and other federal land management practices (http://www.fs.fed.us/biology/fishecology/emp/), or the Environmental Monitoring and Assessment Program (EMAP) protocol, which was designed by the Environmental Protection Agency (EPA) to produce unbiased estimates of the ecological condition of surface waters across a large geographic area (or areas) of the West (Peck et al. 2001).

1.3 Protocol Development Process

The methods described in this protocol were developed in a step-wise process that included literature reviews, field testing, and data analysis. First, the CHaMP development process is founded on the results of work conducted over the last two decades by groups like ISEMP (in pilot Columbia River subbasins since 2003); the U.S. Forest Service (e.g., the PIBO habitat sampling program begun in 1998, AREMP since 2001, and protocol comparison studies such as Roper et al (2002, 2008, 2010)); EPA's EMAP program (started in 1990); the Oregon Department of Fish and Wildlife (habitat programs since 1998); and work by other agencies like the Washington Department of Ecology and Oregon Department of Environmental Quality. We anticipate and encourage future constructive criticism from these and other monitoring practitioners that will provide help improve the protocol's precision, accuracy, and comparability.

The second step in the process of developing this protocol was an assessment of the applicability of commonly used attributes in stream habitat monitoring protocols (Bouwes et al. 2010). Bouwes et al. (2010) reviewed fish habitat requirements in the context of stream habitat attributes and geomorphic processes, assessed whether existing habitat protocols provided information that relates the quality of stream habitat to fish production, and developed a draft habitat monitoring protocol for projects that support the FCRPS and salmonid recovery planning.

The methods and approaches described in Bouwes et al (2010) were field tested by ISEMP during the summer of 2010 and further revised based on the results of those field evaluations in the fall of 2010. At the same time, data collected by ISEMP in the Wenatchee and Entiat subbasins since 2003 were analyzed. Results from both field testing and data analyses were used to further refine the list of metrics and indicators included in CHaMP.

Finally, all possible metrics and indicators envisioned during the protocol development process or that were documented in several other protocols (see Appendix D) were evaluated according to the rule set described in section 1.5. Metrics and indicators that are included in CHaMP are described in Table 1, while those found in other common protocols that are not included in CHaMP are listed in Table 2. It should be noted that the products of the CHaMP surveys (e.g., DEMs) will allow for the calculation of more channel geomorphology metrics than will be used by CHaMP as indicators (e.g., bankfull width, cross-section width, wetted width, width-to-depth ratio, floodplain width, etc.). These additional metrics will allow CHaMP channel geomorphology data to be used by other monitoring programs.

1.4 Summary of the Habitat Survey Protocol

The following is a short description of the field methods that make up the CHaMP habitat survey protocol (a thorough description can be found in sections 4 - 9). CHaMP survey methods fall into two major groups: collection of topographic data (X, Y, Z points) and collection of non-topographic habitat attributes (e.g., LWD, sediment, fish cover, etc.). Two field personnel will collect the former, and a third person will collect the latter. Surveys will be conducted at randomly-selected sites that are approximately 20 times the bankfull width in length and these sites will be classified by geomorphic channel type (Montgomery and Buffington 1997).

1.4.1 Channel Units and Topographic Survey

Channel units will be classified based on a slightly simplified Hawkins et al. (1993) classification system. This hierarchical classification scheme allows for summarization of channel units at different levels of resolution depending on the question asked, and allows comparison to other habitat classification schemes that may be used by other protocols (e.g., pools and non-pools). Perimeters of channel units will be delineated and recorded using a total station to create a planform view of the site that depicts the arrangement of channel units (Figure 1). With this information, areas and volumes of channel unit types can be estimated. In addition, habitat attributes (e.g., LWD, substrate composition, etc.) are collected as they occur within specific channel units, providing distributional information and allowing interactions between channel morphology and structural attributes to be identified. For example, Senter and Pasternack (2010) found that Chinook prefer to spawn in riffles located near large wood cover rather than in riffles with similar substrate characteristics but without cover.

The total station survey will also be used to generate a high resolution DEM of the site. A total station survey requires two people. One person operates the total station instrument while the other person places a stadia rod and prism along topographic features. The spatial information collected during the total station survey is referenced to a known point (collected from GPS) established by the surveyors and compass-derived orientation. This allows sites to be mapped for further watershed spatial analyses in a geographic information system (GIS).

Approximately 500-1000 points are typically collected with the total station in a day of surveying. These points capture the major grade breaks in the streambed and bank topography. Gradient lines are used to capture distinct features such as top-of-bank, edge-of-water, and bankfull indicators. The survey data is then used to generate topographic models of stream channel morphology called TINs (triangulated irregular networks). From the TINs a high resolution DEM (approximately 0.1 to 0.25 m resolution) and water depth map can be created (Figure 2, top panel) and spatially referenced on maps, aerial photos, or Google Earth imagery (Figure 2, bottom panel).

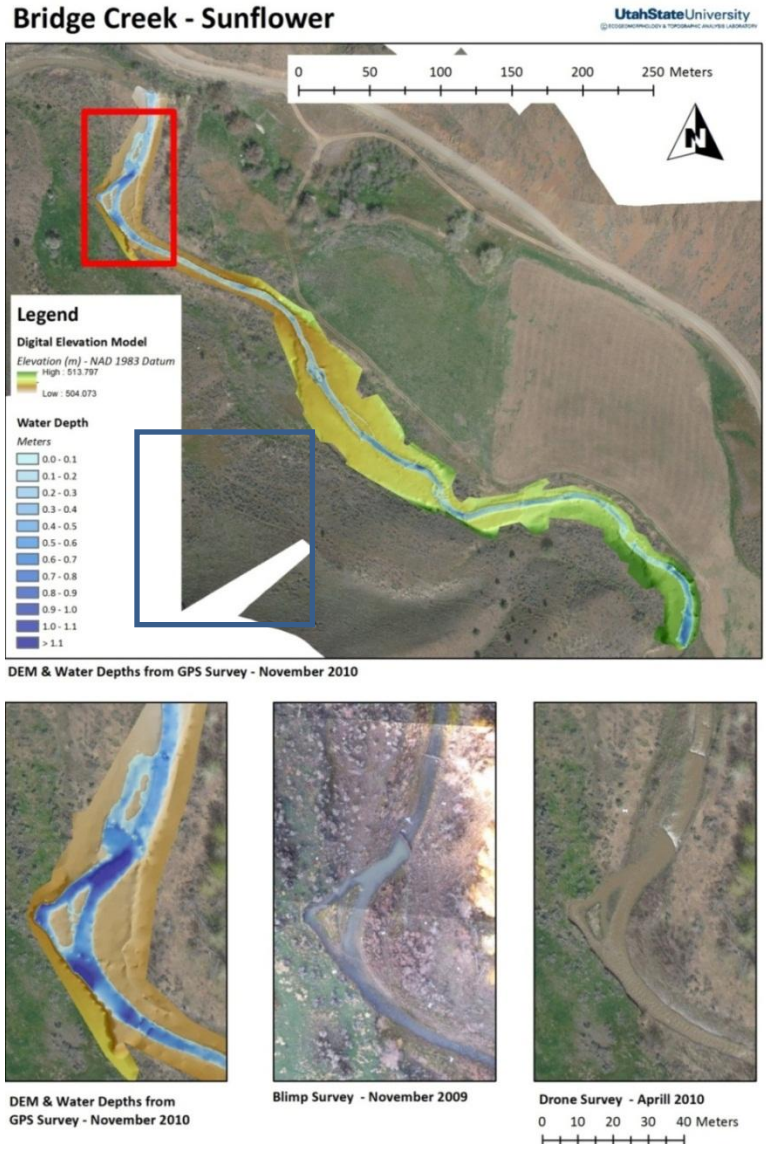

Figure 1. (Top) Topographic survey of a 1 km long site in Bridge Creek. Red box is depicted in 1 B,C,D and blue box depicted in 2 A, B. (Bottom Left) A 0.25 m DEM and water depths created with the topographic survey overlaid on an aerial photo taken from a drone. (Bottom Middle) Aerial photos take from a blimp during base flow. (Bottom Right) Aerial photos take from a drone survey during higher flows.

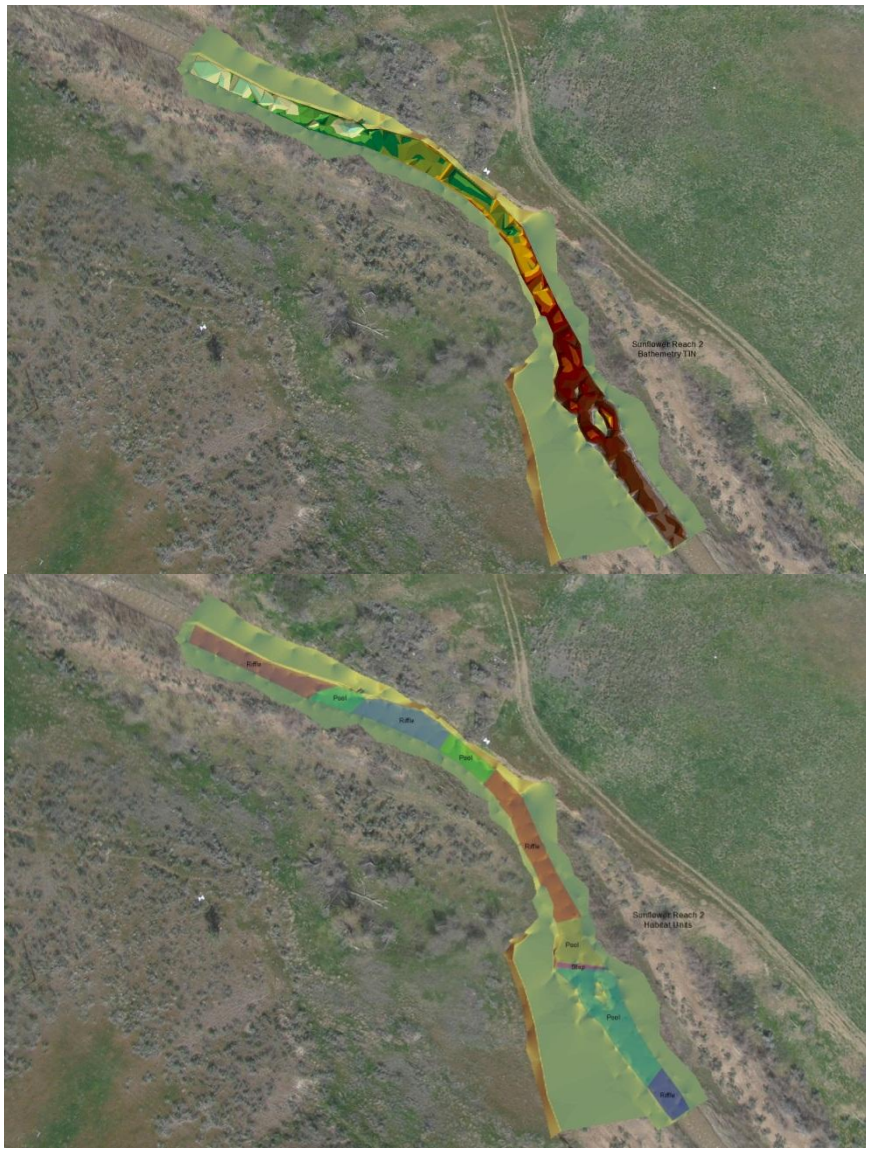

Figure 2. (Top Panel) Example of a TIN created using the CHaMP protocol overlaid on an aerial photo taken from a drone. (Bottom Panel) Creation of the site planform and delineation of channel units.

Field crews will be tasked with the processing of the topographic survey data. Creating, reviewing, and editing TINs by the field crews will be used as part of the quality assurance process and will ensure that data has been collected properly since, in our experience, conducting a topographic survey results in a vivid memory of the site morphology. Thus, the field crew is in the best position for making the appropriate edits to the TINs to reflect the site (e.g., connecting of gradient breaklines, removal of false "dams", etc.). We believe that giving the field crew this responsibility will create a sense of ownership of the data, a visual goal, and a feedback loop that will improve future surveys.

1.4.2 Channel Unit and Site Level Attributes

Other stream attributes will be collected by the third crew member. For each channel unit, estimates of large wood, substrate type, undercut banks and other fish cover will be collected. In fast water units, we will measure 210 streambed particles and pool-tail fines. The sum of the channel unit level information can be summarized by unit type (e.g., pools) or by site, as is commonly done in other habitat monitoring protocols.

Additional site level attributes will be collected at transects throughout the site. A solar pathfinder will be placed in the center of the channel at these transects. The solar pathfinder is a convex plastic dome that reflects the surrounding topography and vegetation. This is captured with a photo and provides an estimate of the amount of solar radiation entering the stream at any time of the year. In addition, the characteristics of a 10 m x 10 m plot of riparian vegetation is noted on both banks at these transects.

At the site level, several attributes are collected including: macroinvertebrate drift, alkalinity, conductivity, temperature and stream discharge. Drift nets will be placed above the site and collect drifting invertebrates over the course of the survey. Discharge will be estimated at a suitable cross-section using the EMAP protocol (Peck et al. 2001). Temperature probes for air and water will be deployed to take hourly temperature for 1 or 3 years, depending on the watershed-specific temporal design that is used. Finally a site map will be drawn for each site to document qualitative information such as human influences and disturbances, as well as benchmark locations, channel unit locations, and other distinguishing characteristics.

1.5 Habitat Metrics and Indicators

Metrics and indicators are the units of information most useful and relevant to making inferences and decisions about the management of salmon habitat (NCEAS 2010). These discrete summarizations of reality are derived from scientific observations made during a process called monitoring and differ from each other by the spatial and temporal scales and by the level of scientific sampling design used in their creation. Metrics are information resulting from the reduction or processing of measurements taken at a site within a particular temporal period, while indicators result from the reduction of metrics across sites and temporal periods. In both cases, metrics and indicators are the common language among data collectors, scientists, and natural resource decision makers, even those involved in different monitoring programs.

Given the central role of metrics and indicators in natural resource management, it is critical to clearly describe which metrics and indicators are included in this protocol, what we mean by each metric and indicator and how they may be used, and the process by which metrics and indicators used in this protocol were selected or rejected. The remainder of section 1.5 describes the metrics/indicators collected by CHaMP at this level of detail.

Metric and Indicator Inclusion Rule Set

All possible metrics and indicators envisioned during the protocol development process or that were documented in several other protocols (see Appendix D) were evaluated according to the following rule set. A measurement and related methodology was included in the CHaMP

protocol if, and only if, it would be used to calculate a metric that met each of the following three rules:

1) Information Content: Habitat metrics and indicators must provide information directly related to salmonid productivity, including survival and growth, as documented by peer reviewed literature, modeling, or existing data analysis.
2) Data Form: Habitat metrics and indicators must provide statistical information with robust data quality. The data generated for a prospective metric must be repeatable, detect heterogeneity, and have adequate properties for modeling/statistics (e.g., variance distributions must meet statistical assumptions for modeling or testing).
3) Feasibility: Habitat metrics and indicators need to be generated by field tools or software that are readily implementable as of the time field testing in fall 2010 (i.e., does not rely on future technological advances). Feasibility is also bounded by the need to fit all survey work within a three-person-day field survey at 80-90 percent of all sites likely to be encountered.

Some metrics that met rules 1 and 2, and nearly met rule 3 will not be included in CHaMP but will receive additional development by ISEMP and may be recommended for inclusion in CHaMP in the future. For example, methods to create DEMs of channel geomorphology that do not require total station survey equipment (i.e., a "stick and tape" method), may be researched and developed further by ISEMP but are not included in this document.

The habitat quality and quantity indicators in the CHaMP protocol have been designed specifically to evaluate the features of stream habitat critical to juvenile salmonid growth and survival from egg to smolt life stages. Data generation through CHaMP will be based on a spatially balanced sampling design (EPA's generalized random tessellation stratified, GRTS; Stevens and Olsen 2004,Stevens and Olsen 2003; see Section 3) that distributes sampling effort across a stream network such that unbiased, representative samples can be collected at discrete monitoring locations. The measurements collected at individual sites are used to derive the generation of site-level metrics from which watershed-scale indicators are constructed. The inference design describes the process used to estimate indicators for the watershed based on metrics collected at the sample sites. This may occur for a single time period resulting in a status estimate for the indicator or it may involve making estimates across multiple time periods when trends are of interest. Table 1 shows the CHaMP indicators, the metrics from which they are derived, as well as a brief outline of the inference design underlying each indicator. Table 2 shows common metrics and indicators that were not included in CHaMP and the reasons why they were omitted.

Table 1. The metrics and indicators used in the CHaMP protocol and the inference design underlying each indicator.

Indicator	Units	Inference Domain	Inference Design	Inference Method	Metrics	Indicator Generation Process	Software	Fish Response Category	Life Stage
Average Alkalinity	Milli-equivalent per liter	Survey frame	Mean, variance over inference domain, annually	Design-based	Site measurement of alkalinity	Estimated annually for entire survey frame with sampling design-based algorithm.	SP Survey	Survival	Parr to smolt
Average Conductivity	Micro-Siemens per meter	Survey frame	Mean, variance over inference domain, annually	Design-based	Site measurement of conductivity	Estimated annually for entire survey frame with sampling design-based algorithm.	SP Survey	Survival	Parr to smolt
Average pH	pH	Survey frame	Mean, variance over inference domain, annually	Design-based	Site measurement of pH	Estimated annually for entire survey frame with sampling design-based algorithm.	SP Survey	Survival	Parr to smolt
Growth Potential	Degree grams	Survey frame	Mean, variance over inference domain, annually	Design-based	Site measurement of drift biomass and temperature	Estimated annually for entire survey frame with sampling design-based algorithm for the product of drift macroinvertebrate biomass and temperature	SP Survey, Thermal Dynamic Model	Growth	Parr to smolt
Percent Below Summer Temperature Threshold	Percent	Survey frame	Total length estimated over survey domain, annually	Model-based	Year-round temperature logger data from sites	Model-based inference for all stream reaches in the watershed based on a continuous stream temperature model calibrated with site specific temperature logger data	Thermal Dynamic Model	Growth	Parr to smolt
Percent Above Winter Temperature Threshold	Percent	Survey frame	Total length estimated over survey domain, annually	Model-based	Year-round temperature logger data from sites	Model-based inference for all stream reaches in the watershed based on a continuous stream temperature model calibrated with site specific temperature logger data	Thermal Dynamic Model	Growth	Parr to smolt
Velocity Heterogeneity	Index	Valley type nested in survey frame	Mean, variance over inference domain, annually	Design-based	Modeled velocity heterogeneity at a site	Estimated annually for valley types nested in the survey frame with sampling design-based algorithm for variance Froude number across a site.	SP Survey, Hydrologic model	Growth	Parr to smolt
Embeddedness of Fast water Cobble	Percent	Valley type nested in survey frame	Mean, variance over inference domain, annually	Design-based	Average of site embeddedness measurements	Estimated annually for valley type nested in the survey frame with sampling design-based algorithm for riffle cobble embeddedness.	SP Survey	Survival	Eggs/Alevin

Indicator	Units	Inference Domain	Inference Design	Inference Method	Metrics	Indicator Generation Process	Software	Fish Response Category	Life Stage
Pool Frequency	Count per meter	Valley type nested in survey frame	Mean, variance over inference domain, annually	Design-based	Site measurement of pool frequency	Estimated annually for valley type nested in the survey frame with sampling design-based algorithm for pool frequency.	SP Survey, River Bathymetry Toolkit	Growth	Parr to smolt
Channel Complexity	Index	Valley type nested in survey frame	Mean, variance over inference domain, annually	Design-based	Site measurements of depth, width, and thalweg sinuosity	Estimated annually for valley type nested in the survey frame with sampling design-based algorithm for variance in depth, variance in width, and variance in thalweg sinuosity.	SP Survey, River Bathymetry Toolkit	Growth	Parr to smolt
Channel Score	Index	Valley type nested in survey frame	Mean, variance over inference domain, annually	Design-based	Site measurements of channel unit volume, LWD, and substrate	Estimated annually for valley type nested in the survey frame with sampling design-based algorithm metrics necessary for RP100 calculations as used by PIBO, AREMP, and EMAP.	SP Survey, River Bathymetry Toolkit	Growth	Parr to smolt
Residual Pool Volume	Cubic meter	Valley type nested in survey frame	Mean, variance over inference domain, annually	Design-based	Site measurement of residual pool volume	Estimated annually for valley type nested in the survey frame with sampling design-based algorithm for residual depth of all pools as given by the site DEM.	SP Survey, River Bathymetry Toolkit	Growth	Parr to smolt
Pool Tail Fines	Percent	Valley type nested in survey frame	Mean, variance over inference domain, annually	Design-based	Site measurement of pool tail fines	Estimated annually for valley type nested in the survey frame with sampling design-based algorithm for pool tail fines.	SP Survey	Survival	Eggs/Alevin
Total Drift Biomass	Gram per square meter	Survey frame	Mean, variance over inference domain, annually	Design-based	Site measurement of total drift biomass	Estimated annually for valley type nested in the survey frame with sampling design based algorithm for total drift biomass.	SP Survey	Growth	Parr to smolt
Bank Angle	Percent	Valley type nested in survey frame	Mean, variance over inference domain, annually	Design-based	Site measurement of bank angle	Estimated annually for valley type nested in the survey frame with sampling design-based algorithm for bank angle from site DEM and channel unit delineation.	SP Survey, River Bathymetry Toolkit	Growth	Parr to smolt
LWD Volume	Cubic meter	Valley type nested in survey frame	Mean, variance over inference domain, annually	Design-based	Site measurement of LWD Volume	Estimated annually for valley type nested in the survey frame with sampling design-based algorithm for LWD volume.	SP Survey	Growth	Parr to smolt

Indicator	Units	Inference Domain	Inference Design	Inference Method	Metrics	Indicator Generation Process	Software	Fish Response Category	Life Stage
Fish Cover	Percent cover	Survey frame	Mean, variance over inference domain, annually	Design based	Site measurement of fish cover	Estimated annually for valley type nested in the survey frame with sampling design-based algorithm for channel unit type and whole reach total fish cover.	SP Survey	Survival	Parr to smolt
Channel Unit Volume	Cubic meter	Valley type nested in survey frame	Mean, variance over inference domain, annually	Design-based	Site measurement of volume (DEM, photos, site map) and channel unit type	Estimated annually for valley type nested in the survey frame with sampling design-based algorithm for channel unit volume from site DEM and channel unit delineation.	SP Survey, River Bathymetry Toolkit	Growth	Parr to smolt
Channel Unit Complexity	Index	Valley type nested in survey frame	Mean, variance over inference domain, annually	Design-based	Site measurements of channel unit volume, LWD, and substrate	Estimated annually for valley type nested in the survey frame with sampling design-based algorithm for residual pool depth, pool tail fines and wood volume. A multivariate measure of channel unit complexity, similar to DSM approach applied by AREMP and PIBO to habitat metrics to capture complexity.	SP Survey, River Bathymetry Toolkit	Growth	Parr to smolt
Riffle Particle Size (D_{16}, D_{50}, D_{84})	Millimeter	Valley type nested in survey frame	Mean, variance over inference domain, annually	Design-based	Site measurement of D_{50}, D_{16}, D_{84}	Estimated annually for valley type nested in the survey frame with sampling design-based algorithm for D_{16}, D_{50}, and D_{84} from riffles.	SP Survey	Survival	Eggs/Alevin
Riparian Structure	Kilometer by type	Vegetation community types nested in survey frame	Total length estimated over survey domain, annually	Design-based	Site measurement of riparian structure	Estimated annually for posthoc stratified domains of historical riparian vegetation types in the survey frame with sampling design based algorithm for each riparian structure.	SP Survey	Growth	Parr to smolt
Solar Input	Degree day	Valley type nested in survey frame	Mean, variance over inference domain, annually	Design-based	Site measurement of solar input	Estimated annually for valley type nested in the survey frame with sampling design-based algorithm for solar input.	SP Survey, Solar Pathfinder	Growth	Parr to smolt

Table 2. Metrics and indicators not included in the CHaMP protocol and the reasons why they were omitted.

Indicator/Metric	Reason Not Included In CHaMP	Reference
Bank Stability	Low information content, poor data format	See Appendix D for details.
Fish Cover by Bryophytes, Macrophytes, Filamentous Algae, Small Woody Debris	These elements of fish cover have been found to have low information content and poor data format as individual metrics. CHaMP rolls some of these metrics into larger fish cover categories. See Section 8.2.	Appendix D conclusions were modified by ISEMP analysis of Upper Columbia habitat data.
Benthic Macroinvertebrate metrics	Low information content, poor data format	See Appendix D for details.
Dissolved Oxygen	Low feasibility (inappropriate as a point measure and too expensive to sample continuously at all sites.)	--
Nutrients - Chemistry	Low information content, low feasibility	See Appendix D for details.
Turbidity	Low information content, poor data format, low feasibility	See Appendix D for details.
Rosgen Channel Classification	CHaMP will use Montgomery and Buffington (1993) to classify channels. While all channel classification systems have Low Information Content, Montgomery and Buffington (1993) fits within the hierarchical geomorphological approach of CHaMP better than the Rosgen(1994) channel classification system.	--
Pesticides	Low feasibility	--
Heavy Metals	Low feasibility	--

1.6 Inference Design

The inference design, or the statistical analysis procedure, is a key component of the CHaMP design – data collection procedures have been developed to generate relevant metrics that are collected at spatially and temporally distributed sites (see Section 3 for more detail). The inference design integrates the site specific data collection and the spatial sampling design. For example, if the spatial sampling design is a survey, the inference design will require knowing the properties of the survey design, such as stratification and unequal probability weighting. CHaMP employs a spatially balanced, split panel survey design and thus can use standard mean and variance estimators, and, because the sampling locations are specified by a spatial design, can also apply neighborhood variance estimators.

For status and trend monitoring designs, the inference design depends on the site selection procedures. Inference designs for model-based spatial designs require the selection of a spatial stochastic model appropriate for the variables of interest, while design-based spatial survey design statistical inferences rely on the randomization procedures used to select the sites. Since spatial survey designs provide (in most cases) a representative sample, an analysis for the spatial stochastic model is more likely to provide unbiased estimates. The use of spatial survey designs also makes it possible to apply either design-based or model-based inference designs.

In design-based inference, the goal is to estimate the statistical properties of a population of interest; in the case of CHaMP, this would be the population of all possible sampling locations within the survey design frame. The design-based nature of the inference comes from the use of a survey design to choose random sites from which to build inference on the entire population of sites. In the case of model-based inference, the sampling sites are used to estimate a process, or model, that describes all possible sites, sampled or not. In practical terms, indicators that are generated through design-based inference are estimated directly from mean and variance estimators appropriate for the sampling design applied. Indicators that are generated through model-based inference are outputs of a process model, the parameters of which are estimated by the site-level sampling data.

CHaMP is focused on status and trends of selected habitat indicators at two spatial scales: across all watersheds and within each watershed (e.g., within watershed by valley type or channel unit type). Status is generally described as a frequency distribution of the metric scores inferred from the spatial/temporal design with indicators derived from these distributions such as mean, median, achievement of a particular criterion, spatial pattern, and differences among component watersheds. At its simplest, trend is expressed as some underlying, consistent (e.g., linear) change over the duration of the study; as more data are collected over time, it might be possible to describe patterns of change in addition to an underlying linear change (at both the watershed scale and aggregated across watersheds).

The ability to estimate the status of a particular stream habitat indicator improves with an increase in the number of unique sites, while the ability to detect a trend in a particular stream habitat indicator improves with revisiting sites through time. Given this apparent conflict in sample site allocation to meet status and trend objectives, CHaMP had adopted a sampling design based on panels to achieve a reasonable balance. Within each watershed, half of the year's sites are allocated to an annual panel and half to unique sites. Over a three year period, CHaMP will generate a new "unique site" panel each year, but then repeat these three panels for future three year cycles. As a result, the annual set of trend sites becomes a set of sites to which a linear model can be fit in as little as three years, but also allows a sample size of 25 for a status estimate each year and about 50 for an aggregate three year status estimate. For the full power of trend estimation to be achieved, after three panel cycles (in this case 9 years), all sites can be used to estimate parameters in a linear trend model of habitat indicator condition.

1.7 Potential Site Analyses and Indicator Development

CHaMP takes advantage of new methods and technology such as GPS, total stations with flexible mapping software, LiDAR, photogrammetry, and sonar, that is easier to use and allows more accurate surveys of topography. These tools allow the acquisition of high density three

dimensional points that no longer requires collection at monumented cross-sections (Brasington et al. 2000). Furthermore, advances in computer technology and GIS or spatial analytical software have removed constraints on storage, processing, and analyzing data. This contrasts with other existing monitoring programs that rely on describing stream channel topography at single or multiple cross-sections and detection of change that relies on revisiting permanently monumented cross-section locations. The traditional approach was done by necessity when acquisition, storage, processing and analyzing data was limited by technology.

1.7.1 Potential Applications

For several applications, including hydraulic modeling (Leclerc et al. 1995, Crowder and Diplas 2000), fish habitat models (Leclerc et al. 1995, Hayes et al. 2007), and sediment budgeting (Brewer and Passmore 2002, Fuller et al. 2003, Wheaton 2008), the development of a high resolution DEM has been shown to provide richer and more accurate and precise information than cross-sectional approaches (Wheaton 2008, Wheaton et al. 2010). In addition, the creation of DEMs does not require reoccupation of monumented cross-sections (Brasington et al. 2000), and is more flexible in the ability to extract information that is comparable to other protocols (e.g., a cross-section at a desired resolution can be extracted from a DEM) with greater repeatability (Wheaton 2008). The biological and physical reach information collected by CHaMP will be used in models that estimate fish responses to the environment with a mechanistic basis. The synthesis of this information will provide metrics of fish performance that are meaningful and intuitive.

Using DEMs for hydraulic and fish habitat models

The physical habitat simulation (PHABSIM) module of the instream flow incremental methodology (IFIM) is perhaps the mostly widely used model to evaluate changes to fish habitat across different flow regimes (Railsback et al. 2003, Williams 2010). Habitat suitability curves are generated by correlating physical stream characteristics (i.e., velocity, depth, and substrate) to fish density to provide an index of habitat preference. A physical template is developed from a 1D hydraulic model based on a series of cross-sections to estimate the velocity and depth of cells throughout a stream reach. Cells are then multiplied by relative preferences (0-1) and are summed to determine a weighted usable area for given flows. The inaccuracies of the 1D model approach has been a main criticism of the PHABSIM model (Leclerc et al. 1995, Kondolf et al. 2000). Hydraulic models that take vertical consideration of flow paths, such as 2D and 3D hydraulic models, can overcome some of the inadequacies of the 1D approach (Leclerc et al. 1995).

Other major criticism of PHABSIM and other weighted usable area (WUA) approaches is that they are based on the assumptions that physical habitat alone can describe the habitat requirements of fishes, and preference can be equated to fitness related performance metrics (e.g., survival). These assumptions are often not valid. For example, Rosenfeld and Boss (2001) demonstrated that the preferred location of a trout changes depending on the amount of food available and the presence of conspecifics. Several foraging models have been developed that describe the interaction between food availability, temperature, and the physical habitat template to estimate distribution, growth, and survival (Hughes et al. 2003, Railsback et al. 2003, Hayes et al. 2007).

Hayes et al. (2007) recently created a model to overcome these two major shortcomings of the PHABSIM model. They developed a high resolution DEM, combined information about surface roughness of the stream bottom, and produced a 2D hydraulic model. The 2D model was used in conjunction with drifting invertebrate density to generate a drift transport and salmonid foraging model. In streams, higher velocity zones tend to have greater delivery of drifting invertebrates, the main food source for salmonids (Hayes et al. 2007). Therefore, encounter rates and often capture of invertebrates for salmonids are higher in these high velocity areas (Hughes and Dill 1990). However, these locations tend to have a higher energetic demand for fish to maintain their position (Rosenfeld and Boss 2001). Hayes et al. (2007) incorporated spatially explicit information about physical habitat, food abundance and energetic costs to map and sum the net rate energy intake, growth potential, and carrying capacity of a reach (Figure 3). Railsback (2006) has created inStream-2D, which is a similar modeling approach but uses other auxiliary information such as the amount of cover, to estimate survival rates and population dynamics in addition to these output variables.

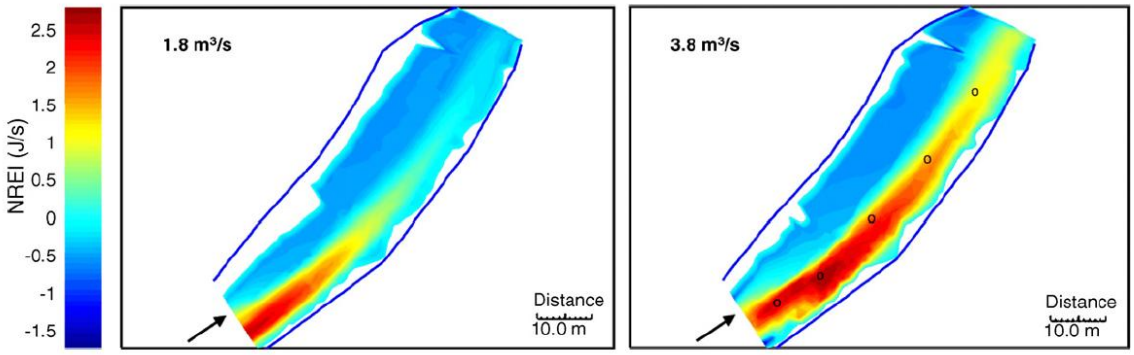

Figure 3. Predicted spatial variation in net rate energy intake, in a pool at two different flows based on observed drift density (from Hayes et al. 2007). Also shown are the centroids of foraging areas of trout (all≥0.5 m) observed over the flow range (open circles). Centroids were equivalent to focal positions for the drift-feeding trout.

DEMs for sediment budgeting

DEMs also have been used to estimate sediment budgets (Brewer and Passmore 2002, Fuller et al. 2003, Wheaton 2008). Many of the sites that will be surveyed in CHaMP will be revisited to evaluate change through time. Changes in site topography can be summarized as erosion and deposition of sediments, which can be summed to create a sediment budget. Many of the traditional cross-sectional approaches evaluating changes in stream topography require reoccupation of monumented cross-section. This approach has been shown to be problematic because it relies on simplistic integration of the volumes between cross-sections and does not include estimates of uncertainty (Fuller et al. 2003). Furthermore, even with monuments, the ability to recreate the same cross-section can have high relative errors (Wheaton 2008). In contrast, comparison of DEMs from repeat surveys do not need reoccupation of the same cross-section, have estimates of uncertainty (Wheaton et al. 2010), have been shown to be more accurate in estimating sediment budgets (Fuller et al. 2003), and are more repeatable (Wheaton 2008).

Differencing DEMs from two surveys provides an intuitive and informative estimate of this change in sediment distribution and volume (Wheaton et al. 2010; Figure 4). A new DEM of a reach can be compared to an old DEM of that reach by simply subtracting the vertical component for an X, Y coordinate. The change in the vertical component for the reach is referred to as the DEM of Difference (DoD; Figure 4a). A negative value can be thought of as erosion and a positive value as deposition or aggradation, which can be depicted to show where changes in the reach occurred (Figure 4b). The sum total of these values is the change of sediments in the reach (Figure 4c). ISEMP has been promoting the development of the tools to create the DoD which are being incorporated in the River Bathymetry Toolkit (RBT) for use in CHaMP.

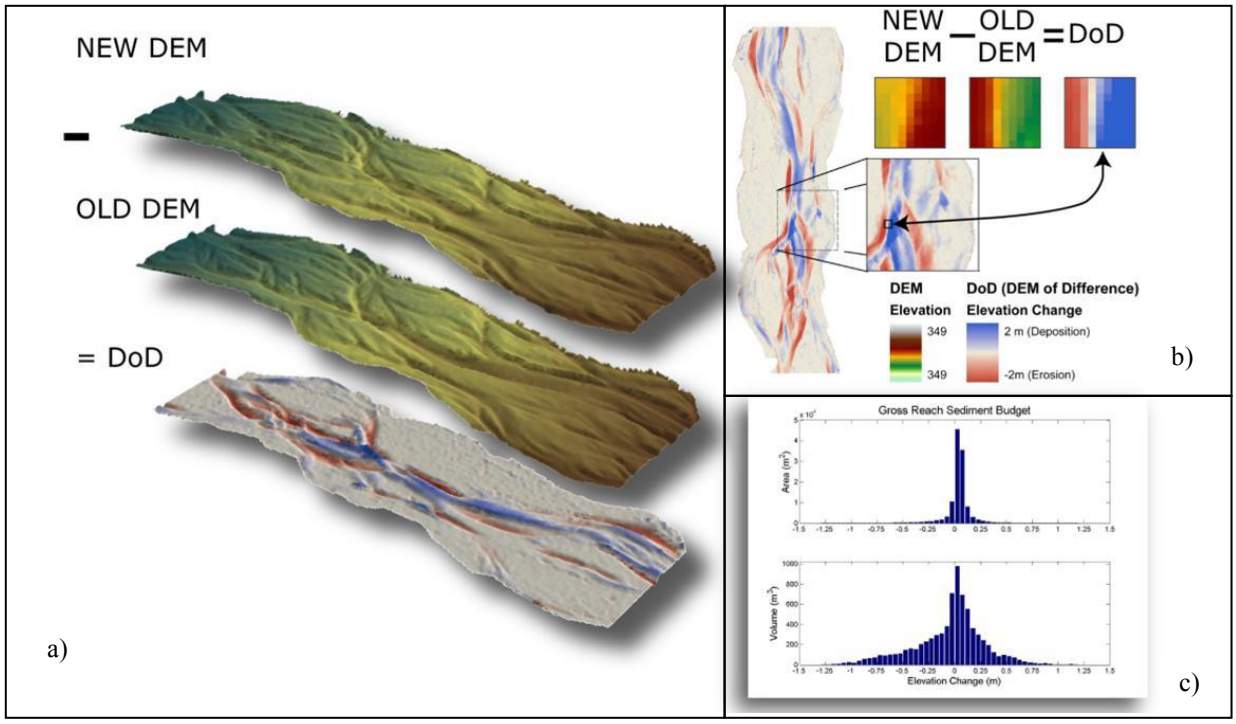

Figure 4. Using a DEM of Difference (DoD) to quantifying spatial variations in change in storage terms of a sediment budget. a) A DoD is created by subtracting the vertical component of old DEM from the new DEM. b) DoD can be displayed to show where erosion (shown in red) and deposition (shown in blue) occurred in the reach. c) A distribution of changes (areas or volumes) can be depicted or summed to estimate a gross reach sediment budget.

1.7.2 The River Bathymetry Toolkit

ISEMP is promoting the development of the RBT by the U.S. Forest Service, ISEMP, Utah State University, and ESSA Technologies as means to evaluate DEMs of stream reaches for CHaMP. Tools were created for ArcGIS to conduct several types of analyses associated with DEMs, including geomorphic change detection (DoD: Figure 4), uncertainty analyses, user-defined density of cross-sections (Figure 5) and longitudinal profiles (Figure 6). These tools can

extract hydrologic parameters such as wetted area, bankfull width, water depths, hydraulic radius, gradient, sinuosity (McKean et al. 2009), erosion and depositional patterns and budgets (Figure 4b and c), and uncertainty in the DEM (Wheaton et al. 2010). The RBT will also allow users to recreate other survey protocols that use cross-sectional and longitudinal profile approaches. For example, 11 or 21 cross-sections for a site can be generated off the DEM, which is equivalent to the PIBO and EMAP protocols, respectively. Currently, other tools are being created to delineate channel units based on user definitions (e.g., criteria of a pool may be 1.5 max depth:pool tail depth, longer than wide, >50% of the channel width). The ability to link this to 1D, 2D, and 3D hydraulic models may be a potential tool as well. We believe these tools will aid in relating channel morphology to fish performance, create user inputs to mechanistic models, and allow cross-walks between other habitat survey protocols.

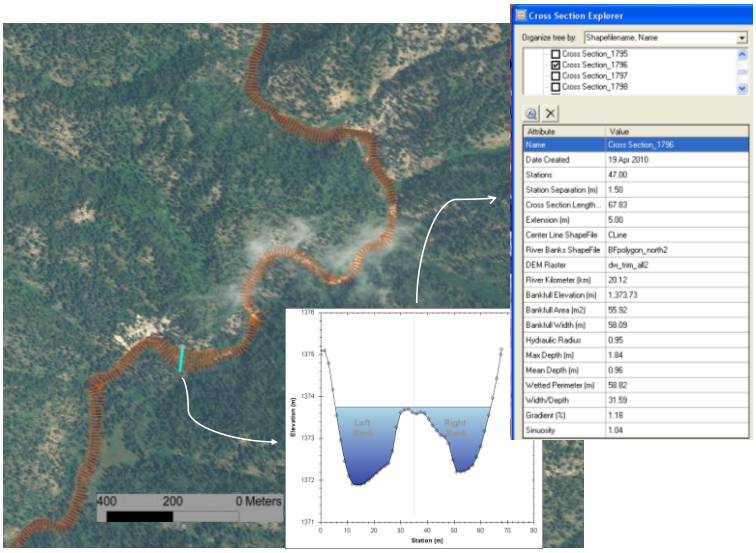

Figure 5. Example of cross-section analyses of a DEM that can be performed with the River Bathymetry Toolkit.

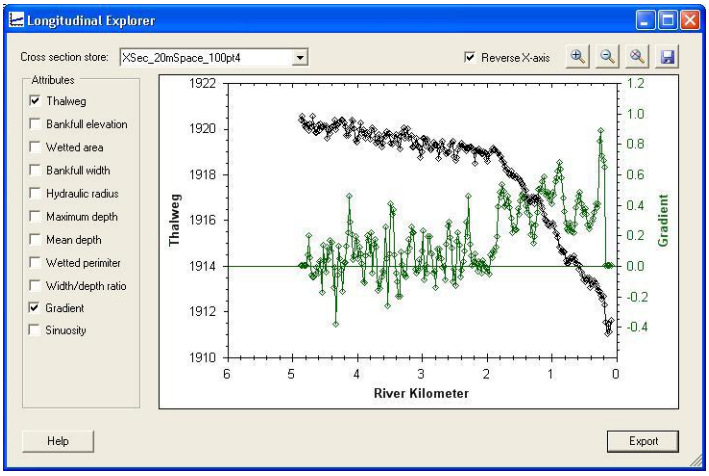

Figure 6. Example of longitudinal profile analyses of a DEM that can be performed with the River Bathymetry Toolkit.

SECTION 2: THEORETICAL BASIS FOR CHAMP

Anadromous salmonids spawn and rear in most of the accessible streams of the Pacific Northwest, and it is reasonable to assume that the quality and quantity of habitat in these environments determines multiple population processes of these fishes. Monitoring programs are expected to describe the physical and biological characteristics of stream habitat across the Pacific Northwest. Recovery and management plans are expected to be based on this information to assess current conditions and to predict future salmonid production under multiple scenarios, from status quo, alternative land and river management strategies, to stream restoration and conservation, and determine if these predictions hold true. This is predicated on the management community understanding how habitat characteristics influence vital parameters at different salmonid life stages. However, considerable uncertainties still exist as to the most effective management strategies to improve salmonid habitat to lead to recovery of listed species.

Possible explanations for the inability to use monitoring information in the development of effective management strategies could include, but are not limited to, a fundamental misinterpretation or misunderstanding of fish natural history, or a failure to characterize physical and biological habitat in a manner relevant to fish population processes. Both explanations are likely true. The first explanation requires ecologists to constantly challenge our current understanding and improve on data collection techniques, approaches, designs, and data analysis. We attempt to resolve the second explanation by reviewing the basic principles of fish habitat requirements and matching these needs with measurable habitat indicators. For example, spawning adults have specific substrate size requirements, hyporheic flow preferences, and proximities to cover that define an optimal redd construction location, while rearing juveniles must balance the need to occupy areas with high flow velocities that allow effective foraging while remaining in proximity to low velocity holding areas and overhead cover to avoid predators. Recognizing these types of complex interactions forms the basis for developing fish monitoring programs; however, in doing so, we assume to have complete knowledge of the habitat requirements of fish. Therefore, monitoring programs must collect information that is rich enough to allow further discovery of presently unknown and potentially important interactions between fish and their habitat.

Another factor potentially hindering effective management of salmonid resources may be an inappropriate scale of inquiry relative to the requirements of different life stages (Schlosser 1991). For habitat characteristics to be quantifiably linked to fish population processes these processes must be controlled by the state or amount of the habitat characteristic in question. For example, spawning salmonids require clean substrate of a particular size, and thus one might expect reach-scale measures of spawning gravel area to predict spawner numbers through time. Assuming we can accurately measure both the fish population response and quantify spawning gravels, this relationship will only emerge if spawning gravel limits population size. However, if factors outside our study site limit populations (e.g., a downstream migration barrier) no apparent relationship between spawning gravel availability and population size will be observed.

Monitoring programs must also be aware of the physical and biological processes across multiple scales. Specific habitat characteristics result from physical and biological processes that function at process-specific spatial and temporal scales. For example, pool-riffle complexes

form as a result of stream power and substrate size and mobility, and will be formed and maintained by watershed specific dynamics and landuse. Similarly, stream productivity depends on watershed-scale thermal regimes and water chemistry, so will be similar at reach scales but diverse across a river basin. These features of spatial and temporal autocorrelation exist in all physical and biological stream characteristics and in the fish populations that depend on them. This determines the amount of information any measurement in the stream shares with a measurement at the same spot at a different time, or at a different spots at the same time. Without incorporating or understanding these "information scales" we cannot make independent measurements of stream physical and biological processes, and thus cannot build quantitative relationships to predict their interdependence.

2.1 Physical Processes

Understanding the linkages between the upland and instream processes can aid in predicting the impacts of land use on fish habitat. A brief discussion is given below on the processes of water temperature and sediment transport. A more thorough discussion can be found in Spence et al. (1996). Changes in each of these processes and the variable used to characterize them might signify changes in impairment due to land use that should prove useful in management of endangered species such as salmonids in the Pacific Northwest.

The factors affecting temperature are well documented in the HeatSource model (Watershed Sciences, Inc. 2003). Temperature is influenced by hydrology, channel morphology, and riparian vegetation and is thus influenced by multiple processes that in turn are influenced by landuse. Therefore temperature can be an excellent indicator of impairment. Temperature is determined by heat transfer and mass transfer. Heat transfer can be broken into five components: solar radiation (direct and diffuse), longwave radiation, convection, bed conduction, and evaporation/condensation. Mass transfer can be summarized by advection, dispersion, ground and surface water mixing.

Heat transfer is any heat added or taken away from the stream. Except in the case of geothermal activity, all heat is derived from the sun. Solar radiation is generally the biggest form of heat input and can be direct or diffuse. Diffuse solar inputs are from light scattered from the clouds and atmosphere. The amount of direct solar radiation entering the stream is estimated from the angle of input, which influences the ratio of reflected/absorbed light and is related to latitude, time of day and year, and stream aspect. In addition, shading effectiveness also influences the amount of solar input within the above parameters. The amount of shade is due to surrounding topography, stream morphology (i.e., steam width), and riparian vegetation. Longwave radiation is emitted from surrounding materials (e.g., rocks and soil) that have absorbed solar radiation. Heat is also produced and absorbed during condensation and evaporation at the air/water interface the amount of which can be influenced by convection currents. The factors influencing these last two processes are air temperature, humidity, and wind. Riparian vegetation can moderate these influences by creating microclimates through insulating properties. Finally, bed conduction can result in heat transfer and is dependent on the bed material type.

Mass transfer is the instream mixing of water and any volume added or taken away. Advection is the downstream movement of heat through the downstream movement of water and

dispersion is the vertical mixing of water. These processes are dependent on the stream morphology, instream structure (e.g., wood, boulders, etc.), and discharge. When water of different temperatures mixes the temperature of the combined water is based on the weighted average of the separate flows. Removal of water, however, has no direct impact on the stream temperature. Overland flow, tributaries, and springs are major sources of surface water mixing, although in some systems return of irrigation water can be substantial. Hyporheic exchange also modifies stream temperature. The amount of exchange is a result of stream substrate porosity and stream morphology. Fine sediments can fill in interstitial spaces between gravel and cobble resulting in an armoring of the stream bottom that reduces exchange with the hyporheic waters. Pools often create a hydraulic head that can force water to go subsurface and exchange with ground water. Likewise, bends in the stream can force water into stream banks also increasing exchange rates. Loss of large wood and beaver dams, diking and straightening can simplify channels and reduce hyporheic exchange.

Channel dynamics are influenced by the rate of delivery of water and sediment, sediment size, gradient, geology type, tributary inputs and structures (e.g., large wood, beaver dams, and boulders). Therefore, geomorphic characteristics are created by the interaction of water and sediments within a valley type. How sediments and water are transported to the stream is another means by which landuse can impact streams. The development of sediment budgets, sediment transport, and other channel forming processes have been beyond the scope of previous rapid fish habitat assessments. However, quantities of different sediment types and their location (e.g., pool tail fines) can be an indicator of stream impairment (Sutherland et al. 2010). Mass wasting events through slumps, earth flows, avalanche debris flows, and debris torrents, can bring in large amounts of sediment to streams. This may or may not be deleterious to fish habitat. Although mass wasting generates fine sediments, these events also result in recruitment of gravel, cobble, boulders, and large wood. Mass wasting events may increase due to landuse through road cutting, removal of vegetation, mining, and forest fires. Similarly, bank erosion can produce excess fine sediments, but is also a natural process that inputs larger substrate and wood. Bank erosion also allows for channel migration, which might result in decreased gradient and increased channel complexity. Loss of vegetation and physical disturbance can also increase the rates of bank erosion to produce excess fine sediments. Flashy delivery of water due to high overland flow of impermeable surface can influence bank erosion.

Other than mass wasting events, sediment transport into the stream requires first a detachment of a soil particle and then transportation of this particle to the stream. Factors affecting soil detachment includes rain drops and physical disturbance from machinery, animals, and removal of vegetation. Exposed soils will have more accessible sediment for transport. Removal of vegetation through timber harvest, agriculture, grazing, and creation of roads include land uses that exposes soil to rain events. Once soil has been exposed, it is transported via overland flow and channelized erosion such as rills and gullies. The rate of water delivery to a stream is a function of precipitation and infiltration rates. If precipitation exceeds infiltration then overland flow occurs that carries sediment. Factors that affect infiltration rates are the amount of interception by vegetation, chemical properties of soil, and soil pore size. Vegetation can attenuate precipitation, but can also produce larger water drops that have more power to detach soils. However, debris such as leaves and branches, and herbaceous plants generally protect soils. Roots from vegetation can increase infiltration rates, as well as high organic

composition from decaying vegetative matter. Some soils are hydrophobic through impacts from fire and low moisture. Soil compaction decreases infiltration and thus leads to higher delivery rates. Physical impacts from grazing, timber harvest, and agriculture tend to compacts soils, reduce soil absorbing properties and lead to greater overland flow and channelized and sheet erosion.

Riparian vegetation plays a key role in mediating the impacts of landuse on streams. Riparian vegetation provides shade which in turn affects temperature and primary production. Naiman et al. (1992) indicated that in the Pacific Northwest 1%-3% of light makes it to headwater streams and increases to 10-25% in wider mid-order streams. Vegetation also acts as insulation and mediates heat gains and losses, which reduce lethal temperatures in the summer and anchor ice formation in the winter. Vegetation also stabilizes stream banks by binding soil particles together with their roots structures, and promotes the development of undercut banks. During bank overflows, grasses, sedges, rushes, stems and branches increase roughness and dissipate energy, as well as protecting and rebuilding stream banks, allowing existing channels to become narrower and deeper. Vegetation can capture sediments and may also prevent mass wasting events (Naiman et al. 2005). The riparian zone also contributes organic nutrients through leaf litter and wood and regulates the flux of nutrients. Finally, riparian zones contribute large wood to streams (Bisson et al. 1987).

Many variables can be measured to provide information on the various processes described above; however, rapid assessment approaches need to capture gross indicators of change due to landuse activities. The major factors that these processes affect can be directly measured (e.g., temperature and discharge), but an indication as to why these factors are in their observed state will be more informative as to how landuse is impacting streams and if restoration opportunities exist. Variables affecting temperature include canopy cover, riparian vegetation, topography, stream width, bed material, channel morphology, and local climate, and can be measured during rapid assessments or via remote sensing data. Variables affecting geomorphic and hydrologic processes include sediment size, quantity, structure (e.g., large wood), gradient, discharge, channel morphology, local climate and riparian vegetation and can also be approximated with these techniques.

2.2 Fish Habitat Requirements

Based on the preceding assumptions, it is apparent that a review of the specific habitat requirements of fish (salmonids) is needed to aid in the identification of habitat attributes that describe meaningful fish – habitat relationships. Here we identify a set of fish habitat requirements for juvenile, adult, and egg life stages based on our experience with salmonids in the Columbia River Basin and a literature review.

An organism's response to its environment is perhaps best measured by its fitness, or the number offspring produced that give rise to further offspring. However, fitness is difficult, if not impossible, to measure, and so ecologists often measure surrogates to fitness, such as growth, survival, and reproductive output. When combined with measures of organism abundance, these surrogates can be used to estimate population production, an informative population level performance metric (Almodovar et al. 2006). Behavioral responses (e.g., habitat preference as measured by local abundances) are assumed to ultimately impact the surrogates of fitness

described above, but are more difficult to link to fitness and production. Therefore, the process of identifying indicators of habitat characteristics that affect salmonid performance begins by linking environmental factors to measurements of salmonid growth, survival, and production. Some highlights of how these responses are influenced by environmental characteristics for juveniles, adults, and egg life stages are discussed below, and presented in Appendix C.

2.3 Juvenile Growth

Juvenile somatic growth rates are directly influenced by food, temperature, and activity. The main food source for salmonids is aquatic and terrestrial macroinvertebrates (Filbert and Hawkins 1995). Although juvenile salmonids occasionally feed epibenthically (Tippets and Moyle 1978), the majority of their food items consist of invertebrates drifting in the water column (Cada et al. 1987; Romaniszyn et al. 2007) and the collection of invertebrate drift is perhaps the most direct measurement of food availability (Filbert and Hawkins 1995). The amount of macroinvertebrates available depends on the canopy cover (terrestrial invertebrate inputs), suitable substrate mainly in riffles, organic material, temperature, and the amount of primary production of suitable periphyton (Poff and Huryn 1998). Thus, the relevant physical characteristics that can be measured in a large-scale monitoring project might include canopy cover, riffle substrate size distribution, and gross primary production.

Temperature influences nearly every physiological process of organisms. For salmonids, this can be summarized as effects on consumption, respiration, processing of food and waste, activity, and growth rates. These effects of temperature on fish physiology are well documented in bioenergetics models (Hanson et al. 1997). Temperature can be measured with temperature loggers at fine temporal resolution, and also at a fine spatial resolution with thermal infrared aerial photography (Torgersen et al. 2001).

In order to forage effectively, fish must maintain their position in flowing water in areas of high invertebrate density. This activity requires an energy expenditure that could otherwise be invested in somatic growth. A common foraging strategy for salmonids is to face upstream and search the flowing water for drifting invertebrates (Hughes and Dill 1990). Encounter rate with potential prey items that a fish experiences while foraging is a function of reactive distance, invertebrate drift density, and water velocity (Hughes and Dill 1990, Guensch et al. 2001). Thus, foraging at higher velocities delivers more potential prey items into the sphere defined by the radius of the reactive distance. However, higher velocity increases swimming activity while foraging. To maximize prey encounter rates while minimizing energy expenditures, salmonids will hold in low velocity positions that offer access to high velocity zones such as the head of a pool, or behind boulders, cobble, and logs. Thus, high and low velocity areas have to be located within the reactive distance of a fish (Hughes 1998, Hughes et al. 2003). These velocity zones can be described by measuring meso- or channel unit scale habitat, such as the characteristics and arrangement of pools and riffles, and the availability of large wood and other structure within those units. The distribution of finer scale velocity gradients is more difficult to measure, but can be recorded with a velocity meter or estimated through hydraulic models. In addition to foraging, activity expenditures also occur for juvenile salmonids to locate refugia from high flow velocities, predators, and temperature.

2.4 Juvenile Survival

Environmental attributes that regulate the growth of juvenile salmonids also affect their survival rates. Fish experiencing negative growth will eventually starve, thus growth is directly related and offers a measurable surrogate for survival. If fish succeed in maintaining sufficient growth to survive, they must also avoid predation and lethal environments caused by high water velocity and water quality issues such as extreme temperatures, low dissolved oxygen (DO), and levels of toxicity (other than temperature and DO, water quality issues are beyond the scope of this document and will not be addressed). The characteristics that provide suitable velocities for foraging and activity are similar to those that provide refugia from extreme high flow events that might result in mortality (Fausch et al. 2001). In simple stream systems, such as a high gradient plane bed channel dominated by small substrate, the lack of low velocity areas during such events may result in relocation to less suitable areas (e.g., areas of high temperature or high piscivore densities). Structure such as boulders, cobble, LWD, pools, and backwaters provides greater capacity for such refugia. Connectivity to the floodplain and riparian vegetation can also dissipate energy during high flow events. These characteristics, along with undercut banks, overhanging vegetation, and macrophytes can also add habitat complexity to reduce predation from terrestrial and aquatic predators (Boss and Richardson 2002).

Habitat features that influence juvenile salmonids also influence piscivores but in potentially different ways. For example, temperature influences the physiological processes of predators that will affect the quantity of salmonids they can consume. During winter, juvenile salmonid often conceal in gravels of pools to avoid homeothermic predators (e.g., otters) and high velocities that may be result from flow constrictions caused by anchor ice (Cunjack 1996). Extreme temperatures in winter and summer may also result in mortality. In winter, the ability to conceal in pool gravels provides a thermal refuge from freezing temperatures. In summer, salmonids seek thermal refugia in the form of thermally stratified pools, hyporheic flows, springs, and tributaries (Torgersen et al. 1999, Poole and Berman 2001, Ebersole et al. 2003).

Greater habitat complexity will likely decrease the distance by which fish must travel to balance risks to predators, velocities, temperatures, and foraging. The relative distribution of depths, velocities, LWD, substrate, temperature, undercut banks, overhanging vegetation, and backwaters can be used to describe habitat complexity (Harvey 1998, Harvey et al. 1999). Knowledge of geomorphic channel type, channel unit type, and the distribution of channel units can provide information about how habitat complexity affects the survival of salmonid species (Bisson et al. 1988; Bisson et al. 2006).

2.5 Adult/Spawner Survival

For the most part, adult salmonids arriving in their natal streams to spawn have ceased feeding and growing. However, spawners must overcome a host of potential challenges in order to survive until spawning. Like juveniles, refugia from temperature, predators, and flows are required to survive in stream environments and spawn successfully. Temperature near or at spawning grounds may prevent successful spawning or result in mortality (Torgersen et al. 1999). Adults are also susceptible to several mammalian and avian predators, increasing the importance of the presence and extent of overhead cover. Migration barriers such as dams and culverts may prevent return to spawning grounds that can easily be overlooked through a reach-

level view of salmonid habitat (Fausch et al. 2002). Temporary barriers may restrict movement to thermal refugia or suitable spawning areas during crucial periods (Schlosser 1991).

2.6 Egg/Alevin Survival

If adults can successfully spawn, several conditions must be met in order for fertilized eggs to survive. Sources of mortality include scour, desiccation, predation, insufficient DO, and high water temperatures (Quinn 2005). Mortality can be reduced if egg burial occurs in the proper location, flow characteristics, and substrate composition. Embryos need oxygen to survive and eggs that are not surrounded by certain levels of DO can suffer developmental abnormalities or mortality. As DO diffuses across the egg membrane the DO in the boundary layer decreases and flowing water is needed to exchange water near the boundary layer to replenish DO. Spawners prefer to build redds in pool tails/riffle crests with large gravels because a hydraulic head is formed in this location that forces water to flow subsurface where eggs are located (Reiser and Wesche 1986, Bjornn and Reiser 1991). Fine sediments in pool tail gravels can prevent the exchange of water through gravels and prevent flows at the egg surface, resulting in oxygen deficiencies (Bjornn and Reiser 1991). Although this location provides adequate water exchange during many flow levels, they are also more susceptible to being scoured during high flows and desiccation during low flows (Quinn 2005). Therefore, stream discharge is also an important factor for egg survival (Becker and Neitzel 1982). Salmon and steelhead redds are also often found in riffles and runs, where fine sediments have similar constraints on egg survival. Temperature influences the incubation time of eggs, and extreme temperatures may result in improper emergence time, abnormal development, or mortality (Quinn 2005). Development is an interaction between temperature and time so the best predictor of emergence is described by cumulative thermal units (e.g., degree days; Quinn 2005). Egg mortality from predation has been shown to be low when suitable spawning substrate is present (Warner 1963), but sculpin and other fish species have been known to consume fish eggs.

A review of juvenile, spawner, and egg life stages of salmonids is used here to provide insight into factors that might be measured to describe habitat quality. Although habitat quality is important, habitat quantity can limit the production of populations as carrying capacity can be achieved very quickly when low amounts of adequate habitat is available or when populations are very high (density dependence). Habitat quantity is often defined with areal dimensions but territories, foraging opportunities, predator avoidance and thermal and velocity preferences can occur in three dimensions and thus volumes may be a more relevant description. Dimensions of habitat and channel units can be used to estimate habitat quantity. A summarization of fish habitat requirements is presented in Appendix C. Habitat requirements are presented in a hierarchical/compartmentalized format (e.g., factors affecting activity → growth → fitness → production). Tables 17-20 represents a synthesis of the primary attributes that contribute to different fish responses at three different life stages based on the a review of the information offered in Appendix C. This condensed list of attributes could potentially be collected as part of a monitoring program.

Table 3. Critical stream habitat features and functions for salmonids at three different life stages.

Life Stage	Fish Response	Attribute
Juveniles	Growth	Food - Drifting and benthic invertebrates
		Substrate composition - Composition in riffles
		Temperature - Temporally continuous
		Water velocity - Microhabitat distribution
		Turbidity
		Channel units - Type, Characteristics, Spatial arrangement
		Cover - Woody debris, Substrate composition, Undercut banks, Overstream vegetation, Instream vegetation
	Survival	Substrate composition - Gravels abundance/quality, Interstitial spaces
		Temperature - Temporally continuous
		Predator density
		Discharge
		Dissolved Oxygen
		Food - Drifting and benthic invertebrates
Adults/Spawners	Survival/ Reproductive success	Barriers
		Discharge
		Temperature
		Cover - Woody debris, Substrate composition, Undercut banks, Overstream vegetation, Instream vegetation
Eggs/Alevin	Survival	Substrate composition - Pool tail crests, Gravel abundance, Riffle crests, Interstitial spaces, Fine sediments
		Discharge
		Turbidity
		Temperature - Cumulative degree day
	Abundance	Channel unit area and volumes

The summary of fish habitat needs from the above section highlights that fish are likely not only responding to reach conditions, but also to the condition of individual channel units. Recognizing the importance of how channel unit scale interactions affect fish performance should lead to an increased emphasis on the quantification of this important scale of fish habitat.

2.7 Scale and Landscape Setting

Catchment geometry, climate, and geology provide the template of stream geomorphology. Catchments can be organized in very distinct network types that have a large influence in how sediment and water are delivered from headwaters to the mainstem (Figure 7). The landscape context of where a reach is located also has implications as to how channels erode, transport sediment, and aggrade (Figure 8). Different channel types will have different responses to landuse and restoration that also need to be considered. For example, many protocols assess sediment distributions in riffles with gradients <2% because these reaches are hypothesized to be most sensitive to upstream changes in sediment input.

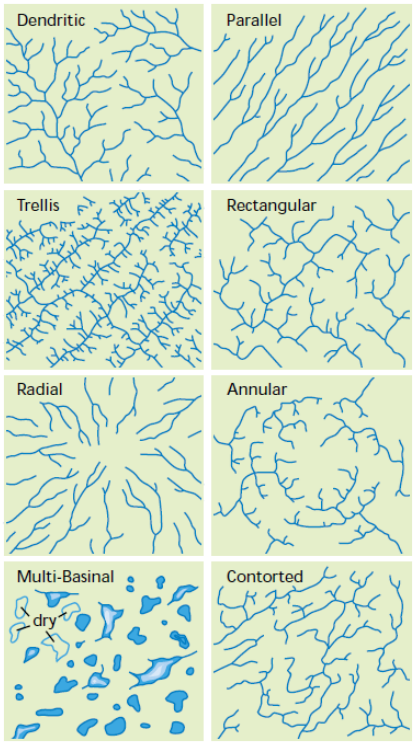

Figure 7. Examples of stream networks that can influence how sediment and water move from headwaters to the outlet of a stream from Brierley and Fryirs (2005).

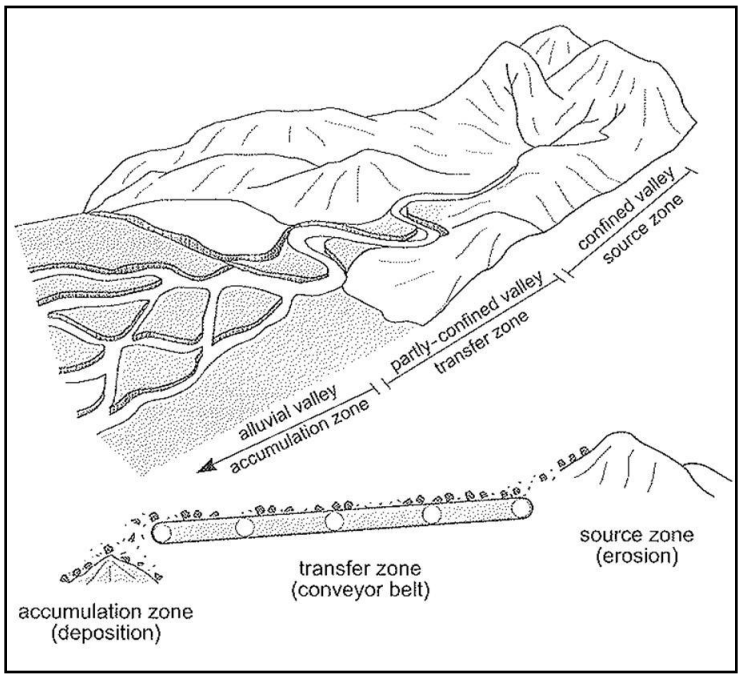

Figure 8. Location and function of reach types within a watershed and how they influence sediment transport and storage (from Brierley and Fryirs 2005).

Changes to fish habitat are driven by geomorphic processes occurring at catchment, landscape (immutable and human induced characteristics), geomorphic reach (e.g., Montgomery and Buffington 1997), geomorphic channel unit (pools, riffles, and bars), and hydraulic unit (areas of common substrate/water velocities within geomorphic channel units). The geomorphic processes shaping fish habitat need to be strongly considered in order to determine the effects of management practices and stream restoration on fish populations. While we often acknowledge these considerations, they are not explicitly considered in most monitoring efforts in the Columbia Basin. For example, within ISEMP site locations are selected using a random but spatially balanced sampling design (GRTS; Herlihy et al. 2000). Hierarchical assessment frameworks that provide these scale dependent considerations have been developed and implemented elsewhere, such as the Fluvial Audits in the UK and the River Styles framework developed in Australia, where conservation and restoration plans have been developed for reaches within catchments (Figure 9; Brierley and Fryirs 2005). These approaches might provide guidance for us to build a more holistic monitoring program and should be reviewed further for guidance in ensuring these hierarchical concepts are considered in our monitoring programs.

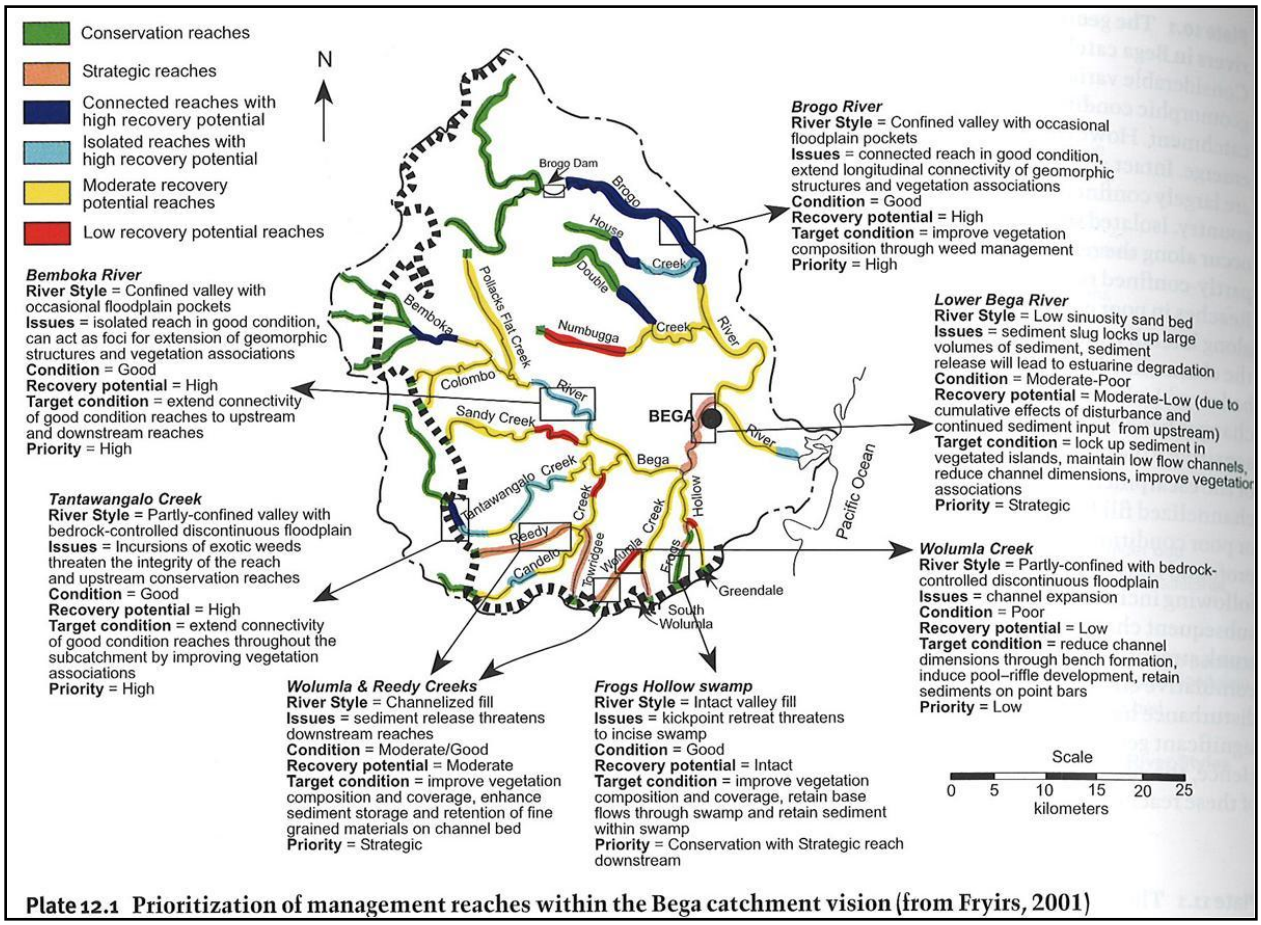

Figure 9. An example of the River Styles framework for prioritizing restoration actions and implementing hierarchical monitoring programs from Brierley and Fryirs (2005).

Some broader regional-scale and watershed scale analyses already exist for the Columbia Basin and could be more explicitly integrated into sampling designs. Beechie and others, at the Northwest Fisheries Science Center (NWFSC), have modeled pre-settlement floodplain and mountain reach types (Montgomery and Buffington 1997, Beechie et al. 2006) for all reaches of all streams in the Columbia River Basin, and historical riparian vegetation for portions of the mid-Columbia and lower Snake River basins. These datasets may provide a huge start to developing the context for sampling designs and interpretation of existing monitoring programs. Such classifications can provide both an initial prediction of the habitat status of individual reaches and cataloging of historic reach types. These classifications could be contextualized in a River Styles type prioritization of management activities. They could also be used to provide more mechanistic explanations of the occurrence of particular reach types and/or conditions based on landuse, soils, geology, hydrology, etc. These broader scale analyses (largely desktop GIS exercises with some rapid ground truthing) could then be used as a basis for stratifying the reach-scale sampling efforts that are a key component of large-scale habitat monitoring. It may be more appropriate to use spatially balanced random sampling within these different reach types (e.g., GRTS), as opposed to across entire subbasins in the Columbia.

Broad-scale analyses would also provide information directly relevant to how salmonids are interacting with their environment. Salmonids are likely making decisions about where to feed, hide, and rest at the scale of 1-3 channel units (i.e., 10-100 m). Within channel units or microhabitats, fish are seeking high velocity gradients to maximize encounter rates of prey, while minimizing activity. In addition, refugia from predators and high flows are provided by gravel (concealment- especially important in the winter), cobble, boulders, undercut banks, and large wood structures within habitat units. However, a habitat unit perspective in isolation of context will be uninformative, if not misleading. For example, migration to different stream reaches to avoid lethal temperatures is a larger scale consideration that cannot be assessed when relying solely on a channel unit level focus. The hierarchical spatial arrangement of these features is a necessary description of salmonid environments that should be incorporated into habitat monitoring programs (Fausch et al. 2002).

2.8 Synthesis of Sampling Protocols

Part of the preparation of this document included a review of how different protocols collect stream habitat attributes and a summary of protocol strengths and weaknesses as they relate to fish habitat requirements (Appendix D). During this process it became apparent that protocols varied considerably on a number of levels including the size of study unit measured (e.g., channel unit versus site/reach scale), whether attributes were measured using quantitative or qualitative techniques (e.g., using instruments or visual estimates), and fundamentally, the questions that they were developed to answer. For examples, the PIBO protocol was developed to determine the change of stream habitat as a function of forest management across the PNW. This protocol collects precise measurements of habitat attributes at sampling transects and uses the average of these measurements to describe a site (usually 150 - 250 m in length). This approach differs considerably from Oregon Department of Fish and Wildlife's Aquatic Inventories Program(ODFW-AIP; Moore et al. 2002), which relies on visual estimates of individual channel unit characteristics at a site. Based on this review of monitoring protocol methods, it also became apparent that methods are not adequately defined, or defined in

numerous ways which complicates data collection, sharing, and interpretation (e.g., bank stability, embeddedness, and bankfull width). Standardized terminology and data definitions are essential to simplify information sharing and ensure that data is accurately interpreted during analysis.

In addition, none of the protocols specifically addressed some fundamental issues related to fish habitat such as velocity zones through hydraulic modeling, changes in geomorphic processes (e.g., aggradation and erosion), or explicitly measured the degree of complexity within and between channel units. Protocols might be much more informative if they could provide a spatial referenced (x, y, z) component to the data collected.

2.9 Summary of Findings by Stream Habitat Category

Due to time constraints not all attributes within a category were reviewed in the same detail and measures of each attributes performance as a monitoring tool were not always readily available. Below are brief summaries regarding each stream habitat category outlining the fish requirements within a category, how current measurement protocols address these requirements, and suggesting what we should measure if measurement of these requirements is of poor quality.

Geomorphic classification

Prior to any field sampling, potential study streams should be reviewed using available remote sensing and map products available for the area. Streams should be classified based on geomorphic criteria. Many commonly recorded attributes such as sinuosity, entrenchment, valley width, etc. can be adequately measured in the office using desktop GIS software. GIS analyses currently being developed at the NWFSC demonstrates the ability to identify Montgomery and Buffington (1997) channel types from standard GIS layers. Additional remote sensing data may improve delineation of valley types and reaches. Pre-season field reconnaissance may also be required to validate valley and reach delineations. Work at the NWFSC shows promise for a prior stratification of a GRTS sample based on channel type. Prior stratification by channel type should improve estimates of habitat condition, provide independent habitat condition parameters for each channel type, and improve the ability to extrapolate findings and make management recommendations.

Habitat unit classification

Previous sections of this document emphasized that the physical arrangement, quantity, and characteristics of channel units affects salmonid population processes at all life stages. Based on this knowledge, it would follow that methods for assessing salmonid habitat would aim to delineate, describe, and document the location of channel habitat units in a manner that is relevant to salmonid populations. A review of current habitat monitoring program methodologies used throughout the Pacific Northwest revealed a gradient in their ability to describe this important scale of stream networks (Johnson et al. 2001). Thus, in the process of recommending a set of methods for monitoring the status and trend of salmonid habitat throughout the Pacific Northwest a set of criteria were developed and used to assess how monitoring program protocols evaluate habitat at the channel unit scale. A selection of specific monitoring programs were chosen to be reviewed as they annually conduct surveys at a diversity of stream environments throughout the Pacific Northwest, and they represent contrasting

approaches for characterizing habitat at the channel unit scale. The specific criteria used in this review are defined below, and an outline of how the representative monitoring programs assess channel unit scale habitat based on these criteria is summarized in Table 4.

Completeness of the Survey - Does the protocol delineate all distinct channel unit types that may be present within a surveyed stream segment, or focus only on describing a target channel type? For example, a protocol lacking completeness would be one that only counts or measures pool habitat types within stream segment.

Spatial Context - Does the protocol describe the spatial arrangement of distinct channel units relative to one another, such as the distance between pool habitat types, or whether a specific unit is found in a secondary channel of a braided stream segment? Also, can the areal or volumetric extent of the unit be assessed?

Relationship to Channel Attributes - Does the protocol measure other channel attributes in a way that can be related back to specific channel units? For example, because cover is important to avoid predation while foraging or spawning, pools or suitable spawning areas with large wood or other structure will be more important for these processes than similar units without structure.

Data Transferability - Does the protocol define channel units in such a way that they are comparable to existing and legacy monitoring program datasets and widely accepted channel unit classification schemas (i.e., Hawkins et al. 1993)? For example, can pool counts from one program's protocol be compared to pool counts collected by a different program?

Table 4. Approaches used by Pacific Northwest salmonid monitoring programs to assess channel unit-scale habitat.

Criteria	AREMP	EPA – EMAP	EMP – PIBO	ODFW – AIP
Completeness of the Survey	Classifies pool habitat types only based on residual depth criteria, pools in non-primary channels are not recorded.	Primary channel is classified into an array of channel unit types along a thalweg profile based on channel and flow characteristics.	Classifies pool habitat types only based on residual depth and width criteria, pools in non-primary channels are not recorded.	Entire surveyed stream segment is classified into an array of channel unit types based on channel and flow characteristics.
Spatial Context	Total station survey describes the spatial arrangement of pool units.	Thalweg profile provides spatial context for all channel units.	Little to none, amount of pool and non-pool habitat within a segment.	Channel units are given an identifier that describes the relative location of units to one another and location in non-primary channels.
Relationship to Channel Attributes	Little ability to relate habitat attributes to specific channel units.	Wood and substrate tied to points along thalweg profile.	Little ability to relate habitat attributes to specific channel units.	All measured channel attributes are tied to specific channel unit
Data Transferability	Only pool habitat, strict definition of pool habitat may limit transferability.	Delineation of an array of pool and non-pool units facilitates comparison with other protocols/unit classification schemas.	Only pool habitat, strict definition of pool habitat may limit transferability.	Delineation of an array of pool and non-pool units facilitates comparison with other protocols/unit classification schemas.

The summary offered in Table 4 demonstrates that monitoring protocols exhibit varying abilities to characterize channel unit scale information, and use different methods to do so. This is especially apparent when considering the completeness by which monitoring groups delineate distinct channel units throughout a surveyed segment of channel. For example, some monitoring groups focus on delineating, counting, and measuring the dimensions of only a target channel unit type, usually pool habitat units. However, non-pool habitat types (i.e., non-turbulent, riffles, rapids, cascades) are important to salmonids as well as to the function of a variety of stream processes. In sharp contrast to protocols that target specific unit types are those that delineate all relatively homogenous sections of stream channel into a variety of unit types based on a combination of hydraulic and geomorphic properties. This more complete approach of describing channel unit scale habitat offers increased opportunities to identify possible limitations to fish population processes, but can also be rolled up to be summarized in a similar fashion to more general approaches.

Protocols also exhibit varying abilities and approaches for describing the spatial arrangement of units throughout a surveyed segment of channel. For example, some protocols that target only specific units types such as pools can calculate volumes and counts of pool units but have no way of spatially referencing those units in relation to others. It is only known that there is pool habitat somewhere within a surveyed section of channel. Perhaps one of the most effective ways of spatially referencing channel units is by mapping their locations relative to one another using survey equipment such as a total station. However, survey equipment like a total station can be expensive, and may be difficult to transport into remote survey locations. Further, of the protocols reviewed here that utilized a total station only the locations of pool units are surveyed. If used in conjunction with a methodology that recognized more channel unit types this would be an extremely effective way to describe the spatial arrangement of channel units throughout a stream segment. Another means of spatially referencing the arrangement of channel units is to delineate units along a thalweg profile. A thalweg profile involves measuring thalweg depths at a systematic interval throughout a surveyed stream segment. If channel unit types are delineated along the thalweg profile, as they were in the protocols reviewed here, the location of units can be referenced to a longitudinal position within a channel segment. Yet another approach to describing the spatial arrangement of channel units utilizes a unit classification scheme paired with a numbering system that describes the sequential occurrence of channel units as well as the location of units that occur off the primary channel in braided segments. This scheme presents itself as an effective and accessible approach for applying spatial context to stream habitat surveys.

Another element of documenting the spatial context of habitat units is the ability to relate other surveyed stream attributes to specific habitat units. For example, several of the protocols reviewed here measure LWD throughout a survey segment without any means of documenting where in the channel wood is occurring. An approach such as this limits associations between channel units and habitat attributes to segment scales ranging from 10 m to 1000 m. Similarly, protocols may also rely on transect-based sampling to describe attributes such as substrate composition, various bank attributes, LWD, and others. If transects are not associated with distinct habitat units it is impossible to determine if, for example, pools contain any structure or cover provided by undercut banks and large wood, or if riffles offer a diversity of substrate sizes to provide velocity refuges for fish and macroinvertebrates. Several protocols demonstrated

more effective approaches for tying habitat characteristics directly or indirectly to distinct channel units. Documenting the locations of channel attributes such as large wood and substrate composition along a thalweg profile allows indirect associations to be made between channel units and habitat attributes. Perhaps a more effective approach is to directly associate all measured attributes with the channel unit they occur in, as was observed in one of the protocols evaluated in this review.

A final important consideration in choosing a protocol that describes channel unit scale habitat is the transferability of the data it collects to other protocols. Two important factors to consider when relating data collected using one method to that collected by another are the resolution of the data collected, and also the generality of the method. Several protocols reviewed here limited their delineation of channel unit types to pool habitat units only, grouping all other sections into a broad non-pool habitat type. This is an example of a protocol that exhibits a low level of resolution, and the data collected cannot be compared to one that recognizes a variety of non-pool channel unit types (i.e., riffles, glides, cascades, etc). Thus, protocols that delineate a large number of specific channel unit types (high resolution) will also feature greater data transferability with other monitoring groups and legacy datasets since they can be rolled up to also recreate lower resolution methods. An example of these aspects of data transferability is made apparent in Table 5, where each row represents an equivalent channel unit type. Those programs with a wider array of unit classifications have more opportunities for sharing data.

Although a standard set of definitions for delineating channel unit types does not exist among stream ecologists and managers, general channel unit classification schemes, such as that proposed by Hawkins et al. (1993) have been used to form the basis for channel unit delineation protocols used by many habitat monitoring programs and salmonid research projects (Bisson et al. 2006). Hawkins et al. (1993) relies on a general framework for classifying channel units based on characteristics of bedform, flow, substrate composition, and water surface gradient. The hierarchical description of these channel units has the potential to further increase data transferability because specific units are defined within general units, allowing high resolution approaches to be combined to describe lower resolution approaches. Several of the protocols reviewed here feature extremely rigid criteria for delineating pool habitat such as specific residual depth criteria, relationship to the thalweg, and a requirement that pools only be counted in the primary channel of braided channel segments. While strict channel unit type definitions such as this have the potential to reduce observer variability, it limits their ability to compare data with other groups that collect similar data types using more process based unit classifications schemes similar to those proposed by Hawkins et al. (1993).

Again, only a handful of protocols used throughout the Pacific Northwest to monitor salmonid habitat have a strong focus at describing stream features at the channel unit scale (Johnson et al. 2001). Of the protocols evaluated in this review, the EPA's EMAP and the ODFW-AIP classify a variety of pool and non-pool channel unit types. Further, the methodologies used by these programs characterizes channel units in a manner that documents their spatial arrangement, links them to other measured attributes, and has the resolution and generality to allow the data they collect to be comparable to data collected by a variety of other stream habitat survey projects. Despite these similarities, these projects use a fundamentally

different method in how they survey stream habitat. The EPA-EMAP collects all channel attributes relative to their systematic position along a thalweg profile, and only records the presence and absence of off-channel units (i.e., alcoves, backwater pools) and non-primary channels (braided stream segments). In contrast, ODFW-AIP collects all channel attributes relative to spatially referenced unique channel units, including off-channel units and the delineation of channel units that occur in non-primary channels.

Table 5.Comparison of channel unit classification schemes used by representative habitat monitoring programs and those proposed by Hawkins et al. (1993).

Hawkins et al. (1993)	AREMP	EPA-EMAP	EMP-PIBO	ODFW-AIP
Cascade	Not Measured	Cascade	Not Measured	Cascade over Boulders
Cascade	Not Measured	Cascade	Not Measured	Cascade over Bedrock
Sheet	Not Measured	Sheet	Not Measured	Glide
Beaver Dam Pool	Beaver Dam Pool	Beaver Dam Pool	Beaver Dam Pool	Beaver Dam Pool
Debris Dam	Dammed Pool	Debris Dam	Dammed Pool	Dammed Pool
Lateral Scour Pool	Scour Pool	Lateral Scour Pool	Scour Pool	Lateral Scour Pool
Plunge Pool	Plunge Pool	Plunge Pool	Plunge Pool	Plunge Pool
Midchannel Pool	Scour Pool	Midchannel Pool	Scour Pool	Straight Scour Pool
Trench Pool	Scour Pool	Trench Pool	Scour Pool	Trench Pool
Rapid	Not Measured	Rapid	Not Measured	Rapid over Boulders
Rapid	Not Measured	Rapid	Not Measured	Rapid over Bedrock
Riffle	Not Measured	Riffle	Not Measured	Riffle
Riffle	Not Measured	Riffle	Not Measured	Riffle with Pockets
Abandoned Channel	Not Measured	Abandoned Channel	Not Measured	Puddled Unit
Backwater Pool	Not Measured	Backwater Pool	Not Measured	Alcove Pool
Backwater Pool	Not Measured	Backwater Pool	Not Measured	Backwater Pool

Banks

Bank stability has been associated with stream health (i.e., eroding banks are often thought of as negatively affecting fish habitat) and attributes such as undercut banks are known to fish provide cover. One of the major limitations with most rapid bank assessment protocols is that they focus on bank erosion as a hazard and often imply that bank erosion is a negative process. Bank erosion is a natural process that can be anthropogenically accelerated to the point that it provides excess fine sediment to the stream. However, bank erosion is a necessary ingredient in meandering channel planforms and can be an essential source of coarse sediment for in-channel bar formation, and recruitment of spawning gravels.

More comprehensive bank geometry measurements and/or fluvial geomorphic audits need to be conducted over large reach lengths in order to assess their impacts to salmonids.

Improvements in the integration between bank attributes and riparian vegetation assessments may also serve to improve the usefulness of bank attribute characterizations. The use of repeat topographical assessments may be more appropriate for monitoring bank characteristics only if bank erosion has been identified as a significant issue.

Fish cover

Fish cover is of critical importance; however, it is an attribute that is often measured inconsistently by regional monitoring programs. Probably the most consistently measured type of fish cover is LWD. LWD can alter the structure and function of stream ecosystems, especially within small streams and can affect the formation of pool habitat, sediment storage, channel morphology, invertebrate abundance, and provide hiding cover for juvenile and adult salmonid life stages (Bisson et al. 1987; Harvey 1998). Comparisons of regional protocols used to monitor LWD suggest that definitions of what constitutes LWD are inconsistent and that variation in site lengths confound estimates of LWD abundance. Also, LWD function and spatial context is rarely recorded. Tallying LWD at the channel unit scale will allow its interpretation as cover for fish (Harvey 1998; Harvey et al. 1999). Other aspects of fish cover include substrate composition, undercut banks, and instream and overstream vegetation. These types of cover will be specifically addressed in additional sections below.

Thalweg profiles

Thalweg profile sampling offers an approach for adding spatial context to the characterization of fish habitat and stream bottom complexity, and is an improvement over transect based survey approaches. Thalweg profile sampling allows channel unit types and locations to be identified within a site independent of stream flow. However, thalweg profiles protocols often do not adequately locate smaller secondary habitat units not associated with the thalweg, or allow accurate determination of individual channel unit volumes or areas. Systematic spacing of depth measurements along the thalweg is the approach most commonly used. While systematic spacing may allow for greater repeatability (assuming reaches are monumented and repeat surveys start from the exact same point) and relative locations can be more easily identified with a depth rod, this approach may not capture important gradient breaks and thus may not be as accurate. Methods that give absolute location along the thalweg (e.g., total station or GPS) and focus on capturing gradient breaks are likely more accurate in describing and delineating habitat units using multiple criteria.

Site level characteristics

Many site level characteristics (e.g., gradient, sinuosity) can be assessed prior to field visits using remote sensing. Field-based measurements of gradient are sufficiently precise among protocols, however, measures of sinuosity and valley confinement are likely more efficiently assessed using remote sensing (e.g., low elevation aerial photography).

We did not formally review the affect of site length on the results of stream surveys. Our basic assumption is that longer sites will better characterize geomorphic reaches than shorter sites. The length of a site is often determined by measuring the width and multiplying that value by 20 - 40 (e.g., AREMP, CDFG, EMAP, and PIBO; ODFW samples between 500 and 1000 m). The CHaMP protocol will use 20 times the bankfull width to generate a site length.

Aquatic Invertebrates

Some regional protocols collect samples of aquatic invertebrates to assess the biotic integrity of a site (EMAP). Benthic macroinvertebrate (kick-net) samples collect all invertebrates occupying stream substrate. In most cases indices of invertebrate community diversity are calculated from this sampling that describe water quality, ecological integrity, or deviation from expected reference conditions. Although these indices can be useful, they have only an indirect relationship to stream habitat features that effect salmonid performance. Additionally, calculation of diversity indices is often expensive, as it requires that invertebrates be sorted from benthic debris and identified to genus or species by professional taxonomists.

Invertebrate drift samples collect invertebrates drifting in the water column where they are vulnerable to salmonids as a food resource. ISEMP research has also shown direct relationships between salmonid food consumption and growth rates and invertebrate drift samples (Weber et al. submitted). Drift sampling is also more accessible and economical as no specialized knowledge of invertebrate taxonomy is necessary to quantify drift abundance. ISEMP is conducting trials that compare benthic and drift samples to determine if a relationship exists between these groups that would allow a more economical assessment of food availability, negating the need to collect drift if benthic samples are collected.

Pools

Pool habitat is often directly associated with fish abundance and increasing pool habitat is often a primary goal of restoration efforts. However, pool volume is often is difficult to characterize by habitat protocols. It is also apparent that a number of "pool-like" habitats are under-recorded during current surveys (i.e., slow water habitats that do not meet strict protocol definitions of pools). We recommend an increase in the number of pool depth and width measurements for more accuracy in pool area and volume metrics. We also recommend adoption of definitions of pool habitat that recognize a variety of high depth, low velocity channel types that function as pool habitat, including pools in all flowing stream channels (i.e., not only from within the primary channel).

Detailed surveys of stream channel topography using a total survey station or GPS provide superior information on stream habitat availability. The resulting DEM from these methods can be used to calculate metrics of pool frequency, area, volume, and percent pools. These types of data can also be incorporated into hydraulic models (e.g., HEC-RAS) to estimate the distribution of velocities throughout a surveyed stream segment.

Riparian habitat

There are well established relationships between riparian health and stream function (Gregory et al. 1991, Naiman and Decamps 1997). Riparian habitat can also strongly influence channel form by strengthening bank stability due to the presence of plants with deep root structures and via the addition of LWD that can cause both an increase in bank stability and scouring by directing flows (Buffington et al. 2002, Chen et al. 2008). Riparian habitat indirectly relates to fish requirements via thermal regulation of stream temperatures, inputs of food and nutrients, and the creation of complex habitats from the addition of LWD. However, riparian sampling poses many problems for rapid assessments because detailed plant identification is often required. Some protocols try to avoid plant identification and use

community typing to assess riparian extent and function but this adds subjectivity to the sampling and decreases consistency within protocols. ISEMP uses the solar pathfinder to measure solar inputs (throughout the year), canopy cover, and visually estimates other vegetation layers (Platts et al. 1987, OWEB 1999). Remote sensing may offer the most cost effective and precise methods to determine extent and status of riparian conditions. The use of low elevation aerial photography to describe riparian vegetation composition is being tested by ISEMP in several watersheds (Vericat et al. 2008).

We recommend that solar pathfinders be used to assess the solar input into the site, which can be used for modeling stream temperature, fish growth, and potential primary production at the site. This would be done at the site level (i.e., average site solar input). To determine shading and fish cover provided by riparian vegetation we recommend the continued use of EMAP/ISEMP protocols that visually estimate cover from instream and overstream vegetation. However, these estimates should be made at the habitat unit level to allow a finer resolution of cover data. We recommend use of remote sensing data and aerial photography to determine riparian cover unless riparian assessments are a specific objective of the monitoring program.

Stream width

Measures of bankfull width/floodplain width are intuitively appealing concepts but have been notoriously difficult to consistently identify in the field; numerous subtle signs have to be identified in the field and these signs are not always present (e.g., signs of recent high flows). Many protocols take transects across the stream at systematic locations or specific habitat units (e.g., riffles). The reason for estimating stream widths should drive the approach taken. For example, the inflection point of a sinuous stream, usually a riffle that has uniform characteristics is often used to establish stream width that is useful in describing a cross-section to develop a stage height/discharge relationship.

Width-to-depth ratios are calculated because it is assumed that wide shallow streams are the result of disturbance (e.g., grazing) and is often determined from multiple transects at bankfull elevation. However, because this metric relies on a ratio it is susceptible to larger errors and has been shown to have poor internal consistency, limited ability to detect environmental heterogeneity, and poor correlation with the truth (Roper et al. 2010). To evaluate changes in transect area and erosion patterns through time, multiple transects monumented above the flood elevation are necessary. To evaluate the amount of habitat types available to fish for a majority of their life spent in a stream, perhaps base flow elevation is most pertinent.

Bankfull width is estimated in most habitat protocols reviewed and provides a reference point that is inclusive of wetted channel attributes most likely to be encountered during habitat surveys. Bankfull elevation, however, is an often misunderstood concept often equated with effective discharge elevation, active channel elevation, or elevation of the 1.5 yr flood reoccurrence interval. The concept of bankfull width is also site dependent and may not be applicable in all situations (e.g., high gradient, confined streams).

Bankfull is best determined at the time water is actually at bankfull flows or when water starts to spill out of the stream banks. Even if this event is witnessed, the variability in widths along the reach makes this estimation problematic. The area of a site polygon (e.g., determined from aerial photos) at bankfull discharge divided by the thalweg length is perhaps the best

indicator of actual stream width, but this is very difficult to observe. Streams with dense riparian vegetation may be particularly difficult to measure bankfull width due to reluctance of observers to leave the stream channel to properly identify high flow characteristics (Roper et al. 2010). Many protocols stop cross-sections at bankfull width; this prevents information being collected in floodplain areas and may make it difficult to detect channel changes or put changes of instream features in context.

Wetted width is obviously highly flow dependent and cannot be used to compare streams when sampling over extended periods. However, if collected at base flow, this measurement can be highly relevant to estimating the amount of fish habitat, and is easy to locate (i.e., water's edge).

Because of the multiple reasons to collect information pertaining to stream width, widths should be measured at multiple bank elevation indicators, including bankfull and water's edge. Total station, GPS, or remote sensing approaches (LiDAR, multispectral and hyper-spectral photography) information can provide X,Y,Z coordinates by which DEMs can be created. Widths can then be determined from multiple perspectives.

Substrate

Stream substrate, either surface or subsurface, is measured by a wide variety of monitoring programs to determine the distribution of stream bed particles, potential bed load and mobility, fine sediment levels in reference and managed watersheds, fish cover, and the quality and quantity of spawning areas (Kondolf 1997; Bunte and Abt 2001; Bryce et al. 2008). In the Pacific Northwest much of the stream habitat monitoring in salmon and steelhead bearing streams occurs in coarse gravel and cobble bed streams that inherently have a wide range of substrate particles sizes (Bunte and Abt 2001). Sampling substrate in coarse bed streams can be difficult because the streambed is frequently inundated and constant scour and deposition results in a spatially diversified streambed.

Three common measures of stream substrate were reviewed and presented in this document: percent fines, embeddedness, and pebble distribution. Measuring the percent fines and estimates of embeddedness can provide a direct measure of the potential impairment or recovery of spawning habitat and the degree of "clogging" of interstitial spaces. Pebble counts can be related to fish requirements by providing information on the characteristics of the stream (i.e., broad classification of stream as gravel or cobble bed streams, etc.), which can be used to predict species presence/absence and habitat suitability. However, the way many protocols measure these attributes of substrate composition may not be adequate to 1) consistently detect change, 2) relate substrate conditions at the appropriate scale, and/or 3) be repeatable over a variety of stream conditions and different observers.

Fine sediment is defined differently in many studies, but for this review the approach evaluated is particles < 2 mm (i.e., sand and smaller). The percent fines within the substrate, either on the surface or within the subsurface, has received particular attention in the literature because increased land use often leads to increases in fine sediment inputs to streams (EPA 2004). Increases in fine sediment have also been shown to decrease the quality of spawning habitat which can lead to poor egg survival (Jensen et al. 2009), lower emergence rates (Reiser and White 1988), and can also reduce cover/interstitial spaces used by juvenile salmonids for

overwintering (Cunjack 1996). A recent review of the impact of fine sediment on aquatic invertebrate and vertebrate populations suggests that 5% fines (< 0.065 mm) and 13% fines and sands (< 2 mm) can reduce species abundance and diversity (Bryce et al. 2010).

None of the protocols reviewed here assessed subsurface fines. Subsurface fines typically have a finer particle distribution than surface material (Bunte and Abt 2001) and several studies have demonstrated the link between subsurface fines and salmonid egg to emergence survival (reviewed in Bryce et al. 2010). Although the distribution of surface and subsurface materials are often correlated, it is not always the case, and there are compelling reasons to measure subsurface particle distribution because many salmon and steelhead species dig redds that are often > 20 cm deep (Jensen et al. 2009, Quinn 2005) and are dependent on the quality of subsurface materials (Kondolf et al. 2000). A recent study by Sutherland et al. (2010) showed that percent of subsurface fines as sampled with a shovel core were the best indicator of the overall level of watershed disturbance. However, current assessments of percent fines that use sampling grids, large sample sizes (~ 1500 particles), and sample specific habitat types (i.e., pool tails; PIBO, AREMP) appear to be able to detect moderate levels of change and are repeatable (Appendix D). Furthermore, measurement of subsurface fines is notoriously difficult to do, especially within a spatially balanced sampling design that requires sampling in remote locations.

Embeddedness has many definitions but in general is a term used to refer to the amount infilling around gravel, cobble, and boulder particles by fine particles (Sylte and Fischenich 2002). As such, embeddedness is an indirect measure of the amount of fine sediment in a stream and the degree to which it fills in the spaces between larger particles, especially cobbles. Measurement of embeddedness was reviewed extensively by Sylte and Fischenich (2002) and they concluded that this attribute has no common definition and is too subjective to be used for monitoring. However, Southerland et al (2010) found significant relationships between embeddedness and land use indices. They also specifically contradicted Sylte and Fischenich (2002) and cautioned that care must be taken when comparing embeddedness data collected using different methods, to ensure that observed differences are due to condition rather than methodology. Similarly, Sennatt et al. (2006) found that a visual estimate of embeddedness used by the USEPA could distinguish between embeddedness upstream and downstream of a dam, but their findings that this technique was better than four other techniques was refuted by Potyondy and Sytle (2008). Embeddedness is not measured by two of the largest regional monitoring programs (AREMP and PIBO) because of inconsistencies in definition and repeatability and a flaw in many common methods that allows for lower embeddedness values as the percent of fines in interstitial spaces increases (Sylte and Fischenich 2002).

Pebble counts are probably the most widely conducted methods for assessing substrate. Pebble counts are typically conducted at cross-sections and particles are picked up and measured across the cross-section at regular intervals. Particle sizes are either binned into size classes or measured directly (Bunte and Abt 2001). Pebble counts can provide an approximation of pebble distribution; however, several reviews of pebble counts have determined that many monitoring protocols do not have sufficiently rigorous methods to provide meaningful results (Olsen et al. 2005, Bunte et al. 2009). Although two methods may have the same general goals for a pebble count sources of variability can occur at multiple levels including 1) the length of reach sampled,

2) allocation of samples within a reach, 3) sampling pattern, 4) portion of stream width sampled, 5) spacing and number of particles collected, 6) sample size, 7) selection of particles, 8) measurement of the particles, and 9) analysis of particle distributions (Bunte et al. 2009). The general conclusions of many reviews is that to increase the value of pebble counts as a monitoring tool sample reaches need to be stratified into geomorphic habitat units (i.e., process based) and the number of particles measured needs to be increased with reduced observer bias (Olsen et al. 2005, Whitacre et al. 2007, Bunte et al. 2009). Many protocols reviewed here measure ~100 particles throughout the entire reach and use these measurements to determine a reach-scale metric for particle distribution (Appendix D).

This review of substrate sampling methods indicates that improvements could be made to commonly used methods for determining the percent fines and particle distributions in gravel and cobble bed streams. If pebble counts (i.e., Wolman pebble count) are to be continued the following improvements could be easily applied to increase their precision: conduct the counts within geomorphic habitat units, increase the number of particles counted, measure the particles rather than visually estimating them, and use less subjective methods to select the particles.

Water quality

Whether being deployed for short or long durations, temperature loggers should be used to collect continuous (hourly) data at all status and trend monitoring sites. Collection of alkalinity and conductivity using field meters at all status and trend monitoring sites can be a key indicator of the potential for primary productivity, a stream ecosystem classification metric. Measures of DO can be informative not only from a water quality perspective but also to determine levels of gross primary production and ecosystem respiration. In general, gross primary production and ecosystem respiration per unit surface area can be determined using single-station dissolved oxygen change method (Mulholland et al. 2005), where the difference in DO between day (when photosynthesis is producing oxygen) and night (where organisms are consuming oxygen) are recorded with a DO sonde. DO sondes are now available that require little maintenance. Nutrient sampling is expensive and may only be relevant when nutrients have been identified as a primary concern.

2.10 Details on the Alternatives: Continuous Methods & GIS

As described above, both site-based and channel unit-based sampling approaches have their shortcomings. These are primarily related to the way in which the data collected creates abstractions of measured stream attributes. Although these are mature and rapid sampling strategies that lend themselves to a specific set of tractable analyses, the raw data lacks the explicit and visual context of scaled maps or aerial photographs. When the data collected at a particular reach is simply used to produce summary statistics that can be inter-compared amongst sites, spatial context may not be necessary. However, if one tries to drill back down to the original data to either help explain an anomaly or look at specific trends within a site, data from site-based and habitat-unit based approaches is of less utility where it is not placed in a spatial context. Given the extensive effort that goes into collecting such data, it is reasonable to want to extract as much information as possible from it. An alternative method to directly documenting the status of habitat across different scales is to employ spatially continuous sampling strategies, which feed into a GIS. This could be achieved with a variety of well-established techniques:

- Remotely sensed imagery and data can be commissioned or existing sources acquired to provide photographic and topographic context.
- Existing GIS layers can be used to provide additional context.
- Total stations and GPS can be used to survey polygons (e.g., channel units, vegetation cover), polylines (e.g., transect locations, thalweg locations, edge of water surface), and points (e.g., LWD locations, boulder locations, sampling points).
- Where existing baseline layers exist (e.g., aerial photography), polygons, polylines and points can be drawn by hand in the field (either digitally or on paper copies) and used to digitize geometric measures at moderate levels of precision.
- Total stations or survey-grade differential GPS can be used to precisely conduct topographic surveys from which DEMs can be produced (note that cross-sections and long profiles can be accurately extracted from such DEMs).

There is little debate that the above data collection techniques provide richer datasets that can support a much broader range of analyses and metric derivations. However, it is often assumed that the above techniques take too long to employ, require expensive equipment, and are not appropriate for rapid assessment techniques. This was true 15 years ago, but the efficiency, affordability and ease of use of such technologies has improved dramatically. In some cases the techniques are more rapid than traditional measurement techniques and provide richer information. Other benefits include the ability to build user-error checking into the field and to eliminate the need for data entry back in the office.

It is clear from the above review that improvements can be made to current stream habitat monitoring protocols to ensure that the attributes measured are directly applicable to the habitat requirements of fish. Protocols can be roughly divided into those that focus on site level measurements, those that focus on habitat unit-based sampling, and those that use either direct measurement methods, or visual assessments to quantify habitat features. None of these approaches alone comprehensively describe the habitat requirements that are critical to fish. In general, site-based approaches suffer from a high degree of abstraction whereas the habitat unit approaches suffer from being overly qualitative. Given that in the short-term these techniques will continue to be used, ISEMP recommends that additional emphasis be placed on:

1) Demonstrating that currently recorded attributes are useful; if not, then they should be abandoned in favor of collecting more relevant data.
2) Developing cross-walking techniques to allow comparisons of the data that has been collected to what might be collected in the future (so as to get a return on the large investment already made in these techniques).
3) Think about how the attributes could be collected such that they can more meaningfully feed into GIS geodatabases, foraging models, and other quantitative analytical approaches.

ISEMP is currently reviewing and testing a variety of ground-based and remotely sensed survey techniques that provide spatially continuous data in the Bridge Creek IMW and the Lemhi IMW projects. Some of these technologies are well established (e.g., aerial photography, topographic surveys), some are more experimental (e.g., green LiDaR), but all require careful

consideration as to how they can be used to derive meaningful measures of salmonid habitat quality and quantity. It is premature to make specific recommendations about how to employ these new technologies, but several advantages are evident:

- Over 90% of the metrics derived using existing transect and habitat-based approaches can be derived from spatially continuous data at similar or sometimes better accuracies. This is important for allowing inter-comparison of this data with legacy data collected by current and former protocols.
- Spatially continuous data facilitates a much richer range of analyses that more directly capture the physical state of the habitat (see section 1.7).
- With good survey control, change detection analyses from spatially continuous repeat surveys are much more reliable and richer than those that can be performed from transect-based or qualitative habitat unit approaches.
- Aerial photography provides a context for better interpreting site specific attributes and explaining trends or anomalies in observations. Moreover, they provide a richer context for explaining fish and macroinvertebrate monitoring data.
- Spatially continuous data is much better suited to doing multi-scalar analyses and helping extrapolate local observations and discrete samples to larger spatial scales.

The wide variety of ground-based and remotely-sensed technologies will not work in all the diversity of conditions where habitat monitoring will take place. Eventual recommendations will need to be context-specific and a hybrid of approaches will likely be employed. Thus, it will be important to understand the significance of uncertainties involved in each approach and how to effectively combine and inter-compare such data streams. A disconnect currently exists between the habitat monitoring at the site scale and the broader landscape and watershed context within which these sites exist. That broader-scale context can be used to effectively stratify the placement of monitoring reaches and to explain why specific patterns and trends exist. Coherent multi-scalar assessment techniques (e.g., River Styles) already exist, which could help make the site-scale monitoring much more useful. Similarly, broad-scale regional and watershed-scale desktop GIS analyses have already been undertaken by researchers of the entire Columbia Basin and these could be more meaningfully used to explain the status and trends revealed from the site-scale monitoring efforts. Combining such desktop analyses with rapid field assessment procedures at the landscape and network scale (e.g., fluvial audits) provides a tractable method for nesting the data in a multi-scalar context.

Monitoring Design Review

A status and trend monitoring program has four basic components: spatial, temporal, response and inference design. A final design is an iterative process to balance the requirements of all four design components. The stream habitat monitoring methods presented here comprise much of the program's response design. In general, these methods are compatible with many choices for spatial, temporal and inference designs, but have been assembled with the intention of developing habitat monitoring indicators from design-based inference of a probabilistic spatial design (GRTS) with annual and rotating panels (temporal design). A brief review of a

monitoring program is presented in Appendix E. For a complete description visit the following site: www.salmonmonitoringadvisor.org.

Recommendations

Based on a review of fish habitat requirements, common stream habitat protocols, and literature evaluating protocol effectiveness we recommend the CHaMP as a standardized protocol to be used for determining the quantity and quality of wadeable stream habitat that supports anadromous salmonids in the interior Columbia River. Protocol criteria include: information is collected within a nested hierarchy (habitat unit or site scale) that can be used to reconstruct commonly measured attributes of the protocols, relevancy to salmonids, precision, spatial context (where and how much), and feasibility under multiple conditions and time constraints.

SECTION 3: SAMPLING DESIGN AND SITE SELECTION

The CHaMP monitoring design is driven by the objectives described in section 1.2, and the indicators described in section 1.5. It is comprised of four component designs as advocated by NCEAS (2010):

1) The spatial design, which describes how sites will be selected for monitoring from the spatial domain;
2) The temporal design, which describes sampling frequency and revisit schedule for monitoring sites;
3) The response design, which describes what and how measurements are taken and how site-level metrics are calculated, and
4) The inference design, which describes how indicators are estimated from site-level metrics across a population and time period.

This section provides details on the spatial and temporal design.

CHaMP monitoring watersheds were selected to represent at least one population within each steelhead and spring Chinook MPG which have, or will have, "fish-in" and "fish-out" monitoring as identified in RPA 50.6 (AA/NOAA/NPCC RM&E Workgroup 2010). Selection of monitoring sites within watersheds follows the GRTS design that aims to achieve spatial balance between a simple random sample and a systematic sample (Stevens and Olsen 2003; Stevens and Olsen 2004). The GRTS algorithm results in samples that are distributed across the target population, where the target population is defined based on monitoring objectives. The CHaMP target population includes all stream habitats for salmonids in wadeable, perennial streams below natural impassible barriers within TRT population boundaries. The target population will be drawn from the National Hydrography Dataset Plus (1:100k scale) with the following criteria:

- Wadeable streams
- Perennial streams
- Below natural impassable barriers to salmonid migration
- Within TRT population boundaries
- Within the union of TRT population boundaries where multiple populations exist
- Accessible within institutional crew safety constraints.

The CHaMP statistician will work with project collaborators to finalize sample allocation during the spring of the initial sampling year.

3.1 Site Allocation

3.1.1 Spatial Design

CHaMP monitoring watersheds will be allocated funding to sample 25 sites in each year, with some exceptions for watersheds with overlapping TRT populations. Sampling effort will be balanced across valley type (source, transport and response valley segments) and landownership since some indicators and site accessibility are dependent upon these factors. Crossing two landownership levels by three valley types creates six unique subsets of the target population, which are called multi-density categories. All potential sites within a CHaMP watershed will be allocated to a multi-density category within the target frame. Based on the distribution of sites across the categories, samples may be allocated to ensure even distribution of the sample effort across categories and to ensure statistical power for indicator estimation. Under the default scenario each multi-density category will receive 4 samples.

3.1.2 Temporal Design

The temporal design for CHaMP monitoring watersheds will follow one of two possible panel designs, where a panel is defined as a set of sites that have the same revisit schedule. For watersheds where trend estimation is of primary concern, a single annual panel design will be used. Under this design all 25 sites will be revisited on an annual basis. A split panel design (Figure 10) will be used for watersheds where there is a need to balance status and trend estimation. Under the split panel design 13 sites will be revisited on an annual basis and 12 sites will be allocated to each of three rotating panels that will be visited once every three years.

The motivation of these two temporal designs stems from a need to balance the power to 1) estimate status of the population at a point in time and 2) estimate trends in the population across time. While status is best estimated by sampling as many sites as possible across the broadest geographical distribution, trends are best estimated by repeated sampling of the same set of sites over time. Establishing two or more panels provides the possibility to balance priority of status estimation versus trend estimation.

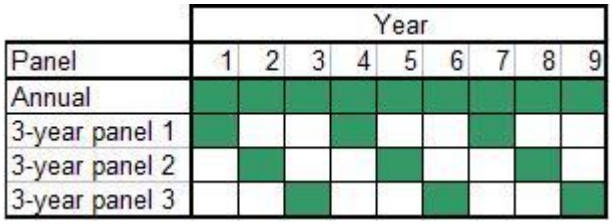

Figure 10. The split panel design to be used by CHaMP in watersheds where status and trend evaluations need to be balanced.

3.2 Site Evaluation

The goal of site evaluation is to relate on-the-ground reality to the sample frame and to assess conditions that may limit a field crew's access to sites. When attributing the sample frame (during the two previous steps) each site is included in the sample frame and is assigned to a multi-density category stage based on one or more attributes derived from a GIS; however, the

GIS layers may not accurately represent on-the-ground reality. During site evaluation, a local biologist evaluates sites to verify that the site lies within the range of the target population and that the site was correctly assigned to a multi-density category. If a site was incorrectly assigned, the site is rejected from sampling and the error is noted. The site evaluation process provides information about error in the sample frame and supports statistical procedures to account for underlying error in the sample frame. The site evaluation process does not aim to "correct" site attributes determined from the GIS, but aims to identify any errors in the sample frame. Evaluations of sites relative to the sample frame are unlikely to change and therefore only need to be performed once.

The second objective of site evaluation is to assess conditions that may limit the ability of field crews' to access the site. The two primary concerns are crew safety and landowner permission. Each institution may have its own policies regarding field crew safety and sites should be evaluated against the institutional constraints of the field crew who will be conducting field sampling. Collaborating agencies must document any institutional safety constraints and get approval for these constraints from the CHaMP coordinator to ensure the adequacy of the final sample design.

Private landownership may also limit access to individual sites. Prior to sampling sites that require access through private lands, access permission must be obtained directly from the landowner. Private landowner permission must be clearly documented. Access conditions may vary from year-to-year and sites that are scheduled for revisiting may need to be re-evaluated prior to each visit.

Site evaluation will be completed following "A Field Manual of Scientific Protocols for Site Evaluation within the Columbia Habitat Monitoring Program" published by ISEMP in 2011.

SECTION 4: SURVEY WORKFLOW

1) Locate the site, establish benchmarks, site markers and monuments, determine bankfull elevation and site width category, lay out the site and determine channel units.
2) Two crew members conduct the topographic survey.
3) The third crew member completes:
    a. Channel unit level tasks: LWD counts, fish cover and ocular substrate estimates, subsurface fines and pebble count measurements in appropriate channel units.
    b. Site level tasks: draw the site map, take water quality and discharge measurements, deploy air and water temperature loggers, take site and solar pathfinder photos, riparian estimates and drift net samples.
4) Once the third crew member has completed collection of the supplemental habitat data, they may assist with the topographic survey as a second rod man.

SECTION 5: SITE LAYOUT

References: Harrelson et al. 1994.

Equipment: Flagging, rebar, monument caps, hammer, identification tag, tape measure, GPS, compass, and map.

5.1 Locating the Site

Step 1. Locate the "X-site".

i. Follow GPS coordinates to the closest point along the stream channel representing the "X-site". These "X-site" coordinates represent the mid-point of a kilometer long sampling area. This location is used to identify and measure the bankfull width.

Step 2. Identify bankfull elevation.

Establish the bankfull stage using the indicators defined by Harrelson et al. (1994) in Table 6.

Table 6. Types of indicators used to determine bankfull stage of a site (modified from Harrelson et al. 1994).

Indicator	Description
Top of Point Bars	Point bars consist of channel material deposited on the inside of meander bends. The top elevation of point bars usually indicates the lowest possible bankfull stage. Multiple point bar levels may be left from flows both above and below the bankfull elevation.
Changes in Vegetation	Look for the lower limit of perennial vegetation on the bank, or a sharp break in the density or type of vegetation. Often willow or alder form lines near bankfull stage. The lower limit of mosses or lichens on rocks or banks, or a break from mosses to other plants, may also help identify bankfull stage.
Change in Slope	The change from a vertical bank to a horizontal surface is the best identifier of bankfull, especially in low-gradient meandering streams. Many banks have multiple breaks, so examine banks at several sections of the site for comparison. Slope breaks also mark the extent of stream terraces, which are old floodplains above the active bankfull. Terraces will generally have soil structure and perennial vegetation. Avoid confusing the level of the lower terrace with that of the floodplain; they may be close in elevation.
Change in Bank Materials	Look for breaks in bank particle size, usually from coarse particles to a finer particle matrix (which is often associated with a change in slope).
Bank Undercuts	Look for bank sections where the perennial vegetation forms a dense root mat. Feel up beneath this root mat and estimate the upper extent of the undercut. This is usually slightly below bankfull stage. Bank undercuts are best used as indicators in steep channels lacking floodplains.
Stain Lines	Look for frequent inundation water lines on rocks. Stain lines are often left by lower, more frequent flows, so stain lines should only be used to assist in identifying bankfull along with another indicator.

Several indicators should be examined to properly determine bankfull height.

i. Indicators should be more distinguishable at non-constrained channel types where the tops of point bars, changes in substrate, and permanent vegetation may be the most reliable indicators.

ii. In constrained channels, especially those dominated by boulders and bedrock substrate, indicators may be more difficult to identify. Under these circumstances the crew may have to depend on stain lines, or move further up or downstream to find reliable indicators.

5.2 Site Layout

Step 1. Determine the site width category and site length.

i. Measure and record the bankfull width perpendicular to the channel at the "X-site".

ii. Measure and record 4 additional bankfull width measurements at distances upstream equal to the first bankfull width measurement.

iii. Average the 5 bankfull width measurements and consult Table 7 to determine the site width category and site length.

Table 7. Width category and site lengths according to the site average bankfull width determined during site layout.

Average Bankfull Width (m)	Width Category (m)	Site Length (m)
≤ 6	6	120
6 and ≤ 8	8	160
8 and ≤ 10	10	200
10 and ≤ 12	12	240
12 and ≤ 14	14	280
14 and ≤ 16	16	320
16 and ≤ 18	18	360
18 and ≤ 20	20	400
20 and ≤ 22	22	440
22 and ≤ 24	24	480
24 and ≤ 26	26	520
26 and ≤ 28	28	560
>28	30	600

Step 2. Establish bottom site location. The bottom site location represents the downstream most extent of the site survey, and is often the "X-site".

i. A site may be shifted upstream or downstream from the X-site as long as the entire site falls within the sampling area.

   a. Sites may be shifted to avoid circumstances listed in Table 8. If the site cannot be located within the kilometer sampling area, it is rejected for sampling.

   b. Do not adjust the site to avoid man-made obstacles such as bridges, culverts, rip-rap, or channelization.

   c. A site must be adjusted to avoid containing tributaries.

   d. Given that the "X-site" represents the middle of a kilometer long sampling area and is often the bottom site location, a site over 500 meter long may need to be moved downstream to ensure that the entire site is within the kilometer long sampling area.

   e. Record the reason for rejecting the site.

Table 8. Recognized reasons for rejecting a sampling site during field sampling.

Reason	**Explanation**
Landowner Denial	Upon arriving at the site, the landowner denies access to the site.
Not safe	The site cannot be sampled safely.
In water body	Site lands in a lake, pond, or reservoir.
In ditch or canal	Site lands in a ditch or a major side channel as seen at the 1:100,000 layer maps. This can only apply if there is an error in the map layer. If it is discovered during a visit to the site, then monument the x-site, or center point, at the nearest point in the main channel and sample.
No defined channel	Site lands in a place with no defined channel that would never have flowing surface water during the low flow period.
Not wadeable	Site is not safely wadeable by crew members.
Dry-not perennial	Site does not have flowing water but may have water early in the season or in wet years.
Permanently dry	Site does not have flowing water and is likely permanently dry. Indicators of this include highly vegetated channels (e.g., sagebrush)
Barrier-natural	Stream is blocked by a natural barrier and not accessible to fish. Description and coordinates of the barrier location must be recorded.
Barrier-human made	Stream is blocked by a man-made barrier and not accessible to the migrating fish of interest. Description and coordinates of the barrier location must be recorded.

ii. When establishing a new site, the bottom site location should be shifted to avoid beginning the site in the interior of a pool.

a. If the bottom site location is in the bottom half of the pool, move the site to the downstream end of the pool.

b. If the bottom site location is in the top half of the pool, move the bottom site location to the upstream end of the pool.

c. If it is not possible to move the bottom site location and remain in the sampling area, then do not shift the site to the downstream or upstream end of the pool.

Step 3. Lay out the site.

Each site will consist of 21 transects spaced at intervals equal to the site width category measured along the center of the bankfull channel.

i. Locate the center of the bankfull channel at the bottom of the site and establish transect 1.

ii. Stretch a tape from the center of the bankfull channel at transect 1 a distance equal to the site width category and establish transect 2.

iii. Continue this process of establishing transects upstream until 21transects have been established.

iv. In braided sections, follow the center of the main channel (the channel containing the greatest amount of the total flow).

Step 4. Establish benchmarks.

i. For a new survey establish 3 benchmarks. Each benchmark must be visible from the other two.

   a. Optimal benchmark characteristics include:

      i. Locations outside of the active channel.

      ii. The ability to acquire a reasonable GPS signal (less than 20 m Estimated Position Error (EPE)).

      iii. Locations distributed as far apart from one another as possible while still visible to one another. Arrangement in an equilateral triangle.

ii. To monument benchmarks drive a 5/8" piece of rebar into the ground using a rock or a hammer. Place a survey cap on it with the proper benchmark number. Place a ring of rocks surrounding the benchmark to make it visible for future surveys.

   a. Alternative, less conspicuous benchmarks may be required at some sites, including all wilderness sites and some private property sites. Benchmarks must be able to be occupied by a prism. Alternative benchmark techniques include:

      i. Rock etching: etch an 'x' into bedrock or a large boulder on or near the stream. Etch the 'x' in a discrete location that can be relocated with explicit instructions.

      ii. Rock cairns: build a stable rock cairn of 5-10 cobbles outside of the bankfull area with a chiseled 'x' on the top rock to mark the benchmark point where a prism can be placed.

b. These benchmarks need to be visible, stable, and easily relocated.

c. When using alternative benchmark techniques, include a detailed description- (e.g., x is on the south side of the boulder, 6 cm from the ground; benchmark is located at the northeast corner of the concrete pad).

Step 5. Establish site monument(s).

Monuments are important for relocating site and benchmark locations. Optimal monuments are easily identifiable, permanent features in the landscape. These features include large trees, large boulders, and artificial structures (e.g., sign posts, concrete pads, etc.). Because benchmarks will be spread out, it may be necessary to establish multiple monuments. Typically, a monument should not be greater than 50 meters from the benchmark it is associated with.

For each monument established:

i. Securely nail or attach a tag to the monument. Record on the tag the site number and monument number.

ii. Record the monument number and type.

iii. Record GPS UTM coordinates and EPE.

a. UTM coordinates include UTM zone, easting, northing and EPE.

iv. Describe the location of the monument(s).

a. Record bank location (left or right) and the distance from the monument to the bank.

b. Include a general description of the site monument location and any other information that would be useful for relocating the monument. If the monument is a tree, record the common name of tree species and diameter at breast height (DBH).

v. Take a photo of the monument. Record the photo number. Include enough of the surrounding environment in the photo to relocate the monument.

Step 6. Establish bottom and top site markers.

i. Place site markers (usually a visible tag in a tree) in line with the bottom and top transects in a place that will not be eroded or disturbed. In some circumstances where there are no trees, rocks, or willows near the bottom and top of the site, it may be necessary to place rebar to attach the tag.

ii. Record GPS coordinates and EPE at bottom and top site markers.

iii. Take a photo of each site marker and record the photo number. Good site marker photos should include flagging on an object near the actual site marker and have a wide enough field of view to relocate the marker.

iv. Record any notes that may be useful when relocating the bottom and top site markers.

Step 7. Record benchmark data.

i. Record a bearing (with the declination set at zero) from benchmark 1 to benchmark 2, benchmark 1 to benchmark 3, and benchmark 2 to benchmark 3. Be careful not to have ferrous-metal objects near the compass when reading bearings.

ii. Record benchmark number and type (e.g., capped rebar, chiseled bolder, chiseled rock on top of cairn, or other). If 'Other' is selected as benchmark type, be sure to include a detailed description of the benchmark so that a prism can be located at exactly the same position in future surveys.

iii. Record GPS coordinates and EPE for all three benchmarks.

iv. Record the bank location (left or right) for each benchmark.

v. Record the monument number used to relocate the benchmark. Take and record a bearing and distance from the monument to the benchmark.

vi. Record notes that may be useful when relocating each monument.

5.3 Channel Class

i. After viewing the entire site during setup, classify the primary, or most prevalent channel class according to the criteria provided in Table 9. This criteria is a simplification of the classification system developed by Montgomery and Buffington (1993).

Table 9. The channel classification system used by CHaMP (derived from Montgomery and Buffington (1993)).

	Braided	**Regime**	**Pool-Riffle**	**Plane-Bed**	**Step-Pool**	**Cascade**	**Bedrock**	**Colluvial**
Typical Slope (%)	< 3	< 0.1	0.1 - 3	1 - 3	3 - 8	8 - 30	Variable	> 20
Typical Bed Material	Variable	Sand	Gravel	Gravel, cobble	Cobble, boulder	Boulder	Bedrock	Variable
Typical Confinement	Unconfined	Unconfined	Unconfined	Variable	Confined	Confined	Confined	Confined
Reach Type	Response	Response	Response	Response	Transport	Transport	Transport	Source

SECTION 6: CHANNEL UNITS

References: Hawkins et al. 1993.

Equipment: Flagging or flags, Sharpie.

6.1 Identifying Channel Units

Channel units are relatively homogeneous lengths of stream channel with similar water surface gradient, substrate composition, flow characteristics, and bedform profile. The identification of channel units provides the context for the survey of fish habitat attributes and channel topography. Channel units are delineated according to a two-tiered hierarchical classification schema (11).

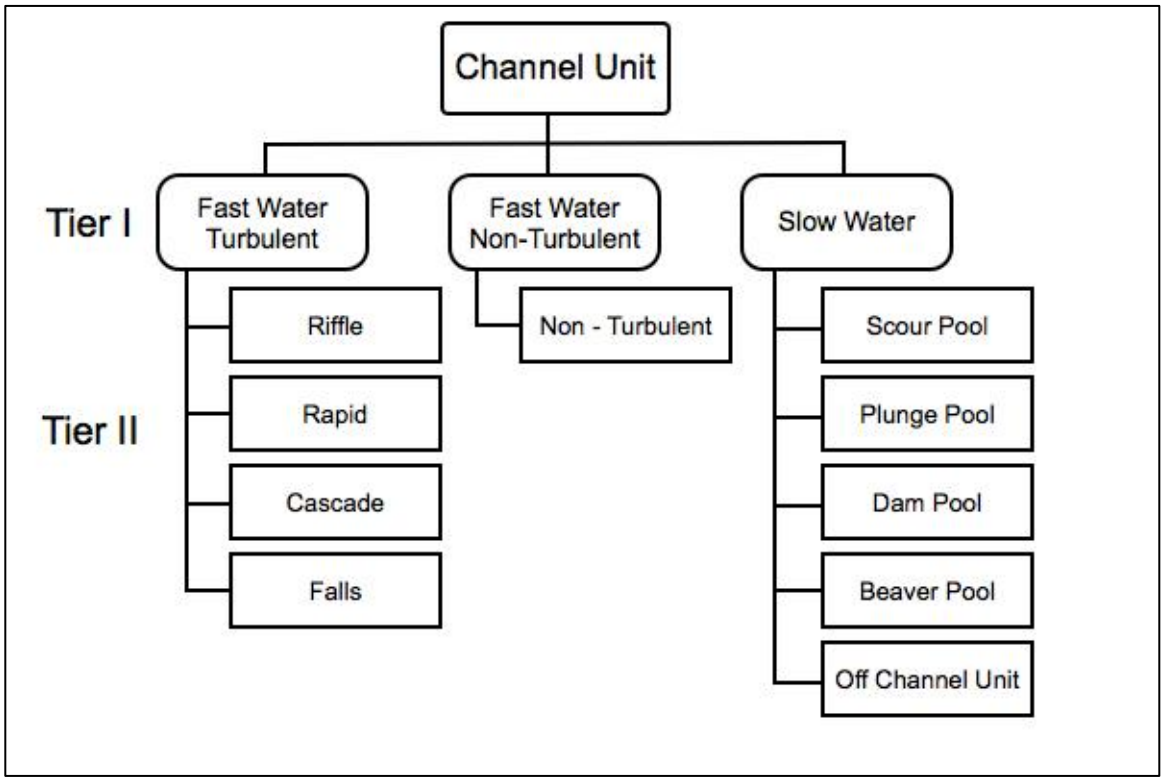

Figure 11. The hierarchical channel unit classification used by CHaMP which is a modification of the system developed by Hawkins et al. (1993) as reported in Bisson et al. (2006).

The following criteria should be used when considering sections of channel for delineation as unique channel units:

i. In general, channel units are at least as long as the wetted channel width.

ii. Slow water units separated by a small gradient drop should have a unit between them even if it is not as long as it is wide.

iii. In large streams (> width category 10) slow water unit types (scour pools and off-channel units) that provide significant fish habitat that are not as long as the wetted channel is wide should also be considered for unit delineation.

iv. Falls, steps, and plunge pools are rarely as long as the wetted channel width, but should be delineated as separate channel units due to their importance as fish habitat and areas of topographic complexity.

Step 1. Identify Tier I channel units.

The first tier of channel unit classification distinguishes between fast water turbulent, fast water non-turbulent, and slow water units. Use the following criteria, as well as the channel and flow characteristics listed in Table 10 to classify sections of channel into Tier I unit types.

Table 10. Criteria used to delineate Tier I channel units.

Habitat	Gradient	Substrate Composition	Flow Character	Bedform	Other Considerations
Fast water turbulent	Variable; > 1%	Generally have courser substrate	Fast turbulent flow identified by white-caps and noise	Topographic high points in the bed profile	
Fast water non-turbulent	Generally low; < 1%	Generally small cobble, gravels, and fine substrate	Smooth laminar flow	Generally broad laterally and lacking longitudinal concavity	Often the second consideration for pool and riffle channel units that do not meet the criteria
Slow water/pool	Low; < 1.0%	Variable; generally sorted or finer substrate or bedrock	Generally laminar flow	Pools are laterally and longitudinally concave, off channel units may be variable	Pools will always have concavity, off channel units are outside of the active channel

i. Fast Water Turbulent channel units are topographical high points in the bed profile that feature moderate to steep gradients, coarse substrate, and tend to have broken, white-capped waves and are "noisy". The bedform of these channel units may lack longitudinal or lateral concavity.

ii. Fast Water Non-Turbulent channel units are topographical high points in the bed profile that feature low gradients, variable substrate composition, and smooth laminar flow. Fast water non-turbulent units often have low slope similar to pools but are distinguished from pools by their overall homogeneity and lack of structure and concavity. These channel units are generally deeper than riffles with few major flow obstructions and low habitat complexity.

iii. Slow Water channel units are used to classify a variety of very low gradient pool and off channel unit types. These units are generally topographical low points in the channel profile, feature smooth laminar flow, have longitudinal concavity, and have fine or sorted

substrates. Slow water channel units that lack the properties of a pool are classified as fast water non-turbulent.

Step 2. Identify Tier II channel units.

Following delineation into Tier I unit types, channel units are further classified into the Tier II unit classification.

i. Fast Water Turbulent channel units are classified into riffles, rapids, cascades, and falls based on the criteria listed in Table 11. These units are separated from one another along a progression of increasing water surface gradients, dominant substrate size, flow turbulence, and bedform irregularity.

ii. Fast Water Non-Turbulent channel units are not further classified, and are simply Non-Turbulent channel units.

iii. Slow Water units are classified into scour pools, plunge pools, dammed pools, and beaver pools. Criteria for these unit types based on the pool forming processes are listed in Table 12.

Table 11. Criteria used to delineate Tier II channel unit classification from Tier I fast-water turbulent units.

Unit type	Gradient	Substrate Composition	Flow Character	Bedform
Riffle	Low; 0.5 - 4.0%	Submerged or partially submerged gravel and cobble	Fast, turbulent flow	Laterally broad and uniform
Rapid	Moderate; 4.0 - 8%	Boulders, boulder clusters, partial bars	Swift, turbulent flow, chutes and hydraulic jumps around boulders	Irregular cross-section, lacks concavity
Cascades	High; > 8.0%	Exposed boulders, boulder clusters, and partial bars organized into step-pool sequences	Swift, turbulent flow, chutes and hydraulic jumps, eddies; 30 - 80% whitewater	Irregular cross-section, lacks concavity, step-pool sequences
Falls	Very High	Bedrock, large boulders, and dam impoundments	Waterfall	Falls are abrupt short, high gradient drops in the channel topography.

Table 12. Criteria used to delineate Tier II channel unit classification from Tier I slow-water pool units.

Unit Type	Description
Scour Pool	Formed by channel scour from fluvial processes or flow impinging against a stream bank or partial obstruction (logs, root wad, bedrock, boulder, etc.). Channel bedform is laterally and longitudinally concave. Generally longer than wide and has more longitudinal concavity than lateral concavity.
Plunge Pool	Formed by channel scour as flow accelerates as it falls over a complete or nearly complete channel obstruction (logs, boulders, bedrock). Channel bedform is generally more laterally than longitudinally concave. The deepest part of the pool is generally at the head or plunge of the pool. Generally wider than long with more lateral concavity than longitudinal concavity. Plunges are sometimes associated with the fast water channel units falls or steps at the upstream end of the channel units.
Dam Pool	Formed by flow being impounded upstream of channel blockage (debris jam, rock landslide, etc….). Dam pools are associated with the fast water channel units' falls or steps at the downstream end of the unit.
Beaver Pool	Formed by flow being impounded upstream of a beaver dam. Beaver pools are associated with the fast water channel units' falls or steps at the downstream end of the unit.
Off Channel - OC	Pool-like units that are formed outside of the active channel. These units include large backwaters and alcoves. The thalweg never passes through off channel units.

SECTION 7: CHANNEL TOPOGRAPHIC SURVEY

Equipment: Total station (with tribrach and data logger), tripod, prism rod with topographic foot, backsight set up, tape measure, notebook, pencils, radios (2), flagging, umbrella or total station cover.

7.1 Setting up a Survey

Step 1. Choose a location for the first total station set up.

i. Optimal locations for the first setup location include:

   a. A vantage point that offers maximum line of sight to the channel for conducting the topographic survey, thereby minimizing the number of additional setups required for completing a survey.

   b. Line of sight to all three benchmarks.

ii. Control points refer to any temporarily monumented points that are occupied by and/or used to orient the total station during a survey.

   a. Control points can be temporarily monumented using a nail-and-whiskers placed in the ground or by making a small "X" on a stable rock. Control points in the wetted channel should be marked using an underwater marker.

   b. Control points are uniquely identified using the code "cp" and numbered sequentially in the order they are utilized during the survey (cp1, cp2, etc…..)

iii. After establishing an optimal location for the first setup point, turn on, level, and measure the height of the total station above the first occupied control point (cp1).

Step 2. Start a survey and establish the first setup location on the total station.

i. Open the template JOB file named **CHaMP_Survey_Template.** Save as and rename the JOB file using the following convention: sample frame ID_ site ID_surveydate_organization and total station ID.

   a. Example of a JOB file name: CBW55032_007395_07272011_TQ1.

ii. Navigate to the station setup menu of the total station instrument and initiate the setup routine. Choose to setup on a known point, and enter the appropriate code for the first set up point.

   a. The first occupied point will always be labeled "cp1".

   b. The first occupied point will always have the coordinates 3000 northing, 2000 easting, and 1000 elevation.

Step 3. Establish a backsight and orient the total station.

i. The orientation of the total station is established by shooting to a backsight. The first backsight used during the initial setup of the total station can be established over any of

the permanently monumented benchmarks or a newly established and temporarily marked control point.

ii. Setup and level a survey rod and prism over the control point used for back sighting.

iii. Set backsight circle to zero.

iv. Make sure that the total station is pointed at the backsight and send circle.

v. Measure backsight and resend circle.

vi. Check backsight by distance and record error in the field notebook. Make sure the error is not greater than .030 for horizontal error and .015 for vertical error. Repeat procedure if backsight error is unacceptable.

Step 4. Survey the benchmarks - bm1, bm2, and bm3.

i. Shoot a single point over each of the permanently monumented benchmarks at some point during the survey, preferably from the first occupied control point.

ii. Extra care should be taken to level the surveyor's rod and prism when shooting benchmark points, as these points will be used to reestablish the location and orientation of the total station during future surveys of the site.

7.2 Point Collection Methods

A three-dimensional digital elevation model (DEM) representing the topographic surface of the stream channel is created by connecting a series of points and lines that have X, Y, and Z coordinates. During the survey of a site, the job of the person operating the rod is to effectively and efficiently survey points and lines that will collectively represent the channel topography. The points selected by this person determine the ultimate utility of the site survey and should be done carefully. Lines are used to represent visible contours in the stream channel topography, and offer an efficient way to capture features including the thalwag, bankfull, toe of bank, and top of bank. Lines are also used to represent the water's edge and the survey extent. Topographic points are used to capture additional changes in relief that are not captured by lines. Use the following descriptions of point and line types to conduct an efficient survey of the stream's topography throughout the site. The codes for each of the point and line types described are listed in Table 13.

Table 13. List of codes used to identify points and lines in the topographic survey.

Code	Name	Type	Description
tp	Topography	Points	Points describing the channel topography.
sx	Survey extent	Polylines	Describes the perimeter of the survey.
tb	Top of bank	Polylines	Lines describing the top of bank elevation, and may be used to define the perimeter of the survey in unconfined reaches.
bf	Bankfull	Polylines and Points	Lines and points describing the bankfull elevation.
lw	Left edge water	Polylines	Lines describing the elevation of the left wetted edge of the channel.
rw	Right edge water	Polylines	Lines describing the elevation of the right wetted edge of the channel.
br	Bar	Points	Points describing the perimeter of mid-channel bars.
wg	Thalweg	Polylines and Points	Line describing the longitudinal thalweg profile.
bl	Breakline	Polylines	Other gradient breaklines as needed.
to	Toe of bank	Polylines	Lines describing the toe of bank, or the line separating the active channel from the beginning of the bank.
u#	Channel unit	Points	Points describing channel unit perimeter within the wetted channel.
cp#	Control point	Points	Temporary control points used as station or backsight set up.
bm#	Benchmark	Points	Monumented benchmarks.

Step 1: Survey extent - sx

i. Survey extent lines are used to represent the bottom and top cross-sections of the survey (transect 1 and 21; Figure 12) and may be used to define the lateral extent of the topographic survey.

   a. These lines should contain enough points to accurately represent the cross-sectional profile of the channel and provide a clean start and finish for the survey.

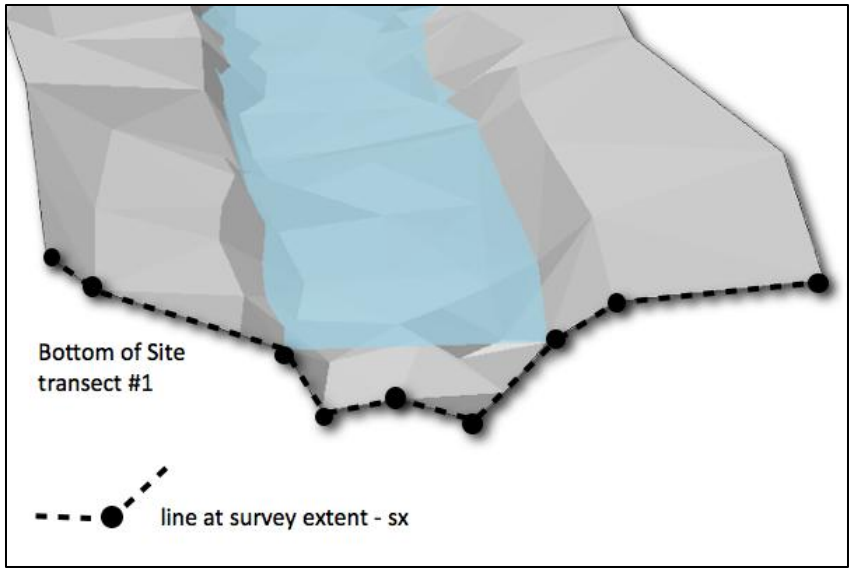

Figure 12. Channel showing proper use of the survey extent line at bottom of site.

ii. Survey extent lines running parallel with the stream channel should be used to define the lateral extent of the survey when the margins of the channel lack any clear flat floodplain-like bank feature (e.g., top of bank), usually at constrained sites.

   a. They should also be used to define the survey extent beyond the top of bank when it is possible to take these points and it is likely that the top of bank may erode in future years.

   b. When used to characterize the lateral margins of the survey, attempt to make the survey extent line represent a consistent elevation.

Step 2: Top and toe of bank features – tb, to

i. Top of bank lines are used to accurately represent sharp gradient breaks that occur where steep streambanks transition to flat floodplain like features (Figure 13).

   a. In general, top of bank lines run parallel to the channel; however, these lines may run perpendicular to the channel on more complex banks.

ii. Toe of bank lines are used to accurately represent sharp gradient breaks that occur where steep streambanks transition to a relatively flat streambed (bed meets banks).

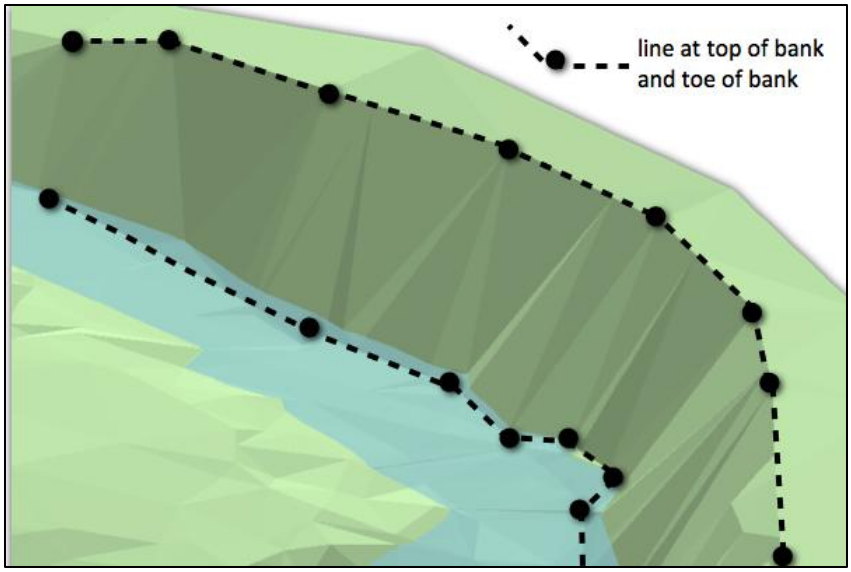

Figure 13. Channel view showing proper use of toe of bank and top of bank lines.

Step 3: Bankfull elevation - bf

i. Survey bank features that are indicative of the bankfull elevation. Bankfull features can be surveyed using points or lines (Figure 144).

   a. Use lines to survey bankfull features along consistent gradient breaks. These lines should be surveyed where streambanks transition to flat floodplain like bank features that are consistent with the bankfull elevation, and anywhere that the bankfull elevation represents a gradient line in the landscape.

   b. Use points to survey bankfull features when it is identifiable but do not represent a gradient line in the landscape.

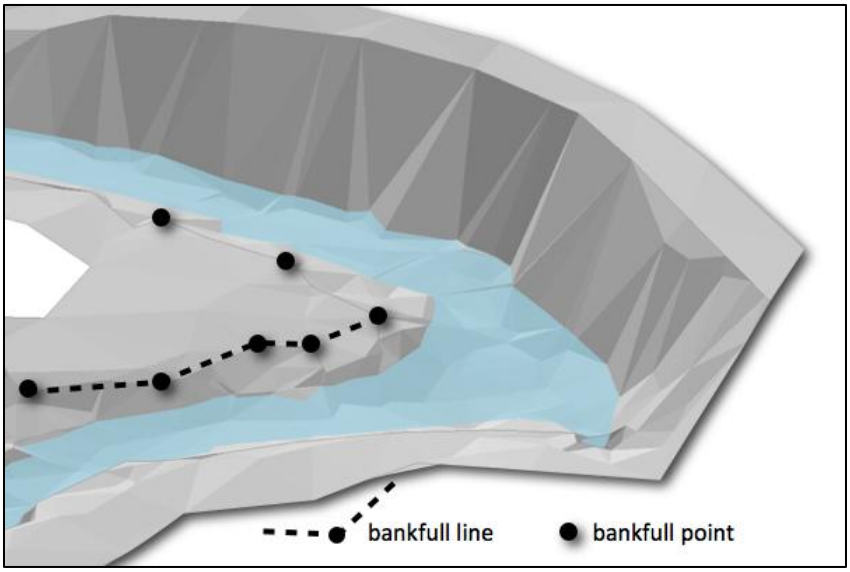

Figure 14. Channel view of lines and points representing the bankfull elevation.

ii. Take enough bankfull points and/or lines to represent the bankfull elevation throughout the length of the site. A minimum of 20 bankfull points should be taken at locations that have good bankfull indicators and represent the site.

Step 4: Channel thalweg - wg

i. Collect points and lines at inflection points that accurately represent the thalweg profile (Figure 15). Take a minimum of 20 points throughout the site.

ii. Use lines to survey the thalweg profile on sections of channel when it is identifiable as a line running roughly parallel to the channel. Thalweg lines should extend the distance of the site in very small streams (usually 6 meters wide or less) and contain enough points to capture inflection points in the thalweg (Figure 16).

iii. In steep streams dominated by rapids, cascades, and in some plane bed streams the thalweg profile will often be discontinuous. In this situation, survey the thalweg profile using a series of points.

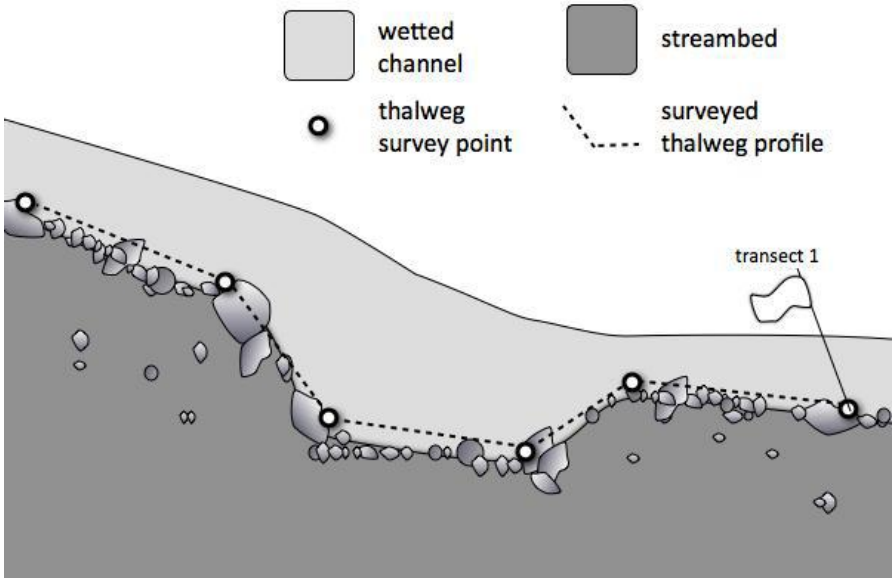

Figure 15. Longitudinal view of the stream channel showing placement of thalweg survey points that effectively capture the thalweg profile.

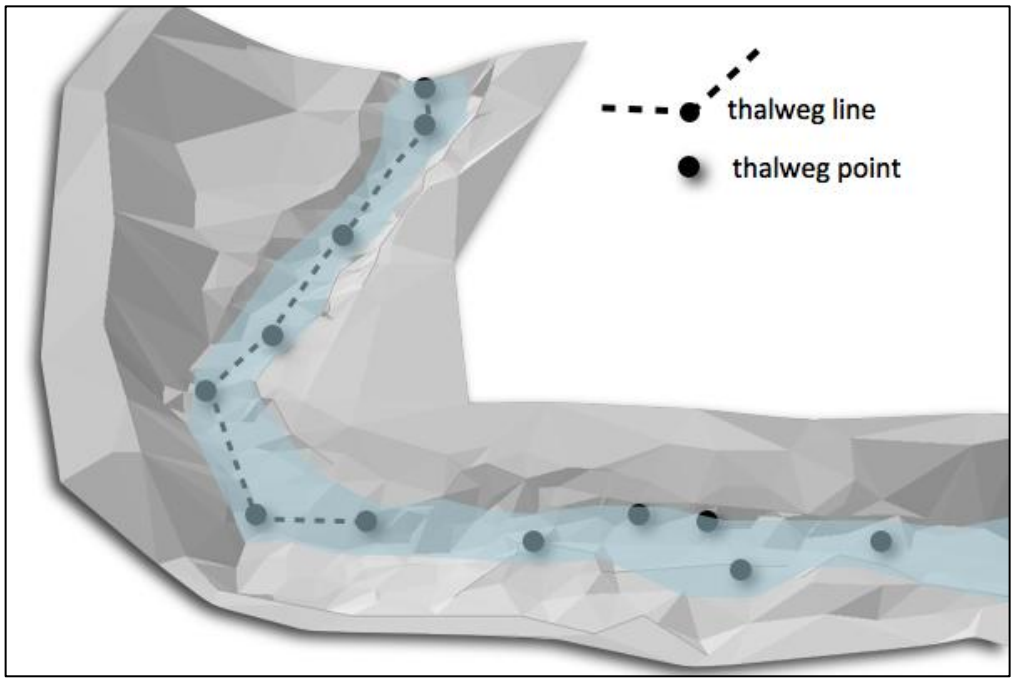

Figure 16. Channel view of lines and points representing the thalweg.

Step 5: Left and right wetted edge of the channel– lw, rw

i. Use a series of lines or points to accurately represent the planform and elevation of the wetted channel.

ii. In streams that are flat and straight, fewer points will be needed in each line to adequately represent the wetted channel. Add more points to edge of water lines for streams that feature a complex planform and water surface elevation.

Step 6: Channel unit perimeter – u#

i. Determine the channel unit perimeter. Perimeter vertices points are a rough representation of the planform view of channel units. Channel units may be adequately represented by at least three vertices and up to 8 vertices in the largest and most complex channel units.

ii. For each channel vertices point, use a code that is consistent with the channel unit attribute data being recorded (i.e., u1, u2, etc.).

iii. In general, points describing the perimeter of channel units are surveyed at the edge of water (Figure 17). However, complex units may require additional channel unit vertices located in the wetted channel.

   a. It is good practice to capture the tail crest of a slow water channel unit with a channel unit vertices point.

   b. In areas where multiple units converge in the wetted channel it may be necessary to survey additional perimeter points that represent the boundaries of each unit.

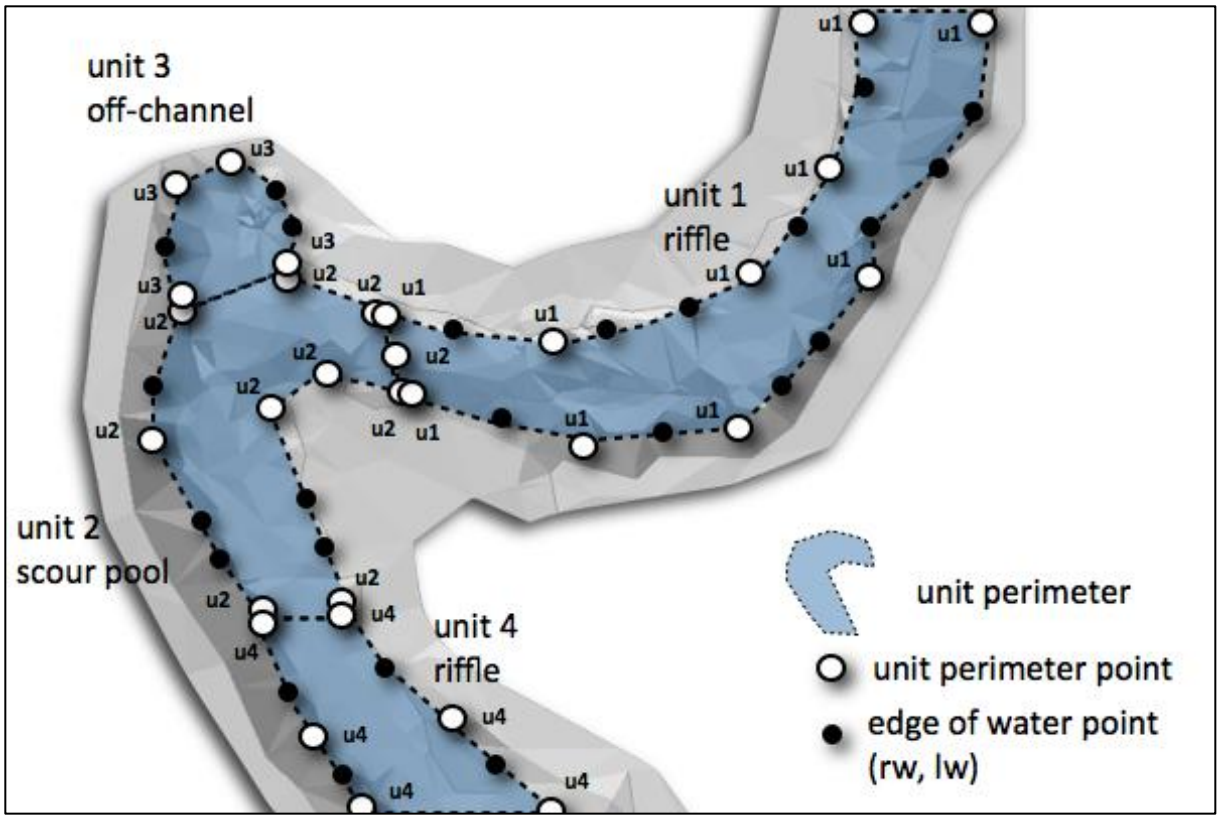

Figure 17. Channel view showing channel unit vertices perimeter points and edge of water points.

Step 7: Additional breaklines - bl

i. Breaklines are used to survey lines in the landscape along any consistent gradient breaks that are not represented by other line codes. These lines are important to efficiently and accurately represent the surface topography of the stream channel.

ii. Breaklines may run parallel or perpendicular to the channel, and are often used to represent obvious breaks in the landscape or artificial structures and restoration at a site (bridge columns, cross-vanes, etc.).

Step 8: Channel topographic points – tp

i. Use topographic points to represent topographic features that do not follow a consistent line.

ii. Topographic points can be sparse in areas that are topographically uniform, and should be dense in areas that are topographically complex.

iii. Always capture the deepest portion of the stream, tail crest of pools, and maximum depth of pools using topographic points.

Step 9: Mid-channel bars (br)

i. Survey enough points at the wetted edge of mid-channel bars to provide a general representation of their wetted perimeter.

ii. Place topographic points (tp) on mid-channel bars that adequately represent their topography.

Step 10: Side channels and islands (br)

i. Qualifying non-primary channels (16% - 49% of total flow) will be surveyed using the same set of procedures as the main channel.

   a. It is not necessary to label thalweg points in side channels; however, the deepest points should be surveyed using topographic (tp) points.

   b. If the island separating the side channel is not as long as the site width category, then treat the island as a bar and do not designate a separate side channel.

ii. Island perimeters should be represented by using the (br) code. Collect bankfull and, topographic points, and use either top of bank or break lines to adequately represent the topography of the island bankfull by top of bank or whichever is the most appropriate.

7.3 Moving the Total Station.

Step 1. After surveying from the first control point, identify the next occupied control point and prepare to move.

i. Move to this control point and enter the set up routine.

   a. Select your occupied point. Input height of instrument.

   b. Select backsight point and choose a point to backsight to. This may either be your last occupied point or a control point occupied by the backsight prism visible from multiple control points.

   c. Set backsight circle to zero and send circle.

   d. Check backsight by distance and record error in notebook.

7.4 Backsight checks

Step 1. It is good practice to check your backsight during the survey. A backsight can refer to the last occupied point, a control point, or a point where a backsight prism is set up at a location visible from multiple control points (a hill or other vantage point). Check backsight by distance and record the error.

SECTION 8: CHANNEL UNIT LEVEL ATTRIBUTES

8.1 Channel Segment Number

Reference: Modified from Moore et al. (2002)

The channel segment number is used to uniquely identify side channels containing between 16% and 49% of the flow. A qualifying side channel is a channel separated from the main channel by an island that is above the bankfull elevation for a distance equal to or greater than the site width category. The main channel is always channel segment 1. The first side channel encountered is channel segment 2, the next side channel is channel segment 3, and so on (Figure 18). Side channels separated by an island that are not as long as the distance of the site width category are not uniquely identified by a channel segment number. The primary channel segment (the main channel segment containing the highest percentage of stream flow throughout the site) will always have a segment number of 1, and its start will always be the downstream boundary of the site.

i. Assign each side channel to a channel segment.

ii. Record the percent flow for each segment number.

iii. If a channel segment contains greater than 16% of the total flow, delineate channel units in the same manner as the main channel.

iv. Side channels containing less than 16% of the total flow are not mapped as part of the topographic survey. Record the estimated length and average width of the side channel.

v. If a qualifying side channel is present at the beginning of the survey begin surveying the side channel in line with the bottom of site transect

vi. If a qualifying side channel continues above the site the side channel "ends" in line with the top of site transect.

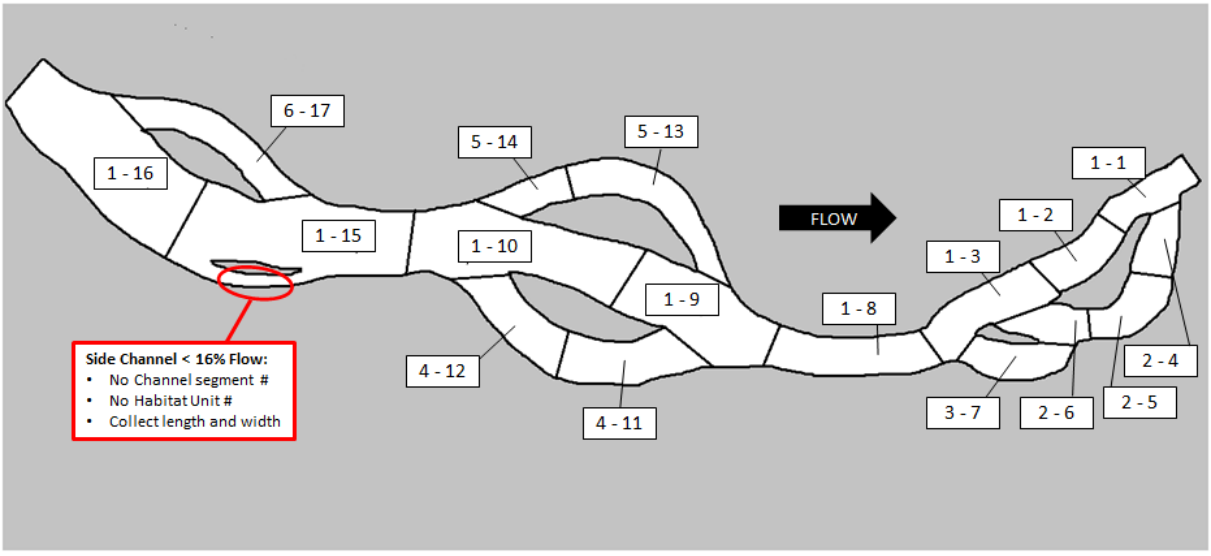

Figure 18. Example of how stream segments and channel units may be ordered.

8.2 Fish Cover Elements

References: Peck et al. 2001.

i. Visually estimate the percent of the wetted area within the channel unit that is covered by each of the fish cover elements listed in Table 14. Round measurements to the nearest 5% and record 1% to denote minimal presence.

ii. Use a depth rod to measure the deepest part of undercut banks to help estimate the percentage of channel unit cover provided by undercuts.

Table 14. Definitions of fish cover elements evaluated at each channel unit.

Cover Element	Cover Element Definition
Large woody debris (>0.3 m diameter)	Larger pieces of wood that can influence cover and stream morphology.
Overhanging vegetation and live trees or roots	Area of the channel effectively covered by vegetation within 1.0vertical meter of the surface water. Include live trees and roots.
Undercut banks	Area of the wetted channel effectively covered by undercut banks. A channel is rarely covered more than 10% by undercut banks.
Artificial structures	Area of the channel covered by artificial structures including riprap, structures placed in the channel for fish restoration, materials discarded in the stream (tires, old cars, etc.), or those placed in the stream for diversions, impoundments, channel stabilization, or other purposes.
Total NO fish cover	Area that does NOT provide fish cover by any of the above elements.

8.3 Ocular Channel Unit Substrate Composition

Visually estimate the percent distribution of substrate material for each channel unit based on the substrate classes listed in Table 15.

i. Estimate the distribution of substrate classes relative to the total wetted area of the channel unit rounding each class to nearest 5% for a total of 100%. Use 1% to denote minimal presence.

Table 15. Ocular channel unit substrate composition types and size classes.

Substrate Type	Size class (mm)	Description
Bedrock	> 4000	Surface rock bigger than a car
Boulders	> 250 to 4000	Basketball to car size
Cobbles	> 64 to 250	Tennis ball to basketball size
Coarse gravel	> 16 to 64	Marble to tennis ball size
Fine gravel	> 2 to 16	Small pebble to marble size
Sand	> 0.06 to 2	Smaller than ladybug size, but visible as particles and gritty between fingers
Fines	< 0.06	Silt, clay, muck and not gritty between fingers

8.4 Particle Size Distribution and Particle Embeddedness

Equipment: Ruler, pencil/field form, tape recorder (optional but handy), graduated cuff.

Twenty one particles will be selected and measured at each of 10 cross-sections for a total of 210 particles per site.

Step 1. Identify sample locations

i. Identify riffle and non-turbulent channel units within the primary channel and evenly distribute 10 cross-sections where particles will be selected and measured.
    a. Cross-sections should be no closer than $1/100^{th}$ of the site length apart.
    b. If 10 cross-sections do not fit in the riffle and non-turbulent habitats, distribute the remainder cross-sections in rapid channel units. If no rapids exist or are fully sampled, place additional cross-sections in cascade channel units.

ii. Once cross-sections are located at a site, estimate the bankfull width and divide it by 12 to obtain the segment distance between points.
    a. From the bankfull point, move one segment distance across the channel and select the first particle. Measure the particle according to the instructions in Step 2.
    b. From this point, move upstream a segment distance 60° to the cross-section and select the next particle to measure.
    c. Continue 60° downstream for one segment distance back to the substrate cross-section and select the next particle.
    d. Next move downstream one segment distance 60° to the cross-section.

e. Repeat this movement zigzagging up and down from the cross-section toward the other bank, ending one segment from the opposite bankfull (Figure 19). A total of 21 particles will be collected for assessment along each substrate transect.

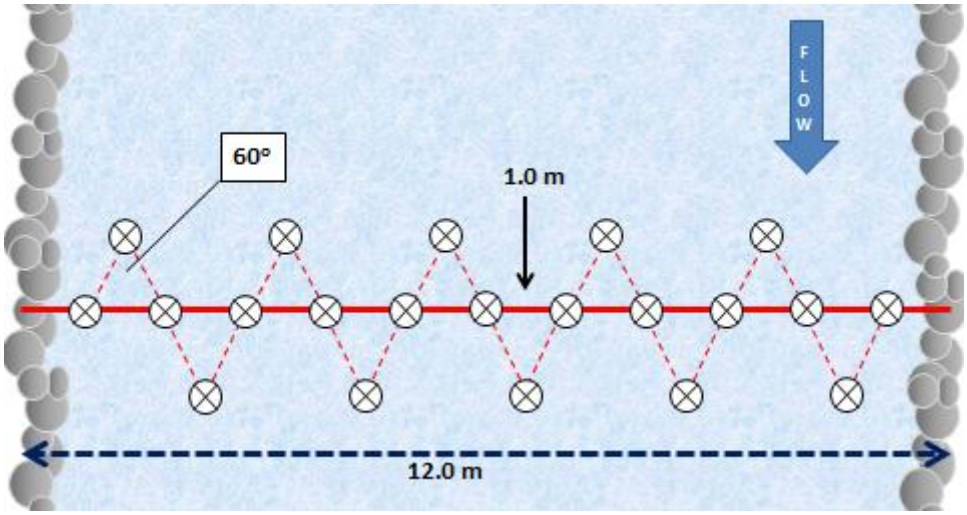

Figure 19. Particle size distribution sample locations (circle with crosshairs) at a 12 m bankfull width cross-section. Segment distance is 1 m.

Step 2. Sample particles

If working alone, we recommend using a PVC cuff and attached pencil to write down the particle size and embeddedness. A voice recorder can be used as well.

i. Select particles at the sample locations by extending your finger directly down and looking away until it comes into contact with the first substrate particle.

ii. Measure the diameter of each particle along the B-axis. Sand particles (smaller than 2 mm) are recorded as "2". Fines particles (smaller than 0.6 mm) are recorded as "1". Fines particles are smooth when rubbed between the thumb and fingers, whereas sand rolls between the fingers.

Step 3. Particle embeddedness (cobbles only).

Embeddedness is the percentage of a cobbles' surface that is surrounded by fine sediments (sand and/or fines, as described above) on the stream bottom.

i. Assess the embeddedness of all cobble size particles (65 mm – 250 mm) that are selected during particle size distribution sampling.

ii. Before removing the cobble from the streambed for measurement, estimate the embeddedness before disturbing them, either visually or by touch.

iii. Stain lines on cobble can be a good indicator of embeddedness. Confirm the embeddedness estimate by picking up the cobble and estimate the percentage of the cobble volume below the stain line.

8.5 Pool Tail Fines

References: Heitke et al. 2008
Equipment: fines grid, underwater sighting tube or snorkel and mask.

Quantify the percentage of fine sediments on the pool tail surface of primary scour and plunge pools.

Step 1. Identify measurement locations

i. Collect measurements in the first ten primary scour and plunge pools of each site beginning at the downstream end. Do not sample in dam pools.

ii. Sample within the wetted area of the channel. Do not overlap fines grid placements (i.e., if only two placements will fit fully in the wetted channel, then only take two measurements at that pool tail).

Step 2. Sample surface fines

i. Assess surface fines using a 14 x 14 inch grid with 49 evenly distributed intersections. Include the top right corner of the grid for a total of 50 intersections.

ii. Take 3 measurements per pool.

   a. Place the center of the grid at 25, 50, and 75% of the distance across the wetted channel, making sure the grid is parallel to and following the shape of the pool tail crest (Figure 20).

   b. The bottom edge of the grid should be upstream from the pool tail crest a distance equal to 10% of the pool's length or one meter, whichever is less.

   c. If a portion of the fines grid lands on substrate 512 mm or larger in size (b-axis), record the intersections affected as non-measurable intersections.

iii. Record the number of intersections that are underlain with fine sediment or sand < 2 mm in diameter at the b-axis.

iv. Record the number of intersections that are underlain with fine sediment < 6 mm in diameter at the b-axis.

v. Aquatic vegetation, organic debris, roots, or wood may be covering the substrate. First attempt to identify the particle size under each intersection. If this is not possible, then record the number of non-measurable intersections.

vi. Make sure you are entering data in the correct channel unit number in the data logger.

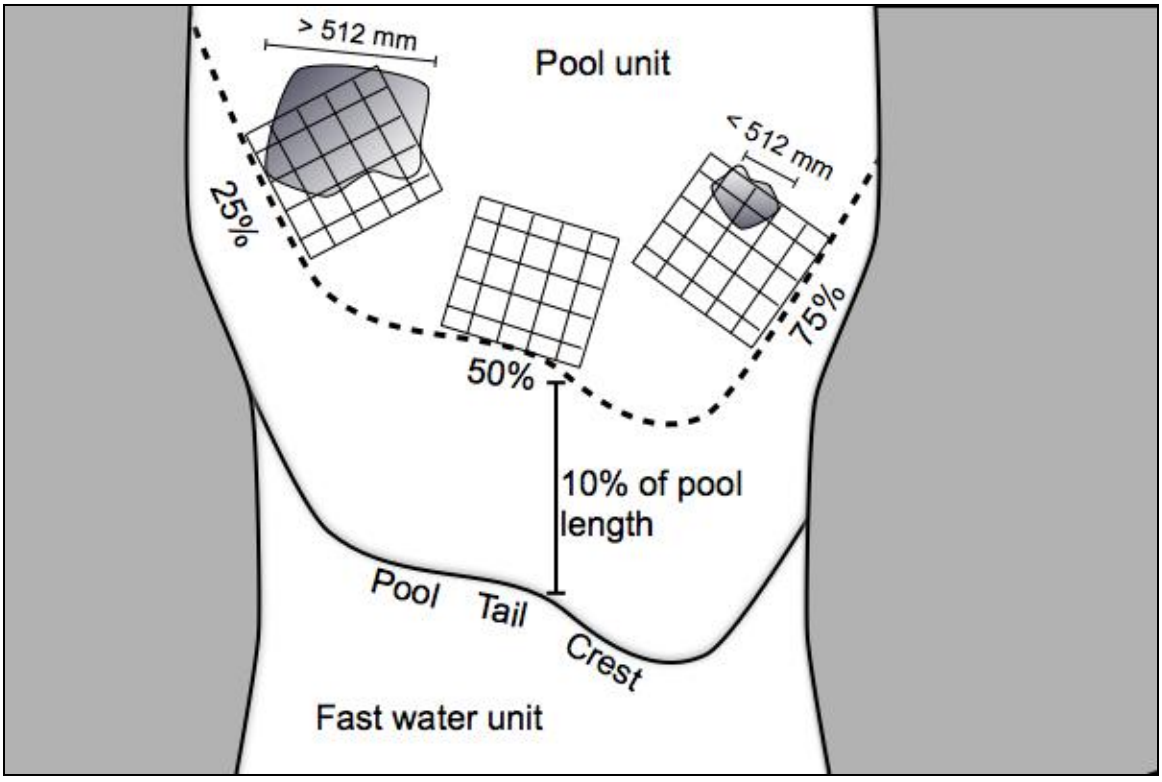

Figure 20. Location and orientation of pool tail fines grids relative to the pool tail crest. In this figure, all intersections of the fines grid at the 50% and 75% placements will be counted and recorded. For the 25% placement, the intersections of the fines grid that land on the boulder (substrate ≥512mm) will be recorded as non-measurable.

8.6 Large Woody Debris (LWD)

All LWD pieces and jams occurring within the bankfull channel are enumerated for each channel unit. LWD outside the wetted channel are enumerated as dry wood for the nearest channel unit.

Step 1. LWD pieces.

i. Qualifying LWD must have a diameter of at least 10 cm and a length of at least one meter and be at least partially within the bankfull channel.

ii. If a piece of LWD is present in two or more channel units, assign it to the unit in which it provides the majority of fish cover.

iii. If a piece of LWD falls outside the wetted channel but within the bankfull channel, assign it as "dry" for the nearest channel unit.

iv. Wood embedded in the stream bank is counted if the exposed portion meets the minimum length and width requirements. Estimate the length and width of the exposed portion of the main stem.

v. Do not count LWD if only the roots extend within the bankfull channel, and do not include roots in the length.

vi. Tally the number of LWD pieces for each unit according to the size classes detailed in Table 16.

Table 16. Size classes used to categorize large woody debris.

Diameter classes	Length classes
• 10 cm to 15 cm	• 1 m to 3 m
• >15 cm to 30 cm	• > 3 m to 6 m
• > 30 cm	• > 6 m

Step 2. LWD jams.

i. Five or more qualifying pieces of LWD that touch each other are considered a jam. Tally the number of qualifying pieces of LWD in each jam and record the unit number the jam occurs in. Jams in the dry channel will be associated with the nearest channel unit.

SECTION 9: SITE LEVEL ATTRIBUTES

9.1 Site Map

The site map will be used in conjunction with site photos, UTM coordinates, and verbal descriptions to assist a crew in relocating a site in the future. Site maps (Figure 21) are important to help characterize a site and relocate benchmarks, control points, site monuments, and temperature loggers. It is essential that the artist takes his/her time to accurately draw to scale the unique and significant features of each site. Attempt to reference the location of Tier 1 channel units and side channels. Also indicate the presence of anthropogenic influence such as logging, cattle grazing, dikes, etc.

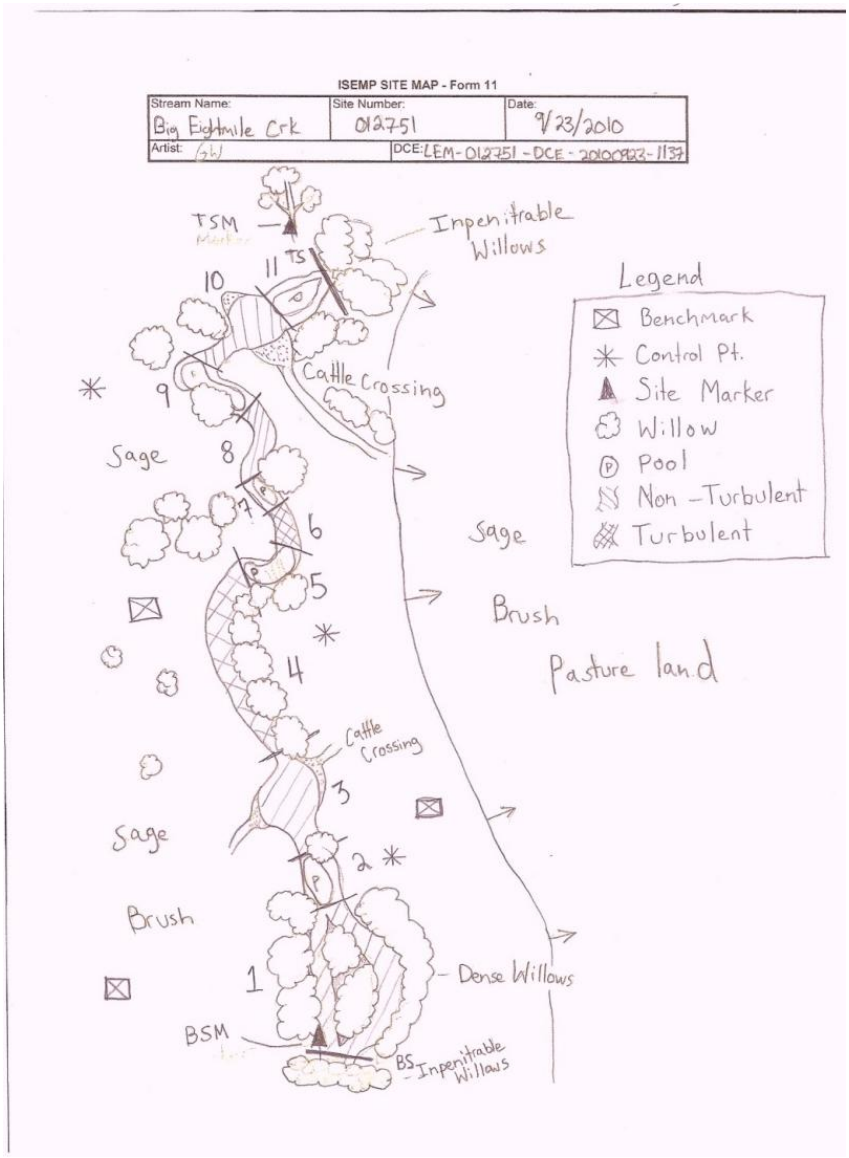

Figure 21. An example of a site map used to help characterize a site's unique and significant features.

Table 17 identifies features that may be included in each site map along with some commonly used symbols.

Table 17. Site map features and commonly used symbols.

Features (Labels)	Symbol	Features	Symbol
Benchmarks (BM1-BM3)	⊠	Road	
Site Monuments (Mon1-*n*)	☆	Fence	
Bottom and Top Site Markers (BSM,TSM)	▲	Coniferous	
Control Points (CP1-*n*)	✳	Deciduous	
Stream Temp Logger location (STemp)	Labeled	Herbaceous	
Air Temp Logger Location (AirT)	Labeled	Stump	
North Arrow	N →	Large Wood	
Flow Direction	Flow →	Wood Jam	
Pools	P	Cut Bank	
Bars		Upslope Area	

9.2 Photos

Equipment: Camera, depth rod.

Photos are taken from the center of the bankfull channel at transects 1, 6, 11, 16, and 21. Photos are used to help characterize and visually assess site conditions and are essential when relocating sample sites for future sampling.

Follow these steps when taking photographs:

i. Record the ID number of the memory card used in the camera.

ii. Always take the data collection event photo first. Record the stream name, DCE number, and date on a blank piece of paper and take a photo of the paper. This should be the first photo in the series of site photos.

iii. Lighting is critical for quality pictures. Always attempt to take photos during optimal light conditions. Avoid photographs where much of the site is shaded and/or only partially illuminated. To ensure quality photos, take photos when the sun is at a low angle in the morning or evening.

iv. Position the camera 1.5 m from the ground (use a depth rod as a guide). Ensure that photos are at least 0.5 m above the wetted surface if deeper than 1.5 m.

v. Take photos from the center of the channel at flag locations 1, 6, 11, 16, and 21. Begin with the center upstream shot (CU), then the center left bank (CL), center downstream (CD), and center right bank (CR) shots. Record the camera number, photo number, transect number, and photo orientation for each photo.

vi. Take photos of both the top and bottom of site monuments. Record the photo number.

9.3 Solar Input

Equipment: Camera, compass, solar path finder

Solar pathfinder photos are taken from the center of the bankfull channel at transects 1, 6, 11, 16, and 21. Take photos at the beginning of the day to ensure that glare from the sun does not affect the quality of the photo.

i. All solar pathfinder measurements will be collected in the center of the bankfull channel.

ii. Holding the solar path finder 30 cm above the wetted or dry surface, align the solar path finder compass to magnetic north and ensure that the level indicator is centered.

iii. Hold the camera directly above the solar pathfinder and ensure that the outer rim of the solar pathfinder fits within the photo. With the flash off, take the photo. Review the photo to ensure that the outline of the canopy is visible. If not the photo does not show the canopy well, delete the photo and reshoot. Block the sun's glare with a stadia rod or other easily recognized object if necessary to capture a useable photo.

iv. Measure the orientation of the main channel perpendicular to the transect using a compass.

9.4 Riparian Structure

References: Modified protocol from Kaufmann et al. (1999) and Peck et al. (2001)

Riparian assessments are collected on both banks at transects 1, 6, 11, 16, and 21 by visually assessing the riparian structure and composition at these transect. For all estimates be sure to include only living vegetation. Discount snags, dead grass, or other dead vegetation.

i. Facing the bank, estimate a 5 m distance upstream and downstream from the transect (10m total length). Estimate a distance of 10 m back into the riparian vegetation from the bankfull stage. Within this 10 m by 10 m square, visually divide the riparian vegetation into three vertical layers: a canopy layer (>5 m), an understory (0.5 to 5 m), and a ground cover layer (<0.5 m).

ii. **Canopy Layer:** Determine and record the dominant vegetation type for the canopy layer and the understory as deciduous (D), coniferous (C), broadleaf evergreen (B), mixed (M), or none (N). Record the appropriate vegetation type in the visual riparian estimate field. Consider the layer "mixed" if two or more vegetation types are present. Determine and record separately the aerial cover class of 1) large trees (>0.3 m diameter at breast height (DBH)), and 2) small trees (<0.3 m DBH). Estimate the percent aerial cover as the amount of shadow that would be cast on the ground below it by a particular layer alone if the sun were directly overhead.

iii. **Understory Layer:** Determine and record the dominant vegetation type for the understory layer as done for the canopy layer. Determine the percent aerial cover separately for 1) woody shrubs and seedlings (including canopy tree stems), and 2) non-woody herbs, forbs, and grasses. Total coverage does not need to equal 100% as open spaces are typically present.

iv. **Ground Cover:** Examine the ground cover (ground level to 0.5 m). Determine the percent of the ground covered by 1) woody shrubs and saplings, 2) non-woody herbs/forbs/grasses, or 3) barren, bare dirt, or duff. Check that the total of the cover classes add up to, but do not exceed, 100%.

9.5 Water Temperature

References: Isaak et al. 2010

Equipment: Onset TidbiT, PVC housing material/wires, epoxy, rubber gloves, underwater viewer

Step 1. Identify sensor placement location

i. 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.
    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 floods.
        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. 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 wire.
    a. Optimal placement locations for wire 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.

iii. 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, EPE, and the date and time installed.

d. Record the stream bank that sensor is nearest to and the distance from that stream bank. If wire is attached to a tree on bank, record the distance from bank as 0.

e. Record the placement location as Boulder if sensor is attached directly to a rock, boulder, or other structure. Record as 'Wire' if the sensor is connected to a wire.

f. Take a photo of sensor location. Include enough of the surrounding environment in the photo to relocate the sensor. Record photo number.

g. Write a detailed description of the sensor location in the notes 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 reach on river right.

h. Note sensor location on site map.

9.6 Air Temperature

Reference: Holden 2010

Equipment: LogTag temperature recorder, housing material

Step 1. Identify sensor placement location

i. Air temperature sensors will only be placed at annual sites.

ii. At the site, search for a large diameter tree with an open area (enough room to place housing unit) on the north-facing side. The tree should be distinct enough to be identified on subsequent site visits. If many options exist, select a tree nearest to the site bottom.

a. Optimal sensor placement locations should be:

i. At least 2 m above the ground.

ii. Discrete, but not too hidden or sheltered to block air flow to the sensor.

iii. Located in riparian areas approximately 10-30 m from stream and no more than 20 m in elevation above the valley bottom (on hillside).

iii. If a suitable location at the site cannot be found, extend your search no more than 100 m upstream or downstream of a site. Do not deploy an air temperature logger at a site

lacking a suitable location. Record the rationale for not placing the air temperature sensor.

Step 2. Install and record sensor location details

i. After identifying a suitable sensor placement location:

a. Record sensor serial number.

b. Install housing units with sensor, activate sensor.

c. Take a GPS reading. Record UTM coordinates, EPE, and the date and time installed.

d. Record the stream bank that sensor is nearest to and the distance from that stream bank.

e. Record which monument is closest to air sensor along with the estimated distance and bearing from the monument. Record the date and time installed.

f. Take a photo of sensor location. Include enough of the surrounding environment in the photo to relocate the sensor. Record photo number.

g. Write a detailed description of the sensor location in the notes field.

h. Note air sensor location on site map.

9.7 Stream Discharge

Reference: Peck et al. 2001

Equipment: Velocity meter, tape measure, pins, depth rod.

Because velocity and depth typically vary greatly across a stream, accuracy in field measurements is achieved by measuring the mean velocity and flow cross-sectional area of many increments across a channel (Figure 22). Each increment gives a subtotal of the stream discharge, and the whole is calculated as the sum of these parts. Discharge measurements are made ***at only one*** *carefully chosen channel cross-section.* It is important to choose a channel cross-section that is as much like a canal as possible. A glide area with a U-shaped channel cross-section that is free of obstructions provides the best conditions for measuring discharge. You may remove rocks and other obstructions to improve the cross-section before any measurements are made.

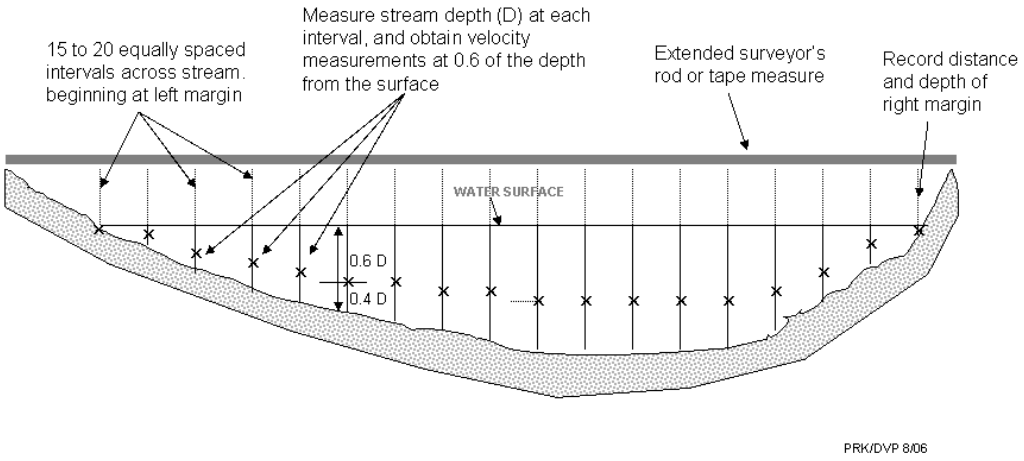

Figure 22. Cross-section of a streambed showing location of discharge measurements.

Step 1. Procedure for determining stream discharge

i. Locate a cross-section of the stream channel for discharge determination that has most of the following qualities:
   a. Segment of stream above and below the selected cross-section is straight.
   b. Depths are mostly greater than 15 cm, and velocities are mostly greater than 0.15 m/s. Do not measure discharge in a pool.
   c. "U" shaped, with a uniform streambed free of large boulders, woody debris or brush, and dense aquatic vegetation.
   d. Flow is relatively uniform, with no eddies, backwaters, or excessive turbulence.

ii. Stretch and secure a meter tape across the stream perpendicular to flow, with the "zero" end on the left bank.

iii. Check to ensure the velocity meter is functioning properly and calibrated.

iv. Divide the total wetted stream width into 15 to 20 equally sized intervals. To determine interval width, divide the width by 20 and round up to a convenient number. Intervals should not be less than 10 cm wide, even if this results in less than 15 intervals. Take the first measurement at one interval out from the left bank.

v. Stand downstream of the velocity meter when taking measurements.

vi. Place a graduated depth rod in the stream at the interval point and record the water depth indicated.

vii. Slide the velocity probe down the depth rod so that the bottom of the rod is at 0.6 of the measured depth below the surface of the water. Face the probe upstream at a right angle to the cross-section, even if local flow eddies hit at oblique angles to the cross-section.

viii. Wait 20 seconds to allow the meter to equilibrate, and then measure. Use the average velocity reading on the meter and hold in place for 40 second. Record the velocity.

ix. Move to the next interval point and repeat steps vi through viii. Continue until depth and velocity measurements have been recorded for all intervals.

9.8 Water Chemistry

References: Heitke et al. 2008

Equipment: Conductivity meter, alkalinity test kit.

Measure conductivity and alkalinity at the upstream end of each site above the last transect flag to ensure that sediment has not been disturbed. Take each measurement in flowing water near the center of the channel. If a beaver dam pool exists at the top of site, measure water chemistry downstream of dam, even if it is within the site.

Step 1. Measure conductivity.

i. Measure conductivity and record in micro-Siemens per centimeter (µs/cm).

ii. Check the meter for accuracy regularly. Recalibrate the conductivity meter according to the manufacture's suggestions.

Step 2. Measure alkalinity.

i. Measure and record Phenolphthalein (P) Alkalinity to the nearest 4 parts per million (ppm).

ii. Measure and record Total Alkalinity to the nearest 4 ppm.

9.9 Macroinvertebrate Drift

Equipment: Drift nets (500 µm mesh, mouth = 40 cm X 20 cm, mesh sieve less than or equal to 500 µm), forceps/tweezers, plastic bucket, spray bottle, plastic wash tub, sample jars, 95% ethanol, sample jar labels, packaging tape, 1 m ½" rebar, hammer or mallet, sharpies and pencils.

Collect a quantitative sample that describes the abundance and composition of macroinvertebrates actively drifting in the water column and at the surface of the stream.

Step 1. Determine the drift sampling location.

i. Two drift samples will be collected at each site.

ii. Drift nets should always be deployed above the site to avoid unintentional introduction of macroinvertebrates to the drift by disturbance of the stream substrate and riparian vegetation.

iii. Drift nets should be set in channel locations with moderate velocities and relatively laminar flow. Drift nets become difficult to maintain and often clog at extremely high

flow and inefficient at extremely low flow. Velocities ranging between 0.3 and 0.6 m/s are ideal for drift sample collections.

iv. Two drift nets should be deployed along a cross-section of the stream channel.

   a. Orient drift nets perpendicular to and facing the stream flow.

   b. In small streams, place nets at channel locations where they will capture a large portion of the total discharge (thalweg).

   c. The bottom of the net mouth should be suspended 2 cm above the streambed to deter invertebrates from crawling into the net mouth. The top of the net mouth should always extend above the stream surface (Figure 233).

Figure 23. View of active drift nets looking upstream.

Step 2. Drift sampling method.

i. Each drift net will be anchored in the stream channel between two pieces of rebar driven into the streambed roughly 25 cm apart.

ii. Because drift rates are highly dependent on light intensity, drift sampling should always begin following low-light periods around dawn, and end prior to low-light periods around dusk.

iii. Strive for a sampling duration of greater than 3 hours.

   a. Drift nets may become clogged at high velocities and in streams carrying large amounts of suspended material causing nets to back up water at the net mouth.

b. Net clogging results in an inaccurate estimate of the total volume of water sampled by a net. In this situation sample for a shorter duration and check nets often for signs of clogging.

iv. Record the start and end time, depth, and flow velocity at each net.

a. Record the start time and end time for each net to the nearest minute

b. Immediately after setting each net, record the depth of flow entering the net measured from the water surface to the bottom of the net mouth.

c. Measure the flow velocity entering each net just after setting and just before removing each net. Measure the flow velocity at the center of the net mouth at a depth equal to 60% of the depth from the water surface to the bottom of the net mouth.

v. After completing the sample, hold the net vertically (cup down!) and rinse material into the bottom of the drift net cup.

a. Transfer the material (invertebrates and organic matter) retained in the net into sample jars with a small spoon and rinse any remaining material in the net into the jar with a squirt bottle.

b. Fill the jar(s) with 95% EtOH. Immediately label the jars with the project, site, date, and net number using rite in rain labels and packaging tape.

c. Preserve the sample in 1 or more sample jars depending on the amount of material collected. If there are multiple jars, label them as 1 of 2 and 2 of 2, etc. Repeat this process for samples collected in each drift net.

d. Do not combine the contents of separate drift net samples.

SECTION 10: DATA MANAGEMENT

The CHaMP data management plan is integral to ensuring successful capture, quality assurance, and archiving of CHaMP field data along with the derivation and reporting of site-level metrics. The data system will be comprised of field data capture tools and a centralized database with an online interface. The online interface will support pre-season site evaluations, tracking project metadata, uploading field data, quality assurance procedures, and reporting derived metrics. Under this plan, data will initially be captured on handheld field computers and then uploaded to the online database when internet connectivity is available. A standard set of field data capture devices will be provided which will include data entry applications for the topographic and auxiliary habitat surveys. This two-part system allows remote capture of data and centralized management of metadata, field measurements, and derived metrics. Collectively, these tools support CHaMP's data documentation, data capture, data quality, information archiving, standard metric calculation, and project reporting needs (Figure 24).

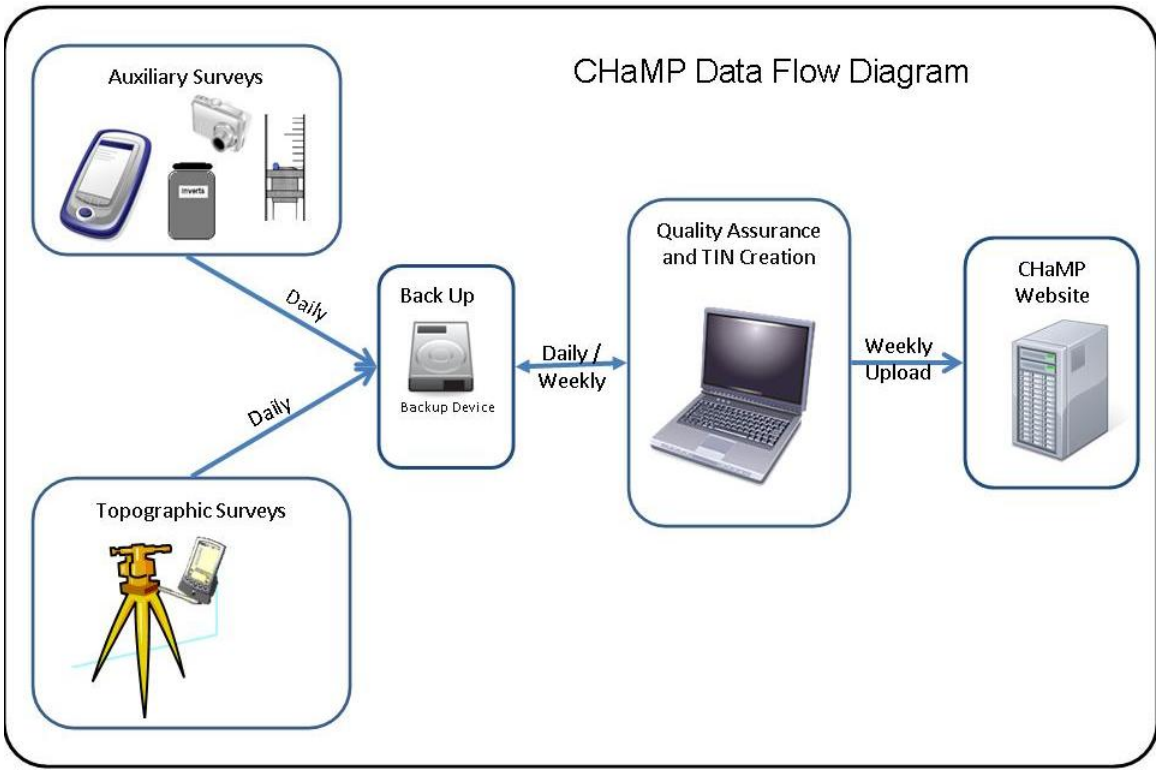

Figure 24. The flow of data through the CHaMP data management plan.

Data management activities will be conducted during pre-season, field-season, and post-season activities (Table 18).

Table 18. Timing of data management activities throughout the year.

Timing	Data Management Activities
Pre-Season (April-June 15th)	Document project, statistical design, and site evaluation metadata.
Field-Season (June 15-Sept 30th)	Daily data capture and quality assurance review of topographic and auxiliary data. Complete weekly quality assurance procedures and generated TIN file for each site. Perform weekly uploads of datasets to CHaMP website.
Post-Season (Oct 1- Oct 30th)	Ensure datasets are complete. Perform quality assurance on completed datasets and derived site-level metrics.

10.1 Pre-season Documentation

Thorough documentation is essential for long-term scientific datasets. Documentation provides the opportunity to use data properly for both planned and unplanned analyses and decision making. Documentation must capture the statistical design for sampling, measurement procedures, data quality, and data reduction steps. Most documentation during the startup year for each watershed will occur in both narrative (e.g., this document) and structured (database) formats. Capturing documentation directly in the CHaMP database will ensure direct linkage with data and will support searching of data.

The project and statistical design information will be entered directly to the CHaMP website using the Project and Study Design utilities by each CHaMP project supervisor. Project information will include agency, staff, roles, BPA project number, watersheds to be monitored, and other pertinent information. Study design information will include the extent of sampling frame, defined stratum, list of GRTS sites within each stratum, sampling allocation across stratum, and temporal sampling frequency. All projects will participate in a three day workshop that will walk participants through the process of defining the study design for their given watershed. Decisions made during the workshop about study design will be recorded through the CHaMP website using the Study Design utility. This information will be stored and tracked directly with raw measurements and derived metrics.

Following the study design workshop, the project supervisor will begin evaluating sites for inclusion in the summer sampling effort. The evaluation process will be completed through the CHaMP website using the GRTS Site Evaluation utility. Each site is evaluated for its conformance to the statistical design, its ability to be safely access by field crew, and to arrange for access permission on private land. Evaluations rely on assessments using Google satellite images, USGS quad maps, landownership maps, other GIS layers, local knowledge, and in limited situations, field reconnaissance. Evaluations will be recorded in the Site Evaluation form. The evaluation process will produce a list of sites to be visited for the given year, along

with latitude and longitude coordinates. The list will be saved as a text file and loaded to a hand-held field computer.

10.2 Field Data Capture and Field Quality Assurance

Topographic survey data and auxiliary data will be captured using separate data logger applications. Auxiliary data (wood loading, substrate composition, etc.) will be captured by a single crew member using a handheld field computer. Upon arriving at the site, the crew member will launch the application, then select the site and crew and enter data about current environmental conditions. As the crew member completes sampling they will enter data into forms under the Site, Channel Unit, and Transect tabs. For categorical data, the appropriate value will be selected from a pull down list. For numeric data, values will be entered using an on-screen numeric pad. Numeric values that fall outside an expect range will produce a warning to the crew member. The warning asks the crew member to review the value and to either accept the value as a correct value or enter a new value. This warning system will limit the potential for entering erroneous data; however, it does not prohibit crew entering of extreme values. Additional warnings will be triggered if required values are not entered for a given data form. A detailed user guide will be provided for the auxiliary data entry application.

Data quality assurance review will be conducted on a daily basis by crew members and on a weekly basis by the crew supervisor. The quality assurance review will test for completeness, outliers in numeric data, and outliers in basic summary metrics. At the end of each day, the crew member will be prompted to verify the number of channel units, total wood pieces, and number of drift samples. Additionally, the crew will be prompted to review any values recorded as a missing value. Next the crew will view and verify any numeric outliers. Finally, a short series of graphs will be presented to allow the crew to verify graphical data against their mental image of the site. At the end of each week, the crew supervisor will perform a similar audit of the data.

The topography survey will create a raw topographic point file (x, y, z data) from which several geo-rectified products will be developed using survey (Leica Geo Office) and Arc GIS 10 software. A triangular irregular network (TIN) and DEM will be created as the base topographic products from the survey.

Data quality assurance for the topographic survey data will take place at four checkpoints within the flow of data from origination on the total station to data storage and web availability. These checkpoints will reduce the likelihood of data errors compounding throughout data processing. The four checkpoints are:

1. Data origination (total station)
2. End of day data review (total station/data logger)
3. End of week data processing and review (laptop)
4. Centralized database checks (CHaMP data system)

The crew lead is responsible for creation and submission of the original point file, a lines file (breaklines), a clean TIN, and a quality assurance report (table in geodatabase). These should be produced within one week of initial data collection.

10.3 Data Back Up and Submittal

At the end of each sampling day field crew should back up data files to an external hard drive. It is critical that a daily back up is made in case the data logger is damaged or lost during field activities. The hard drive must be stored in a safe location and not taken in the field during sampling. The external hard drive should be stored in a waterproof and impact resistant case (e.g., a Pelican case). On a weekly basis, the crew supervisor must upload all data files for the week to the CHaMP website. This upload process will require an internet connection.

10.4 Metric Generation and End of Season Quality Assurance Review

Site-level metrics will be generated from data submitted to the CHaMP website. These metrics will be presented in graphical and map format for all sites. At the end of each field season, crew supervisors will review raw measurements and derived metrics for data completeness, numeric outliers, and ecologic sense. Crew supervisors will be presented with a series for graphs through the CHaMP website and asked to verify data quality.

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SECTION 12: APPENDICES

Appendix A: Equipment Check List

Method	Equipment	Check/Status
All methods	Clipboard with complete set of forms	
All methods	GPS	
All methods	Flagging/flags, Sharpies	
All methods	Metal forestry tags	
All methods	Tape measure	
Site Setup	Monument tops	
Site Setup	Rebar	
Site Setup	Hammer	
Site Setup	Aluminum tag	
Site Setup	Map	
Channel topographic survey	Total station (with tribrach and data logger)	
Channel topographic survey	Tripod	
Channel topographic survey	Prism rod with topographic foot	
Channel topographic survey	Radios (2)	
Channel topographic survey	Umbrella or total station cover	
Channel unit level	Ruler	
Channel unit level	Tape recorder (optional but handy)	
Channel unit level	Marked shovel	
Channel unit level	Sieves	
Channel unit level	Scale	
Channel unit level	Random number generator	
Site level – Map	Rite-in-the-rain paper	

Site level – Photos	Digital Camera	
Site level - Solar input	Solar Pathfinder	
Water temperature	Onset temperature sensor/TidbiT	
Water temperature	Wire brush	
Water temperature	Rubber gloves	
Water temperature	Fox epoxy	
Discharge	30 Meter Tape/surveyors rod	
Discharge	Velocity meter probe	
Discharge	Pins	
Discharge	Depth Rod	
Water Chemistry	Conductivity Meter	
Water Chemistry	Alkalinity Meter	
Drift macroinvertebrates	Drift nets - 1000µm mesh, mouth = 40cm X 20cm, mesh sieve less than or equal to 500 µm	
Drift macroinvertebrates	Sample jars, sample jar labels	
Drift macroinvertebrates	Ethanol	
Drift macroinvertebrates	Waterproof labels	
Drift macroinvertebrates	Stopwatch	
Drift macroinvertebrates	Forceps/tweezers	
Drift macroinvertebrates	plastic bucket, plastic wash tub	
Drift macroinvertebrates	spray bottle	
Drift macroinvertebrates	packaging tape	
Drift macroinvertebrates	portable velocity meter	

Appendix B: Revising the Protocol

As new information becomes available and monitoring efforts are refined, the protocol will be revised. Effectively tracking past and current protocol versions are important for data summaries and analyses that utilize data collected under different protocol versions. Protocol Editor will house previous and current protocol versions and the dates of their implementation. Reviews will be performed for all proposed changes to the protocol and the project coordinator will be notified so that the version number can be recorded in project metadata and any necessary changes can be made to database structure (Peitz et al. 2002).

Consistent with the recommendations of Oakley et al. (2003) this protocol includes a log of its revision history. The revision history log (adapted from Peitz et al. 2002) will track the protocol version number, revision dates, changes made, the rationale for the changes, and the author that made the changes. Revisions or additions to existing methods will be reviewed by ISEMP staff prior to implementation. Major revisions such as a complete change in methods will necessitate a broader review by outside technical experts. When the protocol warrants significant changes the protocol version and date on the title page should be updated to reflect the new version. Version numbers should increase incrementally by hundredths (e.g., Version 1.01, 1.02 etc.) for minor changes and by the next whole number (e.g., version 2.0, 3.0 etc.) for major changes (Peitz et al. 2002).

Some protocols from the "Field Manual of Scientific Protocols for Habitat Surveys within the Upper Columbia Monitoring Strategy" (Moberg 2010) have been incorporated into the CHaMP protocol. Revisions to the Upper Columbia protocol have been tracked in a revision log and can be referenced to inform future decisions. As development of the CHaMP protocol proceeds those revisions will be tracked in the CHaMP log.

Protocol Revision History Log

Previous Version Number	New Version Number	Revision Date	Author	Changes made	Reason

(adapted from Peitz et al. 2002)

Appendix C: Fish Habitat Requirements Summary

Table 19. Habitat attributes that directly and indirectly affects the growth of juvenile salmonids in stream environments.

Limiting Factor	Direct Mechanism	Direct Habitat Attributes	Indirect Mechanism	Indirect Habitat Attributes
Food	Energy inputs to salmonids come mainly from **drifting invertebrates.**	**Drift biomass** is the most direct measure of food availability. **Benthic biomass** and drift biomass may be correlated	Factors that affect the amount of food, are: inputs from **terrestrial vegetation**, **riffle substrate** available for invertebrates, and **primary production**	**Canopy cover** (AP, LiDAR, solar pathfinder).**Riffle substrate** (pebble counts in riffles). **Gross Primary Production** and **Stream Respiration** can be estimated with a DO sonde
Temperature	**Temperature** affects all physiological processes including consumption rate and metabolism which in turn affect growth rates	**Site temperature** measured with temperature logger year round.	see factors related to temperature but include **shade, bed material, thermal buffers from riparian veg, climate, hyporheic exchange, tributaries, upstream flows, channel form**	**Channel unit geometry, Canopy cover** (AP, LiDAR, solar pathfinder, ..).**discharge, air temperature, humidity, substrate composition, valley topography** (estimated from external data sources)
Activity	Activity occurs during **foraging**, and **holding position** in moving water, **migration**, predator and competitor **avoidance** (see below)	Foraging: Requires high velocity (encounter rate) and low velocity (holding) zones found in pool heads (**channel units**) and behind structure in fast moving water (**cobble, lwd**).	**Migration** between resting, foraging, predator avoidance, high velocity currents, and thermal refugia depends on the proximately of microhabitats within the home range and obstacles between them.	**Habitat complexity** is difficult to measure but includes **frequency, size, and location of channel units, and structure.** Location of barriers through inventories and GIS

Table 20. Habitat attributes that directly and indirectly affects the mortality of juvenile salmonids in stream environments.

Limiting Factor	Direct Mechanism	Direct Habitat Attributes	Indirect Mechanism	Indirect Habitat Attributes
Starvation	Consumed energy does not meet energy expenses, see above review for **growth**			
Predation	Salmonids must avoid **predators**	**Predator** presence and abundance	**Hiding cover** for salmonids	**Substrate composition, LWD, channel unit geometry, Undercut banks** measured during field surveys
			Habitat suitability for predator species	Presence of predators will be dependent on **climate, channel unit characteristics, water temperature.**
Physical Processes	High **velocity** causes mortality during high flow events.	Temporally continuous **discharge** measurements	Channel complexity as **LWD, substrate composition, channel geometry and planform** offer refuge from flow events	Field surveys of **channel unit characteristics** and **structure (LWD, substrate)**
Water Quality	Extreme levels of **toxins** or low levels of **required components (DO)**	Temporally continuous measure of **temperature,** which is related to levels of **DO**	**Benthic invertebrate** community composition is related to many water quality parameters	Field collections of **benthic macroinvertebrates**

Table 21. Habitat attributes that directly and indirectly affects the survival to spawning for adult salmonids in stream environments.

Limiting Factor	Direct Mechanism	Direct Habitat Attributes	Indirect Mechanism
Migration barriers	**Barriers** include dams, culverts, waterfalls, diversions	**Location of barriers** through stream networks through inventories and GIS layers	
Temperature	**Temperature** has to be suitable, and in places isolated thermal refugia is highly selected for and necessary for survival.	**Temporally continuous temperature** monitoring at sites, **spatially continuous temperature** information estimated using GIS models	see Temperature review in juvenile growth
Predation	Avoid predation from terrestrial and aquatic predators. Cover such as **boulders, large wood, undercut banks, and pools** to help avoid predators.	Spatially explicit **location of cover elements to suitable spawning habitat** collected by field surveys	see Predation review in juvenile survival

Table 22. Habitat attributes that directly and indirectly affects salmonid egg to fry survival in stream environments.

Limiting Factor	Direct Mechanism	Direct Habitat Attributes	Indirect Mechanism	Indirect Habitat Attributes
Scour	High flows scour substrate which contains deposited eggs		Steep, incised channels have more ability to scour redds during high flows	Measurements of **channel geometry, planform, gradient, and availability of suitable spawning channel types** from field surveys
			Suitable substrate that allows burial of eggs to depths where scour is avoided	Field assessments of f**ine sediment (e.g. pool-tail fines sampling)**
Dissolved Oxygen	Sufficient **DO** to allow diffusion of oxygen to eggs	Field measurements of **DO**	DO is highly dependent on water **temperature**	Temporally continuous **temperature** monitoring
			Certain **channel unit types** (pool tails) have increased **hyporheic exchange**, more flow passing over eggs	Quantity and quality of channel unit types measured during field surveys
			Fine sediment affects flow through substrate to eggs	**Substrate composition** assessments (subsurface fines) assessed during field surveys
Temperature	Temperature affects development time of eggs	Temporally continuous **temperature** monitoring, **cumulative temperature (degree day)** dictates emergence timing		

Appendix D: Monitoring Attribute Review

Table 23. Ranges of precision and accuracy measures of various categories of stream habitat attributes.

Attribute	Metric	RMSE	CV	S:N	Correlation (R^2) to "truth"	Source
Bank Attributes	Bank Angle	-	20.6	17.13		USDA Gen Tech Rpt RMRS-GTR-122. 2004
	Undercut Depth	-	0.06	20.6		Unpublished data
Large Woody Debris	LWD Frequency	1.21 – 1.77	16.4 – 64.5	87.1 – 4.4	.96 - .71	Roper et al. 2010
	LWD Frequency	0.9 – 17.9	18.6 – 42	13.87 - .74	NA	Whitacre et al. 2007
Thalweg Profile	Gradient	0.02 - 1.01	5.9 - 29.5	4.9 - 188.2	0.98 - 0.99	Roper et al. 2010
	Sinuosity	0.04 - 0.11	3.1 - 8.8	1.0 - 13.0	0.76 - 0.95	Roper et al. 2010
Pools	% Pools	5.5 - 12.9	21.8 - 80.7	0.4 - 13.5	0.38 - 0.95	Roper et al. 2010
	Pool Frequency	9.2 - 27.0	22.5 - 77.3	0.2 - 5	0.03 - 0.43	Roper et al. 2010
	Residual Pool Depth	2.5 - 18.4	12.7 - 54.9	0.2 - 11.9	0.12 - 0.94	Roper et al. 2010
Stream width	Bankfull width	0.33-2.58	7.3 - 35.9	2.5 - 58.1	0.52-0.73	Roper et al. 2010
	Width-to-depth	2.9-7.9	19.0 - 30.1	1.5 - 2.1	0.00-0.49	Roper et al. 2010
Substrate	%Fines	4.8 - 14	26 - 64	0.3 - 7	0.07 - 0.84	Roper et al. 2010
	Pebble Counts/D_{50}	14 - 24	28 - 66	1.0 - 6.0	0.73-0.92	Roper et al 2010
	Embeddedness	-	-	-	-	Sylte and Fischenich 2002

Specific measures of each attributes performance can be ranked using the proposed ranking scheme of Roper et al. (2010). These ranks are meant as guidelines only and may not be applicable in every situation: RMSE –attribute specific, can't be ranked across attributes, CV – low > 35%, moderate 20-35%, high < 20%, S:N – low < 2.5, moderate 2.5 – 6.5, high > 6.5, Correlation to the truth – low < 50%, moderate 50-75%, High > 75%.

Table 24. Summary of metric review for various attributes collected under fish habitat monitoring protocols.

Category Reviewed	Stream bank attributes
Metric(s) Reviewed	Bank stability, bank angle, undercut banks
Critical function of the attribute	• For Fish Habitat –how accelerated erosion of stream banks affects quality/availability of spawning gravel, cover, shelter from predators, oxygen levels, stream temp. • Stream Character - sediment budget, how accelerated erosion affects the biological and physical functions of streams.
Protocols reviewed	ISEMP, PIBO, EMAP, MIMs, Winward, USDA – ARS Sedimentation laboratory, EPA WARSS (Rosgen BEHI)
Measurement limitations from the literature	• Difficult to quantify bank stability • Problems with detecting heterogeneity for rapid streambank stability assessments.
Do metrics capture the critical function?	• Stability – No. 90% of Bank stability measurements are considered stable banks. This approach is too gross of a metric and does not detect heterogeneity. • Quantity of undercut banks difficult to determine from point estimates.
If current protocol inadequate, what should be adopted (short term & long-term)	• Either more comprehensive bank geometry measurements and/or fluvial geomorphic audit conducted over large reach lengths. Compliment bank data with finer resolution riparian vegetation assessment. • Undercut depth should be measured continuously at the channel unit scale as a measure of fish cover. • Do not estimate bank stability until measurements are more meaningful.
Category Reviewed	Fish Cover
Metric(s) Reviewed	LWD, undercut banks, visual assessments of 10 cover types developed by EMAP (Artificial structures, Boulders, Small woody debris, Bryophytes, Filamentous algae, LWD, Live trees or roots, Macrophytes, Overhanging vegetation, and Undercut banks.
Critical function of the attribute	• Fish Habitat –LWD and other forms of cover provide velocity predator refuge, rearing habitat, and feeding habitat. • Stream Character – LWD creates channel complexity and low velocity areas next to high velocity habitats that increase feeding opportunity while preserving energy.
Protocols reviewed	AREMP, PIBO, EMAP, CDFG, NIFC, ODFW, and Upper Columbia (ISEMP).
Measurement limitations from the literature	• LWD pieces – the studies reviewed showed that LWD measurements were variable in precision and repeatability between protocols, but relatively precise within protocols. • LWD aggregates – Assessment of aggregates not reviewed in the literature. • Little consistency among protocols on definition of LWD aggregates. • Aggregates are measured at the reach scale and are not informative on how they relate to function.
Do metrics capture the critical function?	• LWD pieces – , LWD metric is reported at the site level (LWD pieces/100 meters), and fish do not likely respond to average reach conditions. • LWD aggregates –LWD aggregates are rarely related to channel unit and therefore do not measure how they function for fish (i.e. LWD aggregates in a pool provide important cover and LWD aggregates in riffles provide slow water refugia near fast water feeding areas.
If current protocol inadequate, what	LWD – Short term • Relate function to fish by assessing LWD at the channel unit scale.

should be adopted (short term & long-term)	• Adopt a minimum LWD size classification that best allows comparison between protocols. LWD – Long term • Develop measurements of LWD recruitment potential, LWD transport, and LWD stability to assess the LWD budgets of monitored reaches. This might best be achieved by remote sensing. Fish Cover – Short term • Continue using established EMAP protocol of visually assessing 10 different fish cover elements. Fish Cover – Long term • Develop measurements of fish cover that are quickly assessed, and directly relate to fish. • Collect cover at the channel unit scale to provide information about function for fish.
Category Reviewed	Invertebrate sampling
Metric(s) Reviewed	Food availability (Benthic, Drift), diversity indices, site impairment
Critical function of the attribute	• Some programs collect benthic invertebrates as a measure of site impairment via diversity analysis or presence/absence of indicator species • Invertebrates are the main food resource of juvenile salmonids, however invertebrates are not evaluated as a food resource.
Protocols reviewed	EMAP, PIBO, ISEMP
Measurement limitations from the literature	• Some start-up time is required to move to processing invertebrate drift samples as most companies are currently process benthic samples. • Benthic samples require professional taxonomists to identify invertebrates at fine taxonomic resolution. • Invertebrate drift samples can be highly variable at the site level, but directly related to salmonid growth.
Do metrics capture the critical function?	• Diversity indices of benthic invertebrate samples may describe water quality, but do not adequately describe food availability for salmonids.
If current protocol inadequate, what should be adopted (short term & long-term)	• Invertebrate data often not related to fish, could improve this by starting to collect drift and benthic samples and relate these to fish growth (Figure 25). • If relationships exist across a broad range of stream and watershed types food abundance could be used as a predictor of abundance and ultimately related to stream habitat features that increase food availability.

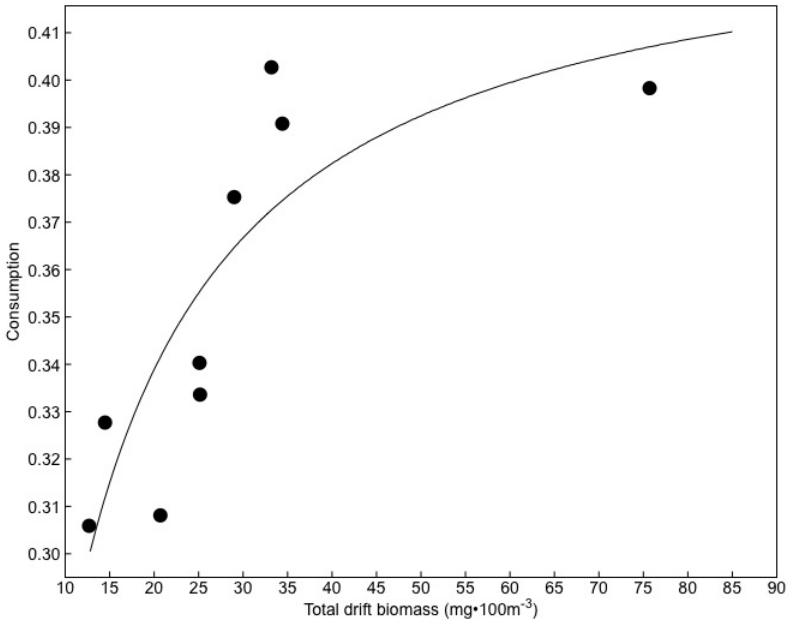

Figure 25. Relationship between fish consumption and total drift biomass in Bridge Creek.

Category Reviewed	Pools
Metric(s) Reviewed	Pool Frequency, Percent Pools, Residual Pool Depth
Critical function of the attribute	• Dimensions - Space to avoid predators, forage effectively, and avoid high velocity. • Velocity - Fish refuge from high velocity, access to high velocity areas for optimal drift foraging. • Spatial Context - Location of pool habitat relative to other channel types (riffles, etc...).
Protocols reviewed	AREMP 2007, Downie 2004, Heitke et al. 2008, Merritt 2009, Moberg 2009, Moore et al. 2006, Overton et al. 1997, Peck et al. 2001, Pleus et al. 1999, USFS 2009
Measurement limitations from the literature	• Depth - Estimates of pool volume highly sensitive to precision of tail crest depth measurement (Keim and Skaugset 2002) • Percent Pools and Pool Frequency are imprecise metrics (Roper et al. 2010). • Velocity - Pool velocities are rarely measured, flow characteristics are visually classified. • Spatial Context - Varying levels of spatial context, from measuring attributes only at the reach scale (Heitke et al. 2008; AREMP 2007) to measuring all attributes relative to individual channel units (Moore 2006)
Do metrics capture the critical function?	Pool Dimensions - • Depth - Majority of protocols collect only residual pool depth (single tail crest and max depth). • Length, Width, Area, Volume - In general only a single wetted or bankfull width is recorded. Spatial Context - • Majority of protocols are not capable of relating cover, LWD, substrate composition, or other physical attributes to a specific pool unit. • Strict definitions of pool habitat (e.g. pools not measured in secondary/tertiary channels, thalweg must pass through pools). Strict definitions may cause channel segments featuring low velocities and high channel depths to be classified as non-

	pool habitat.
If current protocol inadequate, what should be adopted (short term & long-term)	Short Term: • Measure all physical attributes relative to channel units • Increase the number of depth and width measurements for more accurate area and volume estimates. • Sample pools in all flowing stream channels (i.e. not only from within the primary channel). Long Term: • Surveys of stream channel topography using a total survey station or RTK (Real Time Kinematic) GPS. The resulting DEM can be used to calculate metrics of pool frequency, area, volume, and percent pools.
Category Reviewed	Riparian vegetation
Metric(s) Reviewed	Cover, wetland status, bank stability, change
Critical function of the attribute	• Bank stability • Water table connectivity • Sources of LWD • Regeneration
Protocols reviewed	PIBO, EMAP, Coles-Ritchie et al (2004)
Measurement limitations from the literature	• PIBO , Coles-Ritchie et al (2004) require plant identification (community level to species level) • EMAP estimates only cover and neglects streambank vegetation. • Repeatability is a concern with all of the methods that were reviewed
Do metrics capture the critical function?	• PIBO measures bank stability along the greenline and within a Daubenmire plot at each cross-sectional transect. Done by using established values for defined communities that quantifies the community's bank stabilizing status. Estimates woody regeneration along the greenline by aging established plants. Greenline also provides a wetland indicator status by community to detect groundwater connection. (A move from community level to species level identification of late) • Coles-Ritchie et al. (2004) measures bank stability and water table connectivity using species level data and indicator status used in PIBO. • EMAP provides data on regeneration by binning trees by size classes.
If current protocol inadequate, what should be adopted (short term & long-term)	• The amount of vegetation cover as per EMAP cover classes should be collected at each habitat unit to determine average cover at a site. • To estimate potential productivity and solar input a solar pathfinder should be used as per Platts et al. (1987); modified to the habitat unit method outlined in Appendix D.
Category Reviewed	Stream Width
Metric(s) Reviewed	Bankfull width, cross-section width, floodplain width, wetted width, width-to-depth ratio
Critical function of the attribute	• Stream size/potential discharge, incision/channel shape (i.e., is it downcut, large width to depth ratio) • Critical measure for site calculating averages for other metrics • Bankfull width is an important hydrologic concept that can be very important for characterizing various hydrologic measures of stream discharge and sediment transport
Protocols reviewed	AREMP, CDFG, EMAP, NPS, ODFW, PIBO, UC
Measurement limitations from the literature	• All measures of stream/floodplain width are intuitively appealing concepts but has been notoriously difficult to consistently identify in the field; numerous subtle signs have to be identified in the field and these signs are not always present (e.g., signs of recent high flows)

	• The concept of bankfull width is also stream dependent and may not be applicable in all situations • Many protocols stop cross-sections at "bankfull width"; this prevents information being collected in floodplain areas and may make it difficult to detect channel changes • Wetted width is obviously highly flow dependent and cannot be used to compare streams when sampling over extended periods, unless stream is at baseflow • Width-to-depth ratios are calculated because it is assumed that wide shallow streams are the result of human disturbance; however, because this metric relies on a ratio it is susceptible to larger errors and has been shown to have poor internal consistency, limited ability to detect environmental heterogeneity, and poor correlation with the truth (Roper et al. 2010)
Do metrics capture the critical function?	• Stream width (however it is measured) is an important metric for putting other stream habitat metrics in context; despite the problems associated with measuring width consistently, increased training and better protocols have improved consistency in measuring these attributes.
If current protocol inadequate, what should be adopted (short term & long-term)	• If using to detect change in channel morphology and location then transect monuments above active flood plain is necessary. As remote sensing techniques become more available many of the width measurements may be calculated in the office. Tests of the relationship between remote versus field measurements should be continued.
Category Reviewed	Substrate
Metric(s) Reviewed	%Fines, Embeddedness, Pebble Distribution
Critical function of the attribute	• Fish Habitat - interstitial spaces for rearing, food, cover, and quality/availability of spawning gravel • Stream Character - roughness, potential bed load, sediment budget
Protocols reviewed	• AREMP, PIBO, EMAP, CDFG, NIFC, ODFW, UC … all use version of Wolman pebble count or visual estimation into size classes for pebble distribution. Transects are used to systematically select particles (usually 5-10 particles per transect). Transects can be located in specific habitats (usually riffles) or systematically throughout the reach. Wide variety of measures for Embeddedness but most measure or visually estimate depth of cobble substrate within finer material. % Fines are either calculated from pebble counts or surveyed separately, usually in pool tails. Definition of fines seems to range from 1 - 10 mm with the most common 2 mm.
Measurement limitations from the literature	• %Fines - tend to under estimate % fines; measurements taken in inappropriate habitat; • Embeddedness - critical flaw in measurement technique (increased fines can = decreased % embeddedness); also no agreed upon definition; • Pebble distribution - ability of observer to select and measure particles without bias; number of particles may not be adequate; usually conducted in riffles or random sites and not by channel unit
Do metrics capture the critical function?	• %Fines - Gives an idea of spawning habitat impairment if measured at pool tail (i.e., PIBO and AREMP); however, no protocols measure interstitial space in other channel units where juveniles rear and/or overwinter • Embeddedness - Too subjective and not able to assess water flow, DO^2 levels, and other critical elements of interstitial space; poorly defined and typically not measured in all habitat types
If current protocol inadequate, what should be adopted	• % Fines - the PIBO/AREMP use of 3 grids (50 pts/grid) in first 10 pools counting number of 2 mm and 6 mm particles provides a maximum of 1500 particles per reach. Protocol reviews suggest this technique has moderate precision, ability to

(short term & long-term)	detect differences between stream types, and is related to more intensive measurements (i.e., the TRUTH). • Embeddedness - no technique currently available. If this is a real concern and focus of the study; suggest a detailed literature review and more hydrological approach (i.e., sediment cores/sieves, etc) • Pebble count - Wolman pebble count in riffles (min 100 particles) is adequate minimum. However, recent reviews suggest that several improvements are needed. Most current rapid protocols use heel-toe selection method of each particle and visual estimate or ruler for measuring. Bunteet al (2009) suggest using a grid to select particles at each transect, use of gravelometer to measure each particle into ¼ phi size classes, sampling away from bank/water's edge (as per PIBO), and conducting counts of >100 in all habitat types within the study reach.
Category Reviewed	Water Quality
Metric(s) Reviewed	Sampling methods reviewed for water temperature, conductivity, alkalinity, pH, dissolved oxygen, nutrients, turbidity
Critical function of the attribute	• temperature related to many physical habitat conditions, such as geomorphology, climate conditions, riparian vegetation, etc. and also has physiological significance for fish (e.g. behavioral responses, survival thresholds for multiple life stages) • conductivity and alkalinity related to invertebrate metrics. Also related to site geology, soils, and ion availability. • dissolved oxygen and related metrics measured for primary production estimates • nutrients (N and P) commonly limiting in streams and related to primary production, geology, soils and vegetation. • turbidity measured as survey condition for spawning surveys and fine sediment transport.
Protocols reviewed	AREMP, PIBO, EMAP, NPS, ODFW, ODEQ, WDOE, CNCA
Measurement limitations from the literature	• Temperature: handheld field measurements at time of sampling not sufficient for analysis and trend detection with fish or environmental variables. Handheld measurements only useful for determining if fish sampling allowed (permitting reasons). • Alkalinity/conductivity – Handheld field measurements sufficient for site sampling. Less useful as direct environmental variable influencing fish, more commonly relates to fish habitat variables, such as macroinvertebrates. • Nutrients-sampling scenarios expensive for monitoring projects and usually a low priority because other factors more directly related to fish metrics • Turbidity: handheld measurements and methods highly variable when used to quantify water clarity and visibility. Meters preferred method of measure for turbidity, but are expensive.
Do metrics capture the critical function?	• Temperature-. Can be directly related to fish metrics at small and large spatial scales. • Alkalinity/conductivity- Can explain variation in invertebrate metrics. • Nutrients-. Can explain variation in riparian vegetation and correlation to soils and geology. Not directly related to fish (non-pollution sources).
If current protocol inadequate, what should be adopted (short term & long-term)	• In both short and long term deployment of temperature loggers to collect continuous (hourly) data for the entire year at all status and trend monitoring sites. Collection of alkalinity and conductivity using field meter at all status and trend monitoring sites. Nutrient sampling expensive and only relevant when nutrients of primary concern.

Appendix E: Monitoring Design Review

E.1 Spatial Designs

Spatial designs describe how sampling effort is to be allocated across a study area. The most appropriate spatial design depends on monitoring program requirements and constraints. In general, the following types of spatial designs are available:

Census

The census spatial design describes the location of all the sites comprising the domain of interest. In some cases, a single site might be used to estimate the total number of fish in a population, by the establishment of a counting facility located strategically where all fish will pass and be counted. In other cases, the census might consist of counting fish throughout the population's domain occupied (or potentially occupied), e.g., at all reaches where the species occurs. In any case, a census implies that all elements will be enumerated.

Model-based

A model-based spatial design relies on selection of sites based on the need to estimate parameters or coefficients of a model that will be used to make the indicator estimates. Such models typically include one or more independent variables or covariates such as environmental conditions or geomorphic setting. Sites are generally selected along the important gradients governing the model parameters. A simple model might be a relationship between a population's growth rate and temperature. Sites might be selected at locations covering a thermal gradient over the range of the population's thermal tolerance. Then the model would be used to estimate productivity across all sites in the domain. A restricted model-based spatial design refers to situations in which the selection of locations in part of the domain is guided by the candidate model, and locations in other parts are selected by other methods.

Survey

The term survey in the current context implies the use of a randomization rule in the selection of locations across the domain of interest and the caveat that all locations have a positive chance of being selected. Approaches available to achieve these criteria for monitoring natural resources include: simple random sampling, systematic sampling, and GRTS (Stevens and Olsen, 2004) based sampling. A restricted survey design implies that part of the domain will be sampled by application of a survey, and other parts by application of one of the other spatial designs.

Opportunistic

An opportunistic-based design is where you will only be able to sample at sites that are selected based on ease of access or other subjective criteria.

In some instances, categories may be combined to produce hybrid designs. For example, part of a domain may be sampled by counting fish as they pass over a weir (census), and the remaining portion of the domain may be best monitored by a survey.

Each of these spatial designs has strengths and weaknesses. In general, the chance of making poor inferences is highest for opportunistic spatial designs and lowest for census designs. Conversely, opportunistic spatial designs will generally be less expensive to implement than census designs.

Temporal

Temporal designs describe how sampling effort is to be allocated across time. The most appropriate temporal design depends on the monitoring programs requirements and constraints. When developing the temporal design there are two basic units of time to consider:

Study period*:* The entire length of time the study will be operated. For example, the monitoring objectives of the study may include determining the long-term trend in annual abundance over 20 years so the *study period* would be 20 years.

Temporal unit: The unit of time for which a metric or indicator is reported. For most long monitoring studies "year" is a temporal unit. Studies may also have more frequent temporal units that might range from seasonally to hourly. For convenience, in the following discussion, we refer to a year as the temporal unit.

Most long-term monitoring objectives ask questions about patterns of change across years, sometimes decades or longer. These questions might be specific to a single location, or might cover broad regions and include many locations. The basic question for temporal designs is: what is the best allocation of sampling effort across years? Do we need to sample every site every year? Similar questions can be raised if the objectives concern a single site: does meeting your objectives require you to conduct field measurements every year (or every temporal unit if your temporal unit differs from a year)?

In some instances, categories may be combined to produce hybrid designs. For example, part of the domain might be sampled every year, while the remaining portion of the domain may be best monitored by surveys that are not implemented every year.

The temporal design choice is a little easier to think about when the monitoring objectives require sampling a set of sites during the study period. Again, thinking about year as the temporal unit, we could sample all sites every year. However, for some objectives, it might be just as efficient to sample some sites annually, and some sites on a periodic cycle like every "n" years (where n could by 2, 3, 4...years). These *panel designs* allow the opportunity to investigate a greater number of sites during the study period than might be possible with a "sample every site every year" design without a loss of precision for status estimates (e.g., population abundance estimates). In addition, panel designs afford approximately the same mean trend detection power after three monitoring cycles have passed (Urquhart and Kincaid, 1999). For example, a design that includes an annual panel (25 sites), along with three 3-year panels (25 sites each panel, beginning in year 1, year 2, and year 3) will achieve very closely the same power after nine years, as a design with the same 50 sites visited every year. The advantage of the multi-panel design is that a total of 100 sites will have been sampled, compared with 50 for the every site-every year design (see Urquhart and Kincaid, 1999).

Allowing flexibility in the choice of sampling patterns over years offers a variety of possibilities when your monitoring program includes multiple sites. However, a thorough

evaluation of selecting a temporal sampling pattern cannot be done without simultaneously considering both the spatial and response designs. This optimization process will require a knowledge about the spatial, temporal, and "residual" variation (including how well the response design estimates the site's metric score), and costs for collecting the relevant data at a site (including travel cost between sites). Unlike the availability of single site trend detection tools, we are unaware of analogous "off the shelf" tools for multiple site trend detection. However, with an estimate of the important components of variation, the use of simulation tools (along with the computational power of current desktop computers) allows an evaluation the relative merit of different design choices. Several recent publications describe a variety of simulation examples that illustrate how this problem can be addressed (see Wagner et al. 2007; Dauwalter et al. 2009, Jacobs et al. 2009).

E.2 Response Design

Once the spatial and temporal designs are established, we need to determine exactly what, how, where and when to measure the attributes of interest. The response design includes a finer scale spatial and temporal description than that covered by the spatial and temporal design components. For example, you might be able to measure your attribute (such as water temperature) at a point in a stream network. However, for other attributes, such as characterizing the density of redds, or the amount of wood, or the density of pools, it will be necessary to make measurements along the reach. In these cases, calculating a metric, such as spawner abundance using an area under the curve method, requires sampling at multiple times during the spawning season. Documenting when and how data is collected at a site is part of the response design. Descriptions of any laboratory procedures are also part of the response design. Finally, response designs include the methods used to calculate site metric (e.g., the analytical procedure to estimate abundance using an area-under-the-curve method). Field operations manuals and quality control procedures are examples of kinds of documents that describe some parts of a response design. The following is a list of what should be covered in a description of a response design:

- What will be measured or collected in the field.
- How will it be measured or collected.
- Where the measurements be made within each of the sites comprising the sample.
- How sampling will be distributed within the temporal unit (e.g. year).
- Laboratory methods.
- Analytical procedures to calculate the metrics from the measurements.

In many ways the process of developing a response design is similar to selecting tools from a toolbox. There are many tools to choose from but some work better for the job at hand than others. Developing an appropriate response design to meet the objectives will depend on a variety of factors including attributes of interest and how well they can be measured or estimated given costs of making the measurements.

In many cases, sampling must occur during an “index” window, such as the summer low flow period, because all sites cannot be sampled simultaneously. In these cases, it is useful to

sample some sites more than once to estimate this "index window" component of variation. An index window should be chosen so that:

- It is as short as possible within field operational constraints,
- The variation in the measurements is as small as possible within the window, and
- It is ecologically based.

The procedures used to calculate the metrics from the measurements comprise an analytical component of a response design. In some cases, the metric of interest might come directly from the measurement, e.g., maximum temperature during the June – Aug. interval (no calculation needed, except to read logger's maximum temperature). In most cases, a set of measurements is combined to calculate the metric of interest for each site in the sample. For example, an area-under-the-curve method is used to calculate the number of spawning salmon from the measurements taken during each of many visits to the site. Alternatively, the mean width of a stream is calculated from a set of width measurements taken at many locations across the stream's "plot" (e.g., mean of 10 width measurements taken systematically across 500 meters centered on the site, or 40 times the wetted channel width). Some metrics require complex calculations derived from measurements of a variety of attributes at a site. Documentation of these aspects of data collection and metric calculation is part of the response design.

E.3 Inference Design

The inference design describes the process used to estimate indicators for the target population(s) based on information (metrics) collected at the sample sites. This may occur for a single time period and the result is a status estimate for the indicator, or it may involve making estimates across multiple time periods when trends are of interest.

If the study involves only a single site, the inference design is simple since the metric values for the site are the population indicators of interest. Inference for trends at the single site does require choosing a statistical procedure to estimate the trend. The only uncertainty in the status estimate is from the metric measurement error.

If the spatial design is a census, the inference design will require defining the procedures used to calculate indicators for the target population based on the metric values from all the sites in the census. The only uncertainty in indicator estimate is from the metric measurement error.

If the spatial design is a survey, the inference design will require knowing the properties of the survey design, such as stratification and unequal probability weighting. When a temporal design is present, an inference design for trends must also be specified.

If the spatial design is an opportunistic site design, the inference design for estimating status requires defining the procedures used to summarize metrics across all the sites. Extreme care should be made in making inferences to any areas other than the sites sampled since we do not know how representative the handpicked sites are to anywhere other than the locals sampled.

The options available for an inference design are closely linked to the design used to select sites for status and trend monitoring and for mechanism monitoring. Mechanisms designs, in general, have specific statistical analysis procedures associated with them (e.g., Before-After-Control-Impact BACI designs). The inference design is the statistical analysis procedure. Many

of the statistical analysis procedures utilize standard analysis of variance, regression or analysis of covariance. The validity of the inference depends on how well the assumptions of the analysis procedures.

For status and trend monitoring designs, the inference design depends on the site selection procedures. For a census design, no inference design is required since all sites are included and calculation of descriptive summary statistics is all that is necessary.

Inference designs for model-based spatial designs require the selection of a spatial stochastic model appropriate for the variables of interest. For example, a geostatistical model such as kriging may be appropriate. Typically, several models may be available and the selection of which one to use depends on the assumptions required for the model and whether those assumptions are met.

Design-based spatial survey design statistical inferences rely on the randomization procedures used to select the sites. Horwitz-Thompson estimators and variance estimators are available for all common survey designs (e.g., Lohr 1999). In addition to design-based inferences, model-based inference designs such as spatial stochastic models may be used. Since spatial survey designs provide (in most cases) a representative sample, an analysis for the spatial stochastic model is more likely to provide unbiased estimates. Another advantage of using spatial survey designs is that both design-based and model-based inference designs can be used.

E.4 Overall Design Considerations

In designing a monitoring program, we need to optimize the allocation of sampling effort across the potential set of spatial and temporal units during the study period. This balancing requires consideration of the cost of sampling (response design per site and transportation between sites) as well as the variability between sites within and across the study period and the temporal unit.

The following considerations are important for optimizing this allocation of sampling effort:

Degree of certainty - The level of confidence in the results of the monitoring program plays a significant role in determining the appropriate design. In general, the degree of certainty in monitoring results is lowest for opportunistic designs, intermediate for model-based and survey designs, and highest for census designs. It is lowest for opportunistic designs because it is difficult or often impossible to assess how well the chosen sample sites represent the domain for which inferences are intended. Because of the non-statistical nature of sample site selection, it is often impossible to assess the degree of certainty of results from opportunistic sample sites because you cannot determine the precision or bias associated with inferences to entire populations obtained from data collected at opportunistic sample sites. The degree of certainty is intermediate for model and survey based spatial designs because they depend on a statistical sample with its associated uncertainty. In addition, model-based designs can be subject to unknown uncertainties associated with model assumptions. The degree of certainty is highest for census designs because all members of the target population are sampled (either via a fixed counting station or by sampling at all sites in the domain) resulting in no sampling uncertainty or faulty assumptions about the representativeness of selected sites.

Cost - The cost of designs generally varies directly in relation to their degree of certainty. While the high degree of certainty provided by a complete census may be attractive, in many cases the cost associated with conducting a census over a large geographic area or for the entire study period will be prohibitive.

Feasibility - Adopting a design that achieves the desired degree of certainty and that is within the budget may result in a design that is not feasible due to extenuating circumstances. For example, being denied access to a significant portion of private lands in the study area will result in a need to revise the monitoring goals and objectives to recognize that restriction.

Existence of a verified model - Choosing a model-based design will obviously not be an option if currently no models exist that can guide the site selection process.

Flexibility - It is a common occurrence that over the life of a monitoring program, there may be changes in the goals and objectives, monitoring technologies, allocated budgets, or other constraints. Some designs are more amenable than others to the modification that may be necessary to meet these new challenges. For example, an initial objective that requires an abundance estimate over a prescribed monitoring region might be changed to an objective that requires abundance estimates for specific populations within that region. A spatial/temporal design that allows the addition or subtraction of sites without biasing results is more desirable than one that requires an entirely new design.

A framework that can be used to balance the various competing choices in designing a monitoring program consists of:

- understanding the influence of spatial and temporal components of variability in the data
- evaluating the accuracy of the estimates
- the statistical power of the design (i.e., the chance of correctly detecting some situation)
- costs.

Appendix F: Glossary

Term	Definition
Active Channel	The channel within the bankfull.
Aerial Cover	Stream shading from riparian vegetation
Alkalinity	A measure of the ability of a solution to neutralize acids to the equivalence point of carbonate or bicarbonate.
Anadromous	Fish that migrate from salt water to breed in freshwater.
ASCII	The American Standard Code for Information Interchange is a character-encoding scheme based on the ordering of the English alphabet.
Backsight	A point taken looking backwards to a previously occupied point.
Backsight Check	Comparing the results from the foresight to the backsight for the same point to establish accuracy of a traverse.
Bankfull Elevation	see bankfull stage
Bankfull Indicator	Physical indicators left behind from bankfull flow events such as bar elevations, algae lines, stain lines, etc.
Bankfull Stage	The height of the water surface at which a stream first overflows its natural banks during high flow events. The bankfull stage and its attendant discharge serve as consistent morphological indices which can be related to the formation, maintenance and dimensions of the channel as it exists under the modern climatic regime.
B-Axis	The middle axis of an irregular shaped object such as a rock. It is equal to the sieve size substrate will fit through.
Bearing	The direction one object is from another object.
Bearing Monument	A naturally unique object used to identify the top and bottom site monument in wilderness areas where leaving rebar monuments is not allowed. A bearing and distance is recording from the bearing monument to the downstream and upstream end of the site.
Bearing Tree	A tree used to identify the bearing and distance to the rebar monument identifying the top and bottom of the site.
Bedform	Refers to the lateral (cross-section) and longitudinal (upstream to downstream) profile of the stream channel. A depositional feature on the bed of a river (fluvial processes) or other body of flowing water that is formed by the movement of the bed material due to the flow. Bedforms are characteristic to the flow parameters and are particularly to flow depth and velocity, and therefore the Froude number.
Benchmark	Permanent site monuments outside of the active channel. Benchmark locations are established by taking a gps point at one benchmark, using a compass to set the orientation of the total station, and surveying in the other benchmarks. Benchmarks are used to 'tie' surveys into 'real' world coordinates and to re-establish to survey when revisiting. Three benchmarks are established and monumented with rebar in a equilateral triangle within site distance of each other and at least 20 m apart from each other.
Braided Stream	A stream segment that consists of a network of small channels separated by small and often temporary islands called braid bars. Braided streams occur in rivers with high slope and/or large sediment load (Schumm and Kahn 1972). Braided channels are also typical of environments that dramatically decrease channel depth, and consequently channel velocity, such as river deltas, alluvial fans and peneplains.
Breaklines	A linear feature that defines and controls the surface behavior of a tin in terms of smoothness and continuity.
Channel Segment	A linear portion of channel that is separated from other portions of the channel by an island with an elevation that equals or exceeds the bankfull elevation for a distance greater than the site width category. Channel segment 1 is always the main channel, channel segment 2 is the first side channel separated from the main channel by an island for a distance greater than the site width category.

Channel Segment Number	Sequentially numbering system identifying channel segments as they are encountered moving from the downstream end of the site to the upstream end of the site.
Channel Type	Classification of channels following the Montgomery and Buffington (1998) system of classification.
Channel Unit	Areas of relatively homogeneous depth and flow that are bounded by sharp gradients in depth and flow (Hawkins et al. 1993). Channel units must be at least as wide as 20% of the wetted width.
Charismatic Megaboulders	Large, visually obvious, unique boulders that are easily described and relocated.
Constrained Stream	Stream with no depositional floodplain that is usually constrained by valley walls.
Control Point	A point occupied by the total station
Crested Tail Depth	The depth of the water at the point water would first begin to exit the pool, does not have to be the thalweg.
Cross-section	A transect of a stream where depth and velocity measurements are taken to estimate the discharge.
Data Logger	An electronic device that records data over time or in relation to location either with a built in instrument or sensor or via external instruments and sensors. Usually based on a computer. Generally are small, battery powered, portable, and equipped with a microprocessor, internal memory for data storage, and sensors. Can interface with a personal computer and utilize software to activate the data logger and view and analyze the collected data. Others have a local interface device (keypad, LCD) and can be used as a stand-alone device.
Declination	The difference between the north geographic pole and the north magnetic pole. Depending on where you are on the earth, the angle of declination will be different - from some locations, the geographic and magnetic poles are aligned so declination is minimal, but from other spots, the angle between the two poles is pretty big.
Depositional Feature	Floodplain and levees; a floodplain is a low-lying plain on both sides of a river that has repeatedly overflowed its banks and flooded the surrounding areas. When the floods subside, alluvium is deposited on the floodplain. The larger materials, being heavier, are deposited at the river banks while the finer materials are carried and deposited further away from the river. The larger materials at the river banks build up into embankment called levees.
Digital Elevation Model (DEM)	Data files that contain the elevation of the terrain over a specified area, usually at a fixed grid interval over the surface of the earth. The intervals between each of the grid points will always be referenced to some geographical coordinate system. This is usually either latitude-longitude or UTM (Universal Transverse Mercator) coordinate systems.
Estimated Position Error (EPE)	Used to assess the error associated with a GPS reading, this value is usually not recorded with the GPS point and should be recorded separately
Flagging	Colored ribbon used to identify transects, monuments, channel units, or other features during the course of a survey.
Flow Characteristics	The presence or absence of turbulent, broken, noisy, or white-capped flow. Controlled by the interaction of channel unit gradient and substrate.
Fluvial processes	Processes associated with rivers and streams and the deposits and landforms created by them.
Geomorphic Reach	A length of stream with relatively homogenous geomorphic characteristics including discharge, gradient, and confinement.
GIS	A geographic information system (GIS) is any system that captures, stores, analyzes, manages, and presents data that are linked to location
GPS Positions	Global Positioning System provides location coordinates by triangulating position information from orbiting satellites.
Gradient (bed surface)	The rate of change in bed surface elevation over a given distance
Gradient (water surface)	The rate of change in water surface elevation over a given distance

Horizontal Error	The X and Y value difference from a foresight to a backsight of a control point
Human Influence	Impacts on the riparian corridor caused by humans.
Inactive Channel	The area of a channel beyond the bankfull elevation
Inflexion Points	A point of significant change along a line
Island	Areas within a channel that are above bankfull elevation and at least one site width category in length.
Jams	Five or more qualifying pieces of wood in contact with one another.
Large Woody Debris (LWD)	Wood in the active channel that is larger than the minimum criteria of 10 cm diameter at any point and 1 meter in length
Longitudinal Profile	The two dimensional view of a stream moving up the thalweg of the stream
Longitudinal Profile Station	A point along the longitudinal profile that a TOPO point is taken to capture changes in slope along the longitudinal profile
Magnetic North	The direction the red arrow points on a compass.
Maximum Pool Depth	The deepest part of a pool
Mid Channel Bar	An area above the wetted elevation but below the bankfull elevation and surrounded by water on all sides.
Non-constrained Stream	Stream that can access a floodplain.
Non-primary Channel	A side channel with between 16 and 49 percent of the stream flow
Non-qualifying Side Channel	A side channel with less than 16 percent of the streams flow
Orientation	Location relative to a compass
Origin Benchmark	The benchmark first occupied by the total station
Particle	A substrate such as course gravel, cobble, etc.
Particle Embeddedness	The percentage a cobble is buried by sand and finer substrate.
Planform View	The two dimensional view of the stream looking down from above.
Primary Channel	The channel with the most flow.
Priority Benchmark	Benchmark at a site whose GPS coordinates are used to position the site coordinates into 'real' space, same as the Origin Benchmark
Prism	The reflector on top of the survey rod used to reflect the signal from the total station.
PVC Cuff	A piece of PVC fit around the arm with surgical tubing used to collect data in wet environments
Reach	See geomorphic reach
Resident	Fish that do not migrate to the ocean.
Rip-rap	Large rock placed by man in a river or stream
Scour	The fluvial process by which the stream flow erodes and deposits sediment
Site	The specific point, location or length of stream where measurements are taken and metrics derived. Represents a single sample unit within a monitoring program's study design.
Site Map	A map drawn by the surveyors showing the planform view of the site and indicating the relative position of benchmarks, monuments, channel units

Site Monument	A permanent maker that denote location of the bottom and top of the site. Usually, two foot long rebar driven into the ground at a offset distance from bottom or top of site. Rebar monuments should not be used in designated wilderness areas.
Site Width Category	A measurement of length based on binning the average bankfull width. Used in site layout to establish 20 equal spaced intervals along the length of the center of the channel.
Solar Path Finder	A piece of equipment manufactured for the purpose of capturing the solar input of a site.
Substrate	The natural environment in which an organism lives, or the surface or medium on which an organism grows
Thalweg	The line that connects the lowest points along the length of a river bed where there is active flow, and thus the line of fastest flow.
Total Station	An electronic/optical instrument used in modern surveying. The total station is an electronic theodolite (transit) integrated with an electronic distance meter (EDM) to read slope distances from the instrument to a particular point.
Transect	An imaginary line, perpendicular to the bankfull channel that runs through the center of the bankfull channel and intersects the bank.
Triangulated Irregular Network (TIN)	A vector based representation of the physical land surface or sea bottom, made up of irregularly distributed nodes and lines with three dimensional coordinates (x,y, and z) that are arranged in a network of non-overlapping triangles.
Turning Point	Control point that is NOT ever occupied by the total station but can be used during traverses to avoid poor control point setups.
Quality Control	Data quality constrains that limit what values can be entered into the data system
Quality Assurance	Data quality procedures that are implemented to verify information quality after data has been entered into the data system
UTM Coordinate	The Universal Transverse Mercator (UTM) geographic coordinate system is a grid-based method of specifying locations on the surface of the Earth that is a practical application of a 2-dimensional Cartesian coordinate system. It is a horizontal position representation, i.e. it is used to identify locations on the earth independently of vertical position, but differs from the traditional method of latitude and longitude in several respects.
Valley Type	Valley type is used to mean the same concept as “valley segment” as defined in Montgomery and Buffington (1993) and include colluvial, alluvial, and bedrock valley types.
Vertical Error	The Z value difference from a foresight to a backsight of a control point